MEASURING THE STARS AND OBSERVING THE LESS VISIBLE

Australia's participation in the Astrographic Catalogue and Carte du Ciel

Figure 1: Astrographic measurer, Melbourne Observatory ~1900 (Collection Museum Victoria).

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ABSTRACT

Australia's 1887 decision to participate in a major international astronomical project to produce an Astrographic (Star) Catalogue and Carte du Ciel (Chart of the Sky) ultimately involved Adelaide, Sydney, Melbourne and Perth observatories. Participation in this project promised to bring international recognition of Australia's capability in astronomy and access to the latest photographic technology and methods, within a network comprised of leading astronomers and observatories from around the globe. This was not a straightforward process; obtaining the resources required to successfully participate was fraught in terms of seeking support from governments that did not necessarily understand the significance of the projects, the lack of an appropriately trained workforce, and the sheer volume of work to catalogue the star-rich sky of the Southern Hemisphere.

The challenges of participating in major and extensive international projects, during a period when astronomy within Australia wavered between state and federal control, were enormous. The techniques and technologies were not consolidated and often difficult to obtain, due to the impact of two world wars. Recessions and a major depression, along with colonial attitudes to science, made the resources required for progress at times unaffordable within meagre State Observatory budgets.

The participating observatories have been examined through archival research to reveal not only the significance of this star catalogue to the development of astronomy in Australia, but the momentous and unacknowledged contribution made by women in its production. I have investigated the participation of seven women in the projects through in-depth interviews and primary sources, including log books of star positions and magnitudes and observation log books not previously recognised as their work. This thesis reveals the Astrographic Catalogue as pivotal to the introduction of women into paid astronomical work in Australia.

The Astrographic Catalogue and Carte du Ciel are interrogated as products of colonialist ambitions to chart territory. Actor–network theory, centres of calculation and circulation models developed by sociology of science theorists, including Bruno Latour and Michel Callon, have been applied to analyse the control over the participating state observatories by colonial astronomy networks. My research has uncovered evidence of the interference of the

Colonial Secretaries and Astronomers Royal, and the sometimes catastrophic impact of economic, social and political upheavals.

This thesis argues that modernist ideals of automation and global standardisation provided momentum for the techniques of observation to change, and the eye of the astronomer was replaced by the eye of the human star measurer, predominantly women, who became the new point of contention at which individual variation occurred. I reveal that the involvement of women in Australia on the Astrographic Catalogue and Carte du Ciel was of greater significance than previously recognised; in addition, whilst they were restricted due to their gender, these women had agency in the scientific practice, workplace behaviour and employment conditions within the observatory. Furthermore, the creation of sex-specific roles in astronomy developed through the labour requirements of the large data sets for the Astrographic Catalogue, and the historical invisibility of women's work in science, have had contemporary consequences for the status and participation of women in astronomy.

THESIS DECLARATION

I declare that the research presented in this thesis is my own original work, and has not been submitted to any other institution for the award of a degree. To the best of my knowledge all material has been cited in the body of this work and in the bibliography. The thesis meets the requirements of the University of Sydney Human Ethics Committee (HREC) under protocol No. 12550.

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Toner Marie Stevenson, 2016

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My family, Ron and Charlotte Stevenson, made it possible for me to do the research, travel and spend the time required. My parents, Frank and Moira Clatworthy, encouraged my endeavours and told me to never give up.

Abbreviations

Acronyms most commonly used

AC	Astrographic Catalogue
AC-CdC	Two projects, the Astrographic Catalogue and Carte du Ciel
CdC	Carte du Ciel

Organisations, projects, missions and places

AAS	American Astronomical Society
AAAS	Australian Association for the Advancement of Science
AAO	Anglo-Australian Observatory (this has been called the Australian Astronomical Observatory since 2011)
ACT	Australian Capital Territory
ADS	The SAO/NASA Astrophysics Data System (the digital library for Physics and Astronomy)
ANZAAS	Australian New Zealand Association for the Advancement of Science
ASA	Astronomical Society of Australia
ASSA	Astronomy Society of South Australia
ASV	Astronomical Society of Victoria Incorporated

BAA (NSW)	British Astronomical Association (New South Wales branch)
BAAS	British Association for the Advancement of Science
CFA	The Harvard-Smithsonian Centre for Astrophysics
CSIR	The Council for Scientific and Industrial Research (which became CSIRO)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUL	Cambridge University Library
DASCH	The Digital Access to a Sky Century @ Harvard project
GAIA	ESA's space telescope launched in 2013, designed to map the Milky Way Galaxy in three dimensions
GAO	Government Architect's Office, New South Wales
USNO	United States Naval Observatory
ESA	European Space Agency
ESO	European Space Organisation
HREC	University of Sydney Human Ethics Committee
IAU	International Astronomical Union
MAAS	Museum of Applied Arts and Sciences encompassing the Powerhouse Museum, Sydney Observatory and the Discovery Museum
MNRAS	Monthly Notices of the Royal Astronomical Society
MO	Melbourne Observatory

MV	Museums Victoria
NSW	New South Wales
OPO	Old Perth Observatory located in Kings Park, Perth, until 1966
PO	Perth Observatory, located at Bickley from 1966
PROV	Public Records Office Victoria
RAS	Royal Astronomical Society
RGO	Royal Greenwich Observatory, when the Royal Observatory, Greenwich was relocated to Herstmonceaux, from 1957 to 1990 and Cambridge (1990–1998)
ROG	Royal Observatory, Greenwich
ROE	Royal Observatory, Edinburgh
SA	South Australia
SAO/ADS	Smithsonian Astronomical Observatory/NASA Astrophysical Data System
SCS	Sydney City Skywatchers, previously BAA (NSW)
SLNSW	State Library of New South Wales
SLSA	State Library South Australia
SO	Sydney Observatory
SO (RH)	Sydney Observatory at Red Hill (Pennant Hills)

SRNSW	State Records Authority New South Wales
SRSA	State Records South Australia
SRWA	State Records Office Western Australia
USNO	United States Naval Observatory
USYD	University of Sydney
WA	Western Australia
WAAS	Western Australia Astronomy Society
WiA	Women in Astronomy (Chapter of the ASA)
WISRNet	Women in Science Research Network (UK)
WWI	The First World War, 1914 to 1918
WWII	The Second World War, 1939 to 1945

INTRODUCTION: THE STATE OF THE HEAVENS 1887 TO 1964

In 1887 the New South Wales and Victorian State colonial governments endorsed the recommendation from their respective government astronomers that it was in the interests of the colonial states to participate in two major international astronomical projects: the Astrographic Catalogue and Carte du Ciel (Chart of the Sky). According to Wilhelm Gliese, contemporary proper motion astronomer, prior to the Astrographic Catalogue and Carte du Ciel (hereafter AC-CdC):

> "... no fundamental system existed which was usable as a basis for reference stars over the whole sky and was commonly accepted by the astronomical community."
> (Gliese 1988, p. 95)

The final Sydney zone of the Astrographic Catalogue was published in 1964. It has remained a controversial project because of its longevity, the failure to complete the Carte du Ciel, its involvement of women 'computers', and polarised views about the scientific value of the data it produced.

This thesis examines the AC-CdC program and its significance to the history of astronomy in Australia. It reveals the previously hidden social significance of the AC-CdC in Australia and its implications for our national heritage, including the representation of women within that narrative. The AC-CdC is analysed as a scientific work influenced by and performed within a changing social milieu over a period of seventy-six years. This thesis explores Australia's position within the AC-CdC global network, which was the first of its kind in astronomy and amongst the first in the sciences in which Australia was involved. The role of organisations, including museums, in the collection, preservation and interpretation of the AC-CdC is examined within the field of museum and heritage studies.

The AC-CdC projects were the first attempt at a comprehensive catalogue and chart of the entire celestial sphere as viewed from the Northern and Southern Hemispheres. The major technological advantage was the use of photography, which had, in the late nineteenth century, revolutionised astronomy. In colonial Australia, Henry Chamberlain Russell, the NSW Government Astronomer; and Robert Ellery, Government Astronomer for Victoria, were both champions for the application of photography to astronomy. These two authoritative men presented the great advantages of this new technology to branches of the Royal Society and in the popular press (Ellery 1891, p. 14; Russell 1891, 1894, 1895; Evening News 2 Jul 1891, p. 4). In his report to the Royal Society about the progress of photography in astronomy, Russell referred to renowned British astronomy author, Agnes Clerke, when he announced:

> "… the invention of the telescope itself does not mark an epoch more distinctly than the admission of the camera to the celestial armory."
> (Clerke 1890, p. 23; quoted by Russell 1894, p. 101)

Russell was an admirer of Clerke's work and he, like many other lead astronomers during that period, acknowledged her expertise. Clerke was amongst a small number of women who were acknowledged in the late nineteenth century as expert communicators of astronomy. One of the main research foci for this thesis was detailed investigation into the role of women in colonial observatories in Australia, and how the AC-CdC intersected with that involvement.

The AC-CdC endeavour ultimately involved Sydney, Melbourne and Perth observatories, each of which participated in this international program. Adelaide Observatory also participated but to a much lesser extent. The AC-CdC promised to bring international recognition of the Antipodean states' capability in astronomy and access to the latest technology and scientific methods, within a prestigious network comprised of the leading astronomers and observatories from around the globe. The participation of observatories at 'opposite sides of the globe' to the AC-CdC epicentre located at Paris Observatory was fundamental to achieving whole-sky coverage. I will elaborate on why the involvement of Australian observatories was notionally 'Antipodean' to observatories in the Northern Hemisphere, and essential due to the lack of capable and equipped observatories in the Southern Hemisphere.

Participation in the AC-CdC was not a straightforward process because of the application of new technology which required the invention of instruments, materials, methods, formulae and global communication techniques. Obtaining the resources required to successfully participate was fraught because government ministers did not necessarily understand the significance of the project, nor did they appreciate the sheer volume of work involved in cataloguing the star-rich, yet little explored sky, as seen from the Southern Hemisphere.

The Astrographic Catalogue (hereafter AC) required an extensive and appropriately trained workforce, which was not within the existing observatory resources. Initially the measurement for all zones was to be undertaken in Paris (Russell, letter to Mouchez, 23 Nov 1891, in Chinnici 1999, p. 358). In 1892 Ellery questioned the wisdom in transporting the glass plate negatives, suggesting duplicates be made if this were to be the case (letter Ellery to Christie, 5 May 1892, CUL RGO 7/162). By 1893 it was clear that a decision had been made that the plates should be measured locally; this had been communicated to the colonial observatories (Russell, letter to Christie, 28 Jul 1893). The dilemma of who would undertake this work, and at what cost, resulted in women being trained and employed. Debate about who would pay for and organise this process, and who would print the plates and catalogues continued throughout the lifespan of the projects.

Even though the photographs taken in Australia for the Carte du Ciel (hereafter CdC) were never printed, the AC-CdC has left an extensive material culture legacy. This legacy now resides in state cultural organisations including museums, universities, libraries, public archives and amateur astronomy societies. What was once exclusive to the scientific community has now become the property of organisations operating within spheres encompassing public education, heritage, community participation and environment.

Melbourne Observatory, located in the Royal Botanic Gardens Melbourne, ceased research operations in 1944 and the majority of its Astrographic and CdC records, the astrographic telescope and measuring machines were relocated to Sydney Observatory in the historic Rocks precinct. The materials associated with the Sydney and Melbourne zones of the AC-CdC were at Sydney Observatory at the time when it ceased scientific research operations and became part of the Museum of Applied Arts and Sciences (MAAS) in 1982. Under instruction from the International Astronomical Union (IAU Resolution 10, 1982, Appendix 7) and in agreement with MAAS (letter Lindsay Sharp to Evan Williams, 29 Feb 1984, MAAS Archive MRS 342), the AC, CdC and other star catalogue and photographic materials, instruments and the dome were relocated to Macquarie University, northwest of Sydney. The relocation costs were met by Macquarie University. The intention was to build a new observatory and conduct further research (letter Gareth Roberts to Sharp, 20 Feb 1985, MAAS Archive MRS 342; Vaughan 1991).

According to *Exploring the Heavens*, an authoritative history of astronomy in Australia written by astronomers Raymond Haynes, David Malin and Richard McGee and historian Roslynn Haynes, the AC-CdC instruments, records, data and buildings were considered of :

> 'interest neither to the public nor the New South Wales Museum of Applied Arts and Sciences, including the vast holding of photographic plates and the measuring machines that had achieved so much'
> (Haynes et al 1996, p. 68).

After enquiring about a mysterious dome I had seen in a field near Macquarie University, Nick Lomb, Curator of Astronomy for the MAAS (1982–2009) and a previous research astronomer at Sydney Observatory (1979–1982), introduced me to the AC-CdC in 2005 as an area for potential research. Lomb and I visited Macquarie University and met with Professor of Astronomy, Alan Vaughan to view the dome and other related materials. The Macquarie University Library basement shelves contained glass plate negatives and logbooks. In the storage sheds were instruments, which related to Sydney and Melbourne observatories, dissassembled in boxes. My initial research interest was around the lead astronomers, and the relationship between them and their global counterparts. Seeing these primary sources inspired a deeper interest in the heritage of the AC-CdC and what it might reveal. The material culture of the AC-CdC became fundamental to uncovering other previously hidden stories about women's participation in astronomy in Australia.

The heritage of the AC-CdC in Australia can be found in archives held by museums, universities, state records and observatories, and in private collections. There is an abundance of material in distributed collections relating to the AC-CdC; this is due to a previous interest in the original source data by astronomers who wanted to carry out further scientific investigations of these collections. The International Astronomical Union (hereafter IAU) was demonstrably interested in, but not accountable for, the location and condition of these collections for their potential scientific use (Jashek 1985, 1988; Debarbat et al 1987; Bucciarelli et al 2007). In 1987 the IAU supported a centenary symposium and publication (Debarbat et al 1987).

Only after I began to research the primary source materials did I understand that the collections held extensive new sources of knowledge which extended beyond the work of lead astronomers. There was ample evidence about the work of the less visible female star measurers and computers; hence, I could explore less investigated territory. This new evidence, once revealed, would not only be interesting to the field of astronomy, but of great importance to Australia's scientific and social history.

To understand the nature and extent of the networks between the participating Australian observatories, I investigated collections at Perth Observatory. During the primary material research, when I came upon a letter in the Public Records Office Victoria (hereafter PROV), I realised the role that Adelaide Observatory had played and the significance of the work by women there. The Perth Observatory AC-CdC materials were relocated from Old Perth Observatory at Mt Eliza in Kings Park to the outer suburb of Bickley in 1966 when the original Astrograph House was demolished. Through correspondence and interview with Acting Director Ralph Martin, I found out that Perth Observatory had carefully stored its AC-CdC glass plate collection; and during my interview with Education Officer Greg Lowe, I saw one of the few operational Astrographic telescopes demonstrated. Also on display was a measuring machine which was almost identical to that used at Sydney Observatory (Martin, Rowe 2011). During the course of my thesis, scientific research at Perth Observatory ceased scientific operations in March 2013, and the site became a museum and educational facility. A small group of volunteers are currently cataloguing the collection.

Astronomers have studied the Sydney AC glass plate negatives for comparative star magnitude and proper motion research. Between 1977 and 1982 David King, astronomer at Sydney Observatory, re-examined the Astrographic plate negatives of stars photographed from Sydney Observatory in 1893 and from Red Hill in 1900 for comparative research. He re-photographed the same areas of the sky at Sydney Observatory using the Melbourne Astrograph and compared the stellar positions and magnitudes between these and the earlier images (King 1978a,b, 1980, 1981). King also examined the gravitational properties of stars in globular clusters (King 1979).

The complete dataset from the printed Astrographic Catalogues was digitised and analysed by the United States Naval Observatory (hereafter USNO) for comparative star catalogue research in the 1990s (Urban 1997; Urban et al 1996, 1998; Urban & Corbin 1994, 1996, 1998; Urban, Corbin & Wycoff 1998). The AC-CdC data was used for the Tycho and Hipparcos satellite telescope star catalogues (Urban, Corbin & Wycoff 1998). Whilst the Sydney and Melbourne zones of the AC-CdC collection were in the Macquarie University

Library vault, six hundred and fifty of the Sydney zone CdC glass plate negatives were digitised and re-examined (Frew 2004, p. 32; Fresneau et al 2003, 2005, 2007, Bucciarelli et al 2007, p. 96). My research into the Australian AC-CdC revealed that the primary sources had previously been studied within the field of science but not for their sociological significance—this is the point of difference investigated by this thesis.

In the next section I describe how the AC-CdC came about, what problems it was instigated to solve, and what was at stake for the participating observatories in Australia.

WHAT ARE THE ASTROGRAPHIC CATALOGUE AND CARTE DU CIEL?

Little is known about the AC-CdC outside the field of astronomy; and whilst the language around this topic is familiar to astronomers, it is not in general circulation. In this section, I provide an explanation of the purpose of the projects and the terminology used throughout the thesis, which is integral to understanding the AC-CdC. Even amongst astronomers (for example Bhathal & White 1991, p. 28; Haynes et al 1996, p. 61, p. 94) the AC and CdC are regularly confused, or combined generically as the 'Carte du Ciel' even though they were two separate projects.

The human endeavour to map the stars and understand their movement dates back to the earliest civilisations, with evidence of star positions being observed by Aboriginal peoples in Australia (Haynes et al 1996, pp. 7–20; Cairns & Yidumduma Harney 2003, Norris & Hamacher 2009, Norris & Norris 2009), and by indigenous peoples in the caves of Lascaux in France (Rappenglück 1999). These ancient cultures observed and mapped the stars tens of thousands of years ago. The ancient Arabic and Greek cultures used co-ordinate systems to position stars (Hearnshaw 1996, p. 80). Articulation of the brightness of stars (known as magnitude) was recorded by Claudius Ptolemaeus in the first century in his 'Almagest' of 1028 stars (Hearnshaw 1996, p. 1), and illustrated star maps and celestial globes can be found in most cultures and in many forms. Stars are catalogued using a co-ordinate system, most commonly right ascension and declination. These co-ordinates are derived by constructing a theoretical celestial sphere around the Earth, where right ascension is the equivalent of longitude 'measured eastward around the celestial equator in hours of time from the vernal equinox' (Haynes et al 1996, p. 496) with 0 hours determined by the position of the sun on 20

March. Declination is a means of measuring ‘degrees north or south of the celestial equator’ with 0 degrees on the plane that runs through the vernal equinox (p. 487).

A catalogue of star positions is called an astrometric catalogue. The first astrometric catalogue of the southern stars as seen from Australia was the Catalogue of 7385 Stars, up to eighth magnitude, observed from the Parramatta Observatory from 1822 (Richardson 1835). There was a heightened interest and activity in exactly positioning the location of stars, called ‘positional astronomy’, in the late nineteenth century. This was because a new field called astrophotography had emerged; it used photographic methods to record the position of stars.

According to the detailed research by NASA Astronomer and Historian Stefan Hughes, the first successful photograph of an astronomical object was by American John William Draper when he imaged the moon in 1840 (2013, p.vi). However lunar photography is very different to taking images of the stars for scientific purposes and it was two decades before the technology was available for this. The first successful attempt at astrometry using photography was by George Bond, who had been experimenting at Harvard College Observatory (hereafter HCO), and photographed stars through a telescope in 1857 (Hearnshaw 1996, p. 117). As described by John Hearnshaw, Professor of Astronomy at Christchurch University, Bond used wet plate collodion techniques and he remarked on the ‘beauty and convenience of the process’ (letter Bond to Wm. Mitchell, 6 July 1857, quoted in Hearnshaw p. 119). In 1882 Henry Draper and Edward Pickering were experimenting with photography at HCO. Draper photographed the Orion Nebula, and stars appeared on the negative that could not be seen by eye (Hughes 2013, p. 90). According to Hearnshaw the HCO experimental work heralded photography as the future of positional and spectral astronomy and Hughes described this as the birth of Deep Space Astrophotography (Hughes 2013, p. 90, Hearnshaw 1996, p. 127).

Once photography was applied to astrometry, it meant that many more star catalogues (with stars accurately positioned) could be produced than previously, and then compared to future catalogues. These stellar comparisons would mean that the proper motion of stars, and hence also a rough idea of their relative distances, could be determined. In the late 19th century the structure of, for example, the Milky Way galaxy, which was all that was known of the Universe at the time, was not well known and this new data would help future astronomers determine the layout of the Milky Way and to better understand other astronomical objects and their relationships to each other. Similarly, spectral astronomy using photography meant that the device was fitted to the optical telescope and designed to spread out the electromagnetic radiation from a star into its different wavelengths, resulting in a spectrum which could now record these as photographs for comparison and dissemination. This made it possible to research the chemical composition of stars by analysing the emission and absorption lines, and to publish the results with images.

The development of photography for astrometry was fundamental to the instigation of the Astrographic Catalogue and Carte du Ciel (Russell 1890, p. 39; Hearnshaw 1996, pp. 113–179). A photograph taken in 1882 of a comet by David Gill, Director of Royal Observatory Cape of Good Hope, South Africa was remarkable, but this photograph became even more important because it revealed a large quantity of stars never seen. According to NSW Government Astronomer, Harley Wood's account in the Astrographic Catalogue, the origin of the AC-CdC project was accidental:

> "The Astrographic Chart and Catalogue seem to owe their origin to photographs taken of the great Comet of 1882 at the Cape Observatory. The great number of stars appearing on these and other photographs showed the brothers Henry of Paris the possibility of the photographic process …"
> (Wood 1971)

Paul-Pierre and Prosper-Matthieu Henry were brothers born a year apart, and both were assistant astronomers at Paris Observatory. They worked closely together and by 1884 were using photography for positional astronomy (obituary 1905, p. 349). They made lenses and worked closely with instrument maker Paul Ferdinand Gautier, who designed and made the mechanisms. The Henry brothers and Gautier constructed an equatorial telescope (which was essentially a giant camera) called an astrograph in 1885 (Jones 2000, p. 16; Hughes 2012, pp. 384–388). The combination of an objective glass lens (main lens) of 34cm in diameter, with a focal length of 343cm enabled them to consistently produce higher quality photographs of the stars; these were long exposures but still sharp. The first photograph was produced on 17 April 1885 (Weimar 1987, p. 11; Jones 2000). In his summary of the involvement of Sydney Observatory in the AC-CdC, Wood reiterated what had become a priori about the origin of the projects. However, many other imaging projects occurred at that time, and the application of photography to stellar and solar system research developed as a broader global movement. In his address to the Royal Society in 1891, and in a subsequent series of popular astronomy articles (1895, p. 194), Russell noted the developments in Britain, France and North America, most notably by chemist and astronomer Warren De La Rue, and astronomers William Huggins, Jules Janssen and Edward Pickering. According to Russell, the late nineteenth century was ‘an important epoch in the application of photography to the astronomers needs’ (1895, p. 311).

The reason for the sudden interest in photographic star charts and catalogues was a major technological advance which enabled reliable stellar photography. This advance was in the form of increased sensitivity of emulsions, which were pre-applied to glass plates. Because these plates were dry, they allowed for the long-exposure photography essential to capture faint stars. The commercial availability of dry silver gelatin plates at an affordable price by the Eastman Dry Plate Company immediately made this technology available (Russell 1895, p. 311; Hughes 2013, p. 90).

The development of photographic emulsion during the 19th century from the daguerreotype to wet collodion and then to the gelatin dry plate was pivotal to the practicality and results of photographic techniques in astronomy. It was also about developing a method that was safe for humans to use as researched by astronomer and journalist Edwin Aguirre (2004). The daguerreotype technique, invented by Louis-Jacques-Mande Daguerre in France in the 1830s, relied on a sheet of copper that was plated with silver and highly polished, then treated with iodine vapour. Toxic mercury fumes were used to develop the plate, and the image was fixed by being immersed in a solution of sodium thiosulfate (hypo), then toned with gold chloride (Aguirre 2004, p. 40). The result was a detailed direct-positive image of the subject; this method was used to photograph the moon with success, but it had detrimental health effects and was limited in its exposure time to a few minutes. In the mid-nineteenth century, Frederick Scott Archer used a glass plate coated with collodion, which is a highly flammable solution. Once the plate was exposed (for a maximum of a few minutes), it had to be processed immediately before the coating dried, and it was messy, inconvenient and had explosive ingredients (Aguirre; Ratcliff 2008, pp. 66–67). Nonetheless, some astronomers (such as Huggins) produced photographs and spectral images of celestial objects using this method with success. There were momentos failures, including photography of the transit of Venus (Russell 1895, p. 311; Ratcliff 2008, p. 140).

The gelatin dry-plate process was developed in 1871 by English photographer and physician Richard Leach Maddox; it replaced the collodion process. Ratcliff has explained the development of this technology relevant to the 1874 transit of Venus and the significance of Warren De La Rue's experimentation for this event (2008, pp. 66–74). The emulsion of gelatin was safe to apply (even edible) and convenient because the plates could be coated, left to dry and then used later, making commercial production viable (Aguirre 2004; Hughes 2013, pp. 71–78). These plates were reasonably consistent and could also be exposed for hours, which was essential for the magnitudes required by the AC and CdC.

Further to the importance of technological developments in plate emulsions and the objective lens development for astrophotography, Hearnshaw highlighted the influence of Norman Pogson in standardising magnitude measurement (1996, pp. 74–78). The Pogson scale, in which higher numeral values indicate lower brightness, was adopted in the 1880s. It represented a major step in unifying the magnitude scale in photometry so that data from different catalogues could be compared (Hearnshaw 1996, p. 106).

In 1885 Mouchez wrote to the President of the Royal Astronomical Society in London to say that he and Gill were planning to propose an all-sky chart using photographic methods (Mouchez 1885, p. 1). His letter was printed in the widely circulated Monthly Notices of the Royal Astronomical Society. According to Mouchez, this endeavour would take six, eight or ten years to complete if six or eight observatories from each hemisphere were involved. The purpose of the chart was to use the latest photographic techniques for scientific recording and data production of the entire celestial sphere. According to Gill, a printed star chart, made available through publication to all astronomers:

> "... would place every astronomer who possessed a copy of the paper impressioned [sic], in a position to work almost as accurately as the possessor of the original plate … the more I think about the more sure I am that it is the best method for a great international undertaking."
>
> (letter Gill to Mouchez, 4 June 1886, in Chinnici 1999, p. 90)

Gill successfully communicated to Mouchez the advantages of an accessible, photographed and printed, seemingly objective all-sky star chart, with minimised error through standardisation, repetition and comprehensive coverage of the celestial sphere. It was at this point that the idea of the all-sky, international chart of the sky, the CdC was born.

This positivist milieu, which dominated science in the nineteenth and twentieth centuries, relied on empirical methods and a belief in objective observation. Influential sociologists of science including Bruno Latour (1987) challenged the 'objective' nature of the observer—the position of the observer is examined further in this thesis. For the AC-CdC, the aim for objectivity was partnered with an ambition for greater availability of primary source material to astronomers, championed by Gill (letter Gill to Mouchez, 4 June 1886, in Chinnici 1999, p. 89). One-off glass plates were difficult and precarious to transport for research by others, so a printed map of the stars and a catalogue with star positions (both of which were standardised and covered the entire celestial sphere) was a worthy ambition. According to French historian of astronomy, Jerome Lamy, France's leadership in photography, and the opportunity to supersede John Herschel's Southern Hemisphere star catalogue, were amongst the reasons that Gill was able to persuade Mouchez on the merits of the project and to hold a conference of all potential participants and advisers (Lamy 2009a, p. 119).

Fifty-eight astronomers attended the well-known and documented meeting held at Paris Observatory on the 16th of April, 1887 (Winterhalter 1891, p. 9; Gill 1913, Debarbat 1987, Lamy 2009abc). This was the first truly international meeting of astronomers and it was conducted in French. A thorough transcription by USNO Astronomer Albert Winterhalter was published in 1891. At the meeting, Gill proposed that an additional project called the Astrographic Catalogue be undertaken in parallel to the CdC (Gill 1913, p. 131). The Carte du Ciel and Astrographic Catalogue were therefore two separate projects connected by their temporality, organisation and instrumentation.

At the end of the first conference there were twenty-four resolutions of which the 'principal objects' as transcribed by USNO representative, Lieutenant Albert Winterhalter were:

> " (a) To orecord the general appearance of the heavens for the present time; to obtain data which will allow the positions and magnitudes of all stars down to a given magnitude to be determined with the greatest possible precision – the magnitudes being understood in a photographic sense, to be defined later.
> (b) To provide the best means of utilising, as well now as in the future, the data furnished by the photographic processes."
> (Winterhalter 1891, p. 50)

Of note is a subtle change in emphasis of point (a) from the purpose (at the beginning of the conference) to form a 'general photographic chart' (Winterhalter p. 16) to (at the end of the conference) a 'record of the general appearance of the heavens' (p. 50). This change was controversial because the there was debate and no final commitment to the 'chart' at this time;

nonetheless, at the end of the first congress a general direction was set and sub-committees were formed. Over the following decades, decisions would be made about the projects, such as the duplication of photography, which were to have immediate impact on the Australian participants.

In the historiography of Australia's participation in the projects, the AC-CdC is often referred to generically as the 'Carte du Ciel' (Haynes et al 1996, pp. 61–64; White 1987, 45–50), or the 'Astrographic Chart and Catalogue' (Wood 1971). The two projects had many similarities but they were also unique in many of their processes and ambitions. I will now provide a general description of both projects and some of the terms used in the thesis to describe the projects. I will also explain the differences between the AC and the CdC because, whilst both used the same telescope, there was a difference in the processes (as shown in Appendix 3), and it was only the AC which involved the work of women in star measuring and computing.

According to Gill, the purpose of the AC was to produce, in printed catalogue form, the reduced positions of stars on an x and y-axis, and the brightness (magnitude) of stars down to the 11th magnitude (Winterhalter 1891, p. 49; Gill 1913, p. 131). The Henry brothers, working with Paris Observatory Director, Admiral Mouchez, have been widely acknowledged as leading experts in repeatedly working with long exposures to capture high-magnitude stars (Winterhalter 1891, pp. 6–8). The length of exposure for the AC was determined by the requirement to capture stars of magnitude eleven. This was different to the previously mentioned Henry Draper Catalogue, which recorded the spectra of stars down to 8th magnitude, produced by the Harvard College Observatory (Hughes, p. 90). The AC star positions were measured and then mathematically reduced to a single epoch, determined as the year 1900. The AC is the main area of research for this thesis.

The purpose of the CdC was to produce photographic plates of star images and print these as charts (Winterhalter 1891, p. 48; Gill 1913, p. 131). For the CdC, a magnitude limit of 14 was determined after debate about the feasibility of capturing 16th magnitude stars (Winterhalter 1891, pp. 31–33; Klumpke 1895, p. 210). This required even longer exposures than the AC, but determining the exposure time to obtain a standard magnitude was fraught with issues (letter Russell to Ellery, 20 Jan 1891, SRNSW, pp. 112–115). The plates were to be printed using a specific photogravure method to make a chart. According to the historiography of the CdC, this project was commenced by the participating observatories but never completed

(Hearnshaw 1996, p. 141). My research has shown that most of the CdC photographs were taken, but the prints were never made.

An important difference existed between the AC and the CdC. The AC was to catalogue stars down to the 11th magnitude and the CdC was to create printed charts of stars photographed with longer exposures achieving 14th magnitude (directly from the negatives) for others to analyse. Therefore it was only the AC that required measurement and data reduction.

There were many commonalities between the AC and the CdC projects. Each participant examined the same allocated zone of sky for both projects and used photography to capture a record of stars with a standardised astrographic telescope and an innovative lens. The British and British Colonial observatories purchased the lens from Howard Grubb and Sons in Dublin. The AC and CdC glass plate negatives were both exposed to a grid (called the réseau) before they were exposed to the light of the stars inside the astrographic telescope. Both projects required a specific number of reference stars on each plate and the resources to publish the findings. Both projects were in the field of astrometry, which is the accurate measurement of the positions of celestial objects to provide knowledge that informs celestial mechanics, astrophysics and most areas of astronomy and cosmology.

In 1890 the evolution in astronomy brought about by photography was popularised by Agnes Clerke, who published and lectured on astronomy for a general audience in Britain and the British colonies. According to Clerke, photometry, the measurement of the brightness of a photographed star, was essential in order to understand the relative distances between the stars in space. As elaborated by Clerke, the ability for the exposure of starlight on a photographic plate to provide accurate data was subject to the application of averages (1890, p. 20). Clerke explained that astrographic imaging suffered from atmospheric effects as well as the sensitivity of photographic gel to colour variations (1890, pp. 21,27). Therefore at the end of the nineteenth century, astrometry was still an imperfect science. This imperfection was, according to Clerke, partially compensated for by data reduction, a laborious task using calculations derived from experimentation to theoretically place all stars at zenith (directly overhead). This is the point at which there is the least loss of light due to the earth's atmosphere—the ideal location at which the star is photographed; however, this ideal was not practically achievable (1890, pp. 39–47).

The AC-CdC heralded the introduction of large datasets and the need to further determine global standards for measuring magnitude. The scope of the projects was only feasible through international collaboration not previously attempted on this scale. I will now analyse why and how the colonial observatories in Australia became not only involved but also essential to the completion of both projects.

DEFINING THE FIELD AND ITS SIGNIFICANCE

Previous analysis of the Astrographic Catalogue and Carte du Ciel projects has been conducted predominantly within the field of astronomy history. Three distinct fields are brought together in this thesis to examine the AC-CdC: the history of science with a focus on astronomy, the sociology of science and museum studies. The role of women in the AC-CdC has emerged in recent years, but has not been previously examined within the Australian context. In this section, this thesis is positioned within the contested legacy of the AC-CdC and within the history of astronomy in Australia (and its broader social significance).

Australian sociologist of science, David Turnbull has analysed maps as metaphors (1989, 1996). Turnbull has defined maps as cultural constructs with symbols and meanings not obvious to the uninitiated. This analysis applies to star maps and catalogues, which historically had technical names for attributes such as the position of stars, their brightness and colour. The AC-CdC was organised in an era when the creation of a taxonomy of all forms of nature was considered essential work for scientists. Astronomy developed its own taxonometric terms. For this thesis, I have referred to the Glossary of Scientific and Technical Words developed by Haynes et al, who are Australian astronomers and historians (1996, pp. 484–500).

In the historiography of the AC-CdC, there is consensus amongst astronomers that the AC-CdC projects occupied an extensive temporal period, and employed advanced technology and methodology in photography as applied to astronomy in the nineteenth century. It is also agreed that these projects have contemporary, if somewhat limited, application in further scientific research (Hearnshaw 1996, Urban & Corbin 1998, Hirschfeld 2004). Moreover, research into and analysis of the significance and impact of the AC-CdC have been included within the broader history of astronomy in Australia (White 1987; Bhathal & White 1991; Haynes et al 1996). The AC-CdC has been recounted within the histories of individual observatories and their lead astronomers (Utting 1992, 1994, 2000; Pickett & Lomb 2001; Russell 2008; Clark 2006 unpublished, pers comm 2012).

In the past decade, the field of research into the AC-CdC was expanded by analysis of these projects within the sociology of science by European academics (Aubin 2003; Bigg 2000; Lamy 2009; Hutchins 2008). Their publications have revealed new knowledge about the reasons for the AC-CdC (Aubin 2003, p. 99; Bigg 2000, p. 106) and the employment of women at Paris Observatory (Bigg 2000, pp. 96–98), Oxford Observatory (Hutchins 2008, pp. 344–347) and the Royal Observatory Greenwich (Brück 2009). Their investigations theorised the implications of the AC-CdC for observatories located in the city, the development of gender-specific roles in astronomy, and the industrialisation of astronomy. The implication of the AC-CdC as an influence on scientific communication methods was considered a notable development that emerged from the organisation for these projects (Bigg 2000, Lamy 2009ab).

This thesis contributes to an emerging interpretation of the history of science through a wider social and demonstrative lens. By uniquely bringing together Perth, Melbourne and Sydney Observatories into a detailed study, the specificities of the Australian political, social and economic environments, and relevant global conditions—which included economic boom, recession, and the first and second world wars—have been investigated. This thesis contributes to the global body of knowledge of the AC-CdC through research into the Antipodean experience by making the history more 'decentred and polyvocal', a localised view advocated by Carla Nappi, Associate Professor of History at the University of British Columbia, Canada (Nappi 2013, p. 104).

Nappi challenged global interpretations of the history of science and presented a future where 'history looks different as practised in different localities, be they localities of institution, geography, or medium' (2013 p. 103). Nappi proposed 'local case studies as a path towards a more polyvocal and encompassing narrative of science in global history' (2013, p. 103). According to Nappi, the advantage of this is the development of a collective dialogue, which takes into account local diversity; a contrast to the master narrative of the current historiography of science. In Australia, the pursuit of a more local and polyvocal approach to the history of astronomy is evident in recent investigations into Aboriginal cultural astronomy by Hugh Cairns and Bill Yidumduma Harney (2003), Ray Norris and Duane

Hamacher (2009), and John Goldsmith (2015). As I researched, it became clear that the master narrative of the history of Australian astronomy was not a collective dialogue. Furthermore, Australia's participation in the AC-CdC had been extensive, but the retelling and analysis of that participation was from a limited historical perspective.

It became evident during the early stages of the thesis that prior research and analysis of the Australian AC-CdC participant observatories had focussed on the more heroic aspects of astronomy performed by men. The women involved in the AC-CdC, the extent of their work and the instruments they used was an area not previously examined in detail. The research for this thesis has engaged with contemporary discourse on the representation of women in the history of astronomy, and within the broader history of science. I read and found comparative case studies, including research by local academic Claire Hooker, senior lecturer in Medical Humanities at the University of Sydney. Hooker's research into women's work in the sciences in Australia questioned why women who were doing science had been 'hidden' within authorised discourse (2004). The challenge of searching for the less visible aspects of the AC-CdC led me to engage with conferences and organisations which also focussed on the recognition and participation of women in astronomy, both in the past and the present.

In 2011, I presented a paper at Leicester University Museum Studies 'Curiouser & Curiouser' Conference (Stevenson 2011). In 2013 and 2015, I co-presented papers at the Museums Australia Conference, which focussed on my research for this thesis and its relevance to the broader field of heritage and museums. I co-presented three posters which were centred on my research into the history and heritage of the AC-CdC at the annual conferences of the Astronomical Society of Australia (hereafter ASA) in 2012, 2013 and 2014. I joined the Women in Astronomy (hereafter WiA) Chapter of the ASA. In 2013, I presented my preliminary findings about women's early participation in astronomy at the WiA National Workshop held at the University of Western Australia. The resulting paper was published in the *Papers of the Astronomical Society of Australia* (Stevenson 2014). In 2014, I attended the *Revealing Lives: Women in Science 1830–2000* conference organised by the Women in Science Research Network at the Royal Society, London. The papers presented at this conference examined the gender imbalance and discrimination at times evident in the historiography of science. Their findings provided evidence that my research into the role of women in astronomy (as part of the AC-CdC in the field of sociology) was part of a wider movement to re-assess scientific enterprise and reveal new knowledge about the role of women in science.

It became apparent in the early stages of research for this thesis that there had been little previous examination of Australia's participation in the AC-CdC from a social, museum and heritage studies perspective. I have applied museum and heritage theoretical models to the heritage collections relating to the AC-CdC in Australia. The Burra Charter (1976); Significance 2.0 (Russell & Winkworth 2009); and Connecting Collections and Thematic Studies of Museum and Heritage Collections (Winkworth 2001) were used as frameworks to investigate the significance of the distributed collections relating to the AC-CdC. This led me to consider the Sydney, Melbourne and Perth AC-CdC collections as an Australian thematic study of dispersed collections which held valuable social as well as scientific heritage.

Throughout the development of this thesis, I engaged with members of Division XII, Commission 41, History of Astronomy within the IAU, including cultural astronomer Clive Ruggles and astronomers and history of astronomy experts Suzanne Debarbat, Nick Lomb, John Hearnshaw, Wayne Orchiston and Ian Glass. In 2012, at the IAU General Assembly in Beijing, I presented a paper on communicating astronomy through its heritage and history during the Division C, Commission 45, Communicating Astronomy to the Public session (Stevenson & Lomb 2015). At this conference I attended the launch of the UNESCO World Heritage Portal to the Heritage of Astronomy, an initiative of the IAU and UNESCO World Heritage, developed under the direction of Ruggles (Ruggles & Cotte 2010). The Portal is a repository for local case studies of astronomy and a communication technology aid for the identification of significant astronomical heritage with the potential to inform decisions about those sites (Ruggles 2009, p. 14).

According to Ruggles, sites demonstrating Australian Aboriginal astronomy, colonial observatories and radio astronomy instrumentation locations are potential World Heritage sites (Cotte & Ruggles, 2010, p. 193). The publication for the IAU UNESCO Heritage of Astronomy initiative introduced methodologies for determining industrial technology significance of specific relevance to astronomy (Cotte & Ruggles, 2010). When I investigated the discourse amongst astronomers over the past four decades regarding the re-use of the AC-CdC data and the digitisation of the star catalogue plates at Harvard College Observatory (Jones 2000, p. 19; Fresneau et al 2003, 2005; Bucciarelli et al 2007, Laycock et al 2010, p.

1062; Tang et al 2010), I found that contemporary astronomy intersected with historic collections.

Prior to Cotte and Ruggles, industrial archaeologist, Robert Gordon, had advocated for the preservation of instruments and machines, structures and buildings in analysing history, as these were equivalent to documents in terms of heritage significance (Gordon 1993, p. 75). Gordon's theoretical framework was applied in the early stages of this thesis to the measuring instruments used at Sydney Observatory. My investigation into the technologies used for the AC-CdC, inclusive of the technological data, had tangible ramifications for the Museum of Applied Arts and Sciences and Sydney Observatory, as I will now explain.

The dome built at Sydney Observatory in 1950 (to complete the Sydney and Melbourne zones of the AC-CdC), a measuring machine, the Melbourne Astrographic telescope, Sydney and Melbourne zones glass plate negatives and associated journals were removed from Sydney Observatory between 1984 and 1986. These artefacts were held by Macquarie University until they were relocated into the custodianship of the MAAS between 2008 and 2013. In 2011 there was a distributed collection agreement between MAAS and SRNSW (MAAS records DIR/11/0015).

The re-acquisition of the heritage dome by MAAS provided a heritage rationale for the construction of a new building for interpreting the AC-CdC at Sydney Observatory. This building, called the East Dome, was completed in December 2014 and opened in January 2015 (Stevenson 2015). The building supports a dome built for the AC-CdC and houses the Melbourne Astrographic telescope and other related AC-CdC artefacts. The new facility improved access to the AC-CdC artefacts and furthered the protection of scientific buildings, instruments and documents for historical and astronomical research.

Stanford University scholar, Alex Soojung-Kim Pang identified a 'post constructivist strain' as essential to enquiry into the history of scientific practice. According to Pang, there is no neutral viewpoint. Therefore an account of the local, social and cultural conditions, as well as the emotions and 'feeling and flavour' of science, as it existed at the time, is required to understand the full spectrum of past scientific practice (Pang 2002, pp. 5–6). For this thesis, my investigations through interview techniques and primary source material research revealed some unanticipated emotions and interactions between people involved in the AC-CdC.

LITERATURE REVIEW

To examine past discourse relevant to Australia's participation in the Astrographic Catalogue and the Carte du Ciel, I reviewed a broad range of texts within the history of astronomy, the history of science, gender studies, museum studies and the sociology of science. It was not surprising that due to the longevity of the AC-CdC, the type of literature which resulted from the AC-CdC projects, whilst not extensive, was varied in both its nature and intent. I have identified three distinct phases into which the literature relevant to this thesis falls. Distinction between these three phases emerged from my literature review.

The first literature was written during the establishment, development and production of the AC-CdC from the late nineteenth through to the first quarter of the twentieth century. During this phase astronomers communicated the projects' aims, techniques, technologies and their associated experiments with photography in astronomy. The astronomers documented the AC-CdC scientific methods and released research findings. The sources I referred to were published within scientific journals and written primarily by the lead astronomers in the British, French and British colonial (Australian) participatory observatories.

The second phase of literature expressed reflection on the projects, research using the data and critical assessment of the projects, their methods and outcomes. Dating from the mid-twentieth century, this phase reached its climax during the centenary of the AC-CdC, when the IAU Symposium on the Carte du Ciel was held at Paris Observatory in 1987. In this phase there was renewed interest in the projects' contemporary scientific value, and discourse centered around re-examination of the AC-CdC data and resolving how it could be converted into digital form. In Australia, there was a renewed interest in a national history of astronomy during the 1980s and 1990s; reflection on the AC-CdC was part of this. I found that the few accounts of the history of astronomy in Australia during this phase (authored by local astronomers) were an invaluable resource to begin deeper and broader investigations. Local literature around land mapping as intrinsic to colonial studies, particularly by David Turnbull (1989), had relevance for my investigation of the mapping of the sky in the British colonies.

The third literary phase was heralded by divergent scientific and sociological analysis of the AC-CdC. This phase is characterised by a renewed interest in the sociology of the AC-CdC and other similar astrometry catalogues. This phase emerged predominantly in France, the US and Britain. Literature in this phase occasionally acknowledged and was inclusive of the work of women; this thesis is a continuum of such literature. I read the history of the representation of women's participation in science. Barbara Welther (1982) and Margaret Rossiter (1980, 1983) are American historians of science and they were amongst the earliest to gather quantitative and qualitative evidence about the barriers to women's participation in science. Welther has been on the committee and held the chairperson position at the Historical Astronomy Division of the Astronomical Society of America, and worked at the Harvard Smithsonian Centre for Astrophysics. Her research focussed on the women at HCO. Rossiter was Editor of *Isis* and taught at Cornell University. Rossiter's quantitative research findings led to her naming the concentration of women in some disciplines and the absence in others as "territorial segregation". Welther and Rossiter's findings substantiated the prejudice experienced in academia and challenged the previously understood extent of women's involvement in scientific discovery.

Authoritative texts in the broader field of the sociology of science, particularly the theoretical models developed by French sociologists of science Bruno Latour (1987, 1993, 1996) and Michel Callon (1981, 1986) influenced this thesis. The discourse between sociology of science theorists over the past five decades, particularly Latour, Callon and French science historians David Aubin, Charlotte Bigg and Jerome Lamy, provided both a foundation and an analytical framework through which to view the AC-CdC in Australia. My analysis of the progress of the AC-CdC in Australia within the relevant social milieu relied on journalistic writing and comparative studies in related fields. My initial investigation into the sociology of science was through physicist, historian and philosopher of science, Thomas Kuhn, who is widely acknowledged as having changed the way the history of science is framed. Kuhn challenged perceived 'truths' and separated normative science from the more individualistic approaches which resulted in a 'paradigm shift' (Kuhn 1962).

Kuhn has been widely acknowledged as pivotal to the introduction of the sociology of science by introducing cultural, economic and social actants as intrinsic to scientific process and results. According to Kuhn, the struggle to achieve standardisation in the scientific method did not instigate, nor prevent, significant scientific discovery; Kuhn attributed scientific discovery to individual human thought and action. Kuhn's introduction of the human element opened up speculation about the prior importance placed on the accumulative nature of science in making new breakthroughs. This conceptual position is relevant to the AC-CdC project because it supports the impetus behind the projects' instigation, and is one explanation as to why there were few breakthroughs by those who participated in the scheme. The use of photography and the global and collaborative nature of the AC-CdC could be described as creating a resource for use in 'normal science', defined by Kuhn as:

> "... research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice."
> (1962, p. 10).

The projects were designed to fit within the existing 'paradigm' of positioning stars within a celestial map and defining their characteristics in tabular form. It was not a revolution or paradigm shift. For the participants in the AC-CdC, the creation of the data and dispersion of knowledge were the objectives. Individual thought and action with the data, and analysis which may have led to new findings, was not a priority. Kuhn stated that stellar positioning was a process of taxonomy:

> "... that class of facts that the paradigm has shown to be particularly revealing of the nature of things. By employing them in solving problems, the paradigm has made them worth determining both with more precision and in a larger variety of situations. At one time or another, these significant factual determinations have included: in astronomy—stellar position and magnitude… Again and again complex special apparatus has been designed for such purposes, and the invention, construction, and deployment of that apparatus have demanded first-rate talent, much time, and considerable financial backing."
> (Kuhn 1962, pp. 25)

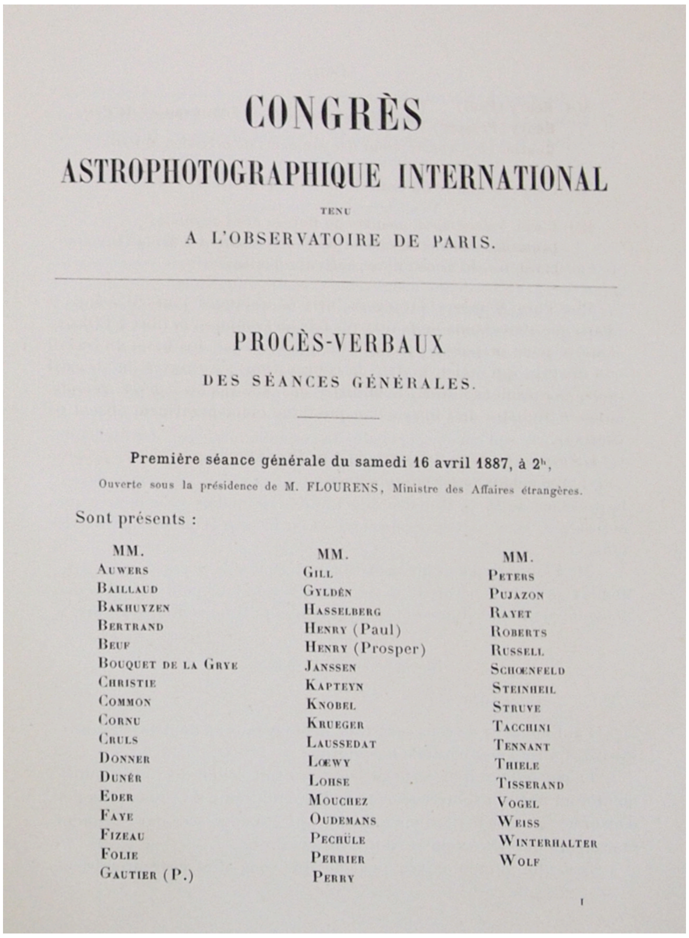
Kuhn's rationale explained why astronomers handed over the examination of the glass plates to lesser qualified persons; yet science historian Jessica Ratcliff referred to Kuhn when she emphasised that Victorian astronomers understood and maintained the intimate relationship between measurer and instrument error, and therefore they did not assume data was an unshakeable bedrock of truth (2008, p.148). Nonetheless, Kuhn's rationale informed my realisation that the AC-CdC was never in the realm of changing astronomy-related theory, but the evolution of the method of photography for astronomy—considerably enhanced by the AC-CdC—impacted on the acceptance of paradigm shifts in physics at the time of the projects. One of these paradigm shifts was proof of Einstein's theory of general relativity using stellar photography, changing previously held beliefs in the nature of space and time.

Sociology of science theorists and historians of science whom I have investigated in researching the AC-CdC were influenced by Kuhn. These included David Bloor (1976), Callon and Latour (1981, 1986), Steve Woolger (1979), and previously mentioned historians of science in America, Welther (1982) and Rossiter (1980, 1983). Their methods of analysis used primary source documents to uncover what went on in the laboratory or in the less investigated areas of science. Their research challenged previously accepted historiographic texts about how scientific enterprise occurred and who was involved in the networks. The investigations by Latour, Callon, Woolger, Welther and Rossiter gave new insights into the less obvious networks (fundamental to scientific process), and the identification of the non-heroic actants and acknowledgement of their agency, influenced my methods.

The following literature review has been divided into the three phases previously mentioned in this section.

Phase One: Development and Promotion

The first phase of literary texts were written during the establishment and development of the AC-CdC, largely by astronomers from participating observatories. The most innovative text was *The Bulletin*, produced by the Permanent International Committee of the Carte du Ciel (Tisserand 1890, 1892, 1895). This was a significant new form of communication in astronomical practice as revealed by Jerome Lamy (2009ab). USNO astronomer, Winterhalter, transcribed the discourse from the 1887 congress from French to English (1891). This and other summaries of the first and, later, 'Carte du Ciel' congresses were seen as having broad global relevance as they were posted, either in summary or full, in the scientific journal *Nature*, instigated and edited by self-funded scientist Norman Lockyer and his son, William James Lockyer (1896, 1901, 1909).


CONGRÈS

ASTROPHOTOGRAPHIQUE INTERNATIONAL

TENU

A L'OBSERVATOIRE DE PARIS.

PROCÈS-VERBAUX

DES SÉANCES GÉNÉRALES.

Première séance générale du samedi 16 avril 1887, à 2h,

Ouverte sous la présidence de M. FLOURENS, Ministre des Affaires étrangères.

Sont présents :

MM.
Auwers
Baillaud
Bakhuyzen
Bertrand
Beuf
Bouquet de la Grye
Christie
Common
Cornu
Cruls
Donner
Dunér
Eder
Faye
Fizeau
Folie
Gautier (P.)

MM.
Gill
Gyldén
Hasselberg
Henry (Paul)
Henry (Prosper)
Janssen
Kapteyn
Knobel
Krueger
Laussedat
Lœwy
Lohse
Mouchez
Oudemans
Pechüle
Perrier
Perry

MM.
Peters
Pujazon
Rayet
Roberts
Russell
Schœnfeld
Steinheil
Struve
Tacchini
Tennant
Thiele
Tisserand
Vogel
Weiss
Winterhalter
Wolf

1

Figure 2: List of attendees at the 1887 Congress, Bulletin I (Guthier-Villiers 1887) (Collection Perth Observatory),

Summaries and proceedings of the congresses and regular reports from the lead colonial astronomers from the participating AC-CdC observatories were published in the Monthly Notices to the Royal Astronomical Society (MNRAS). Reports of AC-CdC which documented the initiation and progress were published in the MNRAS by the following astronomers during the years indicated: Henry Chamberlain Russell (1889–1904), Robert John Ellery (1889–1895), Charles Todd (1894–1897), Pietro Baracchi (1896–1915), Henry Alfred Lenehan (1906–1909), William Ernest Cooke (1900–1912; 1913–1926), John Baldwin (1916–1943), Harold Burnham Curlewis (1913–1917), George Frederick Dodwell (1910–1939), James Nangle (1927–1940) and Harley Weston Wood (1942–1971). These reports, now available digitally on NASA's Astrophysics Data System (hereafter SAO/ADS), indicated inhibitors and catalysts to AC-CdC progress, and were an important research source for this thesis.

In Australia, the government astronomers sought opportunities to promote Australia's involvement in the AC-CdC to the broader community. Transcribed speeches made to the

Royal Society and other organisations featured in newspapers and in *Popular Astronomy*, an American magazine for amateur astronomers available globally (Ellery 1892, Russell 1891a, 1894ab, 1895). The NSW Government astronomers published modest booklets at pivotal historic moments (Russell 1892b, Nangle 1930, Short 1936, Wood 1958, 1982). Russell produced an elaborate fabric-bound and gold-embossed book with technical illustrations and images celebrating the cemented marriage between astronomy and photography titled 'The Star Camera' (1892a). Written within the hegemony of their social condition, this literature celebrating the achievements of Sydney Observatory was political, widely distributed, and aimed to record and promote the observatory and its work, both at home and abroad.

The lack of acknowledgement for the women who measured the AC stars was symptomatic of most reports and research literature published during this phase (eg. Turner 1912, Gill 1913, Wrigley 1911, Pocock 1915, Barton 1936, 1937) but exceptions exist, especially when the astronomers were determining individual error (Christie & Dyson 1894). Dorothea Klumpke, who had a Doctorate in Astronomy from the Sorbonne University Paris, was the only woman to write an account of the Astrographic Catalogue contemporary to its development (1895). The difference between Klumpke's accounts of the measurement process and those written by Christie, Dyson, Gill and Turner is that Klumpke highlighted the expertise required for the AC measurement and named the women who worked at Paris Observatory (1895, 1899). The authoritative literature surrounding the Australian participation in the AC-CdC followed a pattern that lacked acknowledgement of the women's work. Even though Baldwin, Cooke, Curlewis and Wood listed the women's names in the explanatory text and Wood, who wrote the most complete explanation of an observatory's participation in Volume 53 of the Sydney Astrographic Catalogue (1971), acknowledged individual women by name within the AC, this did not translate into acknowledgement in research which resulted from their work.

British astronomers wrote reports, which included detailed concerns about decisions made for the AC-CdC and new methods for the photographic processes (Turner 1902, W J S Lockyer 1901). Of particular relevance to this thesis are the reports by Gill (1887, 1913), Herbert Hall Turner, Director of Oxford University Observatory (1912, 1918, 1926), and Arthur Eddington (1922). Gill was an instigator and promoter of the project, Turner published *The Great Star Map: being a brief general account of the international project known as the Astrographic Catalogue* in 1912 for both astronomers and a general audience. Turner wrote extensively about the role of lead British astronomers and remarked on some of the social and cultural aspects of the project. In 1922 Eddington classified the Astrographic Chart as one of the six major 'landmarks of astronomical progress in the century' (p. 815).

In America at the Harvard College Observatory (hereafter HCO), Edward Pickering was criticised by Turner and fellow editor of *The Observer*, Ainslie Common, for not participating in the AC-CdC and for HCO setting up a rival scheme (Hearnshaw 1996, p. 140). This was a different view to that of Harold Weaver, University of California astronomer, whose research unveiled evidence that Pickering was not interested in an all-sky catalogue because he had developed different methods to produce star catalogues for very specific regions of the sky (Weaver 1946, p. 211, pp. 291–295, pp. 339–341). Whilst Pickering's catalogue had similarities to the AC because it used photography, its main purpose was photometry and spectroscopy. The HCO photometric and spectroscopic research involved women at a deeper research level that the AC-CdC. It is the papers produced with and by the women employed at HCO which are standout comparisons to the male-dominated research output of the AC-CdC.

Very few texts critiqued the nature of the AC-CdC projects, or analysed the sociological aspects of their production, during the development literary phase. One of the earliest analysis of the projects was during an IAU Symposium held on the centenary of the AC-CdC with the proceedings published a year later (Debarbat et al, 1988). Critique and analysis of the AC-CdC, and development of the history of astronomy in Australia, make up the second phase of literature. A review of this phase now follows.

PHASE TWO: DOCUMENTATION, ANALYSIS AND CRITIQUE

Literature in the second phase is characterised by the growth of publications in Australia covering the history of local science, inclusive of astronomy, in which the AC-CdC is critiqued. Science as an expression of national identity coincided with the 1988 bicentenary celebrations in Australia; these expressions often made possible by associated grants. Science historians, social scientists and academics including Roderick Weir Home (1988), Sally Gregory Kohlstedt (1997, 1999), Roy MacLeod (1988) and Ann Mozley Moyal (1976, 1979) contributed to and edited books about the development of science over two centuries, with an emphasis on colonial development and then a maturing national approach to science led by the AAAS, universities and the Council for Scientific and Industrial Research (hereafter

CSIR) . According to Home and Kohlstedt, British imperialism and its lines of authority and model structures dictated the formation of science in Australia (1991, p. 16). MacLeod added that intercolonial co-operation by the formation of the Australian Association for the Advancement of Science (hereafter AAAS) in 1888 was a forerunner to federation (1988, pp. 40–67). David Wade Chambers (1991, p. 24) blamed the lack of intercolonial co-operation for spreading science too thin in the colonies, which would have fared better at the outset from a nationwide approach. Local and global debate about colonialism models, which were inclusive of Australia, more broadly reflected on the relationship between the colonised and colonial power relationships, and produced discourse which was inclusive of science.

To understand the colonial context for naming and mapping regions of the sky, I broadened my literature research beyond the celestial to the mapping of the earth. Cartography of the globe occurred during the late nineteenth and early twentieth centuries, and the application of photography to this cartography was a revolutionary approach. American academic, Norman J. Thrower's cartographic research was a pivotal work in which maps were positioned as an expression of humankind's need for spatial dominance (1972, new edition 2007). According to Thrower, contemporary cartography commenced in 1891 when there was a proposal for a detailed, international map of the world (2007, pp. 162–163). British historian, Ian Inkster, and American historian, George Basalla, battled over Basalla's three-phase scheme of the development of colonial science (Basalla 1967, Inkster 1985). Inkster emphasised the socio-economic influence on science and argued that the young colony was not considered mature enough to attract 'peers', provide reward for scientific endeavour, have original thought or popularise science (1985). Whilst there were differences of opinion between Thrower, Inkster and Basalla about stages of colonial development, when these occurred and how they overlapped; there were also commonalities which bridged the development and application of astronomical and cartographic photography.

This literature was helpful in understanding the rationale behind the AC-CdC and the environment in which these projects were deliberated. In the colonial milieu, as described by the literature, research for mapping and cataloguing was favoured over analysis. Inkster's analysis of the development of colonial education, science and museums during the period 1888–1916 (1985, p. 697) was a useful social framework to the historical background for this thesis.

Literature reflecting on the broader history of astronomy in Australia emerged following the 1970s; a period when there was major investment in radio and optical astronomy by the Australian Federal Government and through international partnerships.

Critical analysis of the scientific value of the AC-CdC was the focus of the centenary of the Carte du Ciel and Astrographic Catalogue conference held at Paris Observatory in 1987. During this conference, historical research was presented and a renewed interest in the projects' contemporary scientific value developed. The proceedings were recorded in a publication produced by the IAU, the conference sponsor (Debarbat et al 1988). Papers were presented about how the catalogue could be converted into a digital form and its potential uses (Corbin &Urban 1988). As optimistically forecast by Arthur Upgren, co-Chairman of the IAU Scientific Organising Committee:

> "At this gathering, the participants looked backward gratefully toward the achievements of those who came before us, and forward with a glimpse of the progress we ourselves hope to make."
> (Debarbat et al 1988, p. 1)

Graeme White was the only Australian astronomer who attended. White's paper summarised the involvement of the state observatories in the AC-CdC, though both projects were encapsulated together as 'Carte du Ciel'. Royal Greenwich Observatory (hereafter RGO) astronomer Nathy O'Hora criticised the state governments in Australia for their lack of support for the AC-CdC observatories. The commitment made to the AC-CdC by the government observatories in Australia emerged during the conference as having been contentious.

The most comprehensive history of astronomy in Australia published to date is *Explorers of the Southern Sky: a History of Australian Astronomy*, a collaborative work between historian Roslynn Haynes and astronomers Raymond Haynes, David Malin and Richard McGee (1996). This and other texts, such as (and to a lesser extent) *Under the Southern Cross: A brief history of astronomy in Australia* by Ragbir Bhathal and Graeme White (1991), defined an era of critique of the AC-CdC projects and emerging opinion that Australia's involvement in the AC-CdC was at the expense of other, more valuable astronomy research.

The view that the AC-CdC and related positional astronomy projects stymied other astronomical work in Australia became hegemonic amongst astronomers. Home clearly stated the shared sentiment that the AC-CdC was ‘a massive and dreary international program of photographic mapping of the skies’ (1988, p. 153); and Orchiston (2004) reified analysis by Hearnshaw (1996) and Haynes et al (1997) that the lack of spectroscopic and astrophysical research by the state observatories was due to their commitment to the AC-CdC:

> “A feature of Australian astronomy between 1880 and 1920 was the continued adherence to positional astronomy by the nation’s professional observatories, at the expense of the newly emerging astrophysics.”
> (Orchiston 2004, p. 69)

Furthermore, research by the Editor of the *Journal of the History of Astronomy*, Associate Professor Wayne Orchiston, identified conflict between amateur and professional astronomers in Sydney, some of which was due to commitment to the AC-CdC by the state-run observatories (Orchiston 1991, 1999; Bhathal & White 1991; Haynes et al 1997, p. 114). The relationship between the AC-CdC and the survival or demise of the state observatories at various times also emerged in the same discourse.

Derek Jones, astronomer with Cambridge University, refuted the preference of astronomers to qualify astrophysics over positional astronomy, stating that they were interdependent and that one was not more important than the other (Jones 2003, p. 267). There have been recent critiques of the AC-CdC, most notably by British astronomer and historian Stefan Hughes (2013) in his epic work about the ‘forgotten lives of the men and women who first photographed the heavens’. Hughes’s summation is that the AC-CdC was ‘years ahead of its time and as a consequence lacked the necessary technology to succeed’ (p. 974).

Hughes’ work consolidated some of the AC-CdC technologies, particularly in reference to the astrographs. Even though the title of his work promised to be inclusive of women, the focus is predominantly on Wilhemina Fleming, an already known bright star for her work analysing star spectra. Hughes did not interrogate the work of women who measured and computed the stars; and some of his research, specifically surrounding the Australian participants in the AC-CdC, is disputed by my analysis of the primary source research undertaken for this thesis. Even though Hughes’s history of astronomical photometry and spectroscopy is outside the temporality of most second-phase literature, its format and content is within this genre.

Local studies of Australian astronomy also focussed on the lead astronomers and instrumentation. Literature about Adelaide Observatory is mainly about Charles Todd and William Ernest Cooke (Edwards 1993; Haynes et al 1996, pp. 81–86; Hutchinson 1980). The history of the Astronomical Society of South Australia by amateur astronomer Brian Waters (1980) documented the participation of women, as well as men, in amateur astronomy; as such, it was a valuable and illuminating resource. Similarly, Barry Clark's documentation of Melbourne Observatory and analysis of primary sources have provided a valuable foundation for my further and more specific research (2006, 2012). Museums Victoria Curator, Richard Gillespie, added substantially to the social analysis surrounding Melbourne Observatory and the Great Melbourne Telescope, which intersected with the early years of the AC-CdC (2000, 2011)

Barry Clark's Melbourne Observatory site report (2006) was a detailed, evidence-based account of the buildings and resources aimed to preserve, reinstate and document the site. In a similar way, James Semple-Kerr's conservation reports for Sydney Observatory (1992, 2002) had the specific purpose of redressing the conservation of buildings and artefacts and advising on the future use of the site. Sydney Observatory Curator, Nick Lomb, contributed to a popular history book which placed Sydney Observatory within the visual, photographed and painted, past and present, social and geographical setting of Observatory Hill (Pickett & Lomb 2001). Women and the AC-CdC are briefly included as part of the 'observed and observer' experience at Sydney Observatory. Muriel Utting was Perth Observatory's Honorary Historian (Candy in Utting 1989; pers.comm., Martin 2011). Utting's publications contain a complex narrative (using primary sources) through which reference to the AC-CdC are woven (Utting 1989, 1992). I examined several biographies of the government astronomers deeply involved in the AC-CdC but their innovations in the workplace to provide the technologies, resources and new workplace structures for the AC-CdC remained elusive. For example academic David Hutchinson (1981) and Utting (1989) examined the career path of William Ernest Cooke. Hutchinson and Utting highlighted the AC-CdC, but neither revealed Cooke's innovations in the introduction of women into the astronomy workforce at each of the three observatories he worked.

The third literary phase is characterised by a deeper analysis of scientific production. Theoretical sociological models, which included the laboratories, the technologies and the people in causal actor networks, emerged through local case studies and were tested universally. Further critical analysis of colonial relationships and the historiography of science produced even more inclusive models which considered the local as well as the broader context for scientific work, and identified past gender and racial colonial prejudices.

Phase Three: Sociology, gender, astronomical heritage and AC-CdC potential

In this section, I examine relevant literary interpretations of science as a social phenomenon in which the relationships between people and things produce scientific outcomes. I begin with the intersection between the literature surrounding the sociology of science and museum theory.

Latour, Law and Callon developed theoretical models for scientific transactions that connected map making, colonialism and science, and influenced museology in three ways (Latour & Woolger 1979; Callon & Latour 1981; Callon 1986; Latour 1987, 1993, 1996, 2005). Firstly, they forced the re-examination of the historiography of museum collections, specifically cartography, astronomy, geography, and artefacts and specimens acquired during the colonial period as part of a knowledge cycle. Secondly, they examined the power museums have as cultural laboratories to influence perceptions of history through acquisition, interpretation and display. Thirdly, Latour, Callon and Law examined the way people, places and things are all involved as actants in producing knowledge.

It is generally accepted that as communicators and keepers of science, museums are embroiled in colonisation and perceptions of science and its history (Macdonald 1998, pp. 1–24). Sociologist and museologist, Tony Bennett, drew comparisons between museums and laboratories and referred to Latour and Woolger's examination of scientific laboratories (Bennett 2005, 2009). Bennett, Turnbull (1989, 1996), and sociologist and museum analyst, Sharon MacDonald (1998), have critically examined the social role of museums which collect and display scientific artefacts. MacDonald was critical of the cultural phenomena created during the development of science museums where order, visibility and the concept of certainty of scientific work, amongst other modernist principles, predominated (1998, pp. 10–11). According to Bennett and MacDonald, museums socially constructed the placement of ideas and the curatorship of objects through classification systems. Bennett (2005, 2009) and MacDonald (1998) drew parallels between how museums acquire and interpret collections and how Latour and Woolger discovered scientific research was arranged and interpreted in laboratories (Latour & Woolger 1979).

Instrumentation and its relationship to humanity are central to this thesis. The transference of vision from the person to the technology, through the development of optical devices and photography in the mid-nineteenth century, was central to the development of the AC-CdC. Art critic Jonathan Crary challenged the notion of an objective observer (1992); he argued that the impossibility of this was due to humanity and machines (1992 p. 147). Crary's analysis is primarily about the camera obscura, however, there are direct parallels with the AC-CdC. With the addition of a camera to the telescope, a large proportion of human interference in the translation of the image to the page (that occurred when sketches and notations were made by hand) was removed by instrumentation. Crary's analysis that the machine as observer was also flawed led to a closer examination in this thesis of how human and instrument-based errors were managed during the AC-CdC.

Turnbull's analysis of terrestrial and celestial maps as powerful territorial instruments referenced Latour's theoretical models within an Australian context (1989, 1996). Turnbull revealed that Latour's 'circulation of reference' model had relevance for colonial artefact collections and museum interpretations. Historian Alex Soojung-Kim Pang also adopted Latour's method of 'following actors' into the field when researching the history of eclipse expeditions (Pang 2002, p. 9). Pang defined 'social construction' as meaning not only the determination of facts through practices, and the influence of interests and ideologies, but also embracing the 'emotional texture of scientific practice and discovery' (2002, p. 5). According to Pang, passions, worry and disappointments are influential forces in scientific work and should be included in historical texts (p. 6). Nonetheless, this must be evidence-based, which is, according to Pang, a challenging proposition over time. Human interpretation, despite standardised and normative techniques, is an enduring contemporary theme which has broadly influenced this thesis and my findings.

Studies of eighteenth- and early nineteenth-century observatories, including those participating in the Carte du Ciel and Astrographic Catalogue, by Jerome Lamy (2006, 2009ab), Charlotte Bigg (2000, 2009, 2010), David Aubin (2003, 2010), Simon Schaffer (2010, 2011) and Otto Sibum (2010) contended that there are distinct 'observatory sciences'. Aubin, Bigg and Sibum defined nineteenth-century observatories as having generalist scientific concerns aligned with the Humboldtian theory of one science, the 'Heavens and Earth' (Aubin et al, 2010). Aubin and Bigg's investigations of colonialism, mapping and astronomy (2003, p. 79) demonstrated that for city-based observatories, strengthening colonial networks and improving survival in a city environment were significant factors for this thesis to investigate. Their analysis led me to reconsider how competing priorities between resources for meteorology and astronomy research were not easily solved. These factors had not previously been raised as relevant to the AC-CdC.

Simon Schaffer, Professor of the History and Philosophy of Science at Cambridge University, has contributed significantly to the social history of science, particularly in his analysis of the politics and social milieu in which the star chart observed at Parramatta Observatory was produced, and the broader influence of astronomy in the early nineteenth century (2010, pp.125–131). Schaffer included the instruments, the layout of the buildings and the need for local skills and innovation in the maintenance of the instruments, as well as the observational and computing skills, and the temperamental behaviour of staff as fundamental to the outcome and the errors—all of which doomed the catalogued to be a failure. Schaffer highlighted that the Astronomer Royal, George Airy, insisted on a 'division of labour' methodology as a panacea for resource issues and behavioural variation (p.131). Ratcliff's research supports Airy as an enterprising project manager who understood that there needed to be central responsibility, but that individuals needed to be trusted in the 1874 transit of Venus network (2008, pp. 57–58). The influence of this transit of Venus on the structure of the workplace, the nature of networks, and the assignment of roles and responsibilities was influential in the sociology and progress of the AC-CdC.

Schaffer's (2011) and Ratcliff's (2008) investigation into failed instrumentation, science at a distance, and colonial power relations highlighted the prior lack of attention paid to projects which were not considered scientific successes. They have drawn attention to the issues surrounding error management, such as changes to instruments once they leave the laboratory, and how their care, maintenance and alterations actively prevent the ideal of consistency . The concept that unacceptable error and disrepair are part of normative science (Schaffer p. 711) led to my investigation of where power lay in the acceptance or rejection of error. This is examined further as particularly relevant to James Short's work on the AC-CdC for Sydney Observatory, and the influence Peel had on the acceptance of Sydney zone photography.

Ratcliff's investigation into Britain's enterprise to measure transits of Venus in the nineteenth century also revealed that this enterprise can be defined as 'Big Science' which is, according to Ratcliff, “intellectual or technological projects executed on what was a dramatic scale for the time” (2008, pp. 21–22). The AC-CdC projects fit this definition, even more so because the AC-CdC were truly international in their networks. This is expanded on in Chapter Two.

The preservation of star catalogue material culture and heritage has been of concern and a subject of discourse amongst astronomers and historians globally. At the 1987 IAU Symposium on the AC-CdC there was an emphasis on history and an exhibition with a small catalogue was prepared (Weimar 1987). A number of papers which presented methods for the AC-CdC data to be used for new astronomy research were also published (Debarbat et al 1988). Sean Urban and Thomas E. Corbin, astronomers at the United States Naval Observatory (1988, p. 287) proposed using the AC-CdC data as a reference catalogue, and they devised a machine-readable Astrographic Catalogue of Reference Stars. The resulting data was used for the Hipparcos Satellite Telescope, which depended on standard stars for calibration (Turon 1988 p. 245; Gómez & Crifo 1988, p. 259). The Tycho 2 Catalogue of Stars, which emerged from these projects, eventually provided tangible evidence of the future use of the AC in contemporary astrometry (Egret & Høg 1988, p. 265).

Many texts and further accuracy in star positions (resulting from Corbin and Urban’s work) related to the Hipparcos and Tycho 2 Catalogues (Robinson 1999, Høg et al 2000, Urban et al 2000). Furthermore, a number of glass plates were scanned and became of interest to the IAU Commission 8 working group research, including the aforementioned plates from the Sydney zone catalogues held at Macquarie University (Fresneau et al 2003, 2005, 2007, Bucciarelli et al 2008).

Literature about the re-examination of astronomical data produced for the AC-CdC consequently renewed interest in preserving and digitising the glass plate negatives, instruments and associated papers. A project to digitise the HCO Star Catalogue glass plate negatives, named the DASCH project, sparked discourse about this process and new research emerged from this historic data (Lieber 2010, Tang et al 2010). This work paralleled renewed interest in the history and historiography of the AC-CdC. The IAU supported transcriptions of correspondence by Italian scientific historian, Illeana Chinnici, between the AC-CdC participants and Paris Observatory Directors (1999). Aubin, Bigg and Lamy uncovered new knowledge about Paris Observatory and the instigation of the AC-CdC (Aubin 2003, Bigg 2000). Their research and analysis revealed innovative communication methods which arose from the projects (Lamy 2009a), and the inclusion of women in the European AC-CdC scientific workplaces (Bigg 2000, Lamy 2006, 2009ab).

In the late twentieth century, there was an impetus in research about women's work in the sciences in North America, Europe and Britain by, amongst others, social scientists Margaret Rossiter (1980,1983), Barbara Welther (1982), Pamela Mack (1990), Gabriele Kass-Simon and Patricia Farnes (1990), Londa Schiebinger (1993), Margaret Wertheim (1995), Naomi Oreskes (1996), Sally Gregory Kohlstedt (1997), Jennifer Light (1999), David Allan Grier (1999), Anneliese Schnell (1999) and philosopher of science, Helen Longino (1997). Their research findings revealed that the history of science, and within it astronomy, had previously and predominantly featured the achievements of men, even though it was considerably populated by women who had remained invisible or been excluded from essential research. Grier and Light's research into early computational and statistical work by women was evidence-based proof of the amplitude that sociological factors had in determining the opportunities for women and recognition of their work in all aspects of science.

Pang's research on historic eclipse expeditions revealed evidence of the work of American Elizabeth Campbell at the 1922 eclipse expedition to Wallal in Western Australia (1996). Pang lamented his own lack of success in uncovering the work of other women on eclipse expeditions and remarked that 'British sources are notable for their steadfast silence on the roles women played in the field' (2002, p. 3). More recent research by Astronomy Professor Kristine Larsen (1995, 2006, 2009), and science historians Mary Brück (2009) and Roger Hutchins (2008) unearthed previously unacknowledged star catalogue, comet and solar eclipse work undertaken by women in the UK at Oxford University Observatory, Royal Observatory Greenwich (ROG) and Royal Observatory Edinburgh, and as amateur astronomers.

The history of women in astronomy and related physical sciences gained momentum in Australia around the millennium. Astronomers and historians Bhathal (2001) and Pickett & Lomb (2001) included women within their histories of Australian astronomy. Ruby Payne Scott emerged as a central figure in the development of radio astronomy in Haynes et al (1996) and in more detail using primary sources by radio astronomers Miller Goss (2010, 2014) and Richard McGee (2010). I examined workplace legislation, Public Service Gazettes and State Government yearbooks for the period 1890 to 1920. Using these sources with annual reports, I collected data on the women employed, and their conditions (such as rates of pay), to clarify how gender influenced allocated roles within the case-studied observatories.

To understand why so few women worked in astronomy in Australia, academic Claire Hooker's analytical survey of women in science in Australia (2004) was a pivotal literary resource. Hooker investigated the reasons behind the fact that so few women had entered and were acknowledged in science in Australia. Further to Hooker's findings, academic psychologist Cordelia Fine debunked myths about gender and the structure of the human brain (2010). Fine focussed on the influence of social engineering on women's participation in science; she identified a link between representation in the public sphere and identity, the extent of which has had marginal debate within museum and heritage studies discourse. An exception is British museum curator, Gaby Porter, who criticised museum curatorship as re-enforcing gender stereotypes (1988). According to Porter, women's work was confined within museums and historic houses to the domestic sphere, and women were excluded from science-related or industry exhibits (Porter 1988, p. 111).

Critical Heritage Studies academics, Laurajane Smith, David C. Harvey, Brian Graham and Peter Howard acknowledged the temporality (Harvey 2001, 2008) and gendered nature of heritage (Smith 2006, 2008; Graham & Howard 2008). Smith, Graham and Howard agreed with Harvey that heritage is about 'how people use the past', and that the way past culture is processed and interpreted has a long history of being challenged and rewritten (Harvey 2008, p. 19).

Literature research indicated that even though there was scant official documentation, there were likely women in Australian colonial observatories who were doing skilled work in astronomy as measurers or computers for the AC, or even taking lead roles in the workplace. Their work could only be found by detailed primary source research. There were also parallels in other areas of science in which I found models to critically challenge and guide my research and conclusions. In the following chapter, I explain the other methodologies used to investigate this thesis and its construction, which has a thematic framework and follows a loose chronology.

CHAPTER 1: METHODOLOGY

This thesis uses empirical and non-empirical methodology to bring into focus new knowledge about the Astrographic Catalogue and Carte du Ciel astronomy projects in Australia. The thesis is developed through thematic sections with an overarching chronological framework. This is not temporally rigid as there are overlaps and crossovers due to the nature of the topic. A literature review in the previous chapter was the method used to research and analyse the historiography of Australia's participation in the AC-CdC. I identified appropriate texts within the broader fields of the sociology of science, museum and heritage studies. This chapter presents the case study methodology.

Of the four observatories involved in the AC-CdC in Australia, a case study methodology has been applied to Sydney, Melbourne and Perth Observatories. Adelaide Observatory was not allocated an astrographic zone and performed a different role to the other three observatories. Ten in-depth interviews were recorded and transcribed, and I examined several other observatories (which were part of the AC-CdC network) to provide context for the case-studied observatory sites. I went into the field and examined sites and technologies; I also conducted expeditions to uncover primary sources which had not been catalogued and archived. This was essential to answer questions about the extent of work conducted for the AC-CdC, and to uncover material heritage which had remained hidden for decades.

The scope of the thesis became clearer as the case studies developed. There is a temporal and sociological framework for the thesis, which positions the AC-CdC within the local historical milieu and broader development of astronomy.

TIMEFRAME AND THEORY

The Astrographic Catalogue and Carte du Ciel occupied a temporal space between the manual and automated processes of astronomy, which occurred during the late nineteenth to mid-twentieth centuries. More specifically, the AC-CdC projects began globally in 1887 and, in Australia, the work effectively concluded in 1964 with the publication of Volume 51 of the Sydney zone. This is the timeframe for this thesis as it is the substantive endpoint to Australia's participation in the AC-CdC, even though NSW Government Astronomer Harley Wood published Volume 53 in 1971. This final volume was a reflective report on the photography, reduction and measurement of the Melbourne and Sydney zones of the Astrographic Catalogue. My thesis sought to prove that, through detailed investigation into the AC-CdC in Australia, it would be possible to better understand why Australia became involved in the projects and what that involvement entailed, especially the extent of the work of women star measurers and computers. I had no expectation of what I would find, nor that existing material was so extensive. I also knew very little about contemporary uses of the data. It was through the preservation of its material heritage that I was able to establish that the AC-CdC had social consequences which, though different in nature, still resonate for women in the field of astronomy today. It was only once I was well into the research that I realised how rich the related primary sources were for social science research.

Whilst I researched broadly for this thesis, the focus was localised on the participation of Australian observatories in the AC-CdC, and sociological (rather than scientific) areas of interest, particularly women's work and the less considered work of the astronomers. Furthermore, through reference to newspapers and popular culture I have included the public as omnipresent spectators of astronomical endeavour and the people involved in it. The other filter I have applied is a concentration on areas of interest for museums, and areas where there were primary sources and material culture to examine.

For the Australian participants, the AC-CdC period between 1887 and 1964 coincides with a number of local, major sociological changes and events, and encompasses both periods of prosperity and economic depression. These include globalisation, federation of the states, major astronomical events, wars, economic booms, recessions, depressions and social changes associated with female franchise.

The colonial observatories in the mid to late nineteenth century had many commitments to provide data to their respective governments on tides, meteorology, standard timekeeping, surveying, weights and measures, seismology, geomagnetism and cloud formation taxonomy. The breadth of their work is recorded in the annual reports to government and the Royal Astronomical Society. Letterbooks provide evidence of the extent of correspondence on these matters, and the newspaper reports show the reliance that the colony had on weather reporting and explanation of astronomy events. Astronomical events such as comet observations and solar eclipse expeditions were a high priority for the state observatories because these were tied into networks involving other observatories and astronomers, and were also of great interest to the public and news media. These typified the institutionalised character of most nineteenth-century observatories, which have been described as having multiple roles and being 'Humboltian' in their nature:

> "In all its manifestations the observatory united heavenly with earthly concerns."
> (Aubin, Bigg & Sibum 2010, p. 4)

These commitments impacted on the resources made available for the AC-CdC. They also interrupted AC-CdC work when they became the main priority for the Government Astronomer or astrographic observers (and other staff) committed to the AC-CdC projects.

The lead astronomers and (because of their expertise in photography) the astronomers working on astrographic photography were responsible for organising complex expeditions. The most important of these for the Australian observatories were either in Australia or the Pacific. Substantial efforts were made to view and photographically record the solar eclipses of 1908, 1910, 1911 and 1922. Furthermore, the 1922 expedition involved taking equipment, which was otherwise used for the AC-CdC, out of commission for months (James Short logbook, MAAS collection uncatalogued; Cooke 1923ab, p. 511).

As responsibility for meteorology diminished, other social demands (such as public tours) increased and made further resource demands on observatory equipment and personnel. Observations required by other observatories, which were difficult to predict and impossible to deny, reflected the desire of the observatories to be considered part of the international astronomy scene. The establishment of a federal approach to astronomy was of fundamental concern throughout the course of the AC-CdC. The impact of wars, federation of the states, and the increasing control of science by the Commonwealth government in Australia, as well as other global, national and local issues, are explored in more detail later in this thesis. These social and political events at times separated and, at other times, bound together the case-studied Sydney, Melbourne and Perth colonial observatories, which were connected by their commitment to the AC-CdC.

State Observatories in Australia defined as a group

When the AC-CdC commenced in 1887, the Commonwealth of Australia was divided into colonies, each reporting back to Great Britain through their respective Colonial Secretaries. O'Hora positioned the AC-CdC work of Sydney, Melbourne and Perth Observatories as a

British colonial contribution which, together with other British colonial observatories, totaled 27.3% of the charted zones (O'Hora 1988, pp. 135–138).

Sydney, Melbourne, Adelaide and Perth Observatories had intrinsically linked histories due to the changes in state and federal control of science. The impact of Federation meant that, as stated in the Commonwealth of Australia Constitution Act Part V, section 51:

> "The Parliament shall, subject to this Constitution, have power to make laws for the peace, order, and good government of the Commonwealth with respect to … (viii) astronomical and meteorological observations"
> (Australian Constitution 1900, p.10)

This put in place the direction for state government observatory responsibilities in astronomy and meteorology to become Commonwealth responsibilities. The Directors of the State Observatories had very different views on whether meteorology should be a state or federal concern, as demonstrated through their correspondence, but they were initially unanimous in wanting to retain control of astronomy. This is examined later as having impact on the progress of the AC-CdC.

The rationale for defining Sydney, Melbourne and Perth Observatories as Australian AC-CdC case studies in this thesis is dependent on their signatory on a commitment to delivering a zone of the night sky. Unique to the case-studied observatories is the full responsibility for an allocated AC-CdC zone. Whilst Adelaide and Royal Observatory Edinburgh were within the scope of research, they were not case studied. Nonetheless, they were part of the extensive global network of observatories involved in the projects.

The State government astronomers had individually forged strong relationships with the Royal Astronomical Society and influential British astronomers. Visits to Britain, reports, correspondence and joint efforts with British astronomers, such as the 1871 Solar Eclipse expedition (Ellery & Lockyer 1872, p. 205), re-enforced colonial ties. The State government astronomers had established local networks of correspondence and the Astrographic Catalogue and Carte du Ciel strengthened these further.
From 1898 to 1912, Sydney and Melbourne Observatories reported jointly on progress on the AC measurement and reduction (Baracchi MNRAS 1889–1912). When the AC was completed, Wood produced a report for the Sydney and Melbourne Catalogues in Volume 53

(1971). This was because the measurement and reduction for the Sydney Catalogue occurred initially in Melbourne, and then a large section of the Melbourne Catalogue was reduced and prepared for publication at Sydney Observatory.

There is a strong connection between Adelaide, Perth, Melbourne and Sydney Observatories through William Ernest Cooke, who was the Assistant Astronomer at Adelaide Observatory during the period when Adelaide Observatory was measuring reference stars (1890–1896). Cooke was then Director of Perth until 1912, followed by an appointment to Sydney Observatory until 1926. South Australian Government Astronomer, Todd, was in regular correspondence with Ellery and Russell; and his Assistant Astronomer, Cooke, corresponded with Baracchi in regards to the positional stars observed by Adelaide Observatory for the Melbourne zone of the AC-CdC (letter Baracchi to Cooke 1898bc, PROV 778/P/0000, pp. 73–74). When Cooke became the Western Australian Government Astronomer, he soon began enquiry as to how Perth Observatory could become involved in the project. There is evidence that Cooke shared these aspirations with Baracchi (letter Baracchi to Cooke, 1899, PROV 867/P/0001,778/P/0000, pp. 130–137). All in all, Cooke was involved at a senior level in the AC-CdC for thirty-six years and with each Australian zone and participating observatory. He also instigated the employment of women in three observatories.

All state colonies experienced major changes in the rights of women to have an education, employment, franchise, self-determination and property ownership from the 1880s (Kramar 1990). Female suffrage was historically concurrent with the introduction of women into the AC-CdC workforce, which is a significant component of the thesis as women undertook, in most cases, the roles of star measurer and computer. The roles the women performed for the AC are significant in their characteristically modernist nature, and because they changed the nature of the symbiotic telescope-and-observer relationship which had existed since Galileo. The next section further analyses modernist theory as applicable to the AC-CdC.

MODERNITY AND OBSERVATION

Jonathan Crary, Professor of Modern Art and Art Theory at Columbia University, New York, described the term 'modernity' as involving forces, events and institutions which are bound together in ways that are tightly and formally constructed (1992 pp. 9–13). 'Modernity' was also a term used to describe the transition from the local to the global, or the hand-crafted to the factory-made; it also described domination through networks and enabled 'acting at a distance', as theorised by Latour (1987, pp. 215–243). David Wade Chambers and Richard Gillespie defined 'modern science' by its 'institutions, procedures and technologies' (2000). This is an encompassing definition, which takes into account nineteenth-century mechanisation, the standardisation of methods, a focus on taxonomy in all areas of science, and the establishment of global networks (Chambers and Gillespie 2000). Crary also married observation and photography, both fundamental to the AC-CdC, with modernity (1992). Modernist ideals had far-reaching consequences for science. These consequences were relevant to the AC-CdC, and influenced decisions made by and for the Australian participant observatories.

Referring to Latour's theoretical models of networks, and specifically polycentric networks, Chambers and Gillespie dismissed a singular Euro-centric nineteenth-century narrative for the development of science in Australia. They supported Roy MacLeod's research into colonial science, which revealed that the local development of science within Australia was complex and driven by individuals within, but not solely because of, the colonial political environment (MacLeod 1988, Chambers & Gillespie 2000). Furthermore, they uncovered that confining the development of science in Australia to a colonial structure did not account for the extent of participation in other networks, local and global, or the impact of the localised environment.

As I investigated Australia's participation in the AC-CdC, and the critical nature of the measurer's observations for the AC, Crary's theoretical views of photography and observation, deeply influenced my understanding of the AC-CdC as a product of modernity. For the participants in the AC-CdC, the consequences of modernity were far-reaching and significantly changed every aspect of what had once been considered standard work practices and workplaces in astronomy.

During the seventeenth and eighteenth centuries, the relationship between the eye and the optical device had been dominated by the power of the 'observer', which was equal to the power of the instrument:

> "During the seventeenth and eighteenth centuries … the eye and the telescope or microscope were allied by a conceptual similarity, in which the authority of an ideal eye remained unchallenged. Beginning in the nineteenth century the relationship between the eye and the optical apparatus becomes one of metonymy: both were now contiguous instruments on the same plane of operation, with varying capabilities and features. The limits and deficiencies of one will be complemented by the capacities of the other and vice versa."
>
> (Crary 1992, p. 31)

Crary critiqued science's reliance on observation because of the variations of the human eye and the inaccuracies inherent in instruments, which used imperfect materials. The superiority of one observer over another when viewing through a telescope was changed by photography in the latter part of the nineteenth century. According to Crary, the concept of 'subjective vision' was enhanced, not diminished, by new technology such as photography and "... what happens to the observer in the nineteenth century is a process of modernisation, he or she is made adequate to a constellation of new events, forces and institutions that together are loosely and perhaps tautologically definable as 'modernity'." (1992, p. 9). This meant the observer became more democratised due to photography (Crary 1992, p. 9). One of the aims of the CdC was to provide theoretically 'objective' stellar photographic images which could be analysed by many others simultaneously.

The astronomers participating in the AC-CdC projects were pioneers in the use of photography for scientific research (Hearnshaw 1996); but the infallibility of technology was an illusion because photography transferred authority from the eye of the astronomer to the eye of the star measurer. New astrometry photographic techniques were on the frontier of the then known 'centre' of astronomy. Using photography, which had the characteristics of objectivity, the observer was removed as the sole interpreter of nature, as Russell described:

> "… the observer must stand aside while the sensitive photographic plate takes his place and works with a power of which he is not capable …"
>
> (Russell 1894, p. 101)

The AC-CdC required the astronomer to hand over 'his' observational prowess to others. It meant new skills, methods, equipment and buildings were required. The frailty of the human eye, its reduced effectiveness with age, and its inability to see and at the same time translate the view through the telescope eyepiece was seemingly surpassed by the photographic evidence of stars imaged in dry gelatin for the AC-CdC projects. The enthusiasm for imaging techniques in astronomy was responsible in reconstructing the dynamics of the observatory and astronomy practice. The international and local networks which were created for the AC-CdC were both essential in the rapid transfer of information about new techniques, and to achieve an all-sky map and catalogue.

The global nature of the local environment in Australia just prior to the advent of the AC-CdC is well illustrated by the penetration of the International Expositions held in Sydney in 1879 and Melbourne in 1880. These grand scientific and cultural displays were indicators of modernity in their expressions of desire for international connections, and local and national pride. The Australian participants were not always peripheral, as would have been the case under a singular colonial model.

Federation in 1901, and the years of uncertainty before and after, had a major impact on society, especially on state-run facilities such as observatories. According to Richard Gillespie, Senior Curator at Museums Victoria, astronomy was determined to be a Commonwealth concern in 1907 but it took decades to resolve (pers comm, Gillespie 2012). At times the AC-CdC was seen as peripheral to other astronomy research, but this was not the case when it was instigated.

Amongst Australian astronomers, there was a temporal 'modern' late nineteenth-century view that the AC-CdC was progressive science, advancing civilisation through seemingly objective means, as explained to the public by Russell (1891a, 1894ab, 1895ab) and Ellery (1891). In Russell's opening speech as the first President of the AAAS in 1888, astronomy was embedded within the formation of national scientific enterprise. In Ellery's address to the AAAS as President of Section A, Astronomy, Mathematics, Physics and Mechanics he highlighted the AC-CdC as progressive astronomy (Liversidge & Etheridge 1889, pp. 3–7, pp. 38–39). According to MacDonald, the desire to be 'modern' was embodied within public visual and textual representations of 'the wonder of science' (1998).

MacDonald argued that a rise in the interest in science by the populace led to the retraction of scientific research activity away from public spaces and into organised laboratories (1998). The nature of scientific research changed from the work of 'gentlemen' in small private observatories and regally patronised establishments, to a new organisational model where the head astronomer managed a significant workforce and was accountable for its output.

Conversely, photography played a significant role in making astronomy a science available to the public eye. According to Bigg this led to increased interest in popular astronomy and the establishment of new amateur societies, public science demonstrations as part of international expositions, and the publication of an increased number of popular astronomy books written by professional astronomers and amateurs (2010). Spaces in which to present science to the public were created in museums, theatres and as part of international expositions. Popular access to information held by a small number of astronomers through representation techniques, such as photography, made it 'possible to exploit the expansion of the middle classes as consumers of science' (Bigg 2010, p. 323).

The AC-CdC were at the forefront of organisational change in astronomy. These projects were ideally suited to procedural work carried out using a very few specialist astronomers who managed increasingly more sophisticated technologies and a hierarchical, pyramid workforce structure. The employment of women for the AC at the base of the pyramid was attributable to the rise of modernity in the late nineteenth century. This era was a period of fundamental change in the organisation of science; public engagement and features of modernity were manifest in the restructuring of the scientific workplace, along the same principles as factories (Bigg 2000).

In Australia in the late nineteenth-century, women embraced new technologies throughout society. For example, in 1898 the *Australian Town and Country Journal* published an illustrated article about the Sydney General Post Office (The General Post Office, 1898). It featured the operation of the telephone exchange where women constituted 50% of the operators, having 'replaced their sewing machines' with a complex exchange system, and they worked night and day. Right across society, including astronomy, women in the workplace had become one of the characteristics of modernity. The AC was a modernist revolution within astronomy, supplementing the single expert observer with a bureau of photographic plate measurers (Bigg 2000), and replacing a small number of male astronomers with a more extensive, lower paid workforce of women at measuring machines and for computing.

To astronomers working in colonial outposts in Australia, which was on the cusp of becoming a new nation, the appeal of the AC-CdC extended beyond modernist ideals of creating an indisputable map of the entire celestial sphere (with globally standardised systems and methods) (Turnbull 1989) to opportunities for political advantage within a global arena. There is evidence that participation in the AC-CdC enabled Australian astronomers to engage with some of the most influential astronomers of that period.

SOCIOLOGY OF SCIENCE THEORETICAL MODELS

The historiography of science has been challenged by a number of scholars over the past three decades. I have applied some of these theoretical models as a method of investigating the thesis topic. In this section, I discuss the models, my analysis and choices.

Latour and Woolger (1979) applied anthropological methodologies to analyse scientific research outcomes by 'following scientists into their laboratories'. Latour defined the word 'sociology' to mean the 'tracing of associations' between the agents (2005, p. 5). Latour further developed a methodology for analysing scientific outcomes called 'actor-network theory' (hereafter ANT) with fellow sociologist, Michel Callon, in 1981. ANT was used to model how artifacts and workplace structures have agency in the production of results (Law 1986, Callon 1986). Associated with ANT are Latour's 'cycles of accumulation' (1987, p. 219), 'centres of calculation' (Latour 1987, p. 232) and Callon's 'moments of translation' sociological model (2007, pp. 57–78).

The ANT theoretical model is complex in its translation, but had resonance with this thesis because of the following three factors which Latour used to explain ANT (1997). Firstly, ANT acknowledged 'objects' as having active forces, agency and influence over science. Secondly, ANT disregarded 'tyranny of distance', meaning that information could sometimes be communicated great distances as easily as very short ones. Finally, the notion of 'network' was based on complex, multi-dimensional nodes. The word 'réseau' was adopted by the AC-CdC congress in 1887 as a gridded mapping methodology to fix relationships between star images and their positions on the photographic film in an x and y axis relationship. Translated from French into English, the work 'réseau' means 'network' and, according to Latour, this word originated in French from the Enlightenment philosopher Diderot. Latour quoted Diderot to explain that actor networks are both 'matter and bodies' (1996, p. 371).

As previously mentioned Latour's theoretical models have been appropriated to analyse museum collections. In the 1980s, Turnbull challenged the past heroic view of the history of mapping the land, sea and sky (1989, 1996). Turnbull applied Latour's theoretical models to examine the control of scientific knowledge and cartography. Turnbull referred to Latour's 'networks' and 'centre of calculation' models to explain the transmission of knowledge from colonial outposts back into the centre. Australian academic and museum theorist, Tony Bennett, applied Latour's 'cycles of accumulation' model to examine the movement of scientific knowledge from colonies to imperial museums (2006, 2009). Bennett drew comparisons between Latour's analysis of the construction of knowledge in the scientific laboratory, with the role of museums as 'civic' laboratories in which assemblages reconstruct our contemporary understanding of culture (Bennett 2005, pp. 527; 2009, pp. 99–116). Bennett used Latour's 'circulation of reference' model and ANT, with museums as sites of anthropological collections brought back from colonies, to examine the Musee de l'Homme collections (2009, pp. 99–116).

Chambers and Gillespie described Australian science as a 'metaphor and means of legitimate colonial aspiration' (2002, p. 226). They described the history of colonial science as 'little more than the gradual connection of the locality into this global scientific communications network, which historically was based in and controlled by the centre'. Aubin referenced these theoretical models devised by Latour when he presented a new interpretation of the history of Paris Observatory (2003, pp. 96–99).

Callon's 'moments of translation' theoretical model demonstrated how a project is instigated in the laboratory, resources are applied and then the project is diminished because it is replaced by other projects (Callon 1986, pp. 206–219). Research methodology academic, Sotirios Sarantakos, Adjunct Professor at Charles Sturt University, situated Callon's moments of translation method within a 'post-positivist' methodology because of Callon's emphasis on project management and the interjection of human thought, opinion and society on the outcome of a scientific project (Sarantakos 1998).

Callon's model, as applied to the AC-CdC, began with 'Problematisation' and 'Interressant'. The AC-CdC was canvassed as a solution to an agreed problem to a number of observatories in the 1880s. By inviting selected astronomers to the first congress, in the prestigious Paris Observatory, the 'Interressement' stage was enacted. The process of 'Enrolment' occurred when the parties accepted the project and committed to a zone from 1887 to 1900. Then, through the establishment of a network, the astronomers embarked on the next stage of 'mobilisation' and engaged the other 'actors', including human and non-human resources. The final stage of 'Competing Problematisations' was when the 'actors' were pulled away from the project because another now more important problem, which required 'actors', had been successfully promoted.

I also considered the Strong Program, another accepted sociology of science model, in which science is observation and theory (Degeling 2009 lecture). The four tenets prescribed by the Strong Program in the sociology of knowledge are causality, impartiality, symmetry and reflexivity (Bloor 1976, p. 7). Bloor, one of the instigators of the Strong Program, attacked Latour's claim that ANT was a new sociological model (1999). Bloor concluded that both his and Latour's methods of analysis rejected the 'weak' program and adopted a 'relativist' understanding of science, where science is performed relative to social conditions. My analysis was that the fundamental differences between the Strong Program and ANT are the the attention and significance ANT placed on the agency of non-human elements and their impact on the scientific program and its outcomes. ANT offered more than acceptance of science occurring in a social context; it acknowledged that the buildings, instruments, logbooks and glass plate negatives played significant roles and had agency in the delivery of the AC-CdC.

The agency of the AC-CdC material culture has not been diminished over time because the inanimate objects are still available, on the whole, for scientific and sociological analysis. Furthermore, Latour's account of how knowledge is circulated through an exchange which involves people, ideas and things (called 'circulation of reference'), and the 'centres of calculation' model in which Latour describes knowledge attrition by colonial powers (at the expense of the colonised), have been adopted by sociologists of science and museum theorists. In both of these ideal models, standard methods, instruments and materials are sent to a reliable collection point to collect data and/or artefacts. These are then sent back to the centre, where deemed authority and expertise lie for the data and collections to be measured, analysed and interpreted.

I have applied ANT, Callon's 'moments of translation' and Latour's 'circulation of reference' and 'centres of calculation' models to Australia's participation in the AC-CdC throughout this thesis. Whilst I have investigated the AC-CdC as a movement of scientific data within astronomy circles, the more recent movement of the AC-CdC collection into a museum and heritage context connects the thesis topic with museum theory. My analysis was that these models adequately described the network-dependant process of the AC-CdC and have led to a deeper understanding of why and where the projects gained and lost resources and dedication.

PROBLEMATISATION

Critical to Callon's 'moments of translation' theoretical model is the process of 'problematisation', meaning that there has to be an articulated and/or created problem to be solved to stimulate involvement and interest in projects. For the AC-CdC, the problem was the lack of an all-sky catalogue and star chart which used globally accepted standards for measuring star magnitude, and was able to be reproduced, distributed to and investigated by astronomers. The AC-CdC problem was also associated with a paradigm. As described by Sarantakos, a paradigm is 'a set of beliefs, values and techniques which is shared by members of a scientific community, and which acts as a guide or map dictating the kinds of problems scientists should address' (Sarantakos 1998, p. 32). The AC-CdC problem was created out of the late nineteenth-century scientific and sociological 'positivist' paradigm of the objectivity of science and the concurrent taxonomy of all things scientific during this period.

At the inaugural meeting of the AC-CdC, the astronomical problematisation that the AC-CdC was designed to solve was the incomplete nature of celestial cartography in existing star catalogues and the global differences in star measuring techniques (Thiele in Winterhalter 1891, p. 59). According to Danish astronomer Thorvald Thiele, star catalogues, prior to the AC-CdC, were open to a wide range of interpretations because stars were observed by the human eye and there were variations in measuring and notation techniques. In this positivist paradigm, the application of standard photographic methods to astronomy through the AC-CdC would solve the 'problem'. Astronomers involved in the AC-CdC were continually seeking mechanised methods and new technological solutions to replace visual observation and decrease human error (Hearnshaw 1996). The 'push' for objectivity using technologies in astronomy and other sciences is further examined in the following section on modernity as an impetus for the AC-CdC. The 'pull' for participation by Australian observatories and astronomers was forming part of the international consortium alongside recognised experts; this was fundamental to the 'Interressant' and 'Enrolment' stages.

Interressant, Enrolment and Mobilisation

According to Callon's theoretical model of how scientific projects are supported, once a problem is identified, supporters are gathered together, enrolled into the project and then mobilised. Global engagement was one of the characteristics of involvement in the AC-CdC, which stimulated the astronomers to move forward with the next phases in Callon's 'moments of translation' model.

The first finding when I applied this model to Australia's participation in the AC-CdC was that the projects were acted out in networks of people, instruments and places, rather than through decisions and actions confined to the lead astronomers. This challenged the established historiography of the AC-CdC in Australia, which had evolved around the lead astronomers. Latour's methods helped me realise early on in my research that the epistemology of the AC-CdC was limited by the narrow sources of its history and the history of astronomy in Australia.

I have applied Latour's and Callon's models to my research and analysis using a case study methodology to understand the sociology of association between organisations, people and things in observatories in Australia. Considering the AC-CdC as a product of modernist ideals has led to the major findings of this thesis. In the following section, I explain the case study methodology which was applied to the three observatories linked by the AC-CdC and the women who worked on the projects.

Case study methodology – From a 'vantage point'

Research into and analysis of Australia's participation in the AC-CdC was undertaken for this thesis using a case study methodology involving the Sydney, Melbourne and Perth Observatories. Case studies (as a method of research) can, according to Richard Howitt, social theorist and indigenous rights researcher at Macquarie University, highlight many qualities and views of a resource system and its processes (Howitt 2001, p. 189). Case studies about the interaction between people and technologies, as well as the changes in systems used in this thesis offer the advantage of a grander scale and broader view of processes within time, space and society. The case studies of the women offer a 'vantage point' through which to view the research. As previously stated, prior to undertaking this thesis there was little research on the women in Australia working on the AC, which is why a different view on the primary source research was essential.

Howitt counselled against adopting a ‘passing parade’ approach to case studies. He promoted rigorous examination of each case study (2001, p. 190). In this thesis Sydney, Melbourne and Perth Observatories have been selected for case study through which to view the AC-CdC system, its relationships and operations. The women who are case studies are framed within the legal and political status of women locally and nationally. A selection has been made of participants who observed through telescopes to obtain reference star co-ordinates, and women who measured and computed the Astrographic Catalogue. Six of these individual case studies represent the early years when the measurement processes and resources were being established: Mary Emma Greayer (Adelaide Observatory 1890–1899), Charlotte Fforde Peel (Melbourne Observatory 1898–1918), Sarah Victoria Noonan (Melbourne Observatory 1907–1911), Muriel Heagney (Melbourne Observatory 1906–1910), Prudence Valentine Williams (Perth Observatory 1907–1921) and Ida Digby (Sydney Observatory 1916–1926). Winsome Bellamy (Sydney Observatory 1948–1968) and Verlie Maurice, nee Lee (Sydney Observatory 1948–1954) were measurers and computers who were working on the AC in the second half of the twentieth century. The interviews with Bellamy and Maurice provided a broader research baseline. As primary sources these individual case studies provided the foundation through which to better understand the workplace and its social interactions.

The case study model described by Howitt aided my inclusion of the women’s perceptions of gender-specific controls within each observatory. The case study process, whether conducted through interview and primary research or solely through primary research, was a frame through which to recognise individual agency. The comparative analysis with women at Paris, Royal Observatories Greenwich and Edinburgh and the Harvard College Observatory provided a broader understanding of how women’s work was essential to the AC-CdC globally. The case studies provided opportunities for qualitative analysis that led to a deeper understanding of how the AC had meaning beyond the scientific outcomes.

QUALITATIVE RESEARCH INTERVIEWS

This thesis references interpretivist qualitative social enquiry methodologies, as outlined by Sarantakos (1998). Qualitative research has been undertaken under the regulations and with the approval of the University of Sydney Ethics Committee. The results of interviews have been applied to this thesis topic within an interpretative methodology which, according to Sarantakos, acknowledges that individuals have agency and interpret what is happening in society in different ways. By way of comparison Lesa Moore's research at Macquarie University focussed on quantitative lists of the glass plate negatives and star plate logbooks (2003). This is a comprehensive spreadsheet of the Sydney AC-CdC zone plate numbers,which included data such as the year they were photographed, co-ordinates and content. Moore's work was used to identify and locate plates for scanning and further research.

The University of Sydney Ethics Committee approved the methodology for the qualitative interviews. Ten people with knowledge of the Astrographic Catalogue, experience with its instrumentation, or a close connection with its history and heritage were interviewed for this thesis: Winsome Bellamy and Verlie Maurice, who worked on the Astrographic Catalogue; Rosamond Madden, who was a child when her father, NSW Government Astronomer Harley Wood, completed the Sydney and Melbourne zones of the AC-CdC; Nick Lomb, astronomer and Sydney Observatory Curator until 2009; Ralph Martin, Greg Rowe and Andrew Williams, astronomers at Perth Observatory; and Barry Clark, Richard Gillespie and Bill Neal, who had strong connections with Melbourne Observatory. The most salient points have been reproduced in Appendix 10.

The interviews were structured to empower the respondents to speak freely and elaborate on the open-ended questions. As recommended by Sarantakos (1998, p. 85), low-inference descriptors were used throughout the process. All ten participants consented to interviews. A thorough literature review and investigation of primary sources was undertaken prior to the formal interviews. All participants read and signed the appropriate ethics and interview permission forms and granted permission for the interviews to be used in the thesis, and in related papers and presentations.

The process for the in-depth interviews was to begin with a standard set of questions related to the AC but there was flexibility to include other aspects outside the set questions, should the participant instigate this or if new material arose during the interview that was relevant. The interviews were held, wherever this was practicable, within the appropriate observatory or where the collection was held. Toner Stevenson conducted the interviews. Mechanical recording devices were used to record eight interviews on video, and respondents were given an opportunity to review and comment on the transcription. Where requested, copies of the transcriptions and recordings have been sent to participants. The techniques employed were thorough, consistent and credible, as recommended by Sarantakos (1998, p. 84). The interviews revealed more about the material culture of the AC-CdC, and were also in accordance with the Significance 2.0 model developed by museum theorists, Roslyn Russell and Kylie Winkworth (2002).

A transcription was made of the audio recordings, face-to-face interviews and phone interviews. Participants received a copy of the transcription, on which they commented in some cases, and they will receive access to the final thesis after it has been assessed. An analysis of the transcriptions is available as an appendix to this thesis. There is an audit trail for the recorded interviews and their transcriptions, which are stored by the University of Sydney.

In most cases the interviews were held at the sites studied, or other fieldwork locations. This enabled the interviewees to recall and be more illustrative of their experiences. The fieldwork experience was in itself a research methodology, which I will now explain.

FIELDWORK, MUSEUM AND HERITAGE COLLECTIONS

When researching the topic, I extensively investigated museum and archival collections and drew on museum and heritage theory to analyse the legacy of the AC-CdC. In order to gain access to the collections held by observatories, archives and persons, I travelled to the four states involved in the project to research state-held records. Wherever possible I pre-arranged site tours and inspected buildings and instruments as part of fieldwork methodology.

I conducted fieldwork at five observatory sites. These were Sydney Observatory, Melbourne Observatory, Old Perth Observatory, Perth Observatory and the original location of Adelaide Observatory (now demolished). I also visited observatories in Britain and Europe which participated in the AC-CdC. These included Oxford University Observatory, Royal Observatory of Belgium and Herstmonceaux Observatory (The Observatory Science Centre), Royal Observatory Edinburgh and Royal Observatory Greenwich.

According to Howitt, when relying on case studies, physicality is an important facet of research:

> "Only a personal visit makes sense of a place, of a context and of a situation to be compared with one's own. Without that context it may be misleading, even dangerous, to think one knows what one is talking about."
> (Jull 1992 p. 4, in Howitt 2001, p. 194).

Howitt investigated indigenous rights claims but his counsel was intended to apply to a broader area of research applications. Latour wrote that 'Although it is a rare outcome, it is essential for us to visit the places where the papers are said to originate' (1987, p. 63). He emphasised the importance of investigating places, instruments and their arrangements in order to better understand the scientific output of laboratories. To understand the relationships between the people, buildings and instruments for this thesis, it was essential to visit the case-studied observatories. As made evident within this thesis, the physical arrangements aided in understanding the 'laboratory' workplace, the relationships between people and technologies, and the men and women working within the observatories. In many cases, the technologies used to create the AC-CdC and the papers produced as works in progress were no longer in their original locations and had been dispersed. In those instances historic photographs were sourced and can be found throughout the thesis. Particular effort was made to locate images of the women who were case studied, and the interiors of the observatories. These were often very difficult to locate and verify.

Yale University Science Historian, Robert B. Gordon, prescribed interpreting the history of technology by engaging with the objects (1993). Gordon advised performing archaeometry on instruments, tools and technologies to understand why they were constructed in certain ways, and where their shortcomings were (to avoid a nostalgic view of past technologies). Examination of the instruments associated with the AC-CdC has been part of the methodology for this thesis. The rationale of physically seeing the instruments was to understand the machines and their design. This informed the design considerations, manufacture, the ergonomics when using the technology, and the daily ease or frustration of use. For example, when examining a star measuring machine in the MAAS collection, the heavy use was obvious through the wear on the surfaces touched by the skin. The microscope required even light to be useful, and so must have been placed near a light or a window. Buildings, instruments and records for the case-studied observatories are held by Melbourne Observatory (managed by Royal Botanic Gardens, Melbourne) and Public Records Office Victoria (hereafter PROV); State Records South Australia (hereafter SRSA); Perth

Observatory and State Records Western Australia (SRWA); Royal Observatory Edinburgh Library (hereafter ROE) Collections; Paris Observatory and the Cambridge University Library (hereafter CUL). The Sydney and Melbourne instruments and dome were held by Macquarie University from 1986 to 2008 and then transferred to the MAAS. The AC-CdC glass plate negatives, logbooks and other related materials remained with Macquarie University until 2013 when they were transferred to a private agency, Australian Disaster Recovery, for cleaning, prior to relocation in the MAAS via a distributed collections agreement between MAAS and SRNSW. There are other records relating to Sydney Observatory's participation in the AC-CdC located at SRNSW.

Related instruments and buildings which influenced decisions made in Australia were examined at Herstmonceaux Observatory (The Observatory Science Centre). Royal Observatory of Belgium (Uccle) was visited because of its involvement in the AC-CdC; its related material culture was intact.

PHOTOGRAPHS BECOME AN ASTRONOMICAL 'TIME MACHINE'

An examination and analysis of photographs was a methodology in this thesis. The camera when attached to a telescope became a 'time machine' because each photographic plate was able to provide a snapshot of the stars in a region of the sky at a particular point in time. The stars could then be compared with an image taken at another point in time to reveal changes, such as changes in stellar brightness, or positions. The AC is known by astronomers as providing 1st Epoch photographs. The astronomical photographs taken for the AC-CdC have not been analysed scientifically in this thesis, but are considered part of the material culture.

Photographs of observatories, of people working in observatories, instruments and the night sky are used as sociological evidence in this thesis. According to anthropologist and Leeds University Arts academic, Jon Prosser, there is nothing neutral about a photograph. The photograph is a 'material object' which has a history that is determined by its situation. Prosser revealed that qualitative research using photographs raised issues of 'representation', 'trustworthiness', 'interpretation' and 'reflexivity' (Prosser 1998, p. 1). Once released into society, a photograph can undergo a 'historical trajectory' and this is increased by virtue of new technologies.

All photographs were constructed and influenced by society or their purpose. Two main reasons for photographs being used in research is for information purposes and to elicit an emotional response (Cronin in Prosser et al 1998, p. 71). Cronin cautioned researchers that the purpose of the photograph will have impacted its meaning and that photographs are often taken at a period of change, when something new happens or during upheaval; hence a photograph has a special relationship to time (p. 73). It is for this very reason that historic images, such as those of women measuring the stars and of equipment, are reproduced in this thesis. These images recorded a major event or represented a period of change identified by photographic journalists, or the images were taken to record and distribute to other astronomers or, in the case study of Winsome Bellamy, her work colleagues.

The temporal relationship between events and the visual documentation of the observatory workspaces, the people and the instruments meant that photographs have informed detailed analysis when few written texts were available. I have taken many photographs as part of fieldwork and during the interviews. A few of these are used to illustrate texts. Approval was obtained from living persons for photographs of those people used in the thesis.

Construction of the Thesis and Synopsis of the Chapters

This thesis and the primary sources, which form the basis of the individual research, are organised by theme and a supple temporality. In the *Introduction* and *Chapter One* I describe the nature of the Astrographic Catalogue and Carte du Ciel projects. I analyse three phases of related literary texts which have been examined in preparation for and cited in this thesis. I define the research fields and present a rationale for the thesis. The root of the AC-CdC projects is established as modernity; the desire to be modern is presented as amongst several reasons for Australia's participation. I present a rationale for the sociological, fieldwork and interview methodologies, as well as the theoretical models determined for the thesis. In the following four chapters, the specific attributes of the AC-CdC that are of relevance to the history of astronomy in Australia are examined.

In Chapter Two, *Colonising the Sky 1887 to 1897: Maps and Centres of Control*, I examine the purpose of the AC-CdC by interpreting mapping and cataloguing the stars as colonial and global imperatives. Participation by the Australian colonial observatories is contextualised within the local and global social milieu of late nineteenth-century modernity. The actor networks and nodes of control are enhanced through a Latourian lens. In Chapter Three, *Visibility of Buildings, Instruments and Computers*, I survey the extent of resources and technologies mobilised for the AC-CdC in the late nineteenth through to the mid-twentieth century. This includes a large force of women employed as star measurers. In Chapter Four, *The Invisible Skirted Labour Force*, I reveal the primary findings of this thesis and demonstrate that the introduction of women into the astronomical workforce in Australia in the late nineteenth through to the mid twentieth century was due to the AC-CdC. The representation of women within the historiography and heritage of astronomy globally provides a broader context for the local conditions. Chapter Five, *Heritage of a Star Catalogue,* presents support for the argument that observatories held their own rich sources of social and cultural history. The *Conclusion* focuses on the main findings of the thesis and why the AC-CdC has relevance to a broader community, as well as the significance of the material culture. This is followed by the *Bibliography*. Examples of and the complete list of Astrographic Catalogues for the Sydney, Melbourne and Perth zones, a list of the women who worked on the AC, primary research source locations and a timeline of major events relevant to Australia's participation in the AC-CdC are found in the *Appendices*. A more detailed synopsis of the thesis follows.

Colonising the Southern Sky – from 1821

In this chapter, the AC-CdC is introduced as a continuum in a long history of stellar observation and mapping. The first Eurocentric map of the southern sky was commenced in 1821 with no reference to Aboriginal Peoples who had been observing Southern Hemisphere stars for tens of thousands of years. The AC-CdC commenced in 1887 and is positioned as embodied within the hegemony of nineteenth-century science, colonisation and cartography, and as a product of society embracing modernity.

Grand international exhibitions showcased the latest in technologies, design and cultural achievements. These were held in major cities with the first in London (1862), then Berlin (1877), Paris (1878), Sydney (1879) and Melbourne (1880). The new global view heralded an era of trade, telegraphic communications and increasingly shared knowledge. Astronomers were engaged in the 'trade' of knowledge in the form of star catalogues. The division of the sky into segments for mapping was influenced by earthly borders, and was not incidental to nationalism and terrestrial ownership.

Driven by curiosity and competition to be at the forefront of new discoveries, astronomers developed communication methods such as newsletters, telegraphic communications and conferences to create networks which crossed regional barriers, bridged language and political differences, and operated even whilst respective countries were engaged in war. Astronomers sought to standardise star catalogues and a new metalanguage created a distinct typology. This effectively separated the world of science from the society within which it was done. My research demonstrates that the organisation for the AC-CdC re-enforced an existing colonial hierarchy, which bound the observatories to imperial control within a global network. I have applied Latour's 'centres of calculation' theoretical model to the AC-CdC to investigate the global, colonial and inter-colonial relationships.

The emergence and expansion of universities and a push towards federal astronomy changed the status of, and resources available to, the state-controlled observatories. However, before the demise of state-controlled astronomy research, there was a substantial investment in technologies for the observatories enrolled in the AC-CdC.

Visibility of technology – 1890 to 1952

The Astrographic Catalogue and Carte du Ciel projects relied on new design developments in buildings, telescopes, photographic materials, processes and measuring instruments. Apart from the texts written during work on the AC-CdC by the lead astronomers, there has been little research into the technologies developed for the AC-CdC in Australia. This chapter begins that research.

The AC-CdC infrastructure required significant planning, approvals and capital expenditure, as well as the invention of machines and processes to suit big data production. New buildings within existing grounds at Sydney, Melbourne and Perth Observatories and the new site at Red Hill for Sydney's astrographic telescope were established. The use of photography for positional astronomy and related projects, such as double star observation, enabled observatories to continue at the cutting edge of astronomy within the confines of, or near to, their city locations into the twentieth century. Conversely, participation in the AC-CdC was also a reason for observatory directors to argue for new dark-sky sites and appoint astronomers who specialised in photography, whilst maintaining a workforce able to provide positional stars using more traditional transit telescope observation methods. Investigation into the architectural designs developed in Australia includes research into technologies and structures built by other AC-CdC participants: the Royal Greenwich Observatory, the Royal Observatory Cape of Good Hope, Paris Observatory and Royal Observatory of Belgium.

One of the major commitments to participate in the AC, not initially understood by the participating observatories, was the provision of human measurers and computers as data production technology. In this chapter we see how accommodation and instrumentation were organised in preparation for the bureau of mainly women to undertake this work. In Chapter Four, I reveal my findings about the significant number of women who were employed as the primary resource for this critical part of the AC project.

THE INVISIBLE SKIRTED LABOUR FORCE – 1890 TO 1964

The letter from Paris Observatory to the colonial observatories, which confirmed that measurement of the AC photographic plates would not take place in a centralised bureau in Paris but would be undertaken locally by participating observatories, significantly changed the history of astronomy in Australia. The scientific method to control how the work was performed, with Paris at the centre, used normative techniques and technologies. The strengths and weaknesses of this model are examined through reference to Bruno Latour's 'centres of calculation' and 'accumulation' theoretical frameworks. The employment of women in the astronomical workforce is positioned as a normative technique, which permeated all observatories involved in the Astrographic Catalogue.

Using references to illustrations and quotes from the popular press, I establish the local Australian view of women and the AC-CdC. In this chapter, my research into archival letters and reports establishes the working conditions, the hours of employment and other information about working life. Comparisons are drawn between the women working in the Australian observatories and the women working in astronomy in the UK, the US and Europe. My case study original research includes interviews with women involved in the AC-CdC at Sydney Observatory, personal anecdotes, photographs of the workplace and social occasions. Furthermore, I have identified some outstanding individuals and provided evidence of their astronomical observations, and other skills, which challenges prior assumptions about the nature, variety and quality of their work.

Recent research by others into the development of astrophysics in Australia, and contemporary astronomy and astrophysics, has established that women are not adequately represented in this field of science. My research for this chapter further investigates what defines astronomical research and whether that definition is historically gender specific. In the next chapter I present evidence that the AC-CdC has a valuable legacy and why its representation has significant social benefits.

Completion of the Star Catalogue – 1964

Chapter Five contributes to the discourse on the preservation of Australia's scientific past. By reference to recent sociology of science research, I affirm that observatories have their own rich sources of social and cultural history. From this perspective, the representation of astronomy in Australia's national heritage and, within this, the AC-CdC is critically examined. In 1964 the final volume of the Sydney zone of the AC was published. This was volume 51, slightly out of sequence as there were 52 volumes of star measurements in the series. The AC was now complete, the CdC remained unfinished. Both projects left considerable material legacy.

The closure of Melbourne Observatory in 1946, and cessation of research in Sydney Observatory in 1982 and Perth Observatory in 2013 involved the disposal and transfer of buildings, instruments and records. Through reference to the AC-CdC, I reveal the historic legacy of astronomy in Australia by an analysis of archival and museum collections, and authorised heritage databases. The significance of landscape and site to the interpretation of astronomical moveable heritage is positioned as critical to the heritage representation of astronomy sites and collections.

The scientific value of Australia's participation in the AC-CdC is reviewed by reference to recent literature about the use of digital technologies to extract data from glass plates. My analysis of the AC-CdC heritage reveals a broader view of all astronomical heritage; the changing technological nature of astronomy and the refocusing of priorities for research means that every astronomical research site will eventually be made redundant. I present evidence that when this happens, society (including museums and heritage authorities) is called upon to assess the value of the material and intangible culture.

Conclusion - The Heavens Revealed

In the conclusion, the primary thesis research findings are revealed. A rationale as to why this thesis contributes to the global history of the AC-CdC and the history of astronomy in

Australia, inclusive of women’s participation, is presented. The relevance of the thesis and its contribution to the representation of women’s participation in science in Australia is framed within contemporary discourse about women’s participation in astronomical research as a career. My findings about the legacy of the AC-CdC are applied to the broader field of the history and heritage of astronomy in Australia to reveal future research and interpretation opportunities.

CHAPTER 2: COLONISING THE SKY FROM 1821

> "Maps, like theories, have power in virtue of introducing modes of manipulation and control that are not possible without them. They become evidence of reality in themselves and can only be challenged through the production of other maps or theories."
>
> (Turnbull 1989, p. 54)

INTRODUCTION

This chapter reveals the Astrographic Catalogue and Carte du Ciel as taxonometric and mapping imperatives symptomatic of colonial science. Australia's participation in the AC-CdC is investigated as part of a continuum to capture local knowledge and send that knowledge back to the colonial power. Furthermore, I examine how involvement in the AC-CdC enabled astronomers in Australia to pursue a modernist ambition and be part of an international network.

To frame my investigations into the creation of celestial maps, I referred to Turnbull, quoted above, and his analysis of terrestrial maps across cultures. Turnbull's research concluded that maps were culturally constructed, and that they are 'metaphors for knowledge' which can only be challenged by other maps. Turnbull referred to Latour's 'centres of calculation' and other models of colonisation as relevant and applicable to the gathering of scientific data and the mapping of land in the nineteenth century. In this chapter, I further investigate the AC-CdC through Latour's and Callon's theoretical models.

By referring to previous discourse on colonialism and science in Australia, my research into stellar photography as applied to astronomy has positioned the AC-CdC as frontier science. My research into the role the AC-CdC played in developing new working models to restructure the observatories from laboratories designed for individual pursuit to those organised for mass data collection and production revealed how invention and communication were characteristics of the astronomers chosen to participate in the projects. These characteristics are further supported in this chapter by my investigation into the 1887 dinner table guests and seating arrangement. I explore the communication and control techniques developed for the AC-CdC and, by referring to the content of letters, I analyse the networks and their effectiveness; these letters were sent across the oceans between the Australian observatories and those in Britain, Europe and the Americas.

The relationship between astronomy and State governmental priorities is examined to understand that when external forces occurred, such as wars and economic expansion and recession, these influenced, interrupted or accelerated the projects. Finally, the growing federal science organisations and networks are exposed as influencing the stability of, and resources allocated to, the state-funded observatories.

COLONIAL PERCEPTIONS OF ASTRONOMY

The first Eurocentric map of the southern sky was commenced in 1821 at Parramatta Observatory (Richardson 1835). There was no reference to the knowledge of the southern stars held by Aboriginal Peoples who had been observing the Southern Hemisphere for tens of thousands of years (Haynes et al 1996, pp. 7–20). Lieutenant William Dawes, astronomer with the First Fleet, logged observations in 1788 and engaged with Aboriginal knowledge (Haynes et al 1996, pp. 31–33).

The evidence about Dawes' encounter with Patyegarang, an Aboriginal woman from whom he learned the nature of the indigenous language of the Sydney Region, has been held in a university and research centre in London since 1835. Dawes' notebook came to the attention of researchers when the title was published in 1972 in a listing of manuscripts relating to Australia. However, it is only since 1993 that the existence of Patyegarang has been more widely known after Jakelin Troy wrote about Patyegarang as being Dawes' teacher and translator (Troy p. 46). This story is of immense importance in understanding the cultural history of the original inhabitants of Sydney and their interaction with the British colonisers during the First Settlement, however, Dawes astronomy work did not, as far as my research has found, result in a published star chart or catalogue.

The first comprehensive meridian star catalogue observed in Australia was the controversial Parramatta Catalogue of 7,385 Stars (Richarson 1835). This catalogue, produced by Carl Rümker and James Dunlop under the instruction of Governor Thomas MakDougal Brisbane, was highly controversial and strongly criticised by the British astronomers who sorted and reduced the observations in Greenwich for publication (Schaffer 2010, p. 118). According to science historians, even once the State observatories were established in Sydney, Melbourne, Adelaide and Perth, the organisation of science in the colonies prior to federation was confined to a small number of motivated individuals with minimal resources to produce scientific research across a wide number of disciplines (MacLeod 1988, pp. 40–60; Haynes et al 1996, pp. 69–95).

American science historian, George Basalla, defined western science as spreading into territories in three stages (1967). In the first phase of colonialism, the ‘unscientific’ colony sends data back in raw form such as maps, data and specimens to be appreciated, analysed and utilised by the imperial power; in the second colonial stage, the European scientific tradition is carried out in the colony. Basalla’s third stage is where the European tradition has been fully implanted and there is the struggle for independence and the establishment of a new national scientific culture. Basalla acknowledged that this is difficult to define and not perceived through one event. Moyal (1976) gave qualified support to Basalla’s model of colonialism, although she emphasised that there were other factors, such as the allure of a ‘virgin sky’, which had consequences for the local development of astronomy in Australia.

Other critics of Basalla’s model described it as an overly simplistic view of the complexity of how science developed in the colonies (Saunders 1991, pp. 2–3; Inkster 1985; MacLeod 1988, p. 6). By including the vertical characteristics of scientific superstructure, a socio-economic base plus the ethos of science policy, a less elegant but more applicable model was required. MacLeod’s comprehensive research into the formation of scientific enterprises AAAS and CSIR provided the foundation for developing that model, which must include the impact these organisations had on the development of a national approach to science, and the loosening of ties with Britain. MacLeod prescribed a ‘finer set of concepts and categories if we are to see the harmonies and disharmonies that remain of enduring importance’ (1988, p. 6). The popular press reflected perceptions of science in the early colony.

The extent of scientific work produced by a nineteenth-century colonial observatory is demonstrated in *Town and Country* magazine. The double-page spread illustrated the breath of work carried out at Sydney Observatory in 1897, as shown in Figure 3. The following quote from the magazine compared astronomy to meteorology:

> “Of the two, meteorology is more appreciated and understood by many. To foretell rain or gales, for the warning of the farmer, the seaman and the pleasure seeker, is a service whose value all can recognise as practical: while the profoundest investigation of the secrets of space … seems to the utilitarian mind a thing of little worth.”

The writer explained the international nature of astronomy, applauded H.C. Russell and briefly described the astrographic process as culminating in an aesthetic, rather than emphasising the scientific outcome:

> "The star photographs obtained by its means are not only astronomical records of high value, but in many cases form pictures of extraordinary beauty …".
> (Town and Country, 1897)

Figure 3: *Town and Country*, 13 Nov 1897, pp. 27–30 (Collection CUL, RGO 7/161)

This article supports other evidence that the colonial view on astronomy was that it was servant to the needs of the colony, such as time-keeping, tidal changes, surveying and meteorology:

> "All too frequently, astronomy, which today we regard as the primary, if not the sole, purpose of an observatory, was pushed aside by the claims of time-keeping, trigonometric surveys, meteorology, magnetic surveys and tide-recording, all of which were perceived by funding bodies as being more 'useful'."
> (Haynes et al 1996, p. 69).

At its inception, the AC-CdC was an exception to this attitude in the states of Victoria and New South Wales. The Great Melbourne Telescope project, two decades earlier, and the investment in the 1874 Transit of Venus in these two states demonstrated local support for research astronomy. The difference is that this support was periodic and not to be relied upon, as is explored further.

In New South Wales, temporal to the inception of the AC-CdC, local statistician Timothy A. Coghlan declared astronomy as one of the least useful services of the nineteenth-century observatory in the 'Wealth and Progress of New South Wales' (1886–1904). A powerful public servant who later became the Colonial Secretary, Coghlan provided a statistical and opinionated perspective on what was officially considered important in the state. In 1904 W. H. Hall took over from Coghlan and the annual editions were re-named the 'Official Year-book of New South Wales' (Hall 1906). It is clear from Coghlan's and Hall's textual descriptions that, by the start of the twentieth century, official opinion in the state was that research science was of interest primarily to the leisured class and was not significant in a young country occupied with the development of its resources (for example Coghlan 1900, p. 192; Hall 1906, p. 566).

The upper echelons of society were interested and engaged in science, or indeed it was a fashionable pastime. Figure 4 is an 1895 etching of Sydney Observatory's South Dome and telescope. It depicts a well-attired lady with a suited gentleman visiting the South Dome of Sydney Observatory. This drawing shows the 'leisure class' enjoying astronomy.

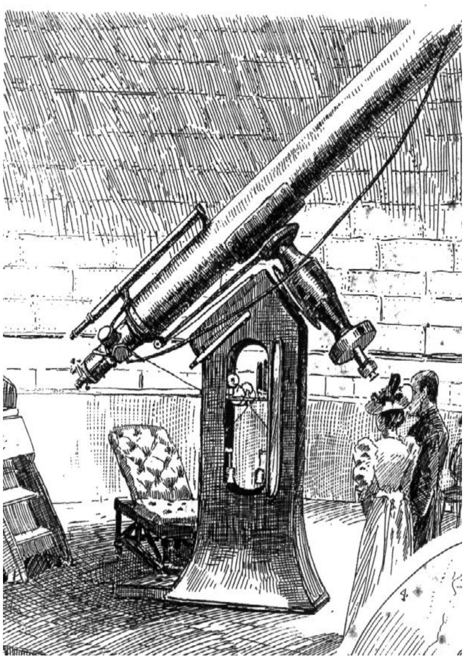


Figure 4: Inside Sydney Observatory South Dome (*Sydney Mail*, 12 Jan 1895, p. 78).

In the colonies, scientific organisations had flourished, attracting men and women from the upper classes of the colonies. These included colonial branches of British science organisations such as the New South Wales branch of the British Astronomical Association

(BAA), established in 1895. Earlier, the NSW branches of the Royal Society (1866) and the Linnean Society (1874) had been established and their membership was strong. This was the same in the other states; most organisations had professional scientists at their helm and deferred to Britain for information and guidance.

Home argued that acknowledgement of scientific expertise within the colony was very much dependent on recognition by the British scientific establishment until after WWII. Home observed that election as a fellow of the Royal Society in Britain was considered the ultimate accolade until recent times:

> "The [Royal] Society thus came to function as the linchpin of an Empire-wide system of scientific patronage and reward that helped to keep colonial science firmly bound to that of the metropolis. By preserving its rules unchanged, even after the breaking up of the Empire after World War II, the Society helped Britain to retain a degree of cultural hegemony, so far as science was concerned, over its former colonial territories, long after they achieved political independence."
> (Home 2003, p. 47).

The view that imperialist networks dominated astronomy in Australia at the time of the AC-CdC and well into the twentieth century is well supported (Basalla 1967, pp. 611–622; Inkster 1985, pp. 677–704; MacLeod 1988, Moyal 1976, Haynes et al 1996, p. 163, Shapin 2010, p. 140). Furthermore, the construction and nature of maps as part of the scientific claims on territory and its inhabitants are central to colonisation theory. This is relevant to the construction of the celestial chart and catalogue, and is explored in the next section.

MAPS AS THEORY

Latour's 'centres of calculation' model (1987) has been a pivotal influence in expanding and adjusting previous colonial models as applicable to science expounded by Basalla (1967); Inkster (1985) and MacLeod (1988). According to Latour, normative colonisation behaviour is characterised by scientists arriving in a foreign land, exploring and collecting data, and then returning to their origins with the acquired knowledge (Latour 1987, p. 220). This behaviour described the Parramatta Star Catalogue, and the organisation of the AC-CdC as it was initially proposed—with the observatories sending their data back to Paris Observatory for measurement and analysis.

Furthermore, according to Latour, the outcome of exploration is often in the form of a map. Arthur Robinson and Barbara Bartz's (1975) work, 'The Nature of Maps', included maps, photographs and catalogues as discourse which embody power. This is the power of selection, of inclusion or exclusion, which is exercised when making a map; once made, the map becomes ‘a priori’ as theorised by Kuhn, whose influential ideas about scientific practise I have previously described. Latour agreed with Kuhn, Robinson and Bartz that maps have power.

Turnbull’s exploration of maps as theory (1989) supported Latour’s analysis of the purpose of maps. The exclusive nature of the creation and interpretation of star maps is one of the ways astronomers revised, created and controlled knowledge. Therefore, an entire map of the celestial sphere set at epoch 1900, photographically imaged through a ‘star camera’, would indisputably mark the positions and magnitudes of the stars well beyond what the eye could see through a telescope, and create a new truth about the position of stars.

Latour also described how scientists gather resources and allies to make dissent impossible (1987, p. 103). Latour’s ‘centres of calculation’ methodology was supported in the way astronomy allies of the AC came to the defence of the colonial observatories when a science that lacked the ‘useful’ nature of other activities undertaken by colonial observatories was threatened by local government intervention. According to Latour, maintaining strength relies on others taking up your project and using it to produce outcomes. The participating AC-CdC observatories should have improved their positions within the scientific community through participation. They accumulated resources and established facts. The major assets were substantial and included buildings, equipment and human resources, which are more fully described in Chapter Three.

The lack of immediate utility was one of the major downfalls of the AC-CdC. Due to the lack of ‘findings’ that could be announced or a suitable system of reward, there was little in terms of media, political or public excitement for those undertaking the project. Until published, the AC and CdC lacked immediate ‘useability’ or utility and outcomes were rarely of major consequence as the focus was on producing the data, not analysing it. The use of the AC-CdC depended on the project progressing at a reasonable pace and each member of the network completing their section of the sky. The long-term use depended on comparison with other epochs. This characteristic is typical of ‘Big Science’ in nineteenth-century Britain, as described by Ratcliff through her investigation into transits of Venus as “... vast measurement projects that involved accumulating unprecedented amounts of data” and supported by government resources (2008, p. 22).

Some of the strength and mystique of the projects lay in the terminology, methods and typologies used to mediate the chart of the sky and catalogue. These could only be produced and understood by those with specialised knowledge. Latour proposed that through specialised knowledge networks, a small group of astronomers were able to muster considerable resources, build new buildings, commission new instruments and establish new ways of working in most parts of the globe. Furthermore, astronomers were very good at performing at a distance with precision, regularity and in tabulated form (Turnbull 1989, pp. 219–221); they were therefore able to maintain an accumulative cycle described by Latour as one of the normative characteristics of modern science (Latour, 1987, pp. 215–223). The project's intention was to enable future astronomers to understand the movement of stars by comparing epochs, thus creating an accumulative cycle of grand proportions.

Australia's participation in the AC-CdC was forged into this British colonial system, but there was also the global network with Paris Observatory at the scientific centre of the projects. With the French leading the way in photographic techniques at that time in the late nineteenth century, the AC-CdC was an exciting enterprise for the participants as many aspects of the projects were as yet unknown.

STELLAR PHOTOGRAPHY AS A FRONTIER SCIENCE

The Astrographic Catalogue and Carte du Ciel projects emerged out of the application of photography to astronomy. The techniques of astrometry were still being improved and communicated throughout the nineteenth century; however, the pace at which this happened was arguably increased by the AC-CdC. Stellar photography was first practical when dry-gelatin plates were invented in the 1880s. This technology stunned the astronomical world. For the first time, the stars of the entire night sky as viewed from Earth were able to be captured using photography, called 'stellar photometry' and 'astrophotography'. Far more stars than had ever been seen through a telescope were able to be seen on the negative plates, and the technology opened up new frontiers in space. Accurate locations and the magnitude of each star on a specific time and date was captured using photographic film and catalogued. The AC was also 'astrometry' but this new 'astrographic' method gave a consistently greater level of accuracy than was previously possible. The original source of observation was not personal, although subject to the aberrations of technology, and the stellar image was recorded on film for others to view and analyse. The NSW Government Astronomer, Henry

Chamberlain Russell, and Victorian Government Astronomer, Robert Lewis Ellery, were at the forefront of this experimental science. According to Robert Holden, Australian historian, Russell was one of the most progressive in the use of photography in science in Australia (Holden 1988).

When David Gill, Astronomer at the Cape of Good Hope Observatory, photographed a comet in 1882, he revealed not only the comet but many stars not previously known that were imaged in the surrounding plate. The Henry Brothers, astronomers at Paris Observatory, improved the photographic technique and their research was directed towards making a chart of the sky. It was the enormity of this project which caused Gill to suggest to Mouchez that international collaboration was essential.

ASTROGRAPHIC CONGRESS INSTIGATORS AND COLONIAL PARTICIPANTS

The first Astrographic Congress was held between the 16th and 27th of April 1887 at Paris Observatory (Weimar 1987, p. 12). Ellery and Russell received their official invitations from the Director of Paris Observatory, Admiral Mouchez, on the 15th of October 1886. Russell replied after some delay, as permissions had to be sought from the Colonial government:

> "The Government of New South Wales has given me leave of absence from duty to enable me to attend the meeting of the Conference on April 16th … I have for some time been working at stellar photography and am very much interested in the work…"
> (letter Russell to Mouchez, 6 Jan 1887, in Chinnici 1999, p. 352)

Ellery replied on the 7th of January 1887 that he was unable to attend, presumably after he had consulted with Russell (Ellery to the Academy of Science, 7 Jan 1887 in Chinnici 1999, p. 260). Russell's invitation was by recommendation from Gill. Furthermore, influential British astronomer, Huggins, advised Mouchez on Russell's suitability and likely availability (letter Huggins to Mouchez, 20 October 1886 in Chinnici 1999, p. 352). Russell had already planned a visit to Europe in 1887, which Huggins was aware of (Chinnici 1999, p. 352).

There were fifty-eight attendees to the conference, which included fifty-three astronomers as well as Aimé Laussedat, Director of the museum Conservatoire des Arts-et-Metiers and a surveyor who used photographic mapping techniques; Admiral Georges Charles Cloué of the French Navy and a member of the French Board of Longitudes; and Louis Liard, high-profile head of the French Office of Public Instruction whose primary concern was education. The list of attendees on the first day of the conference is shown in Figure 2. Winterhalter, who attended the conference, compiled a complete list of all attendees over the ten days (1891, pp.

10–11). The attendees were from around the globe and had received the highest recognition for their research and ingenuity.

The conference theme of international co-operation coincided with an epoch when the term ‘international’ was in prolific use. It is arguable that there was a spirit of optimism, leadership and co-operation within France at the time the Paris Observatory took the lead on the AC-CdC. In 1887, Paris had established a high profile and central position in the arts and sciences; for example, construction had begun on the Eiffel Tower in preparation for the 1889 Paris Exposition and Louis Pasteur had established the Pasteur Institute. The first International Geographical Congress was held in Paris in 1878, prior to the first Astrographic Congress (Marcou 1883, p. 512), and the first International Congress of Physics was held in Paris in 1900 (Guillame 1899, pp. 459–461).

As previously noted, International Expositions were held in London (1851, 1862), Paris (1855, 1867, 1878, 1890), Vienna (1873), Sydney (1878) and Melbourne (1880, 1888); and Australian astronomers, like other scientists, were interested and involved in showing their latest uses of technology at home, in Britain and in the global arena. Russell exhibited in 1886 at the Colonial and Indian Exhibition held in London and at the 1888 Centennial Melbourne International Exposition, for which he won a medal (MAAS collection 91/221) (Holden 1988). Peter Hoffenberg, Associate Professor of History at the University of Hawai’i, highlighted the importance of these expositions to Australian scientists in reducing the disadvantages of distance and preventing isolation (Hoffenberg 2010, pp. 227–253). Other astronomers were exhibiting their images in the public arena; for example, the Lick Observatory won the gold medal at the Paris Exposition in 1890 for photographs of Mount Hamilton and the moon (Holden 1988, p. 125).

In photography for astronomy, the French were innovative. The Henry Brothers, Paul Gautier and the brothers Lumiere were leaders in their experiments and technology development. According to David Aubin, France’s national profile in astronomy had been diminished by the light pollution around Paris Observatory (Aubin 2003, p. 99). Both Bigg and Aubin place Mouchez’s leadership of the AC-CdC as a deliberate move to re-establish Paris Observatory’s central position in astronomy internationally (Bigg 2000, Aubin 2003). Bigg proposed that Mouchez believed he was in a strong position to shape not only the AC-CdC, but also the course of astronomy using photographic techniques to image the stars (Bigg

2000). My research demonstrates that the AC-CdC successfully increased the profile of Paris Observatory in Australia in the popular press for two decades from the 1880s, as illustrated by the graph of articles about Paris Observatory in the text in Figure 5.

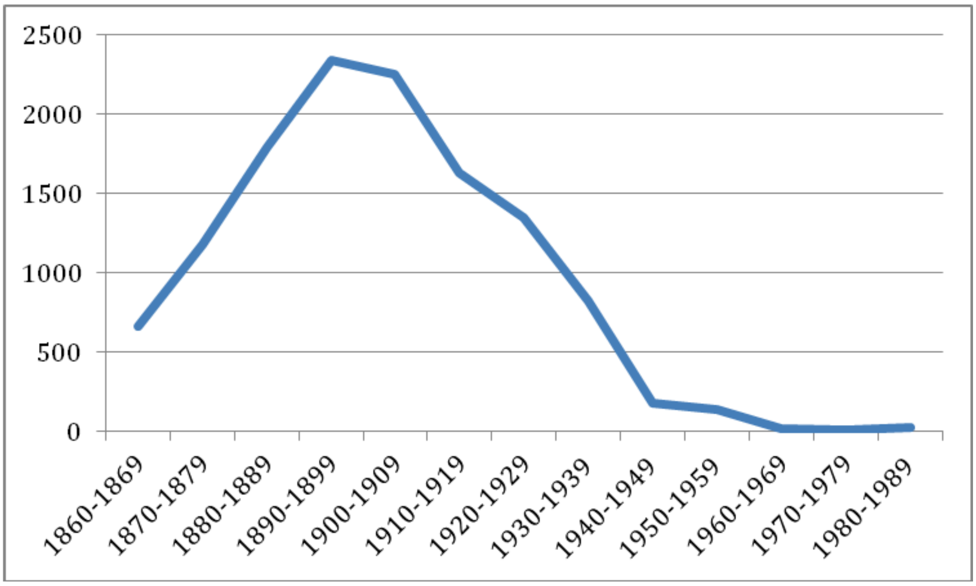


Figure 5: Graph indicating the frequency of the occurrence of the words 'Paris Observatory' in news media in Australia, 1860–1989. Data source: TROVE. Graph by T. Stevenson.

The photograph of the participants in the first Astrographic Congress in Figure 6 demonstrates Mouchez's position as Director of Paris Observatory and instigator of the AC-CdC. Admiral Mouchez (#6) is at the centre of the bottom row, flanked by Astronomer Royal at Greenwich, William Christie (#5) and, on his right, Russian astronomer and Director of Pulkovo Observatory, Otto Wilhelm von Struve (#7). Russell (#18), who represented Sydney and Melbourne Observatories, is in the middle row, sixth from the left, incorrectly labelled in this photograph as C. H. F. (Christian Heinrich Freidrich) Peters (#19) who was one of two astronomers from North America. On the left of Russell is Swiss-French astronomer Emile Gautier (#17).

Figure 6: Astrographic Congress attendees 1887. Photograph by Nadar (Collection Paris Observatory).

Gaspard Felix Tournachon, more popularly known as Nadar, created this image. Nadar pioneered aerial photographic views of Paris and surrounds taken from a hot air balloon. Elizabeth Anne McCauley, Professor of the History of Photography at Princeton University, described him as a caricaturist, an artist and an adventurer (McCauley 1983, pp. 355–363). Nadar's work has been assessed by art historian emeritus, Professor Stephen Bann, as experimental, particularly with photographic techniques and film-making, 'committed to the cult of progress' (Bann 2009, p. 107) and able to 'integrate photography into a thicker history' (Bann 2009, p. 111). The portrait by Nadar is a further cultural dimension to my interpretation of the AC-CdC congress as a product of modernity.

Jules Janssen, President of the Academie des Sciences and sponsor of the first congress, welcomed the participants, and stressed the importance of the scheme with these words:

> "The mapping of the heavens [...] where the bodies themselves record their location and their brightness, will form an unprecedented moment in Science. [...] You have sanctioned a new method, and you have established a revolution that will not be any less fruitful than the one that saw the introduction of telescopes into Astronomy."
> (18 Apr 1887, in Launay 2012)

THE ASTROGRAPHIC DINNER TABLE

As part of the first congress, there were two main social events held: a soiree on the 19th of April 1887 and a formal dinner on the 21st of April. Both were held at Paris Observatory. The social arrangements were significant, as indicated by the programs and menus researched by Paris Observatory astronomers, Suzanne Debarbat and Theo Weimar, and research librarian Anne Marie Motais de Narbonne (1988). These indicate the nature of the conference and its importance as the first international meeting of this kind in astronomy.

At the soiree, the entertainment was extensive including French comedy performances and musical performances by well-known cellist Joseph Hollman. Also performed were Georges Bizet's 'Carmen Fantasy' from the popular opera 'Carmen', and 'Papillon' from 'Scenes from a Masked Ball' composed by David Popper (translated and extracted from the 'Programme de la soiree', Debarbat et al 1988, p. 114). Two evenings later, the official dinner table seating arrangements, as shown in Figure 7, provided global network opportunities, with the participants not grouped in their colonial or first language groups, but spread around the table.

Russell was seated opposite the Director of San Fernando Observatory, Royal Spanish Naval Captain Cecilio Pujadon. Seated on Russell's left was Marie Alfred Cornu, a highly respected French physicist and one of the leaders in spectroscopy; and on his right, Jesuit astronomer, Father Perry. Perry was Director of Stonyhurst College Observatory in the UK, a leading solar physicist and an experimental solar eclipse photographer. Director of Toulouse Observatory, Felix Tisserand, and Colonel Aimé Laussedat were seated nearby as shown in Figure 7. Tisserand became the Director of Paris Observatory after the death of Mouchez. Laussedat had invented the metrophotography technique which combined land-based images with measurement, introducing photography as a tool of terrestrial surveying (as shown in Figure 8). Laussedat pioneered the use of a réseau grid for surveying, and likely influenced the decision to adopt the réseau grid for the Astrographic Catalogue photographs.

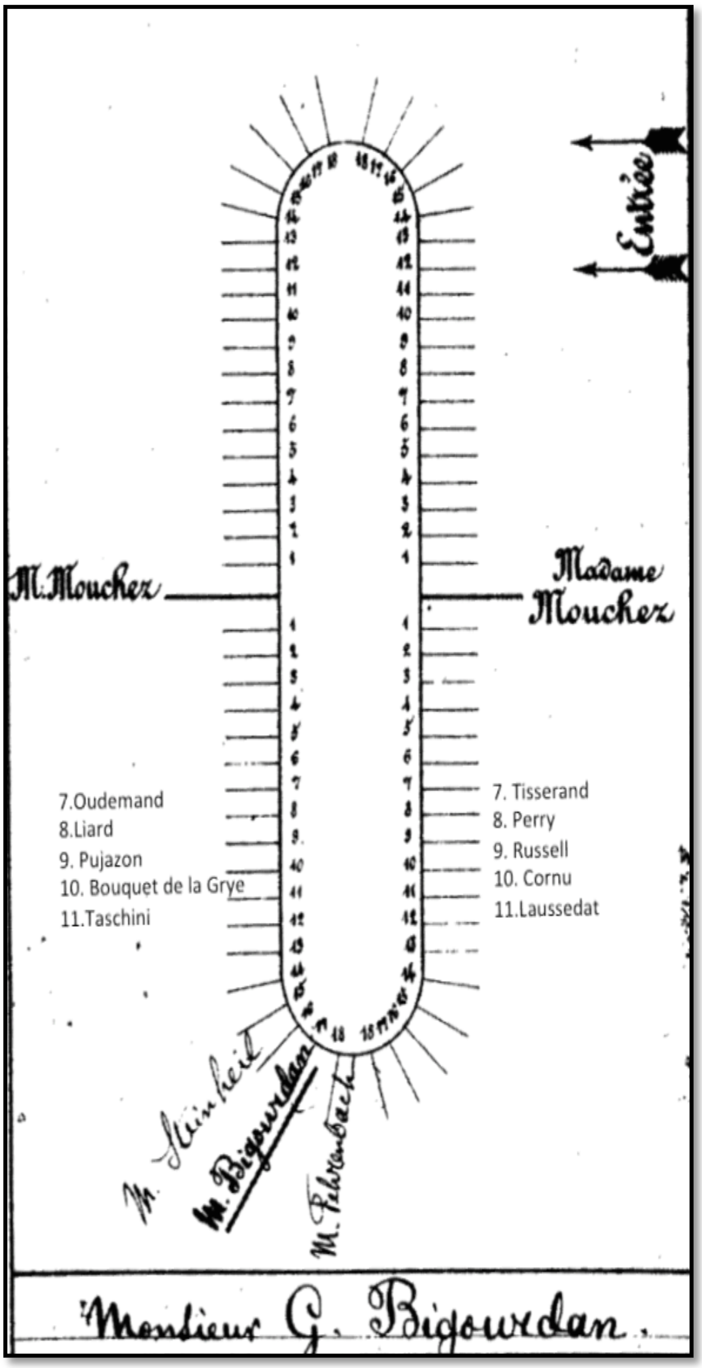


Figure 7: Astrographic Congress official dinner table (Motais de Narbonne 1988, p. 131–132).

The outcome of this first congress was, as reported by British Astronomer Royal, William Christie, definitive (Christie 1887, p. 20). The photographic instruments were determined and the initial photographic objectives agreed, namely that the celestial sphere would be divided into zones, with ten observatories confirming their participation. The first observatories determined for the Southern Hemisphere were, according to Christie: ‘La Plata, Melbourne, Rio di Janiero, Santiago de Chile and Sydney …’ (1887, p. 21).

Figure 8: First experiment in metro-photography - Mt Valonin 1861
Photographed by Aime Laussedat, George Eastman House Collection: 69:0256:0001

There were three representatives from the United States of America in attendance: Frederic Peters, Director of Hamilton Observatory, New York; Winterhalter, the aforementioned Director of the USNO; and William Louis Elkin from Yale University Observatory.
Pickering had sent his apologies and a comprehensive response to questions Mouchez circulated prior to the conference, which was tabled in full (Winterhalter 1891, p. 55). The nature of Pickering's advice was about the telescope focal length and its aperture, the plates, the length of exposure, the epoch, printed copies and reproductions of the plates, the catalogue and an offer that HCO would conduct photometric research using the plates. It was clear that Pickering was interested in the research his team could potentially derive from the plates but he was not interested in undertaking to photograph and measure a zone.
Peters, one of the three American attendees, noted in his report that: 'It is indeed to be regretted that the representative men of astrophysical science in the United States, Messrs. Rutherfurd and Pickering, were not present' (Peters 1888, p. 48). Winterhalter wrote that 'had there been no practical results of the international review at Paris, there would still be much good derived from personal acquaintance and discussion' (1891, p. 61). The AC-CdC was generally acknowledged as an international project not attempted at this level in astronomy before.

Four committees were established (astronomy; photography; stellar magnitudes; publication) as well as an overarching 'Permanent Committee' of which Mouchez was at the head and Christie the Vice President. The Permanent Committee had a hierarchy: first class members were the Directors of the participating observatories, and second class members were eleven experts not directly taking part (Winterhalter 1991, pp. 44, 45). The second class membership initially included Christie, Duner, Gill, Prosper Henry, Janssen, Levy, Pickering, Struve, Tacchini, Vogel and Weiss. It should be noted that Christie, Gill and Henry were to play essential roles in the projects; Christie and Gill were part of the inner circle of decision-makers; and at the time of the conference Christie was not able to commit the participation of ROG until there was approval from the Board of Visitors (Christie 1887, pp. 20–21).

Many decisions were made at the first meeting and some of Pickering's recommendations were adopted. The type of telescopes were determined as metal refractors, with the aperture of the objective lens at 33cm (13 inches) and a focal distance of 3.43 metres. The photographic plates were to be exposed with a grid and engraved with reference numbers. Decisions about measurement, reduction and preservations were left to be resolved in the future (Winterhalter 1891, pp. 49–51), and how the celestial sphere was to be divided was only partially determined.

The addition of the AC to what was originally the simpler Chart (Carte du Ciel) evolved significantly during the first few years of the project and, by 1891, was the higher priority. Furthermore, the original scope of the catalogue, which was to initially determine positional stars, had changed significantly by 1891. This was not met with unanimous support, as demonstrated by the Editors of *The Observatory* journal (Editors 1891) who included Chief Assistant at ROG, Herbert Hall Turner:

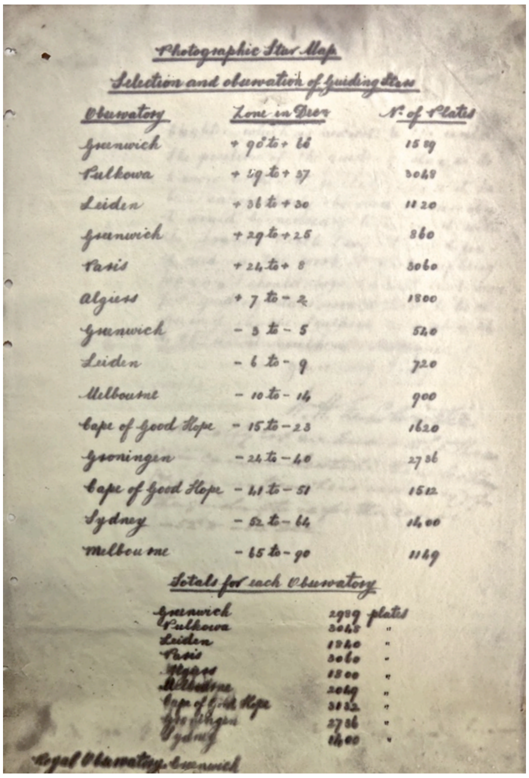
> "So the Catalogue is to be pushed forward and the poor Chart only tolerated … By successive reinterpretations and additions this has now come to mean photographing the heavens six, possibly eight times over … In our view such a catalogue is a mere human reproduction of a Chart, and stands condemned …"
> (Editors 1891, pp. 185, 186).

One of the main complaints in the paper quoted above was the re-interpretation of the project after the first congress. Nonetheless, the AC became the priority over the purely photographic CdC.

Notwithstanding disagreements, one of the defining characteristics of the AC-CdC was the extent of international organisation. Prior to the AC-CdC, there had been co-operation on star catalogues and significant observations, such as transits of Venus as described by Lomb (2011); but none of these prior projects had the same extent of global reach as the AC-CdC. My research has re-affirmed that the AC-CdC involved, at various stages, fifteen countries and twenty-four organisations as listed in Appendix 1, which I will now explain.

DIVIDING THE CELESTIAL SPHERE

The celestial sphere was divided into zones, much like the latitude of the earth. The northern celestial sphere was 0° to +90°, and the southern celestial sphere was 0° to -90°. There was much uncertainty for more than a decade on the AC-CdC zone distribution. As seen in Appendix 1, some of the initial observatories did not start or complete their zones. Relevant to Australia's participation, it was due to the commitment and later withdrawal by Rio de Janiero that Perth Observatory was able to join the project as late as 1900. There were changes in zones allocated to other participating observatories, primarily related to resources, the impact of war or civil disturbance.



Photographic Star Map

Selection and observation of Guiding Stars

Observatory	Zone in Decl.	No. of Plates
Greenwich	+ 90° to + 65	1529
Pulkowa	+ 64 to + 37	3048
Leiden	+ 36 to + 30	1120
Greenwich	+ 29 to + 25	860
Paris	+ 24 to + 8	3060
Algiers	+ 7 to − 2	1800
Greenwich	− 3 to − 5	540
Leiden	− 6 to − 9	720
Melbourne	− 10 to − 14	900
Cape of Good Hope	− 15 to − 23	1620
Groningen	− 24 to − 40	2736
Cape of Good Hope	− 41 to − 51	1512
Sydney	− 52 to − 64	1400
Melbourne	− 65 to − 90	1149

Totals for each Observatory

Greenwich	2929 plates
Pulkowa	3048 "
Leiden	1840 "
Paris	3060 "
Algiers	1800 "
Melbourne	2049 "
Cape of Good Hope	3132 "
Groningen	2736 "
Sydney	1400 "

Royal Observatory, Greenwich

Figure 9: William Christie, 1890, positional stars, CUL, RGO 7/212.

The observation and determination of guiding stars for each zone was a precursor to the start of work. As seen in Christie's handwritten list in Figure 9, by 1890 there were nine observatories committed to providing guiding stars but only three of these (Melbourne, Sydney and Cape of Good Hope Observatories) were able to complete Southern Hemisphere zones.

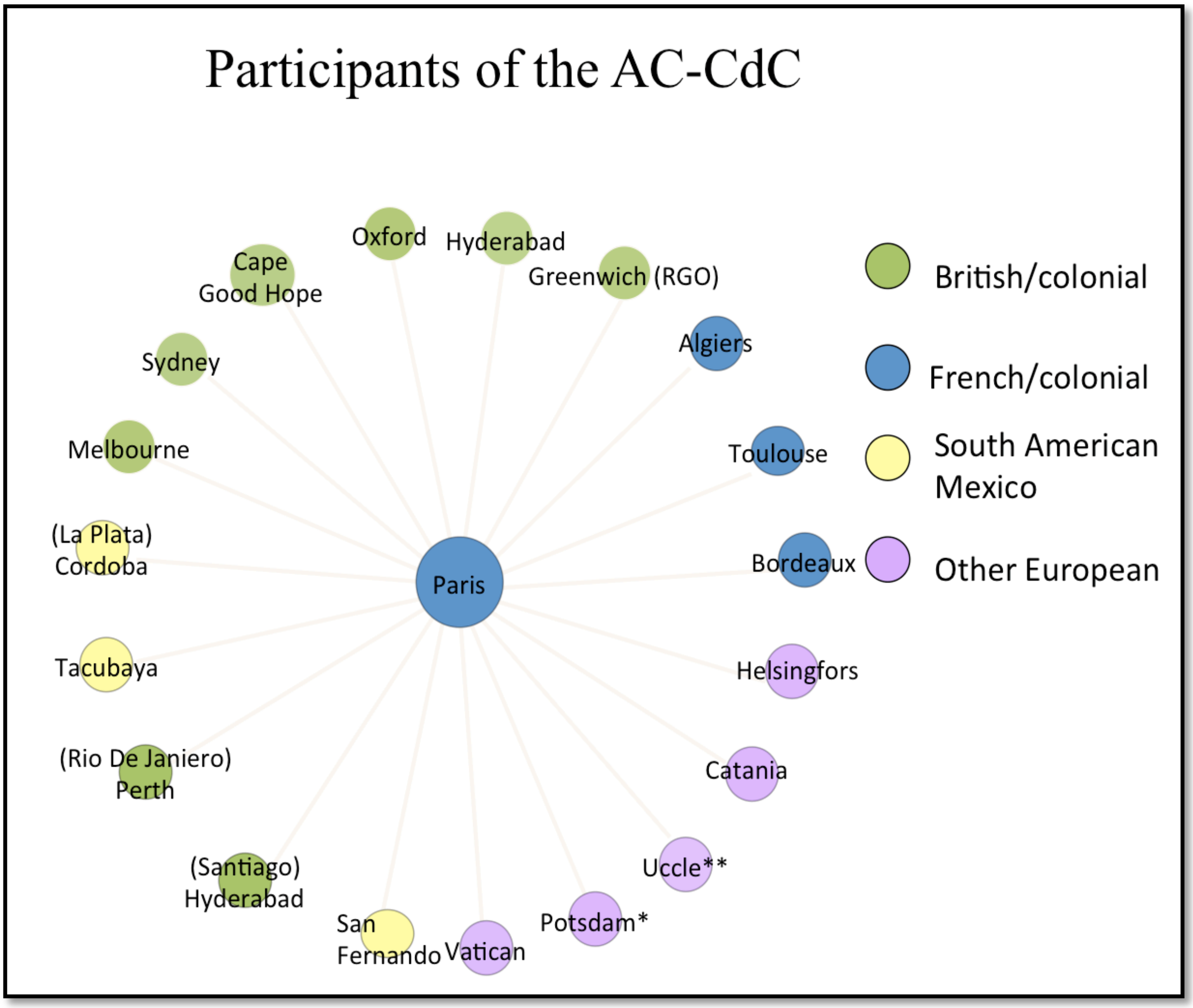


Figure 10: AC-CdC participants by colonial and other alliance. Names of observatories in brackets were originally allocated the zone . T. Stevenson.
*Potsdam was unable to complete due to the WWI **Uccle is Royal Observatory Belgium

The participants of the AC-CdC and their colonial alliances are shown in Figure 10 around the centre of Paris Observatory. The observatories in Australia and South Africa were part of the British group of observatories involved in the project, with ROG a second centre. Even though the Permanent Committee met in Paris and decisions were made about the nature of the technology, it was the colonial, cultural and geographical alliances which determined the makers of telescopes, the glass plate manufacturer, telescope micrometers and measuring machine design, as investigated in Chapter Three. This created a polycentric actor network, as previously mentioned (Hoffenberg 2010, pp. 227–253; Chambers & Gillespie

2000, p. 223) and as elaborated on further in this thesis, the strength of which either improved or weakened the overall network.

In the Southern Hemisphere, the zone originally allocated to Rio de Janiero was mainly taken over by Perth Observatory with Royal Observatory, Cape of Good Hope, allocated a proportion of the zone. Hyderabad Observatory in India completed the Santiago de Chile zone, and the La Plata zone was handled by Cordoba Observatory in Argentina. In the Northern Hemisphere, the zone allocated to Potsdam Observatory was taken over by Uccle, Oxford and Hyderabad Observatories after the Potsdam plates were damaged. On the 14th of April 1945, at the end of WWII, a bomb was dropped on Potsdam near where the plates were stored, shattering all but 34 plates (Dick 1988, p. 156).

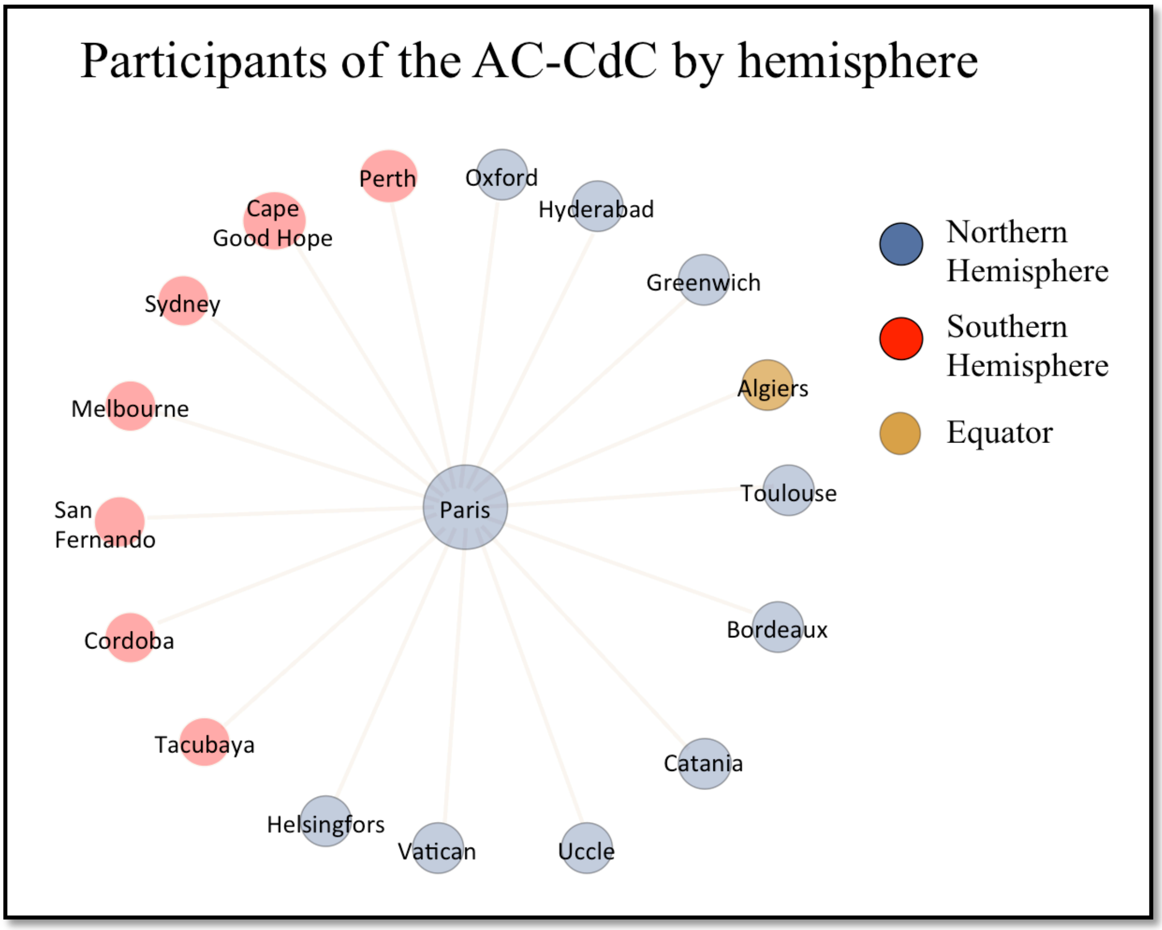


Figure 11: Eighteen participant observatories by hemisphere from 1916. T. Stevenson.

Figure 11 illustrates the final distribution of the Northern and Southern Hemisphere zones. The distribution of the Southern Hemisphere zones is amongst seven observatories, and the distribution of the northern zones is amongst ten observatories, with Algiers Observatory allocated the zone around the equator. In the late twentieth century, there were few well equipped and resourced observatories in the Southern Hemisphere—this is reflected by the unequal distribution.

The weakness in expertise and technical equipment in the Southern Hemisphere zones of the scheme was acknowledged from the onset by the Permanent Committee. My reading of the proceedings of the first congress has uncovered that, at the first congress, Admiral Mouchez made a resolution to approach governments to create new observatories in the south:

> "... believing that the number of observatories in the southern hemisphere is insufficient for the proper and prompt execution of that work, expresses its wish that two new ones be created at least temporarily, one in New Zealand, the other on Reunion Island."
>
> (Mouchez, 1887, quoted by Winterhalter 1891, p. 46)

Nothing came of this plan and in the end, whilst there were nine observatories eventually involved in varying proportions of the southern zones, half of the southern zones (45°) were completed by the three observatories in Australia, as seen in Table 1.

According to USNO astronomers, the total number of stars measured and catalogued by Sydney, Melbourne and Perth Observatories was 1,016,000. Through my research at PROV and SRNSW investigating the correspondence, I discovered that there were more complexities to the Southern Hemisphere work, such as the lack of positional stars and the density of stars on many plates (which had not previously been examined as having major implications for the longevity of the project).

The evidence from the archived correspondence at CUL which involved Christie (RGO 7/161) and Gill (RGO 15/129), the volumes of the Astrographic Catalogue at Perth Observatory (which appears to be the only organisation in Australia to contain the full set) and the proceedings of the inaugaural meeting (Winterhalter 1991) made it clear that inclusion of competent Southern Hemisphere observatories was a concern from the onset.

Zone	Declination Range		Epochs	Number of Stars*
Greenwich	+65	+90	1892–1905	179,000
Vatican	+64	+55	1895–1922	256,000
Catania	+54	+47	1894–1932	163,000
Helsingfors	+46	+40	1892–1910	159,000
Hyderabad North	+39	+36	1928–1938	149,000
Uccle	+35	+34	1939–1950	117,000
Oxford II	+33	+32	1930–1936	117,000
Potsdam	+39	+32	1893–1900	108,000
Oxford I	+31	+25	1892–1910	277,000
Paris	+18	+24	1891–1927	253,000
Bordeaux	+17	+11	1893–1925	224,000
Toulouse	+5	+11	1893–1935	270,000
Algiers	+4	-2	1891–1911	200,000
San Fernando	-3	-9	1891–1917	225,000
Tacubaya	-10	-16	1900–1939	312,000
Hyderabad South	-17	-23	1914–1929	293,000
Cordoba	-24	-31	1909–1914	309,000
Perth	-32	-37	1902–1919	229,000
Perth-Edinburgh**	-38	-40	1903–1914	139,000
Cape	-41	-51	1897–1912	540,000
Sydney	-52	-64	1892–1948	430,000
Melbourne	-65	-90	1892–1940	218,000

Table 1: The final allocation of zones for the Astrographic Catalogue. *Estimated number of stars. **The Perth-Edinburgh section was entirely photographed at PO, but measured at ROE. Urban et al 1998.

SOUTHERN HEMISPHERE STARS: LEAST MAPPED AND RICHEST CONCENTRATION

There were greater consequences of taking on the AC-CdC projects for the Australian participants (initially Sydney and Melbourne Observatories) than for the observatories located in the Northern Hemisphere. The division of the celestial sphere is illustrated in Figure 12. Located in the Southern Hemisphere, with the most concentrated section of stars in the Milky Way directly above, having two, then three of the southern zones meant that Australian observatories were central to the project, not at the periphery.

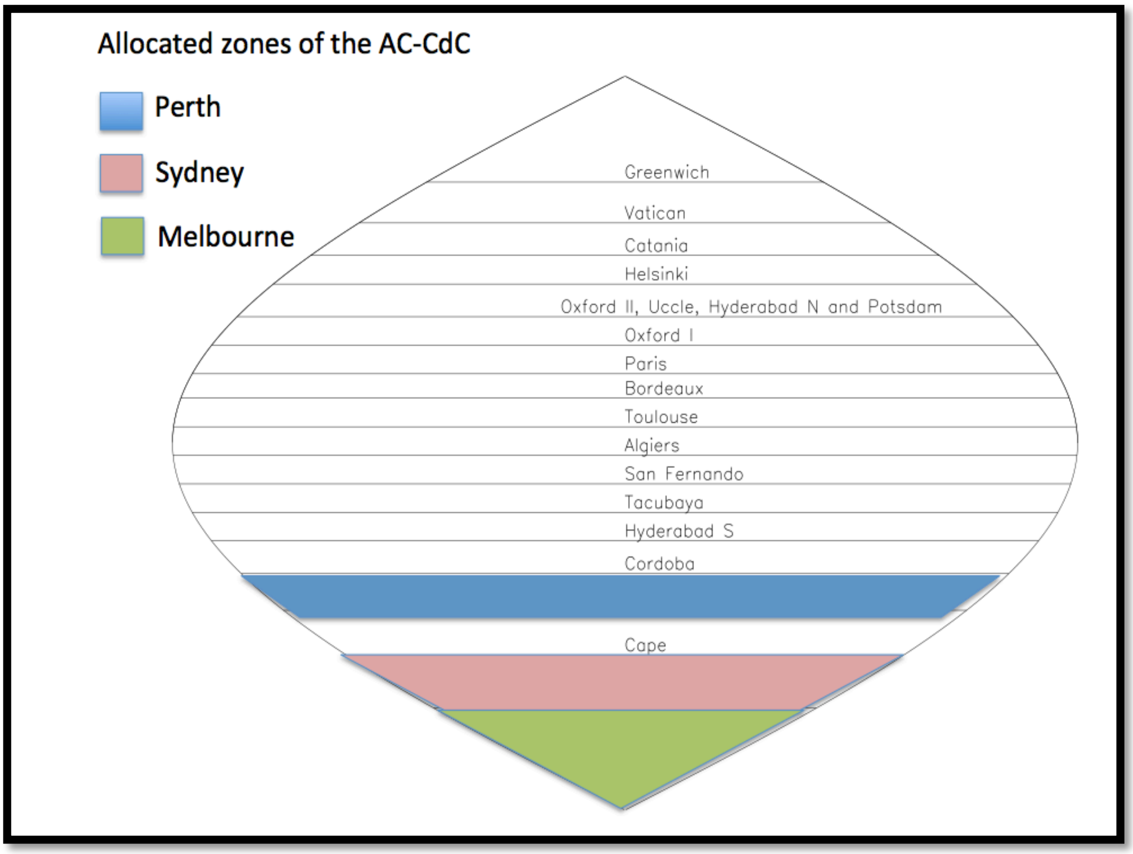


Figure 12: The zones of the AC-CdC (Base diagram Urban & Corbin, 1998). T. Stevenson.

As an outcome of the initial 1887 meeting and confirmed by 1890, Sydney Observatory was allocated the region -52° to -64° and Melbourne Observatory was allocated -65° to -90° (the South Celestial Pole). As well as its own zone, Melbourne Observatory was allocated -10° to -14° to observe positional stars (Ellery 1893). I have found evidence that in 1890 Adelaide Observatory began work on reference stars for the Melbourne zone (Adelaide Observatory 1890–1893, SRSA GRG31/19) and, over the following eight years, produced a catalogue of reference stars (Adelaide Observatory 1898). In 1900, Perth Observatory became a participant in the AC-CdC and its zone for the AC was located between -32° and -40°.

The percentages of the sky allocated to each observatory have been calculated as 5.9% for Sydney, 4.7% for Melbourne and 6.3% for Perth (O'Hora 1988, p. 136). Therefore Sydney, Melbourne and Perth Observatories, with assistance from Adelaide Observatory, completed 18% of the entire project (White 1988, p. 48). However, the percentage of coverage of the celestial sphere does not reflect the number of stars to be measured and reduced. I will now elaborate on this point.

The estimated number of stars measured for each zone of the AC, and as recorded for the digitisation project undertaken in the 1990s by the United States Naval Observatory, is listed in Table 1. Sydney Observatory's section of the sky numbered over 740,000 stars, Melbourne's section over 200,000 and Perth's section over 367,000 of which the majority (228,000 stars) were measured by Perth Observatory staff, and the remaining 139,000 stars measured at the Royal Observatory Edinburgh (Urban et al 1998). This table also indicates the time periods, or epochs, over which the stars were photographed, but not the time period for measurement and reduction, which often occurred more than a decade after the photograph had been taken.

The Southern Hemisphere zones contained the Milky Way as demonstrated in Figure 13, and Sydney Observatory had the most star-rich zone of the galaxy. The implications of this became evident once the measurement bureau began work. Baracchi reported that an average Melbourne zone plate had fewer than 300 stars, whereas for the Sydney zone it was more like 1,000 stars per plate (Baracchi 1901a).

A significant consequence of location in the Southern Hemisphere, known from the onset of the AC-CdC, was that the stars in the most southern zones were not well charted prior to the AC-CdC. This meant that there were fewer known reference stars than in the well-charted Northern Hemisphere sky. Therefore, more work was required in determining reference stars for each photographic plate than required for zones located in the Northern Hemisphere.

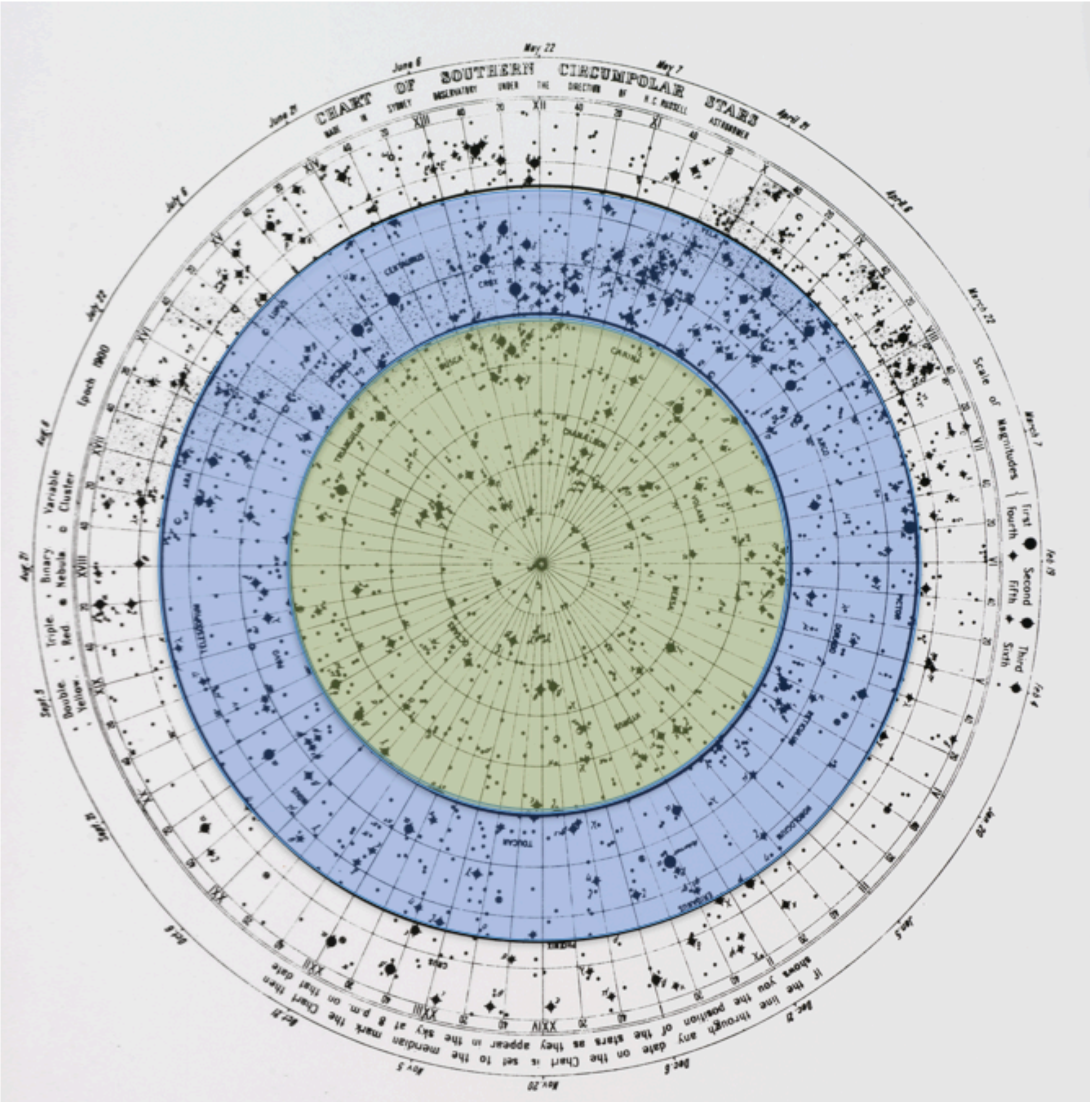


Figure 13: Chart of Southern Circumpolar Stars made at Sydney Observatory under the direction of H.C. Russell, 1894., SLNSW, 082-94. Modified by T. Stevenson. Green indicates the Melbourne AC zone, blue the Sydney AC zone.

My research in the PROV where I investigated the correspondence between Todd and Ellery and Baracchi, and the astronomy log books at SRSA, provided evidence that the lack of existing Southern Hemisphere reference stars was the reason for Adelaide Observatory undertaking the task of observing reference stars, initially from 1890 for the Melbourne zones, and then from the 1914 for the Sydney zones. Charles Todd, Government Astronomer South Australia and Director of Adelaide Observatory, had a past career in astronomy as described by Hayes et al (1996, pp. 81–83). He was an observer at ROG working with Airy. Todd was then Assistant Astronomer at Cambridge University Observatory and had been recommended to the Government of South Australia as the Director of Adelaide Observatory by Airy. However, Todd had demonstrated more interest in telegraphy and meteorology than in astronomy. My research has shown that even though Adelaide Observatory did not pursue an

AC-CdC zone, Todd's first Assistant Astronomer, W. E. Cooke, undertook the positional and reference star work for Melbourne Observatory. In Chapter Four the findings of my research demonstrate how the visual observation, cataloguing and reduction of reference stars at Adelaide Observatory heralded a change in the labour history of astronomy in Australia.

The additional reference star observations and reductions, which were unique to the Southern Hemisphere observatories, have been little appreciated as having a major impact on the Australian participants in the AC-CdC by local and more general researchers in this field (White 1988; Bhathal & White 1991; Haynes et al 1996). Furthermore, as I investigated this thesis, other challenges such as the distances for transporting technologies, access to equipment, the local economic environment and colonial government control emerged as some of the contributors to delays in completing the projects in Australia.

In the next section, I disclose how the colonial nature of these networks meant that participation in the AC-CdC by the few capable Southern Hemisphere observatories was not arbitrary.

INNOVATIVE COMMUNICATION – ACTION AT A DISTANCE

The new global AC-CdC enterprise required different forms of communication to those that existed prior. Latour defined the ability to act at distance as an essential characteristic of the powerful centre of a network (1987, pp. 219–223). Paris Observatory, as the head of the AC-CdC, with the Permanent Committee, established many means of sending out and receiving back essential communication for the AC-CdC. Driven by curiosity and competition to be at the forefront of new discoveries, astronomers developed communication methods such as newsletters, telegraphic communications and conferences to create networks which crossed regional barriers, bridged language and political differences, and operated even whilst respective countries were engaged in war.

Congresses for the AC-CdC were held in Paris in 1887, 1890, 1891, 1896, 1902, and 1908. The innovative 'parliament' structure, as described by Lamy, heralded a new way of collaborating (Lamy 2009, p. 197). The congresses were highly prescriptive of the processes, and there was local resistance which, according to Lamy, led to the congresses becoming more like a parliament where debate occurs and votes are taken. It was highly desirable for the participants in the AC-CdC to attend the congresses. Russell, who (as previously elaborated on) had attended in 1887, was urged to attend the following congresses; but he was unable to do so due to financial and other constraints within the colony. According to Lamy, the effectiveness of this model changed the way astronomy was globally managed.

By 1888 the fundamental principles behind the two projects, the Carte du Ciel and the Astrographic Catalogue, had been decided:

> "(1) Besides the two photographs that are to give all the stars to the fourteenth magnitude, inclusive, there is to be made a series with shorter exposition, in order to secure a greater precision in measuring micro metrically the positions of the reference stars, and to permit the construction of a catalogue.
> (2) The supplementary negatives, serving for the construction of the catalogue, are to include all the stars of the eleventh magnitude."
> (Peters 1888, p. 51)

It may be that Russell and Ellery were satisfied with the progress and the correspondence they engaged in. When Russell was invited to attend the 1889 meeting of the Permanent Committee he declined. This was because the Sydney Astrographic telescope had not been completed, and Russell believed it was essential for him to have experimented with the technology before attending a meeting (letter 6 Sept 1888 Russell to Mouchez, in Chinnici 1999, p. 354). Russell communicated his ideas in advance with Mouchez and they were minuted in the conference proceedings.

Correspondence between Admiral Mouchez in Paris and Christie in Greenwich, and Ellery and Russell in Australia, indicates that communication was constructive and regular (letters transcribed in Chinnici 1999, letter books PROV, letter books SRNSW). The *Bulletins* for the AC-CdC were published in Paris and were much awaited because they resolved issues in regards to methods. French was the main language used for the congresses and in the bulletins, and this did not make it easy for all astronomers. Baracchi informed Cooke when Perth Observatory was invited to participate in the AC-CdC that :

> "The important things, however, are all published in French and all published by the Academie of Sciences, Paris."
> (letter Baracchi to Cooke, 16 Jan 1899, pp. 130–137, letter book PROV)

My research in the Perth Observatory library has revealed that there were eight publications from the conferences, including an inaugural report in 1887 and then bulletins published in

1892, 1895 and 1902. The bulletins published in 1905, 1909, 1913 and 1915 had a major focus on the reports and data from the photographs of the near-Earth asteroid, Eros which was in a favourable opposition, meaning that it's orbit was closest to Earth's orbit, during 1900–1901. The Eros project to obtain solar parallax readings and determine the distance between Earth and the sun (more accurately than the previous transits of Venus) took away an emphasis on the AC-CdC for many observatories. The astrographs were well designed for this purpose and were scattered over the globe. The 1915 *Bulletin* was about the intermediate stars in the Borealis (North) Hemisphere. It is revealing that reports and contributions by Melbourne and Sydney Observatories only appear in the 1892 and 1895 publications and the correspondence indicates that the Australian observatories relied on correspondence from the British astronomers for detailed instruction on the AC-CdC more so than the *Bulletins*. Overcoming geographical distance was not unique to the Australian observatories and the impact that this had on the connectivity within the AC-CdC network was significant.

Australian historian Geoffrey Blainey (1966) positioned the 'tyranny of distance' as fundamental to the political and scientific networks of control. Blainey did not specifically address the influence of distance on how and what scientific research was undertaken, but his theoretical model has been influential in shaping colonial historiography. When criticising 'tyranny of distance' as the primary causal feature of colonialism, Chambers (1991, p. 30) argued that "it is the constancy of the information flow and the regularity of exchange that finally matters." It was the local and international personal correspondence, and the reports to the Royal Astronomical Society, which appear to have been the most useful to the astronomers and which reduced isolation.

Specific to the history of science, the concept of distance as the prohibiting force for the development of science in the colonies was strongly contested by science historians R. W. Home and S. Kohlstedt, who separated distance and isolation as two distinct attributes (Home & Kohlstedt 1991, p. 8). My research has shown that more than distance, it appears to have been the isolation of the population, governments and senior officials from the scientific developments in Britain, Europe and North America, which emerges in the popular press and correspondence of the period. Further to distance and isolation, it was the longevity of the AC-CdC that posed a significant challenge to its completion. Interruptions to the projects by social upheaval and the discontinuity of leadership due to death, for example Mouchez's death in 1892 and Russell's in 1904, weakened the networks and meant that the relationships had to be re-established.

CASE STUDIED OBSERVATORIES, 1887 TO 1908

The main three Australian Observatory participants in the AC-CdC, Sydney, Melbourne and Perth, are case studied in this thesis. In this section, I examine the social milieu in which each observatory was engaged in the AC-CdC, and the tension between the global, colonial and federal networks during the first two decades of the projects. Respective State governments controlled Sydney, Melbourne and Perth Observatories, and the government astronomers maintained a high level of collaboration and discussion about their projects, facilities and personnel. Nonetheless, each observatory had unique local characteristics which influenced their participation in the AC-CdC.

BOOM TIME FOR SCIENCES, 1880S

The 1880s were a pivotal time in the history of science in Australia, and a period when Sydney, Melbourne and Adelaide Observatories, and their Directors, were held in the highest esteem by the governments and their officers. For example Alfred Deakin, who was a political leader in federation and became Australia's second prime minister, was on the Board of Visitors of Melbourne Observatory. In Adelaide, Todd had established a successfully operating telegraph system and was consulted by the Western Australian Government on the establishment of the new Perth Observatory (Edwards 1993, p. 10).

During this period, State governments had begun to invest in science, much of which was previously supported by patrons and individuals. Subsequently, scientific organisations such as observatories flourished. Colonial branches of British science organisations for well-educated and well-off men to pursue scientific discourse were also established in the major cities. Collaboration amongst the colonial State observatories occurred from the earliest days of their establishment and was strengthened during the AC-CdC.

Ellery and Russell's collaboration on ambitious projects had been demonstrated well prior to the AC-CdC. In 1871 they sailed together to observe a total solar eclipse in far north Queensland (Ellery 1872, p. 205). In 1875, after the 1874 transit of Venus, they were both in London and had separately made an impact on the elderly Astronomer Royal, Airy. As individuals, and due to the output of their observatories, Ellery and Russell changed Airy's previously dire opinion of Antipodean colonial observatories (Orchiston 1988, p. 291). When describing his attendance at the bicentenary dinner for the Royal Observatory at Greenwich with Russell, Ellery wrote:

> "Sir George Airy on this occasion paid a high compliment to the Melbourne Observatory, and to the liberal manner with which astronomical science is fostered in Australia generally. This of course brought both the Australian astronomers to their legs, but what they said is not recorded."
> (Ellery, 'Twelve Months Leave' 1876, p. 419 in Gillespie 2011, p. 125)

Russell and Ellery's standing, their history of collaboration, and successful experimental work in astrophotography meant that Sydney and Melbourne Observatories were obvious choices for the AC-CdC.

By the late nineteenth century, scientific endeavour had shifted from Victoria to NSW as a result of changes in the economic base in each colony, and possibly partially attributable to Russell's energy and connections. According to Inkster, whilst infrastructure, government aid, skills and training were important in the development of science in the colonies, so too was the 'internal dynamic' of the activity of individuals, such as Russell, in creating and maintaining a profile with the 'public' (1985, p. 678).

In 1878, H. C. Russell, educated at the University of Sydney, was appointed President of the newly formed Sydney Technical College. With 1,000 students initially enrolled, it grew rapidly to 6,500 students by 1893. In 1883, Russell was appointed to the Board of Technical Education and in 1886, Russell was elected a Royal Society Fellow. This was the first such occurrence for a scientist who was born and educated in Australia. These institutions had colonial imperatives in the development of natural resources and the publication of scientific material for producers and consumers (Inkster and Todd, p. 110). Inkster (1985, pp. 667–690) argued that the savants removed themselves intellectually and mentally from the colony; however, in the period 1888 to 1912 science policy and 'public science activities' were increasingly influencing the development of science but not necessarily sharing the same priorities. For example, the AC-CdC was a pure science project, which had little or no immediate outcomes for the colonies.

In 1888, the centenary of colonisation by the First Fleet in Sydney, the Australian Association for the Advancement of Science (AAAS) was formed. Russell was elected the inaugural President (MacLeod 1987, p. 40). Russell gave the opening speech of the first congress of the AAAS in the Great Hall at the University of Sydney on the 28th of August 1888. He demanded that science not be governed by financial gain, nor become a hobby of the few, but that it be structured to promote enquiry, be promoted to the people and have material gains. According to MacLeod's research, during this period there were moves to establish a distinctly Australian Science, but it was difficult to gain support without connection to the British scientific establishment (1988, pp. 30–39). Russell, who was ambitious and well-connected, was then appointed Vice-Chancellor of Sydney University in 1891. However, with the observatory's dependence on state controlled economic resources and the financial collapse of the 1890s, much of what Russell envisioned within his own organisation could not be realised and he resigned his University post in 1892. Nonetheless even if astronomy did not gain sufficient state government financial support to meet the ambitions of Ellery and Russell, it did gain popular support during this period.

Brian Waters' research substantiated that a popular interest in science by local people was the impetus for the formation of the first purely astronomy focussed community organisation in Australia. In 1891, the Astronomical Section of the Royal Society of South Australia was founded, admitting men and women (Waters 1980). Shortly after, the NSW branch of the BAA was formed in 1895, which also admitted women. By the latter part of the nineteenth century, there were professional and amateur astronomy societies in every capital of Australia (Moyal 1976).

According to the NSW Blue Book, in the 1880s the Sydney population reached one million, and the New South Wales railway reached the north and south borders of the state (Coghlan 1893). Telephone lines had been installed, a compulsory education system established and land administration in the colony had settled after the gold rushes. In Victoria, the situation was similar (Victorian Government Year Book 1890). During the 1880s the AC-CdC was one of many new projects undertaken during the economic and population boom in the colonies.

With enthusiasm, Melbourne Observatory Director, Robert Ellery, presented a paper to the Victorian Branch of the Royal Society on the 16th of July 1887 about the new star map and catalogue of the AC-CdC. He announced that the cost to participate was £4,000 for each observatory, that worldwide over 4,000,000 stars would be photographed and catalogued, and that the work would take at least ‘four to five years’ (*Geelong Advertiser* 16 Jul 1887). This was to prove an optimistic financial and temporal estimate, but at that point in time Ellery was confident and well connected. Melbourne Observatory had already contributed to a major star catalogue, the Cape Durchmusterung, produced at Cape of Good Hope Observatory (Haynes et al 1996, p. 79).

The short lived prosperity of the 1880s, when the AC-CdC projects were initiated due to the gold rushes in NSW and Victoria, was followed by recession in both colonies. As previously discussed a major financial depression had occurred in Britain and its colonies in the 1890s (Coghlan 1893, 1918; Hall 1906 p. 30). This impacted Victoria first, though Russell was convinced that New South Wales would not be so badly impacted when he wrote that the “country is in a flourishing condition” (letter Russell to Mouchez, 1892, in Chinnici p. 362). This optimism was to prove unfounded.

The bubble bursts – 1892 to 1913

In this section, I demonstrate that after the gold rushes had waned, and particularly around the time of Federation, the State observatories were under threat of closure. Whilst finances were forthcoming to build structures, purchase equipment and begin the AC-CdC process, each observatory was to experience a reduction in resources.

Melbourne Observatory was the first of the AC-CdC observatories to discuss the financial recession and its possible implications with Paris Observatory:

> “The financial position of this Country has become very depressed and the Government are making large (extinguishments) in the Public Service. In consequence I am about to lose the service of two of my senior assistants and shall experience a serious reduction in the working expenses of the observatory, but I do not think there will be any hindrance to the steady progress of the Astrographic work, although I was disappointed at not being able to order a parallactic measuring machine at present.”
>
> (letter Ellery to Mouchez, 1892, in Chinnici, p. 266)

W.H. Hall, the acting statistician for the government in 1904 reflected on the state of the economy over the previous decade in the New South Wales Official Year Book (1906). Hall reported that the collapse of the Baring Bank in England had global repercussions which impacted on the colonies.. By 1893, payments by ‘thirteen out of twenty-five banks of issue’ in NSW were suspended (Hall, 1906, p. 30.). There was also unrest in the labour market with strikes, the shearers strike of 1894 had a negative impact, especially on the NSW economy. Financial instability was a major issue for observatories because the pursuit of science was considered a 'leisured class' activity. In the previous decade, many new public facilities, educational organisations and transport infrastructure had been built in New South Wales, but the withdrawal of English capital, almost zero immigration, a succession of floods, severe strikes and unrest meant that the state had little finance for astronomy.

On the 15th of May 1893, Russell wrote to Francois Tisserand, who was then Director of Paris Observatory. Russell stated that the AC-CdC, which had effectively begun only two years earlier with the arrival of the astrographic telescope lens, would be delayed as the State of NSW was in financial difficulties:

> "Since I wrote to you in February serious financial difficulty has overtaken this colony and we are obliged to reduce expenditure generally. I hope this will not stop us from carrying on the work of taking the photographs but it will not be possible to go on with the measuring of the plates just now. I regret this very much but must submit to circumstances. Believe me dear colleague."
>
> (letter Russell to Tisserand, 1893, in Chinnici, p. 365)

When Ellery retired in 1895, his Chief Assistant Astronomer, Pietro Baracchi, was appointed acting Government Astronomer and eventually permanently appointed to this position (Haynes et al 1996, p. 81). Baracchi was ensconced in managing the AC-CdC and, as demonstrated by the records, had determination and put in management practices to complete the projects. Baracchi, with Russell's agreement, came up with the solution to measure the negatives by establishing a Measuring Bureau in Melbourne Observatory, which would be funded by both Sydney and Melbourne Observatories and would measure all the plates. I examine this and the other Measuring Bureaux in Chapter Four.

The financial position in the state of Western Australia was different to that of NSW and Victoria due to the later development of the colony and the discovery of gold in 1886. The well-equipped observatory was designed and constructed under direction from Government Astronomer, W. E. Cooke, from 1896 to 1900. It was fitted with equipment suitable for participation in the AC-CdC prior to confirmation that Perth would be involved.

From 1897 Cooke began corresponding with Paris Observatory:

"I shall have charge of a standard 13-inch astrographic equatorial, which Sir Howard Grubb has just completed. I have not yet determined what work to take up with this instrument …"
(letter Cooke to the Director of Paris Observatory (Tisserand), 14 Sep 1897)

This instrument made participation in the International Star Catalogue possible. In 1898 Pietro Baracchi wrote to William Ernest Cooke, Government Astronomer Western Australia:

"I fully expected you would be allotted a zone of the astrophotographic work and I am glad of it. Australia will thus contribute about 1/7th part of the whole undertaking which is extremely creditable to the colonies."
(letter Baracchi to Cooke, 7 Oct 1898, PROV)

By January 1901, it was official that Perth Observatory would commence the AC-CdC zone previously assigned to Rio de Janiero (letter Colonial Foreign Office to the Ambassador for France in London, Jan 1901). This was as a direct result of the strategic preparation and networks established by Cooke well prior. Cooke had developed strong relationships with the other Australian Government astronomers, and had effectively lobbied David Gill at Cape Observatory in South Africa and the Astronomer Royal in Greenwich to allocate Perth Observatory an AC-CdC zone. Cooke considered participation in the AC-CdC an endorsement of his and the observatory's capability, which 'lifted it (Perth Observatory) firmly from the 19th century of colonisation into the sophisticated world of science' (Utting 1992, p. 152).

In 1901 Cooke visited Sydney, Melbourne and Adelaide Observatories in order to see the progress on the AC-CdC for himself. His letter requesting permission justified this expedition on the basis of the amount of experimental work undertaken on these projects:

"I am just initiating a scheme of work which will take about 15 years to complete. The Melbourne and Sydney Observatories started a similar scheme about 13 years ago … so much experimentation was required that it is only quite recently that they only recently settled into a steady groove [sic]…"
(letter Cooke to the Under Secretary 11 Jan 1901, SRWA 70/1901)

Western Australia's financial security soon evaporated after Federation. Cooke wrote to Christie about the threat to the AC-CdC in 1902:

"It is the growing uncertainty of things colonial which results from our growing mob rule, and which is now even commencing to depreciate our Government securities."
(CUL RGO 7/161)

The text indicated the situation he feared in Western Australia during the separation from Britain. Soon after Cooke expressed his isolation after his return from England when he stated that as an astronomer he has been ‘entirely alone in this State’. A letter to Turner elaborated on the situation and indicated that he would lose the staff dedicated to the AC-CdC by 31 December:

> “I have just received definite instructions to confine my operations to local work only and to dismiss all my officers who are not required for this limited sphere … the amount I am seeking is only 470 per annum for salaries, plates, chemicals etc ... do you think it would be any use to appeal to the Federal Govt. to take up the work? ...”
> (letter Cooke to Turner 1902, CUL RGO 7/212)

There was a major public outcry about the move to reduce the observatory staff (*The West Australian* 27 Nov 1902, p. 7; *The Daily News* 13 Dec 1902, p. 5). It was decided not to disband the State observatories; by 1904 Cooke had appointed Edgar Burnham Curlewis (who was the brother of the Assistant Astronomer and Computer, Harold Burnham Curlewis), George Frederick Johns and Clive Nossiter to work specifically on the AC-CdC (Blue Book, 1904 p. 74). Cooke regularly corresponded with Baracchi and Russell about the AC-CdC, and in early1908 he again visited Sydney and Melbourne Observatories.

Gill was insistent that Cooke attend the 1909 Astrographic Conference in Paris because there had been much correspondence but no representation from the Australian observatories at the congresses since 1887. He wrote to the Director of Paris Observatory, Jules Baillard:

> “Colonial ministers as a rule are quite ignorant of science, but they are also very easily offended on the reverse. A tactfully written letter from the President of the International Committee would have great weight with them, not only in causing them to send their representative to Paris but in providing funds to complete the Australian share of the work.”
> (Gill, letter to Baillard 27 Nov 1908, in Chinnici 1999, pp. 128–129)

A letter from Baracchi to Baillard in Paris reflected that he had not been able to obtain permission to attend the international conference on behalf of Melbourne and Sydney Observatories:

> “The Victorian Government, as you are probably already aware, has found it inexpedient under the present circumstances, to give me leave to attend the Astrographic Conference at Paris next April.”
> (letter Baracchi to Baillard, 1 March 1909, in Chinnici 1999, p. 269).

Gill was aware that Perth Observatory had been under threat of closure and that Cooke was struggling with resources to measure the glass plate negatives. He also knew that the State Government of Western Australia was not sympathetic to astronomical research. A letter from the distinguished head of Paris Observatory would, in Gill's opinion, influence the Colonial Minister. Gill urged that it would be more effective to lobby the Minister in terms of the reputation to be gained by completing the project than by presenting a rationale for Cooke to attend the conference based on science. Gill's anxiety about the understanding that colonial ministers had about science was based on a number of factors, including his own experience at Royal Observatory Cape of Good Hope. Gill's perception of the ignorance of ministers provides an insight into the local indifference and opposition the astronomers had to contend with in Australia, as noted by other researchers in the history of colonial astronomy (Utting 1994, pp. 30–60; Haynes et al 1996, pp. 93–95).

Gill's insight was to prove correct. There are many letters between Cooke and the Colonial Secretary, and in the end Cooke offered to pay to attend the conference himself. The Colonial Secretary, James Daniel Connelly, wrote to the Premier of Western Australia about the matter:

> "Mr. Cooke, the Government astronomer, has seen me again and is particularly keen to attend this conference, for reasons he has fully explained to yourself. So important does he consider it that the State should be represented, that he offered to pay half the cost himself, viz. £150 …"
> (letter Connolly to the Premier, 11 Feb 1909, SRWA 752 1912/2480)

In the end Cooke was granted six months paid leave, but had to meet all travel and accommodation costs himself. He attended the 1909 AC-CdC conference in Paris as the only Australian representative. On his way to the conference he went to Edinburgh Observatory to meet with Frank Dyson, the Astronomer Royal of Scotland, where he observed the measurement of the Perth AC plates. At the conference Cooke made an impression with his ideas on how to simplify some of the AC processes (Utting 1992, pp. 252).

According to Utting on his return to Western Australia, Cooke found that there were other issues that stymied progress on the AC-CdC, such as the reduction in the observatory budget for printing the catalogues. AC-CdC progress was also interrupted by two significant astronomical events which required attention: the return of Halley's Comet in 1910, and a total eclipse in Vavau, Tonga in 1911. At the end of 1911, Cooke abruptly resigned as

Government Astronomer, Western Australia, to take up the post of Director of Sydney Observatory. In 1912, Perth Observatory, now under the acting directorship of H. B. Curlewis, was again threatened with closure. Curlewis wrote to the newspaper, Turner and Dyson, who was now the Astronomer Royal at Greenwich (letter Curlewis to Dyson, 17 Sept 1912, CUL RGO 7/157). According to Curlewis, intervention was required from Britain to influence the government.

As indicated in a letter to Gill, Dyson was initially reluctant to do anything because he suspected that the money saved by closing Perth Observatory was to be invested in the new University of Western Australia (letter Dyson to Gill, 12 Oct 1912, CUL RGO 8/95). This proved unfounded; nonetheless, the threat remained and Gill visited the Agent General for Western Australia (letter Gill to Dyson 17 Oct 1912, CUL RGO 8/95) and organised for a letter to be sent to the Government of Western Australia via the Astronomer Royal from Paris Observatory (letter Baillard to Dyson 5 Nov 1912, CUL RGO 8/95). The closure was avoided due to the AC-CdC, as communicated to Dyson by Scottish born physicist Alexander David Ross, newly appointed Professor at the University of Western Australia:

> "I do not think there is any fear of it being shut up, at least until all the Astrographic work is completed."
>
> (letter Ross to Dyson 10 Mar 1913, CUL RGO 8/95)

Nonetheless, it is significant that Ross, who established himself in Perth scientific societies and proved to be highly critical of Perth Observatory, was in close communication between the Astronomer Royal and the Government of Western Australia. This is an early but significant indication of the rise of astronomy as a university and federal concern.

Analysis of the impact of competing projects on the State observatories and participation in the AC-CdC is developed in Chapter Five. MacLeod's comprehensive research into the formation of scientific enterprises AAAS and CSIR provided the foundation for understanding the impact these organisations had on the development of a national approach to science, and the loosening of ties between Australian science and Britain. MacLeod prescribed a "finer set of concepts and categories if we are to see the harmonies and disharmonies that remain of enduring importance" (1987, p. 6). One of the 'finer' concepts, which my research has shown had significant influence on the AC-CdC, was the nature of the network and role of colonial officers.

Although Paris was determined to be the centre of calculation, the colonial observatories were subjected to the authority of their respective government's Colonial Office and the London Agent's relationship with the Astronomer Royal in Greenwich. In the next section, the attempt by Cooke to purchase a glass plate negative measuring machine for the AC-CdC Measuring Bureau at Sydney Observatory is examined as an example of how the Colonial Office protocol could add significant time and uncertainty to the AC-CdC process.

Colonial Office protocol beyond federation

Government astronomers were used to making submissions for funding and, when ordering goods outside the country, working through a colonial officer whose role it was to facilitate and negotiate on behalf of the astronomer. The work of the Colonial Office extended well beyond Federation and the protocol between the government astronomers, the NSW, Victorian and WA governments, the respective Agents General, Astronomers Royal and the instrument makers often meant delay in orders being filled and extended consultation processes. The patience shown during most of this process is important to understand in light of the Australian astronomers being totally dependent on maintaining good relationships with all parties.

The Colonial Office in London had the responsibility of obtaining equipment on behalf of the NSW Government Astronomer. The correspondence between W. E. Cooke, NSW Government Astronomer from 1912 to 1924, and statistician and public servant, Timothy Augustine Coghlan, who became the Agent General of NSW in London from 1905 to 1926, illustrates that there was little respect for, or communication with, the State Government astronomers when doing business on their behalf.

In 1914, a star micrometer, to measure the glass plate negatives for the Astrographic Catalogue, was required for Sydney Observatory. On receipt of this request from Cooke, Coghlan contacted Dyson seeking advice on suitable companies from whom he could obtain tenders. There were the standard manufacturers in Britain, and companies Cooke was well aware of, although it appears that Cooke's instructions were not transcribed to Dyson, who requested more information on the star micrometer, to which Coghlan replied:

> "I recently received an intimation from my government that the Government Astronomer (Mr. W.E. Cooke) stated that he had in mind the standard pattern of star

> micrometer for measuring the plates of the Astrographic catalogue, single plate only, fitted with glass reticle as designed by Professor Turner."
> (letter Coghlan to Dyson 19 Jun 1914, CUL RGO 8/95, f.6894)

The suitable suppliers recommended by Dyson were: Sir Howard Grubb, T. Cooke and Sons and Troughton and Sims. Coghlan, the Agent General of NSW, sought advice on which firm would be the most suitable from Dyson. In this correspondence, Coghlan also requested that the order be placed and an inspection carried out on the instrument by the Astronomer Royal before it was shipped. During this period, it appears no correspondence was sent to Cooke to advise him of progress and the decisions.

By June 1914, the three tenders were received at ROG and Dyson had made his recommendation to proceed with Troughton and Simms. Six months later the instrument was delivered to the ROG between the 16th and 22nd of December. There were adjustments required as advised by Dyson and, on the 30th of December, Coghlan advised that he had made plans for the shipment of the instrument. The following letter from Cooke to Dyson on the 8th of March 1915:

> "My dear Dyson, can you tell me anything about the Star Micrometer, or better still, can you hurry the maker? I do not even know to whom the order has been given so am obliged to appeal to you."
> (letter Cooke to Dyson, 1915, CUL RGO 8/95, f.6894)

On the 19th of April, Dyson informed Cooke of the instrument maker and that he should, by now, have the instrument. The lack of correspondence and consultation with Cooke about progress on the instrument demonstrates disregard by the Agent General of NSW for the NSW Government Astronomer. At a cost of £50, the star micrometer purchase warranted consultation with the highest level astronomer in the Commonwealth; however, the person who requested the equipment was ignored.

As well as the impediment caused by the Agent General, acting as a go-between, another issue that impacted on the State observatories was the move to Commonwealth control over meteorology, an area resourced by the State observatories.

Meteorology separated from astronomy – 1908

Even though astronomy and meteorology were determined by the *Commonwealth of Australia Constitution Act* to be under the jurisdiction of the federal government, by the beginning of 1908, it was only meteorology which came under federal control and was separated from astronomy in all states. The control of the weather records and reporting was a fiercely fought battle, which had political and economical imperatives. The views were polemic with Baracchi in Melbourne desperate to rid the observatory of the 'intolerable burden of meteorology' work (letter Baracchi to Gill 22 Jul 1902, pp. 416–418, PROV 778/P/0000). Russell and Cooke were not so keen to remove meteorology from State control. Baracchi wrote to Baldwin, who was in Potsdam, Germany:

> "Today for the first time in 13 long years I feel a free man. The weather service is given over to the commonwealth this day. It will now be possible to raise the position of this observatory to its proper level."
> (letter Baracchi to Baldwin 1 Jan 1908, p. 308, PROV 778/P/0000)

By contrast, Cooke wrote after the fact:

> "The fundamental principle of the Commonwealth Meteorologist is absolutely opposed to my re-iterated advice … because local knowledge and prognostics are invaluable … the results are absolutely ridiculous, and the strong public condemnation of the new system is quite justified …"
> (letter Cooke to Meteorologist, Argentina, 14 Jun 1908a, p. 473 in Utting 1993, p. 117).

The decision to make meteorology a federal government concern impacted the AC-CdC work. Financially it meant that the government astronomers had a smaller overall budget and fewer staff. On the other hand it meant they could concentrate their endeavours on astronomy. At Sydney Observatory a new section of the building was constructed for meteorology; however, this was eventually used for the astrographic measurement bureau, as examined in Chapter Three.

The determination that astronomy would also be governed by the federal government had a direct impact on the states' commitment to resource astronomy. It was to take until 2013 for the wave of federal astronomy to engulf or destroy all of the state observatories.

CHAPTER CONCLUSION: MAPPING THE STARS WAS A COLONIAL CONTINUUM

Although there are differing views on the development of colonial astronomy from the late nineteenth through to the mid-twentieth century, as argued by Basalla, colonialism continued past Federation. Astronomers in Australia were well respected and involved in the forefront of the revolution in astronomy due to photography. This revolution changed the nature of astronomy, which became more hierachical and industrial in its nature. The eagerness to engage in the AC-CdC also reflected the desire of the lead astronomers to appeal to a higher authority which continued to be based in Britain.

Past discourse has exaggerated the impact of doing science at a distance (Chambers, 1991 p. 25). From the early 1890s, the State observatories operated within strong astronomy networks, which was in contrast to the landscape of meagre local government funding for what was considered non-essential science, such as astronomy. Further inhibitors, such as the protocols of the Colonial Office and senior public servants who expressed disdain for astronomy, weakened the networks already made fragile by distance, and were the major contributers to the isolation of astronomers, when and where that occurred.

The rhetoric surrounding the AC-CdC, which claimed that the projects prevented the colonial observatories from progressing to the research-based field of astrophysics (Haynes 1996; Orchiston 1988; White 1988), neglected to consider that the autonomy to conduct pure science was not available to the State observatories. By involvement in the global enterprise of the AC-CdC, rather than providing only the more locally favoured and rewarded scientific problems, government astronomers made a move towards scientific independence from their local government authorities. Unfortunately this came at a cost to resources and public support as it represented a less understood method of astronomy and a scientific endeavour that had little outcome for the government and public who funded it.

CHAPTER 3: VISIBILITY OF TECHNOLOGY 1890 TO 1952

In Latour's theoretical model, 'technology' had agency in the production of scientific results (2005, pp. 63–86). According to Latour, the objects (technologies) are part of the social network and these are most obvious when they are innovative, break down or when objects are interpreted in museums (2005, pp. 80–81). In this chapter, the new technical innovations for the AC-CdC and the public investment in buildings, instruments and materials for the two projects in Australia, are revealed as intertwined with social mores and modernist aspirations as well as necessary to the science. The approach in this thesis is to examine the less represented, yet significant actors in the AC-CdC network. Therefore, whilst the telescopes have been included, the main focus is on the star-measuring machines and the built environment.

The relationship between the scientific outcomes, and the sociology of the place in which science was performed has also been investigated by historians of science including Marion Donnelly (1998), Adi Ophir and Steven Shapin (1991). Rebekah Higgitt demonstrated that the purposeful architecture of the Royal Physical Observatory in Greenwich was constructed from 1889 (2014). The extensive negotiation required for funding and approvals demonstrated Christie's goal to expand and continue the existing program, rather than embark on new areas of research. The exception to this, as acknowledged by Higgitt, was Greenwich's central role in the AC-CdC network (p. 635).

For a network to be effective the technologies had to be the same, or at least controlled by the project centre (Latour 1987, p. 121). The technologies, once invented and distributed, were expected to work reliably and predictably, and the makers of the technologies had to be ready to supply them. For the AC-CdC, this was not always the case, and it is at the failure points that the agency of the technologies is best revealed. Once the astronomers were interested in participating in the AC-CdC, their enrolment in the projects was only assured once the technologies required were operational.

The Astrographic Catalogue required five sequential activities. Initially funds, agreement to build new domes and the procurement of equipment and supplies required government approval and commitment. Secondly came the establishment of human resources, the selection and observation of reference stars, and the determination of exposure time to achieve the magnitude requirements. The third stage was astrophotography, which included the exposure of the plate to the réseaux and then exposure to starlight through the telescope lens. The development and quality control of the negatives was part of this stage. In the fourth stage, the measurement of the plates and reduction of co-ordinates had human resource commitments, and required multiple re-measures and checks. The fourth stage included the computation of co-ordinates to a single epoch. The fifth and final stage was the assembly of data for production of the catalogue.

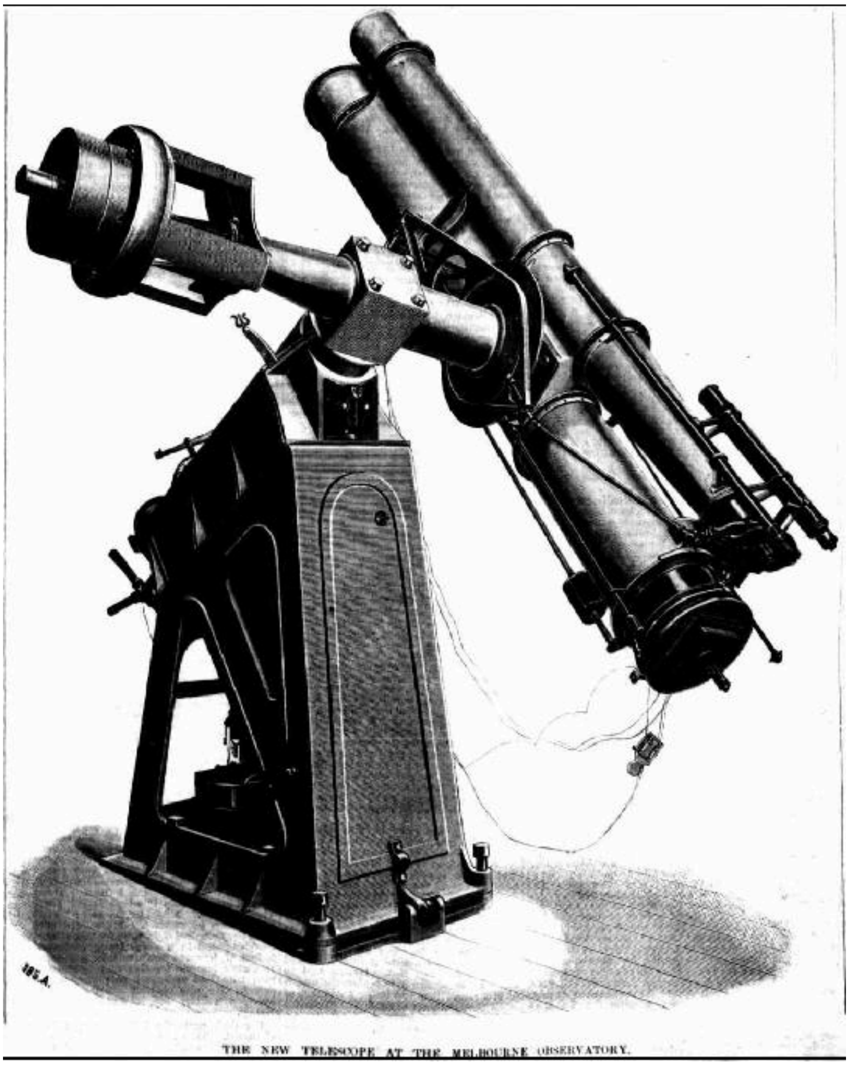
The commitment to building new structures, and the significant purchase of the astrographic telescopes and other instrumentation, demonstrated the influence of the global astronomical forces over local government preferences for investment in the more useful sciences, such as meteorology. The popular interest in astronomy, which emerged during this period in Australia, is examined in this chapter as having a strong relationship with the international nature of the AC-CdC project, and commitment to the AC-CdC.

POPULAR SCIENCES – 1887 TO 1915

A paper entitled 'Carte du ciel: carte blanche' by Swinburne University Centre for Astrophysics and Super Computing (2009) argued that one of the reasons that enormous sums of money and resources were committed to the project was the emergence of popular science in the late nineteenth century, which stirred political enthusiasm. It is difficult to prove this causality, although there is evidence that Russell, Ellery and Cooke realised that astronomy was, in the latter part of the nineteenth century, developing as a popular science in Australia. There was considerable gain to be had in terms of government support by providing public access to astronomy in the form of newspaper reports, public telescope viewings and lectures. For example, the number of public visitors to the observatory is included in the Government Astronomer's reports to State Parliament.

The AC-CdC stimulated a wave of illustrated articles about the instruments, the projects and the participants. Elaborate articles about Sydney Observatory (*The Sydney Mail and New South Wales Advertiser* 26 Oct 1889, p. 1; *The Sydney Mail and New South Wales Advertiser* 7 Mar 1891, p. 532; *The Sydney Mail and New South Wales Advertiser* 12 Jan 1895, p. 78; *Australian Town and Country Journal* 11 May 1904, p. 34), Melbourne Observatory (*The Australasian* 21 Feb 1891, p. 41; *The Australasian* 13 June 1891, p. 40; *The Australasian* 27

Apr 1901, p. 30) and Perth Observatory (*South Australian Register* 13 Oct 1900, p. 36; *The West Australian* 27 Nov 1902, p. 7; *Western Mail* 6 Dec 1902, p. 28; *Western Mail* 20 Jun 1908 p. 45; *Sunday Times, Perth* 1 May 1910, p. 3) appeared in the popular press with etchings and photographs of buildings and instruments, portraits of the astronomers and reproduced photographs of stars, the moon and nebulae. An 1891 etching of the Melbourne Astrographic telescope, as shown in Figure 14, shows the instrument poised, ready to be used, which stirred the public's imagination.



THE NEW TELESCOPE AT THE MELBOURNE OBSERVATORY.

Figure 14: The Melbourne Astrograph (*The Australasian*, Saturday 21 Feb 1891, p. 41).

The word 'astronomy' appeared in articles and literature published in the news media press, as demonstrated in Figure 15. There was a consistent gradual rise in the use of the word 'astronomy' in articles over 1,000 words in length until the 1880s, after which there was a plateau, followed by an upward trend. In all states there was a sharp decline in articles about astronomy after 1910. Further interrogation of this trend shows a correlation of activity in the news media with the appearance of comets viewed in the Southern Hemisphere.

The decline in the years 1910 to 1929 of articles over 1,000 words about ‘astronomy’ in news media is possibly explained by the causal effect the First World War had on society, the uncertainty Federation had on astronomy research, astronomy-themed public lectures and activities (such as visiting astronomers), and subsequent reporting priorities in the news media.

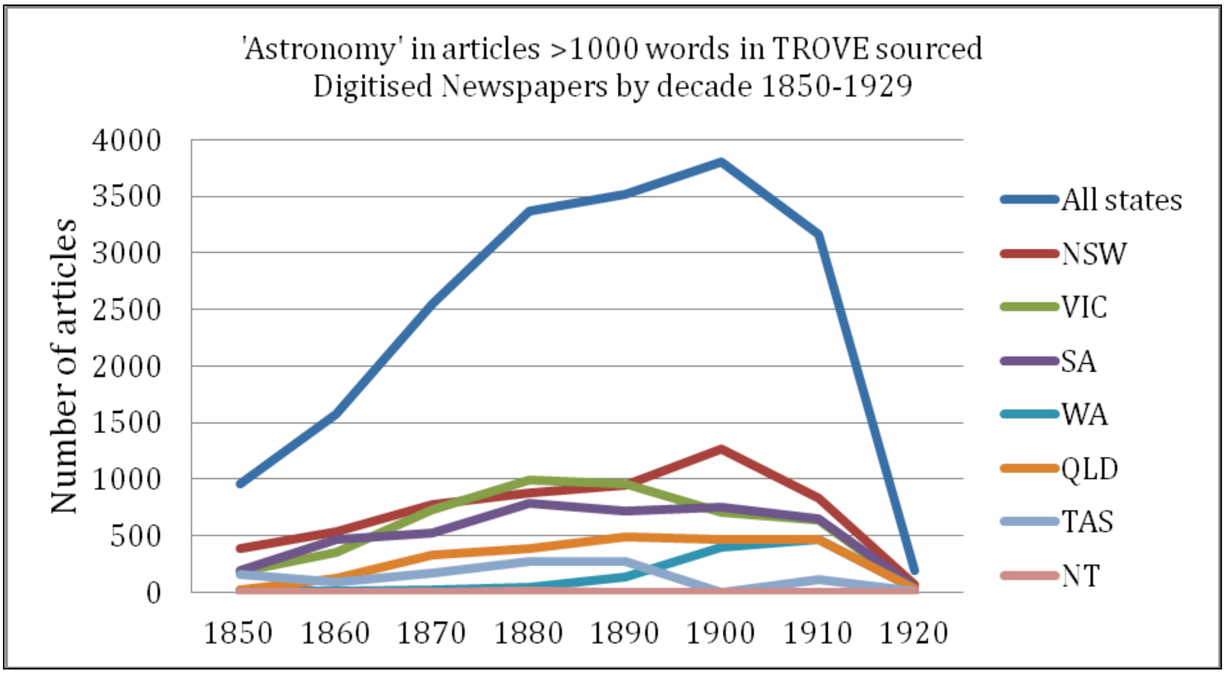


Figure 15: ‘Astronomy’ in articles over 1,000 words in digitised newspapers in Australia by decade from 1850 to 1929. Data ‘Trove’ 17 Sept 2016, T. Stevenson.

There were other factors that contributed to an increase in popular interest in astronomy. These included astronomy books and lectures by local and international scholars. For example, Mary Orr’s *Easy Guide to the Southern Stars*, published in 1897, in Australia was recommended by newspaper columnists (*SMH* 27 Jan 1897, *Town Gossip* 20 Mar 1897). In 1912, American astronomer and popular astronomy writer, Mary Proctor, conducted an extensive lecture tour of Australia. Mayors and dignitaries greeted Proctor’s appearances in Adelaide, Brisbane, Melbourne and Sydney, as well as regional areas including Bendigo and Ballarat. The proceeds of her well-subscribed lectures went towards funding a national solar observatory and were reported in detail in the press (13 Nov 1912, p. 8; 23 Nov 1912, p. 24).

As the cities grew in population, so did scientific interests through new societies, museums and universities. The establishment of astronomical societies during the 1890s, and the admission of women as active members, is examined in Chapter Four. Monthly meetings, the lecture notes which appeared in the local papers, and regular reports from astronomers on astronomical events meant that astronomy was regularly in the press. The negative aspect to city growth was increased light, air pollution and vibration.

Astronomy in the city dust, vibration and lights

The growth of the cities of Melbourne, Sydney and Perth in the late nineteenth century meant increased vibrations, air particle pollution from open fires and light pollution from electrical lighting. All of these had a major impact on the state-run observatories. The observatories involved in the Astrographic Catalogue and Carte du Ciel, due to the use of photography of the night sky, were able to continue at the cutting edge of astronomy within the confines of their original locations.

At Paris Observatory, the city location was given more importance during the eighteenth and nineteenth centuries than a dark sky environment, according to Aubin (2003). Bigg also drew attention to how the city locations for Paris and Potsdam Observatories influenced the adoption of new technologies and work practices for the AC-CdC:

> "The Carte du Ciel had a profound impact on the practice of astronomy by promoting photographic methods, furthering the reconstruction of astronomical observation along industrial models of division of labour, tightening international cooperation in astronomy, eventually paving the way for the International Astronomical Union, and yet decentralizing astronomy as well. From the constraints imposed by the city, new scientific practices had emerged."
>
> (Aubin 2003, p. 99)

Bigg described how, through the AC-CdC, Admiral Mouchez revived Paris Observatory with a new focus on photography as a method suitable for research astronomy in a city environment. Hutchins listed the removal of meteorology from Paris Observatory as one of several strategies of survival in a city environment (2008, p. 243). In Australia, the central city location of most observatories at the end of the nineteenth century had political advantages for the astronomers. Location in the city facilitated access to universities and other scientific academies and the observatory could quickly provide timekeeping, surveying and meteorology records. Notwithstanding, the NSW Government Astronomers periodically sought additional or alternative dark sky environments for astronomical observations.

Russell sent his preliminary astrographic photographs to Mouchez in 1891. The response from Mouchez was that the images were extremely good, which Monsieur Henry had interpreted as due to Sydney having less air pollution than Paris:

> "I note what M. Henry says about the clearness of our atmosphere, but judging by what I have seen of the atmosphere in Paris it is as good as ours …"
> (Russell letter to Mouchez, 11 May 1891, in Chinnici, p. 355)

Russell claimed it was the high sensitivity of the Ilford dry plates, which produced brighter stars and gas in the photograph of the Great Orion Nebula than the Henry brothers had been able to achieve from Paris Observatory. As I have found and elaborate on further in this chapter, Russell was already looking for a site with less environmental interference from which to photograph.

A NEW TYPOLOGY FOR GLOBAL ASTRONOMY

Many of the technologies and methods for the AC-CdC were new and had not even been developed when the projects were agreed to in 1887. This did not deter the astronomers; the project was a stimulant to the improvement of technologies such as measuring devices, glass plate production, emulsions and development techniques. It also required the development of internationally recognised language to describe technologies and methods.

There were 80 resolutions from the AC-CdC congresses held in April 1887, September 1891 and May 1896, which included eleven related to instruments (Wayman, in Debarbat 1987, pp. 139–141). Major decisions about the project were made during these congresses, and new words for instruments and processes articulated during the congress became commonly used. The invention of the word 'astrograph', used to describe a telescope which is used as a camera, is associated with the AC-CdC and David Gill (Lankford 1997, p. 40). The words 'astrophotography' and 'astrometry' were invented to describe particular terms relating to photo imaging in astronomy. When measuring the light emission of stars, a 'magnitude scale' was used. Whilst this term had existed prior to the AC-CdC, some terms, such as the 'réseau plate', were invented..

In many fields, terms are created for machines that give naming rights to their inventor during or after use, such as the 'Verrier Scale'. For the AC-CdC, makers and designers were associated with specific innovations. For example, 'Gill's chase' described a new type of dome opening named after David Gill, who designed it for the astrographic dome at the Cape of Good Hope Observatory. There were a number of star measuring machines which pre-existed or were developed for the AC-CdC. Within the Australian Astrographic Catalogues, the measuring machines included 'Repsold I (R1)' and 'Repsold II (R2)', after the German manufacturers Repsold and Son.

According to Latour, the use of metalanguage creates a distinct typology which effectively separates the world of science from the society within which it is done (1987, p.31). Latour connected the establishment of technical terms with a desire by scientists to create an authority that was shared by a specified and limited number of persons. This is often essential but it makes it more difficult for those not part of the network to understand the processes and equipment requirements and, subsequently, to champion the project. For example, this may have been causal in delays when Australian state government officials were asked to procure technologies on behalf of the state observatories.

The AC-CdC also created a significant increase in sales for the manufacturers able to develop new and improved technologies quickly, and to deliver these across the globe. In Australia the purchase, construction, assembly, commissioning, usage and maintenance of new technologies for the projects required the Government Astronomers to have project management and innovative design skills in construction as well as instrumentation.

Astrographic Architecture 1890 to 1964

The Astrographic Catalogue and Carte du Ciel presented opportunities to develop the observatory sites and build bespoke structures to house the new instruments. In most participating observatories around the globe, a new building was constructed specifically for the AC-CdC photographic work; in some observatories this structure also housed the Measuring Bureau. The three Australian colonial observatories required special buildings to be constructed to house and use the instruments, associated timekeeping instruments and a photographic developing room. They did not incorporate the measuring and computing rooms into the structure for the telescope.

In her book *A Short History of Observatories*, Marian Card Donnelly observed the parallel development of telescopes and observatory buildings (1976, p. 1), and noted that observatories were not buildings but enterprises which could be several buildings and sites (p. 146). She noted innovations by architect Graham Moyers for Dunsink Observatory in 1785, which included the central isolated pier for the telescope to reduce vibration and a revolving dome "to aid in the maintenance of a constant temperature in the dome" (p. 54). Sydney, Melbourne and Perth Observatories benefitted from these design features. A century later, photography for astronomy meant darkrooms were required and engineering requirements became more complex (pp. 95–96). Mechanical dome rotating systems were common and electrical rotating systems were introduced from 1897 (Donnelly, p. 146).

This infrastructure for new buildings required approvals, planning and capital expenditure. Whilst standards were set for the instrumentation, the buildings to house the astrograph and photographic equipment varied considerably in style and arrangement.

The astrograph building had to allow a clear view of the sky zone being photographed and ideally a complete panorama for other projects. The astrographic telescopes were large pieces of equipment, requiring an automated rotating dome with an open space of almost six metres in diameter, and access to darkroom facilities. The dome had to rotate with the telescope to enable stars to be tracked for, at times, thirty or more minutes. At Melbourne and Perth Observatories, substantial new buildings were constructed within their existing grounds. At Sydney Observatory, it may seem that the first astrograph building was substandard because of its structure. As examined below, the selection of materials and building types was, in all cases, purposeful.

Even though most of the participants in the AC-CdC organised new buildings, little has been written of their architecture and the processes involved in funding and commissioning them as working laboratories. There is related research which is inclusive of structures built for the AC-CdC (eg. Donnelly 1973, Hutchins 2008 and Higgitt 2014) and, as previously mentioned, the importance of spatial structure on the human, technological relationships which occur within the observatory, or laboratories more generally, and the political nature of scientific structures have been acknowledged and explored in recent decades (Aubin, Bigg & Sibum 2010; Higgitt 2014; Opher & Shapin 2008; Smith et al 1998).

In order to research the structures built for the AC-CdC, I visited the astrograph houses constructed for the AC-CdC in Melbourne, Belgium and Paris to examine the architectural design and layout. The astrograph houses varied in each circumstance, influenced by the pre-existing architectural style of the other buildings on the properties and the aesthetic of individual architects and budgets.

In 1888, David Gill, Director at the Cape Observatory, designed and built a minimal square two-level building with the dome on top, and a room for measuring and photographic development underneath as shown in Figure 19 (Gill 1913, pp. 120-122; Glass 2012).

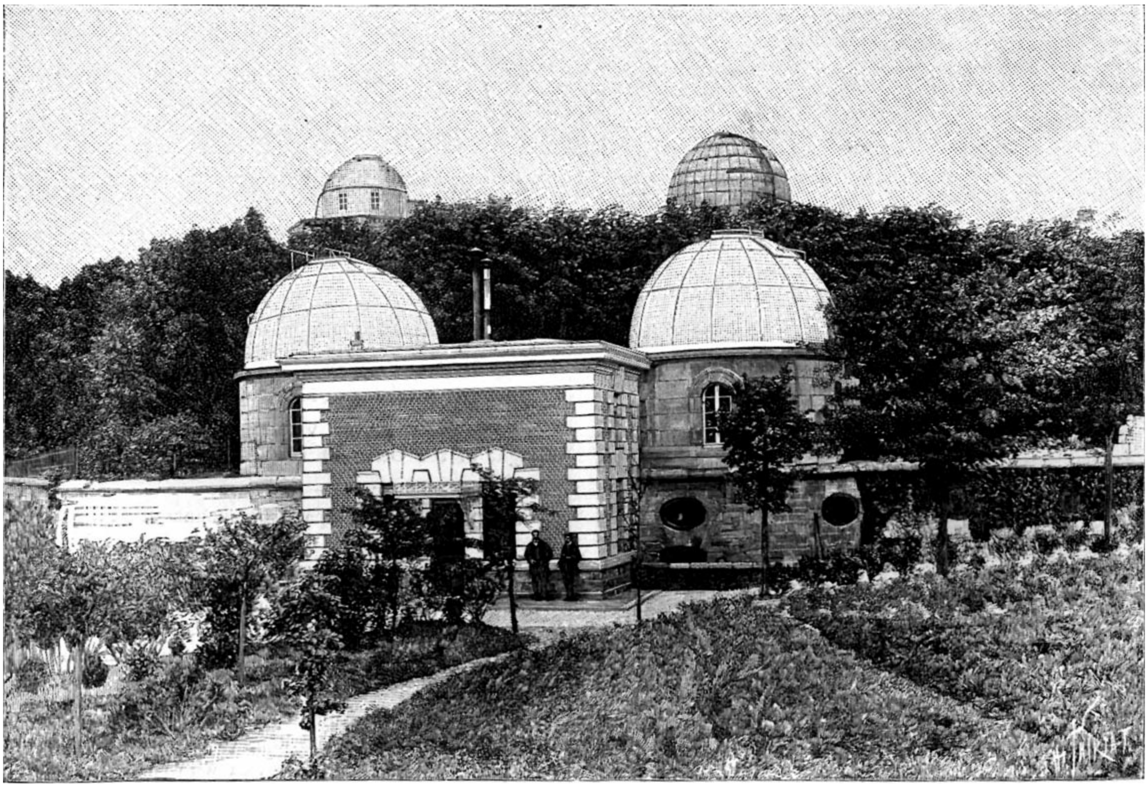


Figure 16: Astrograph House, Paris Observatory, in the foreground, with the domes of Paris Observatory behind on top of the hill (*Nature* 1893).

At Paris Observatory, the astrograph house was built in 1892 within a short walk of the main observatory, as shown in Figure 16. It had two domes on the first level and a lower level for the Measuring Bureau to use (Lockyer 1893, pp. 617–618). The Paris astrograph house still exists as shown in Figure 17.

Figure 17: Astrograph House, Paris Observatory. Photograph by T. Stevenson, 2009.

At the Royal Observatory of Belgium, in Uccle, a two-story astrograph house was built in 1907 with an impressive dome on the top story, and a photographic developing room. It was able to accommodate preparation spaces on the ground floor and had a distinctly colonial architecture with a portico entry. The design of this brick building is very similar to that of Perth Observatory, constructed a decade earlier.

Figure 18: Astrograph House, Royal Observatory of Belgium. Photograph T. Stevenson, 2009.

New constructions of this nature in all participating observatories were evidence of the major changes to the working environment caused by the move to photography as a method for astronomy. Participation in the AC-CdC was the impetus for the Australian observatories to embrace this new technology and equip themselves appropriately for the large task ahead.

MELBOURNE'S ASTROGRAPH HOUSE 1890

In his 1890 report to the Board of Visitors, Ellery described the astrograph building, which was completed in March of that year, as:

> "This building … consists of a rectangular structure about 19 feet square inside, and 28 feet from ground to base of dome. The dome itself is 18ft. 4in diameter inside, the base is of framed angle iron, carrying twelve roller wheels … this form of opening and shutter was designed by and is known as Dr. Gill's chase and so far as can be judged at present appears extremely good and effective, weather tight and easily managed."
>
> (Melbourne Observatory 1890, p. 5)

There were improvements made by David Gill to the design of the Cape Observatory astrograph house dome operation, which was completed in 1889 (Gill 1913, p.cxlix, pp. 122–123). Its mechanical design was directly applied to Melbourne Observatory's new structure.

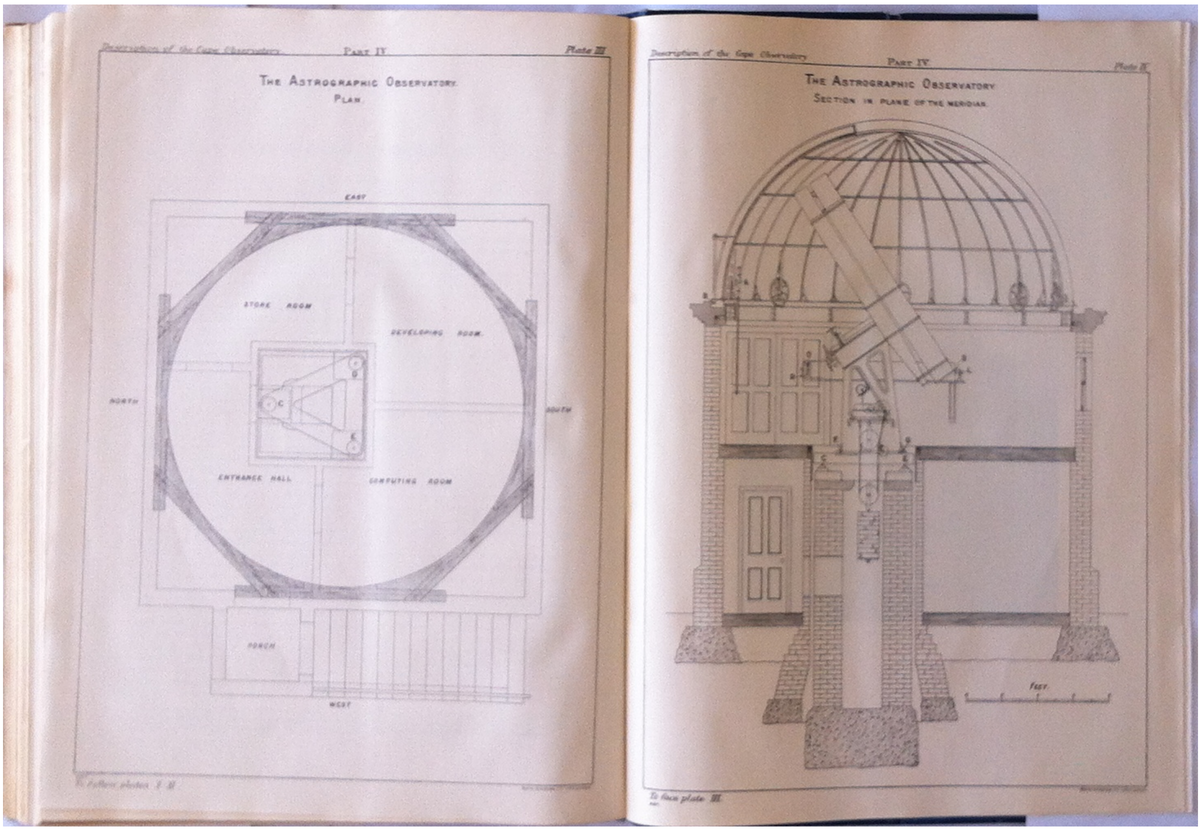


Figure 19: Astrograph House, Cape of Good Hope (Gill 1913, plate III, IV).

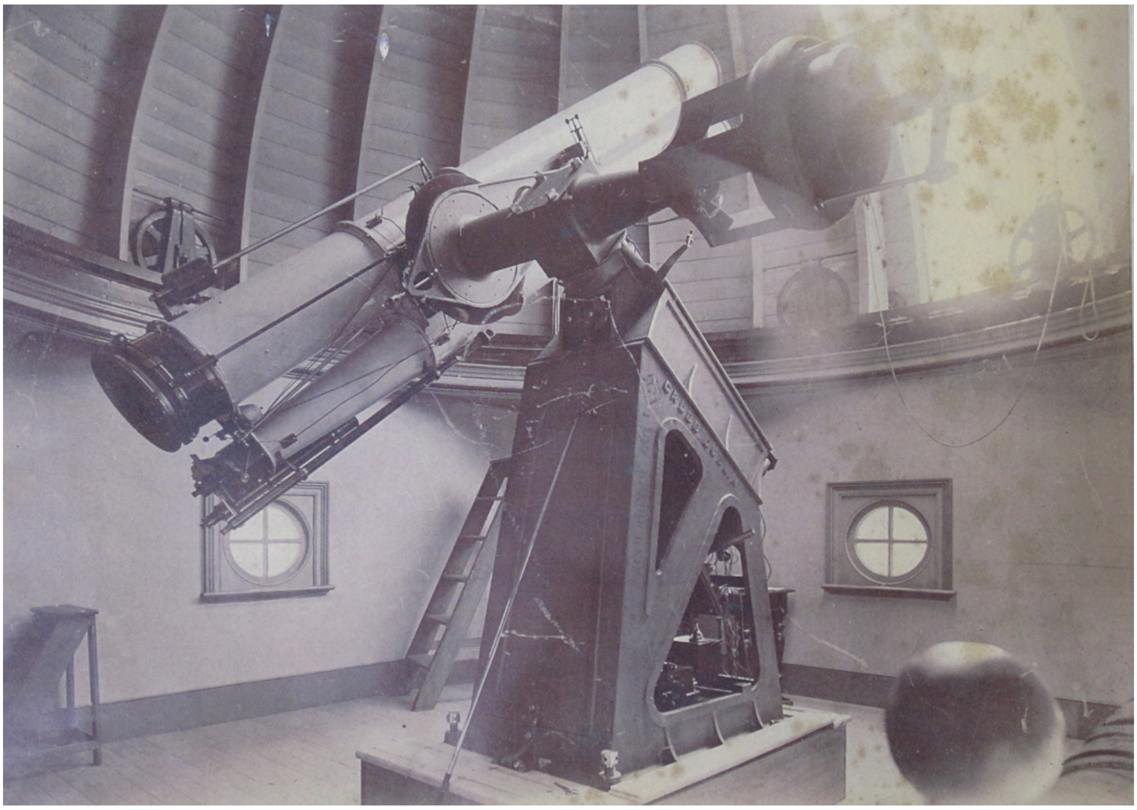


Figure 20: Astrograph House, Melbourne Observatory, c1893 (Collection MAAS P32549–P11).

Features of Gill's design were adapted for Melbourne Observatory's new astrograph house completed in 1889 (Ellery 1889). Gill noted that his layout allowed for maximum floor space around the telescope (which is on the top floor), facilities for developing the plates, a computing room and a store area underneath on the ground floor. Gill described this as a most 'convenient' design (Gill 1913, pp. 122–123). Alexander James MacDonald, who was the Assistant Architect with the Public Works Department of Victoria, designed the elegant Art Nouveau style Melbourne astrograph house (Victorian Heritage database H1087). MacDonald's training in Edinburgh, Scotland influenced his design and its decorative elements, which were inspired by the Scottish Art Nouveau style (Neale 1999). It is very similar to Gill's ROCGH astrograph house, apart from the absence of an external staircase. The internal staircase at Melbourne Observatory meant that there was no space for the 'computing' room on the ground floor, which was part of Gill's design.

Figure 21: Astrograph House, Melbourne. Photograph T. Stevenson, 2009.

The photographic development dark room was underneath the Melbourne astrograph dome, and this required access to water. In 1906 the Board of Visitors reported to parliament that the rainwater tank had been removed from the side of the astrograph building and a new unit was to be fitted which would provide sterilised and filtered water (unfiltered water had been deemed unsuitable for developing negatives) (Board of Visitors 1906, p. 831). When Melbourne Observatory was closed in 1944, the astrograph was removed from the dome. As shown in Figure 21, the astrograph house has remained intact; however, inside a telescope belonging to the Astronomy Society of Victoria is mounted instead of the astrographic telescope, which is now located at Sydney Observatory in the East Dome display.

Sydney Observatory's first Astrograph House 1890

The structure built at Sydney Observatory for the AC was less impressive than those constructed at Melbourne and Perth, but it was fit for the purpose of photographing the sky. In 1890 a circular domed timber and corrugated iron shed was constructed on the site. Russell described it this way:

> "The walls and roof are made of thin iron in a light wooden frame, which is 26 feet in diameter. This construction secures the same temperature inside as outside."
>
> (Russell 1892, p. 5)

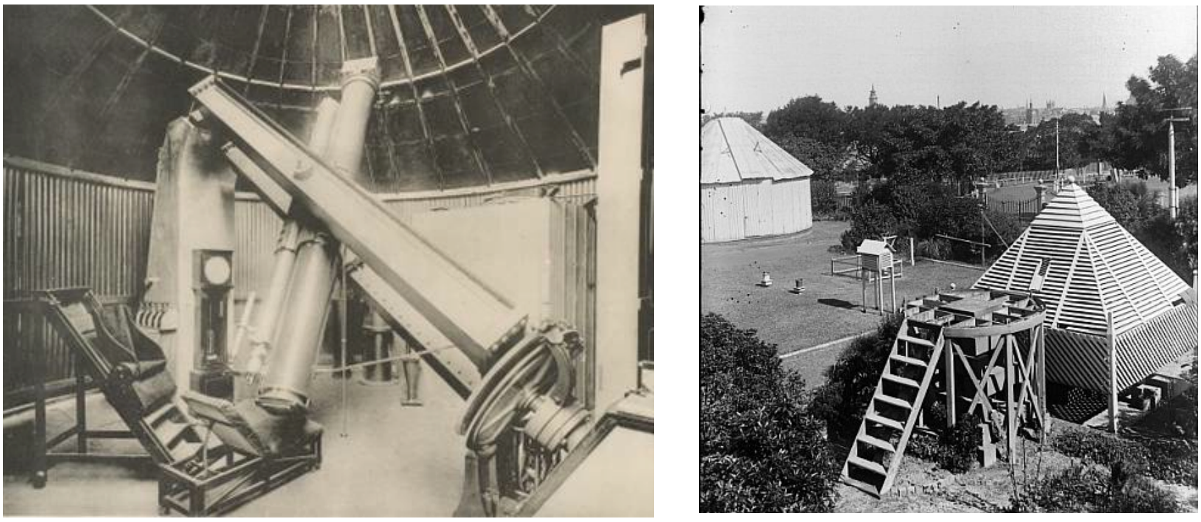


Figure 22: (L) Sydney Observatory's first Astrograph House (Russell 1892). (R) Exterior view of astrograph house c1900 (Collection MAAS P3548–791).

The entire structure, the walls and the roof, revolved. There was a metal runner ‘about 1 foot above the ground’ which had five cannonballs in it. One could say it was uniquely ‘Australian’. There was a ‘3 metre wide shutter’ and two solid brick piers, north and south. The sidereal clock was mounted on the south pier and the star camera mount was fixed to the north pier. The design of the polar axis astrograph telescope tube is shown in Figure 22. Its movement was made possible by a standard ‘English mounting’ design not unlike the Paris astrographic telescope designed by Gautier and shown later in this chapter. Proud of his achievements, Russell published photographs, drawings and descriptions of the astrograph house in an impressive illustrated book (1892). The first structure for the AC-CdC lasted at least until 1943 as illustrated by the aerial view in Figure 23.

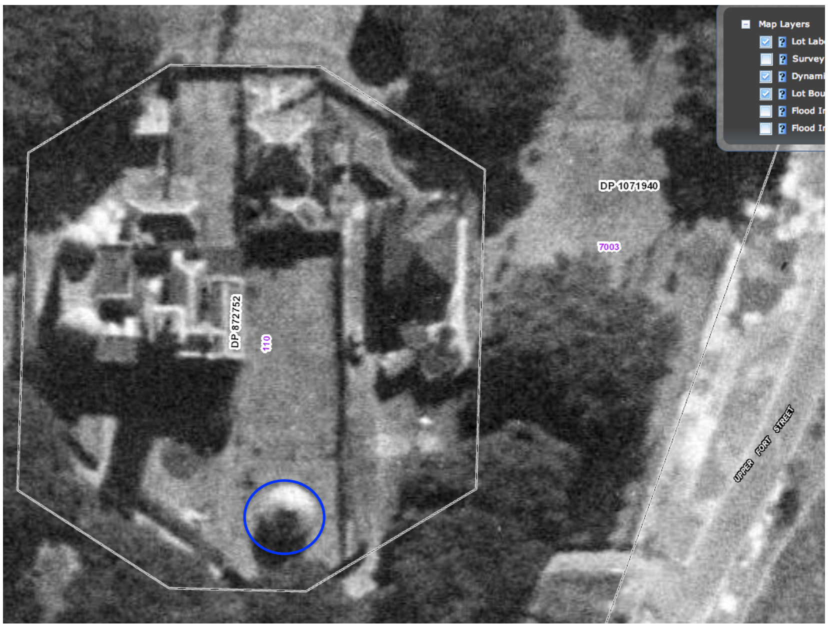


Figure 23: 1943 aerial view of Sydney Observatory. Source: <http://maps.six.nsw.gov.au>.

SYDNEY OBSERVATORY'S RED HILL OBSERVATORY 1898

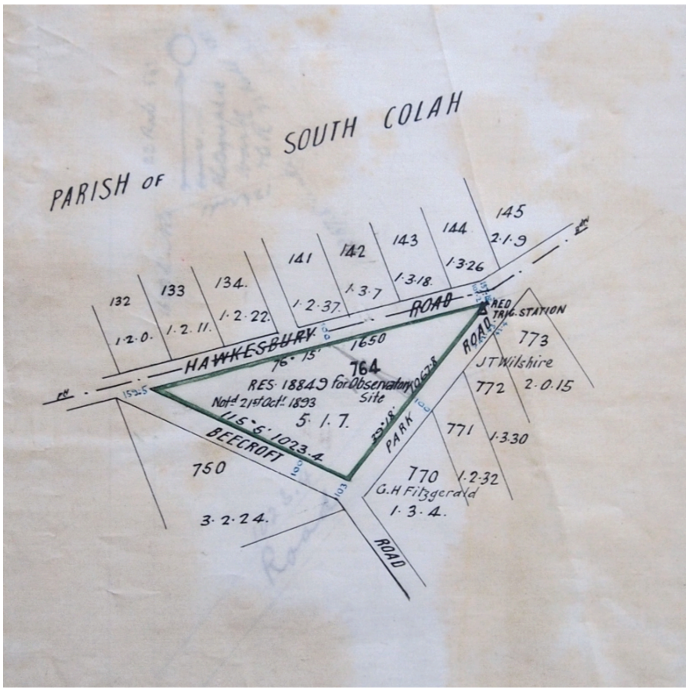


Figure 24: Survey of reserve 18849 Observatory site, Atchison and Schleicher, 1886 (Collection SRNSW).

Russell had a plan to relocate the astrographic telescope out of the city environment. He was concerned about the vibration threat of the proposed city railway line about which he had been informed (letter from the NSW Government Under Secretary to Russell 24 Jan 1890, SRNSW) and increased smoke haze (Russell 1890, p. 214).

My research at SRNSW (Series A3003, box 159) has uncovered that Russell had tested a site out of the city, '620ft above sea level' within a few hours by horse from Sydney Observatory, even before participation in the AC-CdC was confirmed. This is indicated by the 1886 site survey of a triangular piece of land on a site called Red Hill as shown in Figure 24. Bounded by three roads, this area is now called Observatory Park at Pennant Hills. Russell's plan was that all the photographic work would be done at Red Hill, but the reduction, measurement and management of the project would be handled at the city observatory site.

A recession in 1893 prevented an early move to the new site (Russell 1894, p. 235). Astrographic Assistant, James Short, tested the site for suitability as shown in Figure 25. It was not until 1898 that a modest building was constructed for the photographic work. A house was built for Short and an Astrograph House. The telescope and equipment was relocated and operational by August 1899 (Russell 1900, p. 362).

Figure 25: James Short at Red Hill during the test phase of the site.(Collection MAAS 2005/124/1-1 (detail)).

Short kept a logbook of his work and any obstructions such as weather or problems with instruments and supplies were noted. I have examined this logbook and Russell's, Lenehan's and Cooke's correspondence and reports relating to the operations at Red Hill. Short reported on his astrophotography, but he also wrote comments, as quoted below:

> "All plates from October 15th, 1898 not developed until February 1900. Delay caused by instrument being moved to Pennant Hills many plates were rejected having become defective during their protracted delay."
> (Short, log book, 15 Oct 1898, note added in 1900, MAAS Collection uncatalogued)

In 1903 Russell was taken ill and Lenehan took over the Government Astronomer responsibilities. Lenehan organised repairs and improvements to Red Hill astrographic facilities, including a new dark-room (Lenehan 1908, p. 205). Even so, problems such as the one quoted below regularly emerged:

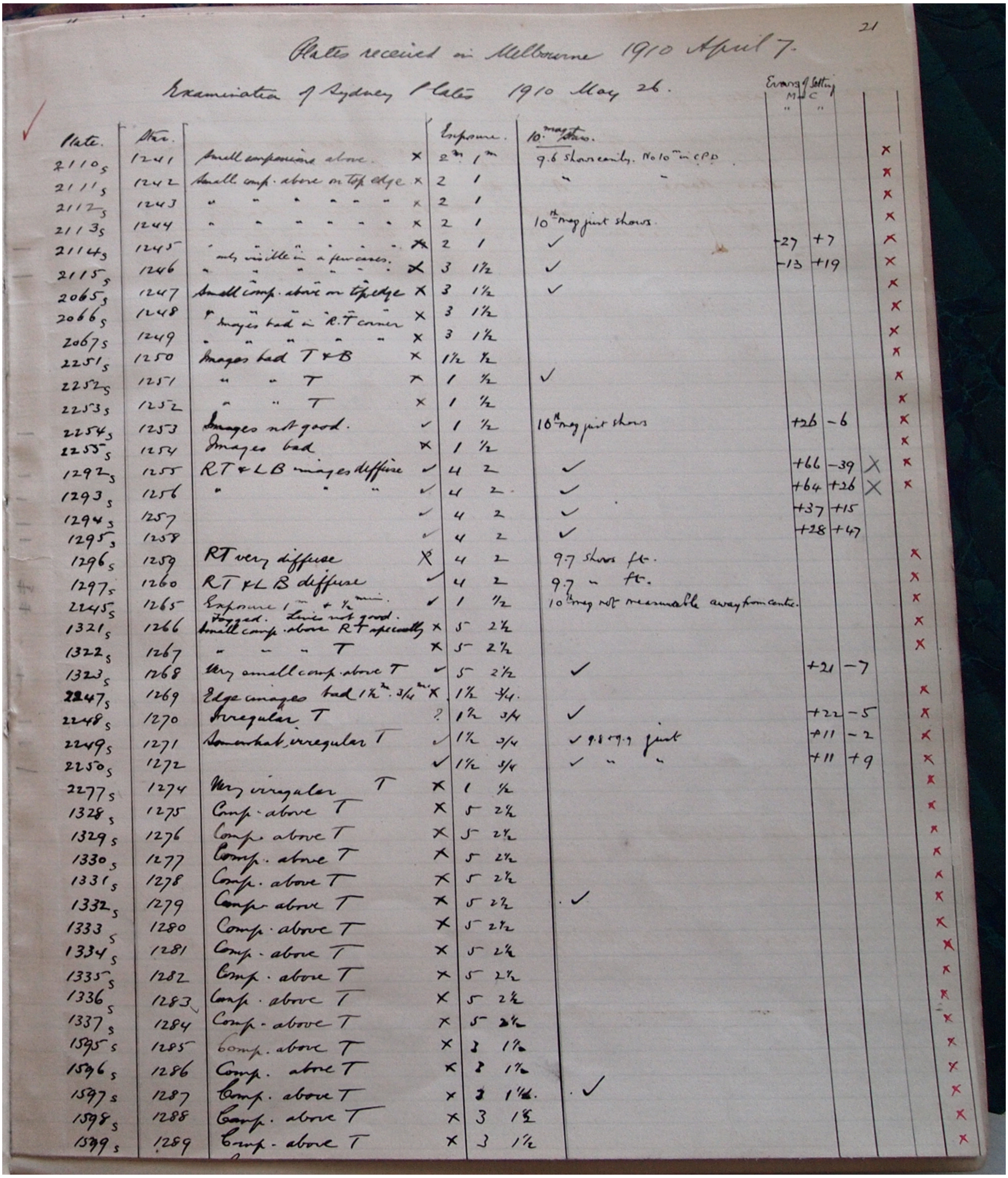
> "Upon development plates 436 to 447 proved defective through some fault in their manufacture. I found afterwards that this dozen of plates were a doz. of very old such plates that had been in the Obs at Sydney for years, and W. Graham not knowing had sent them up to me."
> (Short, log book, 27 Aug 1908).

Short's notes include minutiae, such as the time he took to pick up the supplies sent from Sydney Observatory to Pennant Hills railway station which was about 20 minutes walk from the Red Hill observatory. On the evening of the 28th of August 1908, Short noted that he was absent from the observatory:

> "Between 19:38 and 22:27: the interval to allow me to obtain a parcel of chemicals (from Railway station), which was sent from Sydney Obs today."
> (Short, log book, 27 Aug 1908, Collection MAAS uncatalogued).

This and many other notes indicate that the distance between the astrographic work at Red Hill and Sydney Observatory caused confusion and delay and that successive Government Astronomers had problems supervising Short's work.

There were problems with the Sydney plates photographed by Short. This is made evident in the assessment of the condition of the plates made by Astrographic Assistant, Charlotte Emily Fforde Peel, in 1910 at Melbourne Observatory (Figure 26). Of the forty-eight plates listed as received at Melbourne Observatory for measurement, there are only three which are suitable. 'Images not good', 'images bad', and 'diffuse' are some of the descriptors she used. On some of the plates the magnitude of stars required for the AC, which was meant to be down to magnitude 11, was not achieved. Peel assessed that on some of the plates only magnitude 9.6 or 10 was achieved. Other variations from the acceptable standard made the plates unsuitable for the AC.



21

Plates received in Melbourne 1910 April 7.

Examination of Sydney Plates 1910 May 26.

Plate.	Star.			Exposure.		10th mag stars.	Errors of Setting M	C		
2110s	1241	Small companions above.	×	2m	1m	9.6 shows easily. No 10m in CPD.				×
2111s	1242	Small comp. above on top edge	×	2	1	" "				×
2112s	1243	" " " " " "	×	2	1					×
2113s	1244	" " " " " "	×	2	1	10th mag just shows.				×
2114s	1245	" " " " " " only visible in a few cases.	×	2	1	✓	-27	+7		×
2115s	1246	" " " " " "	×	3	1½	✓	-13	+19		×
2065s	1247	Small comp. above on top edge	×	3	1½	✓				×
2066s	1248	" Images bad in R.T corner	×	3	1½					×
2067s	1249	" " " " "	×	3	1½					×
2251s	1250	Images bad T & B	×	1½	½					×
2252s	1251	" " T	×	1	½	✓				×
2253s	1252	" " T	×	1	½					×
2254s	1253	Images not good.	✓	1	½	10th mag just shows	+26	-6		×
2255s	1254	Images bad	×	1	½					×
1292s	1255	RT & LB images diffuse	✓	4	2	✓	+66	-39	×	×
1293s	1256	" " "	✓	4	2	✓	+64	+26	×	×
1294s	1257		✓	4	2	✓	+37	+15		
1295s	1258		✓	4	2	✓	+28	+47		
1296s	1259	RT very diffuse	×	4	2	9.7 shows ft.				×
1297s	1260	RT & LB diffuse	✓	4	2	9.7 " ft.				×
2245s	1265	Exposure 1m + ½min. Fogged. Lines not good.	✓	1	½	10th mag not measurable away from centre.				×
1321s	1266	Small comp. above RT especially	×	5	2½					×
1322s	1267	" " " T	×	5	2½					×
1323s	1268	Very small comp. above T	✓	5	2½	✓	+21	-7		
2247s	1269	Edge images bad 1½m. ¾min	×	1½	¾.					×
2248s	1270	Irregular T	?	1½	¾	✓	+22	-5		×
2249s	1271	Somewhat irregular T	✓	1½	¾	✓ 9.8 & 9.9 just	+11	-2		×
2250s	1272		✓	1½	¾	✓ " "	+11	+9		×
2277s	1274	Very irregular T	×	1	½					×
1328s	1275	Comp. above T	×	5	2½					×
1329s	1276	Comp. above T	×	5	2½					×
1330s	1277	Comp. above T	×	5	2½					×
1331s	1278	Comp. above T	×	5	2½					×
1332s	1279	Comp. above T	×	5	2½	✓				×
1333s	1280	Comp. above T	×	5	2½					×
1334s	1281	Comp. above T	×	5	2½					×
1335s	1282	Comp. above T	×	5	2½					×
1336s	1283	Comp. above T	×	5	2½					×
1337s	1284	Comp. above T	×	5	2½					×
1595s	1285	Comp. above T	×	3	1½					×
1596s	1286	Comp. above T	×	3	1½					×
1597s	1287	Comp. above T	×	3	1½.	✓				×
1598s	1288	Comp. above T	×	3	1½					×
1599s	1289	Comp. above T	×	3	1½					×

Figure 26: Peel's logbook of assessment of Sydney plates received 7 Apr 1910, (Collection SRNSW).

Figure 27: Astrograph House, Red Hill 1922, James Short (Collection MAAS 2005/124/1-7).

Another impediment to progress was the total solar eclipse of 1922. In 1922 work on the AC-CdC was suspended so that the astrographic telescope could be sent to Goondiwindi in Queensland to photograph the total solar eclipse (Cooke 1923a, pp. 511–515). The movement of equipment and its repurposing had consequences because in the end the instrument did not behave as hoped. This is an example of what Schaffer described, through examples of instrument issues in Bombay, as an expectation by London astronomers that the "observatory managers should be able to improvise repairs on site, not demand perfection" (2011, p. 712).

After the expedition the astrographic telescope returned to Red Hill where Short continued to work until 1931, when he retired. By the close of 1932, the telescope and other equipment was relocated to Sydney Observatory (Nangle 1933, p. 261).

SYDNEY OBSERVATORY'S THIRD ASTROGRAPH HOUSE 1952

The transfer of Melbourne's zone of the AC to Sydney resulted in the revitalisation of Sydney Observatory with the construction of a new dome to house the Melbourne Astrographic telescope.

In 1947 Wood confirmed that the Government of Victoria had agreed to accept £251 for the purchase of the astrographic telescope by Sydney Observatory (SRNSW 47/348). The building was designed by NSW Government Architect's Branch Architect Edward (Ted) Herbert Farmer, who became NSW Government Architect in 1958 (http://search.records.nsw.gov.au/persons/154). The astrograph house construction, as shown in Figure 28, was originally estimated at £2,000 with an additional £300 for clocks. This total was revised, after savings, to £2,200 which left £100 for maintenance (SRNSW 47/303). In 1948, an additional £50 was estimated for freight by rail of the large telescope (SRNSW 48/80).

Figure 28: Astrograph House construction c1951 (Collection MAAS).

The design was finalised and the construction contracts signed at the end of 1949 (Wood 1950). By 1952, the new dome, made by local engineering company Morts Dock Engineering, was completed and the Melbourne Astrographic telescope had been installed (Wood 1953). Wood proceeded to complete the Astrographic Catalogue. He and the other astronomers re-photographed sections where the old glass plates were damaged or had poor focus. Photography as the means of producing accurate and standardised data was now the normative method, as indicated by Wood:

> "The camera has now almost completely replaced the meridian circle as the instrument for the production of zone catalogues of many stars."
> (Wood 1960)

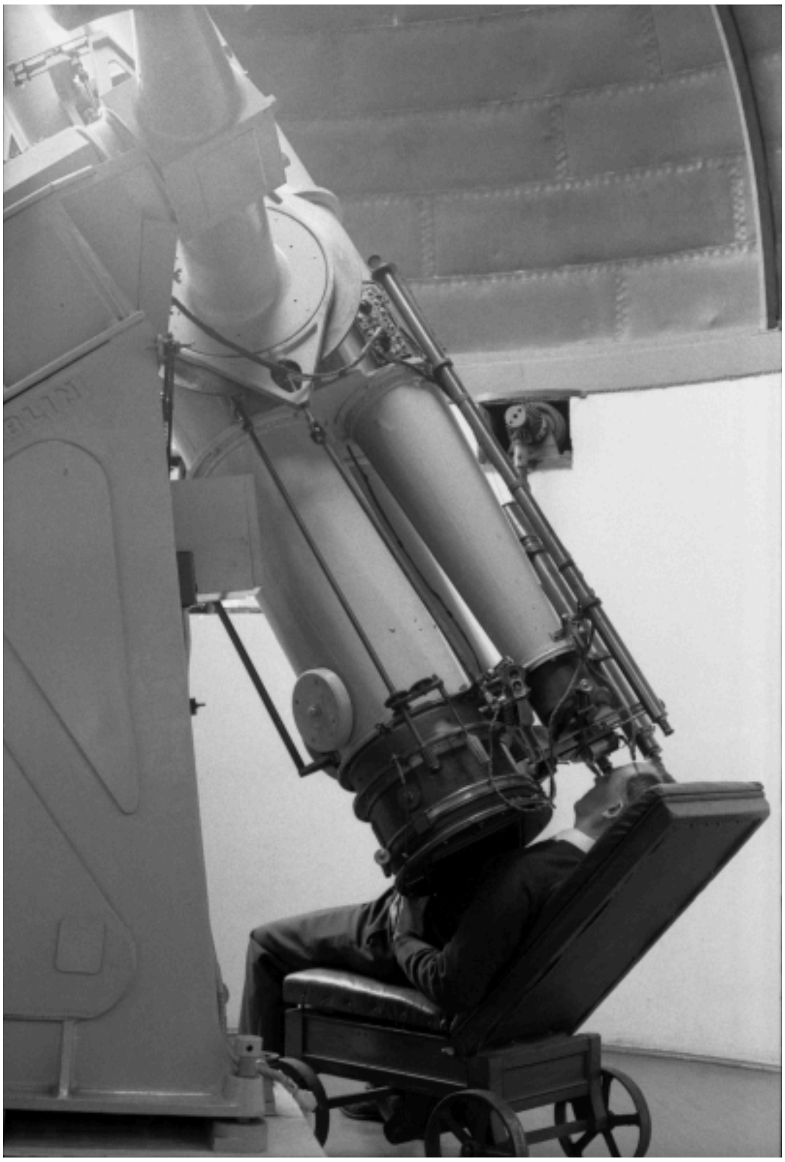


Figure 29: Harley Wood using the Melbourne astrograph at Sydney Observatory, 1969 (Collection MAAS David Mist Archive 96/44/1-5/5/19/1).

The astrographic telescope and a new measuring machine offered opportunities for astrometric research beyond the Astrographic Catalogue. In 1955 Wood began a new photographic survey of the sky zone -36° to the South Celestial Pole for comparison with the Astrographic and other star catalogues. He purchased a telescope fitted with an f/8 lens made by English firm Taylor, Taylor and Hobson with a scale 116.1" per mm and a 23cm aperture which was fitted onto the old Melbourne Astrograph (Wood 1960, p. 190; King & Lomb 1983, p. 53). The difference with the new photographic work was also in the increased accuracy of measurement. Wood purchased a new photoelectric measuring machine by Grubb Parsons, which produced a magnetic tape from the measurement data (Wood 1960). The measurers for this new Sydney Southern Star Catalogue were also women acknowledged as Mrs J. Close (nee Fitt), Miss D. Teale, Mrs A. Brown and Miss J. Westaway. In 1983 the region -51° to -63° 30' of 26,926 second epoch star measurements was published by King and Lomb (1983).

When Sydney Observatory ceased operation, the astrograph building was demolished and dome removed to Macquarie University in 1986 (pers comm Nick Lomb 2011). A new masterplan (Stevenson et al 2007 unpublished) included re-instatement of the dome on a new building to house the old Melbourne Astrographic telescope. A new telescope was mounted in the old dome, which was made accessible to people with disabilities. Construction began on a new building in 2014 and it was completed and launched on the 27th of January 2015 (Stevenson 2015cd).

PERTH OBSERVATORY'S FIRST ASTROGRAPH HOUSE 1898

Mt Eliza, which rises 200 metres above sea level and is located on the western boundary of the city of Perth, must have seemed an ideal location for an observatory for Western Australia. This was the site chosen by the government in consultation with the Director of Adelaide Observatory, Sir Charles Todd (Hutchinson 1981, p. 60; Haynes et al 1996, p. 91) and the Premier, John Forrest, laid the foundation stone for Perth Observatory's buildings in September 1896. This was a lavish ceremony as reported in the news media (*The West Australian*, 29 Sep & 28 Mar 1896). The photograph of the foundation stone ceremony in Figure 30 shows the names of four of the best known astronomers: Copernicus, Galileo, Newton and Herschel, emblazoned on banners erected where the main building would stand. In the centre of the photograph, on the viewer's right, is Henry Chamberlain Russell standing next to William Ernest Cooke. Forrest, unveiled the foundation stone. On advice from Todd, Forrest had selected Cooke for the position of Director of Perth Observatory (Utting 1989, p. 5).

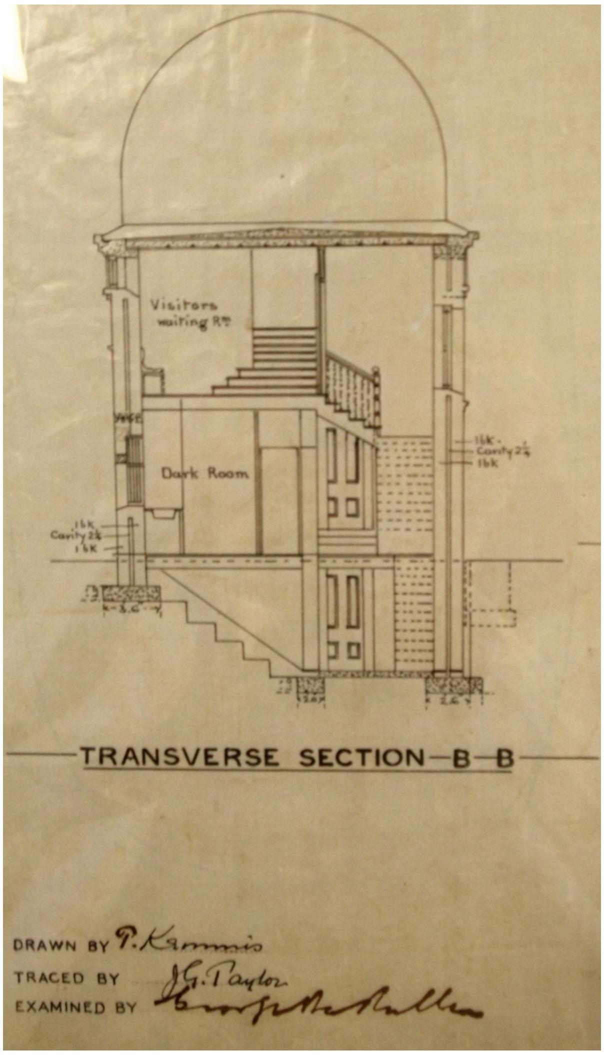
George Thomas Temple Poole, Superintendent for Public Works in Western Australia, designed the Perth Observatory buildings. Poole was a notable architect in Western Australia as demonstrated by the Government of Western Australia's Heritage list on which there are 104 buildings designed by, or engineered by Poole (Oldham et al 1980). Perth Observatory was a considerable investment in site and buildings. A cost of £1,250 was estimated for the buildings and instruments but the final cost was closer to £5,000 (*The West Australian*, 29

Sep 1896, 10 Jul 1897, 24 Aug 1898, & 16 Sep 1899). Its astrograph house is shown in Figure 31, which provided public viewing as well as a substantial dark room and storage.

Figure 30: Perth Observatory foundation stone celebrations, 29 Sep 1896. Photograph Clarke and Son, Royal Studios, Perth (Collection MAAS P3549-189).

The buildings and instruments included a standard double tube astrographic telescope made by Howard Grubb. By 1898 observation work had begun, although the observatory was not officially opened until 1900. The Perth astrograph house was a more substantial building than those at Sydney and Melbourne (as seen in Figure 31). The original designs show a three-level building with a basement, a ground floor with a workshop and darkrooms, and a first floor with the dome, photographic dark room and visitors waiting space. The dome, also manufactured by Grubb and transported to be assembled on site, had been ordered in 1896 (*South Australian Register*, 13 Nov.1896).

The offices and computing rooms were located in the main building on the ground floor in adjoining rooms. The majority of the main observatory building was a private residence for the astronomer (shown in Figure 32).



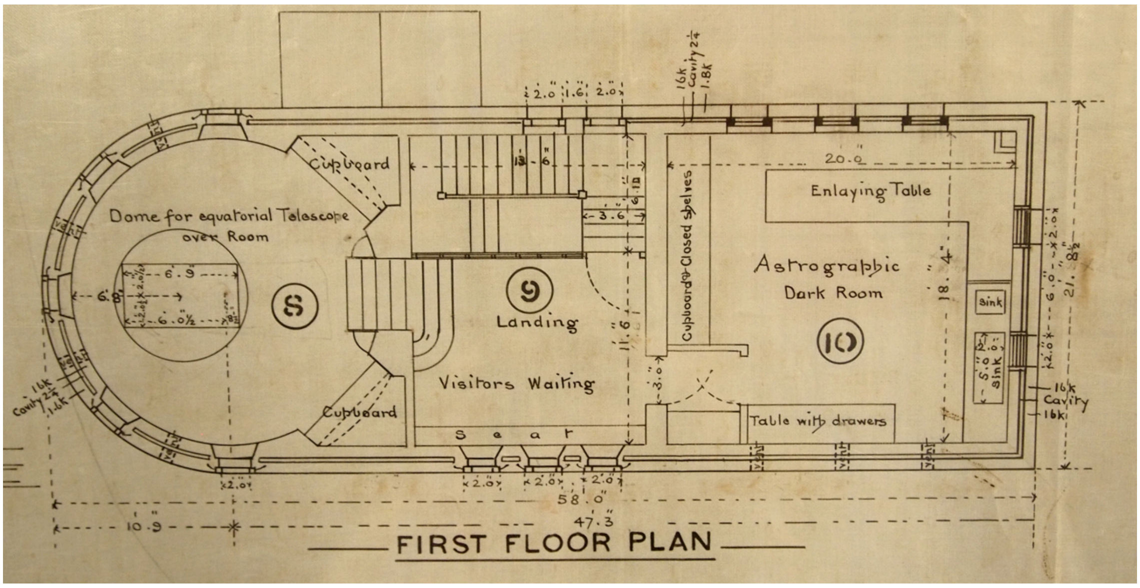


Figure 31: Plan, section & east elevation of astrographic house 1897, A. Kemmis (Collection SRWA).

Figure 32: Perth Observatory, astrograph house in the foreground (Collection SLWA 008471D).

PERTH OBSERVATORY BICKLEY & A NEW ASTROGRAPH HOUSE 1964

According to Perth Observatory Astronomers, Ralph Martin, Andrew Williams and educator Greg Rowe, the decision to relocate Perth Observatory to a less light polluted site on the outskirts of Perth in 1964 (Bickley) resulted in the astrographic telescope and dome being moved and the original building being demolished, as shown in

Figure 33 (pers.comm., Martin, Williams, Rowe 2011). This was seen as a positive move for research at Perth Observatory. By that stage the photography for the CdC and the AC had been completed. In the new buildings at Bickley, the AC-CdC plates were stored, and a new measuring machine was purchased for further research projects.

Figure 33: Demolition of the old astrograph house, 1964 (Collection Perth Observatory).

According to Lowe, the astrographic telescope was modernised with an electric motor after the move and several modifications have been made since so it can track a fast moving object; at the time of interview, it was functionally operational. The dome is original and has been painted and restored, as shown in Figure 34.

Inside the administration building at Perth Observatory, Bickley, there is a complete archive of the AC-CdC. A timeline of full-time male astronomy staff produced by Williams (unpublished 2010) demonstrated that the number of research astronomers and technicians doubled as a result of the relocation to Bickley, as did the innovative and expansive research work undertaken by Director Mike Candy during this period (Martin pers comm 2012). The AC-CdC plates and catalogue were stored and periodically used.

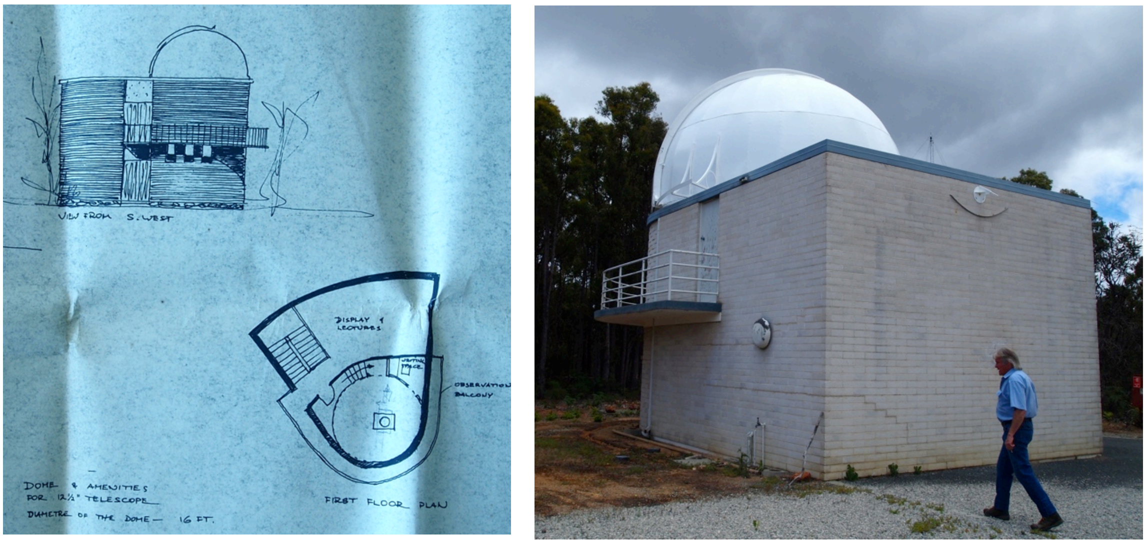


Figure 34: Astrograph House, Bickley, conceptual drawing and the completed structure. Photograph T. Stevenson 2013.

A SEPARATE SPACE FOR THE WOMEN

The system of employing women as an available resource for scientific data collection transformed the observatory workplace. Whilst Airy had counselled 'division of labour' as a normative observatory workplace structure in the early nineteeenth century (Schaffer 2010, p. 131), Bigg (2000) and Lamy (2006) observed that the AC roles were segregated by gender and science was undertaken in a mass production line method. Despite some initial mistrust in the science produced using this method, as described by Bigg, this new modernist model would become normative to other areas of science and business. It impacted on the physical, as well as the organisational structure of the observatories. In Sydney, Melbourne and Perth, changes were made to buildings, furnishings and operational regulations. The architectural layout of new building works at Melbourne and Sydney Observatories reflected both the desired segregation of workers and mass production method.

The observatories did not initially include provision for measurement offices and facilities; this was because the measurement of the star co-ordinates for the entire scheme was to take place at Paris Observatory. The decision that the measurement was the responsibility of each observatory required planning for accommodation of a Measuring Bureau. It emerged that the work was best undertaken by women working in pairs, one reading out co-ordinates to the other, and this was separated from the other activities of the observatory. Melbourne Observatory was the first to consider how the workplace would accommodate women.

In 1891 Ellery reported that for a ‘long period of time we have been short of room for our computing staff’ and that approval had been given for a new computing room on the north side of the Melbourne Observatory building, which would offer commodious accommodation. This work was delayed due to staff and financial cutbacks (Melbourne Observatory 1891, pp. 4–5). A new computing room was fitted out in 1892 at the cost of £189 (Victoria Government Gazette 1892, p. 1769); this was additional to the new building constructed in 1889 for the telescope and developing the photographic plates.

In 1898 six astrographic measurers were employed, and they were accommodated in the office next to the Great Melbourne Telescope. This room was, reported Baracchi, “fitted with tables resting on masonry pillars, and accessories required for the purpose” (Melbourne Observatory 1899, p. 4). In 1899 a large window was created in the south wall of the same office for the “convenience of the Astrographic Measuring Bureau”, whose work required even natural light, but not direct sunlight (Melbourne Observatory 1900, p. 4).

Figure 35: Photograph of the Melbourne Measuring Bureau (*The Australasian*, 27 Apr 1901, p. 30).

By 1901 the bureau was well established, as pictured in Figure 35. In his 1901 report, Baracchi provided a detailed rationale for approval to construct more space for several purposes, including the AC Measuring Bureau (Melbourne Observatory 1901, Appendix B). Baracchi complained that further space was required for the computers and measurers; and in 1903 Baracchi reported that “a new large room for the Astrographic Measuring Bureau has been built at the south end of the main building” (Baracchi 1903, Board report, p. 4). The men and women were separated at all of the observatories.

Apart from finding space for the women to work that was separate to where the men were located, issues arose in regards to providing facilities for the women. New toilets had been constructed for the women to use in 1903, but the sewerage connection to the internal toilets was not completed until 1913 (Baldwin 1915 Board report, p. 4). According to Clark, the lack of toilets was a contentious issue for this extensive period of time (pers comm, 2012).

At Sydney Observatory a new wing was constructed and the observatory was renovated after Russell retired on the 28th of February1906, by acting Government Astronomer, Lenehan (1907, p. 265). The plan was that the new Federal Meteorology section would move into the new wing; however, when Russell died a year later, the newly appointed Federal Bureau of Meteorology offices moved into what had previously been the Government Astronomer’s apartment. By 1916 the wing was allocated to the Astrographic Measurement Bureau, and an internal toilet and small kitchen were constructed in the main part of the building (remains of the plumbing and the air ventilation fan can still be seen inside cupboards at Sydney Observatory). Accommodation was required for the four to six women working on the catalogue and the numerous logbooks and reference catalogues which had accumulated for the project. It was possible for the women to work almost completely isolated from the rest of the observatory staff, except when plates were delivered for measuring or the Astronomer requested assistance with calculations (pers comm, Bellamy, 2011). Adequate lighting was important in order to view the plates, but this could not be direct sunlight so access to a south facing window was required (pers comm, Maurice 2013).

The rendered brick two-story building designed originally for the Meteorology Bureau but used by the astrograph bureau is pictured in Figure 36. It abutted the sandstone structure of the North Dome. This was considered a poorly constructed addition, not in keeping with the main observatory building; it was demolished in the 1980s. According to heritage expert James Semple Kerr, it was due to the lack of a conservation plan prior to work commencing and ill guided direction given by the museum’s Sydney Observatory Committee that heritage was not recorded. Kerr reported that Bhathal, who was the Committee Chairman, said that "The Museum stressed that the Observatory was a working museum not a historic house" (Kerr 1991, p. 36). Kerr expressed disappointment that there were few records of the interior spaces as they were during their operation (p. 37). Fortunately, Winsome Bellamy took photographs and kept a photographic album when she was employed in the astrograph bureau; one of these photographs can be seen in Figure 37.

Figure 36: Sydney Observatory c1968, with the 1906 extension. Offices on the top floor were for the Measuring Bureau, switchboard and clerical duties (Collection MAAS P3549-216).

Winsome Bellamy described the working environment:

> "Well, we came in the front door, and there was a little set of curvy stairs, very worn stairs, that brought us up to this level. And we came through the library, which had a large table as Ros described earlier, in the middle. And around the sides of the room were narrow bookcases loaded with leather-bound books of vast age. And we came through here and past the table and through this door here, which led to our measuring room."
>
> (pers comm, Bellamy 2011)

Figure 37: Sydney Observatory Astrographic Bureau c1960. (LtoR) Roslyn Logan, Yvonne Donohue, Shirley Wall (front), Winsome Bellamy (back). (Collection MAAS, uncatalogued).

At Perth Observatory, the Astrographic Assistants were located in the main office building. When in 1905 Prudence Valentine Williams and Miss E. Kendall were employed for the astrographic measuring work, their office was in the same large room which accommodated their male supervisor, the First Assistant Astronomer, Clive Nossiter, and Mr Wintle, who was a junior assistant. There was a separate exterior toilet for the women and, according to Utting, small considerations were made for them, such as 'toilet soap'. Cooke explained the minutiae of his expenditure on this 'luxury' item to the Colonial Secretary:

> "The soap was obtained for the lady assistants. It works out at 4d. per cake. That contract rate for Starlight at the Union Store is 3 1/2d. to which must be added freight from Fremantle. The toilet soap we bought was obtained from a store a few yards away."
>
> (Cooke 1908b in Utting 1992, p. 119)

The extent to which steps were taken to make observatories more comfortable to the women star measurers infers that their employment conditions were important to the astronomers, and that, once trained, the objective was for them to stay at the job for a period of time.

Astrographic telescopes and a 'Star Camera'

The astrographic telescopes were a major investment in leading edge technology. A power driven telescope was vital to follow the stars because it recorded the stars as pinpricks on the

photographic emulsion, rather than lines generated by a fixed camera which could not compensate for the earth's rotation. Decisions about the telescopes were based on informed opinion and efficient demonstrations at the 1887 Congress, according to the transcript of proceedings (Winterhalter 1891, pp. 1823). The choice was made of a refractor over a reflector, with approval for the arrangement and size of telescope to be based on that constructed by the Henry Brothers at Paris Observatory, with an aperture diameter of 33cm (13 inches) and a focal length of 3m, 44mm (Klumpke 1895, p. 210).
There were two types of mounts used for the astrographs: the Henry Brothers type which was used by the observatories with allegiances to Paris Observatory (as seen in Figure 39); and the other designed for the British contingent by Irish instrument makers, Howard Grubb and Associates of Dublin (hereafter 'Grubb') as seen in Figure 38. Grubb was the preferred supplier for the British and British colonial observatories; they were commissioned to make seven of the telescopes (Greenwich, Oxford, the Cape, Melbourne, Perth, Hydrabad and Tacubaya) and the lens for the Sydney star camera (Russell 1892a, p. 4; Wayman 1988, p. 139, Hughes 2013, pp. 1039–1046).

Ellery ordered the Grubb telescope for Melbourne Observatory and the Governor of Victoria approved the cost of £1300 on the 25th of November 1890 (Ellery, Annual Report to the Government Victoria, 5 Dec 1890, p. 4718). Perth Observatory also ordered a Howard Grubb telescope. Both of these telescopes and their mounts still exist. The Melbourne Astrographic telescope has been installed in a new building at Sydney Observatory (partly due to the research for this thesis), having been transferred from Melbourne Observatory to Sydney Observatory in 1948, and then to Macquarie University in 1986, then in 2008 to the MAAS Collection store. The Perth astrograph is operational in a building constructed in 1966 at the Perth Observatory site in Bickley.

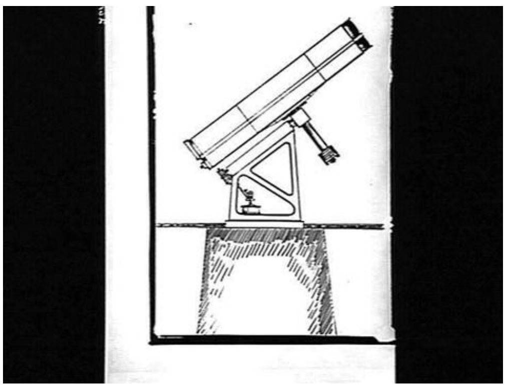


Figure 38: Sketch of Melbourne astrograph by Howard Grubb, 1887 (Collection Museum Victoria).

In 1887 Russell saw the Henry Brothers design for the astrographic telescope in Paris. Russell attributed the rationale for his individual telescope design to a suggestion made by the Minister for Public Instruction that the colony could build most of the telescopes and save money (Russell 1892, p. 4). Russell acknowledged the similarity between the Sydney astrograph and the French design, but he made modifications to suit the Sydney environment. These included a much heavier construction to minimise vibration. Grubb manufactured the standard lens as designed for the British and British colonial observatories.

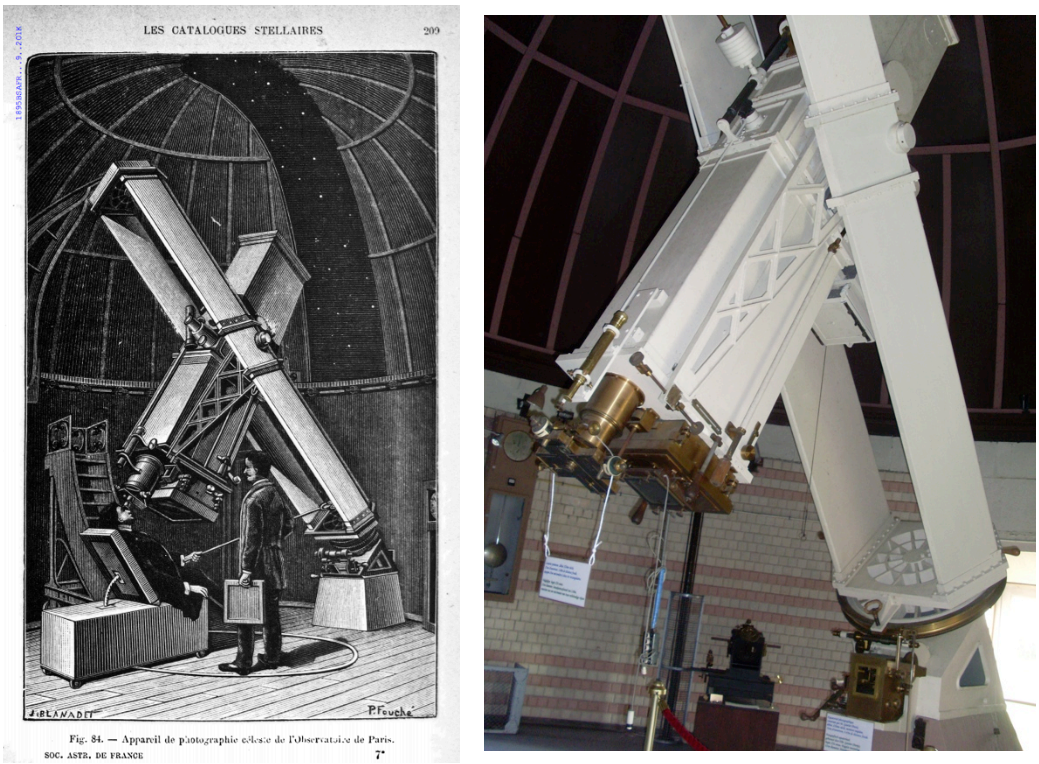


Figure 39: (L) Astrographic telescope, Paris Observatory (Klumpke 1895); (R) Royal Observatory of Belgium astrograph. Photograph T. Stevenson 2011.

Russell described the lenses, mount, tangent and focusing screws, and driving clock in detail with simplified engineering drawings. Russell's design of a plate-changing box, which could be easily operated in a dark room, meant that the process to change the glass plate negatives took two minutes (Russell 1892, p. 14). Russell's astrographic observatory and telescope mount was constructed before the Grubb lens arrived and, with a portrait lens made by Dallmeyer fixed to it, he was able, working with James Short, to take some of the first photographs of the Orion Nebula and Eta Carinae:

> "The star camera has been used to investigate important regions, and the densest part of Nubecula Major, n Argus, the Trifid Nebula, &c,. with remarkably good results …

the camera shows ten times as many stars, and entirely new features of nebula with 5¾ hours' exposure."
(Russell 1892, p. 267).

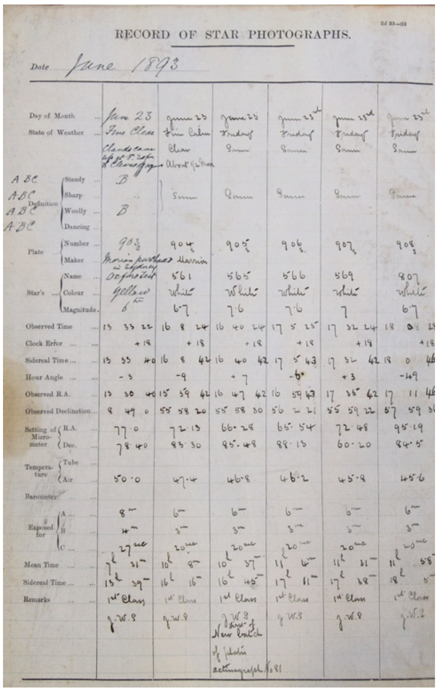


Figure 40: (L) James Short's logbook 1893; (R) Short using the Sydney astrograph at Red Hill (Collection MAAS uncatalogued).

Apart from the Howard Grubb objective lens and a dividing wheel by Troughton and Sims, all other components for the telescope were made locally (Russell 1892, p. 4). Russell was proud of the local manufacturing of the telescope, and the observatory instrument maker's work:

"… some of the heavier parts were made at Morts Dock and Engineering Co's, others at Atlas Engineering Co, but the clockwork microscopes, all the smaller parts, and the putting together of all the parts, into a smooth working and highly satisfactory instrument have been done by Mr. W.I. Masters, Instrument Maker Sydney Observatory."
(Russell 1892, p. 4)

The Perth Observatory astrographic telescopes had both the mounting and the lenses designed and manufactured by Grubb. A description of the development and improvements made to this design by Dunsink Observatory Astronomer, Patrick Wayman, highlighted the innovative pendulum control and the robust nature of these instruments (19 88, pp. 139–142). Perth Observatory's astrographic telescope was the last one manufactured for the AC-CdC. It remains one of the most complete astrographic telescopes with only minor alterations. Thomas and Howard Grubb, and the telescopes they designed for the AC-CdC, have been thoroughly researched by astronomer Ian Glass (1997). There are also several sources of knowledge about the instruments used for the AC-CdC in Australia (White 1988, pp. 45–52;

O’Hora 1988, pp. 135–138, Wayman 1988, pp. 139–142; Haynes et al 1996, pp. 62, 80). The quality of the glass plate negatives, and the emulsion applied to them, was critical to successful stellar photography for the AC-CdC.

THE GLASS PLATES

There was considerable project management and technical skill required by the astronomers throughout the process. The lead astronomers had to exactly divide their zones so that there were the prescribed overlaps of plates and sufficient guide stars which could be observed through the telescope prior to exposure.

The quality of the glass plates and the emulsion applied to them were critical to achieving a good photographic result. All the AC-CdC glass plates were 16cm x 16cm. Typically they had a curved corner, which was used to position the plates when measuring them in reverse. This is evident in Figure 42. There were several challenges with securing and preparing the glass plate negatives, which were required in abundance for the AC-CdC. The astronomers found that to obtain consistently high-quality glass plates, the application of the emulsion, exposure to the réseau grid, and stellar photography were not simple processes, due to the experimental nature of the work and the weather, as described by Russell:

> “My dear Sir,
> I have the honour to report that, acting upon your advice, we made a beginning upon the Catalogue plates in December 1891. We have not got on so well as I anticipated owing to the cloudy weather and the summer haze which always affects the clearness of our atmosphere at this time of year … We are still using Ilford plates, an order sent to Lumiere of Lyon some months since not having been supplied yet …”
> (letter from Russell to Mouchez, 25 Jan 1892 in Chinnici 2008, p. 358).

Robert Ellery, Director of Melbourne Observatory, had sent a sample glass plate negative of an image taken through his newly assembled astrographic telescope to the Director of Paris Observatory, Admiral Mouchez, to gain his approval. This was a requirement prior to the 1892 International Astrographic Congress to check that the participating observatories had assembled the resources required for the project. Russell had recommended that all participating observatories submit their trial images to compare the uniformity of results (letter to Mouchez 6 Sep 1888, in Chinnici 1999, p. 354). Mouchez responded that the Melbourne Observatory results were excellent.

> “I am very pleased indeed to find our proof plate was found satisfactory … now we know we are on the right track …”
> (letter from Ellery to Mouchez 5 July 1892 in Chinnici 2008, p. 266).

An analysis of the accuracy of the Sydney zone by Wood concluded that the emulsion on the glass plates was the cause of greater error than the measurement techniques, in agreement with an earlier study by Schlesinger:

> "We see once more that the errors inherent in the plate are much greater than errors of measurement, so that in the present state of our knowledge any good method is practically as satisfactory as a perfect method would be."
> (Schlesinger 1937, quoted in Wood 1960).

Other problems included an incident in 1904 where Cooke reported that the glass plates he had ordered were lost at sea (Haynes et al 1996, p. 92; Cooke 1905).

A letter from Baracchi to Russell (29 Jun 1901, SRNSW) indicated that Baracchi intended to make duplicates of the CdC plates when he thought the plates would be shipped to Paris for printing. In preparation for this, he had timber boxes made, each of which accommodated 50 plates. There are 86 boxes, as seen in Figure 42, which are now part of the Astrographic Collection held by the MAAS, and another nine boxes are held at Melbourne Observatory (Barry Clark pers comm 2015).

Figure 41: Melbourne plate boxes at Macquarie University. Photograph T. Stevenson 2011.

Conservators have recently treated the Sydney and Melbourne zone plates; at the time of writing, these were in the process of being rehoused in museum standard conditions at the Powerhouse Museum. At Perth Observatory in Bickley, the glass plate collection has been successfully stored and the plates are in consistently excellent condition, as seen by the plate held by Ralph Martin in Figure 42. However, the Perth Observatory logbooks and other ephemera have not yet been catalogued.

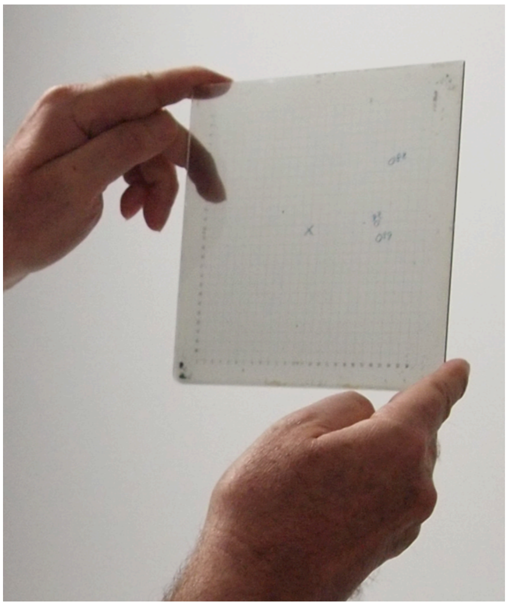


Figure 42: Ralph Martin holds up a Perth zone plate. Note the lower left curved corner. Photograph T. Stevenson 2012.

My research has revealed that whilst there were some film loss and breakages of Australian zone AC and CdC glass plate negatives, and there is some dispersal of the collections, the glass plate negatives and accompanying logbooks are mostly in existence and intact.

The réseau grid

A grid of lines 5cm apart, printed onto a standard glass plate 16cm x 16cm, was devised as a method by which to check movement in the emulsion on the negatives over time (Turner 1912, p. 27, p. 146). Agreement was made at the Astrographic Congress that the standard réseau used by all observatories had to be inspected and approved. Paul Ferdinand Gautier in Paris supplied most of the réseau plates but there were exceptions. In 1891 Vogel supplied two réseau plates to Melbourne Observatory at £14 each (letter Ellery to Mouchez, 8 Aug 1891, in Chinnici 1999, p. 261). By comparison, in 1895 a Gautier réseau was £2 10s and £3 (Turner 1895, p. 401). Melbourne Observatory produced its own réseau plates to a high standard but the Gautier plate became the standard, and most observatories used this.

In 1891, Sydney Observatory purchased three réseaux from Gautier. Russell reported that the silver changed chemically and “developed troublesome *pin holes*, easily mistaken for stars” (Russell 1892, p. 266). The Sydney Observatory réseaux are catalogued as H10271 in the

MAAS Collection; catalogue H10270 is a box of fifteen réseaux by Gautier from Melbourne Observatory. According to the Perth Observatory AC, only two réseaux were used, no. 151 and no. 152.

Each réseau plate was covered in silver to prevent light, aside from the lines, getting through. The lines on the plate were clear and fine; these let enough light through to make a fine grid on the negative once the réseau was exposed to light with the plate, but before the plate was exposed to the stars. The process of exposing the negatives to the réseau and inspecting the réseau required inventiveness. Russell designed a holder for the plates and réseaux, which was made at Sydney Observatory and featured in the 'Star Camera' book (1892). The original drawing is in SRNSW, with a similar artefact in the MAAS collection (H10373 1:2). One of the challenges was to ensure the réseau grid was exposed identically on each plate. Russell described his method and the process in detail, as well as the method of four to five minutes' exposure (1892, p. 12). This contradicts Gill's description of the method of exposure of the réseau plate to the negative, which said that 15 to 25 seconds was all that was required (Gill 1913, p. 122). My research indicates that the method of applying the réseau was slightly different in each observatory and dependent on other technological 'actors', such as the lamp wattage.

The Gautier Company maintained the supply of réseau plates for the extent of the AC-CdC. In 1952 Wood ordered réseaux from Hilger and Watts, as seen in the MAAS collection (H10272 1:2). This is the same company from which he purchased a more advanced measuring machine.

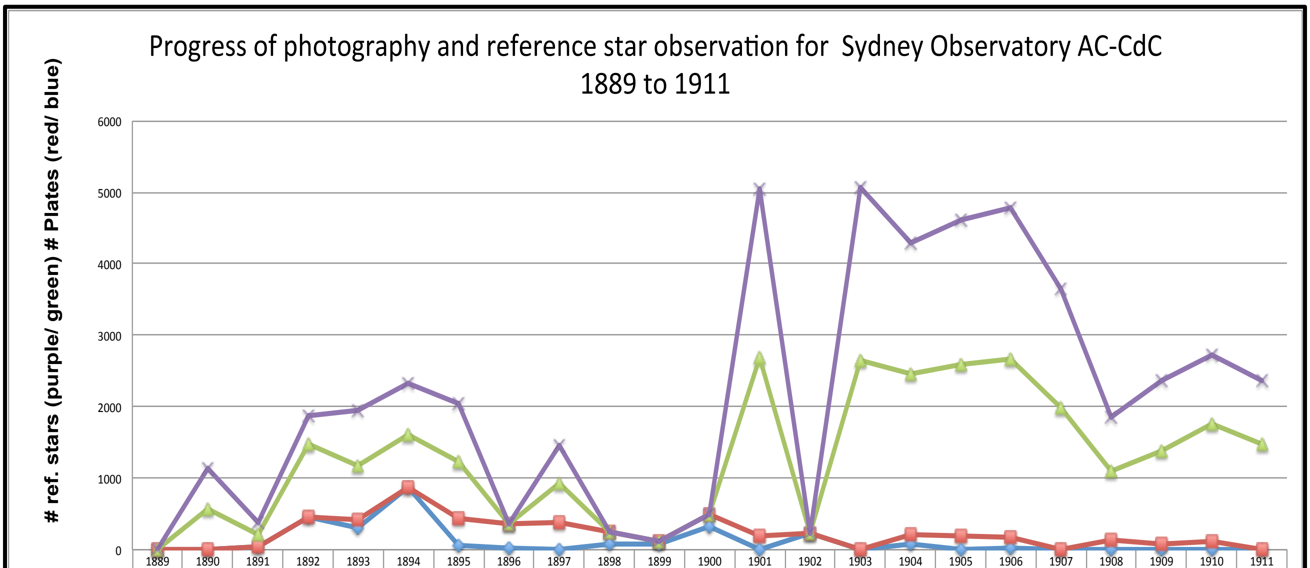
REFERENCE AND POLE STARS

Each plate had to have at least six previously identified stars called 'guide stars', which Ellery specified (letter Ellery to Mouchez, 8 August 1891, in Chinnici 1999, p. 261). These were observed by eye using a transit telescope. The reference stars had to be established before the plate constants, which were required to convert x and y measures to right ascension (RA) and declination (Dec), could be calculated. The stars on the AC plates were relative to the reference star positions. Wilhelm Gliese from the Astronomisches Rechen-Institut in Heidelberg, presented a paper at the 100th anniversary conference for the Carte du Ciel, in which he noted that the Southern Hemisphere observatories had a unique problem because of the lack of existing reference catalogues:

> "In some respects the Southern Hemisphere presents more interesting phenomena than the northern sky – for instance the galactic centre, and the Magellanic Clouds. For meridian observers, however, the lack of bright stars in the vicinity of the pole has been a handicap for observing absolute catalogue systems. Furthermore the southern observatories active in astrometry in the past are 55deg or more from the South Pole in latitude."
>
> (Gliese in Debarbat et al 1988, p. 96)

The graph in

Figure 42 shows the number of stars observed as reference stars (green and purple) as well as the number of plates photographed for the CdC (red) and for the AC (blue) at Sydney Observatory from 1889 through to 1911, as reported in the MNRAS. It is clear that the reference star work was of major consequence in terms of time and resources. From this graph it is easy to detect when major changes were made to the project or when the telescope was moved in 1898; or any other occurrence which caused the project to either accelerate or be delayed. For example, in 1896 the International Committee decided that a second series of the AC plates should be taken so that the date of photography was closer to epoch 1900 (Gill 1913, cxxxii).



	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911
REF stars NPD	0	567	165	404	765	713	800	0	535	0	0	0	2365	0	2431	1839	2032	2124	1665	754	971	966	890
REF stars RA	0	567	165	1003	765	741	800	0	535	0	0	0	2503	0	2644	2248	2395	2495	1986	973	1304	1637	1469
CdC Plates	0	0	0	0	101	0	381	355	385	152	53	175	187	0	0	115	193	137	0	120	75	111	0
AC Plates	0	0	50	465	311	876	59	16	1	88	72	323	0	231	0	87	0	31	0	6	6	12	0

Figure 42: Graph of the number of stars observed as reference stars and the number of plates photographed at Sydney Observatory from 1889–1911.

The other reason for photographing a second set of stars was to compare the stars on the first and second series of plates in order to calculate their proper motions. Therefore, not long after Russell reported the near completion of the AC plates in 1896, another series of photographic work commenced (Russell 1897, p. 298). In Short's logbook he reported that all work stopped on the AC-CdC between 1898 and 1900. The reason for this was so the astrographic telescope could be moved to the dark sky site at Red Hill Observatory where Short became the main photographer of the Sydney zone and the reference stars.

Adelaide Observatory's involvement in the AC-CdC was to provide pole and reference stars for the Melbourne and Sydney zones. These are observed using a transit telescope and the human eye. Further examination of the process is provided in Chapter Four.

MEASURING MACHINES, MAGNITUDES, LOGBOOKS AND REDUCTIONS

A measuring machine or star plate micrometer (micrometer) was used for measuring the stars on the glass plate negatives. In this section, I examine the development of the measuring machines used for the AC in Australia. The determination of which machine was used and how well it was maintained and checked for error were critical to the Astrographic Catalogue's accuracy. Prior to the AC-CdC, star plate micrometers existed, but my research has shown that the AC-CdC spurred on the development of more efficient, accurate and affordable machines.

The micrometer was a critical piece of equipment which, with the observer's skill, determined the accuracy of the catalogue readings, the pace at which work was done and the well-being of the user. There is little investigative research about micrometers beyond the papers published by the inventors and a small number of users during the initial phases of the catalogue (Turner 1895, pp. 102–119; Gill 1898, pp. 61–75; Hinks 1901, pp. 444–458; Russell 1902, pp. 39–40C). Yet they are very important participants in the AC as, according to Latourian theory, these instruments are 'actants' in the process, with influence and agency over the users as well as the results. Furthermore, Schaffer has advised that "much is to be gained from historical study of instruments' breakages, defects and recuperation" (201, p. 706), and it appears that the micrometers were recalcitrant instruments, requiring continual recalibration and with varied measures for error, and that their use was very close physically to the person using them, as is made obvious by the wear on these instruments.

My research has connected an early micrometer (designed in 1870 by pioneering astrophotographer Lewis Rutherfurd in America) to a progression in the design of more ergonomic, affordable and fit-for-purpose micrometers, due to the AC. Deborah Jean Warner, Curator for the National Museum of History and Technology Smithsonian Institution, examined Rutherfurd's measuring instruments (Warner 1971, p. 199). According to Warner, Rutherfurd was dissatisfied with the wear on the screw mechanisms and this led him to design a superior machine which had a graduated scale measurement built into the mechanism. Nonetheless, this machine appears to have influenced the design and functionality of star measuring devices, as shown in Figure 43.

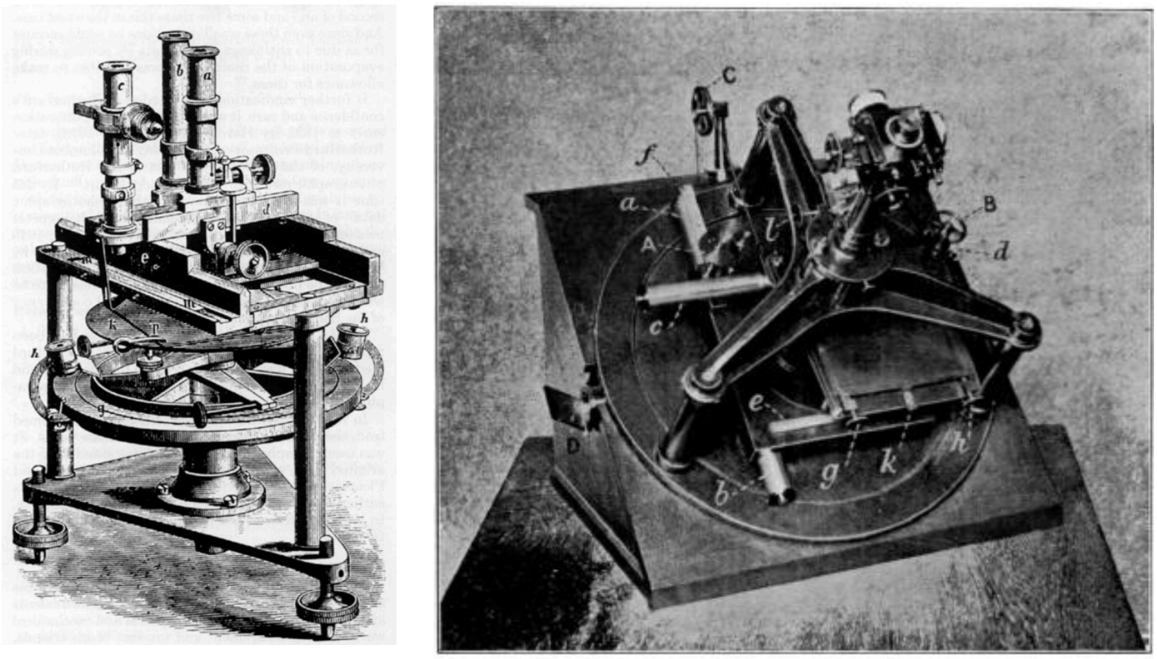


Figure 43: (L) Micrometer for plate measurement by Rutherfurd (*American Cyclopaedia* 1875); (R) Repsold micrometer designed by Gill (Gill 1898, plate 2).

Rutherfurd's design and method was analysed by Florence Ellen Harpham, Chief Computer and Astronomer at Columbia University (Creese 1998, p. 235). Harpham explained the operation of the machine and credited Rutherfurd's method, which positioned a known star in the centre of the plate to enable measurement, as the method that became standard. According to Harpham, Rutherfurd's micrometer influenced the design by German instrument makers Repsold; and was further adapted for the micrometer by Gill with the resulting Repsold/Gill design used extensively for the AC (Harpham 1900, pp. 129–126).

In Britain, Charles Pritchard, who held the prestigious position of Savilian Professor of Astronomy at Oxford University and established Oxford University Observatory (Hutchins 2008, pp. 42–49), developed a star plate micrometer machine in the 1880s which was constructed by Troughton and Sims. My observations of this machine, as shown in Figure 44 (collection number 68261) at the Museum of the History of Science, Oxford, concluded that it was based on Rutherfurd's design but that it offered an ergonometric advantage due to the tilt of the eyepiece. Rutherfurd's principle of moving the plate and keeping the eyepiece stationary, plus Pritchard's angled design were further simplified by Gill to decrease the costs of manufacture and increase the accuracy by eliminating the number of moving parts. Another improvement was the use of natural light from a window, which was reflected by a mirror onto the back of the glass plate (Gill 1898, p. 71).

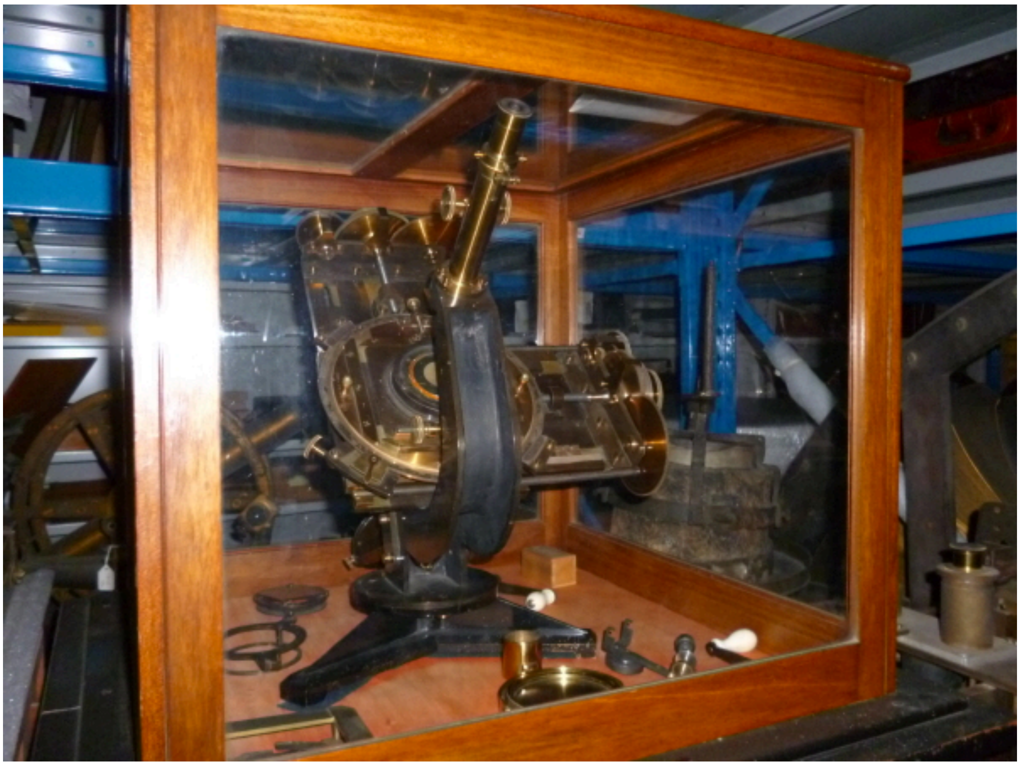


Figure 44: Pritchard designed measuring machine used at Oxford University Observatory (Collection Museum of the History of Science, Oxford 68261). Photograph T. Stevenson 2011.

In Australia, the AC-CdC was measured by different types of measuring machines. The machines used for the Melbourne and Sydney zones of the AC-CdC were the 'Slide', the 'Comb', the 'Repsold I', the 'Repsold II', the Turner/Hinks type machines which were called 'Sydney A' and 'Sydney B', and the 'Hilger'. Each micrometer had its technological error calculated and this is noted in the Astrographic Catalogue on the page for each plate measured. At various times the associated human error was checked and measured. In this section, the evolution of the measuring machine, which was accelerated at the end of the nineteenth century because of the AC project, is mapped. My research focussed on the micrometers designed for and used at the Australian participating observatories; there has been no previous research with that focus, or using the primary sources that I have accessed.

Gautier designed the micrometers used by Paris Observatory for the AC. These instruments were documented in Klumpke's report about the Paris Measuring Bureau in 1895, as shown in Figure 45. In this image, constructed to reveal the measurement method to the viewer, you can see two women: one observing, the other noting the measurements. They are seated near a window with the drapes pulled back for light to glow behind the plate. The instrument is on a sturdy base. These were very similar to the Pritchard design. The non-British observatories adopted the Gautier micrometer, manufactured in Paris.

LES CATALOGUES STELLAIRES

La construction des catalogues stellaires, c'est-à-dire des volumes où sont

Fig. 80. — Le Bureau des mesures des clichés à l'Observatoire de Paris.

Figure 45: The astrographic bureau at Paris Observatory (Klumpke 1895).

It was critical that an efficient and accurate machine be used for the AC and Turner resolved the three main criteria for the design of micrometer machines thus:

> "(1) Rapidity, the turning of a micrometer screw being avoided, (2) An accuracy which is found to be sufficient while avoiding too many decimal places, which would add seriously to the work. (3) Convenience to the observer, it being no longer necessary to withdraw the eye from the microscope to read the screw-a tiring operation."
>
> (Turner 1895, p. 103)

Of these practical considerations, the most important was ‘a glass scale in the eyepiece’, as had been earlier determined by Rutherfurd, and was specified for the AC-CdC by Turner, Christie and Simms (of Troughton and Simms) (1895 MNRAS Vol. 55, p. 102). This meant that the work could be done quickly, without the need to turn screws for alignment, provided enough (but not too few) decimal places were on the scale. Turner, who worked closely with Troughton and Simms, later designed what became the standard scale. Furthermore, the ergonomics were important for efficiency, and Turner made a point that the operation should be “convenient for the observer”.

In 1897, the measuring machine designed by David Gill reached the Cape Observatory (Gill 1913, p.cliii). Gill was completely satisfied with the machine, which was manufactured in Hamburg by Repsold and Sohne, and a second one was ordered. It arrived at the Cape in 1897 and he presented an illustrated description to the Monthly Notices of the Royal Astronomical Society (1889, Vol. 59, pp. 61–72).

Once the decision had been made that there would be no centralised Measuring Bureau, there was a focus by the Australian observatories on the available micrometer designs and the costs:

> “I have just heard that my minister has approved our proposal for measuring the astrographic plates, and that the money for the purpose has been duly placed in the estimates; but I can take no action until Mr. Turner has given his consent. I have just received a letter from Dr. Gill in which he urges us to adopt an instrument devised by him for measuring the plates. It consists principally of a complicated micrometer with two systems of three sets of quadruple wires or, on all accounts, a great number of wires fixed and moveable: The instrument is made by Repsold at a cost of £180.”
> (Baracchi to Russell, 16 May 1898, NSWSR, Box 159).

To which Russell replied:

> “I should like to see Gill’s machine. Generally I have not found his mechanical designs first class like his other work and £180 is a large sum from our point of view.”
> (Russell to Baracchi, 20 May 1898, NSWSR, Letter book).

Figure 46: Melbourne Observatory star measurer using the ‘Repsold’ micrometer (Collection Museum Victoria).

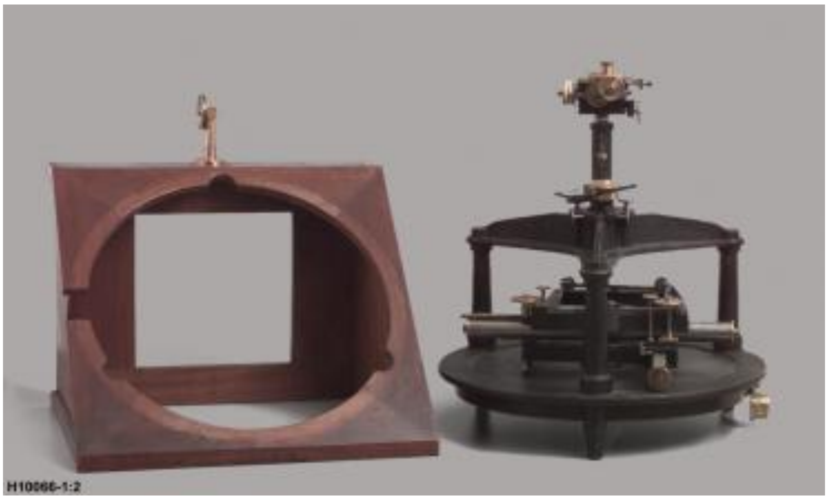


Figure 47: Micrometer designed by David Gill, maker Repsold and Sohne, Hamburg Germany (Collection MAAS H10066).

The micrometers were vital to the completion of the catalogue; their efficiency impacted directly on the time taken to complete the AC. The micrometer recommended for use by the British observatories was Gill's design manufactured by Repsold as shown in Figure 47. This was purchased by Baracchi for Melbourne Observatory at a cost of £180 (Baracchi to Russell, 1898). The micrometer arrived in 1900 and is shown in use at Melbourne Observatory by one of the first star measurers in Figure 46.

When meeting with Baracchi Russell got to use the micrometer and he was impressed:

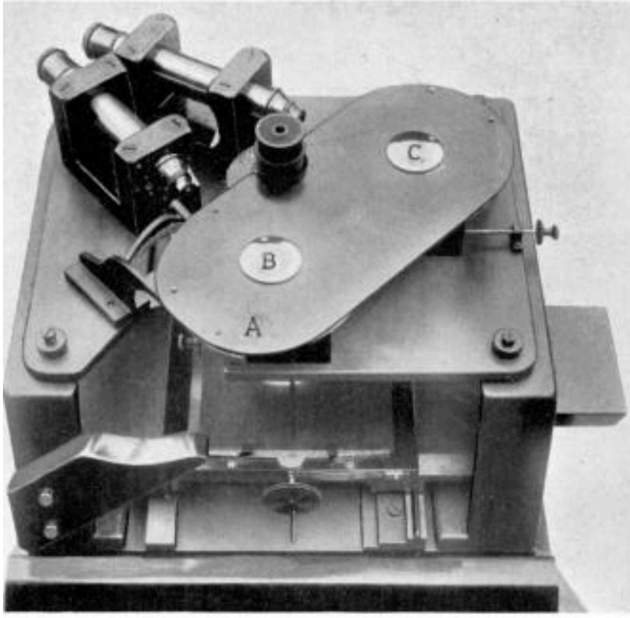
> "When working with the beautiful Star-measurer designed by Sir David Gill, I noticed the accuracy of the work, and its convenience for the purpose; but I was struck with the time taken to move the micrometer spider lines across a réseau square …"
> (Russell 1902, p. 39).

Baracchi reported that Repsold I worked well and on average 170 stars could be measured in an hour. When Russell visited Melbourne Observatory to discuss the progress made in measuring the plates, he was impressed with the accuracy of the machine, but not the pace at which it could be used to measure stars. Baracchi ordered a second machine, Repsold II, which arrived late 1902 (Baracchi 1903, p. 244). As previously quoted, Russell found the cost of purchasing the Repsold machine exorbitant and he pursued his own ideas and designs.

New evidence about the micrometers, including the discussion between Russell and Baracchi where Russell revealed that he had invented a unique design for a measuring device, emerged when I researched the letterbooks at SRNSW (letter Russell to Baracchi, 8 Mar 1902, A3003/Box 37A, R21, pp. 618–619) . Russell designed a micrometer (as seen in Figure 48) which he considered superior in cost, effectiveness, accuracy and the comfort of the measurer. He published its design at the time (Russell 1902, p. 39).

Russell's micrometer was manufactured in the Sydney Observatory instrument workshops and completed in 1903. Russell considered his machine to be superior to the Repsold type, which had been designed by Gill, particularly because the observer could also record the results and did not need a partner to record the measurements. Russell wrote to Baracchi:

> "But to refer to the Starplate micrometer I have only to get some photographs and it is ready to go. It stands on a cedar base 16 5/8 inch x 12 in and height of 26 ½ inches. And will be rather large compared with those you have and I hope soon to hand it over to you."
> (letter Russell to Baracchi, 8 Mar 1902, SRNSW pp. 618–619).



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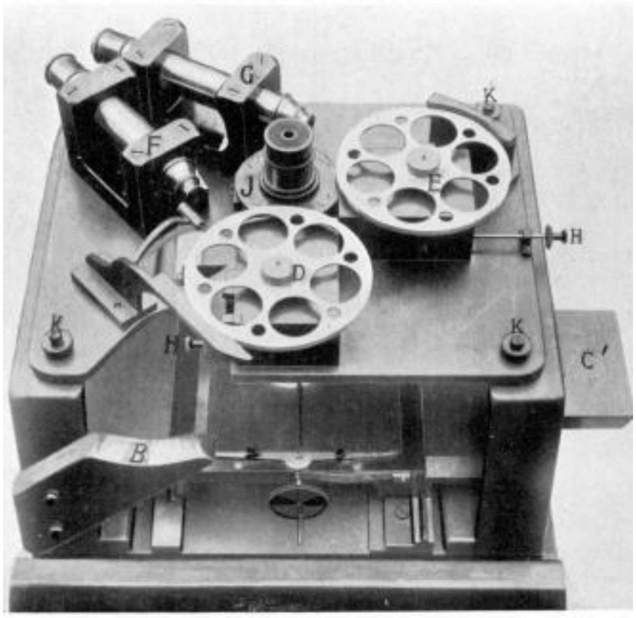


Figure 48: Design for a new micrometer by Russell (1902, pp. 39–40, Plate 4)

According to Russell, his design would be perfected when, at a later date, a small typewriter was installed as a recording device on which the measurer could touch-type whilst observing. Russell's design was dustproof and provided a more stable temperature for the plates. The device used the balance spring of a watch instead of screws, providing what may have been a smoother movement for the spider-web threads across the plate. My research has shown that Russell's micrometer was completed and delivered to Melbourne Observatory (Baracchi & Russell 1904, pp. 337–338). From the measuring records and Turner's analysis of the magnitude errors (Turner 1926, p. 64), Baracchi only used Russell's measuring machine for training the measurers and not for actual AC work. It is not clear why this was the case.

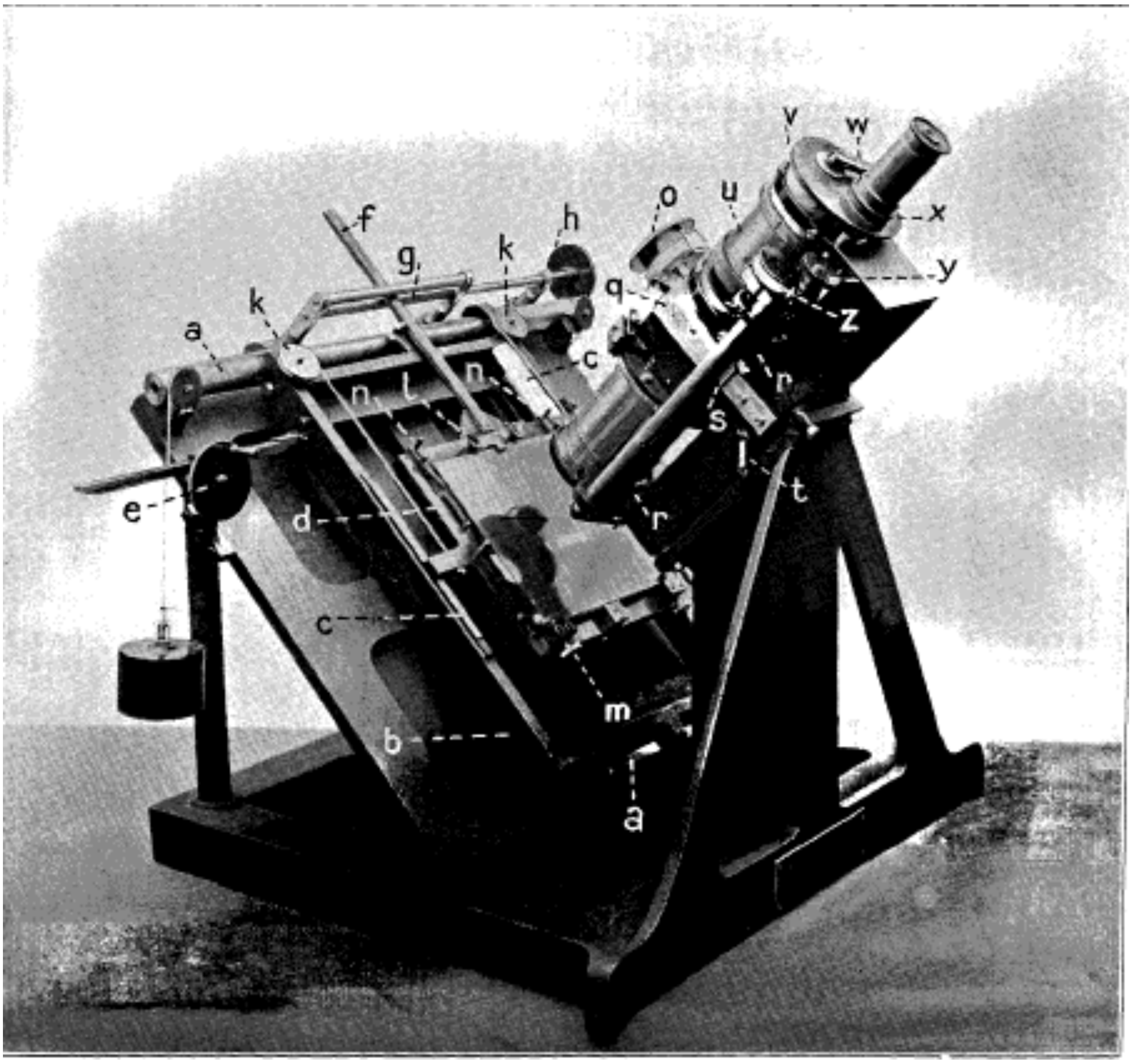


Figure 49: Micrometer designed by Hinks at Cambridge University Observatory (Hinks 1901, plate 12).

Each star measuring machine was regularly tested and checked for errors. The measurement wires had to be routinely checked and adjusted and attention was paid to the accuracy of the micrometer machines. At Melbourne Observatory, Charlotte Emily Fforde Peel undertook this work. There are logbooks from 1903 where Peel tested the Repsold machine, making comparisons between it and the other machines from 1900 to 1904 (SRNSW, Box 27). In 1911, the Repsold II micrometer, in use since 1898, was rejected for further use due to inaccuracies (SRNSW 1911, Box 7).

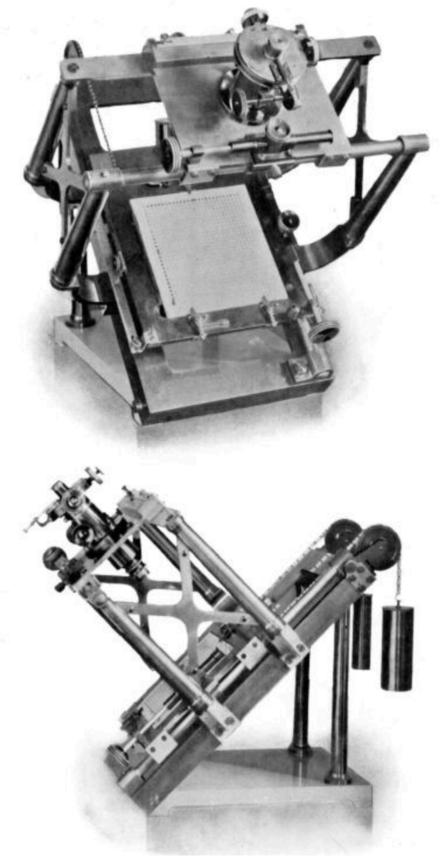


Figure 50: 'Greenwich Micrometer' design by Christie. Hinks and Turner (Christie 1904, plate 15, p. 626A).

In 1901 Cambridge Observatory Astronomer, Arthur Robert Hinks, developed a new micrometer. This machine, which used Turner's measuring scale, complied with the AC regulations. According to Hinks, this ended up being the preferred machine as it was an improvement in accuracy on the Gill and Repsold devices, and provided ease of use and ergonomics for the user (Hinks 1901). This new machine became the standard. Greenwich Observatory ordered one and then Christie made several improvements (Christie 1904, pp. 626-67) which are evident in the comparison between Figure 49 and Figure 50. These improvements, which reduced the cost and better supported and stabilised the eyepiece, were included in the machines ordered by Perth and Sydney Observatories.

Cooke ordered a 'Greenwich micrometer' for Perth Observatory, which arrived in 1906 and is shown in Figure 51. This machine was referred to as the 'Simms' by the Perth Measuring Bureau, as described by Astrographic Assistant Prudence Valentine Williams (letter Williams to Curlewis 26 May 1913, SRWA WAA 1005, 1916/2603), because it was manufactured by the company Troughton and Simms. This was engraved on the eyepiece.

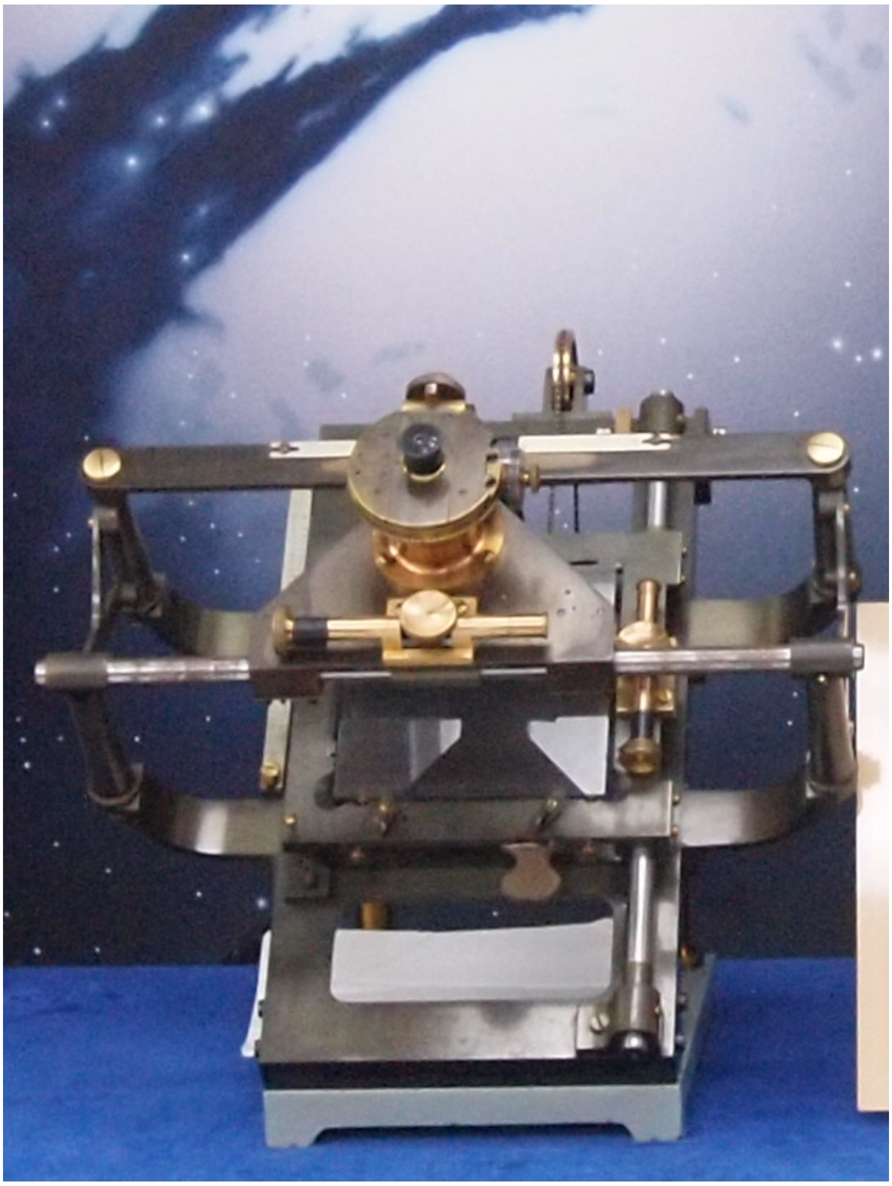


Figure 51: The 'Greenwich' micrometer ordered for Perth Observatory from Troughton and Simms in 1906 (Collection Perth Observatory). Photograph T. Stevenson 2011.

In 1915 Cooke established an AC Measuring Bureau at Sydney Observatory. A 'Greenwich' micrometer with modifications made by Christie was ordered in 1914 for delivery the following year (Cooke 1914, 1915). It took over eighteen months to arrive and cost £50, considerably less than the Repsold device. This was called 'Sydney A' and is shown in Figure 52.

A second machine of similar design was ordered in 1919 named 'Sydney B' (as shown in Figure 53). Royal Observatory Edinburgh had two micrometers of the Hinks & Turner design, as seen being used by the star measurers in Figure 74 of Chapter Four.

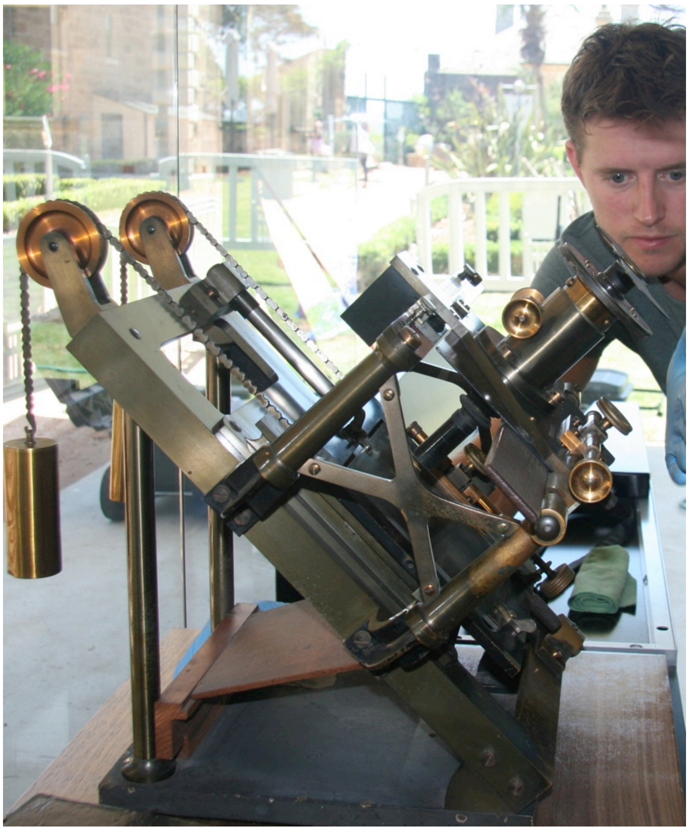


Figure 52: ‘Sydney A’ MAAS Collection. Photograph T. Stevenson 2015.

Figure 53: ‘Sydney B’ in the MAAS Conservation Laboratory. Photograph T. Stevenson 2010.

When Wood undertook the completion of the Sydney and Melbourne zones of the AC, he ordered a new measuring machine from the well-known instrument makers, Hilger and Watts (as pictured in Figure 54). This was quoted at the considerable sum of £1,500, which he accepted (SRNSW 48/478, 48/367). The Hilger machine had considerable advantage over the Turner micrometers. It had an inbuilt light to illuminate the glass plate, increased accuracy in moving the threads and a decrease in the time taken to measure each star (Wood 1971).

Figure 54: Winsome Bellamy and the Hilger machine. Photograph ~1954 (Collection MAAS).

After measurement was completed for the AC-CdC, Wood ordered a new measuring machine from Grubb Parsons for measuring a new star catalogue. This machine was far more technological in its output, but still relied on the expertise of the female measurer. This machine was housed in the annexe building where the other measurements took place. According to Chris de Vegt, designer of micrometers for contemporary astrometry and photometry, the mechanisation of measuring stars using scanners was only implemented after the completion of the AC, with practical use from the 1980s (de Vegt 1988, p. 216).

The micrometer instrument was essential to the AC, and the errors that occurred within a single machine, between machines and between measurers were a constant source of concern. This was because the machines were intended to minimise, even though they could not remove, personal error. What was required was that the error was able to be calculated and the machine calibrated to perform with the same error constantly or within a reasonable range of fluctuation. Even though principal instrument makers with considerable reputations—such as Repsold, Troughton and Simms, and Hilger and Watts—were chosen to supply the instruments, they partnered with the astronomers in their design and production (Schaffer 2011, p. 711). The history of the development of the micrometer, its limitations and the challenges faced by the users assist a deeper understanding of social behaviours in the workplace, such as the regular rotation of the user. Knowledge about the micrometer errors was essential and the charts which document this informed the contemporary digitisation and application of the AC (described in Chapter Five). The AC error management included correction calculations for the variation in magnitude according to the machine being used, as shown in Figure 57.

Measurement, error and a standard measure for magnitude

It was not only the determination of error, but the speed of measurement (using different micrometers and by different measurers) as well as the accuracy of magnitude determination which were of major concern to the astronomers. When Melbourne Observatory undertook to measure the Sydney and Melbourne zones, Baracchi requested detailed information from the Astronomer Royal, William Christie (letter Baracchi to Christie 12 March 1898, CUL RGO 7/161). The process required each star on each photographic plate to be measured twice, once on the front face, then again on the reverse by a different measurer. Furthermore, the overlaps with other plates were compared. Baracchi relayed this method to Russell in Sydney:

> "One half of a plate is measured in connection with half of another, then the other half is done at different times in connection with other different plates, then the whole of the measurements must be done again in reversed positions of the plate, then each plate has to go through another machine to ascertain the straightness of the lines, orientation etc.… This makes five handlings of the negatives."
> (Baracchi to Russell, 28 Oct 1898 PROV, pp. 76–77)

The measurement was recorded as 'X' and 'Y' co-ordinates and then co-ordinate measurements were compared between measurers to eliminate the 'human' factor. On each plate the sides overlapped other plates, meaning that each star could be measured three or four times. A senior observer, who was often the most senior female star measurer and computer, compared the work of each measurer for error. At Paris Observatory, the senior star measurer and computer was Dorothea Klumpke; my research has shown that at Melbourne Observatory, Charlotte Peel fulfilled a similar role to Klumpke, except she did not publish, nor did she give presentations. The number of stars each woman measured each day was recorded to compare speed against accuracy. It is likely, though not proven, that poor performance had consequences. For example, in 1910 N. E. McKay left Melbourne Observatory not long after her work was reported unfavourably against H. M. Browne's (SRNSW 1910, Box 7).

The attention paid to resolving a standard for photographed stellar magnitudes (the brightness of the star) was, according to photometry expert and astronomer John Hearnshaw, one of the few worthwhile outcomes of the AC-CdC (1996, p. 142). The determination of magnitude had been fraught by variation in the method, which dated back centuries. Weaver described its importance:

> "Stellar magnitude, or in a broad sense stellar brightness, is a caliper with which to measure stellar distances, a thermometer with which to measure stellar temperatures, a probe with which to examine stellar interiors and atmospheres."
> (Weaver 1946, p. 211)

The AC created a need for new standard technologies and methods to judge the magnitude of each star. The decision to measure the image diameter to determine its magnitude required conversion formulae which took into account the exposure time of the plate. Hearnshaw has described the various methods in detail and concludes that one of the weaknesses of the AC was the decision that each observatory would determine its own magnitude measurement method. The Australian observatories adopted the method advised by Christie and used a scale provided by Turner at Oxford University Observatory. The ultimate aim was a catalogue in which the magnitudes could be easily compared to other catalogues in order to, for example, understand the distribution of magnitudes in a particular zone of the sky (Sampson 1917). The magnitudes were expressed in letters A through M in descending order of brightness, M being barely visible. The magnitude scale is shown in Appendix 11: Perth zone AC Magnitude Scale. There was also a formula to allow for the deterioration of image quality from the centre to the edges of the image on the glass plate negatives. Furthermore, each star's magnitude was measured twice:

> "It is therefore hoped that by the adoption of this method the relative values are truly measured, without personality depending either upon the observer or the plate."
> (Cooke 1912, p. 8).

According to Sampson, Cooke had developed more accurate magnitude values for the letters than Turner when compared to the Cape Photographic Catalogue (hereafter CPD), which only went down to magnitude 10 (Sampson 1917, p. 614). Once the position of the star and its magnitude were established, the plate could be put away and the equatorial position of the star computed. The methods employed by the women measuring the AC plates, which my research has revealed, included using small stars on a clear acetate-type film which was inserted into the micrometer. An example of these films was found in a box which was from either Sydney or Melbourne Observatory (as seen in Figure 55).

Figure 55: Box of magnitude scales for comparative use (Collection MAAS uncatalogued). Photograph T. Stevenson

Apart from variation in how magnitude was registered, there was also variation in the micrometer scales which required error correction. This is made evident in Table 14 of the explanation of the Sydney zone Astrographic Catalogue, which is shown in Figure 56 (Wood 1971, p. 30). This table provides the magnitude correction for each micrometer, which changes depending on the position of the star on the plate. Machine 'Sydney A' had no errors and the 'Machine Slide', which was one of the original machines used from 1898 at Melbourne Observatory, had the greatest error correction requirement. For all six types of machines, the star magnitudes when read in the centre of the plate (réseaux lines 9 to 23) had minimal error.

Each measurer made a logbook of their plate measures and magnitudes. Nick Lomb listed the logbooks, which had been generated for the Melbourne and Sydney zones, when these were distributed to Macquarie University and SRNSW. All of the Perth Observatory logbooks are at Perth Observatory, Bickley; the Adelaide Observatory zone and pole star logbooks are at SRSA.

TABLE 14

Magnitude Correction According to Position on Plate

MACHINE SYDNEY A

Y/X	1–5	5–9	9–19	19–23	23–27
30–34	0·0	0·0	0·0	0·0	0·0
34–38	0·0	0·0	0·0	0·0	0·0
38–48	0·0	0·0	0·0	0·0	0·0
48–52	0·0	0·0	0·0	0·0	0·0
52–56	0·0	0·0	0·0	0·0	0·0

MACHINE SYDNEY B

Y/X	1–5	5–9	9–19	19–23	23–27
30–34	+0·2	+0·1	0·0	+0·1	+0·2
34–38	+0·1	0·0	−0·1	0·0	+0·1
38–48	0·0	−0·1	−0·2	−0·1	0·0
48–52	+0·1	0·0	−0·1	0·0	+0·1
52–56	+0·2	+0·1	0·0	+0·1	+0·2

MACHINE REPSOLD I

Y/X	1–5	5–9	9–19	19–23	23–27
30–34	−0·2	−0·1	0·0	−0·1	−0·2
34–38	−0·1	+0·1	0·0	+0·1	−0·1
38–48	0·0	0·0	0·0	0·0	0·0
48–52	−0·1	+0·1	0·0	+0·1	−0·1
52–56	−0·2	−0·1	0·0	−0·1	−0·2

MACHINE REPSOLD II

Y/X	1–5	5–9	9–19	19–23	23–27
30–34	−0·3	−0·1	0·0	−0·1	−0·3
34–38	−0·1	0·0	+0·1	0·0	−0·1
38–48	0·0	+0·1	0·0	+0·1	0·0
48–52	−0·1	0·0	+0·1	0·0	−0·1
52–56	−0·3	−0·1	0·0	−0·1	−0·3

MACHINE SLIDE

Y/X	1–5	5–9	9–19	19–23	23–27
30–34	−0·4	−0·2	−0·1	−0·2	−0·4
34–38	−0·2	+0·1	+0·1	+0·1	−0·2
38–48	−0·1	+0·1	+0·2	+0·1	−0·1
48–52	−0·2	+0·1	+0·1	+0·1	−0·2
53–56	−0·4	−0·2	−0·1	−0·2	−0·4

MACHINE COMB

Y/X	1–5	5–9	9–19	19–23	23–27
30–34	+0·4	+0·1	+0·1	+0·1	+0·4
34–38	+0·1	0·0	−0·1	0·0	+0·1
38–48	+0·1	−0·1	−0·2	−0·1	+0·1
48–52	+0·1	0·0	−0·1	0·0	+0·1
52–56	+0·4	+0·1	+0·1	+0·1	+0·4

Figure 56: Astrographic Catalogue star magnitude correction according to position in plate (Wood, 1971 p. 30).

METHODS OF REDUCTION

The calculations, called reductions, were applied to the raw x-y axis measurement for each plate, to adjust for the errors of the measuring machine. Furthermore, it was necessary to calculate the plate constants for every plate from the reference stars. This was so that in the future the x and y co-ordinates could be reduced to RA and Dec. Another calculation was applied to reduce the data to a common epoch. This enabled each star to be positioned in relationship to other stars on other plates and in other zones. The procedure required the ability to apply pre-determined mathematical formulas. Prior to the invention of calculators and computers, this work required mental agility and the rigorous use of tables. Turner devoted much effort into standardising the reduction formulas for the AC; he stated that it was “the first importance that useless labour be avoided.” His explanation as to why rectangular co-ordinates were decided upon, due to the simplicity of the equations and less error, is clearly expressed as follows:

> “Bring up the places of the few thousand known stars to 1900.00, and then convert them into rectangular coordinates … for this is bound to be a most important epoch. Tables which can easily be constructed for each zone will facilitate the expression in ideal or standard rectangular coordinates … the alternative process is to laboriously reduce all the measures on all the plates to spherical coordinates by formulae which differ slightly in every case.”
>
> (Turner 1894, p. 142)

In 1895, Turner produced a more detailed paper in which he further emphasised that reduction to RA and Dec “entails a very large waste of labour”. He referred to his discussions with Dyson and Christie to emphasise his authority on this matter (Turner 1895, MNRAS Vol. 55, p. 102). This was not the end of the discourse between astronomers on the reduction of the x and y co-ordinates. For example, in 1896 Astronomy Professor at Columbia University, Harold Jacoby, on the request of Gill, brought together the work of several astronomers and published an explanation of stellar reduction, why it was necessary and what was peculiar to the AC plates (Jacoby 1896, pp. 101–123). It was not simple, nor was Jacoby’s paper the final piece of negotiation on this matter. The following year, Dunsink Observatory Astronomer, Arthur Albert Rambaut, praised Turner’s decision to use rectangular co-ordinates as the standard measure for the AC (Rambaut 1897, p. 591), but questioned his mathematics. Turner’s decision to confine the measurements to rectangular measures was the most expedient one at the time, but not, according to Hughes, a good decision to promote use of the catalogue (Hughes 2013, p. 1042).

The Sydney, Melbourne and Perth zones were recorded and reduced to rectangular measurements, namely the x and y co-ordinates. This was required from the beginning of the project (Turner 1894, pp. 141–142), but the user then had to perform complex logarithmic calculations to convert to equatorial co-ordinates of RA and Dec, which are the minutes and seconds of an arc. According to Hughes, only a few observatories, including Greenwich and Paris, published their catalogues in both rectangular and equatorial co-ordinates; the lack of equatorial co-ordinates was one of the reasons that the catalogue was not extensively used (Hughes 2013).

According to Latour, numbers (used in tables and with mathematical formula solutions to reduce error and provide other solutions to inaccuracies) have the power to make an approximate look like an absolute. Furthermore, they are able to be easily controlled at a distance and distributed within a cycle of accumulation (1987, pp. 227–228). Mathematical reductions accounted for micrometer error management and the position of the star on the plate. These were the end results of the AC, printed in quantity and formatted in specific ways to make them of use to astronomers around the world.

In Australia the observatories used methods to reduce the time spent on calculations by devising charts and purchased calculating machines as the technology developed. Melbourne Observatory obtained a machine called 'The Millionaire' between 1905 and 1915. This machine was fast and could be set to do repeat calculations with a crank handle (Croarken 1990, p. 15). It was possibly used for the AC, but there is no immediate evidence of this except that it was transferred to Sydney Observatory with the astrographic materials and is now in the MAAS collection (Registration number K969). Further research in this area is required to match calculators in museum collections with the AC.

ASTROGRAPHIC PRINTING

The promise of the AC-CdC was that the new catalogue and the printed charts would be used as a basis for extensive future research. This was not to be the case during the twentieth century due to the delays in communicating the findings, publishing the catalogue and printing the chart plates. The lack of available, reasonably priced technological processes to print the CdC plates caused frustration, as seen through Baracchi's attempts to find a local solution. In the early twentieth century, there were high risks in transporting glass plate negatives by sea and land.

In 1901, Baracchi told Russell of a scheme he had devised for contact printing the CdC plates onto glass, so that he could keep a duplicate set of CdC plates in Melbourne and send the originals to Paris for printing in large format through a photogravure method (letter Baracchi to Russell, 29 June 1901b, PROV). Baracchi's sketch in Figure 57 and his question to Russell about whether he should varnish the plates demonstrate that the astronomers were inventing the techniques at each stage of the process.

Baracchi acknowledged that his methods were "too rough and unscientific", with consistency of light one of the most difficult problems to overcome. His letter also confirms that the 560 plates for the Melbourne zones of the CdC, with one-hour exposure, were completed. Their correspondence reveals that over a decade had passed and there were many unresolved aspects of the AC-CdC. Apart from the risk in transporting the CdC plates, there was also no option to print locally because the photogravure method, which had been devised by the Permanent Committee, was not available at the scale required in Australia. However for the Astrographic Catalogues local printing was available.

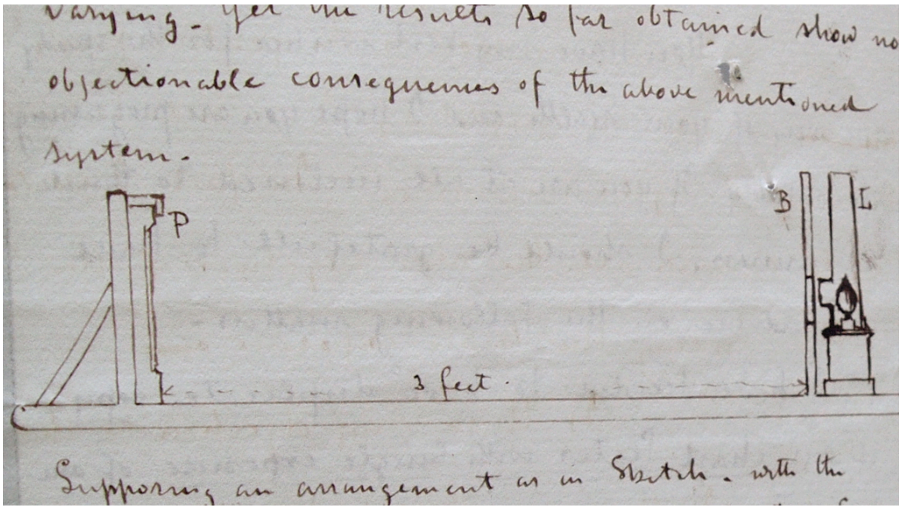


Figure 57: Baracchi's diagram of a method for contact printing the CdC plates; P = printing frame; B = perforated screen, L= light from a flame (Collection PROV).

The AC volumes were not published in order, but rather reflected the completion of the measurement and calculated reduction of a zone. In 1911 the first volume of the AC was published in Australia. This was Catalogue IV of the Perth Zone -31° (Cooke 1911). The last three of the Perth zone's thirty-six volumes for the AC, whilst completed at Royal Observatory Edinburgh and made ready for printing in 1930 (Sampson 1931, p. 341), but they were not printed until 1949 and 1952 (Greaves 1950, p. 140; 1953, p. 314). The eight volumes of the Melbourne zone were printed between 1926 and 1963. An introduction to the

Melbourne Zone was written by Baldwin and published in 1926 in Volume 1. The Sydney zone was completed in 1964 under Wood, and a full description of Sydney Observatory's work was written by Wood in Volume 53 and published later in 1971. This volume details the names of most of the people who worked on the Melbourne and Sydney zones, although not all are listed.

The main issue with the printing was the cost. The final volumes of the Perth zone, which were measured and compiled by ROE, and the Melbourne zone, compiled by Sydney Observatory were funded by the IAU due to the lack of state government commitment.

CHAPTER CONCLUSION: INGENUITY, NEW TECHNOLOGIES & NETWORKS.

In this chapter, I have examined many of the technologies that were developed and invented for the AC-CdC. The most visible technology was the telescope (and the building surrounding it); but the less visible technological actors in the AC-CdC (such as the micrometers and methods of printing) were highly influential on the accuracy, the progress of the projects, and the communication of findings.

Latour and Callon's theoretical model, 'moments of translation', demonstrated that scientific projects only become realised once influential people support them. Latour argued that even the most groundbreaking work is ignored unless others take up your paper or your work in an active way (Callon 1986, pp. 196–200; Latour 1987, p. 104). I have demonstrated that in the late nineteenth century Russell and Ellery were influential people. Furthermore the Australian astronomers were able to gain approval for resources through their allegiances to the Astronomer Royal and they harnessed their own ingenuity to solve problems that existed due to a lack of technological advancement. When the colonial and centralised networks were not responsive, the local network, and collaboration between the lead astronomers, helped solve technological problems and, as demonstrated in the next chapter, helped resolve resourcing the measurement of the stars. My research has found new evidence about how the AC-CdC accelerated the development and availability of new technologies, such as the star plate micrometer. These technologies were all designed to ensure the AC was, as described by Latour, "immutable and combinable mobiles" (1987, p. 227), meaning that the AC contributed to the number of star charts and catalogues which were able to be distributed globally without alteration, and it distilled stars down to numbers which described their magnitude and relative locations. However, whilst numbers are convincing, their existence in tables and mathematical formula to manage errors did not guarantee absolute accuracy.

According to Latour, for a scientific work to be successful it must also be referenced extensively, thereby becoming the foundation for many other works and hence embedded into its field. Based on this model, one of the reasons that the AC and CdC did not become the primary reference sources they were envisaged to be was due to the longevity of the project, the lack of local technology at many of the observatories, and financial constraints. The AC-CdC has become more popular in recent decades due to new technologies and projects, which benefit from an epoch 1900 star catalogue which is examined further in this thesis.

I have introduced women in this chapter as part of the technology applied to the AC-CdC. In the following chapter, I reveal the enormous involvement that the women had in the AC-CdC and the unexpected agency they exercised.

CHAPTER 4: INVISIBLE SKIRTED LABOUR FORCE (1890 TO 1964)

Figure 58: (Front L to R) Margaret Colville, Renee Day, Jean Campbell; (Back L to R) Verlie Maurice, Patricia Lawler at Sydney Observatory. Photograph Winsome Bellamy, 1949.

In this chapter I focus on the fourth stage of the Astrographic Catalogue (AC), namely the measurement of the glass plate negatives and reduction of co-ordinates. My research reveals new information about the women who worked on the AC in Australia, and the extent of their work. Whilst the seven women case studied have been researched in depth, I have sought to find out and use the names of many other women who also worked on the AC in Adelaide, Melbourne, Perth and Sydney Observatories. This has not always been straightforward, due to the hidden nature of the work the women performed.

The subject of women who worked on the AC was, as mentioned earlier, the subject of one of my earlier papers emanating from this research. In 'Making Visible the First Women in Astronomy in Australia: The Measurers and Computers Employed for the Astrographic Catalogue' I focussed on Greayer and Peel and presented evidence that they were vital to the completion of the AC and other astronomical work and had agency within their respective observatories (Stevenson 2014, pp. 1–10). In this chapter, I expand on my findings and discuss in greater depth the contribution made by Greayer, Peel and other women working at Sydney and Perth observatories through case study methodology.

Historiography of Women in Astronomy

"We think about the History of Astronomy as the History of men. A History of a few men: Ptolemy, Copernicus, Kepler, Newton… ", according to Spanish astrophysicist Mar Alvarez Alvarez and theoretical physicist Angeles Diaz. Their study of the history of astronomy indicated that women's work had an ebb and flow characteristic "… an on off affair, a history of sudden and dramatic cuttings and historical biases, sometimes real and sometimes promoted by historians who later ignored their works" (Alvarez & Diaz 1999). Furthermore, the Scientific Revolution brought on a new wave of participation for women as 'assistants' wife, daughter or sister. A very few outstanding women were acknowledged, whilst the majority, according to Alvarez and Beltran, were ignored. My research has found that in Australia, this majority included the women who worked as star measurers and computers on the AC.

There are many substantial texts which share Alvarez and Diaz's view that women have had intermittent roles in astronomy since ancient times (Schiebinger 1993, Lankford 1997; Hoskin 1984 &1995; Hughes 2012). Furthermore, there is a long history of academic research and writing about women in science, inclusive of astronomy, who have not been appropriately acknowledged within the authorised history (Klumpke 1899; Rossiter 1980 & 1983; Ogilvie 1986; Kass-Simon & Farnes 1990; Mack 1990b; Benjamin 1991; Brück 1994, 1995, 1998, 2009; Larsen 1995 & 2009; Schnell 1999; Kidwell 1999; Ogilvie & Meek 1996; Hooker 2004; Armstrong 2008, Rosser 2008).

In the historiography of astronomy, the women who worked on the AC have been called 'computers' (Bigg 2000, p. 96; Brück 1994, p. 282) but the titles given to the women employed in Australia were various. The pay scale was in the lowest clerical range but descriptions and titles included 'Temporary Astrographic Measuring Bureau' at Melbourne Observatory (Report to Board of Visitors 1905, p. 4), 'Plate Measurers' at Sydney Observatory (Report to Board of Visitors 1941, p. 1, SRNSW) and at Perth Observatory 'Star Plate Measurers' (Public Service List, *W.A. Government Gazette* 1916, p. 82), 'Astrograph Assistant' (Public Service List, *W.A. Government Gazette* 1912, p. 53); 'Junior Computer' (Public Service List *W.A. Government Gazette*, 1919, p. 105) and 'Assistant Computer'

(Public Service List *W.A. Government Gazette* 1923, p. 103). Charlotte Peel's title was both 'Assistant Astronomical Computer' and 'Astrographic Assistant' when she was appointed to a permanent position in 1900 (Public Service Gazette Victoria, No.122, 7 December 1900, p. 4478; Board of Visitors Report, 1900 p. 6). The position was titled 'Assistant Computer' when it was advertised for Peel's replacement (Public Service Gazette Victoria, 17 Sep 1919, p. 2086).

As was the normative procedure for the AC, many of the Australian star measurers are listed in the introduction and/or summative text from each observatory. Most volumes included a table which listed the plate number, the photographer and the measurer's initials. Volume 53 of the Sydney zone, written by Wood, included the names of most of the people who worked on the Melbourne and Sydney zones, although my research has uncovered that many more women worked on the AC than those listed. In order to provide a global perspective for my research into the lesser known women employed for the AC in Australia, I examined prior research into women's work on the AC. As previously stated, in Australia there has been some acknowledgement of the work of the women who measured the stars (Wood 1971; Bhathal 2001; Pickett & Lomb 2001; Clark 2012 unpublished). In 1997 the women who worked at Sydney Observatory were included in the By the Light of the Southern Stars exhibition (1997) and publications about the history of the site (pers comm Lomb, 2009; Lomb & Pickett 2002); an exhibition at Perth Observatory featured a measuring machine; and there was a small display mounted inside the astrographic house at Melbourne Observatory (pers comm Clark 2013).

The extent of the work and the individuality of the efforts of the women who measured the stars had not previously been investigated in detail; as there was nothing of a substantial nature written about the women in Australia who worked on the AC, I referred to research about women working in Britain and Europe, as well as related star catalogues in North America, to better understand the context of women's work in astronomy and its historiography. I found that the lack of acknowledgement of the female workers in stereotypical computing and star measurement roles had been recognised as gender prejudice by science historian, Pamela Mack, who researched women in astronomy in the US extensively (1990a). Mary Brück, astrophysicist with the University of Edinburgh, wrote a history of women in astronomy in Britain. She described the women who worked at British observatories on star catalogues as grossly underpaid 'slave-wage earners'. More recently, research into Paris and Toulouse Observatory by Bigg (2000), Aubin (2003) and Lamy (2009) described the women's work on the AC as a 'labour market' for scientific research.

Prior to the AC, the young men employed as 'computers' to do repetitive work at observatories had also been invisible in the scientific publications which relied on their work. There is evidence of these young men working at Sydney and Melbourne Observatories and, in some instances (eg. Russell), they progressed to positions as astronomers. This reflects the existence of a hierarchical structure in the observatory workplace prior to the AC-CdC, exactly what Airy had recommended to be an ideal management practice (Schaffer 2010, p. 131). The difference in the hierarchy established by the AC was that it was gender-specific. Due to this hierachy, clearly the men had career opportunities not available to the women who were doing the same work. According to Bigg, the introduction of females into the paid workforce was substantial and it created a 'social revolution' driven purely by economic and pragmatic motives (2000, p. 97). As I will describe through the case studies, the number of women employed at the observatories created a social dynamic which was not exclusive but rather centred around the women star measurers. In the next section, I examine how quantitative astronomy changed the structure of observatories and astronomy research.

Women and Quantitative Astronomy

At a meeting of the Royal Astronomical Society in 1903, Oxford University Observatory Director, Turner, explained why papers published in astronomy journals had become highly technical, and that this was to do with the application of photography to astronomy:

> "… Twenty years ago photographic work and spectroscopic work were largely in the qualitative stage with photographers seeing pictures for the first time and learning a great deal from a mere glance at them. Since then we have had to settle down and measure millions of star-images on photographs … and as a consequence our work has become quantitative."
>
> (Turner 1903, p. 239).

Turner's analysis was that once photography entered the realm of positional astronomy, it changed the way data was gathered, measured and shared in papers. He was implying that photography, the AC-CdC and spectral photography had impacted on every aspect of astronomy. There was no discussion about how the large quantities of data were to be processed, but by this time the focus of the AC-CdC turned from the photographic work to the accurate and consistent measurement of the stars on each plate. It is generally recognised that the measurement and computation was the major hurdle to finalising the data for each zone of the AC (Bigg 2000; Haynes et al 1996; Hearnshaw 1996; Lomb and Pickett 2002).

Prior to the new photographic method, astronomers had trained young male assistants, aged fifteen years or more, in logging data and performing calculations (Grier 2005, p. 50); and this model had been practised in Melbourne and Sydney Observatories where ‘pupils’ were employed for four years (Victorian Government Gazette 1888). The system of employing young men for astronomical computation was greatly reduced once the female AC measurers commenced work. Nonetheless, young men were still employed as computers in other areas, such as measuring magnetic curves, and there were women employed in meteorology (Baracchi 1900b, p. 4).

Even though Gill had advised that star measurement and reduction was most efficiently organised in a central bureau in Paris, each participating observatory was requested to make its own arrangements at the 1892 congress (Tisserand 1892). Melbourne and Sydney Observatories combined forces for the measurement and computational work. The astrographic bureau was established in 1898 under the direction of the Assistant Victorian Government Astronomer, Pietro Baracchi, at Melbourne Observatory. Measurement of the Perth plates was predominantly undertaken at Perth Observatory, instigated by the Western Australian Government Astronomer, William Ernest Cooke, from 1906. Cooke arranged with the Astronomer Royal, Scotland to pay the Royal Observatory, Edinburgh for measurement and the publication of about one third of the Perth plates. From 1915, Cooke also took the initiative to measure the Sydney zone plates at Sydney Observatory.

Due to participation in the AC, the ideal hierarchy of the colonial observatory in Australia transformed from a relatively flat structure into a pyramid with significant numbers of women as computers, calibrators and measurers on the bottom tier, medium-level astronomy assistants observing and photographing, and the lead astronomer at the top. The lead astronomer managed the data collection for transformation into publications and reports. According to Bigg, despite some initial mistrust in the science produced using this new modernist model, the pyramid structure became normative to other areas of science and business for many decades (Bigg 2000, p. 95).

Computing & measuring in Britain and Europe from 1890

In Europe, Britain and Australia, the AC workforce model imposed a new division of labour adopted by the participating observatories. This would be, as described in the 1889 Paris Observatory annual report:

> "… a great number of persons all doing the same work using identical measuring procedures, under a single authority."
> (Mouchez 1889, p. 9 quoted in Bigg 2000, p. 95).

According to Bigg, there were precedents for this model, and one such example was when French astronomer Anatole Bouquet de la Grye employed women at Paris Observatory to measure the transit of Venus photographs taken in 1874 (p. 95). Paris Observatory took the lead in establishing an astrographic bureau, or otherwise called 'Bureau des Mesures'. Dorothea Klumpke began her work at Paris Observatory in the late 1880s, when she translated presentations from the first meeting of the Astrographic Congress into French for the official record (Aitken 1942). In 1891 Klumpke was employed by Paris Observatory to establish and head its 'Bureau des Mesures', supervised by Prosper Henry (Klumpke 1895, p. 212). As described by Henry:

> "Dans l'exécution de ce travail, nous avons été heureux de rencontrer en M^{lle} D. Klumpke un collaboratrice savant et zélée, C'est sous sa surveillance que sont venues successivement coopérer aux mesures M^{lle} Dupuy, Bimm, Thomy, Duguen et Coniel. Nous avons la satisfaction de reconnaître ici tout le soin, la précision et l'assiduité que ces demoiselles apportent à leur tâche délicate."
> (Prosper Henry, Bulletin, 1895, p. 305)

> (Translation by author): In carrying out this work, we were pleased to meet with Miss D. Klumpke, a learned and zealous collaborator. It was under her supervision that the measurers Misses Dupuy, Bimm, Thomy, Duguen and Coniel were employed. We recognise with satisfaction the care, precision and diligence that these girls bring to their delicate task.

Measurement of the Paris AC zones began in 1892. As well as M^{lle} Dupuy, Bimm, Thomy, Duguen and Coniel, Klumpke also worked with M^{me} Schott and M^{lle} Marquette.

Klumpke wrote one of the first descriptions of a measuring Bureau and acknowledged the work of her staff, M^{me} Schott and M^{lle} Marquette (Klumpke 1895). Whilst Klumpke praised the work, she made it clear that it was under the direction of the lead astronomers, with the reductions directed by M^{r} Boinot (Klumpke 1895). Even though each observatory coordinated the star measurement of their zone; the participants aspired to the French ideal of regimentation as described by Klumpke:

> "Le travail des mesures, comme celui de l' exécution des clichés, doit être fait systématique ; aussi en 1889, le Comité Permanent du Congrès affirma-t-il l'utilité de creer un bureau central, ou un petit nombre de bureau chargés de la mesure des clichés du Catalogue."
> (1895, pp. 212–213).

(Translation by author): The measuring work, in the same way as the photographic work, must be systematic and factual. Furthermore, in 1889 the Permanent Committee of the Congress advocated creating a central office, or a small number of offices, responsible for measuring the Catalogue plates.

In 1894, Klumpke was conferred a doctorate from the Paris-Sorbonne University in mathematical sciences (*Publications of the Astronomical Society of the Pacific* 1894, vol.6, no.34, p. 54). Her thesis examined the rings of Saturn and was the first doctorate in astronomy awarded to a woman. In 1899, Klumpke presented a paper about women's work in astronomy to the International Congress of Women in London. She described the work of producing astronomical almanacs as 'astronomical labour' and, although tedious, this work was 'truly scientific' in its nature. According to Klumpke women have:

> "… qualities prerequisite for producing lasting results – concentration and enthusiasm, powerful levers that move worlds. Ours is a work of the night and day! ... astronomical science now becomes universal! She knows no boundaries, no rank, no sex, no age! ... "
>
> "… In photographic astronomy women in the national observatories of Paris, the Cape of Good Hope, Helsingfors, Toulouse, Potsdam, Greenwich, Oxford, have contributed to the International Photographic Chart of the heavens. Day by day, women bending over the micrometers examine the photographic skies and measure the star-positions to form the catalogue which is to be a legacy of our century to future generations."
> (Klumpke 1899).

The quote above indicates that Klumpke, who published over twenty papers and was respected as the first woman awarded a doctorate in astronomy, regarded the star measurement and computational work as astronomy. According to Bigg, most of the star measurers were trained as teachers and remained at a low status (2000, p. 97), but Klumpke had a superior education and was recognised as an astronomer. Klumpke made a career in astronomy due to her work on the AC. American star measurer, computer and astronomer, Robert Grant Aitken, described Klumpke as an ‘internationally known astronomer’ (1942).

Lamy has investigated the astrographic bureau at Toulouse Observatory, and the nature of the women’s work in what he called the ‘Bureau des Dames’ (2006). According to Lamy, women were employed because of economic imperatives, the global nature of the AC, and the changes in society which permitted women to work in professions such as astronomy. Their work was considered part of the mechanisation, in much the same way as the women who worked on the British zones of the AC were considered, and in contrast to some of the women employed in the US (2006, p. 103).

Mary Brück, astronomer and historian of astronomy at ROE, researched the participation of women in the AC at ROG. In 1890–1891, Christie employed four female Cambridge mathematics scholars, one of whom was Alice Everett, to observe, photograph, measure and calculate the ROG zone of the AC (Brück 1994, pp. 280–291 & 2009, p. 206). Brück’s research uncovered that even though Everett was a temporary employee, she undertook a program of photographing the stars by night and plate measurement by day at a salary of £30 per annum.

My research has shown that Everett published regularly between 1892 and 1900. Her papers included the changing magnitude of novae (1892), binary star measurements (1895), stellar orbits (1896), and a general paper about the total solar eclipse of 1893 in South America (1893). Everett acknowledged all the measurers and computers whose data was used in her research. When Everett joined the AC project at Potsdam Observatory in 1896 as the first woman to be employed in astronomy in Germany, she seemed to have established her career. In 1898 Everett was employed for a year at Vassar College in New York State, where she co-published a technical paper on the measurement of comets and minor planets with Mary Whitney (1899). It was at this point that Everett’s career in astronomy disintegrated until the First World War, when she was offered an opportunity to work in the physical sciences (Brück 2000, p. 212).

It appears that in Britain, even women with a high level of education and proven research abilities, such as Everett, had no long-term career opportunities in astronomy.

At Oxford University Observatory, Director Herbert Hall Turner employed Ethel Frances Butwell Bellamy as the astrographic computer and measurer from 1899. Hutchins' research has revealed that Bellamy became Turner's Second Assistant in 1912, and that her work on the AC was extensive, yet she is not mentioned at all by Turner in his book *The Great Star Map* (1912). Bellamy was also responsible for completing the Vatican zone computations (Hutchins 2008, p. 344) and publishing her variable star discoveries and her findings on magnitude limits (Bellamy 1920). Despite the enormous amount of work she did on the AC, Bellamy is not acknowledged in papers published by Turner and others, though the results of her work were used as the basis for their research. In contrast, Turner thanked Miss Riddle, who was a volunteer, for her work on the data for a research paper (Turner 1908, p. 398).

Everett and Klumpke had the agency to work on a broad range of observatory tasks, which included original work. This was due to the coincidence of a number of factors. For Everett, it was the ability for Astronomer Royal Christie to employ low-ranked and low-paid female staff to do research without going against civil service policy. For Klumpke, it was excellence in scholarship and many hours of unpaid labour in astronomy which led to her position at Paris Observatory and her research pursuits, which went well beyond computation. Educational opportunities, such as the admission of women into universities and colleges, made women more suitable candidates for astronomy work than young, less educated men. This resulted in a small number of women, including Everett, observing, researching and photographing, as well as computing and measuring (Brück 2009).

In the 1980s there was targeted research into women in science in North America, and many more women who worked in US observatories during the early twentieth century were 'discovered' (Mack, 1990; Rossiter, 1980). The women who did systematic, repetitive work were predominantly considered within the same sphere as those working in garment and other factories. However, women who achieved intellectual, mathematical or scientific prominence were generally considered to be performing outside their 'natural sphere' (Fine, 2010).

The role of astrographic measurer suited the late nineteenth century feminine ideal and 'natural sphere' which Fine discussed. The AC work could be performed in the comfort of the observatory interior. It required little physical strength and the women could be isolated to some degree from the men. Strict rules left little opportunity to work outside the realm of what had been specified and the quota of 100 stars a day, more or less. Furthermore, the measuring work could be completed during daylight hours, which was not possible for the photographic work (which had to occur at night). The isolation of women from the rest of the observatory, and the discouragement of women working at night, meant that the male exclusivity of the main instruments in observatories was one of the major impediments to women pursuing more research based work (Larsen 1995, 2009).

MEASURING STARS & SPECTRA IN THE US FROM 1886

The competition between American observatories to classify stars had led to the influx of women into observatories. Photographic methods meant astronomy could be performed by day. This generated a need for larger numbers of employees doing systematic, data related work to classify and catalogue stars and their spectra (Rossiter 1980). New 'feminised' and segregated roles were established at the data processing end of the process, and were seized upon by the popular media as offering great opportunities for women (Rossiter 1980, p. 383). Edward Charles Pickering, Director of Harvard College Observatory (hereafter HCO), was keen to pursue an all-sky catalogue of stars. Pickering was wealthy in his own right and attracted sponsorship for his observatory, importantly for the development of astrophysics. As previously noted, he had success with the Henry Draper spectroscopic star catalogue. Whilst he did not attend the AC Congress in 1887, Pickering sent information and examples of photographic plates from HCO (Winterhalter 1891, p. 55; Hughes 2013, p. 90).

Pickering engaged with the AC-CdC participants even though he did not take part in the project, quite possibly due to his commitment to the Henry Draper Memorial research project into the spectra of stars from 1886. He preferred women for the measurement and computational work required for the spectra analysis because, according to Mack, they were cheaper to hire and more patient than men (Mack 1990, pp. 87–94). According to Margaret Rossiter, these women were poorly paid though the nature of the work required high levels of detail and repetition (1982, p. 53). Nonetheless, the investigative scientific endeavours of some of the women working on the Harvard College Observatory (HCO) Star Catalogue have been recognised within the history of astronomy.

Alvarez and Diaz wrote that the women who measured stars at HCO paved the way for the professional employment and equal inclusion of women in astronomy (1999). Kristine Larsen's research revealed that equality was only available to the minority in the coming decades, and that the women operated within unique situations and relationships (2009, p. 104). The unique few women employed in astronomy at HCO in the late nineteenth and early twentieth century, such as Williamina Fleming, Henrietta Swan Leavitt, Annie Jump Cannon and Antonia Maury, authored or co-authored publications with the Observatory Director, Pickering (Fleming 1895; Maury & Pickering 1897; Leavitt 1908, Leavitt & Pickering 1912; Cannon & Pickering 1918). Hughes's research into Fleming's personal journal revealed that Fleming oversaw a laboratory of twelve women who were measuring the spectra of stars, reducing the measurements and preparing the data for printing (Hughes 2013, p. 696).

The HCO women deviated from the repetitive star catalogue measurement and made new discoveries in spectral analysis. These are rare instances where systematic computing and star measurement was the entry for females into the paid scientific workforce and the world of scientific research (Hearnshaw 1996; Lankford 1997; Hoskin 1984 & 1995; Hughes 2013, p. 696; Mack 1990, pp. 87–94; Lipscomb 1995; Oreskes 1996; Grier 2005). American computer technology historian, writer and academic, David Grier, examined a number of the female 'computers' at HCO and analysed a theatrical parody of the Gilbert and Sullivan production, 'HMS Pinafore' (Grier 2005,pp. 84–88). In 1879, astronomer Winslow Upton created the script for 'HMS Observatory', but Wilhelmina Fleming wrote the original copy. The action occurred in the HCO computing room and, according to Grier, the story was told from the astronomers' perspective, however the lines below (sung by the HCO 'computers') appear to be from the women's perspective:

We work from morn 'till night,
For computing is our duty;
We're faithful and polite,
And our record book's a beauty;
With Crelle and Gauss,
Chauvenet and Peirce,
We labor hard all day;
We add, subtract, multiply and divide,
And we never have time to play.
(Grier 2005, p. 84).

The parody provides insight into the positional measurement and photometry work in a descriptive way not found elsewhere. The text reflects the fact that the women were segregated within the observatory and, according to Grier, although the astronomers taught them, they were not considered part of the scientific endeavour.

As I examine in the case study of Muriel Heagney later in this chapter, the Melbourne Observatory women were also featured in a piece of creative writing, in this case a poem. Although, as portrayed in 1879, the women at HCO had very restricted work practises, this did change over time as women, such as Fleming, Maury and Swann Leavitt, demonstrated research skills and acquired agency. The difference between the women working at HCO and those employed on the AC in Australia and Britain was the opportunity for a few women to rise through the ranks because of their discoveries; and for the lead astronomer, Pickering, to acknowledge their research (Mack 1990, pp. 94–96).

Mack's analysis was that the number of women who rose to prominence in the US was attributable to the women's colleges in late nineteenth-century America where astronomy was taught. The women's colleges in the US were successful at attaining positions for their students doing measuring and calculations at the observatoryies. Mack demonstrated that whilst colleges were successful in fostering women in astronomy, major obstacles were still encountered; the advice they received from men on which areas of astronomy to pursue was skewed towards what was considered 'women's work' (Mack 1990, pp. 81–85).

After detailed research into the employment of women in science in America, Rossiter concluded that women who had made a name for themselves in science in the 1880s and 1890s were "ousted from major or even visible positions in science". According to Rossiter, even though women had "opened the doors", most would not be allowed, even with higher levels of education, to go beyond the threshold for decades to come (1983). Having chosen a scientific career, most women were confined to being 'support' for the men and denied any opportunity for research or advancement, therefore posing no competitive threat to men working in the field (Rossiter 1980; Grier 2005; Schiebinger 1993).

In the US, Britain and at Paris Observatory, women had limited access to higher education in fields related to astronomy. In Australia, astronomy education was in its infancy during this period, and very few women were educated beyond matriculation. In the next section, I examine changes in educational opportunities and the status of women, as well as the legalities surrounding employment conditions for women in Australia as relevant to the astronomical workforce.

The Nature of Women and Astronomy: an Australian Perspective

Australian feminist and historian of science, Margaret Wertheim, equated belief in science in the late nineteenth century to belief in religion (1995, p. 248). In both instances the masculine role was, as according to Wertheim, 'saviour'. Femininity was considered the opposite to what was required for 'hard' physical sciences, and it was the notion of what was acceptably 'feminine' which perpetrated society and was fundamental to the opportunities afforded to women (Wertheim 1995, p. 248). Wertheim's assessment that work was gender specific, with a dominant masculine hierarchy, is supported by my research into the introduction of women into the astronomy workforce for the AC.

My research included the popular press reporting on women employed for the AC at Paris Observatory (*Australian Town and Country Journal* 9 Nov 1895, p. 36; *Adelaide Advertiser* 12 Jun 1897, p. 40) and the women who analysed the spectra of stars at Harvard College Observatory (eg. *The Dawn*, 4 Jan 1893, p. 12; *The Sydney Mail* and *New South Wales Advertiser* 25 Feb 1903, p. 489). What emerged was amazement that women could perform these duties and admiration for their persistence in processing the vast amount of data. At the same time derogatory remarks about women and their analytical abilities (eg. *Mornington Standard*, 25 Jan 1894, p. 4) also appeared in the popular press. These conflicting attitudes both shaped and reflected social mores. Once the astrographic bureaux were established at Melbourne, Perth and Sydney Observatories, the press included these local women in their observations, as examined in the following section.

Women in Astronomy as Represented in the Popular Press from 1892

Fine researched the impact of gender stereotyping on the choices women make, including how women are represented in the popular press and advertising (2010). Fine's research indicated that gender stereotypes are created and re-enforced by images and texts depicting women, which have consequences on women's career aspirations (2010, p. 43). According to Fine, the portrayal of women as indecisive, or needing a man's guidance, reduced women's likelihood of taking leadership roles. Therefore, the way women were portrayed in the popular press had consequences and was important in the scope of this thesis in order to better understand the social milieu.

In the late nineteenth and early twentieth centuries, the press was vocal about matters to do with women, including the nature of their abilities and their rights to equality. The popular press reported on women's aptitude for astronomy in European and North American observatories; this pre-empted the widespread employment of women in astronomy in Australia. For example, reports about the women employed at Paris Observatory reached the regional newspapers in Victoria:

> "A new opening is being afforded to young ladies wanting employment, in the spectro-photographic departments of Observatories. … Miss D. Clumpke [sic]… is attached to the Paris Observatory where M. Bouquet de la Grye has formed a staff of young ladies for the examination of the photographs of the transit of Venus …"
> *(*Bendigo Advertiser, *2 Apr 1892, p. 3).*

This is only one example of many newspaper articles which reported that women were productively engaged in astronomy in Europe and North America, but attitudes in Australia questioned women's aptitude for astronomy (and any sort of non-domestic work in general). The following comic sketch, which appeared in the popular press during the period 1892 to 1940 illustrates the derogatory perception of women's capabilities in Australia:

> "A party of young ladies visit the Observatory to have a peep through the monster telescope at the new comet. The astronomer conducts them to the instrument, and the ladies look through in turns. 'Oh, Laura, isn't it charming, heavenly, enchanting, wonderful?' and so on ad libi tum. After a while the sly astronomer observes 'Now, ladies, I will remove the cover, and place the instrument in position, if you will allow me.'"
> (*The Capricornian* 26 Mar 1892, p. 6; *Mornington Standard* 25 Jan 1894, p. 4; *Healesville and Yarra Glen Guardian*, 5 Sep 1903, p. 4; *The Advertiser* 10 Mar 1928, p. 6.; *Nepean Times* 12 Dec 1940)

This short comedy portrayed women as bedazzled by science to the point of stupidity, an opinion that must have had social validity in order to be published more than twenty-five times (five of which are cited) in all states of Australia.

Not all news media reports shared the view that women were limited in their capacity and that knowledge was the exclusive realm of men. A journalistic article written by American historian and author, Helen Lea Reid, reached the *Wagga Advertiser* in 1892. Reid emphasised the work of the women at Harvard College Observatory as being equivalent to that performed by men, and that there was an optimistic future for other women to work in astronomy (*Wagga Advertiser* 16 July 1892). Acknowledgement of the potential for women to work in astronomy, with direct reference to Melbourne Observatory, was demonstrated by a poem which appeared in the Melbourne based labour newspaper, *The Tocsin*, in 1897:

"The official visitors to the Melbourne Observatory recommend the employment of a staff of young ladies to conduct astronomical work:

The jewel-sprinkled skies
Throw many nasty slurs
Upon the jaundiced eyes
Of male astronomers.

The dust of vanished suns
Is thick on all their work —
Wayfarer as he runs
Can see how much they shirk.

Baracchi shuts his eyes
And says it won't be wet:
We see the clouds arise
And umbrellas get.

He tabulates
And barometric lies,
Yet seldom he confides
What nights the moon will rise.

The music of the spheres
The price of Saturn's rings
Through all these dreary years
Have been forgotten things.

The heavenly influence
Of Venus upon Mars
Is quite beyond the sense
Of men who count the stars.

And Double Stars — those goals
Of matrimonial bliss —
They are above the souls
Of weather men like this.

A vaunt, all men who mar
And make the heavens drear,
Each world, each sun, each star,
Is henceforth woman's sphere."

(*The Tocsin* 11 Nov 1897, p. 7)

The poem above makes specific reference to Melbourne Observatory, its Director Baracchi, and astronomical work hindered by meteorology. The influence of 'Venus upon Mars' could be interpreted as the influence of women upon men. The poem was possibly written by Patrick Bernard O'Dowd, one of the writers for *The Tocsin*, who was a school teacher and well known as a 'radical poet' (Wallace-Crabbe 1988). *The Tocsin* political platform included 'one adult one vote' and 'abolition of all Laws which Place the Woman, whether in a private or a public capacity, at a Disadvantage as compared with the Man' (*The Tocsin* 11 Nov 1897, p. 2). There was a connection between the astrographic measurers at Melbourne Observatory and the Labour party, as is revealed in the case study of Muriel Heagney.

Periodically, the popular press in Australia featured the women who worked on the AC. The earliest report, which I have located, emphasised the arduous nature of the work:

> "Six young ladies, whose sole equipment for the work was good health, good eyesight, quickness at figures and aptitude for microscopic observation have … for the last 18 months, been bending, and will so bend for the next five or six years if their health and eyesight last at the Melbourne Observatory over photographic plates of the heavens, measuring and recording, recording and measuring for alternate hours from 9 o'clock till 5, to complete the Victoria's share of a magnificent world work—an astro-photographic catalogue of the heaven as seen from the world at the close of the nineteenth century. The young ladies receive £40 a year each."
> (*South Australian Register* Saturday 13 Oct 1900, p. 8).

The popular interest in the details of the measurement process, how the women had been selected, their training and the accuracy expected, is gender specific information not typically provided about the male astronomers:

> "Each lady has a microscope with spider-web threads stretched across the field of view, so as to divide it into minute squares. Fine screws move the plate up or down, to right or left, and then the position of the star can be read off. Each young lady has to pass the matriculation examination before she begins this observatory work, and she requires about six months before she acquires a satisfactory facility at it. Then she ought to be able to measure and catalogue about 400 stars a day, or about 1,500 a week, for the bureau. At this rate it will take three or four years for Melbourne to accomplish its share."
> (*The Australasian* 27 Apr 1901, p. 30)

The articles about the women working on the AC often featured photographs of the women at work inside the observatory, comments about the number of stars they had to measure and rhetorical questions about the monotony and intensity of the work. The concept of a 'greater purpose' was presented as the rationale for the AC; the women were portrayed by the media as engaged in painstaking but nonetheless worthy work, but not in any way applying their intellectual capacity.

The interest in the AC continued on for decades. In 1938, a report in the *Sydney Morning Herald* on the Sydney Observatory work included the names of the women:

> "Only four other girls in Australia, and not more than a hundred in the whole world, share the unusual profession of Miss Muriel Mills and Miss Beth Macara. They photograph that portion of the heavens allotted to Sydney in the great work of making a detailed star map … As further maps are to be made at intervals of fifty years, these two young women will go down in history as pioneers in a branch of science which, it is expected, future generations will develop."
> (Holmes 1938, p. 11).

The article above shows a shift in social acceptance of women working, even though their work in science is considered 'unusual'. The recognition of Mills and Macara's work as having scientific validity is significant.

During my canditure I attended three conferences in preparation for this thesis (*Women in Astronomy* 2013, *Women in Astronomy* 2014, and *Revealing Lives: Women in Science 1830 to 2000*, 2014) on this subject matter. The way the popular media reports on the work and lives of female scientists past and present was topical. This is considered to be of serious concern because the lack of representation of women in science in the media, and the emphasis on gender differences, has been examined as important when young women make career decisions (Rosser 2008, p. 114; Steinke, 2012).

Historians, historians of science and sociologists of science who research gender and work have highlighted that clear distinctions were made in the newsmedia between what women were expected to do, or thought capable of, compared to males and that these distinctions permeated society almost unchallenged in the nineteenth century (Fine 2008; Yount 2010). In the next section, an Australian perspective is provided on the status of women and their participation in amateur astronomy societies, as relevant to the AC.

WOMEN AS AMATEUR ASTRONOMERS IN AUSTRALIA FROM 1893

In the late nineteenth century, amateur astronomical societies were established in Australia. Amateur astronomers played an important role engaging with the 'new astronomy', as well as with the established amateur roles of comet and object discovery in the Solar System (Orchiston 1998, 1999). These societies provided a network of like minds and, in an effort to become part of this network, women joined (or attempted to join) amateur astronomy societies from the 1890s.

The records of amateur astronomy societies in Australia from 1893 to 1930 are difficult to access. My research mainly involved journalistic reports about elected members and meeting attendees, uncatalogued record books belonging to the BAA, NSW Branch, now Sydney City Skywatchers (hereafter SCS) held at Sydney Observatory, reference to past research by members of societies Brian Waters from the Astronomical Society of South Australia (hereafter ASSA), Barry Clark from the Astronomical Society of Victoria (ASV) and Gary Dalrymple (SCS). My results, as shown in Table 2 is the first listing of women amateur astronomers in Australia from 1893 to 1927. This list demonstrates that at least thirty-one women were accepted into and participated in astronomy societies from their formation in South Australia (1892), Victoria (1922), New South Wales (1895) and Western Australia (1912). In November 1893, Greayer, Alice Maud Mary Todd and Lorna Gillam Todd were the first women elected to the South Australian Astronomical Society (*The Advertiser*, 11 Apr 1894, p. 6).

There is evidence that the women were active in these societies; for example, the Todd sisters read papers to the South Australian Astronomical Society in 1895 and 1897 (*South Australian Register,* 13 Nov 1895, p. 7*; South Australian Register*, 16 Jun 1897, p. 10). Membership provided intellectual opportunities to present observations and interact with like-minded people. Most of the women who joined amateur astronomy societies were connected through family or friends to males who were engaged in astronomy as a career or as a pursuit outside their workplace; but some women, such as Greayer, Williams, Harvey and Lewis, were connected through their professional work in astronomy. AC measurer Lillian E. Lewis was in the first group of women employed at Melbourne Observatory, where she worked from 1898 to 1903. According to Barry Clark, Lewis became a member of the Royal Society of Victoria and a foundation member of the Astronomical Society of Victoria (hereafter ASV) in 1922, later becoming the ASV Assistant Secretary and then Librarian from 1931 to 1949 (pers comm., Clark 2012).

Amateur astronomy organisation	Surname	First name	Elected
ASSA (South Australia)	Todd	Lorna	1893
ASSA (South Australia)	Greayer	Mary Emma	1894
ASSA (South Australia)	Todd	Maude Alice	1894
ASSA (South Australia)	Brown	Lady Campbell	1895
BAA (NSW Branch), reformed as SCS	Foreman	Mrs Jane	1895
BAA (VIC Branch), reformed as ASV	Hogg	Evelyn G	1897
BAA (VIC Branch), reformed as ASV	Brown	Miss E.	1897
BAA (VIC Branch), reformed as ASV	Ashley	Miss M	1897
ASSA (South Australia)	Kimber	Emma Millicent	1898
BAA (NSW Branch), reformed as SCS	McLelland	Cecilia	1898
ASSA (South Australia)	Adcock	Jessie Janet	1899
BAA (NSW Branch), reformed as SCS	Deane	Edith	1902
BAA (VIC Branch) reformed as ASV	Whiting	Mrs R. S.	1905
BAA (VIC Branch) reformed as ASV	Jepson	Miss T.	1905
BAA (Western Australia), reformed as ASWA	Ross	Euphemia.	1913
BAA (Western Australia), reformed as ASWA	Silverwood	Mrs	1913
BAA (Western Australia), reformed as ASWA	Shelton	Mrs	1913
BAA (Western Australia), reformed as ASWA	Rees	Mrs	1913
Astronomical Society Western Australia (ASWA)	Williams	Prudence	1915
Astronomical Society Western Australia (ASWA)	Harvey	Minnie Elizabeth	1915
BAA (NSW Branch), reformed as SCS	Gullet	Lucy	1917
BAA (NSW Branch), reformed as SCS	Gullet	Minnie	1917
BAA (NSW Branch), reformed as SCS	Chisholm	Miriam	1922
BAA (NSW Branch), reformed as SCS	Daniel	Nina	1922
BAA (VIC Branch), reformed as ASV	Lewis	Lillian E.	1922
BAA Queensland	Dafter	Rosina	1923
BAA (NSW Branch), reformed as SCS	Clemesha	Ida	1924
Astronomical Society Western Australia (ASWA)	Gordon	Dora	1926
Astronomical Society Western Australia (ASWA)	McCreeth	Miss	1926
Astronomical Society Western Australia (ASWA)	Nagel	Miss	1927
Astronomical Society Western Australia (ASWA)	Petersen	Mrs	1927

Table 2: Female members elected to amateur astronomy societies in Australia from 1893 to 1930. Highlighted names were also professionally employed in astronomy.

In 1915 Williams and Harvey, who worked at Perth Observatory, were elected at the opening meeting of the Western Australia Astronomical Society, which "was held at the Observatory on Tuesday evening before a large attendance" (*The Daily News*, 25 Feb 1915).

Women were admitted to the New South Wales Branch of the British Astronomical Association (BAA) from its inception in 1895. According to Mary Creese's research, Mrs

Jane Foreman was elected as a member of the BAA in 1895 and Cecilia MacLelland was elected as a member in 1896, and then to the council from 1899 to 1900 (Creese 2010, p. 59). MacLelland presented her observations on meteors and solar eclipse expeditions to the meeting (*Journal of the British Astronomical Association*, vol.8 1898, p. 373 in Creese 2010, p. 59). Other women were keen to study and communicate to others about the southern sky.

John Tebbutt, prominent self-funded astronomer who had a substantial observatory at Windsor, encouraged women to pursue astronomy (Brück 1998, p. 45). Brück's research revealed that Mary Orr, who arrived in Australia from England with her mother and sisters in 1890, visited Tebbutt before moving to Queensland. In 1891, Orr was elected a member of the Astronomical Society of the Pacific, which included Tebbutt in its membership. She wrote an *Easy Guide to the Southern Stars* in 1896, the first popular guide published in Australia. Orr had an extraordinary life in India. When she returned to England, Orr founded the Historical Section of the British Astronomical Association in 1930 (Brück 1998, p. 55).

Higgitt and Charles Withers, historians of the geography of science, presented their findings about women members of the British Association for the Advancement of Science (BAAS) in the nineteenth century. The BAAS and its equivalent in Australia, the AAAS, were professional associations of career scientists and had very few women members. Higgitt and Withers' research revealed that there were many women in the audiences, and this received comment by the popular media at the time (2008, p. 2). By focussing on the women who were consumers of science, and through diary entry and media reports, they uncovered the names of women who regularly attended meetings, the attitudes to these women, and the restrictions they faced. MacLeod's research into the AAAS (1988) includes photographs showing many women attending the inaugural AAAS Congress President's Address in 1898 (plate 7) and the Adelaide meeting in 1907 (plate 9). The research for this thesis has not extended to a more detailed account of the attendees at the congresses. It is nonetheless likely that Higgitt and Withers' conclusion that the attendance of women was important in the popularisation of science during this era would apply.

In this chapter, I have so far established that there was a gap between what was popularly perceived as the capability of women and what some women were able to achieve through participation in astronomy in Europe and North America. Opportunities for women in Australia during the late nineteenth and early twentieth centuries were restricted due to the slow pace of education reform, workplace legislation and overwhelming social forces such as the often unfavourable and gender-prejudiced representation of women in the popular press. Women were restricted due to barriers on education and participation in professional science, yet they participated in, and were consumers of, popular science. In the next section, evidence of the women who were employed in Australia in astronomy (in extraordinary numbers) is presented.

THE FIRST WOMEN EMPLOYED IN ASTRONOMY IN AUSTRALIA

According to the employment records for each observatory, the lists within the Astrographic Catalogues and archival correspondence (PROV, SRNSW, SRSA, SRWA) over seventy women were employed for the Astrographic Catalogue in Australia during the period 1890 to 1964. The first woman, Mary Emma Greayer, was revealed in archival correspondence between the government astronomers. Greayer is case studied in this thesis and I have presented evidence of her work to Australian astronomers (Stevenson 2014).

At least twenty-seven women worked on the AC for Melbourne Observatory from 1898 to 1930. Perth Observatory employed eleven women over the period 1907 to 1912, and Sydney Observatory employed at least twenty-nine women from 1916 to 1964, the date of practical completion of the AC. However another three women who worked from 1968 to 1971 were included by Wood in his list of persons involved in the AC (Wood 1971).

Observatory	# Stars**	#Plates**	# Women	From - To	# Years*, **
Adelaide Observatory	6,818 observed	Not applicable	2	1891-1898	8
Sydney Observatory	740,000	1400	29	1916-1964	219
Melbourne Observatory	392,615	1149	27	1898-1930	125
Perth Observatory ROE***	228,000 194,000	944 139	11 8	1907-1922 1908-1922	55 35

Table 3: Women who worked on the Sydney, Melbourne & Perth AC zones.
* Whole years even if only part of the year may have been worked. **Estimate. ***Royal Observatory Edinburgh.

The number of women who were employed specifically on the AC zones allocated to Sydney, Melbourne and Perth Observatories is illustrated in Table 3. The complete list of names and years of employment is in Appendix 6: List of women who worked on the Australian zones of the AC-CdC Adelaide Observatory has been included in the table because the two women were paid to observe positional stars through the transit telescope, and reduce these using complex formulae for the Melbourne AC zone. This was a different type of work to the glass plate measurement work undertaken by women at Sydney, Melbourne, Perth and Edinburgh Observatories. The Royal Observatory Edinburgh astrographic assistants are included in Table 3 because of their work on the Perth zone. I have estimated that women spent a combined total of 439 working years at Adelaide, Melbourne, Sydney, Perth and Edinburgh Observatories observing, measuring, computing and compiling the Australian zones of the AC.

The number of women employed at any one time on the AC was limited by the availability of the measuring machines and the restricted budgets of observatories in Australia. The largest number of women employed at any one time was at Melbourne Observatory, where there were six women using at least three serviceable machines.

In the next section, I examine what the requirements were for entry into the observatory workforce.

A FEMININE 'TYPE' AND AN APTITUDE FOR COMPUTING FROM 1898

My examination of the Melbourne Observatory records revealed that Baracchi established a dedicated scientific bureau to measure the Sydney and Melbourne plates on a scale not previously seen in the colonies. He wrote about his experience to Cooke:

> "I have been trying a lot of girls to ascertain their aptitude for the work. We are going to have six of them for six months, and four afterwards- commencing November 1st I hope. You may imagine what a good time I am having."
> (letter Baracchi to Cooke, 17 Oct 1898, PROV867/P/0000 box 73, p. 64).

The quote above was written to Cooke and copied in the official letterbook, but it is unclear whether Baracchi was being sarcastic or, having had to recently retract the staff at Melbourne Observatory due to government budget cuts, he now enjoyed the process of selecting the best women for the work, and then training them. The 'aptitude' Baracchi was seeking from the

Melbourne Observatory computers was based on the positive experience Paris Observatory, Royal Greenwich Observatory and Oxford University Observatory had already had employing women for the work. The AC-CdC Bulletin report by Gautier about the Measuring Bureau at Paris Observatory emphasised the advantages of the delicate, yet precise nature which the women applied to their work (Tisserand 1895, p. 305). According to Bigg, Lomb and Pickett, women were chosen for the astrographic bureaux because of their accuracy, patience and willingness to do repetitive work precisely (Bigg 2000, p. 96; Pickett & Lomb 2001, p. 35). My primary research shows that women under twenty years of age were selected for Perth Observatory because they had excellent eyesight, 'nimble fingers' and they sat examinations and had to pass tests with a thorough selection process:

> "Further with regard to age it is a distinct advantage for a girl to start this kind of work as early as possible when her fingers are pliable and there is more chance of her acquiring a delivcate touch – the same applies to the manipulation of musical instruments. Thus Miss Williams who started at 15 is by far the most capable measurer we have had …"
> (letter Curlewis to the Under Secretary, undated 1913, SRWA WAA-1005 1916/2603)

Women employed at Adelaide, Melbourne and Sydney Observatories were over 17 years at least, and most often over twenty years, with an intermediate leaving certificate or trained as teachers. I have investigated individuals specifically through the case studies. My research has revealed that the women who worked on the AC in Australia had been well educated at a high school level. Most often they attended a convent school (eg. Noonan and Heagney case studies) or they had been trained as teachers (eg. Greayer and Peel case studies). As a rule they achieved awards and were noted for their achievements at school in geometry, arithmetic and other subjects. In the Williams case study, she sat a junior examination for the University of Adelaide (*The West Australian* 5 Jan 1907, p. 5). Natalie Claire De Moulin and Susan Oates, employed at Sydney Observatory, were typical examples of women with superior mathematical ability but little qualifications and a rudimentary education.

De Moulin completed her Intermediate Leaving Certificate, the equivalent of the Year Ten School Certificate, from St Ursula's School, Armidale (*The Sydney Morning Herald* 16 Feb 1917, p. 5). Her subjects included mathematics I & II and she was awarded a High Achievement in French, which was her father's first language. Similarly, Oates was awarded Honours in mathematics II at Our Lady of Mercy College, Parramatta (*Freeman's Journal*, 25 Jan 1917, p. 28). Both women commenced work at Sydney Observatory in 1917. Level A achievement in mathematics and other subjects appear to have been pre-requisites for the astrographic work.

The appointment of women to the Melbourne Observatory workforce as measurers was via the matriculation exam:

> "Each young lady has to pass the matriculation examination before she begins this observatory work, and she requires about six months before she acquires a satisfactory facility at it. Then she ought to be able to measure and catalogue about 400 stars a day, or about 1500 a week, for the bureau …"
> (*The Australasian* 27 Apr 1901, p. 30).

The examination papers, that may have revealed what the women were being tested against, and how they performed, have been difficult to locate. In 1905 Baracchi reported to the Melbourne Observatory Board that he examined candidates in "trigonometry and logarithmic computations … to show fitness and aptitude for micrometric measurements". To assist with the examinations, Baracchi informed the Board that he had acquired the services of mathematical physicist, Professor Thomas Ranken Lyle, who was also Chairman of the Board of Melbourne Observatory, and the Surveyor General, Joseph Martin Reed (Melbourne Observatory 1905, p. 4). For Baracchi to require these two very senior experts to be involved implies that this was a rigorous process with high expectations of the candidates.

THE MEASUREMENT BUREAUX – 1898 MELBOURNE, 1906 PERTH, 1916 SYDNEY

The initial plan for measuring the AC was to establish a grand central bureau of measurement in Paris to measure all the plates of the participating observatories. Gill described the reasons why this was a desirable approach to Mouchez in Paris:

> "The measurement of the plates is another matter – and I feel convinced it can be best and most economically done in a Central Bureau. Of course if we can get the money there is no reason why we should not make the measures here, but women's work for this purpose can be procured in Europe at so much less cost than here, and could be so effectually organised and so economically supervised in a single establishment, that I am convinced we shall all be ultimately compelled to adopt that method of working."
> (letter Gill to Mouchez, 30 Aug 1891 in Chinnici 1999, p. 107).

As already discussed, this grand plan did not eventuate but was decentralised, with a bureau of measurement established in the participating observatories. In March 1893, Russell wrote to Christie and explained that the Barings Bank collapse in London had ramifications in New South Wales, and that this had thrown the economy into a recession (Russell, Letter to

Christie March 1893; Coghlan 1893, pp. 644–645). Similarly, Baracchi continued to seek an economically viable answer to the measurement bureau, which was a resource problem. At a meeting held in Melbourne in January 1898, Russell and Baracchi decided to join forces and Baracchi informed the Astronomer Royal:

> "… at a conference held in January last, Mr. Russell of the Sydney Observatory and I decided that the measurement of the plates of both the Sydney and Melbourne stations should be measured under my supervision at Melbourne ..."
> (letter Baracchi to Christie 12 Mar 1898).

The letter stipulated Sydney and Melbourne would both contribute to the annual salary cost which would amount to less than £300. Having established the way forward, and as previously discussed in Chapter Three, Baracchi requested that Christie send all the information possible about the measurement, reduction and publication of the catalogue:

> "… What I would be glad to indeed have is a description of all the operations, the order in which they are made, how they are distributed among the observers, recorders and computers; how the measures are registered (with specimens of all the forms used for entries), how they are checked and reduced and finally prepared for publication; also whether the magnitudes are derived from measurements of diameters, or estimated ... in exactly the same manner as you have adopted, which is my desire …"
> (letter Baracchi to Christie, 12th March 1898 RGO 7/161).

This request was fulfilled in part by the regular bulletins, written in French, sent to all AC-CdC participants (Tisserand 1890, 1892, 1895). Baracchi organised standard measurement logbooks based on the samples Christie sent and he purchased the Gill designed Repsold measuring machine as specified by Christie. In the same manner as the instruments were selected specifically for purpose, the women astrographic measurers and computers were also carefully selected as having a specific skill set for their employment.

Due to a financial recession in the colonies in 1893, there was a reduction in funds available for State observatories. In Victoria, boys and men between the ages of 16 and 20 were already employed to do calculations, and they were paid a starting annual wage of £52 for computing and measuring work (Victorian Government Public Service Gazette, no.78, 1888). Once lower rates of pay for women were legislated, the employment of women was seen as a satisfactory solution to providing the resources for the AC at an even lower rate. Furthermore, the method of employing women fitted the international model for astrographic measurement and reduction.

The Measuring Bureau's finances, which had been agreed as £300 per annum, was split between the two observatories. The women employed at Melbourne Observatory from 1898 were generally paid £40 per annum as the starting rate:

> "The present temporary staff of girls consists of 4 girls whose aggregate salary amounts to £186 per annum; Mr. Wallace's salary is £212 per annum and, as he is giving half his time, as arranged, to the conduct of the work of the measuring staff, one half of his salary is charged ... therefore ... the cost in salaries alone is £292." (letter Baracchi to Russell, 21 May 1902, PROV 778/P/0000, vol.1, p. 465).

This was a lesser wage than the junior men employed years earlier. Perth Observatory paid its first women Astrographic Assistants within the clerical range of £48 to £108 in 1912 (Public Service List, *WA Government Gazette*, November 29 1912, p. 53). By comparison, the lowest teaching salary for women in the State Education System of Victoria, NSW and South Australia ranged from £66 to £72 (Goyen 1902). As detailed further, Peel was already a teacher at Patyah school when she was transferred to Melbourne Observatory. Patyah school was located near the border of South Australia and Victoria. It is possible that employment with Melbourne Observatory was appealing for a number of reasons, including its locality. Unusually, Peel retained her teaching salary and when she was permanently appointed in 1900, her salary was above that of the other Astrographic Measurers.

Baracchi entered the following details in the Measuring Bureau's diary which he instructed Wallace to keep:

> "Assistants Employed in the Astrographic Bureau: November 2nd 1898. The following ladies were employed in the Astrographic Bureau for the measurement of the plates, the salary for each being £40. The initials opposite each name are those used to determine the work:
> Lillian Elmblad Lewis (L); Charlotte Emily Peel (P); Emily Harker (H); Mary Adelaide Phillips (MP); Jane Winifred Hall (WH)."
> ('Measurement of Astrographic Plates', 20 Apr 1900, VPRS 778, PROV).

When Baracchi was interviewed in 1902 for a popular article about the women employed at Melbourne Observatory, he outlined the leave conditions and hours:

> "They have three weeks holiday a year in addition to all public holidays. Their hours are from 9am to 5pm on weekdays and to noon on Saturdays, an hour being allowed

> for lunch. Their salary is £40 a year. … (The editor … has only one remark … and that is that £40 a year is an utterly inadequate re-numeration for such work. No man would undertake it at more than double the amount).”
>
> (*The Brisbane Courier* 31 May 1902, p. 13)

The journalist’s comment demonstrates that the wages the women measurers were paid were considered unreasonable and biased by gender. These rates of pay had been established based on the premise that the work the women did in the observatory required less skill and knowledge than other work. However, there were not many other opportunities for educated women to find employment.

The effectiveness of the Measuring Bureau is evidenced by the 1901 annual report which states:

> “… one hundred and one Sydney plates containing 71,223 stars completely measured in the direct and reverse positions and eleven Sydney Plates containing 4,949 stars also completely measured in two positions …”
>
> (Baracchi & Russell 1902).

This is an impressive number of stars measured from the Sydney section because the Melbourne Bureau had only been established for three years in 1902. It had three measuring machines and an average of six measurers. During this period, the women in the bureau had also measured 383 Melbourne plates and over 25,000 stars in the Melbourne zone.

The women employed at Melbourne Observatory in 1898 were engaged on a temporary basis for computing and measuring. Baracchi described the progress he had made in establishing the bureau when he wrote to Russell:

> “Everything has now been settled about the assistants. The six girls appointed on probation to commence work on November 2nd (next Wednesday) are: These three are very promising: Miss Peel (public school teacher), Miss Lewis and Miss Hall (matriculated with honours in mathematics). These promise to be fairly good at observing; but are bad at computing: Miss Phillips, Miss Harker, and Miss Skoglund. I have three more very good ones who will be taken on in case of vacancies. The conditions are that these girls’ services can be dispensed with at a week’s notice …”
>
> (Baracchi Letter to Russell 28 Oct 1898, PROV 867/P/0000, pp. 76–77).

Despite Baracchi’s initial intentions, Charlotte Emily Fforde Peel was gazetted into a permanent position in 1900 (Victoria Government Public Service Gazette no.122, 7 December 1900, p. 4478). Peel was the only permanently appointed female staff member in an observatory in Australia for two decades. In 1913, Curlewis requested that four Perth Observatory Astrograph Assistant positions be made permanent, but my research shows this did not eventuate. He did have improved wage conditions approved so that the most senior of the women would have an extended range to £132 under a new position title 'Assistant Supervisor' (letter from Williams, Tothill, Harvey, Allen to Curlewis, forwarded to the Under Secretary by Curlewis 28 May 1913, SRWA 752 1913/0963).

In Figure 60, the Melbourne astrographic bureau employment trends are illustrated. The overall trend shows steady employment up until 1912. It also shows that the three women employed after WWI worked in the astrographic bureau until it was disbanded in 1930. The mean length of employment was four and a half years, with a small number of women working for periods of nine to twelve years. Given that women had to leave employment on marriage, and that the women who were employed were between the ages of sixteen and twenty-three, this would indicate that the workplace and the work was satisfactory, if not enjoyable.

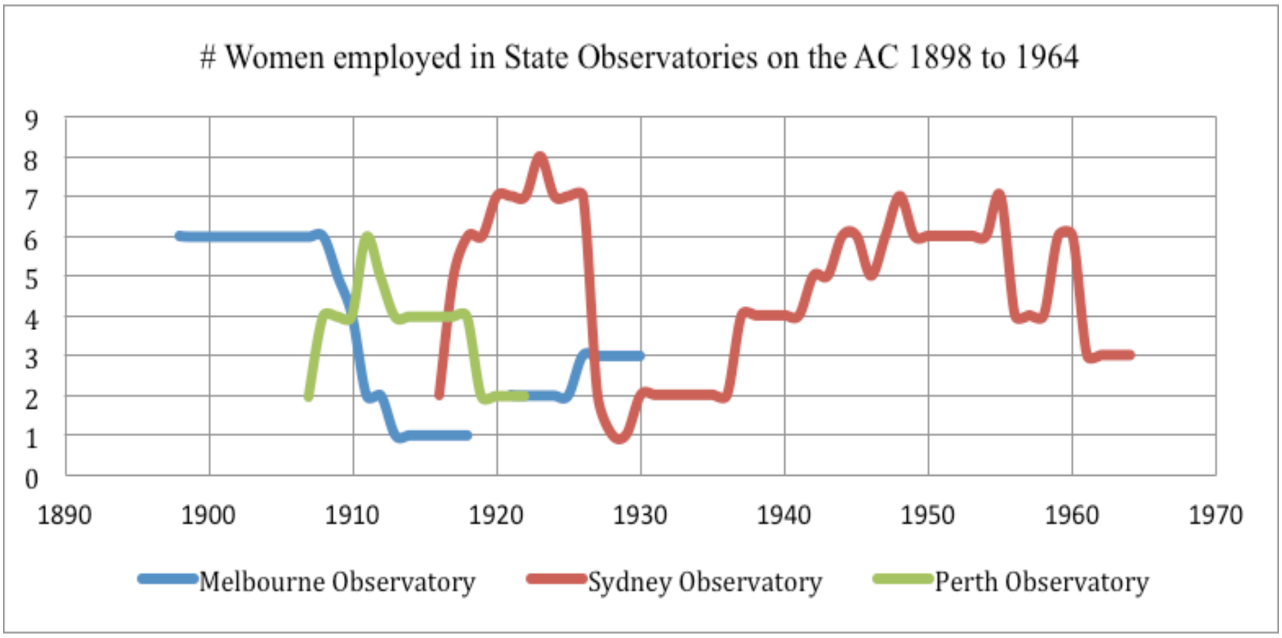


Figure 59: Chart indicating employment trends for women working on the AC at Melbourne, Sydney and Perth Observatories from 1898 to 1964.

Perth Observatory astrograph bureau managed to complete the measurement and reductions for two thirds of the Perth zone from 1907 to 1922. In Figure 60, the Perth Observatory astrographic bureau employment trends are illustrated. The overall trend shows that the first women, Prudence Valentine Williams and E. Kendall, were employed in 1907. Kendall left after one year and Jones, Harrington and Hilda Rachel Urquhart Arnold were employed to make a complete bureau of four women, the number it remained throughout WWI. The bureau prevailed with longstanding employees Williams, Minnie Harvey, Ida Tothill and Ethel Allen. In 1918, the bureau was reduced to two women, Harvey and Allen, until it was disbanded in 1922. The mean length of employment at Perth Observatory was five years, but seven of the eleven women only worked for an average of two years. The archival evidence presented in the Prudence Valentine Williams case study indicates that there were tensions in the workplace over payment, the temporary nature of the positions and the supervision of the astrographic bureau by Clive Nossiter.

The Sydney Observatory astrographic bureau was the last one to be established, but it eventually employed the largest number of women over the longest period of time, as shown in Appendix 6. At Sydney Observatory, the women were employed on a temporary basis from 1916. In 1920, four women were gazetted in permanent positions at £169 per annum (NSW Government Gazette no.192, 29 Oct 1920). They were Ida Digby, Irene Maud McDonald, Winnifred Madalene Cronin and Ellen Louisa Clements. In 1926, when Cooke retired from Sydney Observatory, the women were transferred to other government departments (Sydney Observatory Records, uncatalogued).

In Figure 60, the Sydney astrographic bureau employment trend shows steady employment from 1916 up until 1923. It indicates that during 1926 and 1927, the bureau was drastically reduced. Only one woman, Mary Alice Allen, was employed during the period 1927 to 1930. Allen, who began work in 1923 and continued until 1946, worked for twenty-three years and had the longest employment period of all the women who worked on the AC in Australia. Allen worked alone until 1930 when Carol Arkinstall was employed. From 1937, there was a period of steady employment of two women at any one time. It was from 1947 until 1960 that there was a steady stream of new employees and departures. As expected with the completion of the Sydney zone AC for printing in 1964, all but one of the women, Winsome Bellamy, had left by1965. The mean length of employment was six years, with a small number of women working for periods of nine to twenty years, and seven women staying for two years or less between 1954 and 1960. This would indicate that some women were suited to the work and enjoyed it, and others were not interested in, or capable of the work.

The employment of women on the AC was temporal with female franchise and the introduction of legislation to regulate women's pay and workplace rights in Australia, as examined in the next section.

NINETEENTH CENTURY CONDITIONS FOR WOMEN IN AUSTRALIA

Female franchise was granted to the colony of South Australia in 1894 and women were granted the right to vote in Australian Commonwealth elections in 1902 (Lees 1995). As can be found on the electoral rolls, many of the women employed at Melbourne Observatory registered their vote in 1903. Among the women case studied for my research, one of the women employed at Melbourne Observatory was politically involved with the Labor Party and campaigned for equal rights for women.

In her report on 'Women's Employment and Professionalism in Australia', Dr Maria Nugent made a direct connection between women entering the public sphere of employment in science and access to higher education (2002, p. 23). Nugent and Lees also intrinsically tied changes in political rights for women and female franchise with the employment of women in professional fields (Nugent 2002, p. 38. Lees 1995, p. 27). In the late nineteenth century, there were new opportunities for women to be educated and these led to employment opportunities, such as at the observatories.

Compulsory school education was introduced first in South Australia in 1875, followed closely by the admission of women into university in South Australia in 1876. The Advanced School for Girls, a public secondary school, opened in Adelaide in 1879. Generally, women were admitted into universities in the 1880s (Nugent 2002, p. 23). Nugent's research showed that the dominant occupation outside marriage in the late nineteenth century was domestic service (Nugent 2002, p. 11). There were not many opportunities to work in professional fields, and teaching was one of the few exceptions. In Victoria there were new standards established for teachers with formal training from 1889 to 1893, and by the late nineteenth century women dominated teaching in the growing school system in Australia. This impacted on the employment of women in astronomy because teachers proved to be a major source of recruitment for Adelaide Observatory's computers and Melbourne Observatory's first measurers.

In 1907 'The Harvester Case' determined the basic wage that men and women should be paid as stipulated in the Commonwealth Arbitration Report (CAR) and quoted by Kramar (CAR 1907, p. 3). It states that the basic wage was determined on "the normal needs of the average employee regarded as a human being living in a civilized community". Women were considered different to men by the judge J. Higgins, who determined the living wage for women was less than that for men "on the basis of the reasonably necessary requirements of a woman living in a civilised community". These requirements were less than that of a man as determined by Higgins due to the need for a man to provide for his family; even if that man was single, this was determined as the need to save for a family. There was no consideration that a woman would have to provide for anyone; therefore women were not awarded a basic wage.

Around 1912 the CAR determined the basic female wage as 64% that of men (Kramar, p. 2). Women's rights to equal pay was debated as is demonstrated later in this chapter by the case study of Muriel Heagney, and there was dissatisfaction at the rate of pay for what was perceived as work equal to that of men, as made evident further in this chapter by the correspondence written by Prudence Valentine Williams. In 1917 the Commonwealth Arbitration Commission determined "… that women and men should be paid equal wages if women are employed to do a man's work – or where the work done by a woman is as great a value as the man's work… " (CAR vol 11, pp. 14–16 in Kramar). What 'equal' meant was highly subjective. Within the observatory, measuring was considered lesser work and women's work. However, the position of computer was shared by men and women, so even if women were doing the computational work, my research has shown that they were not formally acknowledged as such (this point is further articulated in the case studies).

In 1919 this ideal of equal pay for equal work was retracted and the Court of Conciliation and Arbitration reduced the minimum wage for women to 54% of the national basic wage for men (CAR 1919, pp. 647–695).

By 1919, when Peel resigned from her position, the rate of pay for the most senior position able to be held by a woman in astronomy was specified at £144 a year (Victoria Government Public Service Gazette 17 Sep 1919, p. 2087). As stated, this rate of pay for women was not arbitrary; it was 54% of a male-equivalent position and a direct result of the Court of Conciliation and Arbitration case (Kramar 1990, p. 2; CAR 1919, vol.13, p. 647). This percentage was retained until after WWII when (in 1950) the female rate of pay was increased to 75% of a male's wage (Kramar 1990, p. 2). Although equal pay for women was legislated in 1969, arbitration which favoured different rates of pay for women to those of men continued until 1972 when the different rates of pay method was abolished for most areas of work (Kramar).

The other disincentive for women to work was that until midway through the twentieth century, only single women could be employed in the public service. In Victoria, the Public Service Act of 1890 (No. 1133 Section 43) made it impossible to employ a married woman. This meant that once betrothed, a single woman resigned her position. Other State Governments had similar restrictions on women's permanent employment; the 1902 Commonwealth Public Service Act deemed women as retired once they married. In 1947, the NSW Public Service repealed an Act, making it possible for female teachers to retain a permanent position after they married. By 1966 married women could finally retain a permanent position in the Federal Public Service. But it was not until 1969 that a woman could continue to work in a public service position as a permanent staff member once she married (AWAVA 2011).

As I have outlined, for the women who measured the stars, the low rate of pay was not the only drawback. Continuity of employment was uncertain because the majority of women were on the temporary payroll. Women who worked in public service roles, such as observatories, often left after a few years to marry. Although some women stayed single and worked for numerous years at the observatories, most of these highly skilled women never established what would be considered a career in astronomy by contemporary standards.

Case Studies

The women whom I have researched as case studies for this thesis worked on the AC. None of the women had been extensively researched previously for their work in astronomy. These particular women were selected because they were exceptional either in their work, their social interactions or in their lives once they left employment on the AC. Six of these individual case studies represent the early years when the measurement processes and resources were becoming established. They are Mary Emma Greayer (Adelaide Observatory 1890–1899), Charlotte Emily Fforde Peel (Melbourne Observatory 1898–1918), Sarah

Victoria Noonan (Melbourne Observatory 1907–1911), Muriel Heagney (Melbourne Observatory 1906–1910), Prudence Valentine Williams (Perth Observatory 1907–1921) and Ida Digby (Sydney Observatory 1916–1926). Of these women, Mary Emma Greayer, Charlotte Emily Fforde Peel, Prudence Valentine Williams and Ida Digby were 'firsts', and extraordinary in the extent of their scientific work and management of the scientific process. Sarah Victoria Noonan had an impressive social life and Muriel Heagney was exceptional in that she was highly influential in her political career once she left Melbourne Observatory. Previous research by Clark (2012) had revealed Peel's employment history but my research further investigated and substantially added the extent of her work to this body of knowledge. Some of my findings about Greayer, Peel and Noonan were presented in 2014 to the ASV and published in their magazine (Stevenson 2015ab).

Winsome Bellamy (Sydney Observatory 1948–1968) and Verlie Maurice (Sydney Observatory 1948–1954) were measurers and computers who worked on the AC in the second half of the twentieth century. Bellamy is case studied due to the longevity of her work, but the interviews with both Bellamy and Maurice provided insights into life and working practise for the AC at Sydney Observatory.

MARY EMMA GREAYER (B1861–D1910, WORKED 1890–1899 AO)

Mary Emma Greayer was the first woman employed in astronomy in a professional observatory in Australia. When she resigned, Todd, Government Astronomer South Australia, wrote in a letter to Russell, Government Astronomer New South Wales:

> "You will probably have heard that Mr. Griffiths recently married Miss Greayer, who was a very valuable assistant at the Observatory, indeed a veritable Caroline Herschel."
> (letter Todd to Russell 29 Mar 1899, SRNSW).

Similarly, Todd also wrote to Baracchi:

> "Since Mr. Griffith's marriage, which has deprived me of Miss Greayer's services, we have been unable to observe any of your astrographic stars …"
> (letter Todd to Baracchi 3 Oct 1899, p. 386 SRSA).

Todd was referring to the quantity and quality of work that Greayer, who was employed by Adelaide Observatory as a computer for an eight-year period from 1890 to 1898, had undertaken for the Melbourne zone of the AC-CdC (Todd 1894, 1896). My research has found evidence that Greayer was Australia's first woman professionally employed in astronomy. As her employment and acknowledgement of her work were very difficult to find, a summary of my sources and findings on her observations and reductions are provided in Appendix 9: List of selected archival research records & sources. In 1898 or 1899, Greayer resigned from Adelaide Observatory to marry the Assistant Government Astronomer, Richard Fletcher Griffiths. Her departure profoundly impacted the work of Adelaide Observatory and the local amateur astronomy group. The logbooks at SRSA show that Greayer's observing and computing insignia was 'M.E.G.' or in the latter years of her work 'M.G.'.

Mary Emma Greayer was born in Port Elliot, South Australia, in 1861. She was appointed as an Assistant Teacher (number 8944) at Gepps Cross School on the 1st of January 1886, and then transferred to Angaston School on the 1st of July 1886 (University South Australia Teacher Records online database). Greayer resigned from teaching on the 21st of August 1886 (*Educational News*, 1886) and it is possible, but not conclusive, that she began work at Adelaide Observatory as one of two computers employed the following year. In 1887 Greayer's younger sister, Jessie, married the Adelaide Observatory First Assistant Astronomer, Cooke (*South Australian Register* 2 July 1887, p. 4).

Figure 60: Adelaide Observatory, the dome and the transit room in which Greayer worked (Collection SLSA).

It is certain from the observatory attendance books that Greayer was in paid work at Adelaide Observatory from 1890 (Adelaide Observatory, SRSA GRG 31/19). She was observing reference stars for the Melbourne astrographic zone through the transit telescope and reducing their locations, evident through the logbooks held by SRSA (GRG31/52). Greayer was not a photographic plate star measurer, but rather she entered observations made directly through the telescope by the observer. Her initials in the logbooks show that she was also a regular observer through the telescope, as well as reducing almost all of the co-ordinates. Greayer mainly worked with Cooke, but occasionally she worked with the other astronomers. The photograph in Figure 61 shows Greayer pictured with Todd and Cooke. This photograph was located at Perth Observatory and was, with other photographs, donated by a relative of Cooke's (B. Minchin), and it appears to be part of a larger image as it also includes the sleeve of another woman (who is not visible).

Greayer entered her work hours into an attendance record of which the years 1891 to 1893 have been preserved (SRSA GRG 31/19). She had regular day and night shifts, usually working from 9am to 3pm, then returning to work from 7:30pm to 10pm, two or three nights a week. The observation logbooks substantiate that this was the case through to 1897; and the correspondence between Todd and Russell, and then Todd and Baracchi, previously quoted in this section, indicates that she likely worked through to 1898 (SRNSW, PROV).

During the period 1890 to 1893, Adelaide Observatory reported 7,726 observations in right ascension and 6,864 observations in declination. Todd reported to the Royal Astronomical Society that observations for 1892 included 1,673 zenith stars and 573 circumpolar stars (Todd, 1893). From 1894 to 1898, Adelaide Observatory undertook two astronomical projects in conjunction with other observatories, as well as observing comets and the planet Jupiter. Positional stars for comparison with Melbourne and Sydney observations were prepared, and a catalogue of standard stars for Melbourne Observatory to use for the Astrographic Project was produced.

Entitled 'Astrographic Stars Melbourne', 1894–1895, this document is also called 'Stars for Photographic Durchmusterung [Melbourne List]' (SRSA GRG 31/122). Despite the title of the book, the work went well beyond 1895, with pencil and ink notations consistently taken through to 1898. Greayer's work required observation, recording the co-ordinates and reduction. Zenith distances were observed from at least January 1892 to the end of December 1897, with most of the observations by Greayer, Griffiths or Cooke, and the reductions calculated primarily by Greayer (SRSA GRG31/51). The reductions are not dated and most likely occurred in 1898.

Figure 61: Adelaide Observatory staff c1895 (L to R) Charles Todd, William Ernest Cooke and Mary Emma Greayer (Collection Perth Observatory) Photograph donated B. Minchin.

From the quoted correspondence between Todd and Russell, it is clear that Greayer was respected as Todd referred to her as a ‘veritable Caroline Herschel’ and regretted her departure (Todd letter to Russell 29 Mar 1899). This comparison with Caroline Herschel could be due to her dedication at recording and reducing the observations of others, but it also raises the question as to whether she made further contribution to observations and reductions for which the logbooks have not yet been identified. For example, the comet observations reported by Adelaide Observatory in 1892 were attributed to Cooke (*Adelaide Observer* 9 April 1892, p. 22), but the comet was observed on nights when Greayer also worked. Further investigation would be required to find evidence to support a direct connection between Greayer and specific comet observations.

Despite evidence of work on thousands of stars, Greayer has not been recognised by name in reports or papers in research to date. As well as working professionally in astronomy, Greayer was a keen amateur astronomer and was elected to the South Australian Astronomical Society in 1894 (*The Advertiser*, 11 April 1894, p. 6).

On 3rd March 1899 Greayer married Griffiths. To date there is no evidence that Greayer pursued astronomy further. Greayer and Griffiths had four children whilst living in Adelaide. In 1906 Griffiths succeeded Todd as the Government Astronomer but he resigned in 1907 to join the new Federal Bureau of Meteorology in Melbourne. Greayer died on the 3rd of September 1910, aged forty-nine, at "Ellesmere" Wattle Valley Road, Canterbury, Victoria. Her body was privately interred at Kew Cemetary (*The Argus*, Tuesday 6 Sep 1910, p. 1).

In 2013 I visited the site of Adelaide Observatory with the Professor of High Energy Astrophysics at the University of Adelaide, Roger Clay. The Adelaide High School Redevelopment Project was under construction. Following my visit, I explained my interest in the observatory to the school; later, Dr Cameron Hartnell, Senior Heritage and Historical Archaeology Specialist of Australian Heritage Services contacted me. Hartnell had conducted archaeological investigations around the foundations of the old observatory during a major renovation of the school (Hartnell 2014).

Due to my published research and presentation at the Women in Astronomy Conference (WiA Perth 2013), my research into women working at Adelaide Observatory was referenced in Hartnell's archaeological report. My research into Mary Emma Greayer, a woman who was previously unknown but who worked extensively in astronomy, informed interpretation of the Adelaide Observatory site.

CHARLOTTE EMILY FFORDE PEEL (B1877–D1974, WORKED 1898–1918 MO)

In 1898, Melbourne and Sydney Observatory combined forces to begin the star plate measurement at Melbourne Observatory (Baracchi, 1898a). Baracchi sought to employ women who could meet high standards in accuracy and who had the mathematical ability to be able to measure the stars and compute accurately. Charlotte Emily Fforde Peel was selected as 'very promising' in the first group of six (letter Baracchi to Russell, 28 Oct 1898a, PROV 867/P/0000, pp. 76–77). Peel's insignia is 'P'.

In 1896 Peel sat an exam for the 'Non-Clerical Division of the Victorian Public Service', the purpose of which was to recruit telephone switch operators, an occupation women were encouraged to enter. She was eligible to be a teacher (no.12698) and was employed at Patyah School. In 1898 Peel sat another exam to be tested in mathematics and was immediately identified as an outstanding applicant. Her previous employment as a teacher meant that, although she was a little older than what Baracchi had originally considered the desirable age for a measurer, she was an outstanding applicant. Peel was initially offered a temporary position at Melbourne Observatory as a transfer from teaching. In 1900 Peel, whose substantive position was head teacher of Patyah School (Victoria Government Public Sevice Gazette 1900, p. 3926), secured a permanent post with Melbourne Observatory. Baracchi reported to the State Government:

> "Miss C. Peel, who was temporarily transferred from the Education Department to the Observatory on 2nd November, 1898, was permanently appointed to the position of assistant astronomical computer on the 9th of November, 1900."
> (Melbourne Observatory 1901, p. 6).

This was a unique situation because Peel had been initially appointed on a temporary basis, as had all the other astrographic assistants. Her permanent appointment was a first in Australia in astronomy as identified by Clark's research (pers comm. Clark, 2012). Peel's role was to lead the Measuring Bureau, calibrate instruments, perform calculations, and carry out and log measurements.

Peel's work was reported to be superior to those around her and she was held up as an example to the others, as reported in letters and attendance books. All staff had to sign the attendance books and Baracchi complained to Russell in 1900 about the tardiness of some of the measurers:

> "As the excuse given is, most frequently, 'missed train' the above is regarded as a list of failures to comply with the regulations in which chief offenders are Misses Skoglund, Levy and Stanbury … it would be well for the ladies of the temporary staff to follow the good example of Miss Peel and Miss Harker."
> (letter Baracchi to Russell 1900a, PROV p. 275).

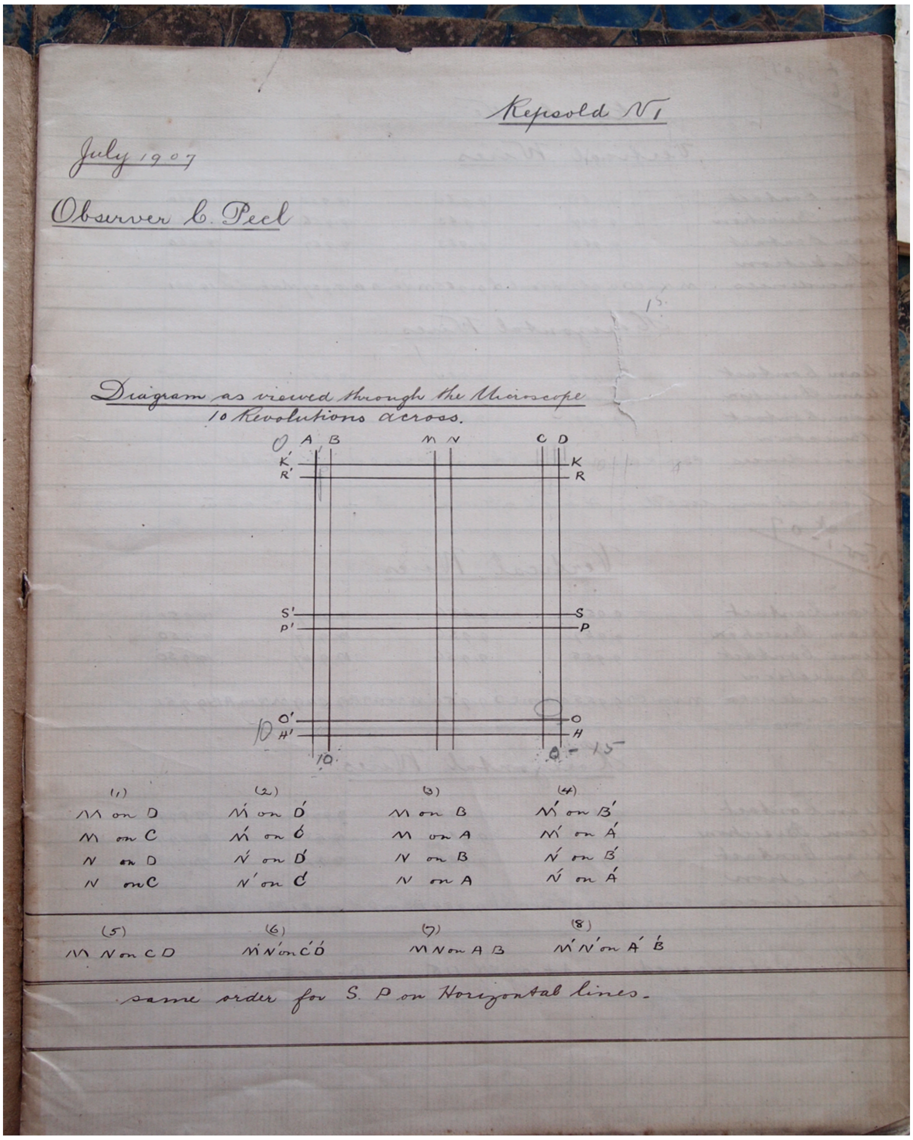


Figure 62: Wire readings for the Repsold machine, 1907, by observer C. Peel (Collection SRNSW).

Peel is acknowledged in a paper about comet observation. In 1917 James Baldwin, the Government Astronomer for Victoria, reported to the Royal Astronomical Society that comet C/1913 YI (Delavan) and comet C/1915 CI (Mellish) were measured by Peel, as shown in Figure 63. This acknowledgement is significant because the women were not, as a rule, acknowledged by name when their AC meaurements were used for further research, as discussed further in this thesis. It also indicates that Peel, as a permanent member of staff, was considered differently to the other women in the Measuring Bureau, as is also indicated by a photograph taken of the Melbourne Observatory staff.

Photographic Observations.

Instrument: astrograph. Observer: J. M. Baldwin. Measurer: C. Peel.

Comet 1913*f* (*Delavan*).

	Melbourne Mean Time.	Astrographic Positions.		Annual Aberration.		Parallax Factors.		Catalogue.
		α_{1915}	δ_{1915}	$d\alpha$	$d\delta$	log $p\Delta$.	log p/Δ.	
1915	h m s	h m s	° ′ ″	s	″			
May 6	9 10 30	17 2 33·83	−51 30 21·4	+1·85	+ 3·7	9·8569n	0·2815n	Cp. Ast00.
,, 17	7 53 48	16 35 36·30	−53 47 15·2	+2·21	+ 0·4	9·8828n	0·2683n	Gou.
June 1	6 47 23	15 56 38·33	−55 17 25·7	+2·32	− 5·1	9·8800n	9·9846n	Gou.
July 1	9 10 49	15 0 38·05	−54 14 13·9	+1·41	−12·5	9·1791	0·3816	Gou.
,, 13	10 57 56	14 50 26·28	−53 17 45·8	+0·92	−13·2	9·7878	9·3277	Gou.

Comet 1915*a* (*Mellish*).

1915	h m s	h m s	° ′ ″	s	″			
July 3	6 30 13	5 42 52·54	−48 5 8·7	−1·98	+ 4·6	9·8084	0·7433n	Cp. Ast00.

The astrographic positions are referred to the equator and equinox of 1915·0, and are corrected for the part of the aberration due to the earth's motion.

Melbourne Observatory:
1917 *Jan.* 22.

Figure 63: C. Peel's measurement of comets Delavan and Mellish (Baldwin 1917).

A staff photograph taken at Melbourne Observatory between 1910 and 1914 (shown in Figure 64) has been the subject of research by Clark (2012). Clark believes that one plausible reason for the photograph was that it was taken in preparation for the 1914 visit by the British Association for the Advancement of Science. Peel and one other woman (possibly meteorologist Moroney) flank the men, with Baracchi in the centre. The photograph is interesting in that it includes workers at all levels of the organisation, but the commonality, according to Clark's theory, is that they are all permanent employees.

Peel resigned her position of 'Assistant Computer (Female), Class "I", Professional Division' on the 31st of August 1919 to marry George Sangster, who was employed at Melbourne Observatory as a clerk and librarian. The position was advertised within the public service, and the qualifications included "A knowledge of elementary algebra and trigonometry; accuracy and speed in computing, combined with neatness of work; good eyesight; to be not less than age of 24 years." No further evidence of Peel working in astronomy has been located. In 1974 Charlotte Emily Fforde Peel, the first woman in Australia to be permanently employed in astronomy, died aged 98 in Caulfield, Melbourne.

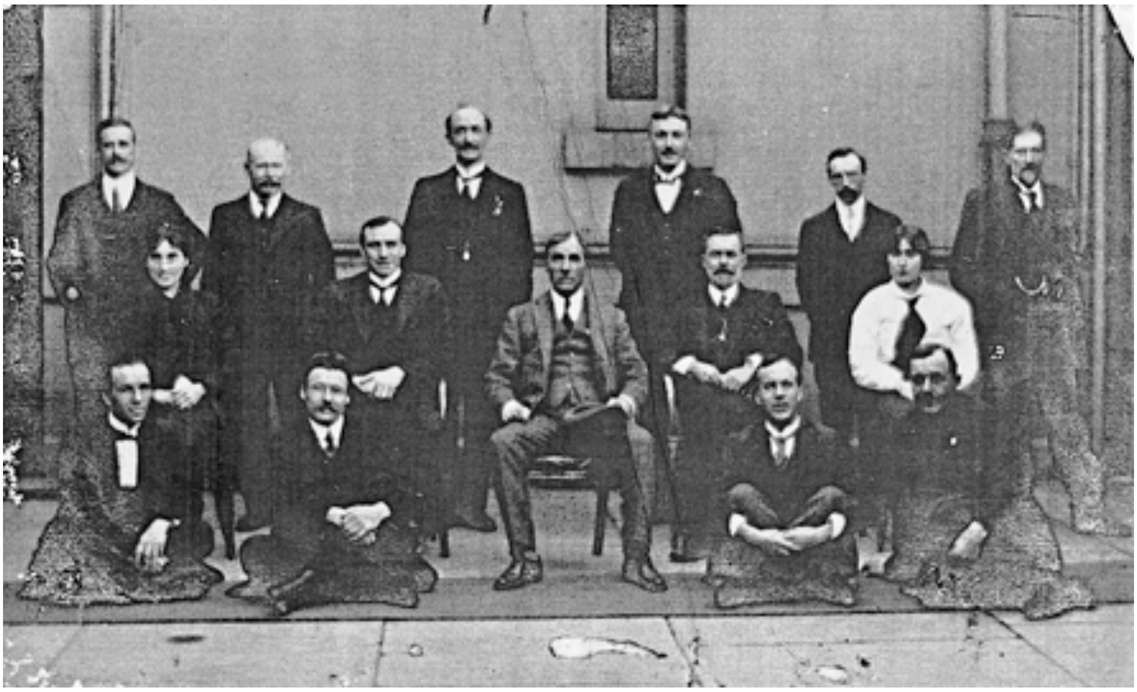


Figure 64: Staff photograph, Melbourne Observatory ~1914. Peel is centre right. Courtesy Clark 2012 (Collection ASV)

SARAH VICTORIA (VICK) NOONAN (B1887–D1973, WORKED 1907–1909 MO)

Sarah Noonan was born on the 31st of March 1887. She was employed at Melbourne Observatory as a star measurer and computer in 1907 at the age of twenty. Noonan's grandson, Bill Neal, was interviewed for this thesis and he remembered his grandmother well (pers comm, Neal 2013).

Noonan's insignia in the Astrographic Catalogue is 'N' and she was called Vick or Vicki, according to Neal and as recorded in the logbooks. Noonan was from a well-to-do family who resided in St Kilda. She attended the Presentation Convent in Windsor with her two sisters. This school was progressive in its academic education for Catholic women of the middle class. Evelyn Hockin and G. O'Donnell, attended this school and, after matriculation, began work at Melbourne Observatory, also as astrographic measurers.

Noonan's supervisor was Peel and her work colleagues were Eileen Sheldon, Hockin and Muriel Heagney who started in the same year, as well as I. Trigge, H. M. Brown and N. E. McKay. Whilst at Melbourne Observatory, Noonan had an active social life as is revealed in her autograph book, which dates from 1908 to 1910 (shown in Figure 65). The U.S.S. 'Georgia' was in Melbourne in 1908 and the program of ship arrivals, as well as autographs and short notes from crew members, are found in the book pictured in Figure 65. Noonan's colleagues, Sheldon, Heagney and Hockin, wrote popular quotes of the day in the book.

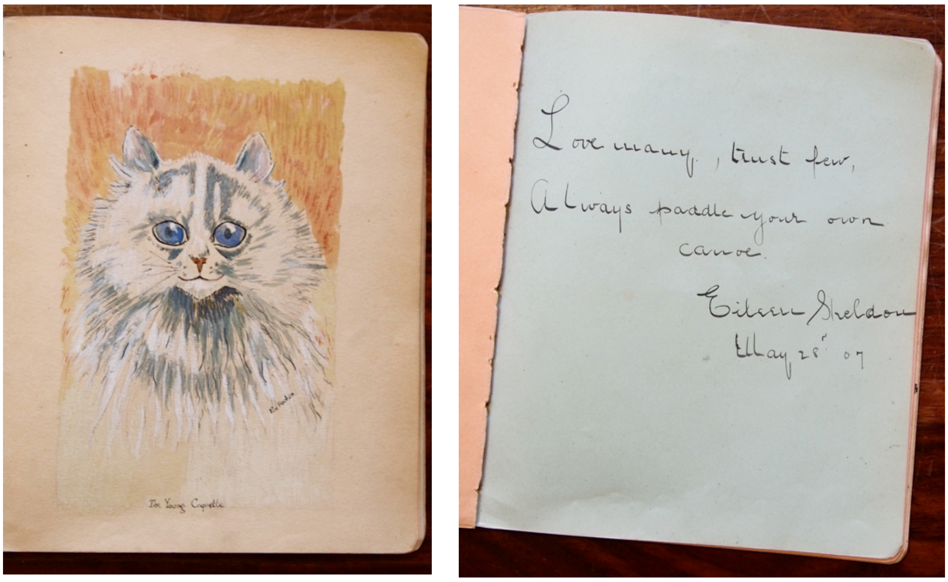


Figure 65: Victoria Noonan's autograph book, private collection; and entries by Evelyn Hockin (Collection Bill Neal).

Sheldon wrote: "Love many, trust few, always paddle your own canoe" in Noonan's autograph book. Bill Neal noticed that the pages from Eileen Sheldon and Muriel Heagney both have the same date of the 28th of May 1907, and that Hockin's picture of the cat is undated. This autograph book indicates that a highly social life was part of working at Melbourne Observatory. In contrast, on a small piece of paper found loose inside Vick Noonan's logbook (no.1218 written in 1907) was an excerpt from the poem 'Death in the Desert' by Victorian poet Robert Browning:

"For life, with all it yields of joy and woe
And hope and fear,
Is just our chance o' the prize of learning love,
How love might be, hath been indeed, and is; …"

In this philosophical poem, faith and belief are challenged by evidence. There are references to stars and, whilst there is not enough surrounding information to throw light on why it is in the log book, its presence reveals that philosophical ideals may have also been discussed in the Melbourne Astrographic Bureau.

Noonan resigned on the 14th of April 1909. In 1912, at the age of 25, she married Doctor Thomas Murphy who was aged 46—21 years her senior. They had ten children together, the youngest of whom, Enid, was born in 1930 and is Bill Neal's mother. Thomas Murphy died in 1939. Vick Noonan died on the 26th of May 1973, aged 86. Two of her children, Alison and Brendan, attended the 150th anniversary of Melbourne Observatory where I presented on the history of women at Melbourne and Adelaide Observatories, inclusive of their mother Sarah Noonan (Stevenson 2015ab).

Muriel Agnes Heagney (b1885–d1974, worked 1906–1910 MO)

Muriel Heagney was employed as an astrographic measurer and computer at Melbourne Observatory from the 28th of November 1906 until the 14th of August 1910, (Board of Visitors 1907, 1911). Her insignia was 'M.H.'. In a similar manner to Noonan, Heagney's employment came after her matriculation from FCJ Convent School in Richmond. Heagney was the daughter of Patrick Reginald Heagney, one of the founders of the Australian Labor Party, and she became a member of the Labor Party in 1905 (Francis 2011). Heagney was active in the Labor movement and is well known as a pioneer of women's rights and equal pay, as demonstrated by research into her life and influence by academics Patricia Ranald (1979), Jenny Bremner (1983), Beverley Symons (1997) and Rosemary Francis (2011).

The evidence of Heagney's four rigorous years of work at Melbourne Observatory, as one of the first women working in astronomy in Australia, had not previously been examined. Patricia Ranald researched Heagney's campaign for equal pay for women during the Depression; and Beverley Symons examined her contribution to the Labor movement (Ranald 1979, Symons 1997). Heagney's employment in teaching and defence, and her work in equal rights and the women's rights movement in Victoria, was further researched and documented by Rosemary Francis (2011, pp. 205–217). Heagney is featured in a publication commissioned by the Australian Heritage Commission in 2002 (Nugent, pp. 40-41) but there is no mention of Heagney's employment in astronomy.

The logbooks held by the MAAS, SRNSW and PROV reveal that Heagney's work was mainly measuring the Sydney Zone and her regular measuring partners included Eileen Sheldon, H. Browne and A. Alexander. A test was held in 1910 to compare the speed and error of the seven women. Sheldon demonstrated high speed and consistent accuracy whilst Heagney's speed and accuracy as an astrographic measurer was not exceptional, as shown in Table 4.

Observer	Initial	Machine	Plate #	# Stars	Time	Errors	Stars per minute	Stars per error
Charlotte Peel	C. P.	Repsold I	3259	1108	511	213	2.17	5.2
Charlotte Peel	C. P.	Repsold I	3241	860	456	15	1.89	57.3
Eileen Sheldon	E. S.	Repsold II	3257	220	125	6	1.76	36.7
Eileen Sheldon	E. S.	Repsold II	1414s	799	365	30	2.19	26.6
Eileen Sheldon	E. S.	Repsold II	1496s	472	227	13	2.08	36.3
Muriel Heagney	M. H.	Repsold II	3257	178	131	9	1.36	19.8
Muriel Heagney	M. H.	Repsold II	1414s	566	377	31	1.5	18.3
Muriel Heagney	M. H.	Repsold II	1496s	337	247	16	1.37	21.1
H. M. Browne	H. M. B.	Repsold I	3261	478	248	45	1.93	10.6
H. M. Browne	H. M. B.	Repsold I	853s	901	455	60	1.98	15
N. E. McKay	N. McK.	Repsold I	3261	473	271	63	1.75	7.5
N. E. McKay	N. McK.	Repsold I	853s	979	552	88	1.77	11.1
G. Moore	G. M.	Repsold II	2071s	218	768	133	0.28	1.6
G. O'Donnell	G. O'D	Repsold II	2071s	218	765	123	0.28	1.8
G. O'Donnell	G. O'D	Repsold II	855s	848	738	84	1.15	10.1
Eileen Sheldon	E. S.	Repsold II	855s	942	524	29	1.8	32.5

Table 4: Error tests for the 30th of August & the 18th of September 1910. Peel & Sheldon have the best results as highlighted.

In 1910 there was a proposal to form a Labor Women's Guild (*The Worker*, 9 Jun 1910, p. 5). Heagney's father was one of the main organisers, and from this initiative the involvement of the Labor Party in women's rights escalated. On the 14th of August 1910, Heagney resigned her position at Melbourne Observatory.

From 1914, Muriel Heagney was the press secretary for a branch of the Labor Party (*Labor Call* 19 Mar 1914, p. 10). She actively campaigned for women to have equal employment rights and pay, and to be able to maintain their employment after marriage. Heagney's rationale included statistics, as shown in Figure 66, where she is quoted as saying that "… 90 per cent of women worked for sound economic reasons" (*The Telegraph*, Brisbane, 13 Mar 1937, p. 11). In 1972 women were granted equal pay to men through the Equal Pay Decision 1972 (Kramar 1990, p. 4). In 1975 Heagney was posthumously featured in the Canberra Times as:

> "… the person who worked hardest and longest for equal pay in Australia died in May last year. Tiny, redoubtable Muriel Heagney stood for women's rights … all her life she was a rebel and a fighter."
> (Browning 1975, p. 17).

MARRIED WOMEN IN JOBS

Evils Resulting From Their Dismissal

Woman Investigator's Views

DISCUSSING the question of married women in industry, Miss Muriel Heagney, the noted social and economic writer and investigator, said that a careful study showed that there were relatively very few married women in industry. Of these, 90 per cent worked for sound economic reasons.

The gain in dismissing married women was negligible, and though it might benefit an individual here and there, it curtailed employment in other directions. The housekeeper would be the first to be affected, and other home services would be restricted, and education of children probably curtailed.

This had been proved by investigation in America and foreign countries, as well as here, Miss Heagney pointed out.

From a trade union point of view, if married women were employed, it was better they should be in protected than in unprotected industries.

SURVEY OF AWARDS' EFFECTS.

Miss Heagney is engaged in a survey of the position of the wage earning women in Australia under court awards and industrial legislation.

Her work is to evaluate the Federal and State awards applying to women, and to find the common denominator. She is convinced from her study of the position so far that the laws give little protection to the woman wage earner. What the law guarantees to women in Australia in wages is little, and is confined to a few groups of workers.

OPPORTUNITIES IN QUEENSLAND.

From the information she has obtained of women in Government services, she thinks that Queensland offers far greater opportunities than the other States. In Victoria, in many instances, for example, women always remain temporary employees, and have no long service rights such as are given to men.

PAY BY VALUE OF WORK.

She believes that the only way in which the differentiation between men and women can be settled is by fixing the value of occupational work without regard to sex. This has already been done by the Municipal Officers Association in Victoria.

In Victoria not so long ago a common rate was paid to all clerks in certain concerns, irrespective of sex. This did not put women out of employment in [illegible] ing women who knew their work in favour of men who would require years of training.

In Queensland there is more opportunity of arriving at an adjustment of wages for men and women, as the principle has already been laid down here.

YOUTH TAKES US TASKS

Miss Heagney's work has taken her very much among young people. It is her opinion that since the depression started, there has sprung up in Sydney a number of groups of young people, discussing ways out of the present situation in a surprising clear and informed way. There are amongst them also a growing number capable of expressing the opinions of youth on social and industrial matters in a coherent and carefully reasoned way that has not been found in previous years. She hopes that the survey in which she is now engaged will be of service in stating concisely the industrial position at the present time, giving the young people a basis on which to build even more securely.

Travel organiser for the Queensland Government Tourist Bureau in Sydney, Miss Heagney has been showing films of Brisbane and the Barrier Reef in Sydney schools, making the most of facilities afforded by the introduction there of visual education. Recently, too, she showed films of Brisbane and Heron Island to a large audience, including twenty exchange teachers, who will bring Queensland before their friends when they return to England. Miss Heagney hopes to persuade exchange teachers to spend one of their vacations in Queensland.

Miss Muriel Heagney

Figure 66: Article supporting Muriel Heagney's efforts to gain equal employment opportunities for women (*The Telegraph*, Brisbane, 13 Mar 1937, p. 11).

It has been difficult to prove if the precision required for the AC work, Heagney's use of mathematical formulae, or her employment conditions (where she was paid 54% that of her male counterparts for the same work at Melbourne Observatory) influenced her life once she left the observatory. Whilst there are log books within the MAAS uncatalogued collection and SRNSW (A3003/Box17) and Melbourne Observatory letterbooks at PROV (VPRS 866) I could not locate correspondence relating to her departure from Melbourne Observatory, and the archive of Heagney's papers held by La Trobe Library, State Library of Victoria

(MS901), are for the period of her life from 1936. Heagney's work at Melbourne Observatory has potential for further detailed research.

PRUDENCE VALENTINE WILLIAMS (B1891–D1968, WORKED 1907–1918 PO)

Prudence Valentine Williams was born in 1891 to Elizabeth Ann and William Williams. Williams, nicknamed 'Billy', received a good education through to high school and achieved in the sciences and the Arts. Her sister, Florence, was married in 1903 to Clive Nossiter, the Astronomical Computer and Observer at Perth Observatory. Her insignia was 'P.W.'.

Prior to completing her high school education at St Joseph's Sisters of Mercy School, Williams passed the University of Adelaide junior primary entrance examination in 1906 (*The West Australian*, 5 Jan 1907). St Joseph's was the first high school for girls in Western Australia and it 'assisted' girls or provided free education. Williams continued to her final year of school and, in 1907, was awarded a gold medal prize. Williams' subjects were English literature, English history, Latin, French, arithmetic, algebra and geometry (*The West Australian* 20 Dec 1907, p. 8).

When Williams commenced work at Perth Observatory in 1907, she was 16 years old. She was employed as a junior clerk; in the departmental Observatory Budget papers her title was Astrographic Assistant (SRWA 1813/0963/752). When Kendall commenced in 1908, Jones and Harrington joined the Astrographic Bureau to make a team of four measurers and computers. Williams was exceptional in that she stayed on until 1918, whilst the other three Astrographic Bureau staff left after only one year.

In 1909 Netta O'Dea, Minnie Elizabeth Harvey and Hilda Arnold commenced employment. O'Dea left that same year to marry. They were photographed for an article promoting the work of Perth Observatory and its value to the community, which included the star catalogue work. Names were not put to faces in the photograph shown in Figure 67. There are photographs of the male astronomers in other records, which made it possible to identify them, but this is the only photograph of the women who worked at Perth Observatory (which I have been able to locate).

In 1910 the temporary appointments section of the Western Australia Public Service Gazette listed the women as employee #317 P. Williams age 19, #318 H. Arnold age 21, #320 M.

Williams age 18, and #321 M. E. Harvey age 16 (Western Australia Public Service List 1910, p. 194). A. P. Thompson was a clerk. Arnold left in 1910 and Mary Alice Williams left in 1911 to marry. They were replaced by Ethel Allen and Ida Tothill, which meant there were consistently two measuring teams, each of two persons. In 1912, the Perth Observatory Astrographic Bureau included Prudence Williams, Minnie Elizabeth Harvey, Ethel G. Allen and Ida Tothill. On the 28th of November 1912, Williams, Harvey, Allen and Tothill attended the first meeting of the Astronomical Society of Western Australia (Minute Book ASWA in Utting 1994, p. 37). On the 25th of February 1915, Williams and Harvey were elected to the ASWA (*The Daily News*, p. 2).

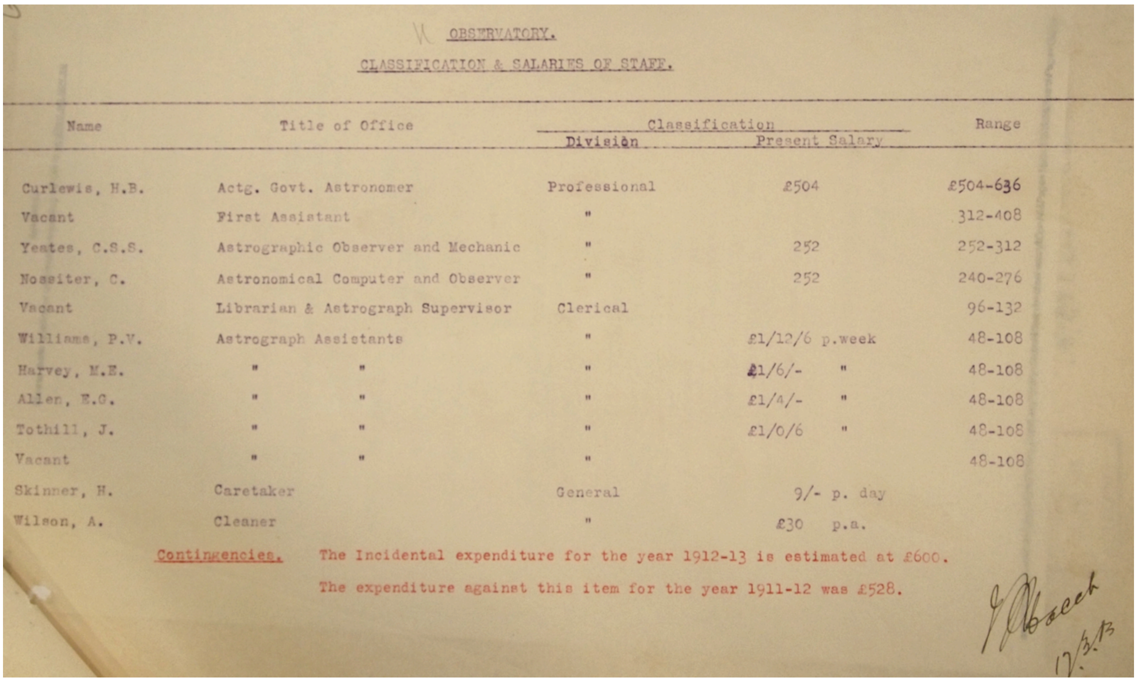
Figure 67: Perth Observatory Staff photograph. Women: P. Williams, M. Williams, M. E. Harvey, H. Arnold. Men (L to R): C. Nossiter, C. S. Yeates, W. E. Cooke (seated), H. B. Curlewis (*Sunday Times* 1 May 1910, p. 3).

The women's working days were typically 9am to 1pm, then 2pm to 5pm (1913 Timebook, PO). In 1913 there was dissatisfaction about wages amongst the four women and their claim for an increase—"£48 min and £96 max for the assistants and £96 min and £132 max for the Assistant Supervisor"—was granted. Williams, Harvey, Allen and Tothill wrote to the Acting Government Astronomer, Curlewis, and complained that a promise to make them permanent public servants, as well as an increase in their wages, had not been fulfilled:

"… we are quite sure that no other girls in the service engaged upon such responsible and exacting work, are so poorly paid …"
(letter Williams, Harvey, Allen, Tothill to Curlewis 26 May 1913, SRWA 752).

Curlewis wrote to the Under Secretary of the Colonial Secretaries Department emphasising that the nature of the work was not clerical, but that they were 'professional officers' or, in other words, doing equivalent work to astronomers:

"… their duties are of a purely technical nature and quite dissimilar to ordinary clerical work. They might very well be treated from the standpoint of professional officers."
(letter Curlewis to the Under Secretary, 30 May 2013, SRWA 752 1914/3046).



OBSERVATORY.

CLASSIFICATION & SALARIES OF STAFF.

Name	Title of Office	Classification		Range
		Division	Present Salary	
Curlewis, H.B.	Actg. Govt. Astronomer	Professional	£504	£504-636
Vacant	First Assistant	"		312-408
Yeates, C.S.S.	Astrographic Observer and Mechanic	"	252	252-312
Nossiter, C.	Astronomical Computer and Observer	"	252	240-276
Vacant	Librarian & Astrograph Supervisor	Clerical		96-132
Williams, P.V.	Astrograph Assistants	"	£1/12/6 p.week	48-108
Harvey, M.E.	" "	"	£1/6/- "	48-108
Allen, E.G.	" "	"	£1/4/- "	48-108
Tothill, J.	" "	"	£1/0/6 "	48-108
Vacant	" "	"		48-108
Skinner, H.	Caretaker	General	9/- p. day	
Wilson, A.	Cleaner	"	£30 p.a.	

Contingencies. The Incidental expenditure for the year 1912-13 is estimated at £600.
The expenditure against this item for the year 1911-12 was £528.

17.3.13

Figure 68: Perth Observatory 'Astrograph Assistants' annual wage £48–£108. (Collection SRWA).

Figure 68 shows the salaries in 1913. As seen in this chart, the astronomers were paid under the 'professional' division, whereas the women who were 'Astrograph Assistants' were considered 'clerical'.

Williams was eventually elevated to the vacant role of Librarian and Astrograph Supervisor, however, the women were not granted permanent employment.

Issues arose between the measurers and Clive Nossiter, the Acting First Assistant Astronomer, who was also the Astrographic Bureau Supervisor and Williams' brother-in-law. In 2014 Curlewis requested a written explanation from Williams after Nossiter submitted a report claiming 'lax discipline' and "Miss Tothill and Miss Harvey's carelessness" in the measuring branch (Curlewis, 27 July 2014, SRWA 752 1914/3046). The three more junior women responded by writing in support of Williams, and Williams responded with a five-page explanation. Both of these documents are revealing of the work and the attitudes in the workplace. Williams and Harvey were acknowledged in the first volume of the Perth zone of the Astrographic Catalogue (Cooke 1911, p. 5), but Tothill and Allen (who started in 1910) were not. Williams' acknowledgement included her work in computing plate constants, which was a complex equation.

Williams explained why faint or blurred stars were often difficult to measure without disagreement; and that on a cloudy day the magnitude of the stars is different to observe than on a clear day when the light is much brighter. Williams stated that in six months the Measuring Bureau had taken direct and reverse measurements and compared them to another star catalogue, the CPD. They then revised and produced the documentation for the printer for 60 plates which totalled 21,221 stars. Furthermore they had also almost completed another 4 plates with 4,500 stars. Much of this work was by Tothill and Harvey. This was because Williams was also the Librarian, and she and Allen were engaged in computations. Williams wrote that Nossiter was not as productive: "I am afraid he cannot show a corresponding amount of work for the same period." Nossiter had accused the women of talking, to which Williams replied:

> "… Mr. Nossiter must have a vivid imagination when he states that some days we talk almost incessantly; he is evidently judging us by himself, as for about two months … he and Mr. Whitby talked almost incessantly …"
> (letter Williams to Curlewis, 1914, SRWA 752 1914/3046).

Williams claimed that Nossiter had spoken inappropriately towards the women, had a 'vivid imagination', and was a 'bully', a 'cad' and a 'sneak'. She disagreed with his supervisory methods and behaviour, particularly because he had accused the measurers of 'faking' their results:

> "… he has spent the last few months going through every detail of the work completed in our office, not with a view of supervising it, but because he is our enemy … we have often noticed some slight peculiarities with regard focus, eyepiece, scale etc. which if rectified might make the measuring much easier but when calling Mr. Nossiter's attention to the fact he sometimes has not been able to detect anything wrong , & has then asked if we had been out all night, or what did we drink …"
> (letter Williams to Curlewis, 1914, SRWA 752 1914/3046).

One of the main points made by Williams was that although the astrographic assistants were criticised for errors of computation, they were taking on the work of others, without specialist training or being raised to a position of ‘computer’. Williams’ report convinced Curlewis that he could have “complete trust in them” (letter Curlewis to the Under Secretary, 10 Aug 2014, SRWA 752 1914/3046).

In 1916 Curlewis made a further application to the Colonial Secretary for their wages to be reviewed with an increase of £12 per annum as they were still on a temporary award. This would bring Williams’ salary that year to £108 per annum and the others to £96 per annum, in line with a clerical wage but well below that of the Perth Observatory astronomers.

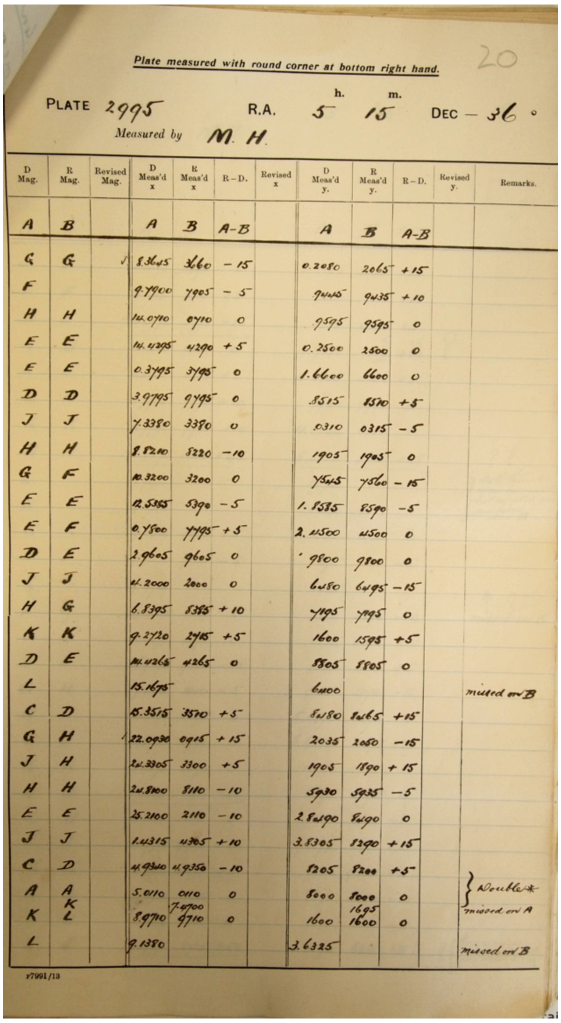


Figure 69: Magnitude, computation and double stars by Minnie Harvey at Perth Observatory for Plate 2995 (Collection SRWA 752 1914/3046).

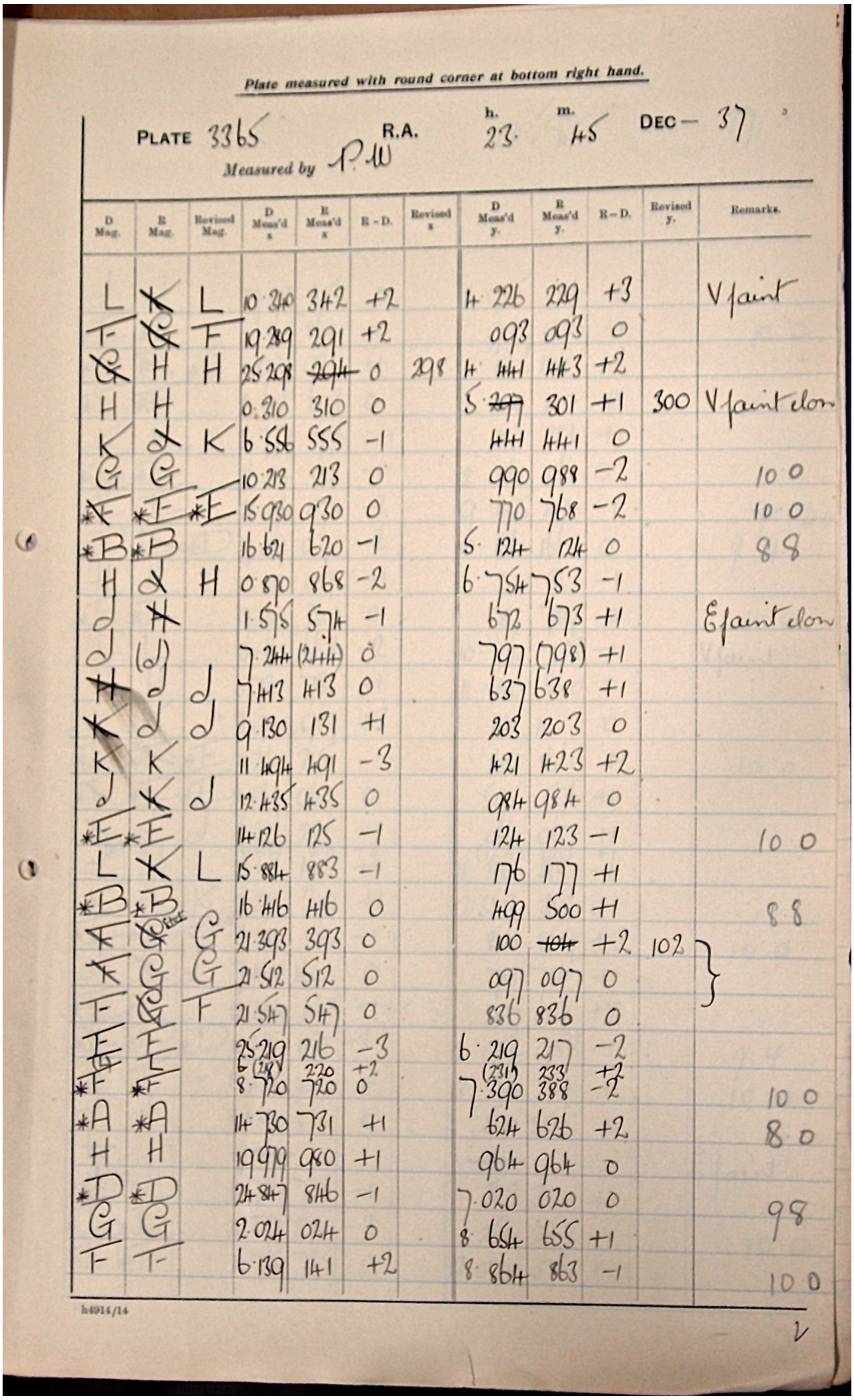


Plate measured with round corner at bottom right hand.

PLATE 3365 R.A. h. 23 m. 45 DEC — 37

Measured by P.W.

D Mag.	R Mag.	Revised Mag.	D Meas'd x	R Meas'd x	R − D.	Revised x	D Meas'd y.	R Meas'd y.	R − D.	Revised y.	Remarks.
L	K	L	10·340	342	+2		4·226	229	+3		V faint
F	G	F	19·289	291	+2		093	093	0		
G	H	H	25·298	294	0	298	4·441	443	+2		
H	H		0·310	310	0		5·299	301	+1	300	V faint elon
K	J	K	6·556	555	−1		444	441	0		
G	G		10·213	213	0		990	988	−2		10 0
*F	*E	*E	15·930	930	0		770	768	−2		10 0
*B	*B		16·621	620	−1		5·124	124	0		8 8
H	J	H	0·870	868	−2		6·754	753	−1		
J	K		1·575	574	−1		672	673	+1		E faint elon
J	(J)		7·244	(244)	0		797	(798)	+1		
K	J	J	7·413	413	0		637	638	+1		
K	J	J	9·130	131	+1		203	203	0		
K	K		11·494	491	−3		421	423	+2		
J	K	J	12·435	435	0		984	984	0		
*E	*E		14·126	125	−1		124	123	−1		10 0
L	K	L	15·884	883	−1		176	177	+1		
*B	*B		16·416	416	0		499	500	+1		8 8
K	G	G	21·393	393	0		100	104	+2	102	}
K	G	G	21·512	512	0		097	097	0		
F	G	F	21·547	547	0		836	836	0		
E	E		25·219	216	−3		6·219	217	−2		
			6·(218)	220	+2		(231)	233	+2		
*F	*F		8·720	720	0		7·390	388	−2		10 0
*A	*A		14·730	731	+1		624	626	+2		8·0
H	H		19·979	980	+1		964	964	0		
*D	*D		24·847	846	−1		7·020	020	0		98
G	G		2·024	024	0		8·654	655	+1		
F	F		6·139	141	+2		8·864	863	−1		10 0

h4914/14

Figure 70: Magnitude, computation and double star identification by Prudence Valentine Williams at Perth Observatory for Plate 3365 (Collection Perth Observatory, uncatalogued).

My detailed study of the Perth Observatory bureau revealed that the women did measurement and computation, checked errors and also identified double stars (indicated by brackets), as seen in the magnitude log prepared by Harvey in Figure 69 and Williams in Figure 70. The women also compared the stars to other star catalogues. This was part of their every day work. A paper published by Barton (1936, pp. 33–39) revealed that Nossiter had published double star measurements that had been previously identified by the Astrographic Bureau.

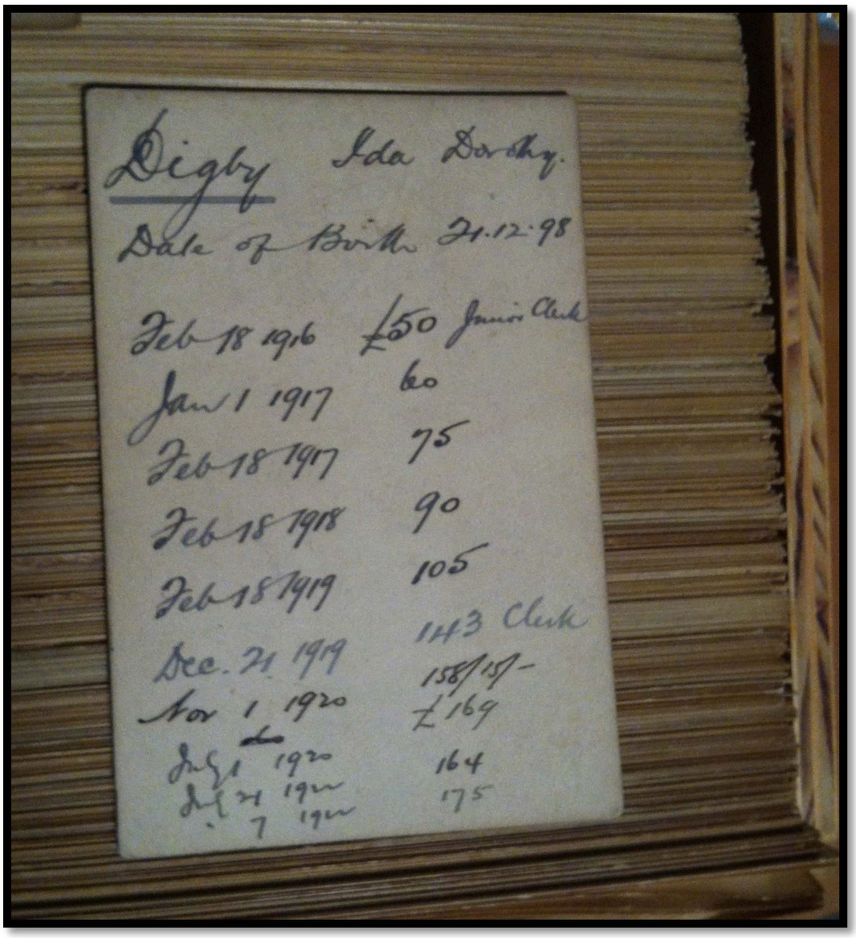
Williams left employment at PO in 1918 (WA Blue Book 1919) and Tothill left the following year. Harvey and Allen stayed on as 'Junior Computers' and then became 'Assistant Computers' until 1922. Harvey married John Adams in 1928; Allen married Ellis Smellie in 1921; and Tothill is recorded as attending social and heritage related events over the following two decades.

It is not known why Williams resigned or what she did in the period between 1918 and 1927. What is known is that her brother returned to Australia from WWI in March 1919 (Australian War Memorial Service records) and that her married sister, Ethel May Smith, died in 1920 aged 37, leaving two children. In 1927 Prudence Valentine Williams married newsagent James Leonard Larkin. In 1928 there was a court case in which her husband, Larkin, was charged with threatening to murder her brother, Walter C. Williams (*The Daily News* 1928). The charges were dismissed but what emerged was that Prudence was ill in hospital and this had something to do with her husband's threat to her brother. James Larkin died in 1963 aged 65. Prudence Valentine Larkin (nee Williams) died in 1968; according to records she was aged 79. She is buried in Karrakatta Cemetery, Anglican, VC, 0362 in Perth, which is close to the old observatory site.

IDA DOROTHY DIGBY (B1898–D1985 WORKED 1916–1926 SO)

Ida Dorothy Digby and Irene Maud McDonald were the first women to begin star measurement work at Sydney Observatory under Cooke. Digby was seventeen when she started work on the 18th of February 1916; McDonald, who was the same age, started three days later. Digby and McDonald sat the public service clerk's exam at the same time as their intermediate exam on the 15th of December 1915. They were admitted to the public service as clerks on £50 per annum; the boys who sat the same exam were admitted at £60 per annum (*The Sydney Morning Herald* 15 Feb 1916, p. 12). Digby's starting wage was £60 per annum and this progressed steadily up until 1926 when she left employment at the observatory on £175 per annum, as shown in her employment card (Figure 71).

Ida Digby's address is given in the attendance book for 1920 to 1923 as the 'Sydney Fire Station on George Street West' (SRNSW box 138, A3003). My research has shown that Digby's father was the Fire Inspector at the station where the family lived (*The Canberra Times* 1926, 10 Sept, p. 4). Digby was amongst the first women to be employed in NSW on an ongoing or permanent capacity in astronomy when she was gazetted in 1920.



Digby Ida Dorothy.
Date of Birth 21.12.98
Feb 18 1916 £50 Junior Clerk
Jan 1 1917 60
Feb 18 1917 75
Feb 18 1918 90
Feb 18 1919 105
143 Clerk
Dec. 21 1919 158/15/-
Nov 1 1920 £169
July 1 1920 164
July 21 1920 175

Figure 71: Ida Digby's employment card (Collection MAAS, uncatalogued).

In 1926, the women left their employment at Sydney Observatory and were transferred to other government departments or resigned. Digby was transferred to the Building Branch and McDonald to the Records Branch of the NSW Education Department; Cronin transferred to the Insurance Branch of the NSW Treasury. Both Clements and De Moulin resigned in order to marry. In 1938 Digby married Keith James Baxter in Randwick, and in 1939 they had a son, Paul Digby Baxter. Ida Dorothy Digby died in Northbridge, Sydney, on 23rd August 1985.

WINSOME BELLAMY (B1928, WORKED 1948–1968 SO)

Winsome Bellamy was interviewed for this thesis (2011). Her work at Sydney Observatory spanned twenty years and Harley Wood praised her, and co-worker Margaret Colville, for their work in completing the Astrographic Catalogue (Wood 1971, p. 7). Bellamy was among several measurers and computers who completed the Sydney and Melbourne sections of the AC under Wood's direction at Sydney Observatory. According to Bellamy, her prior training was nursing and office work at the Temperance and General Insurance Company. In 1947 she passed the exam for Infant Nurses (*Sydney Morning Herald* 20 Dec 1947, p. 7), after which she sat the public service exam and was surprised to be placed at Sydney Observatory. There she found the work to be uncomplicated but boring:

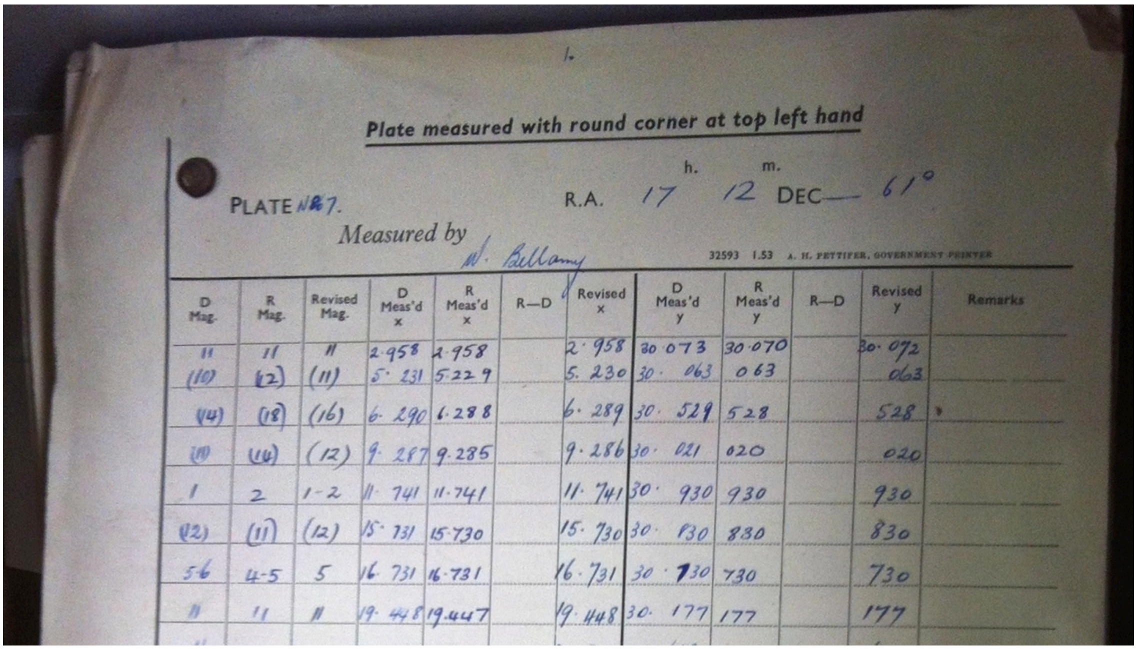
> "There were four of us working on the micrometers, and two were measuring star positions and two were writing down the details of the measurements. And in between times we were knitting or doing crosswords or whatever … not having an interest in astronomy it was just routine work that we'd been taught and we just got on with it."
> (pers comm, Bellamy 2011).

According to Harley Wood's daughter, Rosamond Madden (pers comm. 2009), and as documented by Roslyn Russell, the women working on the Astrographic Catalogue were highly respected by Harley and Una Wood (Russell 2008, p. 131).

Bellamy was employed for over twenty years at Sydney Observatory and, when interviewed, she explained the process of measuring for the AC:

> "Dr Wood and Mr. Robertson taught us how to measure. There was nothing complicated about it. It was just centering a cross line, which was made of spider web. And the interesting part was that my father, who was a gardener, used to have a lot of spiders in the garden. And I would bring them in a little jar. They had to be garden spiders, because they spun the plainest web, and Mr. Pinnock would make the crossbars for the micrometers out of the spider webs, which I thought was rather great. It was an extra feather to my wing."
> (pers comm, Bellamy, 2011).

The process had remained constant from 1898 through to 1961 and Bellamy's description of working life at the observatory implies that even if the work was repetitive, there were many other interesting distractions.



1.

Plate measured with round corner at top left hand

PLATE №7. R.A. 17 h. 12 m. DEC — 61°

Measured by W. Bellamy

32593 1.53 A. H. PETTIFER, GOVERNMENT PRINTER

D Mag.	R Mag.	Revised Mag.	D Meas'd x	R Meas'd x	R—D	Revised x	D Meas'd y	R Meas'd y	R—D	Revised y	Remarks
11	11	11	2·958	2·958		2·958	30·073	30·070		30·072	
(10)	(12)	(11)	5·231	5·229		5·230	30·063	063		063	
(14)	(18)	(16)	6·290	6·288		6·289	30·529	528		528	
(11)	(14)	(12)	9·287	9·285		9·286	30·021	020		020	
1	2	1-2	11·741	11·741		11·741	30·930	930		930	
(12)	(11)	(12)	15·731	15·730		15·730	30·830	830		830	
5-6	4-5	5	16·731	16·731		16·731	30·730	730		730	
11	11	11	19·448	19·447		19·448	30·177	177		177	

Figure 72: Comparative measurements of AC Plate 867 by Winsome Bellamy (Collection SRNSW).

As shown in Figure 72, Bellamy's work was neat and precise. In many ways Bellamy found the observatory work 'routine', but she revelled in the social interaction with the other star measurers, evident by the photographs from her album taken during lunch times on Observatory Hill or at social events. There were occasional lunchtime shuttlecock games when the Wood family and the observatory staff played together. According to Bellamy, the women often went out onto Observatory Park for lunch as shown in Figure 73. They sat under the Moreton Bay Figs, watching the ships on the harbour, or played badminton on the flat piece of lawn that used to be a tennis court. If it was wet they stayed indoors and made a ping pong table in the library.

As described by Bellamy, the social life was vigorous, with the occasional engagement party or wedding signifying the departure of a work colleague such as Verlie Maurice, who left Sydney Observatory to marry. Maurice recalled:

> "I had the intermediate certificate; we all had a basic education. When we left school at around 15 years old we straight away sought jobs, it was what girls did then. I did basic, or general math. Margaret Wilson (nee Colville) seemed to be very bright. I did have to call out numbers for Harley Wood sometimes and I learnt how to memorise and check numbers. I must have been quite capable at that but I don't remember doing any complicated calculations. I did have to do tidal readings and the positions of the Sun and, I think also the planets."
> (pers comm, Maurice, 2013).

Figure 73: (L to R, F to B) Verlie Lee, Renee Day, Margaret Colville, Patricia Lawler, Margaret Brown. Photograph W. Bellamy, 1947 (Collection MAAS, uncatalogued).

The social consequences of the AC included friendships that lasted decades, such as described by Maurice and Bellamy, and the occasional marriage between the observatory staff. Maurice described the work as routine but revealed that her affinity for numbers had continued throughout her life (pers comm., Maurice, 2013).

EDINBURGH WOMEN MEASURED THE SOUTHERN STARS

For many reasons Cooke insisted that Britain measure some of the Perth Observatory stars for a fee. It is unclear whether this was to engage in closer ties with the ROE Astronomer Frank Dyson, and open up prospects for his own career, or because of a genuine lack of resources to finance the measurement at Perth Observatory. Turner wrote to Dyson and congratulated him on this decision: “Hurrooo! Good for you” (letter Turner to Dyson, 13 Jun 1907, Correspondence ROE A44.330 1906–10).

Figure 74: Royal Observatory Edinburgh Astrographic star measurers and computers c1911. One pair is likely the Falconer sisters, the other Knott and Makintosh (Collection ROE in Brück 2008, p. 217).

The Government of Western Australia paid the British Government for the work to be done and this was assigned to ROE at £60 per annum, which determined the payment of the women's wages. The plates were sent by sea via the West Australian Agent General. The work began in 1908 (Dyson 1909, p. 270). The photograph in Figure 74 shows the women working in pairs. One woman would measure with the micrometer (which appears to be a similar type to the 'Greenwich' micrometer purchased for Perth and Sydney Observatories by Cooke) while the other wrote down the XY co-ordinates. Brück estimated the date of this image as 1906; however, the measurement did not commence until 1908 (Dyson 1908, p. 267) with four women employed in 1910 to complete the measuring and for computing (Dyson 1911, p. 296).

The names of the supervisors, and most of the measurers and computers, as printed in the AC are seen in Figure 75. The first women employed were in 1908 sisters S. A. Falconer (Sophia or Sabina) and J. C. Falconer (Janet or Jane, who is notated as I. C. Falconer) who lived a short walk from the Royal Observatory (ROE Staff Absence Records A44.382) and in 1910 E. G. Knott, J. G. Makintosh. Good progress appears to have been made in the first few years, as in 1910 Cooke wrote to Dyson:

> "I am very pleased to hear you are getting on so well with our plates."
> (letter Cooke to Dyson 1910, ROE A44.330).

The work of measurement was carried out under the direction of Professors F. W. Dyson and R. A. Sampson, Astronomers Royal for Scotland. Mr R. W. Wrigley has been responsible for the preparation of the material for press. In the final stages he has been assisted by Miss M. Le Harivel.

The following persons have taken a share in the measurement of the plates: —

Name	*Initials*
Mr G. Clark	G. C.
Miss L. V. Cornish	L. C.
Miss I. C. Falconer	I. F.
Miss S. A. Falconer	S. F.
Miss E. G. Knott	E. K.
Mr J. L. MacGregor	J. L. M.
Miss J. G. Mackintosh	J. M.
Mr J. Storey	J. S.
Miss E. M. Wrigley	M. W.
Mr R. W. Wrigley	W.

Figure 75: The Edinburgh women who measured stars for Perth Observatory. Perth Astrographic Catalogue Vol.31 (Greaves, 1939 p.V).

In 1912, L. V. Cornish and E. M. Wrigley (the daughter of the Astrographic Supervisor, R. W. Wrigley) began work. On the 21st of May 1913, there was a bomb attack on ROE. This was attributed to suffragettes although the perpetrators were never charged (http://www.roe.ac.uk/whatsnew/event/20130521/). That same year Knott and Makintosh left, and in 1914 so did Cornish and Wrigley.

S. A. Falconer left ROE on the 8th of Sep 1916 for the war effort. She departed on the 25th of September for France. In many ways the war impacted on progress on the AC, as reported by Sampson, the Astronomer Royal for Scotland:

> "War conditions throughout the year have again severely restricted the work which it was possible to do … The claims of war service have also severely interfered with the supply of lady computers."
> (Sampson 1919, p. 242).

I have found evidence of women who were employed for the AC but are not listed in the archival catalogues of the ROE. They include K. A. Williams, who measured and computed from 1917 to 1919. In 1919 Williams was replaced by M. D. Smith, who worked until 1920 and is also not listed. Sampson complained about the difficulty of getting the right sort of women for this work because wages for computers were insufficient. According to Sampson, the ladies deserved a higher wage (than £30) because they:

> "... became very capable members of the staff … no special training is asked for on entry."

Within four months, the annual wage for computers had increased to £50 per annum *yet according to Sampson this was not sufficient because:*

> "… owing to the rise in women's payment the right class cannot now be engaged for this sum."
>
> (letter Sampson to Dyson 16 Aug 1919, ROE 52.447).

The women's names were not noted in the associated research papers, which relied on their measurements and observations for the findings. For example, when in 1911 Wrigley published a paper on double stars shown in Figure 76, he used the term 'astrographic' to denote that this star was photographed for the AC (Wrigley 1911, p. 34). Two double stars from the Perth zone of the AC measured at Edinburgh Observatory by Falconer, Falconer and/or Knott, Mackintosh, were compared by Wrigley to the measurements obtained by optical observers: (h) John Herschel, Lawrence Hargrave, John Tebbutt, Joseph Lunt and Robert Innes. C. G. A. denotes the Catalogue General Argentine (Wrigley 1911, p. 34).

Ref. Cat. 10^{h}·78. *h.* 4373. *Combined Mag.* 8·8.

Distance.	Position Angle.	Epoch.	Observer.
25″±	226°·1	1835·2	*h.*
12·66	337·0	1879·4	Hargrave.
10·44	339·1	1882·3	,,
6·01	…	1892·5	Tebbutt.
10·8	344·0	1900·4	Innes.
11·0	344·5	1902·5	,,
10·74	345·6	1903·4	Astrographic.
10·50	346·2	1903·3	,,

Ref. Cat. 18^{h}·7. *h.* 5023. *Combined Mag.* 8·0.

Distance.	Position Angle.	Epoch.	Observer.
9″·76	275°·8	1836·5	*h.*
8·99	276·5	1837·5	,,
10·42	276·3	1879·3	C.G.A.
5·85	277·5	1880·7	Hargrave.
	277·3	1900·6	Lunt.
9·14	276·2	1900·6	,,
8·97	275·1	1903·6	Astrographic.

Figure 76: Two double stars from the Perth zone of the AC measured at ROE (Wrigley 1911, p. 34).

In 1920, A. I. Clarkson and C. S. Strachan calculated the reductions and prepared the catalogue documents for publication. In 1922, the papers for printing were handed over to Perth Observatory (Sampson 1923, p. 263).

Chapter Conclusion –women had agency in the observatory

Surprisingly a significant number of women were involved in the Astrographic Catalogue and Carte du Ciel. They worked not only in supporting roles but also had responsibility for telescope observation of reference stars, data collection, star measurement, double star identification, error management and technologies. Their analysis of magnitude and other star attributes was central to the outcome of the project. The AC-CdC were extraordinary examples of scientific projects at the leading edge in adopting modernist ideals that would permeate science more broadly.

Evidence supports that women were first employed in observatories in Australia to work on the AC. At Adelaide, Melbourne, Perth and Sydney Observatories, their work was essential to the project. By examining archival letters, records of employment and archival logbooks used to record who observed, catalogued and reduced the star positions, I have uncovered that the women who worked on the AC were selected as outstanding in their mathematical ability, and those who became the leaders were intelligent, analytical and able to work in areas previously considered to be ‘professional astronomy’.

A substantial number of women worked as measurers and computers. This work used standard astrometry reduction formulas to determine the true star co-ordinates, but had previously been done by men who were called ‘computers’. The women were called ‘assistant computers’ or ‘star measurers’ and their wages were generally 54% of that of their male peers. In some cases the women performed equivalent work to the men, even though the lens of gender discrimination led to restrictions on the type of work women were given, rather than work being assigned on the basis of skill and merit. Mary Emma Greayer worked directly alongside the astronomers at Adelaide Observatory during the evening, doing equivalent work.

New techniques and technologies, which had not previously been used for measuring stars, the determination of star magnitudes and the computation of star positions, were developed for the AC-CdC. As such, it was inevitable that the observatory staff who implemented the techniques and used the new equipment were involved in the discovery of new knowledge surrounding the methodology and its errors, in addition to participating in the project's rigorous recording and data capture priorities. As a number of the women were employed for many years, they gained experience; the contribution of these senior women to the observatory went beyond the repetitive work.

Clearly some women had greater agency than had previously been acknowledged, and there is evidence that their contribution was scientific in nature. The contribution of my research is twofold: to provide substantial evidence that the type of work the women actually performed exceeded what was officially reported, and that the technical work performed for a scientific endeavour is part of, not separate from, the science.

I have demonstrated that the structural confinement of the AC 'computers' to star measurement, reduction computation and catalogue related work followed the lead of the Royal Greenwich Observatory, where the Astronomers Royal, Frank Dyson (1910–1933) and later Howard Spencer Jones (1933–1955) insisted that the colonial observatories play a subservient role. They focussed on completing the Astrographic Catalogue zones and providing data for use by other astronomers.

This was a very different model to the spectroscopic program at Harvard College Observatory, which enabled the female computers who measured stars for its astrographic catalogue to produce and publish new research. This, and significant government and private funding to build large new telescopes and well-resourced observatories, enabled the US to become a leader in astrophysics. The capacity to enable research was made possible by a visionary directorship by Edward Pickering, who was independently wealthy and well connected. It was leveraged by philanthropic funding for institutions to educate women in astronomy, with a level of autonomy for some of those women to pursue specific investigations.

Even though women were members of astronomy societies, this has been little represented in the mainstream history of astronomy in Australia. The lack of recognition can be rationalised due to their lesser roles within the societies, but it is also symptomatic of the gender bias typical in recorded history. This gender bias has also permeated how historic significance is perceived and hence how evidence is preserved. It is why researching a woman in science is, in most cases, remedial and less complete than the evidence of men's work (Benjamin, 1991). Fortunately, the AC-CdC heritage collections are still relatively complete, and through the attendance and logbooks it was possible to glimpse not only the extraordinary collaborative work produced by the women, but also the standout women who concurrently engaged in scientific research, and whose operational, mathematical and technical skills deserved greater recognition. The working lives of Mary Emma Greayer, Charlotte Emily Fforde Peel, Sarah Victoria Noonan, Muriel Heagney, Prudence Valentine Williams, Ida Dorothy Digby and Winsome Bellamy, as well as many others, are recoverable from the hundreds of logbooks produced for the AC-CdC. Daily routines, as well as the occasional unusual occurrence (such as a comet reduction or double star recognition) can be traced through these records.

A final observation is that the roles of the women working on the AC in the observatories changed over time. The first women—for example Greayer, Peel and Williams—had greater access to make observations and participate more fully in the scientific and analytical work. Later on in the project, when Winsome Bellamy was employed, the work was almost solely data management, measurement and calculation, with little need to understand the astronomy behind the work. This change in the type of work may have reflected the different phases of the project or that the roles for women in astronomy had become further differentiated from the male roles over time. This would parallel the 'professionalisation' of astronomy from the late nineteenth to the mid twentieth centuries. A further factor is that by the time Harley Wood took over the project, the priority was to complete the work; and whilst Wood published to some extent about the project, his emphasis was on its completion and this was, most likely, restrictive.

By observing the Astrographic Catalogue through a social and collection based lens, the legacy of the measurers and computers has come into focus as holding new significance. This significance is different to the scientific outcomes of the project, but it is interwoven into the fabric of scientific organisations and has relevance today.

CHAPTER 5: COMPLETION OF THE STAR CATALOGUE (1964)

> "… our real concern is not with the state of the heavens at any particular moment, but with the changes which may be discerned by comparing one epoch with another ..."
> (Turner 1912, p. 135).

As quoted above and substantiated throughout his publication entitled *The Great Star Map* (1912), Turner argued that there was no expectation of immediate research findings from the AC-CdC. He prophesised that the AC had potential to overturn what was considered fact at that time. This chapter examines the heritage of the AC-CdC and investigates Turner's claim that the AC-CdC had long-term research value through an examination of past and more recent uses of the AC data by investigating the broader heritage of the AC-CdC to include the contemporary sociological relevance of the project to astronomy, astronomical practice and the heritage of astronomy in Australia.

The technologies developed for the AC-CdC were called on for leading-edge research. At the International Astrographic Congress of 1900, President Maurice Loewy rallied participants to observe a minor planet called Eros (1900, pp. 488–491). The photographic images of Eros (taken using astrographic telescopes) resulted in Arthur Hinks, Cambridge Observatory Astronomer, determining an accurate measure for the solar parallax, much more so than had been obtained through transit of Venus measurements (Dyson 1912, pp. 352–365). Whilst Cambridge Observatory was not responsible for a zone of the AC, Hinks was instrumental in the design of the measuring machines, as examined in Chapter Three, and he used the AC results for research. Hinks used AC photographic records from Britain, Europe and South America for further research, including the nature and distribution of nebulae and other phenomena (Hinks 1911, p. 63). Turner encapsulated the ambition that theories posed by other astronomers about the nature of the solar system, stars, the galaxy and beyond would be overturned by new evidence from the AC:

> "… we cannot say how far it will fit in with facts to be discovered in the future, when we have compared plates taken at greater intervals, and begin to learn something of the movements of the more distant stars."
> (Turner 1912, p. 89).

The period required to reap the scientific research from the AC-CdC, according to Turner, could be hundreds of years, after which the comparative differences in relative star positions and magnitude between two epochs would be significant. Turner had foreseen that the real value of the work on the Astrographic Catalogue would be realised well into the future (1912, p. 84).

Turner directly instructed the Australian observatories and, along with other British astronomers, was contacted by the Australian observatory directors when attempts were made by state governments to close Melbourne, Sydney and Perth Observatories before the AC-CdC was completed; this is examined more closely in this chapter. The various intentions of the State Governments to close the observatories was seen by the Permanent Committee as a major threat to the fundamental success of the AC as a whole sky project.

This chapter also investigates the material collections amassed from the projects and their destinations as a tangible heritage legacy once the AC was completed and the observatories ceased operation.

A Global Astronomical Enterprise

One of the unique attributes of the AC-CdC was its attempt at international collaboration. Turner perceived that the AC-CdC instigated radical change in how scientific research was managed. Turner forecast that the "organisation of the world's resources … will have a notable effect in economising our labours in the future" and that science's 'sacred past', where economy of labour was not considered important, no longer existed (1912, p. 19). In observing this, Turner recognised that the AC-CdC had fundamentally changed the nature of astronomical practice. He recognised that the AC-CdC was one of the earliest attempts at systemised globalisation in astronomy, and he remarked on the new project management methodologies, such as setting deadlines and the concept of time, cost and quality:

> "It does not seem unreasonable that the changed conditions should leave their mark on the methods of work, and that the relation of cost to value of product should be considered in other enterprises… in the old days the value of the product was so high that any cost could be neglected …"
> (Turner 1912, p. 81).

The global nature of the AC-CdC had posed new and numerous challenges, including different languages, different ways of solving problems and the lack of an existing paradigm 'for conducting public business' in a transnational enterprise (Turner 1912, p. 20).

One of the methods that the Congress developed to resolve communication issues and to cope with the different socialised behaviours was a system of bells to stop one country speaking over another. Even well into the twentieth century, the AC was seen as contributing to the global good of science when, in 1934, Riet Van Woolley, who five years later would become highly influential in Australian astronomy policy making and decisions, confirmed the value of the project and that the AC:

> "… will be a very valuable document because … astronomers of AD2400 will be able to measure the right ascension and declination (the celestial longitude and latitude) of any eleventh magnitude star and look up the records to see where it was five hundred years ago …"
> (Woolley 1934, p. 115).

Other methods, previously discussed in this thesis, included the regular *Bulletin* and conferences.

The State Observatories Complete their Zones

The Astrographic Congress, Paris Observatory and the Astronomer Royal demanded that the observatories in the far-flung corners of the globe give the AC-CdC priority. In this section, I examine how this determination became entwined in state politics in Australia from the early twentieth century through to the completion of the zones.

When the AC-CdC project commenced, it was estimated that it would take 'a few years' to complete if ten or more observatories around the globe were involved (Winterhalter 1891, p. 6). Despite the AC-CdC becoming the main astronomical work of Sydney and Melbourne Observatories from 1892, and from 1902 at Perth Observatory, the ambition of completing the work within the first decade of the new millennia was not viable. My research has shown that the original time estimate did not account for the amount of preparation and infrastructure required for the project, and that some of the processes were not as straightforward as they initially appeared. Nor did it account for the many societal internal and external forces such as recession, the demise in funds following the removal of meteorology and the First World War, as examined in Chapter Two. Work on the AC-CdC continued notwithstanding these issues.

My research has also uncovered evidence of delay within the organisations due to instrument failure and internal workplace issues. These include the difficulty Cooke had supervising James Short, the main photographer of the Sydney zone of the AC. Because Short had entrenched work practices and was based a few hours away at Red Hill Observatory, efforts by Cooke to understand the problems with the Sydney Astrograph and other instruments were seen as interference and an antagonistic relationship ensued. Short's logbook notes reveal his dissatisfaction with his supervisor and fellow workers (Collection MAAS, uncatalogued). Another example of workplace disharmony was found at Perth Observatory where the Acting Assistant Astronomer, Nossiter, was accused of bullying Williams, Harvey, Tothill and Allen as discussed in Chapter Four.

Workplace relationships and other human factors had not previously been examined as having causality on the project's accuracy and the time it took to complete. Latourian theory emphasised that whilst 'the boss' rallied political resources and made decisions outside the laboratory, those who were inside the laboratory were constantly making decisions on behalf of the boss. From a social analysis perspective, this made it difficult to decide who was actually doing the work (Latour 1987, pp. 146–163). Latour raised questions about who should be most studied, the leaders or the workers. Most historical research in science is focussed on the lead astronomers. However, as examined further in this chapter, the specific instruments and the individuals using them also had a vast impact on the ability to complete the AC.

By midway through the twentieth century, science in Australia had changed drastically in its institutional structures and allocation of resources, and this had a significant impact on the completion of the AC. Science historian Ann Moyal called this an 'institutional change':

> "… the politics of science has moved us from a period of fragmented, laissez-faire, ad hoc arrangements of our scientific estate to a more cogent analysis of our overall resources … Institutional change lies at the core of Australia's diversifying policy for science and technology."
> (Moyal 1979, pp. 80–81)

The 'laissez-faire' attitude which Moyal detected was the lack of strategic management of scientific enterprise. The early days of federal organisation lacked strategic direction. This was at the heart of the criticism of how astronomy was organised in the early to mid-nineteenth century in Australia. This analysis was re-enforced by O'Hora when he reflected on the AC-CdC. According to O'Hora, the Australian state observatories were let down by their colonial governments with "local autonomy entrusted to state governments" (Debarbat et al 1988, p. 51). Hence, in times of fiscal recession, progress on the AC was jeopardised and this meant the project took much longer than it should have. According to O'Hora:

> "In these observatories astronomy took second place to services such as meteorology and education and when, in times of economic recession, the observatories' budgets were reduced and the support for astronomy appears to have been the first to suffer."
> (O'Hora 1988, p. 137)

In further agreement, Mt Stromlo Observatory Astronomer, Sidney Charles Bartholomew Gascoigne, argued that the colonial observatories were established as scientific 'workhorses' to serve the needs of state government rather than progress scientific knowledge (Gascoigne 1990, p. 5). The AC-CdC was an exceptional project in that it changed the role of the observatories and refocussed them on research science. Despite the obvious intention of the *Commonwealth of Australia Constitution Act*, it is with hindsight that the process of removing astronomy from the control of the states and the closure of state run observatories now seem inevitable. The attitudes of influential astronomers, such as Gascoigne, had considerable bearing on the nature of the networks, which infrastructure and astronomy services would be retained for research, and how the competition for resources (once astronomy became ensconced within a functional federal system) would be resolved.

The closure of observatories and determination of the heritage of the AC-CdC occurred during periods of State Government economic malaise. Coincidentally, the tangible heritage of the Adelaide, Melbourne and Sydney Observatories was also subject to the hegemony of heritage practice and processes undertaken from 1946 to 1985, in which architectural, aesthetic and development attributes presided over the interpretation of the scientific significance of the sites and the entirety of the collections. I will now discuss the attempted and successful closures of Adelaide, Melbourne, Sydney and Perth Observatories in relationship to the completion of the AC in Australia, and its heritage.

ADELAIDE OBSERVATORY 1946

The Melbourne Durchmusterung was the name of the reference star catalogue project for the AC-CdC undertaken by Adelaide Observatory. My research has uncovered that under the supervision of Cooke from 1890 to 1897, half of the observations and all of the calculations were performed by Mary Emma Greayer, as detailed in Chapter Four. Furthermore there are logbooks in SRSA which indicate that from 1909, under Dodwell's direction, Melbourne zone stars were once again observed and Sydney zone reference stars from -51° to -60° were observed between 1914 and 1920. The observatory was taken over by the University of Adelaide in 1930 (Haynes et al 1996, p. 86) but the promised Professor of Astronomy position did not eventuate for Dodwell, and he pressed on with few resources. Demolition of Adelaide Observatory commenced in 1946 to make land available for Adelaide High School (Dodwell 1952). According to the archival files, transit and other observations continued until 1948 (GRG 31/50 SRSA). Dodwell continued to operate Adelaide Observatory until 1952 when he retired.

In 1952 the remaining buildings were demolished and the instruments relocated. Dodwell made a last public plea for an observatory to be built as part of Adelaide University (Dodwell, *The Advertiser*, 8 Jan 1952, p. 2). Adelaide University built an observatory to house the equatorial telescope, but the historic collection was scattered. Roger Clay had documents relating to the collection held by the University of Adelaide. Recent archaeological work on the old Adelaide Observatory site by Hartnell (2014) was described previously in the Mary Emma Greayer case study.

MELBOURNE OBSERVATORY 1944

Work on the AC-CdC progressed very efficiently at Melbourne Observatory during the first decade of the new century. It seemed feasible that had the pace continued, the projects could have been completed by the end of the decade. In 1907 Wallace, who had directed the AC photographic work and overseen the Measuring Bureau, died and there was a discontinuity in the photographic work (Baracchi 1908b, p. 283).

By 1909 the chart plates had been photographed, but another series was to be undertaken. Baracchi was confident that most of the AC photographic work had been completed. The measurement work had progressed steadily with most of the Melbourne AC plates measured, but the new challenge was the requirement for at least ten reference stars to be identified on each plate (Baracchi 1910, p. 336). By 1911, Baracchi reported that the catalogue of 7,000 standard stars was complete and had been reduced, but the resignation of three measurers, and an unsuccessful attempt to recruit replacements, stymied progress. The last Sydney zone plates were measured on the 30th of June 1912. Baracchi departed Melbourne Observatory in 1915 to head the new National Solar Observatory, which had been agreed in 1909 by the

AAAS Congress held in Melbourne; and Baldwin, who had been the assistant, became Acting Government Astronomer (*The Argus* 16 Jan 1909, p. 20).

With the beginning of the First World War in 1915 and 1916, more AC measurers and computers resigned, and the work stalled because these staffers were not replaced. In 1919 Peel resigned, and it was not until 1923 that substantial work recommenced with arrangements made by Baldwin for the printing of the first Melbourne zone catalogue (Baldwin 1924, p. 255). In 1923 Baldwin and Baracchi surveyed and selected a site for the new Commonwealth Solar Observatory, which was announced that year (Bhathal et al 2013 p. 23). By 1926 a fourth AC volume was ready to be printed but it, and the fifth volume, remained unprinted due to a lack of funds.

Political power struggles between the State observatories and Federal ambitions are well illustrated through the proceedings of the Astronomical Conference held in Melbourne on the 25th of March 1927 at 2pm. At the conference there was a pivotal meeting that forecast that astronomy in Australia would change. The heads of the State Observatories, Nangle (Sydney); H. B. Curlewis (Perth); Dodwell (Adelaide); and Baldwin (Melbourne) met with the Council of Scientific and Industrial Research (CSIR), represented by CSIR Deputy Chairman and Chief Executive Officer, Albert Cherbury David Rivett (MacLeod 1988, p. 64), and the Commonwealth Solar Observatory Director, Geoffrey Duffield. According to MacLeod, Rivett was a powerful political force in strengthening the CSIR and moving science in Australia towards autonomy. Duffield made a public statement that a decision had been made for Perth Observatory to be transferred to the Commonwealth; this caused a series of statements and letters back and forth in Western Australia, with the State Government declaring its intention to close the observatory and a debate playing out in the press (*The West Australian* 24 Nov 1927, p. 16).

In January 1930, the remaining computers and measurers, Miss Lloyd and Miss Lanley, were transferred to other departments (Baldwin 1931, p. 414). Despite the uncertainty of funding and the reduced staff of only two computers, Baldwin sent volumes of the AC to the printer and completed the photographic work for the Carte du Ciel with the support of Assistant Government Astronomer Merfield (Baldwin 1930, p. 364). In 1934 there was a Premier's conference, as reported:

> "Its recommendations resulted in the proposal that the Mount Stromlo and Melbourne Observatories should be retained as research institutions; that the other three State observatories should be retained as educational and cultural institutions with opportunities of research work for their staff; and that the control of the State observatories should be modified by placing each under the management of its adjoining university."
> (*The Advertiser* 14 Jul 1934 p. 16)

The transfers did not occur but the resources kept dwindling at Melbourne Observatory until, as reported by Baldwin, on the 8th of March 1944 Melbourne Observatory "passed under the control of the Commonwealth Solar Observatory" (Baldwin 1945, p. 120). This did not satisfy the requirements for the AC-CdC to be completed, and Sydney Observatory Director, Harley Wood, recounted that a meeting of the National Committee on Astronomy recommended that Sydney Observatory take over the work (Wood 1958, p. 26). The IAU Commission 23, in which Wood was requested to undertake the Melbourne Observatory AC-CdC work, is translated in Appendix 7.

Barry Clark has documented the history of Melbourne Observatory and has personal experience relating to its closure (Clark 2006). One of the reasons for closure of Melbourne Observatory in 1944 was its location on the Botanic Gardens. The Victorian Premier revealed a vision for the new Museum of Victoria to transfer to the Observatory site and assume responsibility for the Observatory's collection (*The Argus* 1 December 1944, p. 6).

When Melbourne Observatory closed in 1945, the AC-CdC work was transferred to Sydney Observatory. The astrographic collection of glass plates, logbooks and pages ready for printing the catalogue was sent to Sydney Observatory, which also purchased the astrograph. Clark has prepared an inventory of the instruments, which were located at Melbourne Observatory prior to its closure (2006 pp. 10–15).

SYDNEY OBSERVATORY 1909, 1982

After Russell's retirement in February 1906 due to illness, the NSW State Government made clear its intention to relocate the astronomical work of Sydney Observatory to Red Hill, thereby it would solely continue the AC-CdC, and administration would be transferred to the University of Sydney (Lenehan1906, p. 212; Wood 1958, p. 18). There was a public outcry when the government revealed that The Mint was to relocate to Observatory Hill in order to enable the Macquarie Street site to be occupied by the law courts (*Evening News*, 10 April 1906; *Evening News* 24 April 1907 p. 6). It was mooted that the University of Sydney would take over control of Sydney Observatory. Prominent astronomer John Tebbutt had strong views that the university had no interest in astronomy, and he made these views known to the popular press, although he reverted to a prior view that the Observatory move out of the city location:

> "I trust the Observatory may not be handed over either to the Federal authorities or to the University, but that it may be maintained by the State itself. Mr. Merfield's suggestion that the Observatory be removed to Pennant Hills, and that the observers be provided with house accommodation on the spot is an excellent one for reasons which it is scarcely necessary to state …"
> (*The Sydney Morning Herald*, 3 Sep 1906, p. 5)

The Acting Government Astronomer, Lenehan, achieved a reprieve from this solution, but he died in 1908. Between the death of Lenehan and the appointment of William Ernest Cooke in 1912, the President of the BAA, James Nangle, wrote to the press complaining of the poor state of Sydney Observatory, and the need for capital funds of £5,000 for more advanced astronomical equipment; he also advised that a new observatory which aligned with the University would be strategic (*The Sydney Morning Herald* 20 Jul 1911, p. 5).

As a condition of his employment as NSW Government Astronomer, Cooke was appointed as the inaugural Professor of Astronomy at the University of Sydney. Cooke established an advisory board at Sydney Observatory, believing this would help put the Observatory on stronger footing and help negotiate more resources with government. Cooke spoke publicly about the delay in the AC-CdC work at Sydney Observatory. He lobbied for the AC-CdC work to be completed and for the observatories to re-equip for new astronomy methods (*The Sydney Morning Herald*, 21 March 1914). Cooke believed the Observatory Board's influential members, many of whom were university professors, would agree with his vision. This was to prove otherwise.

The minutes of the Board of Visitors (16 Aug 1916, SRNSW) show that discussion about the AC dominated the meetings. Cooke, having almost completed the Perth zone photographs and published three volumes of the Perth catalogue, declared the Sydney photographic plates unfit for measurement. Cooke claimed that:

> "… for the last quarter of a century the astronomical activities of the Sydney Observatory have been mainly concentrated upon its share of the International Photo-Durchmusterung and although nothing has been published … I understood the work was nearly completed … A brief survey of the work already accomplished, however, sufficed to destroy that aspiration. It is no use trying to disguise the fact that the bulk of the labor so far expended upon that great work has been in vain, and we must practically commence again."
> (Cooke Notes for Board Meeting 16 Aug 1916, p. 7, SRNSW).

There is no doubt that Cooke was correct about the poor photographic work on the Sydney plates, as Peel had earlier discovered, and as later ratified by Baldwin who wrote to Innes:

> "… you have my sympathy in having to work on the Sydney plates. When I first came here they were being measured at this observatory, and I started rejecting some hundreds of them. I only remember seeing one that I would have passed if they had been taken here, so I know pretty well what they are like."
> (letter Baldwin to Innes, 29 May 1918, PROV 778/P/0000/ 867, vol. 3 pp. 115–116).

Nonetheless Cooke's proposal to abandon the AC-CdC and commence a new series of Astrographic photographs was not well received by the Board. He was asked to put his request in writing by Francis Leverrier, the Vice Chancellor of the University of Sydney (hereafter USYD) (letter Leverrier to Cooke, 15 Sep 1916, SRNSW, p. 44). On receipt of Cooke's written proposal, the Board decided to defer the decision to the Astronomer Royal.

Turner became involved when he was unofficially sent a copy of Cooke's letter by Horatio Scott Carslaw, a member of the SO Board and Professor of Pure Mathematics at USYD. Cooke had proposed to the Board that he wished to abandon the AC-CdC because of the condition of the instruments, the unsatisfactory glass plate negatives and because it was old technology. Furthermore, Cooke had in his sights a new project using a 'blink comparator' to see changes in photographs taken at different epochs (letter Turner to Carslaw, 4 Oct 1916, SRNSW, p. 67).

Robert Thorburn Innes, Director of Transvaal Observatory, proposed to Cooke and others that the resources for measurement of the AC plates would be applied to comparing the stars on the plates using a 'blink comparator' machine to observe proper motions (Innes 1916, pp. 178–181). This would have been research astronomy but Turner saw it as a threat to the AC; he was publicly adamant that the AC-CdC had to continue, with other research undertaken in parallel. This discussion had already become public and involved published correspondence between Turner and Innes, who wrote in agreement with Turner that the Astrographic Catalogue should be completed. Turner projected that the Sydney work should be completed by 1923. Turner made it clear that participation was no longer a decision which could be made by Sydney Observatory without causing an international incident:

> "… a single participant like Sydney cannot at the same time modify the plan essentially and respect its treaty obligations."
> (letter Turner to Carslaw 4 Oct 1916, SRNSW, p. 69).

In reality, progress on the AC-CdC depended on the stability of staff resources and the funds to procure equipment and plates. The focus of the lead astronomer on completion of the project was a fundamental necessity which Sydney Observatory had lacked. There had been four years between the last Sydney Observatory Director's death and Cooke's commencement, which was acknowledged by Turner as unproductive.

Despite his lack of enthusiasm for the project, and his disapproval of the irregularities in the photographic work, Cooke managed to restart the AC-CdC work, but it was not completed within the following decade. By 1916, the Measuring Bureau was established, Sydney A machine arrived, and the first volumes of measured plates were prepared for publication (Cooke 1917, p. 322). However, it took until 1919 for the photographic work to recommence due to problems with the astrographic telescope and the dome. Cooke had reported to the Board on the parlous state of Red Hill Observatory and that it was riddled with white ants (Cooke, Nov 1918, SRNSW). It was not until 1922 that the first two volumes of the Sydney zone were published (Cooke 1924, p. 256).

In analysing the delays, attendance records held by SRNSW (A3003 Box 136–142) reveal the regularity of timekeeping and dedication of staff to get on with the work at Sydney Observatory. This was not the problem, as is clearly seen by the attendance books. For example on the 11th of November 1918, the day the end of WWI was declared, in the margin are written notes that two days of holidays will follow. Nonetheless, the women came in for two hours on the 12th of November and two of the astronomers attended work both days (Attendance Book, A3003, Box 137, SRNSW). Similarly, the timebooks of Melbourne and Perth Observatory show that there was a predictable regularity. Astronomy and measurement staff arrived around 9am and departed either at 4:30pm or 5pm. If nights were worked then there were rostered days off.

In 1920, there was a further interference to the AC-CdC work when Cooke was ordered by the Astronomer Royal to measure the bending of light during a total solar eclipse, proving Einstein's General Theory of Relativity. As reported to the Board the Astronomer Royal required Cooke to use the Sydney Astrographic telescope (Cooke 1922, SO Library); this appeared to be against Cooke's wishes. The astrograph was chosen because the telescope lens matched the one used by Eddington in 1919 for an experiment of the same nature. Cooke dutifully carted the large telescope to the racecourse in Goondiwindi, Southern Queensland, amongst a scientific gathering. The large telescope was assembled and a shed constructed around it, as seen in Figure 77.

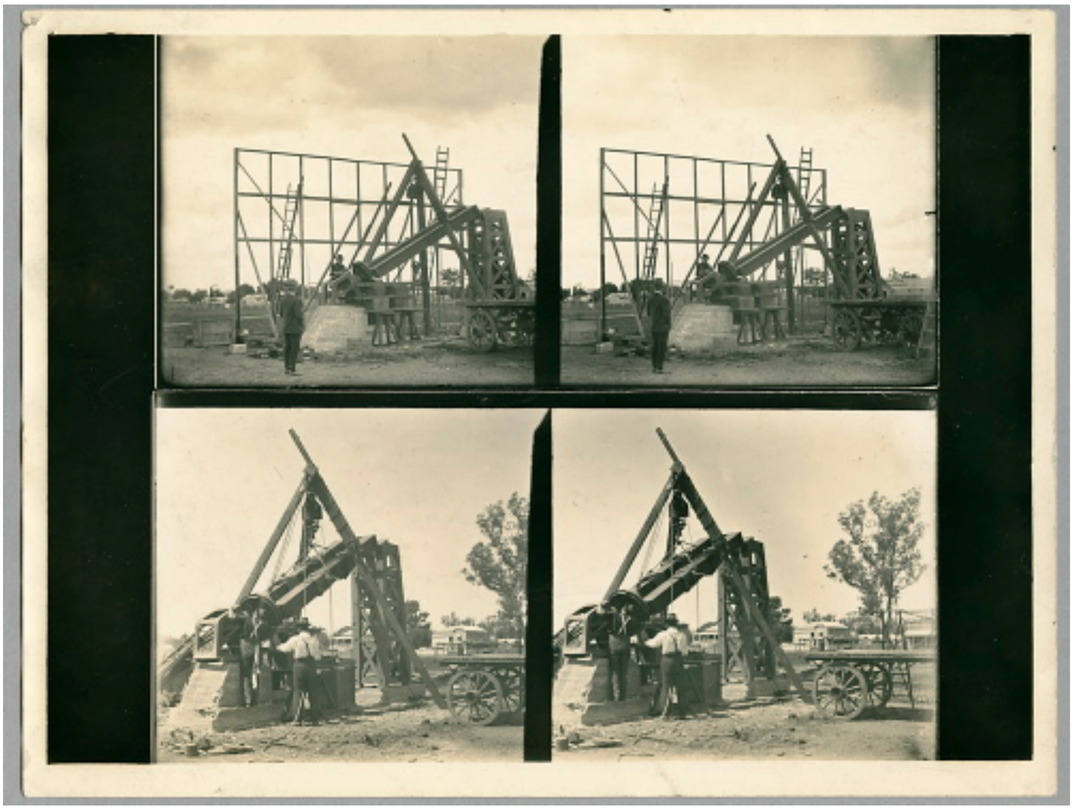


Figure 77: Assembling the astrographic telescope, Goondiwindi, Queensland (Collection MAAS P3549-118).

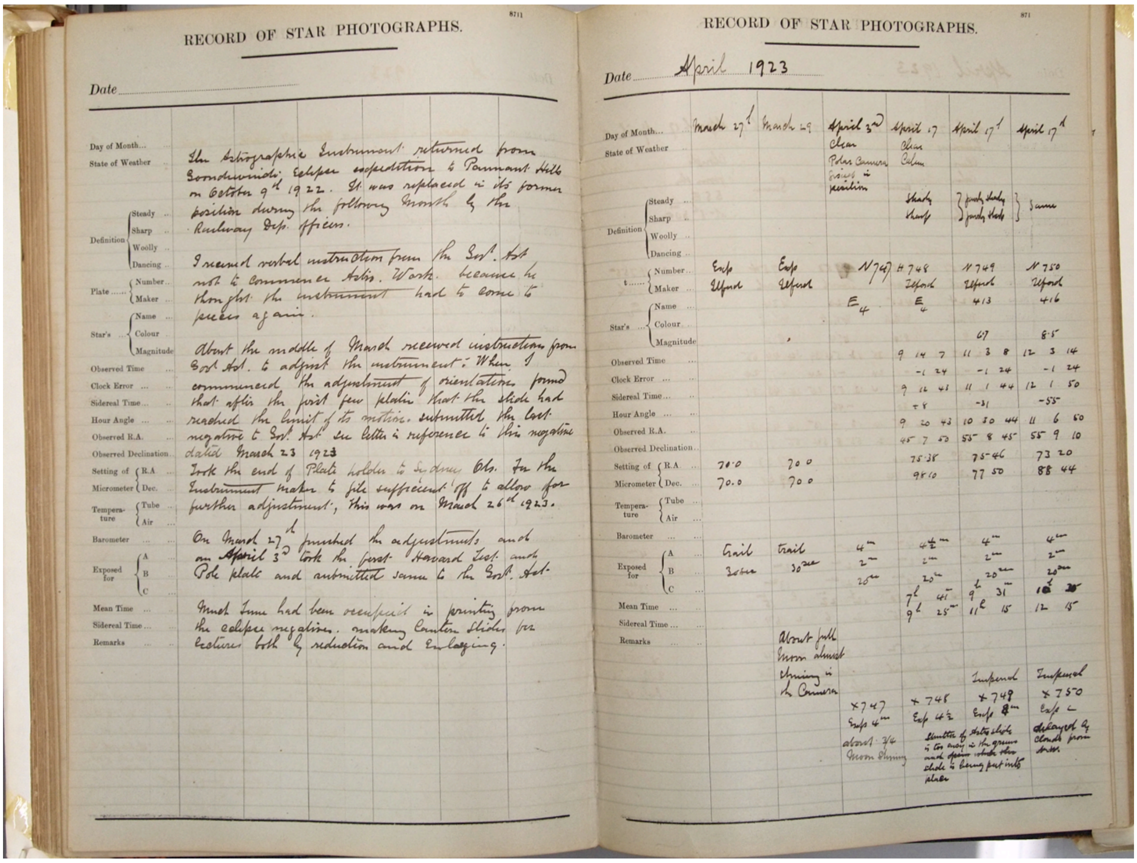


Figure 78: James Short 'Record of Star Photographs' (Collection MAAS, uncatalogued).

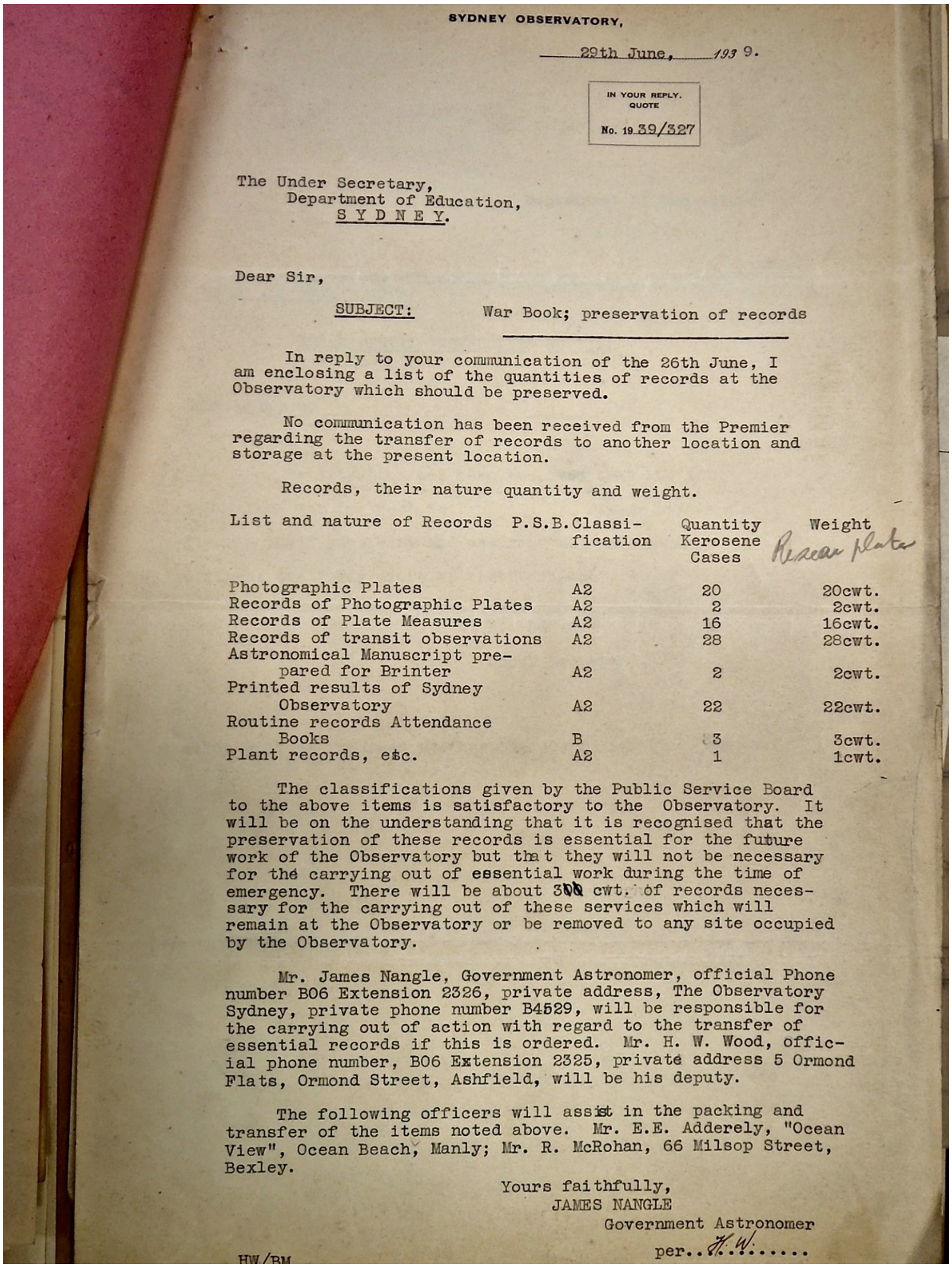
Transporting the astrographic telescope to Goondiwindi in 1922 delayed the AC-CdC photography; this followed the previous eight years when the photography was irregular. My research into the collection housed at Macquarie University uncovered the book in which James Short recorded his work. According to Short's logbook, it was months from the return of the astrograph on the 9th of October 1922 until the first star plates were taken on the 3rd of April 1923.

According to Wood, Cooke continued to pursue plans for an alternate site, which was refused. Due to the nature of the request, in 1925 the State Government planned to close Sydney Observatory altogether (Wood 1958, p. 22). By 1926 nearly all of the photographic work had been completed for the AC, and four volumes had been published. Wood explained that in 1926 James Nangle was commissioned to report on the Observatory by the State Government. The decision was made to retain Sydney Observatory, but to reduce its work. When Cooke retired later that year, Nangle was appointed Government Astronomer (Wood 1958, pp. 24–25). In 1926 the Astrographic Bureau was disbanded, and the six women who worked there were transferred to other government departments or resigned.

In 1926, Turner was concerned at the rate of progress of the AC, and the uncertainty of Sydney Observatory's future. Turner reported that the plates photographed and measured under Cooke's direction using Sydney A and Sydney B had 'fewer stars' than those photographed during Russell's term and measured by Melbourne Observatory (Turner 1926, p. 64). The main reason for this, according to Turner, was because Cooke had reduced the exposure times for the Sydney plates to 4 minutes, 2 minutes and 13 seconds. By comparison the Melbourne zone plates were exposed for 5 minutes, 2 minutes 30 seconds and 20 seconds. The Sydney and Perth plates were originally exposed for 6 minutes, 3 minutes and 20 seconds. In 1910 Cooke had reduced the exposure of the Perth plates to 4 minutes, 2 minutes and 13 seconds because this still included the higher magnitude stars as required for the project, and had been accepted. Therefore, he had simply followed the same principle to efficiently increase the number of plates, which could be photographed each clear night.

The 1930s Depression impacted the government's subsidy for the Observatory further and Nangle closed Red Hill Observatory in 1931, when Short retired (Wood 1958, p. 24). The astrograph was returned to Sydney Observatory and, in 1936, Nangle appointed Harley Wood. From 1937 Wood re-established the measurement bureau and focussed on preparing volumes of the catalogue for the printer, two of which were printed in 1937 and another two prepared. From the time of Wood's appointment, the AC project gained momentum.

The correspondence records revealed evidence that World War II further delayed the completion of the AC due to potential relocation of the Observatory and interrupted cable communications. In an envelope marked 'State War Instructions' (SRNSW A3003 Box 44) papers reveal the extent of concern and the preparations that were made. On the 30th of June 1939, Sydney Observatory Director James Nangle was instructed by the Director of Education, G. Ross Thomas, to safeguard buildings, articles, machinery and exhibits by employing watchmen to patrol the grounds. Further notification was given to "cancel all leave and without publicity recall all absent officers to their posts." (Letter from Thomas to Nangle 2 Sep 1933, SRNSW Trans 44 2). On the 4th of September 1939, Nangle received a letter marked 'Secret' and 'Urgent' which announced that war had been declared and the enemy was Germany (letter from Thomas to Nangle, 1939, SRNSW). Further instructions were given to prepare to relocate the Observatory's most important records. These were priority listed in Figure 79 and the astrographic photographic plates, measures and manuscript were classified as A2, of the highest importance.



SYDNEY OBSERVATORY,

29th June, 1939.

IN YOUR REPLY, QUOTE
No. 19 39/327

The Under Secretary,
Department of Education,
S Y D N E Y.

Dear Sir,

SUBJECT: War Book; preservation of records

In reply to your communication of the 26th June, I am enclosing a list of the quantities of records at the Observatory which should be preserved.

No communication has been received from the Premier regarding the transfer of records to another location and storage at the present location.

Records, their nature quantity and weight.

List and nature of Records	P.S.B. Classification	Quantity Kerosene Cases	Weight
Photographic Plates	A2	20	20cwt.
Records of Photographic Plates	A2	2	2cwt.
Records of Plate Measures	A2	16	16cwt.
Records of transit observations	A2	28	28cwt.
Astronomical Manuscript prepared for Printer	A2	2	2cwt.
Printed results of Sydney Observatory	A2	22	22cwt.
Routine records Attendance Books	B	3	3cwt.
Plant records, etc.	A2	1	1cwt.

Reseau plates

The classifications given by the Public Service Board to the above items is satisfactory to the Observatory. It will be on the understanding that it is recognised that the preservation of these records is essential for the future work of the Observatory but that they will not be necessary for the carrying out of essential work during the time of emergency. There will be about 300 cwt. of records necessary for the carrying out of these services which will remain at the Observatory or be removed to any site occupied by the Observatory.

Mr. James Nangle, Government Astronomer, official Phone number B06 Extension 2326, private address, The Observatory Sydney, private phone number B4529, will be responsible for the carrying out of action with regard to the transfer of essential records if this is ordered. Mr. H. W. Wood, official phone number, B06 Extension 2325, private address 5 Ormond Flats, Ormond Street, Ashfield, will be his deputy.

The following officers will assist in the packing and transfer of the items noted above. Mr. E.E. Adderely, "Ocean View", Ocean Beach, Manly; Mr. R. McRohan, 66 Milsop Street, Bexley.

Yours faithfully,
JAMES NANGLE
Government Astronomer
per.. H.W.......

HW/BM

Figure 79: War Book list 20 Jun 1939, James Nangle via Harley Wood. (Collection SRNSW: A3003 Box 44).

Nangle wrote to the Director of Education in regards to finding other locations for the observatory equipment; he feared that the site could be bombed during possible air raids (letter Nangle to Thomas 8 Sep 1939; SRNSW). John Tebbutt's son agreed to make available Tebbutt's Observatory at Windsor, one of the sites considered; however, the preferred option was to build a small observatory near Mudgee, and Nangle prepared and submitted the plans. Timekeeping would be the main purpose of the observatory and the AC would not be worked on during this period as the records would be located elsewhere. There were other plans to move the instruments and records to Katoomba in the Blue Mountains. It appears that none of these eventuated and the Observatory stayed where it was.

When Nangle died in 1941, Harley Wood became Acting Government Astronomer. He re-invigorated the Observatory through publishing papers and engaging in education programs closely linked with universities, including the Australian National University. Wood also played a pivotal role in the establishment of the Astronomical Society of Australia (Lomb 2015).

On the 4th of February 1947, Astronomer Royal, Sir Harold Spencer Jones, visited Observatory Director, Harley Weston Wood, at Sydney Observatory (Wood 1948). Under advice from Jones, Wood inspected the AC records, equipment and plates at Melbourne Observatory (Wood 1958, p. 26) and proposed to the NSW State Government that Sydney Observatory complete the Astrographic Catalogue and take on completion of the Melbourne zone now that Melbourne Observatory was closed (22 Dec 1947, SRNSW Box 44). A letter from Jules Baillaud, who in 1948 was still President of the Commission Carte du Ciel (by then part of the IAU), confirmed that Sydney Observatory would take over the Melbourne zone of the AC-CdC and that, as it was a priority for the Australian zones to be completed, the IAU would organise and fund the catalogue manuscript printing (letter Baillaud to Wood 16 Aug 1948, SRNSW, Box 44). Baillaud had discussed this proposal with SO Board members Von Willer and O'Connell, as well as Woolley who was now the Director of the Commonwealth Solar Observatory at Mt Stromlo.

Figure 80 shows Wood using the Melbourne Astrograph in the new dome he commissioned for Sydney Observatory. He had re-established the Astrographic Bureau in 1936, and taken on the challenge of completing the Sydney and Melbourne zones for the International Astronomical Union. In 1941 Wood employed Margaret Colville, and in 1948 he employed Winsome Bellamy. Colville and Bellamy stayed at the Observatory for two decades and became pivotal in the completion of the Sydney and Melbourne zones of the AC.

The final Volume (8) of the Melbourne zone was sent to the printer in 1961 (Wood 1962, p. 214) and published in 1963; and the last of the fifty-two volumes of the Sydney zone of the AC was completed in 1964. The final fifty-third volume was a report on the Sydney and Melbourne work, and it was printed in 1971 (Wood 1972, p. 463). With Ben Gascoigne and

Bart Bok from Mt Stromlo, amongst other astronomers, Wood was responsible for locating a site for Siding Spring Observatory to house the new Anglo Australian Telescope (AAT). In 1973 a General Assembly of the IAU was held in Sydney, with Wood as head of the organising committee.

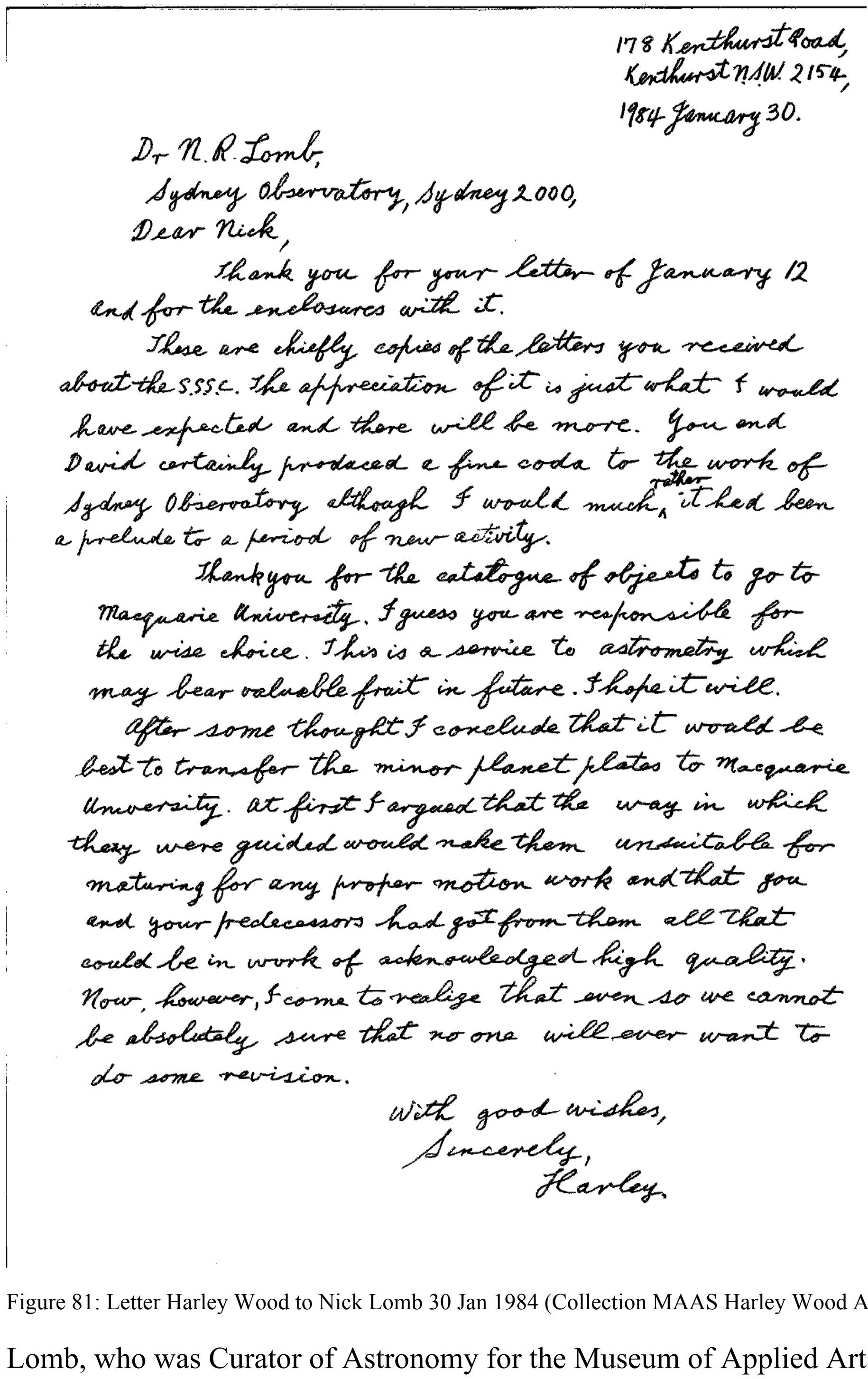
Figure 80: Harley Wood using the Melbourne Astrograph, 1958 (Collection MAAS).

At Wood's retirement in 1975, Sydney Observatory performed a number of research projects in proper motion and minor planetary work. As previously identified in this chapter, my research indicates that a Federal Government commissioned report clearly indicated that astronomy was a Commonwealth concern, and that astronomers involved in and supportive of Sydney Observatory clearly identified the priorities in astronomy as the AAT and AAO at Siding Spring (Westfold 1978, 1980; Gascoigne 1988, Gascoigne et al 1990).

On the 6th of July 1982, Sydney Observatory ceased its role as an astronomy research centre and became part of the Museum of Applied Arts and Sciences (MAAS). The official explanation for the cessation of research was sent in a letter from Premier Neville Wran to the Chair of the Board of Visitors, Donald Morton:

> "… the decision ... has been prompted both by the financial constraints and the limitations of the present site, and by a recognition that modern astronomical research is probably best conducted as part of the work of the major national and international

institutions … transfer the Observatory to the Museum of Applied Arts and Sciences and discontinue scientific work."
(letter from Wran to Morton, 8 Jun 1982, SRNSW: Agency 113, Abolition)



178 Kenthurst Road,
Kenthurst N.S.W. 2154,
1984 January 30.

Dr N. R. Lomb,
Sydney Observatory, Sydney 2000,
Dear Nick,

Thank you for your letter of January 12 and for the enclosures with it.

These are chiefly copies of the letters you received about the S.S.S.C. The appreciation of it is just what I would have expected and there will be more. You and David certainly produced a fine coda to the work of Sydney Observatory although I would much rather it had been a prelude to a period of new activity.

Thankyou for the catalogue of objects to go to Macquarie University. I guess you are responsible for the wise choice. This is a service to astrometry which may bear valuable fruit in future. I hope it will.

After some thought I conclude that it would be best to transfer the minor planet plates to Macquarie University. At first I argued that the way in which they were guided would nake them unsuitable for maturing for any proper motion work and that you and your predecessors had got from them all that could be in work of acknowledged high quality. Now, however, I come to realize that even so we cannot be absolutely sure that no one will ever want to do some revision.

With good wishes,
Sincerely,
Harley

Figure 81: Letter Harley Wood to Nick Lomb 30 Jan 1984 (Collection MAAS Harley Wood Archive).

Lomb, who was Curator of Astronomy for the Museum of Applied Arts and Sciences, consulted with Wood when the instruments, glass plates and logbooks were transferred to Macquarie University in 1986, as demonstrated in Figure 81. Wood and others believed that the AC-CdC had scientific potential which had not yet been realised, and that the transfer to

Macquarie University would help realise this potential. However, for a number of reasons (which could form part of a future research project), the International Astronomical Union would not officially intervene in the closure of Sydney Observatory, although letters from prominent astronomers representing the IAU were written to the Premier (Wood 1983, p. 281).

PERTH OBSERVATORY 1912, 2013

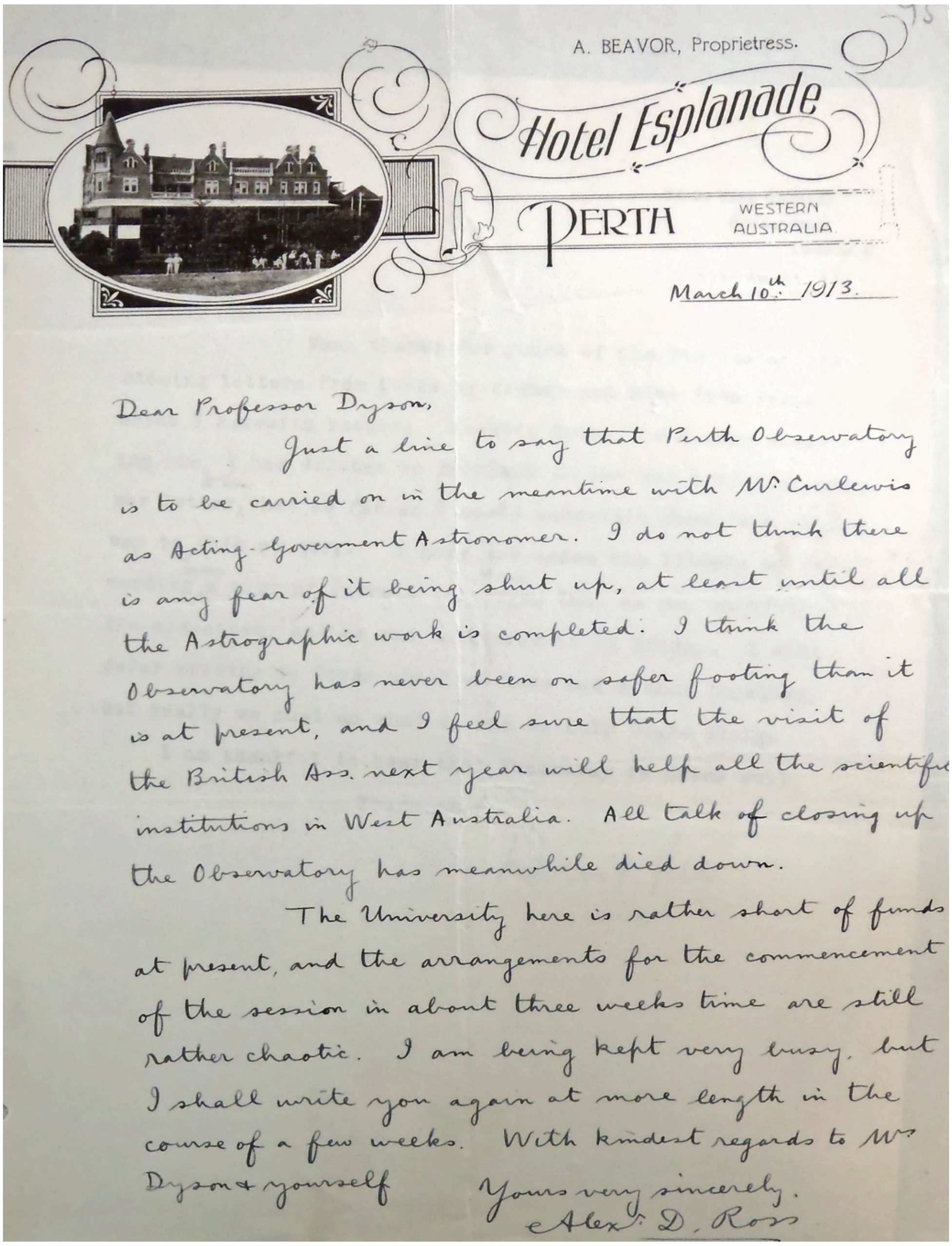
In 1912, soon after Cooke's departure, it was announced that Perth Observatory was to be closed. Whilst most of the photographic work for the AC had been completed, and measurement was well underway (with the Astrographic Bureau established since 1907), there was a steady flow of reject plates which had to be retaken. As explained in Chapter Four, the Astrographic Bureau at ROE had been working on the plates since 1908. Curlewis, who was Acting Government Astronomer, wrote to Sampson, the Astronomer Royal Scotland, ROE, that:

> "… a Labour Government is in power, very hard up and quite antagonistic to any science which cannot show and direct gain in the shape of lucrative returns."
> (letter Cooke to Sampson 17 Sep 1912 in Utting 1994, p. 9)

In 1913 the University of Western Australia sought to replace Perth Observatory as the centre for astronomy in the state. Dyson, the Astronomer Royal, made it clear to the Government of Western Australia that there was an agreement to complete the AC. The letter in Figure 82 from Alex Ross, Professor of Physics at the University of Western Australia, informed Dyson that "at least until the Astrographic work is complete" Perth Observatory would not be closed. This signalled to the Perth Observatory Acting Director, Curlewis, the importance of the AC and he set about ensuring the work was not only undertaken, but that there was public and political awareness its nature and progress.

By 1919, under Curlewis' directorship, Perth Observatory completed nineteen of the twenty-four volumes for the Perth zone of the AC. There was pride in the completion of this work, and Curlewis presented a lecture entitled 'Millions of Stars' to a full house at the Perth Literary Institute (*The Daily News* 14 Jun 1919, p. 4, 3rd Edition). When doubt had been cast on the accuracy of the measurements produced by the women in the Measuring Bureau by Nossiter (letter Nossiter to Curlewis, 19 July 1914 SRWA 1914/3046) as previously examined in the Prudence Valentine case study Curlewis sent the records to ROG for examination prior to printing (SRWA 1914/3046). These were examined by Dyson, Turner and Eddington and on return of the results, which concluded that the results were completely acceptable. Similarly the quality of the measurement of the magnitude scale was praised (Turner 1918, p. 584). Curlewis was later quoted in the newspaper as saying:

> "… the officers engaged upon this work— the lady measurers especially— were to be congratulated, and should be extremely proud that their undoubted skill and hard work had met with such welcome recognition."
>
> (*The Daily News* 14 Jun 1919, p. 4, 3rd Edition)



A. BEAVOR, Proprietress.

Hotel Esplanade

Perth WESTERN AUSTRALIA

March 10th 1913.

Dear Professor Dyson,

Just a line to say that Perth Observatory is to be carried on in the meantime with Mr Curlewis as Acting-Government Astronomer. I do not think there is any fear of it being shut up, at least until all the Astrographic work is completed. I think the Observatory has never been on safer footing than it is at present, and I feel sure that the visit of the British Ass. next year will help all the scientific institutions in West Australia. All talk of closing up the Observatory has meanwhile died down.

The University here is rather short of funds at present, and the arrangements for the commencement of the session in about three weeks time are still rather chaotic. I am being kept very busy, but I shall write you again at more length in the course of a few weeks. With kindest regards to Mrs Dyson & yourself

Yours very sincerely,

Alexr. D. Ross

Figure 82: Letter from Ross to Dyson 1913, (Collection CUL, RGO 8/95).

In another report Curlewis further praised the Perth Astrographic Bureau as quoted:

> "Over 10 years' work they had charted 95 fundamental stars, 420 standard stars, 9,600 reference stars and nearly a million zone stars. Already the work had resulted in interesting and important discoveries regarding the movement of the star streams …"
> (*The West Australian,* 13 Jun 1919, p. 6)

By 1921 Perth Observatory had provided ROE with all the plates required to complete the measurement of the three volumes they were responsible for, and this work had been completed as Curlewis reported to the Legislative Assembly:

> "Only three zones remain to be printed. The measuring of these has been carried out under the supervision of the Astronomer Royal for Scotland. The manuscript is expected shortly, and it is hoped that the printing will proceed without hindrance. When these three zones have been published the Perth Observatory will have finished the share of the great International Star Catalogue entrusted to it by the Paris Conference of 1900."
> (*The West Australian* 29 Sep 1921, p. 6).

Unfortunately, the completion of the AC also signalled the cessation of the State Government's commitment to keep the observatory functional. In 1928 the Western Australian Government unsuccessfully sought for the Commonwealth to take over Perth Observatory. There were public protests and the popular media reported that if the Federal Government did not take it over, the Observatory would close, for example:

> "The Perth Observatory, doomed to extinction, despite strong public protests, unless the Federal authorities take control, as the Collier Government refuses to accept responsibility for its continuance."
> (*Sunday Times*, 15 Jan 1928, p. 13).

In the end, the Federal Government made an offer to take control of the Observatory so long as it did not have to relocate its functions for a long time. On the 28th of June 1928, it was announced that a twenty-five year lease had been arranged for the Commonwealth to take over the Observatory (*The Sydney Morning Herald*, 28 Jun 1928, p. 12). However, this was not a done deal as Duffield, Director of the Commonwealth Solar Observatory, arrived on the 10th of July to make an assessment and negotiate an offer. On the 26th of September 1928, it was announced in the press that the State Government had rejected the Federal Government's offer, and that the Observatory would be maintained under State control and continue its operations (*The West Australian*, 26 Sep 1928, p. 14). Even though the main work of the AC was completed, there was a dispute about who should print the catalogues. This was finally resolved and Baillard, the President of Commission 23 of the IAU (Carte du Ciel), agreed that the IAU would pay for the printing (Wrigley 1948, p. 1). This was completed by 1952.

Perth Observatory was relocated in 1963, taking with it the astrographic telescope, dome and equipment to undertake further scientific research at Bicknell, just outside Perth. In 2013, scientific research ceased and the Acting Government Astronomer, Ralph Martin, retired. The Observatory's prime mission then became education and heritage.

The old Perth Observatory building, located in Kings Park, was handed over to other organisations in 1966. The main building eventually became the National Trust of Western Australia's headquarters in 1988.

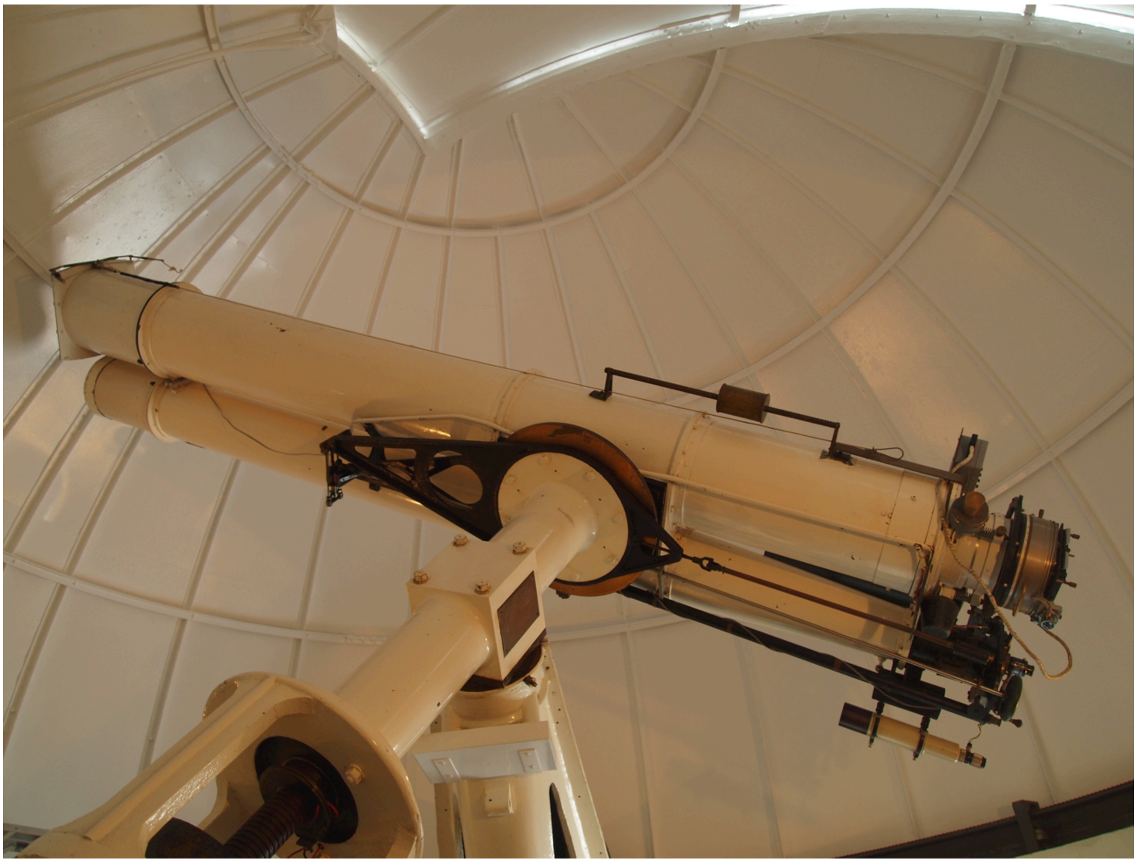


Figure 83: The Perth astrograph reassembled at Bickley. Photograph T. Stevenson 2011.

Throughout the AC-CdC project, it became evident to the Australian participants that the attitude of influential British astronomers, such as Gill, Turner, Christie and Dyson, had considerable bearing on the networks, infrastructure, lobbying and competition for resources at a local level. Latour rationalised that scientists rally resources outside the scientific field by "making the laboratories indispensible" (Latour 1987, pp. 152–155). This was not always possible for the local astronomers once meteorology was removed and other technologies replaced timekeeping. It was only when the British astronomers became involved that the State Government ministers changed their minds about closing the observatories.

THE CARTE DU CIEL 1892 TO 1930

"So the Catalogue is to be pushed forward and the poor chart only tolerated …"
(Editors of *The Observatory* 1891, p. 186)

There were complaints after the first meeting of the Permanent Committee for the AC-CdC that preference was being given to the Catalogue, where personal selection and interpretation had already taken place, over the Carte du Ciel, which was considered a purer form of data. The rationale was that the CdC plates only required photography, whereas the AC plates required measurement and computation, thereby taking longer to process. The photography of the AC images was given precedence. The complexity of the CdC plates was that each one required three exposures, each of 30 minutes; therefore, it took 1.5 hours to complete each photographic plate. This is because the stars recorded were down to magnitude 14. The completion of the Carte du Ciel in Australia emerged as an area where there has been some confusion.

When I investigated the collections of glass plate negatives and the astronomer reports, I found that Melbourne Observatory began experimental work for the CdC in 1891 (Ellery 1892). The Melbourne Chart plates are two separate series—the first was a single exposure of 60 minutes, and the second was a photograph with triple exposures of 30 minutes each. In Australia, all of the CdC plates were exposed to a réseau prior to stellar photography, and this caused problems in the early years because the silvering was not stable (Ellery 1894). According to Ellery, a method for making a réseau locally had greater success with the first CdC plates taken in 1894 (Ellery 1895). By 1906 Ellery reported that there were 556 Chart plates completed. This was all of the first series; the second series of the Melbourne zone was completed in 1929 (Baldwin 1930, p. 364).

The Melbourne CdC plates do not appear to have been transported to Sydney by Wood. During my interview with Barry Clark, he revealed that there were CdC plates left at Melbourne Observatory (pers comm, Clark, 2012).

In Lomb's inventory of items which were transferred to Macquarie University from Sydney Observatory, he listed 776 plates in the 'C' Red Hill series taken by Sydney Observatory between 1905 and 1910. There were also 'C' series amongst the 2,245 plates mixed in with the 'N' and 'H' series (Lomb 1984, unpublished). Lesa Moore's spreadsheet indicated that between the years 1905 and 1930, there were a total of 1,266 CdC plates produced at Red Hill (2003). These were mainly exposed in triplicate for 30 minutes each exposure, but some were exposed for 40 minutes (which was an earlier standard) and others only exposed twice.

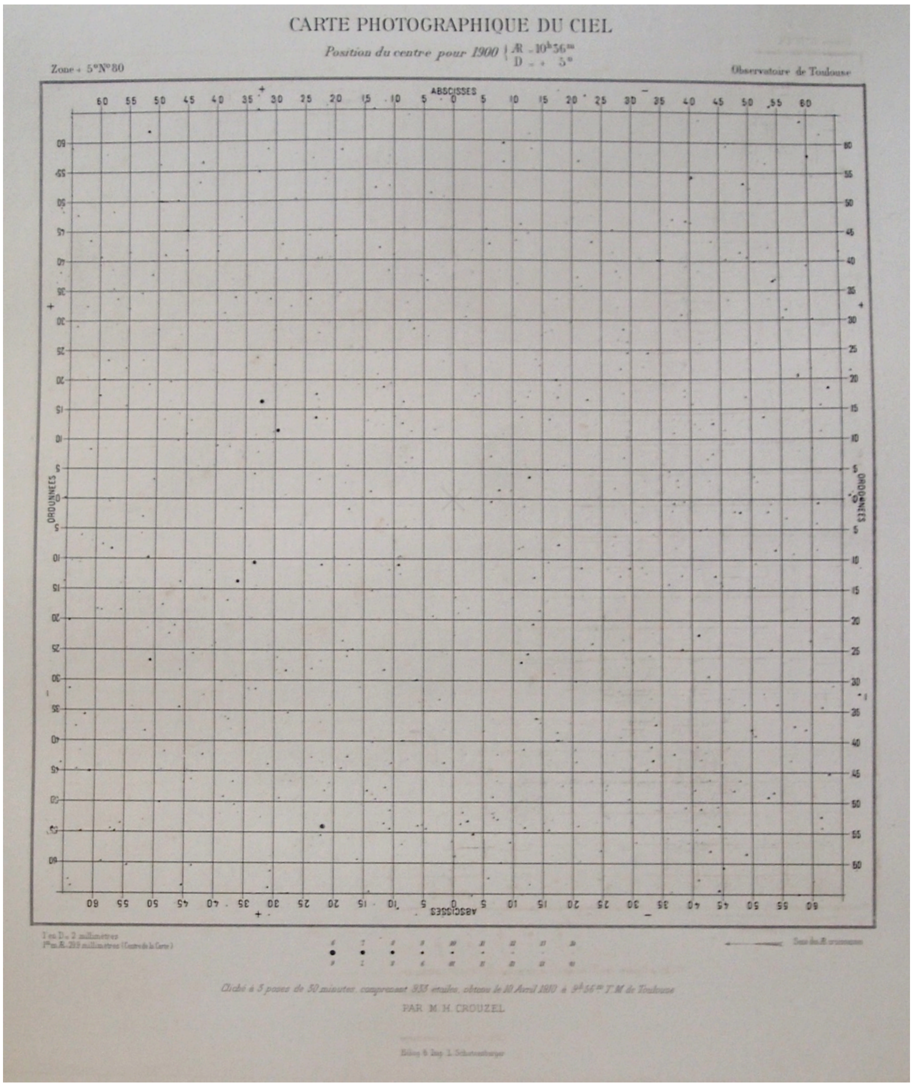


Figure 84: CdC print from Toulouse Observatory, photograph T. Stevenson (Collection SRNSW).

My findings agree with those of other researchers that the Australian CdC plates were never printed. There is evidence that copies of the CdC, which were published by other participant observatories, were received by either Sydney or Melbourne Observatories. Sandra Warner identified printed CdC star maps from Cordoba and Pulkovo Observatories at Sydney Observatory before they were sent to SRNSW (Warner 1984, p. 16, unpublished). My investigations into the Sydney Observatory archives at SRNSW also uncovered copies of printed CdC plates from Toulouse Observatory (as shown in Figure 84), Oxford, Bordeaux and Paris Observatories.

Perth Observatory appears to have abandoned photographic work for the CdC from 1903 (Cooke 1904, p. 236). During 1903, according to Cooke's report to the Royal Astronomical Society, there were 42 photographic plates taken which would have made a total of 100 negatives for the CdC. My investigation into this was not exhaustive and further investigation into the Perth Observatory archive may reveal more.

Competing Projects with New Problems replace the AC-CdC

The AC-CdC followed a process recognised as 'typical' of scientific projects by sociologist of science, Michel Callon (1986). In Callon's application of the actor-network theoretical model (ANT) to science, there are five distinct stages called 'moments of translation' (1986, pp. 203–219). These were introduced in Chapter One of this thesis. The first four phases are: 'Problematisation', 'Interressant', 'Enrolment' and 'Mobilisation'. In this section I examine the final phase, 'Competing Problematisations'. This is when the influence of the actors in a network is diminished as other, new actors enter the project. I have interpreted Callon's model for Australia's participation in the AC-CdC, as shown in Table 5.

According to Callon (1986) and Latour (1987) when a new network is created, it is characteristic to enrol actors and break linkages to previous 'problematisations'. The very nature of scientific enterprise was, according to Callon, that new enterprises dismissed the findings of the diminished networks which they replaced (Callon 1986). When applied to the AC-CdC, this model demonstrated that after the end of the First World War, the AC-CdC lost support as there was a realisation that observational astronomy, which led to the creation of star catalogues, was not leading to major new research. The fields of discovery were astrophysics and, after WWII, radio astronomy. During the early twentieth century, astrophysics research was not well supported in Australia.

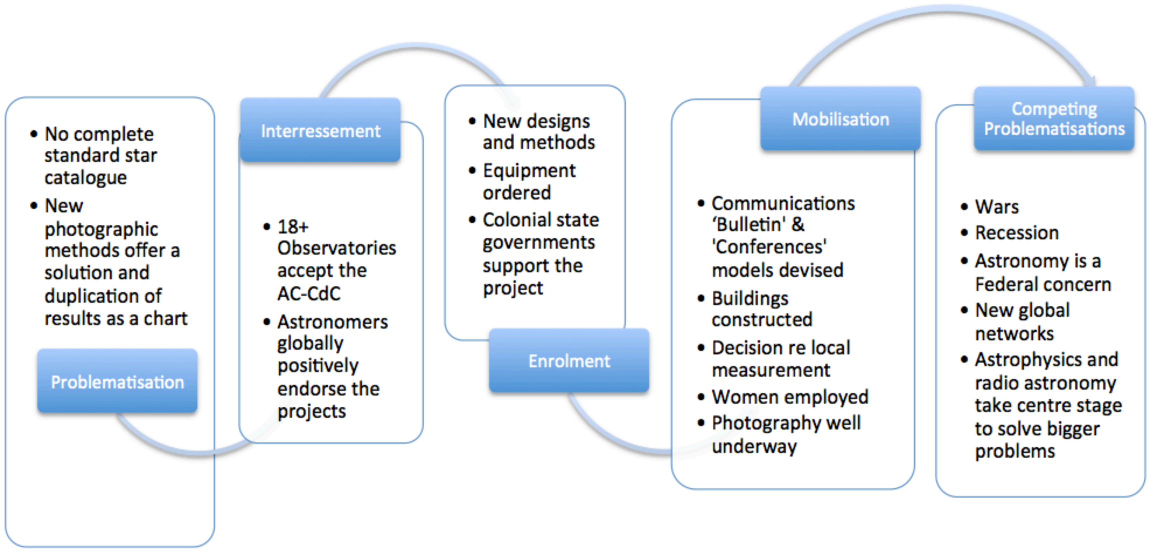


Table 5: Callon's 'Moments of Translation' theoretical model (1986) adapted to the AC-CdC.

The ability to adopt some form of astrophysics amidst the labour of meridian work became the "litmus test of an observatory's development" in the nineteenth and early twentieth century, so concluded Roger Hutchins, historian and expert on the history of university observatories in Britain (Hutchins 2008, pp. 219–222). Hutchins examined institutional evolution in observatories against a background of disciplinary politics, financial constraints, bureaucracy and advancing technology. According to Hutchins, astrophysics was observation led until 1921, and the development of instruments to make much of the early data possible had been stimulated by the evolution of photographic star catalogue technologies (p. 221). Progress in astrophysics relied on larger telescopes, as well as major research endowments to fund these and their operation. This was only available in North America (p. 222). In Australia the slow response to astrophysical research has been connected with the AC-CdC.

Since the completion of the AC, the discourse amongst astronomers and historians surrounding the project has focussed on its longevity and the negative impact it had on available resources for other astronomy research in Australia, including astrophysics (Bhathal 2009, Gascoigne 1990, Haynes et al 1996 p. 153, Hearnshaw 1996, Orchiston 1988, White 1987). Participation in the AC-CdC has been depicted as limiting the development of spectroscopy and astrophysics in Australia during an era when astrophysics developed in the United States (Haynes et al 1996, p. 95).

Derek Jones, an astronomer at the University of Cambridge Institute of Astronomy, who has also worked at the Royal Observatory Greenwich, argued against the causal effect of the Astrographic Catalogue on the progress of astrophysics. Jones explained that a causal relationship between the two is impossible to prove or disprove (Jones 2002, p. 267). Jones spent two years at Mt Stromlo and Siding Spring Observatories in Australia, and tackled the paucity of making a connection between the impact of the Carte du Ciel and the progress of astrophysics in Europe:

> "Scientifically this is a meaningless question because of the impossibility of performing a controlled experiment. Neither is there the possibility of making falsifiable predictions. Nevertheless it is interesting to review the progress of astrophysics during the period when the Carte du Ciel was active and review some alternative explanations."
> (Jones 2002, p. 267).

During the early twentieth century, the astronomy research environment in the US was well resourced and prospering in contrast to that of Britain and Europe, with many differences emerging from the 1890s (Lankford 1997, p. 370). According to Mack, private patrons were in a race for the prestige of building the biggest telescope (Mack 1990). Due to the boom in the industrial economy of the US, donations from these rich benefactors "resulted in the 36-inch refractor at Lick Observatory in 1889, the 40-inch refractor at Yerkes Observatory in 1897 and the 60-inch and 100-inch reflectors at Mount Wilson in 1908 and 1917" (Mack 1990, pp. 73–74). These larger telescopes made it possible to see and record well beyond the limits of the telescopes being used in Australia by the state funded observatories.

Funding from government sources, predominantly the US Naval Observatory, Harvard College Observatory, and schemes such as the Draper Memorial fund, meant that astrographic work was able to continue in North America using the new large telescopes that, by their nature, pushed America to the forefront of astrophysics. Another reason for the progress of astrophysics in the US was the influence of the work performed by women from Harvard College Observatory, a direct result of the Harvard Catalogue of the spectra of stars (Mack 1990, pp. 73–74; Howard 1990). Whilst Hughes subscribes to the idea that AC-CdC participation restricted astrophysics research, he has examined other astrographic catalogues produced around the turn of the century (2013, p. 1038). Hughes has revealed that, contrary to previous discourse, the AC-CdC was the only complete sky catalogue until the recent use of space telescopes (Hughes 2013, pp. 1027–1028).

In Australia, the general public was aware of astrophysics from the latter part of the nineteenth century, as demonstrated in Figure 85 which illustrates the use of the term 'astrophysics' in the popular news media in Australia from 1880 to 1959. The highest occurrence was during the period when Einstein's Theory of General Relativity was being tested during a solar eclipse in Australia in 1922.

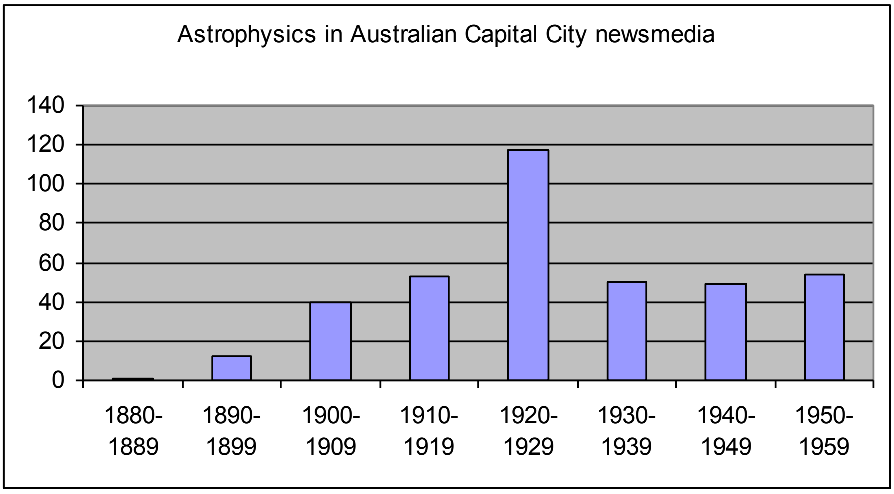


Figure 85: Graph showing how the word 'Astrophysics' was used in the popular press in Australia 1880–1959.

Latour described how even a weak concept can become stronger and greater in time as resources are applied, arguments written, supported and proffered by those with an authoritative voice, making it very difficult to be a voice of dissent—this creates *a priori* (Latour 1987, p. 103). Astronomers Russell, Ellery, Cooke, Nangle and Wood went some way to engage in the research academy and spectroscopy, but with meagre resources competitive research was an elusive endeavour.

The federal astronomy network, which included universities and CSIRO, was organisationally strong by the 1970s. After the completion of the AC at Sydney Observatory, and then the following retirement of Wood in 1974, the remaining state observatories in Sydney and Perth were outside this new network, and their existence was again called into question. Due to the *Commonwealth Act* of 1900, and by applying Latour and Callon's models, the eventual demise of Sydney and Perth Observatories was inevitable.
In 1976, the Astronomical Society of Australia was asked by the Commonwealth Government to produce a national review of observatories. Chaired by early radio astronomer and Professor of Astronomy at Monash University, Kevin Charles Westfold, The Review of Observatories: Report of Expert Sub-Committee (hereafter the Westfold Report) was published in 1978. Six of the universities were represented. Two professors from the ANU

and one each from the Universities of Sydney, Tasmania, Melbourne and Monash were on the committee, the members of which also included S. C. B. Gascoigne from Mt Stromlo and Don Morton, Director of the Anglo-Australian Observatory. Morton was Chair of the Board of Visitors for Sydney Observatory. In this concise report, the national astronomical research and education position was presented and the international position summarised with regards to relationships as well as funding models.

The Westfold Report argued that existing organisations should be funded to improve or install new telescopes on the basis that, on merit, all astronomers would have access to them as 'national facilities':

> "… forward planning for astronomy is closely associated with the funding process …. We recommend that each major astronomical facility, which may in the future be acquired with Commonwealth funds, should be operated as a 'national facility', or as a 'multi-national facility' if other nations are involved."
> (Westfold 1978, p. 33).

The recommended new facilities included a new 1.5m optical telescope for the ANU at Siding Spring and a synthesis radio telescope to be located at Parkes. The concluding remarks in the report positioned the ANU as central to maintaining the momentum since WWII (Westfold 1978, pp. 49–50). The major thrust of the report was its conclusion that research efforts be maintained at the current level and priority given to the Australia Telescope. According to Gascoigne, investment in astronomy should only be at a national level. He later commented that it was imperative "future government-funded instruments be regarded as national facilities" (Gascoigne 1990, p. 365).

Haynes et al remarked upon the changing nature of astronomy in Australia and how this had mirrored social, economic and political changes (Haynes et 1996, p. 2). Intrinsic to this historical change had been the move from the work of individual astronomers to international projects, which were collaborative (p. 3). Furthermore, the science shifted significantly from optical astronomy to exploration in other wavelengths. By the 1980s the idea of a national astronomy was, according to Haynes et al, 'anachronistic', and multi-national collaborations were then the normative model for technological development and research (p. 6).

The Westfold Report (1978) had significant influence on the future of the two remaining state observatories, Perth and Sydney. This report galvanised the national focus on astrophysics, and represented a move away from positional astrometry. The launch of astrometry satellites instigated a renewed interest in the proper motion of stars and extracting data from the Astrographic Catalogue and Carte du Ciel glass plate negatives.

AN ASTROGRAPHIC RENAISSANCE

In 1985, C. Jashek from Strasbourg Astronomical Data Centre reported on investigations he had made with all the AC-CdC participants about the location and condition of the AC-CdC glass plate negative and logbook collections (Jashek 1985). This document included a report about the Sydney and Melbourne plates from Alan Vaughan, Professor of Astronomy at Macquarie University, and it sought to determine if there was interest in re-measuring the AC plates. Following this study, Jashek concluded that there was no interest in re-measuring the plates, that most plates were in good condition, and that there was interest in the CdC plates for potential digitisation (1988, pp. 375–381). Jashek realised that the original problematisation for the AC-CdC still existed, but there was no comprehensive all sky star catalogue in digital form. Furthermore, he proposed that even after the data from the space telescope Hipparcos was made available, there was a high value in combining the data of catalogues produced in the past century to provide a long baseline for calculating the proper motions of stars:

> "It is clear that the longer the time base and the smaller the positional error at each of the epochs is, the better the proper motions are … This is in short the justification for using the Astrographic Catalogue (AC) and the Carte du Ciel (CdC) material – or better said to start using it."
> (Jashek1988, p. 377).

In 1972 Thomas Corbin, Head of Cataloguing at the USNO, and astronomer Paul Herget combined many reference catalogues to produce a global reference star catalogue called the Astrographic Catalog Reference Stars (hereafter ACRS) (Corbin & Urban 1998, p. 41). There was a resurgence of interest in the old star catalogues and use of the ACRS findings for comparing positional stars with findings from the space telescope Hipparcos, launched in 1989 and operational until 1993.

The data from the printed AC was digitised by the USNO for comparative star catalogue research (Urban 1997; Urban et al 1996, 1998; Urban & Corbin 1994, 1996, 1998; Urban, Corbin & Wycoff 1997, 1998). This extraordinary catalogue, which used the original AC data reduced to equatorial co-ordinates, was called AC 2000 and included 4,621,836 stars over the entire celestial sphere with the average epoch of 1907 (Urban et al 1998, p. 1212). The analytical data demonstrated the areas of greatest measurement error, stellar density and magnitude concentration and variation. In a concluding text, Urban et al thanked the USNO team who re-entered the AC data and performed further reductions. He said:

> "… a special gratitude is extended to the hundreds of men and women, most of whom have long since passed away, who exposed and measured the 22,600 AC plates."
> (Urban et al 1997, p. 1222)

The AC2000 data was then combined with a number of other historic star catalogues to create the Tycho-2 star catalogue. Tycho was a mapping device attached to the European Space Agency's Hipparcos satellite telescope (Fresneau 1998, Urban, Corbin & Wycoff 1998). The catalogues were further combined as explained in the following abstract:

> "The U.S. Naval Observatory has completed the compilation of the ACT Reference Catalog, containing 988,758 stars covering the entire sky. The motivation behind the ACT was to provide accurate proper motions for the majority of the stars in the Tycho Catalogue (ESA SP-1200). To do this, positions from new reductions of the Astrographic Catalogue (AC 2000) were combined with those of Tycho. The large epoch span between the two catalogs yields proper motions about an order of magnitude more accurate than those published in the Tycho Catalogue."
> (Urban, Corbin & Wycoff 1997, p. 1)

This combination of old and new catalogues eventually produced a catalogue of 2.5 million of the brightest stars. The AC 2000 has also been used to investigate double stars (Wycoff et al 2006, p. 50).

There have been a number of digitisation projects to extract the data from the CdC and other star catalogue glass plate negatives (Dick et al 1993; Jones 2000, 2002; Fresneau et al 2003, 2005, 2007; Lieber 2010). Derek Jones, who was an astronomer at the RGO, confirmed the significance of the AC and the CdC glass plates in the study of star kinematics. According to Jones, once the CdC glass plate negatives with their longer exposures are in digital form, further accuracy would be obtained and it is most likely they will hold further extensive scientific research potential.

Astronomers studied the glass plate negatives for comparative star magnitude and proper motion research whilst the AC-CdC collection was in the Macquarie University Library vault (Frew 2004, p. 32; Fresneau et al 2007). Macquarie University Professor of Astronomy, Alan Vaughan, and French astronomer, Alain Fresneau, provided evidence that the CdC plates could be used as comparative measures to determine proper motion (Fresneau 1998). Lesa Moore catalogued the glass plate collection and helped identify suitable plates to be scanned (Moore 2002, pers comm, 2015). Six hundred and fifty of the Sydney CdC plates were sent to be digitised using the Automatic Plate Measuring (APM) machine at the National Astronomy Facility, Cambridge. This process provided data which was analysed and compared to other epoch stellar images by Vaughan, who was working with Robert Argyle from Cambridge University and other astronomers.

In 2003, one hundred of the scanned Sydney Observatory CdC plates were used in a research study around the Coalsack (Fresneau et al 2003). David Frew re-measured twenty-five of the CdC plates with the Eta Carina nebula as part of a comparative survey (2004). In 2005 another ten plates were analysed in the Sagittarius constellation, and a table of a further 291 first-epoch Sydney Observatory plates listed for further research (Fresneau et al 2005). There has been further research studies based around the first-epoch CdC Sydney zone plates scanned by Vaughan (Bucciarelli et al, 2006; Fresneau et al 2007).

CdC plates from other zones have been digitised including Toulouse, Cordoba, Bordeaux, Uccle and San Fernando (Tsvetkova et al 2009). In 2009 the Potsdam CdC plates were investigated and the scientists concluded that, by using specialist flatbed scanning technology:

> “CdC plates continue to be used for proper motion determinations … or discovery of quick brightness changes (time scales up to 20min and amplitudes larger than 0.5mag) in stars with brightness in the photographic range 10-14 mag (Fresneau et al. 2001).”
> (Tsvetkova et al 2009, p. 882)

The Sydney and Melbourne zone AC-CdC glass plate negatives have been preserved and re-housed in conservation conditions with the related data, as one of the outcomes of the research for this thesis. They are located in the MAAS under a Distributed Collection agreement with SRNSW. This will facilitate future research.

Chapter Conclusion: Heritage data has social & scientific relevance

For the state observatories, the AC-CdC enabled continued astronomical operations by providing a project with an international network. This network, which had its centre in the Royal Observatory Greenwich and Paris Observatory, included influential astronomers who could lobby the Australian State Governments and those establishing the new Commonwealth of Australia astronomy network. This gave resilience to Sydney, Melbourne and Perth Observatories in times of war and financial depression. It also meant that when these institutions were closed for research, the AC collections and instruments were, by and large, preserved for further research uses. Adelaide Observatory contributed essential data, but was never part of the global AC network to the extent of the other state observatories. Its closure resulted in greater dissipation and loss of instruments and records.

Conversely the AC-CdC was an astrometric project in which the colonial observatories produced data for use by other scientists for research, and this use has continued. The observatories had always been under the control of higher authorities and were not driven by their own research projects. Due to this, it has emerged that the observatories developed very little new research from the data they collected, and the astronomers who used the data did not always acknowledge the individuals who produced it. Therefore, even though the AC was very similar to Harvard's astrometric projects, it was also distinctive because attributed published research using the data did not occur locally by the staff at the AC-CdC observatories in Australia. Latour's 'centre of calculation' theoretical model applied.

Financial support for astronomical research was not forthcoming from the State Governments once the federation of astronomy was announced in 1907. The First World War further extinguished the opportunity for Sydney Observatory to move to a dark sky site, and the financial depression almost closed all the state observatories.

As the twenty-first century progressed, it emerged that the greatest threat to the existence of the state observatories, and the completion of the AC-CdC, was the federation of astronomy —the move towards this occurred sporadically up until WWII. The leading university astronomers propelled the focus on a singular world class organisation for research science. My research has shown that whilst some of the state government astronomers, in particular Pietro Baracchi and Harley Weston Wood, were pivotal in establishing the new federal networks and astronomical sites, these networks (once established) excluded the state observatories and astrometry. More recent astronomy research now depends on global networks and international co-operation and communication. The AC-CdC has emerged as a model for astronomical projects that, although fraught with technological impediments in the past, has currency today.

In the following chapter, I conclude this thesis and more closely examine the legacy of the Astrographic Catalogue and Carte du Ciel projects in Australia. Parallels are drawn between the recognition and representation of the contribution made by the first women in astronomy in Australia, and the demographics of contemporary astronomy research organisations. History and heritage representation are interrogated as avenues of gender prejudice, but also potential advocates for social change.

CONCLUSION: THE HEAVENS REVEALED

The heavens were revealed in the latter part of the nineteenth century through advances in photography, which made stars and other celestial wonders never seen before visible. The sky visible from the Southern Hemisphere was a rich offering, and the largest portion of its stars were photographed and catalogued by observatories located in Australia.

My research has affirmed that the Astrographic Catalogue and Carte du Ciel, which date from 1887 to 1964, were the first all-sky catalogue and chart. It was due to participation in the AC-CdC that women were introduced into the workforce of four state observatories in Australia from 1890. In assisting the astronomers, they too were at the forefront of what has been heralded a revolution in astronomy.

By reference to the work of feminist historians, such as Pamela Mack, Margaret Rossiter, Margaret Wertheim and Londa Schiebinger, my research demonstrates that the power of selection, of inclusion or exclusion, determined how the AC-CdC has been interpreted over the past century. My interpretation of the work performed by women is based on new primary research. It has for the first time centralised the work of the predominantly female star measurers and computers within the narrative and analysis of the AC-CdC in Australia. My research has revealed that involvement by women in the projects was more significant than previously recognised in the historiography of astronomy in Australia. At least seventy-one women were involved in the AC-CdC, and the more contemporary applications of the AC have revealed that they made meaningful, if little acknowledged, contributions to science.

The AC-CdC was part of an active network of people, instruments, astronomical laboratories and scientific processes which reflected the social milieu in which astronomy was performed in Australia. In this final section of the thesis, I conclude my findings by presenting participation in the Astrographic Catalogue and Carte du Ciel as an ambitious, innovative and modernist construct. I conclude that my research for the AC-CdC has cultural consequences for women in astronomy today and the history and heritage of astronomy in Australia.

A Fresh View of the AC-CdC in Australia

In this thesis, I have uncovered revelations about the rich history and sociology of the Astrographic Catalogue and Carte du Ciel and the involvement of women. This thesis has revealed that the AC-CdC had some unexpected outcomes in Australia. It inspired poetry, instigated women to articulate their value in the workplace and fight for improved working conditions, and created an impressively large and significant scientific and museological heritage, which has contemporary relevance. In this thesis I have examined the AC-CdC and discovered it to be more than a scientific project. I have uncovered that the AC-CdC was symptomatic of hegemonic colonial mapping ambitions; however, it changed the way astronomy was performed by influencing the structure and hierarchy of observatories, and it introduced women into astronomy in Australia. There are other more subtle findings which collectively change the way the AC-CdC has been recognised within the history of astronomy in Australia.

One of the fresh approaches that this thesis has contributed to the examination of the AC-CdC in Australia is the reference to sociological theoretical models as investigative tools. In Chapter One, I defined the methodology for this thesis, which included the actor-network theory models developed by French anthropologists and theorists on the process of science, Bruno Latour and Michel Callon. These theoretical models had been previously applied to the involvement by Paris Observatory in the AC-CdC (Aubin 2003), the theory of map making and colonial science (Turnbull 1996; Chambers and Gillespie 2000) and colonial museum collecting practices (Bennett 2005, 2009). This thesis applied the ANT theoretical models as research and analysis tools to both broaden and deepen the investigation of the topic.

ANT drew attention to all the proponents of the AC-CdC. This refocussed the thesis from the well-known government astronomers to what emerged as a significant and little understood labour force primarily populated by women. Within ANT, Latour described ‘centres of calculation’ as typical of the colonial model and networks, which have human, technological and material ‘actants’ of influence (Latour 1987, p. 84). It was the application of Latour’s circulation model to the relationships between local observatories that guided my research into Adelaide Observatory's role in the AC-CdC, and led to rich revelations about the role of women in the AC-CdC which went beyond the official participants.

This emerged as providing one of the most significant findings of the thesis. Adelaide Observatory provided reference stars, initially to Melbourne Observatory in the 1890s and then to Sydney Observatory in the 1920s. This collaboration had had passing acknowledgement (Haynes et al 1997, p. 83), but it was within the detail of this investigation that proven evidence of Mary Emma Greayer's work was uncovered, which involved using telescopes. Greayer's work proved to be extensive research and pivotal to the accuracy of the Melbourne zone of the AC-CdC.

Latour's centres of circulation model, when applied to the AC-CdC, offered an explanation as to why so little astronomy research was produced in the colonial state observatories during the production of the AC-CdC data. Southern Hemisphere colonial observatories were engaged in the AC-CdC as collectors of data, which was to be sent back to a colonial centre, Paris or Greenwich Observatory, for analysis. However, this changed so that more responsibility was placed on each of the colonial observatories, which together assembled a network for information exchange. At this pivotal moment, there was potential for the state observatories to step towards independent or nationally focussed astronomy, and to use the data for local research; but no evidence of this realisation nor any move towards this action emerged in my research.

When I applied Callon's 'moments of translation' model to the AC-CdC in Australia this revealed why the AC-CdC emerged in the late nineteenth century as a powerful problem which required a global network to solve. In Australia, the 'problematisation' of not having an all-sky catalogue was later replaced (in the mid-twentieth century) by the nationally focussed astronomy sector with new 'problematisations' around astrophysics and radio astronomy. Callon's theoretical model provided a new and previously untried framework by which to investigate why support for the state observatories, and their strength in positional astronomy, disintegrated. Callon's theoretical model also provided a plausible rationale for the struggle to obtain adequate resources to complete the AC-CdC. This methodology demonstrated the political nature of scientific research, and the replacement of the old with new ideas and projects (Callon 1986, pp. 196–233).

In the first chapter of this thesis, I described the AC-CdC as a multi-faceted modernist ambition. My research has established that the differentiation between the AC-CdC and all the other star catalogues prior to 1887, such as the Bonn, Cordoba and Cape Durchmusterung (Star Catalogue), the Draper Memorial Catalogue and the Harvard Catalogue, was the level of co-operation which led to standardisation between observatories around the globe. According to Gillespie and Chambers, modern science operated in polycentric communication networks (Chambers & Gillespie 2000, p. 223).

As demonstrated in Chapter Two, the enrolment of the colonial governments to mobilise and invest in technologies for the AC-CdC during the period 1887 to 1900 was tied to colonial ambitions. The resources committed to the projects were equal to, if not greater than, the investment made by the established observatories in the Northern Hemisphere.

The colonial observatories had been actively engaged by the British contingent. Russell, Ellery and Cooke had seen great opportunity to be part of the project's network for reasons of influence, to obtain the latest equipment and participate in the photographic revolution. My research has proven that the lead astronomers in all the state observatories embraced the AC-CdC. The undertaking was considered a great opportunity, not an onerous task, which varies from some authorised histories of the project.

Earlier in Chapter Three, my analysis of the resources expended on technology revealed that once the participating state-run observatories in Australia became embedded within imperial and global networks, significant local resources became available. This was coincidental with an advantageous boom in colonial finances and a developing national ambition. The buildings, equipment and technologies have survived to become rich sources of new research.

Contrary to the initial support for the AC-CdC my research has confirmed that the State Governments had little interest in astronomy, which was seen as an adjunct to the main work of observatories. Whilst other social and scientific problems impeded progress on the AC-CdC, the Commonwealth Government jurisdiction over astronomy emerged as the primary reason that the state governments were reluctant to continue financing the state-run observatories. Conversely, the responsibility for the AC-CdC, which was vested in State Government observatories as part of the British contingent, became the sole lifeline for their existence after federation and especially after the opening of the Commonwealth Solar

Observatory in 1924. Once local astronomical knowledge and equipment was not required for more useful services—such as timekeeping, weather, sun and moon rise and set times, and tidal data—and the Constitution determined that astronomy was a federal government concern, the state governments had no reason to fund the observatories apart from their commitment to complete the AC-CdC.

In my examination of the development of star measuring machines in Chapter Three, it became evident that the demands of the AC-CdC accelerated the development of affordable and easier to use star measuring devices during the period 1895 to 1904. This and improvements in photographic methods and materials was accelerated due to the AC-CdC and influenced other research in astronomy. This analysis has not previously emerged in the historiography of the AC-CdC because of the opposing theoretical position that the AC-CdC stymied research.

My research into the AC led me to case studies of women who were employed in astronomy from the very beginning of the project. These women were unlikely to achieve prominence or have career advancement because of a number of social factors. The confinement of women to gender-specific roles had, according to Fine, been proliferated by social legislation and workplace structures (2010, p. 8). The perceived aptitude of the female for empathy meant that she was deemed suitable to support the male, who had a perceived innate ability to systematically understand the world through science, engineering or in business.

Consequently, the data gathering work was demoted. My research has shown that, from the onset, it was envisioned that the new technical role in measurement for the AC in Australia would be far more specific than previous 'computing' roles undertaken by men, which had existed for some decades. The new role had attributes of the idealised feminine traits including care, consistency, diligence and the ability to work at a determined pace without contemplation or originality.

I have found evidence that some of the women employed for the AC at Adelaide, Melbourne, Sydney and Perth Observatories performed duties that were outside the feminine 'type', such as using telescopes, calibrating instruments and supervising others. These were considered 'masculine' roles. The term 'sex-typing' originated in the early 1980s and has become a common term to describe the way men created hierarchical borders based on gender, and segregated the workplace (Schiebinger 1987, Bhathal 2001, Hooker 2004).

The evidence from my research has increased knowledge about women's work on the AC, but it brings into question whether this work was clerical data processing or astronomy. In order to deliberate on this comparative analysis, the era in which the work was produced and the society in which that production occurred must be considered. Furthermore, past historical accounts have added a gender-specific lens through which we view the work (Smith 2008).

The scientific nature of the astrographic assistant role must be determined if any of the women who measured the stars are to be called 'astronomers'. If it were scientific it would have involved observation, data-recording, analysis and decision-making. A purely clerical role would be restricted to note-taking and copy work. A clerical role would require very little analysis or technological adjustment. It would also not require any knowledge of astronomy to do the work. Finally, whether the work was published, and therefore formed a foundation for future research, is an important factor.

The most important conclusion of this thesis is the significant contribution made by the female labour force in the development of the AC-CdC. My research has found that the first woman employed on the AC-CdC, Mary Emma Greayer, was indisputably observing through the telescopes and her observations were the basis for the reference stars used in the Melbourne zone. From 1898 in the Astrographic Bureau at Melbourne Observatory, the women observed stars on glass plates and made judgements about the nature of those stars; this would also appear to be research using classification systems. Moreover, women employed for a considerable period of time (eg Greayer, Peel, Williams, Allen, Digby) often performed management and decision-making work which was equivalent to that undertaken by the male 'assistant astronomers'. The contribution of these senior women to the observatory went beyond the measurement and computational roles to error checking and instrument adjustment, but they were not acknowledged equally for this senior role in the printed Astrographic Catalogues, or in the authorised history. The role and authority of some of these women in the development of the AC has been substantiated in my research for this thesis.

My research revealed the women who worked on the AC were highly ranked amongst those who completed their high school matriculation. They were selected as outstanding due to their mathematical ability, with successful results most often in algebra and/or geometry. During the late nineteenth and early twentieth centuries, it was not uncommon for males to progress through the ranks in astronomy without qualifications but based on their experience and the quality of their work. Curlewis argued that the work performed by the women was not clerical, but technical in its nature and thus deserved a higher rate of pay than the clerical rate.

Whilst Winsome Bellamy claimed that she knew little of the astronomy (pers comm. 2011), there is evidence that the women employed earlier in the project , such as Greayer, Peel and Williams, did have an interest in research astronomy. As my findings revealed, Greayer and the Todd sisters, who joined the Astronomical Society of South Australia in 1893, are the earliest examples of women who actively participated in astronomy societies.

Finally, when the Astrographic Catalogue was published, there was considerable evidence that the astrographic assistants' work was used for further research (Barton 1937ab; Pocock 1915; Wrigley 1911). Moreover, it is possible to link the individual women to each star they measured. The AC star positions were digitised and the results were further reduced for contemporary analysis and use as a comparative dataset (Urban et al 1996; Urban et al 1998aba).

No doubt, the women deserve acknowledgement for their technical ability and contribution. The question of agency is an important part of deliberating the influence the women had in the scientific outcomes of the AC. The women, whilst employed for the same or similar purposes, achieved different levels of agency within the observatories. The way the work was performed, and their isolation, enabled the women to bond together. This facilitated their ability to lobby for small, and sometimes more significant changes—as clearly emerged through the letters written on behalf of the Perth star measurers by Williams for improved pay and conditions. Williams drew attention to the extended work undertaken to identify double stars and, whilst "… she was engaged here as an astrographic plate measurer, and has not yet , to her knowledge, been raised to the position of computer... " this work as well as other tasks assigned to Nossiter, was nonetheless being done (letter Williams to Curlewis undated Aug 1914 SRWA 1914/3046).

The separation of the women from the men, a normative arrangement, had scientific and social consequences. The nature of the work meant that women formed partnership teams amongst themselves. This enabled them to produce a great quantity of work accurately, but it also removed them from opportunities to progress their knowledge in astronomy.

Despite restrictions on the type of work women were given, I have uncovered at least three women who were exceptional in astronomy in Australia in the late nineteenth and early twentieth centuries. My research has established that they had attributes which would equate them to the title 'astronomer' were they of a different gender.

Mary Emma Greayer worked directly alongside the astronomers at Adelaide Observatory during the evening, undertaking observations, notation and reduction involving complex calculations. Charlotte Emily Fforde Peel rose to a position at Melbourne Observatory where she supervised the work of others, calibrated instruments and determined errors, overseeing the Astrographic Catalogue measurement and computation. Peel became the first woman professionally employed in astronomy in Australia and she was involved in comet observation and measurement, and was acknowledged for this. Prudence Valentine Williams supervised and trained Perth Observatory star measurers and computers, in a similar manner to Peel. She stood up for the rights of the women, including their conditions of work, the temporary status of their employment and their pay award and in doing this established that the work that she was doing was of the same, or similar , nature to the work performed by the supervising astronomer. Williams and Peel identified double stars and undertook quality control of their respective Astrographic Bureaux.

Ida Dorothy Digby supervised the Sydney Astrographic Bureau but there is still more to investigate about her and her fellow measurers. Muriel Heagney emerged as a leader in the Labor and Equal Rights for Women movements. Whilst her agency may have been limited within the observatory, she changed the way society viewed women's work, and her high profile challenged gender prejudiced social mores and helped instigate change. Heagney is an outstanding woman who began her career in astronomy and went on to succeed in other areas. Winsome Bellamy, Verlie Maurice and many of the other astrographic measurers went on to have families and/or careers in nursing and small business, and they also contributed to society.

My research has shown that despite the confines of the AC-CdC computing and star-measuring role, the more analytical contributions of the individual existed. As discussed in Chapter Four, none of the women employed on the AC had specialist education in astronomy, but I found evidence that they had an aptitude for geometry and were selected because of their excellent examination results. Nevertheless, they were not, as far as my research has shown, encouraged to pursue research using the data. I have demonstrated that their work, which extended to the detection of double stars, was used in research publications but they were rarely acknowledged.

As examined in this thesis, some of the women who worked on the AC, such as Greayer and Peel, were involved in new discovery; and others, such as Williams, had a deep interest in astronomy and were involved in the amateur societies, demonstrating an aptitude that went beyond what has been previously understood of the role of an AC measurer and computer. According to Bigg and Lamy, the legacy of the AC and Carte du Ciel is not measured by scientific outcomes, but by social outcomes, the most significant of which were changes in how science was organised around new processes involving the handling of large datasets (Bigg 2000; Lamy 2009).

Some historians of astronomy and astronomers acknowledged the AC-CdC projects' resources and ambitions, but took a theoretical position that other scientific research could have been pursued if the State Government observatories had not participated in the AC-CdC (Orchiston 1988, Bhathal and White 1991, White 1987). This is examined earlier in Chapter Five. My analysis, which involved extensive research, found no evidence of unrealised potential due to the AC-CdC. On the contrary, I have found that the instrumentation developed for the astrographic photography was highly successful in its application to other research before, during and after the AC-CdC. Further to this point, the measurement instrumentation for the analysis of photographs was in its infancy in 1887.

In Chapter Five, I examined the Carte du Ciel and disclosed that contrary to the authorised histories of the project (Haynes et al 1997, p. 62), the triple exposure photography for the CdC was completed at Melbourne Observatory, substantially completed at Sydney Observatory, and at least half completed at Perth Observatory. During the period 1905 to 1930, over 1266 Sydney CdC zone plates were photographed. The Melbourne CdC zone was photographed from 1892 through to completion in 1929. The Perth zones appear to have been initially undertaken but abandoned in 1903. Test contact prints of a series of plates were made at Melbourne Observatory in 1902 (Baracchi 1903, p. 234). However, the highly specialised printing required was beyond the financial resources of the observatories, and their respective governments were not forthcoming with funds to print the CdC.

Experiments to determine proper motions using Perth and Melbourne CdC plates by Innes in the Cape of Good Hope Observatory provided different research opportunities than originally intended (Innes 1916, 1921, 1926). The CdC is especially significant because of the deeper field stars, down to 14^{th} magnitude, which were recorded through the long exposure photography. As a sizeable section of the celestial sphere, the photographs of stars down to 14^{th} magnitude taken at Sydney, Melbourne and Perth Observatories hold potential for further comparative epoch, double star, proper motion and other galactic research, as examined further in this section.

The photographic methods employed for the AC required the human eye to detect and measure the location of each star on the glass plate negative, and to measure or estimate the size the star appears on the negative as that indicates its brightness or magnitude. The astronomers realised that this method relocated the 'observer' from the eyepiece of the telescope to the eyepiece of the micrometer. They implemented systems to minimise the human error each measurer would bring to the project. Despite the reliance on the individual's precision, my research concluded that the 'observers', who were almost exclusively women, were rarely acknowledged for the production of the raw data when it was then used for further research. The mechanisation of measuring stars using scanners was only implemented after the completion of the AC with practical use from the 1980s (de Vegt 1988, p. 216; Fresneau et al 2007; Tsvetkova et al 2009).

In Chapter Five, I revealed that the significance of the AC-CdC extended beyond the individual participatory observatories to influence the structure of work within scientific organisations in Australia. The impact of the AC-CdC in establishing and permeating hierarchical roles and structures, which resembled modernist factories of astronomical labour, was recently recognised in the historiography of astronomy in France (Aubin 2003; Lamy 2006, 2009; Bigg 2000). This was one of the causalities of the standardised global structure for observatories which emerged out of the AC-CdC. According to Bigg, the AC created hierarchical barriers which stymied the advancement of women as research scientists. My research has shown that this theory has resonance in Australia because the extensive employment of women for the Astrographic Catalogue did not produce a clearly traceable path to the advancement of women in astronomy.

Women in astronomy today

Although my research has shown that women constituted a significant proportion of the astronomical workforce in Australia, at times equating to one third of all employees, the employment of women for the Astrographic Catalogue did not lead to them having career opportunities in astronomy. Of the seventy-one women employed, only five were made permanent employees, and only one, Charlotte Peel, was officially acknowledged as having a professional scientific role in an observatory.

In Australia, and in many other countries, the hierarchical typology of employment constructed for the Astrographic Catalogue was entrenched by social barriers and enforced through gender discriminatory legislation. These factors were bound together and became hegemonic for decades, severely limiting the scope of the AC women to engage with astronomy at a research level. The correspondence between the observatory directors and the government ministers provided new proof that the government astronomers valued the women, and they sought, at times successfully, to make them permanent staff members. Apart from Greayer and Peel, there appear to have been too few opportunities for the women who were the 'foot soldiers' of the AC-CdC to advance their knowledge, and no possibility for them to continue in any professional capacity after wedlock. However, as I investigated the contemporary status of women in astronomy, I realised that there is a connection between the first women in astronomy in Australia and statistics surrounding women working in astronomy today. As I will now demonstrate, my investigations revealed that there have been changes in the representation of women in astronomy since the early twentieth century, but these are not to the extent that might have been anticipated.

Australian astrophysicist and Nobel laureate, Brian Schmidt OA, set a benchmark for the growth of women employed in permanent positions in astronomy from 23% in 2015 to 44% in 2025 (Schmidt et al 2015). Whilst it may appear that our society has changed since the AC-CdC was completed, the figure of 23% of women in professional astronomy (quoted by Schmidt) demonstrates that there is still a significant underrepresentation of women in astronomy.

To address the gender imbalance in astronomy, a ‘Women in Astronomy’ (WiA) chapter of the Astronomical Society of Australia was formed in 2010. The main aim of WiA is to “monitor the status of women working in astronomy in Australia and recommend future actions that will improve the environment for all astronomers.” WiA’s charter is to increase the retention of women in astronomy practice, further women’s careers to more senior positions and encourage women to partake in and continue tertiary education in this field.

At each annual workshop, Sarah Maddison, Professor of Astrophysics at the Centre for Astrophysics and Supercomputing at Swinburne University, presents the latest demographics of women in astronomy. In her 2014 report Maddison’s statistical presentation showed a dramatic decline in the representation of women in professional science and at the executive level in Australia’s national science organisation, CSIRO. Maddison presented evidence that whilst women constitute 35% of CSIRO scientists, only 8% of the executives are female (Annual Report 2009, CSIRO; Bell 2009, p. 21). Maddison’s most recent data about membership of the ASA at the WiA 2015 workshop, as shown in Table 6, demonstrated that there has been a steady improvement in the gender balance of the ASA, but as of 2015 still only 26% of the memberships were women.

Australian anthropologist, Professor Sharon Bell, prepared a report for the Federation of Australian Scientific and Technological Societies about the status of women across science, technology, engineering and maths (STEM) in 2009. Bell’s report revealed much the same trend as Maddison’s WiA statistics. In 2008, women represented 22% of the professionals working in design, engineering, science, ICT and transport (Bell 2009). Bell revealed that there had been marginal increase in the representation of women in STEM professions in the period between 1996 and 2008; however, in engineering, ICT and science, the percentage of females had decreased (Bell 2009, p. 76). These statistics show that over a century since women entered the astronomy workforce, and despite the fact that women are highly educated in astronomy and other STEM fields, the majority of them are not achieving permanent employment in senior positions.

Membership	July 2015	July 2013	Nov 2011	June 2009	June 2007	Oct 2003	Oct 1999
Fellows	107 (14.0%)	103 (13.6%)	105 (13.3%)	79 (12.7%)	77 (11.7%)	53 (3.8%)	59 (1.7%)
Honorary	19 (10.5%)	16 (6.3%)	16 (6.3%)	16 (0%)	16 (0%)	15 (0%)	14 (0%)
Member	297 (26.3%)	279 (24.0%)	243 (20.6%)	229 (19.7%)	204 (18.1%)	214 (16.4%)	260 (20.4%)
Associate	26 (38.5%)	20 (25.0%)	19 (26.3%)	13 (15.4%)	10 (20%)	9 (22.2%)	10 (30%)
Student	240 (35.8%)	228 (35.0%)	190 (37.4%)	153 (33.3%)	106 (46.2%)	84 (42.9%)	68 (39.7%)
TOTAL	689 (27.7%)	646 (26.0%)	573 (24.6%)	490 (22%)	413 (23.5%)	375 (20%)	411 (20.4%)

Table 6: Statistics showing the total number of ASA members in each category with the percentage of women in brackets (Maddison 2015).

Fine presented her findings about gender bias and women's career choices at the WiA 2014 workshop (WiA, Canberra ACT, 28 August 2014). Fine argued that there is a culture of researchers and society emphasising and creating difference between what women and men can do, both physically and mentally. According to Fine, culture is at the core of gender imbalance in the sciences. Fine's research has shown that society has rewarded men for their careers and originality, and rewarded women for their domesticity and compliance; she argues that the 'ideal' woman image has persisted (2010). This 'ideal' image of a woman is domestic, supportive of males and lacking in originality. These are characteristics which male astronomers sought in the women who were employed in the Astrographic Bureaux.

Claire Hooker's investigation of women in science in Australia brought to the surface questions about why, well into the latter part of the twentieth century, women were hidden and doing the more mundane work in the laboratories whilst the males published papers, received recognition and were rewarded with career advancement (pp. 167–169, 2004). Hooker summarised the gendered classification of 'women's work' as the repetitive, "painstaking and not conceptually innovative" (p. 17). According to Hooker, women have experienced 'vertical' segregation, tied to the poorly paid positions by their gender (p. 5). In many of Hooker's case studies, especially about women involved in the physical sciences and astronomy, the Second World War was a turning point for women's work in science (pp. 145–152; pp. 168–169). Hooker's research demonstrated that whilst improvements have been made in the gender balance of the sciences (providing many inspiring examples of women who have and are still working in science), there is still a long way to go (pp. 170–172). Hooker concluded that women had been discriminated against in the scientific workplace and in less obvious ways, such as through a lack of recognition of their achievements (p. 167).

The issue of underrepresentation of women in astronomy, and more broadly the sciences, is not confined to Australia. In May 2014, I attended the Women in Science Research Network (WISRNet) 'Revealing Lives: Women in Science, 1830–2000' conference at the Royal Society, London. Athene Donald, Professor of Experimental Physics at the University of Cambridge, addressed the conference with her findings on the impact of stereotyping and cultural expectations on women's participation in science. There were discussions and presentations at the conference about the gender inequality in heritage representation and the lack of acknowledgement of women's roles. A presentation about the work performed by laboratory technicians, who were predominantly women, and how it was essential to the scientific research (but the technicians were not acknowledged) (Hartley & Tansey 2014) was relevant to my research into the women who worked on the AC-CdC. The common theme which emerged during the conference was that the 'factory-like' work which women performed in many areas of the sciences did not lead to a career or, in most cases, to acknowledgement.

Larsen's aptly titled *A Woman's Place is in the Dome, Gender and the Astronomical Observatory* (2009) traced women in the past who had been acknowledged for their work. Nonetheless, most of these outstanding women had 'slipped back into oblivion' and Larsen revealed that "those who found the greatest success prior to the twentieth century were able to feminise the observatory in some creative and unique way, making it more of a 'female space'" (2009, pp. 106–107). According to Larsen, and as previously examined by Lamy and Bigg, the revolution in astronomy (due to photography) was one of the instigators of the astronomy factory. The observatory became segregated with a clearly defined regimen of what was considered suitable work for women. This restricted women further and once more confined their opportunities. Larsen perceived a major and positive shift in opportunities for women in astronomy stem from the reliance on computer technology for research science (pp. 120–121). This made the workspace and hours more flexible; however, as Maddison and Bell's demographic research shows, cultural perceptions continue to prejudice women's uptake of and admission into the physical sciences.

According to Fine, the public sphere has had an impact on the decisions women make and the opinions created within society about what women are capable of doing (2010, p. 227). The gendered nature and power of representation was described from a feminist perspective by Simone De Beauvoir:

> "Representation of the world, like the world itself, is the work of men; they describe it from their own point of view, which they confuse with the absolute truth."
> (De Beauvoir 1949, p. 196).

Although the historiography of astronomy in Australia has understated the role played by women in colonial astronomy, the AC-CdC has left a rich repository of tangible cultural records and artefacts, forming astronomical treasures through which to rediscover the past. My research has revealed the heritage value of the logbooks; the detail of the contents demonstrate the individual attributes of the women who observed the stars, and that they were intelligent about their work, as made evident when they recorded double stars and other irregularities. Ultimately the work produced by the women in the Astrographic Bureaux contributed to and continues to be part of new research. This thesis has contributed significantly to the representation of women in the history of astronomy in Australia.

The tangible evidence of women's participation in the AC-CdC has further potential, beyond this thesis, to change the authorised history of astronomy and reinstate the role of women as an essential, culturally influential and fascinating legacy.

The Temporality of Astronomical Heritage

The research for this thesis had a timely, substantial and long-term consequence for the interpretation of astronomy in Australia and the return of AC-CdC heritage to Sydney Observatory and the Museum of Applied Arts and Sciences. The observation of the AC-CdC through a museum studies and collection-based lens in this thesis has enabled the legacy of the measurers and computers to come into focus as holding new significance. In the centre of the lens is the relationship between gender prejudices and the history and heritage of astronomy in Australia.

As discussed, in deference to actor-network theory, the heritage of astronomy is embodied in the processes of its making. This view is the nexus of this thesis because by examining original artefacts, instruments, documents and heritage sites, this thesis has led to new interpretations and original findings. The significance of this research is underpinned by concurrent recognition by an UNESCO World Heritage initiative, which was instigated by the IAU. In this study, astronomical heritage was defined as including cultural practices as well as buildings, interiors, instruments and papers. The foundation study identified that the heritage of astronomy is underrepresented in heritage sites globally, and largely unacknowledged despite its cultural permeation globally (Cotte, Fauque & Ruggles 2010). The Astrographic Catalogue and Carte du Ciel projects are now recognised in the ICOMOS IAU Thematic Study as significant in global, cross-national astronomy in the nineteenth and early twentieth century (Cotte et al. 2010, p. 193). The location and identification of the AC-CdC material, as summarised in Appendix 6, holds rich scientific research potential. This, and the focus on the Australian AC-CdC participants, has been a point of difference in this thesis to other historiographical studies of the project.

The AC-CdC projects were the nexus between the nineteenth century astronomers—who left their handwritten notebooks, correspondence, and well-used brass, polished glass and timber instruments—and mass-produced industrial astronomy. The material culture of the AC-CdC included telescopes, micrometers and other measuring and calculating devices, handwritten tables, notebooks and logbooks, glass plate negatives and printers proofs. These legacies are utilitarian in appearance and use and, as such, they faced many hurdles (Stevenson 2013). In this final discussion about the AC-CdC in Australia, I reveal how research for this thesis has provided a springboard for the AC-CdC collections in Australia to be reassembled, researched and reassessed.

The accessioning of astronomical artefacts is often by chance and not considered during the time when that instrument is in use. This is indicative of the path that the AC-CdC collections have travelled. To investigate methods of using the data from the AC-CdC, the IAU established Division 23 as one of the inaugural divisions. In 1922, the IAU urged the Governments of Victoria and New South Wales to provide the resources to complete the IAU (Appendix 7). In 1948 the IAU, as indicated in Appendix 7, showed its appreciation to Wood for taking on the Melbourne Observatory zone of the AC-CdC. In 1982, the IAU urged that the Sydney Observatory instruments be made available for other organisations to use for astronomical purposes (Appendix 7). In 1987, Suzanne Debarbat, Paris Observatory Astronomer and an authority on the AC-CdC, assembled a body of knowledge on the AC-CdC through an international symposium and an exhibition at Paris Observatory entitled “La

Mesure di ciel" (Measuring the sky) for the centenary (sponsored by IAU Commissions 24 and 41). Conservation of the AC-CdC output was the focus of Debarbat's paper on the Paris Observatory collection.

Paris Observatory has had a long history of preservation dating back to Admiral Mouchez, the instigator of the AC-CdC, who founded a system for collection, registration and conservation of artefacts in 1879 (Thiele 1987: Debarbat 1987, 104–109). Even so, Debarbat noted that the sources of many collections were 'good luck' legacies. According to Debarbat, official archival collections include inventories and official letters, but not always the personal documents which she considered to be the heart of the collection. Whilst archival documents are considered the core sources for research, Debarbat discussed the fate of the AC-CdC instruments and how the chief dangers had been cannibalism and adaptation for other uses not aligned with their original purpose (Debarbat 1987, p. 108).

Debarbat's experience was that when observatories are transferred, collections become dissipated; this is exactly what happened to all the instruments and papers from Adelaide Observatory and a major proportion of the Sydney and Melbourne Observatory AC-CdC collections. Through the process of this thesis, some of the more personalised records (such as photographs taken by women and a personal autograph book) have come to the attention of collecting organisations as holding wider societal significance beyond family momenta.

Jim Bennett, Director of the Oxford Museum of the History of Science, has been at the centre of discourse around the acquisition, interpretation and preservation of the heritage of astronomy. Bennett argued that often the most important time in an artefact's life is when it crosses the museum 'institutional threshold' and that "what is less evident is our appreciation of the potential of the museum as a public platform for the history of science" (2005, pp. 604–605).

This thesis is a timely contribution to acknowledging the astronomical heritage of the Astrographic Catalogue and Carte du Ciel, and has contributed significantly to its preservation. The research for this thesis formed part of the business case for the MAAS to contribute to the preservation of the collection and rehouse it in archival conditions (Stevenson, 2011). In support of the return of the collection, Astrophysicist Bryan Gaensler wrote:

> "I should first emphasise what an invaluable resource these plates are for research. And it is great to hear they will be returning home catalogued and cleaned. I also should mention that the Centre for All sky Astrophysics very much sees itself as 21st Century descendants of the Astrographic catalogue and Carte du Ciel."
> (Gaensler, email to A. Jacob, T. Stevenson 30 April 2011).

In 2013, the AC-CdC collection of glass plate negatives, logbooks, papers and the Hilger measuring machines were relocated from Macquarie University for conservation cleaning, rehousing and cataloguing, prior to returning to the MAAS collection store. In 2015, a new building was constructed at Sydney Observatory to return the heritage dome to the original site and display the Melbourne astrograph and micrometer Sydney A, with photographs of Winsome Bellamy, Ethel Willcocks and Mary Allen measuring the stars. The heritage dome, which was originally constructed by local company Mort's Dock Engineering under instruction from the NSW Government Astronomer, Harley Weston Wood, in 1951, was reinstated. The new building has brought back the AC-CdC heritage and narrative to a prominent location on the Sydney Observatory site, and reinstated and acknowledged the role of women at the forefront of the project. Winsome Bellamy and Rosamond Madden, Harley Wood's daughter, attended the opening ceremony held on the 28th of January 2015.

The future and legacy left to those inhabiting it is difficult to fully grasp, but one who captured the enigmatic quality was British astronomer, Herbert. H. Turner. In 1912, Turner, then Director of Oxford University Observatory, wrote about the photography of stars for the Astrographic Catalogue and Carte du Ciel in his book, *the Great Star Map*:

> "… Our real concern is not with the state of the heavens at any particular moment, but with the changes which may be discerned by comparing one epoch with another … we are not at the end but at the beginning."
> (Turner 1912, p. 185).

Turner realised that he and others involved in the project were creating astronomical heritage by photographing star positions in the early twentieth century. Comparisons to this first epoch catalogue would be possible in future epochs, well into the next millennium. To the instigators and participants of the AC-CdC, it was the future purpose, not yet clear, that was considered important.

The tangible outcomes of this thesis have confirmed that museums are essential partners in the discussion of the heritage of astronomy, including the recognition and care of its material culture and the representation of those who, in the course of history, have become less visible. Furthermore, the buildings, furniture and instruments hold significant information about the process of science which, as I have discussed throughout this thesis, can impact on the scientific results and their future uses.

The Astrographic Catalogue and Carte du Ciel were previously dismissed in historical accounts of astronomy in Australia and, more broadly, presented as momentous failures. The heritage artefacts created for the AC-CdC have emerged in this thesis as revealing new understandings about changes in astronomical practice within the social milieu of the late nineteenth and early twentieth centuries. Moreover, this thesis provides evidence that the Astrographic Catalogue and Carte du Ciel documents, instruments, artefacts and associated built heritage hold significant social and scientific research potential for further reinterpretation of the history of astronomy in Australia inclusive of the involvement of women.

Figure 86: Winsome Bellamy at the launch of Sydney Observatory East Dome, 28 Jan 2015. Photograph Ryan Hernandez, (Collection MAAS).

APPENDICES

APPENDIX 1: LIST OF INTERNATIONAL PARTICIPANTS IN THE AC-CDC

The number of observatories involved in the AC-CdC is often quoted as eighteen (eg Curtis 1909, p. 235; Turner 1912, p. 62; Haynes et al 1996, p. 62; Bigg 2000, p. 93; Lamy & Davoust 2009, p. 190). This is because the sky was divided into eighteen zones and it is accurate for the period during which the zones were originally allocated—around 1900. In some texts the number of AC-CdC participants is quoted as twenty (Smith 2012, p. 243; Urban et al 1998, p. 1213), which reflects the number of observatories that completed the printed Astrographic Catalogues. All in all, twenty-four observatories were involved at some stage during the projects' duration, as demonstrated in the table below.

Zone	**Country**	**Observatories in 1892**	**Observatories in 1900**	**Final List (publications)**
+90 to +65	England	Greenwich	Greenwich	Greenwich
+64 to +55	Italy	Vatican (Rome)	Vatican	Vatican
+54 to +47	Spain	Catania	Catania	Catania
+46 to +40	Finland	Helsingfors	Helsingfors	Helsingfors
+39 to +32	Germany	Potsdam (Berlin)	Potsdam	Potsdam
+39 to +36	India			Hyderabad (North)***
+35 to +34	Belgium			Uccle (Brussels)
+33 to +25	England	Oxford	Oxford	Oxford
+18 to +24	France	Paris	Paris	Paris
+17 to +11	France	Bordeaux	Bordeaux	Bordeaux
+05 to +11	France	Toulouse	Toulouse	Toulouse
+04 to -02	France	Algiers	Algiers	Algiers
-03 to -09	Spain	San Fernando	San Fernando	San Fernando
-10 to -16	Mexico	Tacubaya	Tacubaya	Tacubaya
-17 to -23	India			Hyderabad (South)***
-17 to -23	Chile	Santiago de Chile	Santiago de Chile	Discontinued
-24 to -31	Argentina	La Plata	Discontinued	
-24 to -31	Argentina		Cordoba	Cordoba
-32 to -37	Brazil	Rio de Janiero	Discontinued	
-32 to -37	Australia		Perth	Perth
-38 to -40	Scotland			Edinburgh **
-41 to -51	South Africa	Cape Good Hope	Cape Good Hope	Cape of Good Hope
-52 to -64	Australia	Sydney	Sydney	Sydney
-65 to -90	Australia	Melbourne	Melbourne	Melbourne
	Australia	Adelaide *	Adelaide*	

*Observing reference stars for the Melbourne zone.
**No photography. ROE measured one third of the Perth zone.
***Hyderabad zone by Nizamiah Observatory (Lasania, *The Hindu*, 13 June 2014).

Total number of observatories involved in AC-CdC at some time = 24 (including Adelaide Observatory, ROE, Santiago, La Plata and Rio de Janiero). HCO was involved but is not included.

Total number of observatories which completed printed volumes of the AC = 20

APPENDIX 2: TIMELINE RELEVANT TO AUSTRALIA'S PARTICIPATION IN THE AC-CDC

The timeline below was developed during the thesis to better understand the major events surrounding the AC-CdC which were relevant to the Australian observatories over the period from 1871 to 2015. The solar eclipse expedition to remote Northern Queensland was considered an appropriate starting point for the timeline as this was an early scientific collaboration between the Colonial governments of Victoria, South Australia, Queensland and New South Wales, and Norman Lockyer, who led the British contingent. Social as well as astronomical events are included.

Sources for the timeline include the Monthly Notices of the Royal Astronomical Society (MNRAS). The relevant MNRAS reports and papers can be viewed on NASA's Astrophysics Data System <http://adsabs.harvard.edu/>.

The timeline:

- 1871 Solar eclipse in Northern Queensland. Collaboration between Colonial State governments and British astronomers (Ellery & Lockyer 1872, p. 205).
- 1872 Ellery photographed the Moon at MO (Russell 1895, p. 311).
- 1874 A transit of Venus was successfully observed at SO, and short film made at MO using Janssen apparatus (Lomb 2011).
- 1876 Dry gelatin emulsion for photographic plates perfected for astronomy. This meant longer exposures to capture star light were possible (Russell 1895, p. 311).
- 1878 Huggins photographed star spectra (Russell 1895, p. 312).
- 1879 Grand International Exhibition held in Sydney. This created opportunities for international networks and scentific exchange (Hoffenberg 2010).
- 1880 Grand International Exhibition held in Melbourne similarly provided 'polycentric' world view (Hoffenberg 2010).
- The 1880s was a significant period in the advancement of astro-photography globally in all its forms. The Henry Brothers in Paris, David Gill in South Africa, and Henry C. Russell and Robert J. Ellery in Australia experiment with photography for astronomy. (Russell 1895, pp. 457-463).
- 1885 Edith Emily Dornwell graduated as a Bachelor of Science, University of Adelaide. She was the first female university graduate in science in Australia (Nugent 2002, p. 19).
- 1887 Russell attends the first International Congress in Paris on the 16th of April and the AC-CdC projects are inaugurated under Admiral Mouchez, Paris Observatory (Russell 1887, Winterhalter 1891).

- 1888 The University of Sydney hosts the first congress of the Australian Advancement of Science (AAAS). Russell is elected the Society's first President and gives the inaugural speech (Russell 1888b, Lomb 2015, p. 39).
- 1890 Construction of the 'star camera' at Sydney Observatory is completed (MNRAS, Vol.51, p. 233). Using this and a portrait lens Russell's and instrument maker James Arthur Pollock's experiments place SO at the forefront of celestial photography (Russell 1890, p. 96; 1891a, pp. 494-498; 1891b). Pollock later became USYD Professor of Physics.
- 1890 Mary Emma Greayer commenced employment at Adelaide Observatory (Stevenson 2014).
- 1891 Russell visits Melbourne Observatory to define the AC-CdC zones for observation and measurement (Russell 1891d).
- 1891 Astrographic telescope by Grubb assembled at Melbourne Observatory (Ellery 1892a).
- 1892 Ellery writes to Paris Observatory warning of the financial crisis in the State of Victoria (Chinnici 1999, p. 266).
- 1893 Russell writes to Paris Observatory warning of a delay in the project due to the financial crisis in the state of NSW (Chinnici 1999, p. 365).
- 1892–1915 Measuring devices are re-developed to improve efficiency. 1892 The first plate is measured in Melbourne but the majority of plates are measured from 1898.
- 1896 Cooke appointed WA Government astronomer. Perth Observatory foundation stone laid (Hutchinson 1981, p. 61).
- 1898-1904 Measuring micrometers re-developed to improve efficiency (Gill 1898, Hinks 1901, Russell 1902, Christie 1904).
- 1898 Six women employed by Melbourne Observatory to measure the Melbourne and Sydney zone star plates (Baracchi 1898bcd).
- 1898 Mary Emma Greayer ceases work at Adelaide Observatory (Todd 1899ab).
- 1899 Perth Observatory operational. Sydney Observatory's Astrographic telescope moved to Red Hill (MNRAS vol.60, p. 362).
- 1900 Australian Constitution determines that astronomy and meteorology are under the jurisdiction of the Federal Government (p. 10).
- 1900 Government of WA invited to carry out the Astrographic Catalogue originally assigned by the Paris Congress of 1887 to the Rio de Janiero Observatory. Letter sent by M. Loewy to the WA Government, and Government Astronomer Cooke requests that Perth take on the zone -28° to -40° (Chinnici 1999, p. 303).
- 1900 Charlotte Emily Fforde Peel gazetted in a permanent position at Melbourne Observatory (Clark 2012).
- 1901 Federation of colonial states to form the Commonwealth of Australia. This changed the governance of astronomy and meteorology from State to Federal.
- 1902 *Commonwealth Franchise Act* was passed giving women the right to vote in federal elections.

- 1905 Sydney Observatory Director, Russell, retired due to illness. Lenehan becomes Acting Government Astronomer, although he dies eight months later. (Wood 1958, p. 19).
- 1906 to 1910 Lack of official NSW Government Astronomer for 4 years results in delays in the AC-CdC projects
- 1907 First batch of Perth Observatory's glass plate negatives arrive at Edinburgh Observatory for measuring (Dyson 1908, p. 267).
- 1907 *Harvester Case* legalised lower rates of pay for women (Nugent 2002, p. 40)
- 1908 Commonwealth Bureau of Meteorology formed. Sydney and Melbourne Observatories cease meteorology responsibility. Perth maintains its meteorology works (Baracchi 1908a).
- 1909 Cooke attends the International Astrographic Conference where his new method of determining plate constants is adopted as the new standard for the AC (Cooke 1912, pp. 4-7).
- 1909 Assessment of progress of the AC-CdC. Turner's report for the Royal Astronomical Society published in 1912 as *The Great Star Map*. This report does not reflect the measurement issues which had arisen unilaterally (Turner 1912).
- 1911 The first Perth Astrographic Catalogues are published by Cooke.
- 1912 Cooke appointed NSW Government Astronomer. The Board of Visitors is re-established (Wood 1958, p. 19).
- 1914 Visit from the British Association for the Advancement of Science to Australia cut short by declaration of war (MacLeod 1988, pp. 31-32).
- 1915 Australia's involvement in WWI announced.
- 1916 Report sent to the SO Board of Visitors by Cooke about poor quality AC-CdC plates. The Astronomer Royal wrote about the lack of progress on the CdC (Cooke 1916).
- 1918 Australia's involvement in WWI ceased.
- 1919 (Nov 17) The birth of the Einstein legend as Eddington 'proves' general relativity- theoretical astronomy (cosmology) changes ways of thinking.
- 1919 IAU founded (Lomb 2015, p. 43).
- 1919 Clothing Trades Case sets women's wages at 54% that of mens (Nugent 2002, p. 40; Kramar 1990, p. 2).
- 1920 Digby, McDonald, de Moulin, Cronin and Clements gazetted as permanent employees of the NSW Public Service in the clerical division.
- 1922 Publication of *Catalogue of 1068 Intermediate Stars* by Cooke at SO (Cooke 1923b).
- 1922 The Sydney Observatory 'star camera' taken to Goondiwindi for a total solar eclipse expedition as part of an experiment to conclusively confirm the general theory of relativity (Cooke 1923ab). Public opinion, not government, sends Melbourne and Perth Observatories on similar ventures.
- 1923 First Sydney Astrographic Catalogue published by Cooke.
- 1925 Sydney Observatory threatened with closure.

- 1926 Cooke resigns and measurers given notice and transferred to other public service departments. CdC put on hold (Wood 1958, p. 22).
- 1926 Mt Stromlo National Observatory begins operation (Haynes et al 1996, p. 158).
- 1926 First Melbourne Astrographic catalogue published by Baldwin.
- 1930 Adelaide Observatory transferred to Adelaide University (Haynes et al 1996, p. 86).
- 1931 Sydney Astrographic telescope relocated back to SO after Short retires in 1930 (Wood 1958, p. 24).
- 1933 Conference of physicists recommends Perth and Mt Stromlo observatories be retained when asked by Commonwealth Government (Lomb 2015, p. 42).
- 1935 Equal Status Committee established by Muriel Heagney in Victoria to campaign for equal pay for women (Nugent 2002, p. 41).
- 1938 The last Perth Astrographic Catalogue, measured in Western Australia, is printed in France through IAU funding.
- 1943 Harley Wood appointed NSW Government astronomer (Wood 1958, p. 25)
- 1944/1945 Melbourne Observatory closed for research (Baldwin 1945, p. 120)
- 1945-50 Ruby Payne-Scott was part of the team to make early discoveries in Radio Physics at Dover Heights, Sydney (Goss & McGee 2010)
- 1947 Visit to Sydney by Astronomer Royal, Harold Spencer Jones (Wood 1958, p. 29)
- 1947 ASV provides volunteers to continue Melbourne Observatory public tours on site now operated by Melbourne Museum (Clark 2006, p. 41).
- 1948 Sydney Observatory (Harley Wood) takes over the Melbourne zone of the AC (*ibid*., p. 26).
- 1949 The Melbourne Astrographic telescope and other items relevant only to the AC not already in Sydney Observatory are moved there (Wood 1950, p. 162).
- 1949 Adelaide Observatory closed (Haynes et al 1996, p. 86). By 1952 it was mostly demolished (Dodwell 1952)
- 1952 The new Astrographic building and dome are completed at Sydney Observatory (Wood 1953, p. 350).
- 1952 Last Perth Astrographic Catalogue, measured by ROE, is printed in France through IAU funding.
- 1955–1963 The Melbourne Catalogue is compiled at SO by Wood and the Astrographic Bureau, and published in France through IAU funding (Wood 1973).
- 1961 Parkes Radio Astronomy Telescope opened in rural NSW with partial funding by the US (Haynes et al, p. 246).
- 1964 Sydney Astrographic Catalogue is completed under the supervision of Harley Wood (Wood 1973)
- 1966 Old Perth Observatory closed and a new observatory established at Bickley on the outskirts of Perth under the directorship of Bertrand John Harris (Haynes et al 1996, p. 93).

- 1969 The Apollo Moon landing is televised globally through signals received by the Parkes Radio Astronomy Telescope antenna (Haynes et al, p. 269).
- 1971 Publication by Wood of an explanation of Sydney Observatory's participation in the AC.
- 1972 The *Equal Pay Decision* awarded women equal pay to that received by men (Kramar 1990, p. 4)
- 1973 IAU held in Sydney with Wood at the head of the organising committee (Russell 2008, p. 171).
- 1973 The Anglo-Australian Telescope was completed at Siding Spring Mountain on the site partially chosen by Wood.
- 1975-78 A review of observatories for government recommended that all astronomy research be undertaken by national facilities (Westfold 1978, 1980).
- 1982 Trustees of the MAAS are given custodianship of Sydney Observatory, IAU and astronomers object to no avail (Russell 2008, pp. 186-192).
- 1983 The publication of the Sydney Southern Star catalogue by King and Lomb (1983) and with this Sydney Observatory ceased research operations and, under guidance from the IAU, plans are made to transfer the AC-CdC collections (Russell 2008, pp. 193-194; pers.Comm., Lomb 2011).
- 1986 The dome and collection are transferred to Macquarie University (Stevenson 2012, p. 29).
- 1991 Conservation plan for Sydney Observatory site and its structures written by James Semple Kerr.
- 1996 Heritage assessment of Melbourne Observatory written by Richard Gillespie. Allom Lovell writes a Conservation Management Plan (Clark 2006, p. 11).
- 2006 Lomb and Stevenson visit Macquarie University to view the AC-CdC collection with Professor Alan Vaughan.
- 2006 Barry Clark writes a comprehensive list of the Melbourne Observatory instruments and their locations, inclusive of AC-CdC collections.
- 2007 Sydney Observatory Masterplan includes the relocation of the dome and astrographic telescope on a new building.
- 2008 Sydney Observatory re-acquires the dome and Melbourne Astrographic telescope and what appeared to be the remains of the original Sydney star camera from Macquarie University (Stevenson 2015c, p. 85).
- 2010 Agreement from SRNSW and Macquarie University that the glass plate negatives, catalogue originals and printed versions will be a state distributed collection and re-instated in the MAAS Sydney Observatory collection.
- 2013 Perth Observatory closes for research due to focus investment on Square Kilometre Array project. Volunteers run education programs and collection management.
- 2015 The Astrographic dome is returned to Sydney Observatory in a new building designed by the Government Architects Office. Inside the building, the Melbourne astrograph and the Sydney A measuring machine are displayed. Winsome Bellamy and Rosamond Madden attend the opening ceremony (Stevenson 2015d)

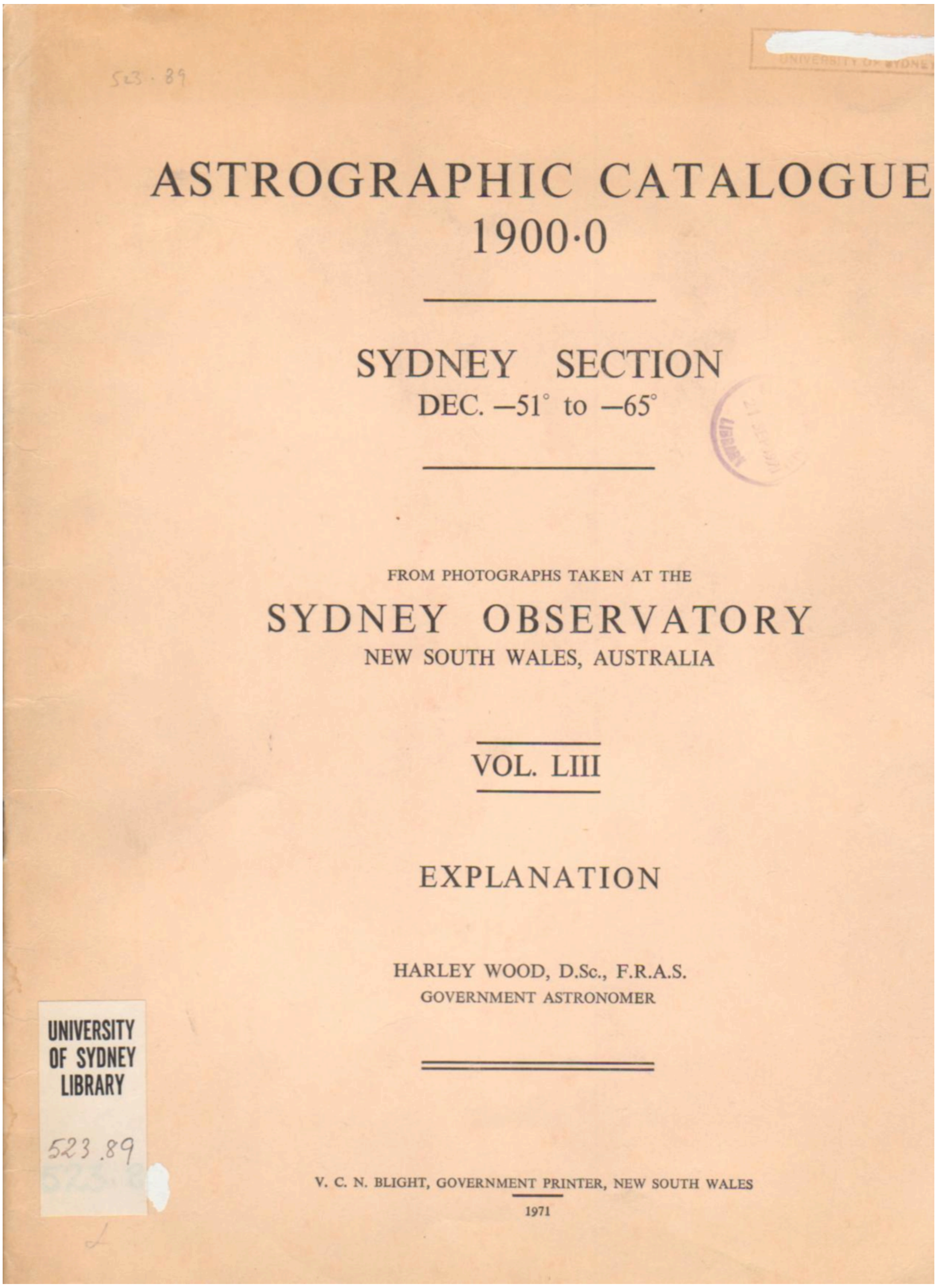
Appendix 3: List of steps used in the production of the Astrographic Catalogue

According to Turnbull (1996) maps of the sky follow the tradition of western map making, which requires skills in astronomy to calculate the latitude and longitude positions of zones, and stars within those zones, on the celestial globe. The production of the AC-CdC required a series of steps, which were standardised, with local variation. Listing these steps was essential for my research because there was no existing list that I could use to guide my understanding of the process. According to Latour, understanding the process of science and the relationship between the actants is essential to understanding the parameters that produce the research results (1987).

Step 1: The sky was divided into eighteen zones. Each observatory was allocated a zone.
Step 2: Each zone was divided into photographic plates with overlaps occurring on 50% of the plate.
Step 3: On each photographic plate, it was specified that there were 12 reference or positional stars able to be identified for reduction (Wood 1971, p. 18). These were obtained through visual observation using a transit telescope. The reference stars provided the constants from which the standard co-ordinates of each star were computed.
Step 4: Guide stars were sighted through a micrometer mounted on the sighting telescope of the star camera.
Step 5a: The CdC photographic plates were exposed to the starlight for 3 minutes, 8 minutes, and 20 or 30 minutes with a slight shift in position of the telescope between each exposure.
Step 5b: The AC photographic plates were exposed to the starlight three times. The length of exposure was determined by experiment to ensure stars down to 11th magnitude were captured. This was determined as 4 minutes, 2 minutes and 13 seconds on each plate for the Sydney zone by Cooke (Wood 1971, p. 5).
Step 6: Photographic plates were exposed with the silvered plate and a grid on it called a réseau. Most réseau were supplied by Gautier. The emulsion side of the plate and the silvered side of the réseau faced each other with minor shim metal separation.
Step 7: The plate was chemically processed and left to dry.
Step 8: Data of exposure—including date, time, weather, observer, length of exposure, RA and Dec, and the plate number—was recorded in a logbook by the observer.
Step 9: The photographic plate was put into an envelope with the same data on it as in Step 8.

Step 10: The photographic plate in the sleeve was then placed into a box with associated zone plates.
Step 11: The photographic plate was given to the measurer and placed in a micrometer (measuring machine). Each star's x and y co-ordinates were measured with the plate the right way up, and the magnitude scale applied. This was either a number or a letter. This data was entered into logbooks by the second measurer.
Step 12: The photographic plate was re-measured by turning it 180° by the same or another measurer. The data was entered into the logbook by the second measurer.
Step 13: The mean of the two measurements was calculated. The data was entered into the logbook.
Step 14: Depending on the error, a third measurement was taken by a different measurer.
Step 15: Plate constants were calculated using ~12 reference stars with previously observed positions with respect to Equinox 1900 on each plate. For the Sydney zone Cooke observed and measured 1068 "intermediate" stars, which means they are stars observed prior to establishing reference stars, but, combined with the La Plata Observatory Astrographic Catalogue to reduce errors, these star positions and as approved by the 1909 Congress, these were used as reference stars (Cooke 1921; Wood 1971, p. 18).
Step 16: The list of stars was prepared to go to the printer for typesetting in order of zone, right ascension and declination.

EXAMPLE OF THE SYDNEY ZONE ASTROGRAPHIC CATALOGUE



ASTROGRAPHIC CATALOGUE
1900·0

SYDNEY SECTION
DEC. −51° to −65°

FROM PHOTOGRAPHS TAKEN AT THE
SYDNEY OBSERVATORY
NEW SOUTH WALES, AUSTRALIA

VOL. LIII

EXPLANATION

HARLEY WOOD, D.Sc., F.R.A.S.
GOVERNMENT ASTRONOMER

V. C. N. BLIGHT, GOVERNMENT PRINTER, NEW SOUTH WALES
1971

R. A. $0^h\ 0^m$

Plate 2137s; 1894 Oct. 27.

Machine Repsold I.

Constants.

A	B	C
+ ·00500	+ ·00111	— ·0840
D	**E**	**F**
— ·00103	+ ·00493	— ·0709

Star No.	Diameter	X	Y
1	2·2	6·024	30·356
2	2·5	6·947	345
3	2·9	11·339	819
4	4·0	12·712	861
5	3·6	16·225	515
6	2·5	18·193	659
7	2·9	19·009	641
8	8·2	19·664	585
9	2·2	19·952	855
10	3·5	20·096	301
11	2·2	26·641	336
12	2·6	26·905	30·742
13	2·4	11·414	31·867
14	3·2	14·422	488
15	3·5	16·801	218
16	4·6	20·775	661
17	2·2	24·136	31·684
18	4·1	4·256	32·879
19	2·5	4·936	798
20	3·8	7·140	776
21	3·0	8·631	970
22	2·2	11·149	162
23	3·9	13·048	965
24	2·2	13·251	791
25	2·2	15·878	094
26	17·0	23·807	528
27	2·8	24·959	32·732
28	2·9	1·341	33·906
29	7·5	12·409	353
30	2·2	13·524	652
31	3·6	20·159	786
32	2·5	20·813	590
33	4·8	24·090	33·183
34	2·2	11·515	34·815
35	4·0	14·691	34·096
36	2·2	10·386	35·035
37	2·2	10·962	585
38	3·5	13·304	592
39	2·2	14·270	026
40	2·5	15·141	390
41	3·1	20·709	35·489
42	2·2	12·793	36·761
43	2·2	15·716	482
44	2·6	16·041	259
45	2·2	17·083	36·713
46	2·5	3·978	37·807
47	2·2	5·898	105
48	4·1	12·478	350
49	2·2	15·520	915
50	2·6	24·162	37·528
51	2·2	2·310	38·158
52	2·2	2·698	265
53	2·2	2·784	990
54	2·5	3·963	617
55	2·2	8·222	307
56	3·4	15·204	296
57	2·5	18·246	722
58	2·2	18·326	648
59	2·2	20·742	145
60	2·4	21·262	686
61	3·0	24·744	38·436
62	2·2	11·675	39·369
63	3·6	11·894	713
64	2·2	13·438	450
65	3·4	16·187	942
66	4·5	16·256	459
67	4·8	18·412	39·447
68	5·0	6·570	40·605
69	2·2	7·865	925
70	3·0	10·075	952
71	2·8	11·048	629
72	2·2	13·705	607
73	2·5	15·383	255
74	2·2	16·748	691
75	2·4	21·355	885
76	2·2	25·256	40·402
77	2·2	4·844	41·331
78	5·4	7·807	176
79	2·2	10·075	706
80	2·2	10·398	155
81	2·5	12·782	777
82	2·2	13·451	401
83	3·6	15·623	058
84	5·5	15·782	072
85	2·2	17·445	285
86	2·4	17·847	025
87	2·2	18·941	500
88	2·9	19·249	870
89	2·2	20·370	911
90	2·2	26·072	41·310
91	3·0	6·004	42·884
92	2·4	6·312	220
93	2·2	8·109	830
94	2·2	10·899	277
95	3·0	11·768	068
96	2·2	11·918	420
97	2·9	13·925	186
98	2·2	17·171	735
99	2·6	17·501	043
100	2·2	17·699	700
101	2·6	18·127	203
102	3·0	18·329	880
103	2·2	18·599	877
104	4·0	24·954	42·581
105	2·2	6·744	43·721
106	2·2	7·211	412
107	2·2	7·462	229
108	3·9	14·883	530
109	2·5	15·590	090
110	2·4	18·752	43·505
111	2·8	1·379	44·712
112	2·4	5·723	255
113	9·0	7·246	698
114	3·9	14·219	604
115	2·5	22·499	44·790
116	3·0	2·173	45·147
117	2·5	2·512	802
118	2·2	3·212	151
119	3·5	8·029	133
120	2·2	8·188	45·576
121	2·6	8·622	45·803
122	2·2	9·773	720
123	2·2	10·843	413
124	3·1	11·958	850
125	3·2	13·061	638
126	3·9	15·187	499
127	2·2	15·843	591
128	2·2	19·430	758
129	2·2	20·887	45·283
130	2·2	2·918	46·172
131	3·0	3·547	445
132	2·9	5·955	412
133	3·2	11·813	488
134	3·9	15·394	327
135	2·5	22·401	264
136	2·5	24·324	399
137	2·5	25·816	46·633
138	2·9	2·758	47·996
139	2·2	5·542	790
140	2·2	6·293	449
141	2·2	6·627	940
142	2·6	8·475	508
143	2·2	17·723	902
144	2·9	26·279	47·439
145	2·5	12·155	48·098
146	2·5	12·536	306
147	2·2	18·861	917
148	12·8	23.187	136
149	2·2	23·915	519
150	17·0	24·645	48·665
151	2·2	9·368	49·683
152	3·2	10·696	516
153	4·1	11·361	239
154	2·5	12·250	257
155	2·2	13·134	525
156	2·8	16·677	962
157	5·5	16·950	851
158	12·0	18·919	206
159	2·2	23·115	694
160	2·2	23·188	459
161	14·5	26·283	49·629
162	5·5	1·216	50·851
163	2·2	8·571	678
164	6·9	13·903	183
165	3·8	14·448	519
166	2·2	14·453	173
167	2·8	21·771	50·752
168	2·8	3·630	51·686
169	2·9	8·656	439
170	3·6	11·415	989
171	2·2	23·805	51·949
172	2·2	7·371	52·167
173	2·2	12·509	52·740
174	2·2	5·704	53·049
175	2·2	6·159	157
176	3·5	11·520	354
177	2·2	18·032	889
178	3·2	19·614	53·150
179	2·2	10·148	54·876
180	2·2	17·767	604
181	4·1	19·564	448
182	2·2	25·006	54·904
183	2·2	3·865	55·852
184	2·8	5·942	305
185	2·2	24·939	55·146

R. A. $0^h\ 18^m$

Plate 2121s; 1894 Oct. 26.

Machine Repsold I.

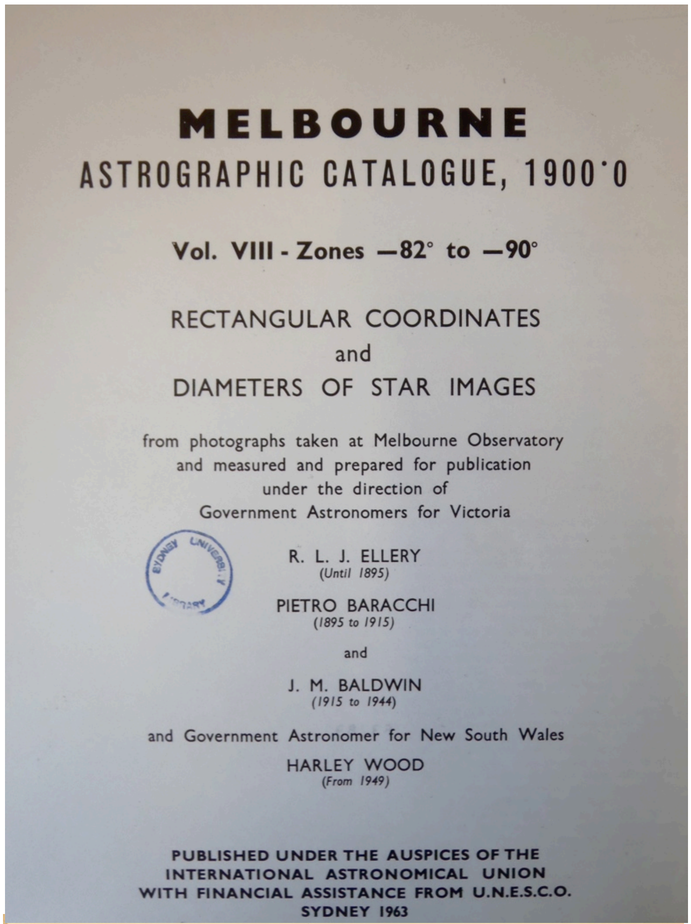
Constants.

A	B	C
+ ·00530	+ ·00912	— ·1788
D	**E**	**F**
— ·00883	+ ·00486	+ ·0819

Star No.	Diameter	X	Y
1	2·6	2·980	30·065
2	2·2	4·025	836
3	2·2	6·052	249
4	2·5	10·481	666
5	2·2	11·206	110
6	2·2	12·612	30·793
7	2·2	1·287	31·974
8	3·0	3·707	873
9	3·0	5·624	807
10	2·9	5·701	066
11	2·8	7·250	993
12	2·2	8·817	278
13	2·2	10·105	495
14	3·1	10·574	386
15	4·1	15·160	842
16	2·2	20·601	660
17	2·8	20·828	148
18	3·1	21·106	31·840
19	2·2	1·643	32·190
20	3·6	2·846	742
21	2·2	7·840	900
22	2·2	9·904	173
23	2·5	11·794	430
24	2·2	12·392	519
25	2·2	14·114	32·959
26	2·2	1·533	33·086
27	3·1	4·508	802
28	2·2	5·683	265
29	2·5	9·060	318
30	2·5	12·476	970
31	2·5	13·057	898
32	4·1	14·982	976
33	2·6	15·134	971
34	2·4	16·372	441
35	2·9	17·257	401
36	4·1	24·438	33·924
37	2·2	1·967	34·605
38	2·2	7·066	585
39	2·4	11·261	963
40	2·5	16·182	082
41	3·2	21·050	34·470
42	2·2	7·060	35·100
43	2·5	7·076	908
44	2·9	8·471	848
45	2·2	9·339	365
46	2·6	14·021	180
47	4·4	14·026	750
48	3·6	20·065	544
49	4·9	22·334	35·660
50	2·6	2·315	36·882

(Standard ξ = X — 14 — A (X — 1) — B (Y — 30) — C; Standard η = Y — 43 — D (X — 1) — E (Y — 30) — F.)

EXAMPLE OF THE MELBOURNE ZONE ASTROGRAPHIC CATALOGUE.



MELBOURNE

ASTROGRAPHIC CATALOGUE, 1900·0

Vol. VIII - Zones —82° to —90°

RECTANGULAR COORDINATES
and
DIAMETERS OF STAR IMAGES

from photographs taken at Melbourne Observatory
and measured and prepared for publication
under the direction of
Government Astronomers for Victoria

R. L. J. ELLERY
(Until 1895)

PIETRO BARACCHI
(1895 to 1915)

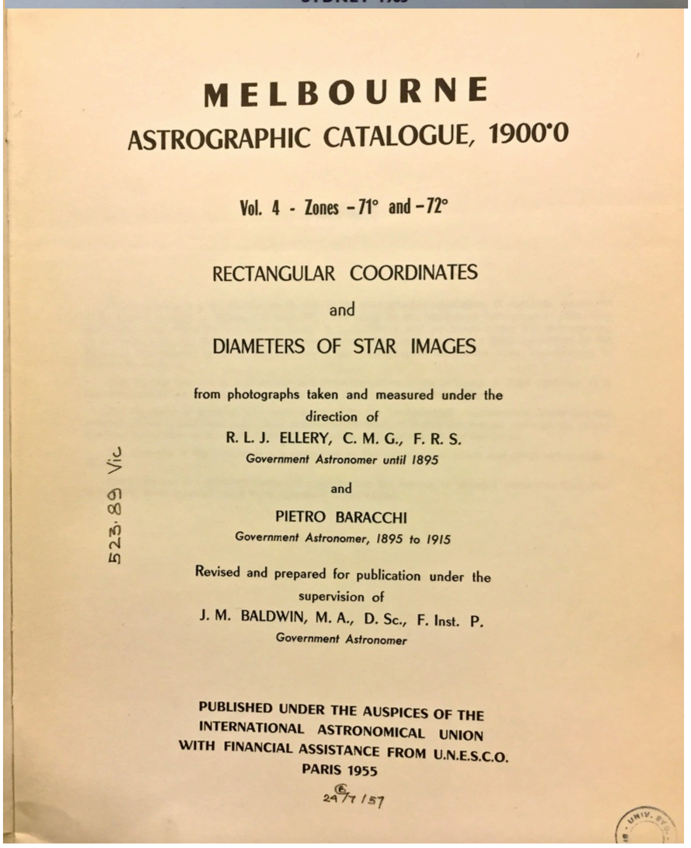
and

J. M. BALDWIN
(1915 to 1944)

and Government Astronomer for New South Wales

HARLEY WOOD
(From 1949)

PUBLISHED UNDER THE AUSPICES OF THE
INTERNATIONAL ASTRONOMICAL UNION
WITH FINANCIAL ASSISTANCE FROM U.N.E.S.C.O.
SYDNEY 1963



MELBOURNE

ASTROGRAPHIC CATALOGUE, 1900·0

Vol. 4 - Zones −71° and −72°

RECTANGULAR COORDINATES
and
DIAMETERS OF STAR IMAGES

from photographs taken and measured under the
direction of
R. L. J. ELLERY, C. M. G., F. R. S.
Government Astronomer until 1895

and

PIETRO BARACCHI
Government Astronomer, 1895 to 1915

Revised and prepared for publication under the
supervision of
J. M. BALDWIN, M. A., D. Sc., F. Inst. P.
Government Astronomer

PUBLISHED UNDER THE AUSPICES OF THE
INTERNATIONAL ASTRONOMICAL UNION
WITH FINANCIAL ASSISTANCE FROM U.N.E.S.C.O.
PARIS 1955

RECTANGULAR CO-ORDINATES

7 h 12 m — 72°

Plate Centre

7h 12m - 72°

Plate 602. 1893, February 8.

Plate Constants

a = −·01163 d = −·00008
b = +·00008 e = −·01141
c = +·0107 f = +·0059

To obtain Standard Coordinates ξ η

$\xi = x + ax + by + c$
$\eta = y + dx + ey + f$

Dia.	x	y	C.P.D. N°	Mag.
1				
12	− 63·399	+ 4·480		
19	− 63·275	+ 4·572	71° 506	7·8
14	− 63·020	+ 26·379	71° 508	9·4
11	− 62·816	+ 15·962	71° 507	10·1
9	− 62·640	+ 44·131		
12	− 61·534	+ 3·186	71° 509	10·0
14	− 56·871	+ 52·455*	71° 511	9·0
19	− 56·274	+ 2·616	71° 510	8·6
14	− 55·091	+ 26·299	71° 512	9·0
10	− 54·524	+ 17·237		
11				
10	− 53·156	+ 17·633		
13	− 51·172	+ 50·653*	71° 513	9·2
9	− 50·913	+ 37·337		
13	− 49·370	+ 55·961	71° 514	10·0
22	− 48·744	+ 44·491*	71° 515	8·0
10	− 47·136	+ 31·169		
9	− 46·554	+ 15·161		
10	− 42·927	+ 61·323		
10	− 42·285	+ 6·229		
12	− 39·000	+ 19·320	71° 516	10·1
21				
9	− 38·132	+ 45·516		
10	− 36·968	+ 46·674	71° 517	10·1
9	− 34·757	+ 49·800		
14	− 34·488	+ 28·138*	71° 518	9·2
10	− 32·813	+ 21·092		
20	− 32·706	+ 8·892*	71° 519	8·4
9	− 32·608	+ 2·783		
11	− 32·110	+ 41·199	71° 520	10·0
13	− 29·777	+ 30·484	71° 521	9·8
11	− 28·689	+ 17·027	71° 522	10·2
31				
11	− 26·207	+ 12·362	71° 523	9·9
9	− 26·015	+ 20·232		
26	− 25·689	+ 53·038*	71° 524	8·1
10	− 24·716	+ 51·706	71° 526	10·3
13	− 24·208	+ 41·024	71° 527	9·9
9	− 23·886	+ 43·966		
9	− 20·930	+ 32·042		
9	− 20·242	+ 24·520	71° 528	10·2
14	− 20·172	+ 43·202	71° 529	9·8
10	− 19·860	+ 12·317	71° 530	10·3

Dia.	x	y	C.P.D. N°	Mag.
41				
10	− 18·123	+ 37·632	71° 531	10·3
12	− 18·069	+ 38·662	71° 532	9·8
9	− 14·273	+ 54·059	71° 533	10·4
11	− 13·716	+ 52·446	71° 534	9·8
9	− 12·386	+ 60·730		
10	− 11·800	+ 7·704	71° 535	10·3
10	− 7·650	+ 53·211	71° 536	10·3
12	− 6·265	+ 54·006	71° 537	10·0
10	− 5·307	+ 35·879	71° 538	10·4
12	− 4·975	+ 19·805	71° 539	9·9
51				
10	− 4·967	+ 32·926		
9	− 4·268	+ 27·908	71° 540	10·4
14	− 3·732	+ 63·228	70° 606	9·7
10	− 3·066	+ 27·466	71° 541	10·3
10	− 1·738	+ 48·733	71° 542	10·3
9	− 1·143	+ 31·146		
10	+ 0·050	+ 54·277	71° 543	10·3
13	+ 0·140	+ 23·476	71° 544	9·7
13	+ 1·332	+ 5·185	71° 545	9·7
10	+ 1·778	+ 52·351	71° 546	10·2
61				
9	+ 6·006	+ 49·439		
20	+ 9·649	+ 10·369*	71° 547	9·0
10	+ 12·341	+ 30·561	71° 549	10·3
12	+ 13·297	+ 41·322*	71° 550	10·0
10	+ 16·253	+ 5·320	71° 552	10·4
9	+ 16·583	+ 19·788		
10	+ 16·704	+ 53·761	71° 551	10·4
13	+ 18·368	+ 26·994	71° 553	9·6
13	+ 20·690	+ 7·826	71° 554	9·7
9	+ 21·098	+ 43·991		
71				
10	+ 21·565	+ 59·213	70° 615	10·4
9	+ 21·767	+ 33·817		
9	+ 22·763	+ 47·787		
10	+ 26·728	+ 22·496	71° 556	10·2
10	+ 29·512	+ 34·214		
24	+ 29·671	+ 25·898*	71° 557	7·7
10	+ 31·168	+ 9·054	71° 558	10·4
11	+ 32·076	+ 59·017	70° 625	10·2
14	+ 32·703	+ 51·183*	71° 559	9·4
9	+ 32·858	+ 22·188		
81				
9	+ 34·406	+ 38·355		
11	+ 37·055	+ 53·544	71° 560	10·2
9	+ 37·476	+ 12·620		
10	+ 38·409	+ 39·065	71° 561	10·4
12	+ 38·535	+ 59·359	70° 626	9·9
9	+ 39·081	+ 21·327		
9	+ 39·570	+ 12·684		
9	+ 41·162	+ 17·931		
10	+ 42·311	+ 46·028	71° 563	10·3
10	+ 42·935	+ 31·131		
91				
9	+ 44·146	+ 13·374		
12	+ 44·269	+ 49·014	71° 564	9·8
9	+ 46·844	+ 63·898	70° 629	10·3
18	+ 48·594	+ 39·147*	71° 565	9·0
9	+ 48·636	+ 14·970		
9	+ 50·110	+ 37·526		
10	+ 51·649	+ 51·485	71° 566	10·2
14	+ 52·315	+ 36·200	71° 567	9·4
14	+ 52·440	+ 34·716	71° 568	9·4
11	+ 54·763	+ 15·832	71° 569	10·3

Dia.	x	y	C.P.D. N°	Mag.
101				
9	+ 55·908	+ 9·364		
9	+ 56·031	+ 1·790		
19	+ 57·277	+ 13·033*	71° 570	8·0
9	+ 59·272	+ 40·498	71° 571	10·4
9	+ 62·078	+ 2·298		
9	+ 64·217	+ 39·374	71° 572	10·4
12	+ 64·640	+ 27·303	71° 573	9·6
9	− 62·744	− 15·076		
15	− 62·740	− 32·721	72° 544	9·0
9	− 62·136	− 47·015		
111				
13	− 60·798	− 11·516	72° 545	9·8
9	− 60·275	− 40·847		
9	− 60·197	− 2·375		
9	− 58·869	− 11·341		
9	− 55·741	− 39·924		
15	− 53·832	− 25·291	72° 546	9·0
9	− 52·360	− 8·154		
19	− 51·747	− 55·065*	72° 547	9·0
10	− 49·959	− 15·946	72° 548	10·0
9	− 48·431	− 6·847		
121				
14	− 47·845	− 32·410	72° 549	9·0
12	− 45·179	− 18·533	72° 550	10·0
30	− 42·904	− 25·902*	72° 551	7·7
10	− 42·868	− 58·378		
9	− 41·618	− 21·088		
23	− 41·048	− 38·251	72° 552	8·9
22	− 40·363	− 56·514*	72° 553	8·6
9	− 38·222	− 17·711		
9	− 37·907	− 27·678		
11	− 37·419	− 29·791	72° 554	10·0
131				
9	− 37·386	− 17·867		
9	− 34·743	− 61·756		
9	− 34·586	− 26·572	72° 555	10·0
10	− 34·414	− 10·307	72° 557	10·2
9	− 34·167	− 25·963	72° 556	10·4
10	− 33·962	− 4·793	72° 558	10·4
9	− 32·976	− 10·117		
9	− 32·725	− 47·665		
10	− 31·058	− 4·353	72° 560	10·3
24	− 30·553	− 37·487*	72° 559	8·9
141				
9	− 28·352	− 38·533		
9	− 28·343	− 62·375		
9	− 27·158	− 46·935		
9	− 26·035	− 18·561	72° 561	10·4
9	− 25·749	− 19·634	72° 562	10·4
11	− 24·293	− 2·575	71° 525	10·2
28	− 21·799	− 50·778*	72° 563	8·5
14	− 20·753	− 27·248	72° 564	9·4
9	− 19·031	− 64·496		
9	− 18·976	− 3·964	72° 566	10·3
151				
10	− 18·790	− 37·489	72° 565	9·8
9	− 18·608	− 0·172		
9	− 18·579	− 14·568	72° 567	10·3
9	− 15·902	− 4·979		
11	− 14·635	− 11·484	72° 568	10·0
19	− 14·272	− 3·150	72° 569	9·1
11	− 12·577	− 5·286	72° 570	10·0
14	− 11·603	− 58·167	72° 571	9·5
10	− 10·648	− 43·389		
9	− 10·360	− 12·919		

Table IX - Particulars of the Plates in Vol. IV - Continued.

Zone -72°.

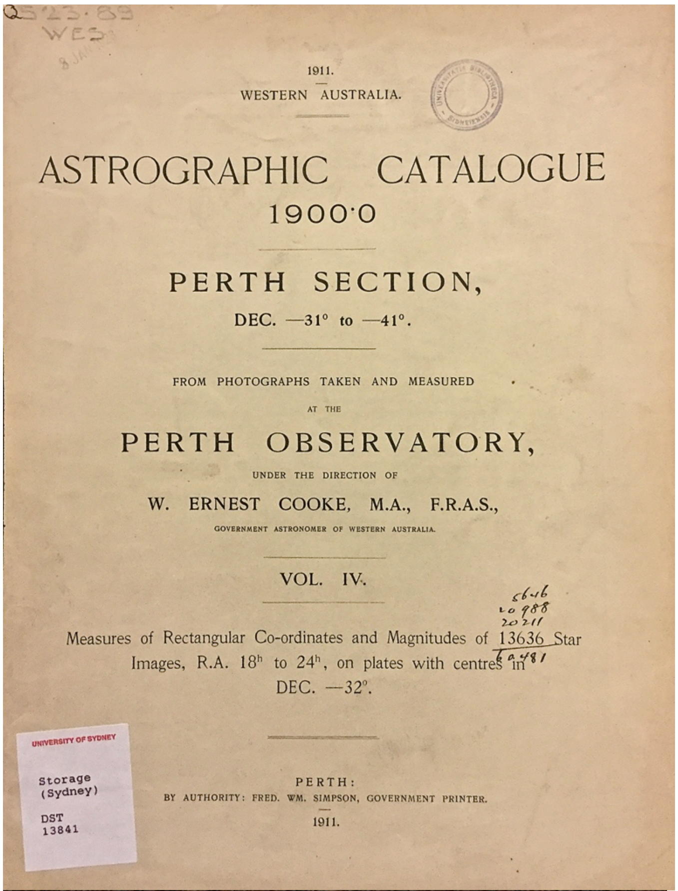
R.A.	Plate	Exposed on	Exposed by	H.A.	Réseau	Measured in	Measured by	Micr.	Mag. Corr.
$0^h\ 0^m$	4001	1915 Nov. 5	B	2^mE	M 23	1918 June	P, P	R2	+0·7
0 24	501	1892 Nov.15	W	2 W	G 27	1908 July	T, MH	S	+0·1
0 48	3157	1909 Nov.17	J	3 W	M 23	1909 Dec.	EH, MH	R2	-0·5
1 12	1152	1894 Nov.22	W	0	M 23	1906 Oct.	T, A	S	-0·1
1 36	1626	1896 Dec.10	W	22 W	M 23	1904 Sep.	BS, BS	S	+0·8
$2^h\ 0^m$	833	1893 Dec. 4	W	1^mE	M 6	1908 Oct.	ES, N	R2	+0·2
2 24	1157	1894 Nov.22	W	2 E	M 23	1906 Oct.	T, A	S	0·9
2 48	827	1893 Dec. 2	W	2 W	M 6	1902 May	L, P	R1	+0·3
3 12	846	1893 Dec. 8	W	5 E	M 6	1902 May	EL, H	S	-0·2
3 36	1176	1894 Dec.18	W	3 W	M 23	1907 Jan.	HB, HB	S	-0·2
$4^h\ 0^m$	1173	1894 Dec.17	W	2^mW	M 23	1906 Nov.	ES, EH	R2	-0·4
4 24	862	1893 Dec.30	W	1 W	M 6	1902 May	EL, H	S	-0·6
4 48	577	1893 Jan.18	W	6 E	M 6	1903 Mar.	EL, H	S	-1·3
5 12	569	1893 Jan.12	W	0	M 6	1903 Mar.	MP, HB	*CR1	-0·8
5 36	586	1893 Feb. 7	W	4 W	M 6	1903 Nov.	ES, P	R1	-0·8
$6^h\ 0^m$	597	1893 Feb. 8	W	6^mE	M 6	1903 Mar.	ES, P	R1	-0·3
6 24	574	1893 Jan.13	W	2 W	M 6	1903 Mar.	EL, H	S	-0·8
6 48	563	1893 Jan.10	W	20 E	G 27	1903 Mar.	ES, P	R1	-0·8
7 12	602	1893 Feb. 8	W	2 E	M 6	1903 Mar.	EL, H	S	-0 5
7 36	634	1893 Feb.17	W	1 W	M 6	1908 Aug.	ES, N	R2	-0·5
$8^h\ 0^m$	622	1893 Feb.16	W	8^mE	M 6	1902 July	MP, MP	* C	-1·0
8 24	668	1893 Mar.13	W	9 E	M 6	1925 Dec.	L, L	R2	-0·8
8 48	238	1892 Mar.29	W	5 W	G 33	1908 Apr.	ES, T	R2	-0·8
9 12	239	1892 Mar.29	W	3 W	G 33	1908 Apr.	ES, T	R2	-0·5
9 36	240	1892 Mar.29	W	1 E	G 33	1908 Apr.	A, HB	R1	-0·6
$10^h\ 0^m$	241	1892 Mar.29	W	5^mE	G 33	1908 Apr.	N, MH	S	-0·4
10 24	3874	1915 Mar.10	B	4 W	M 23	1918 Aug.	P, P	R2	+0·4
10 48	243	1892 Mar.29	W	8 E	G 33	1908 Apr.	ES, T	R2	-0·7
11 12	723	1893 Apr.14	W	6 E	M 6	1908 Sep.	ES, N	R2	-1·4
11 36	725	1893 Apr.14	W	1 W	M 6	1902 June	L, P	R1	-1·5
$12^h\ 0^m$	1228	1895 Apr.24	W	3^mW	M 23	1908 Oct.	T, MH	S	-0·9
12 24	1253	1895 May 17	W	1 W	M 23	1902 Aug.	L P	R1	-1·1
12 48	1254	1895 May 17	W	10 E	M 23	1902 Aug.	MP, MP	* C	-0·8
13 12	1534	1896 June 5	W	8 W	M 23	1905 May	ES, BS	R1	-0·8
13 36	324	1892 June14	W	3 E	G 23	1902 Apr.	L, P	R1	-1·1
$14^h\ 0^m$	325	1892 June14	W	7^mE	G 23	1908 May	N, MH	S	-0·5
14 24	1540	1896 June10	W	11 E	M 23	1905 May	ES, BS	R1	-0·9
14 48	3824	1913 July 6	B	15 W	M 23	1913 July	P, P	R2	-1·0
15 12	329	1892 June14	W	5 W	G 23	1902 Apr.	L, P	R1	-1·5
15 36	1691	1897 July23	W	25 W	M 23	1903 Mar.	ES, P	R1	+0·8
$16^h\ 0^m$	1308	1895 June17	W	3^mE	M 23	1902 Oct.	EL, H	S	-0·7
16 24	3941	1915 July 1	B	9 W	M 23	1918 Sep.	P, P	R2	+0·3
16 48	369	1892 July28	W	7 E	G 33	1908 June	ES, T	R2	-0·4
17 12	1005	1894 June28	W	3 W	M 11	1906 May	R, P	R1	-0·5
17 36	1377	1895 Aug.16	W	12 E	M 23	1903 Jan.	EL, H	S	-0·3
$18^h\ 0^m$	4378	1927 Apr.30	B	18^mW	M 23	1927 May	L, L	R2	-0·2
18 34	374	1892 July28	W	6 E	G 33	1908 June	ES, T	R2	-1·0
18 48	417	1892 Aug.30	W	2 E	G 33	1908 July	N, MH	S	-0·3
19 12	1045	1894 Aug.28	W	2 E	M 11	1906 Sep.	T, R	S	-1·4
19 36	1381	1895 Aug.16	W	6 W	M 23	1905 Apr.	ES, BS	R1	-0·4
$20^h\ 0^m$	413	1892 Aug.19	W	5^mE	G 33	1908 July	A, HB	R1	-0·4
20 24	1054	1894 Aug.31	W	2 E	M 11	1906 Oct.	BS, P	R1	-1·6
20 48	1072	1894 Sep.27	W	4 W	M 23	1906 Oct.	ES, EH	R2	-1·0
21 12	1936c	1898 Oct. 4	W	10 W	M 23	1899 Oct.	P, P	* C	+0·8
21 36	437	1892 Sep.15	W	1 E	G 33	1902 May	EL, H	S	-0·2
$22^h\ 0^m$	1118	1894 Oct. 2	W	5^mW	M 23	1908 Oct.	T, MH	S	-0·2
22 24	465	1892 Oct.15	W	2 W	G 33	1908 July	A, HB	R1	-0·R
22 48	3758	1912 Sep.16	J	3 W	M 23	1912 Dec.	GM, P	R2	+0·4
23 12	468	1892 Oct.15	W	4 W	G 33	1902 July	L, L	R1	-0·4
23 36	3999	1915 Nov. 5	B	7 E	M 23	1919 Oct.	P, P	R2	+1·0

* Diameters measured by L on R2

- XV -

Volume Four of the Melbourne Catalogue was printed in 1955, under Wood's direction but all the preparation had been done prior under Baldwin. Uniquely to the Melbourne zone the measurers who did positive and reverse are both listed. For example plate 4001 was measured in positive and reverse by 'P' (Charlotte Emily Fforde Peel) and plate 417 was measured by 'N' and 'MH' (Vicki Noonan and Muriel Heagney).

EXAMPLE OF THE PERTH ZONE ASTROGRAPHIC CATALOGUE



1911.
WESTERN AUSTRALIA.

ASTROGRAPHIC CATALOGUE
1900·0

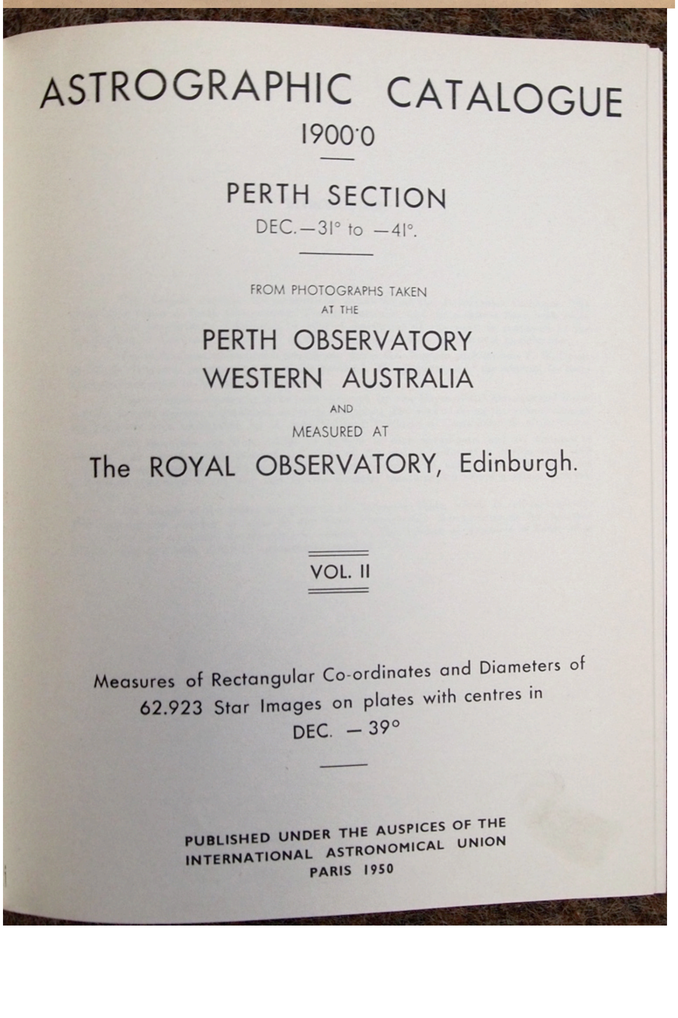
PERTH SECTION,
DEC. —31° to —41°.

FROM PHOTOGRAPHS TAKEN AND MEASURED
AT THE
PERTH OBSERVATORY,
UNDER THE DIRECTION OF
W. ERNEST COOKE, M.A., F.R.A.S.,
GOVERNMENT ASTRONOMER OF WESTERN AUSTRALIA.

VOL. IV.

Measures of Rectangular Co-ordinates and Magnitudes of 13636 Star Images, R.A. 18^h to 24^h, on plates with centres in DEC. —32°.

PERTH:
BY AUTHORITY: FRED. WM. SIMPSON, GOVERNMENT PRINTER.
1911.


ASTROGRAPHIC CATALOGUE
1900·0

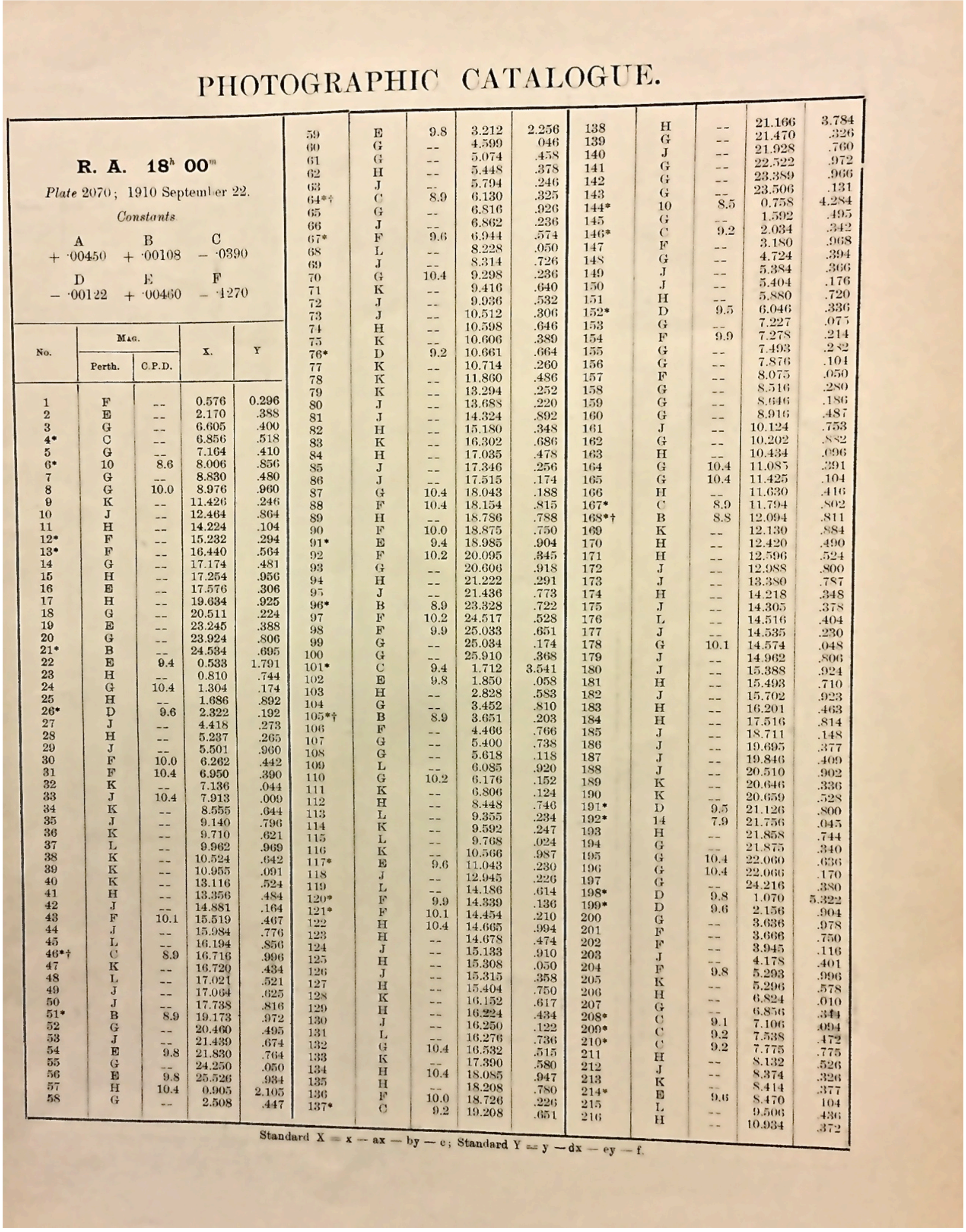
PERTH SECTION
DEC.—31° to —41°.

FROM PHOTOGRAPHS TAKEN
AT THE
PERTH OBSERVATORY
WESTERN AUSTRALIA
AND
MEASURED AT
The ROYAL OBSERVATORY, Edinburgh.

VOL. II

Measures of Rectangular Co-ordinates and Diameters of 62.923 Star Images on plates with centres in DEC. —39°

PUBLISHED UNDER THE AUSPICES OF THE
INTERNATIONAL ASTRONOMICAL UNION
PARIS 1950



PHOTOGRAPHIC CATALOGUE.

R. A. 18h 00m

Plate 2070; 1910 September 22.

Constants

A	B	C
+ ·00450	+ ·00108	− ·0390
D	E	F
− ·00122	+ ·00460	− ·1270

No.	Mag. Perth.	Mag. C.P.D.	X.	Y	No.	Mag. Perth.	Mag. C.P.D.	X.	Y	No.	Mag. Perth.	Mag. C.P.D.	X.	Y
1	F	--	0.576	0.296	59	E	9.8	3.212	2.256	138	H	--	21.166	3.784
2	E	--	2.170	.388	60	G	--	4.599	.046	139	G	--	21.470	.326
3	G	--	6.605	.400	61	G	--	5.074	.458	140	J	--	21.928	.760
4*	C	--	6.856	.518	62	H	--	5.448	.378	141	G	--	22.522	.972
5	G	--	7.164	.410	63	J	--	5.794	.246	142	G	--	23.389	.966
6*	10	8.6	8.006	.856	64*†	C	8.9	6.130	.325	143	G	--	23.506	.131
7	G	--	8.830	.480	65	G	--	6.816	.926	144*	10	8.5	0.758	4.284
8	G	10.0	8.976	.960	66	J	--	6.862	.236	145	G	--	1.592	.495
9	K	--	11.426	.246	67*	F	9.6	6.944	.574	146*	C	9.2	2.034	.342
10	J	--	12.464	.864	68	L	--	8.228	.050	147	F	--	3.180	.968
11	H	--	14.224	.104	69	J	--	8.314	.726	148	G	--	4.724	.394
12*	F	--	15.232	.294	70	G	10.4	9.298	.236	149	J	--	5.384	.366
13*	F	--	16.440	.564	71	K	--	9.416	.640	150	J	--	5.404	.176
14	G	--	17.174	.481	72	J	--	9.936	.532	151	H	--	5.880	.720
15	H	--	17.254	.956	73	J	--	10.512	.306	152*	D	9.5	6.046	.336
16	E	--	17.576	.306	74	H	--	10.598	.646	153	G	--	7.227	.075
17	H	--	19.634	.925	75	K	--	10.606	.389	154	F	9.9	7.278	.214
18	G	--	20.511	.224	76*	D	9.2	10.661	.664	155	G	--	7.493	.282
19	E	--	23.245	.388	77	K	--	10.714	.260	156	G	--	7.876	.104
20	G	--	23.924	.806	78	K	--	11.860	.486	157	F	--	8.075	.050
21*	B	--	24.534	.695	79	K	--	13.294	.252	158	G	--	8.516	.280
22	E	9.4	0.533	1.791	80	J	--	13.688	.220	159	G	--	8.646	.186
23	H	--	0.810	.744	81	J	--	14.324	.892	160	G	--	8.916	.487
24	G	10.4	1.304	.174	82	H	--	15.180	.348	161	J	--	10.124	.753
25	H	--	1.686	.892	83	K	--	16.302	.686	162	G	--	10.202	.882
26*	D	9.6	2.322	.192	84	H	--	17.035	.478	163	H	--	10.434	.096
27	J	--	4.418	.273	85	J	--	17.346	.256	164	G	10.4	11.085	.391
28	H	--	5.237	.265	86	J	--	17.515	.174	165	G	10.4	11.425	.104
29	J	--	5.501	.960	87	G	10.4	18.043	.188	166	H	--	11.630	.416
30	F	10.0	6.262	.442	88	F	10.4	18.154	.815	167*	C	8.9	11.794	.802
31	F	10.4	6.950	.390	89	H	--	18.786	.788	168*†	B	8.8	12.094	.811
32	K	--	7.136	.044	90	F	10.0	18.875	.750	169	K	--	12.130	.884
33	J	10.4	7.913	.009	91*	E	9.4	18.985	.904	170	H	--	12.420	.490
34	K	--	8.555	.644	92	F	10.2	20.095	.845	171	H	--	12.596	.524
35	J	--	9.140	.796	93	G	--	20.606	.918	172	J	--	12.988	.800
36	K	--	9.710	.621	94	H	--	21.222	.291	173	J	--	13.380	.787
37	L	--	9.962	.969	95	J	--	21.436	.773	174	H	--	14.218	.348
38	K	--	10.524	.642	96*	B	8.9	23.328	.722	175	J	--	14.305	.378
39	K	--	10.955	.091	97	F	10.2	24.517	.528	176	L	--	14.516	.404
40	K	--	13.116	.524	98	F	9.9	25.033	.651	177	J	--	14.535	.230
41	H	--	13.356	.484	99	G	--	25.034	.174	178	G	10.1	14.574	.048
42	J	--	14.881	.164	100	G	--	25.910	.368	179	J	--	14.962	.806
43	F	10.1	15.519	.467	101*	C	9.4	1.712	3.541	180	J	--	15.388	.924
44	J	--	15.984	.776	102	E	9.8	1.850	.058	181	H	--	15.493	.710
45	L	--	16.194	.856	103	H	--	2.828	.583	182	J	--	15.702	.923
46*†	C	8.9	16.716	.996	104	G	--	3.452	.810	183	H	--	16.201	.463
47	K	--	16.720	.434	105*†	B	8.9	3.651	.203	184	H	--	17.516	.814
48	L	--	17.021	.521	106	F	--	4.466	.766	185	J	--	18.711	.148
49	J	--	17.064	.625	107	G	--	5.400	.738	186	J	--	19.695	.377
50	J	--	17.738	.816	108	G	--	5.618	.118	187	J	--	19.846	.409
51*	B	8.9	19.173	.972	109	L	--	6.085	.920	188	J	--	20.510	.902
52	G	--	20.460	.495	110	G	10.2	6.176	.152	189	K	--	20.646	.336
53	J	--	21.439	.674	111	K	--	6.806	.124	190	K	--	20.659	.528
54	E	9.8	21.830	.764	112	H	--	8.448	.746	191*	D	9.5	21.126	.800
55	G	--	24.250	.050	113	L	--	9.355	.234	192*	14	7.9	21.756	.045
56	E	9.8	25.526	.934	114	K	--	9.592	.247	193	H	--	21.858	.744
57	H	10.4	0.905	2.105	115	L	--	9.768	.024	194	G	--	21.875	.340
58	G	--	2.508	.447	116	K	--	10.566	.987	195	G	10.4	22.060	.636
					117*	E	9.6	11.043	.230	196	G	10.4	22.066	.170
					118	J	--	12.945	.226	197	G	--	24.216	.380
					119	L	--	14.186	.614	198*	D	9.8	1.070	5.322
					120*	F	9.9	14.339	.136	199*	D	9.6	2.156	.904
					121*	F	10.1	14.454	.210	200	G	--	3.636	.978
					122	H	10.4	14.665	.994	201	F	--	3.666	.750
					123	H	--	14.678	.474	202	F	--	3.945	.116
					124	J	--	15.133	.910	203	J	--	4.178	.401
					125	H	--	15.308	.050	204	F	9.8	5.293	.996
					126	J	--	15.315	.358	205	K	--	5.296	.578
					127	H	--	15.404	.750	206	H	--	6.824	.010
					128	K	--	16.152	.617	207	G	--	6.856	.344
					129	H	--	16.224	.434	208*	C	9.1	7.106	.094
					130	J	--	16.250	.122	209*	C	9.2	7.538	.472
					131	L	--	16.276	.736	210*	C	9.2	7.775	.775
					132	G	10.4	16.532	.515	211	H	--	8.132	.526
					133	K	--	17.390	.580	212	J	--	8.374	.326
					134	H	10.4	18.085	.947	213	K	--	8.414	.377
					135	H	--	18.208	.780	214*	E	9.6	8.470	.104
					136	F	10.0	18.726	.226	215	L	--	9.506	.436
					137*	C	9.2	19.208	.651	216	H	--	10.934	.372

Standard X = x − ax − by − c; Standard Y = y − dx − ey − f.

Volume Four of the Perth AC was the first volume to be printed. There was an errata inserted into the catalogue after it was printed stating that the titles on the pages should be ‘Astrographic’ not ‘Photographic’. Cooke’s painstaking comparison to the CPD Catalogue star magnitudes, where they existed, can be seen, as was the case for the Melbourne zones published by Baldwin. Complex tables and formulae at the front of this catalogue described how to calculate the standard star co-ordinates from the x and y co-ordinates provided.

The following Observers have taken plates as under:—

Mr. G. F. Johns, from 1901 (October 14) to 1904 (June 23).
Mr. C. Nossiter, from 1904 (May 5) to 1908 (June 4).
Mr. C. S. Yeates, from 1908 (February 27) to present date.

and the following ladies have taken part in the measurement of the plates:—

	Initials.
Miss E. Kendall, from 1907 (June 1) to 1908 (December 1).	E.K.
Miss P. Williams, from 1907 (June 1) to present date.	P.W.
Miss E. Jones, from 1908 (January 20) to 1909 (June 30).	E.J.
Miss E. Harrington, from 1908 (January 20) to 1908 (July 31).	E.H.
Miss N. O'Dea, from 1909 (January 1) to 1909 (May 31).	N.O.
Miss M. Williams, from 1909 (June 8) to 1910 (November 30).	M.W.
Miss M. Harvey, from 1909 (July 1) to present date.	M.H.
Miss A. P. Thompson, from 1909 (September 3) to present date.	A.T.
Miss E. G. Allen, from 1910 (December 1) to present date.	E.A.

Mr. Nossiter has had general control of all the arrangements for taking and measuring the photographs, has personally undertaken those portions of the work requiring special consideration, and has decided whether a plate is to be accepted or retaken. The plate constants were computed by Mr. Cooke.

LIST OF PLATES IN THE PRESENT VOLUME CENTRES IN — 32° DEC.

No. of Plate.	Year and Fraction.	R.A. of Centre.	Hour Angle.	Reseau.	Micro-meter.	Measurer.	No. of Stars.	Ratio to C.P.D.	No. of Standard Stars.	Interval between Exposure and Measure-ment.
			h. m.							months.
2070	1910 ·72	18 00	1 10W	151	A	P.W.	1427	4·3	15	½
2063	1910 ·68	18 09	0 03E	151	B	M.W.	1458	5·1	16	0
2071	1910 ·72	18 18	1 07W	151	A	M.H.	709	4·5	14	½
2105	1910 ·74	18 27	1 23W	151	B	A.T.	844	5·4	16	½
2064	1910 ·68	18 36	0 16E	151	A	M.H.	677	3·9	17	0
2110	1910 ·75	18 45	1 15W	151	B	A.T.	700	3·5	14	½
2066	1910 ·68	18 54	0 09E	151	A	M.H.	569	3·4	14	½
2067	1910 ·68	19 03	0 05E	151	B	A.T.	602	3·6	14	½
2111	1910 ·75	19 12	1 22W	151	B	M.W.	535	3·1	17	½
2112	1910 ·75	19 21	1 27W	151	A	M.H.	519	3·7	16	½
2075	1910 ·72	19 30	0 55W	151	B	M.W.	409	4·2	14	½
2106	1910 ·74	19 39	0 23W	151	B	A.T.	244	3·0	13	½
2077	1910 ·72	19 48	1 07W	151	B	M.W.	259	3·9	15	¾
2078	1910 ·72	19 57	1 09W	151	A	P.W.	232	4·5	14	1
2113	1910 ·75	20 06	0 54W	151	A	M.H.	292	6·0	14	¾
2114	1910 ·75	20 15	0 56W	151	A	P.W.	291	4·3	12	¾
2115	1910 ·75	20 24	1 00W	151	B	M.W.	409	6·0	16	¾
2116	1910 ·75	20 33	1 02W	151	B	A.T.	285	3·7	14	1
2140	1910 ·85	20 42	1 53W	151	B	M.W.	259	3·0	17	½
2141	1910 ·85	20 51	1 57W	151	B	A.T.	190	2·0	14	½
2142	1910 ·85	21 00	2 00W	151	B	A.T.	133	1·6	13	¾
2143	1910 ·85	21 09	2 07W	151	B	M.H.	135	1·5	12	1
2144	1910 ·85	21 18	2 09W	151	B	A.T.	126	1·4	17	¾
2145	1910 ·85	21 27	2 12W	151	B	M.H.	157	2·6	15	¾
2146	1910 ·85	21 36	2 16W	151	B	A.T.	159	4·1	16	¾
2147	1910 ·85	21 45	2 21W	151	B	M.H.	141	5·7	16	¾
2119	1910 ·83	21 54	1 05W	151	B	A.T.	133	4·0	17	¼
2120	1910 ·83	22 03	1 11W	151	B	M.W.	135	4·6	16	¼
2121	1910 ·83	22 12	1 18W	151	B	M.W.	143	3·0	14	¼
2135	1910 ·84	22 21	1 28W	151	B	A.T.	93	1·8	15	1
2136	1910 ·84	22 30	1 31W	151	B	M.H.	69	2·5	12	1
2137	1910 ·84	22 39	1 33W	151	B	A.T.	87	3·1	14	1¼
2122	1910 ·83	22 48	1 04W	151	B	A.T.	112	5·1	12	¼
2138	1910 ·84	22 57	1 27W	151	B	M.H.	95	3·1	12	1¼
2123	1910 ·83	23 06	0 02E	151	B	M.W.	135	3·1	13	½
2124	1910 ·83	23 15	1 03W	151	B	A.T.	120	2·5	16	½
579	1903 ·85	23 24	0 40W	102	A	E.K.	151	3·1	14	56
580	1903 ·85	23 33	0 44W	102	A	P.W.	187	3·2	15	56
585	1903 ·86	23 42	0 07W	102	B	E.H.	210	3·1	17	56
586	1903 ·86	23 51	0 11W	102	B	E.J.	203	3·0	14	56

APPENDIX 4: SUMMARY LIST OF AUSTRALIA'S PARTICIPATION IN THE AC-CDC

This list documents the quantitative data of Melbourne, Sydney and Perth's participation in the AC-CdC. It draws on data from a number of sources (O'Hora 1988, p. 135; Urban et al 1998).

	Melbourne Observatory	**Sydney Observatory**	**Perth Observatory**
Zone of the sky*	Latitude -37.50. Zone: -65° to -90° declination. Allocated in 1887.	Latitude -33.52. Zone: -52° to -64° declination. Allocated in 1887.	Latitude -32.00. Zone: -31° to -41° declination. Allocated in 1900.
# AC plates, stars	4,507 plates; 218,000 stars.	9,514 plates; 743,593 stars.	Final # plates unknown; 369,000 stars
# AC volumes	8	52 + Explanation 53	28 (1–25, 31–33)
Estimated % sky	4.7%	5.9%	6.3%
AC plates photography	1st plate 1890. By 1914 most of the zone had been photographed. Last plate 1940. Except some replacements by SO.	1st plate 1891. Most by 1919. Last replacement plate photographed 1948.	1st plate 1901. By 1908 most of the zone had been photographed. Last plate photographed 1919.
Measuring the plates	29 women and 1 man. employed during the period 1898 to 1930. 15 plates measured later in Sydney by Bellamy and Colville.	28 women employed from 1916 to 1964. Sydney plates were measured in Melbourne prior to 1915.	11 women employed from 1907–1922. 7 women and 2 men at Royal Observatory Edinburgh (ROE) 1908–1952.
AC publication	First 3 volumes published by 1929. Final 5 catalogues published between 1953 and 1962.	First 2 volumes published 1922. 6 volumes published by 1925. Catalogue 52 published by 1964. Catalogue 53 published in 1971.	First 4 volumes published by Cooke between 1911 and 1916. Remaining 21 by Curlewis 1913–1921. ROE published 3 volumes during the period 1948–1952.
Carte du Ciel Source: MNRAS	584 plates photographed. Final plates of triple exposed charts taken in 1929.	59 plates required to complete in 1903 but 950 overlapping plates required. CdC 50% complete in 1928. Suspension of CdC photographs in 1930.	At least 100 plates for CdC were taken, each one in triplicate, by 1903. Faintest stars mag 13.5.

* Zone -41° to -51° allocated to the Cape of Good Hope Observatory.

APPENDIX 5: TABLE OF THE VOLUMES PUBLISHED FOR THE AUSTRALIAN ZONES OF THE ASTROGRAPHIC CATALOGUE

Australian Zone Astrographic Catalogues				**Date**	**Publishing**
Observatory and Zone	**Volume #**	**Declination**	**RA**	**Published**	**Astronomer**
Melbourne	1	-65° to -66°	0h to 6h	1926	Baldwin
Melbourne	2	-67° to -68°	6h to 12h	1928	Baldwin
Melbourne	3	-69° to -70° + Explanation	12h to 18h	1929	Baldwin
Melbourne	4	-71° to -72°	18h to 24h	1955	Wood
Melbourne	5	-73° to -74°	0h to 6h	1956	Wood
Melbourne	6	-75° to -77°	6h to 12h	1958	Wood
Melbourne	7	-78° to -81°	12h to 18h	1958	Wood
Melbourne	8	-82° to -90°	18h to 24h	1963	Wood
Sydney	1	-51° to -53°	0h to 6h	1925	Cooke
Sydney	2	-51° to -53°	6h to 12h	1926	Cooke
Sydney	3	-51° to -53°	12h to 18h	1923	Cooke
Sydney	4	-51° to -53°	18h to 24h	1923	Cooke
Sydney	5	-52° to -54°	0h to 6h	1929	Nangle
Sydney	6	-52° to -54°	6h to 12h	1925	Cooke
Sydney	7	-52° to -54°	12h to 18h	1925	Cooke
Sydney	8	-52° to -54°	18h to 24h	1925	Cooke
Sydney	9	-53° to -55°	0h to 6h	1933	Nangle
Sydney	10	-53° to -55°	6h to 12h	1933	Nangle
Sydney	11	-53° to -55°	12h to 18h	1930	Nangle
Sydney	12	-53° to -55°	18h to 24h	1930	Nangle
Sydney	13	-54° to -56°	0h to 6h	1939	Nangle
Sydney	14	-54° to -56°	6h to 12h	1939	Nangle
Sydney	15	-54° to -56°	12h to 18h	1937	Nangle
Sydney	16	-54° to -56°	18h to 24h	1937	Nangle
Sydney	17	-55° to -57°	0h to 6h	1943	Wood
Sydney	18	-55° to -57°	6h to 12h	1946	Wood
Sydney	19	-55° to -57°	12h to 18h	1944	Wood
Sydney	20	-55° to -57°	18h to 24h	1946	Wood
Sydney	21	-56° to -58°	0h to 6h	1941	Wood
Sydney	22	-56° to -58°	6h to 12h	1940	Nangle
Sydney	23	-56° to -58°	12h to 18h	1942	Wood
Sydney	24	-56° to -58°	18h to 24h	1941	Wood
Sydney	25	-57° to -59°	0h to 6h	1948	Wood
Sydney	26	-57° to -59°	6h to 12h	1947	Wood
Sydney	27	-57° to -59°	12h to 18h	1948	Wood
Sydney	28	-57° to -59°	18h to 24h	1949	Wood
Sydney	29	-58° to -60°	0h to 6h	1951	Wood
Sydney	30	-58° to -60°	6h to 12h	1952	Wood
Sydney	31	-58° to -60°	12h to 18h	1950	Wood
Sydney	32	-58° to -60°	18h to 24h	1951	Wood
Sydney	33	-59° to -61°	0h to 6h	1955	Wood
Sydney	34	-59° to -61°	6h to 12h	1953	Wood
Sydney	35	-59° to -61°	12h to 18h	1954	Wood
Sydney	36	-59° to -61°	18h to 24h	1955	Wood
Sydney	37	-60° to -62°	0h to 6h	1955	Wood
Sydney	38	-60° to -62°	6h to 12h	1957	Wood
Sydney	39	-60° to -62°	12h to 18h	1957	Wood

Observatory and Zone	Volume #	Declination	RA	Published	Publishing Astronomer
Sydney	40	-60° to -62°	18h to 24h	1957	Wood
Sydney	41	-61° to -63°	0h to 6h	1957	Wood
Sydney	42	-61° to -63°	6h to 12h	1959	Wood
Sydney	43	-61° to -63°	12h to 18h	1960	Wood
Sydney	44	-61° to -63°	18h to 24h	1959	Wood
Sydney	45	-62° to -64°	0h to 6h	1960	Wood
Sydney	46	-62° to -64°	6h to 12h	1961	Wood
Sydney	47	-62° to -64°	12h to 18h	1962	Wood
Sydney	48	-62° to -64°	18h to 24h	1961	Wood
Sydney	49	-63° to -65°	0h to 6h	1962	Wood
Sydney	50	-63° to -65°	6h to 12h	1962	Wood
Sydney	51	-63° to -65°	12h to 18h	1964	Wood
Sydney	52	-63° to -65°	18h to 24h	1963	Wood
Sydney	53	Explanation		1971	Wood
Perth	1	-32° to -37°+ Explanation	0h to 6h	1911	Cooke
Perth	2	-32° to -37°	6h to 12h	1912	Cooke
Perth	3	-32° to -37°	12h to 18h	1912	Cooke
Perth	4	-31° to -41°	18h to 24h	1911	Cooke
Perth	5	-31° to -41°	0h to 6h	1920	Curlewis
Perth	6	-31° to -41°	6h to 12h	1921	Curlewis
Perth	7	-31° to -41°	12h to 18h	1921	Curlewis
Perth	8	-31° to -41°	18h to 24h	1921	Curlewis
Perth	9	-31° to -41°	0h to 6h	1914	Curlewis
Perth	10	-31° to -41°	6h to 12h	1914	Curlewis
Perth	11	-31° to -41°	12h to 18h	1914	Curlewis
Perth	12	-31° to -41°	18h to 24h	1913	Curlewis
Perth	13	-31° to -41°	0h to 6h	1913	Curlewis
Perth	14	-31° to -41°	6h to 12h	1919	Curlewis
Perth	15	-31° to -41°	12h to 18h	1920	Curlewis
Perth	16	-31° to -41°	18h to 24h	1920	Curlewis
Perth	17	-31° to -41°	0h to 6h	1916	Curlewis
Perth	18	-31° to -41°	6h to 12h	1915	Curlewis
Perth	19	-31° to -41°	12h to 18h	1916	Curlewis
Perth	20	-31° to -41°	18h to 24h	1916	Curlewis
Perth	21	-31° to -41°	0h to 6h	1916	Curlewis
Perth	22	-31° to -41°	6h to 12h	1917	Curlewis
Perth	23	-31° to -41°	12h to 18h	1919	Curlewis
Perth	24	-31° to -41°	18h to 24h	1919	Curlewis
Perth	25	-31° to -41°	0h to 6h	1919	Curlewis
Perth by ROE	31 (Vol 1)	-31° to -41°	6h 0m to 23h 50m	1949	Greaves/Dyson/
Perth by ROE	32 (Vol 2)	-38 to -41	0h to 24h	1950	Wrigley/ Sampson
Perth by ROE	33 (Vol 3)	-38 to -42	0h to 24h	1952*	Wrigley/ Sampson

* Curlewis attempted to print this catalogue in 1922 however the Western Australian Government refused to provide the funding.

APPENDIX 6: LIST OF WOMEN WHO WORKED ON THE AUSTRALIAN ZONES OF THE AC-CDC FROM 1890 TO 1971

The list below is of the women who worked in Australia on the AC. It includes those who worked at Adelaide Observatory and observed and reduced reference stars for the Melbourne zone of the AC. It includes the women whose initials were listed in the AC as measurers, women who did the calculations of the stars which were used as 'constants', and the women who transcribed the log books into documents for the printer.

The women who worked at Royal Observatory Edinburgh on the Perth zone are listed separately.

Observatory	Start Year	End Year	Name	# Years	Cat. abbrev	n = 1
Adelaide***	1890	1898	M. E. Greayer	8	MEG	1
Adelaide***	1892	1893	A. Pittman	1	AP	1
		TOTAL	ADELAIDE	9		2
Melbourne	1898	1903	M. A. Phillips	5	MP	1
Melbourne	1898	1901	H. F. Skoglund	3	S	1
Melbourne	1898	1901	J. W. Hall	3	WH	1
Melbourne	1898	1918	C. E. Peel*	20	P	1
Melbourne	1898	1903	E. Harker*	5	H	1
Melbourne	1898	1903	L. E. Lewis*	5	L	1
Melbourne	1901	1902	M. Suthmeir*	1		1
Melbourne	1901	1903	E. Langley*	2	EL	1
Melbourne	1901	1904	R. Rayson*	3		1
Melbourne	1902	1912	E. Sheldon*	10	ES	1
Melbourne	1904	1907	B. C. Scott*	3	BS	1
Melbourne	1904	1905	E. Watts	1		1
Melbourne	1904	1905	M. C. Greer*	1	G	1
Melbourne	1904	1911	N. E. McKay*	7	M	1
Melbourne	1905	1911	E Hockin*	6	EH	1
Melbourne	1905	1909	A Alexander*	4	A	1
Melbourne	1905	1909	I. Trigge*	4	T	1
Melbourne	1906	1912	H. M. Browne*	6	HB	1
Melbourne	1906	1910	M. A. Heagney*	4	MH	1
Melbourne	1907	1909	V. Noonan*	2	N	1
Melbourne	1909	1912	G. M. Moore*	3	GM	1
Melbourne	1909	1911	G. O'Donnell*	2	O	1
Melbourne	1911	1912	C. Frayne*	1		1
Melbourne	1912	1914	W. Appleton	2		1
Melbourne	1921	1930	J. C. Prigg*	9		1
Melbourne	1921	1930	M. Hunt	9		1
Melbourne	1926	1930	L. M. Lloyd	4	ML	1
		TOTAL	MELBOURNE	125		27
Perth	1907	1908	E. Kendall**	1	EK	1
Perth	1907	1918	P. Williams**	11	P.W	1
Perth	1908	1909	E. Jones**	1	EJ	1
Perth	1908	1908	E. Harrington**	1	EH	1

Perth	1908	1910	Miss Arnold	2		1
Perth	1909	1909	N. O'Dea**	1	NO	1
Perth	1909	1911	M. Williams**	2	MW	1
Perth	1909	1922	M. Harvey**	13	MH	1
Perth	1909	1912	A. P. Thompson**	3	AT	1
Perth	1910	1922	E. G. Allen**	12	EA	1
Perth	1910	1918	I. Tothill	8	IT	1
		TOTAL	PERTH	55		11
Sydney	1916	1926	I. D. Digby*	10	ID	1
Sydney	1916	1926	I. M. McDonald*	10	IM	1
Sydney	1917	1924	N. C. de Moulin*	7	NC	1
Sydney	1917	1926	L. E. Clements*	9	LC	1
Sydney	1917	1926	W. E. Cronin*	9		1
Sydney	1918	1927	B. J. Mawson*	9		1
Sydney	1920	1926	S. Oates*	6	SO	1
Sydney	1923	1946	M. A. Allen*	23	MA	1
Sydney	1930	1947	Miss Arkinstall	17		1
Sydney	1937	1941	B. Macara*	4		1
Sydney	1937	1939	M. B. Mills*	2		1
Sydney	1939	1944	E. Willcocks	5		1
Sydney	1941	1961	M. Colville* (Wilson)	20	MW	1
Sydney	1942	1946	M Tierney	4		1
Sydney	1944	1960	B. M. C. Dignam	16		1
Sydney	1945	1947	M. Browne	2		1
Sydney	1947	1956	P. M. Lawler*	9		1
Sydney	1947	1956	J. M. Campbell	9		1
Sydney	1947	1955	N. J. Nolan	8		1
Sydney	1948	1968	W. L. Bellamy*	20	WB	1
Sydney	1948	1949	R. G. Day*	1		1
Sydney	1948	1954	V. J. Maurice*	6	VM	1
Sydney	1954	1956	Y. Donohue	2		1
Sydney	1954	1955	D. O. Paltarokaite	0.4		1
Sydney	1959	1959	J. C. Bassett	0.3		1
Sydney	1960	1960	J. Fleming	0.3		1
Sydney	1961	1965	J. Hawkes*	4		1
Sydney	1965	1968	B. M Frank*	3		1
Sydney	1961	1964	Y. Welch*	3		1
Sydney	1968	1969	E. J. Weigold*	1		1
Sydney	1969	1971	R. N. Bleakley*	2		1
Sydney	1969	1971	A. M. Davis*	2		1
		TOTAL	SYDNEY	224		32
			TOTAL ALL	413	years	72

* As confirmed by Wood (1971). Wood did not list women who worked for a short time on the AC. The women not named by Wood have been identified through employment cards, public service notices, annual and newspaper reports.

** As confirmed in the first volume of the Perth Zone AC by Cooke (1911, p. 5). The women not named by Cooke have been identified through correspondence, public service gazette and plate measurement logbooks.

*** Adelaide Observatory was not officially an Astrographic Catalogue participant. The women listed were identified through the time record books, logbooks and public service gazettes.

The list below was checked by researching the Royal Observatory Edinburgh archives as well as referring to the list provided in volumes 31,32 and 33 of the Perth Astrographic Catalogue.

Observatory	Start year	End Year	Name	# years	Cat. abbrev	n = 1
Edinburgh	1908	1922	I.C. Falconer**	14	IF	1
Edinburgh	1908	1916	S. A. Falconer**	8	SF	1
Edinburgh	1908	1922	E.G. Knott**	14	EK	1
Edinburgh	1911	1912	J.G. Mackintosh**	1	JM	1
Edinburgh	1912	1913	L.V. Cornish**	1	LC	1
Edinburgh	1912	1913	E.M.Wrigley**	1	MW	1
Edinburgh	1917	1919	K. Williams*	2	KW	1
Edinburgh	1920	1923	C.S. Strachan*	2	CS	1
Edinburgh	1920	1928	I. Clarkson*	8	IC	1
Edinburgh	1919	1920	M.D. Smith*	1		1
Edinburgh	1922	1923	E.E. Aitken*	2		1
Edinburgh	1924	1926	A.J. Young*	3		1
Edinburgh	1928	1929	M.C. Rose*	2		1
Edinburgh	1929	1929	M. Dalziel*	1		1
Edinburgh	1931	1931	M. Donald*	1		1
			TOTAL Edinburgh	61		15

*Source ROE archives A44.382/ 52.448. Plate constant calculators not listed in AC and from 1918 magnitudes were remeasured to match Perth method (Sampson 1918, p. 266)

**Source ROE achives A44.382 and AC Perth Zone catalogue

Appendix 7: Astrographic Catalogue And Carte Du Ciel Collections

Adelaide Observatory's collection was distributed to the University of Adelaide and State Records South Australia, and some records were lost or destroyed when the observatory closed and was demolished in 1948. The records and instruments from Melbourne Observatory, which was closed for research in 1945 but is still a site of active astronomical observation and heritage significance, are widely distributed between the Royal Botanic Gardens Victoria, the Museums Victoria collections, the Astronomical Society of Victoria, Public Records Office Victoria, State Records New South Wales, and the Museum of Applied Arts and Sciences (Powerhouse Museum which includes Sydney Observatory) collections.

Although the original Perth Astrographic Building was demolished in the 1960s, Perth Observatory holds a complete AC-CdC collection of instruments, glass plate negatives and archival logbooks at the Bickley Observatory, established in 1966. The astrograph is still operational within a purpose-designed building on which the original Astrographic Dome is mounted. Perth Observatory ceased scientific research and was declared a public observatory in January 2013. It has an active public telescope viewing program run by volunteers.

In 1986 the Sydney and Melbourne AC-CdC collections were removed from Sydney Observatory to Macquarie University under a letter of agreement between the Museum of Applied Arts and Sciences (Powerhouse Museum) and Macquarie University. In 2006, six hundred and fifty of the Sydney glass plates were sent to Cambridge University to be digitised by Alan Vaughan (Bucciarelli et al, 2006). This collection in its entirety has now been returned to the care of the Museum of Applied Arts and Sciences. In 2015, a new building called the East Dome opened on the Sydney Observatory site. This building, designed by the NSW Government Architects Office, houses the Melbourne Astrographic telescope and the Sydney A measuring machine. The dome commissioned by Harley Wood and originally made by Mort Dock Engineering, sits on top of the building. Sydney Observatory is active in communicating astronomy to the public, as well as the research and care of astronomical heritage.

APPENDIX 8: IAU GENERAL ASSEMBLY, COMMISSION 23 & RESOLUTION 10

Translation from French by T. Stevenson

1st General Assembly, Rome, Italy, 1922

Commission 23

(1) We acknowledge that all are concerned with the wish expressed by Prof. Schlesinger to see the positions of intermediate stars, chosen by the Astrographic Committee, determined in order to assemble the entire map of the sky.

(2) So that we can print this at the University of Paris, it is necessary to know if the catalogue of the intermediate stars in the area -15 deg to +15 deg are prepared because this manuscript is ready for printing.

Original text:
(23) CARTE DU CIEL (I) que l'on fasse connaitre il tous les interesses le voeu exprime par le Prof. Schlesinger de voir determiner les positions des etoiles intermediaires, choisier par le Comite Astrographique, en vue de la carte de l'ensemble du Ciel qu'il se propose d'etablir. (2) que l'on fasse savoir il l'Universite de Paris qu'il serait a desirer que l'on imprime Ie catalogue des etoiles intermediaires de la zone -15deg +15 deg dont le manuscrit est pret pour l'impression.

VIth General Assembly Stockholm, Sweden 1938, Commission 23 (Carte du Ciel)

1. The Commission considers the seven volumes of the photographic catalogue, which the observatories at Hyderabad, Edinburgh and Oxford had accepted responsibility for, instead of Potsdam and Rio de Janeiro Observatories, are now ready for printing. The funds currently set aside by the IAU are insufficient to cover the costs of printing, and (Commission 23) urges the IAU to draw on the reserves until the completion of the publication. The annual subsidy was 1300 (French francs) agreed by the IAU before 1932. The payment of which was, at that time, not made because the manuscripts were not completed for printing.

2. The Commission wants the order to be followed for printing the volume of the photographic catalogue prepared by the observatories of Hyderabad, Edinburgh and Oxford and for which funds have been made available by the Astronomical Union; (1) Completion of printing, now under way, the volume of the zone +37° prepared by the Observatory of Hyderabad; (2) Printing a volume of one of the areas prepared by the Observatory of Edinburgh -38° to -40°; (3) Printing the volume of the zone +32° prepared by Oxford Observatory. Once these three volumes are printed, printing of the following volumes will be by agreement between the interested observatories.

3. The Commission considered that the delay in the publication of any of the volumes of the photographic catalogue not only robs astronomers of knowledge of peculiarities of this region of the sky, but also prevents them from using the results obtained by other observatories together for a discussion of all the data of the Map of the Sky, strongly requests the Union to convince the Governments of Victoria, New South Wales and Mexico to provide their respective observatories the resources to publish in a reasonable time the photographic catalogues they were allocated.

Original text:
1. La Commission considérant que les sept volumes du Catalogue photographique dont les observatoires d'Hyderabad, d'Edimbourg et d'Oxford avaient accepté la charge à la place des observatoires de Potsdam et de Rio de Janeiro, sont maintenant prêts pour l'impression, et considérant que les fonds mis en réserve par l'Union sont insuffisants' pour couvrir les frais de leur impression, demande instamment à l'Union Astronomique de lui continuer jusqu'à l'achèvement de la pubücation, la subvention annuelle de 1300 qu'elle lui accordait avant 1932 et qui avait été alors interrompue parce que les manuscrits n'étaient pas terminés.
2. La Commission désire que l'ordre suivant soit suivi pour l'impression des volumes du Catalogue photographique préparés par les observatoires d'Hyderabad, d'Edimbourg et d'Oxford et pour laquelle des fonds ont été mis à sa disposition par l'Union Astronomique; (1) Achèvement de l'impression, actuellement en cours, du volume de la zone+37° préparé par l'Observatoire d'Hyderabad; (2) Impression d'un volume de l'une des zones préparées par l'Observatoire d'Edimbourg-38° ou -40°; (3) Impression du volume de la zone +32° préparé par l'Observatoire d'Oxford. Une fois ces trois volumes imprimés, l'impression des volumes suivants se fera par entente entre les observatoires intéressés.
3. La Commission considérant que le retard apporté à la publication d'un quelconque des volumes du Catalogue photographique non seulement prive les astronomes de la connaissance des particularités propres à cette région du ciel, mais encore les empêche d'utiliser les résultats obtenus par les autres observatoires pour une discussion d'ensemble de toutes les données de la Carte du Ciel, prie l'Union de demander instamment aW1' Governements de Victoria, de New South Wales et de Mexico de fournir à leurs 6bservatoires respectifs les ressources nécessaires pour publier dans un temps raisonnable les catalogues photographiques dont ils ont été chargés.

VIIth General Assembly Zurich, Switzerland 1948, Commission 23,

Commission 23

1. The General Assembly of the IAU and the Commission for the Carte du Ciel has attracted the attention of the Australian Commonwealth and State Governments on the importance attached to the completion of the zones of the Astrographic Catalogue that were entrusted to Australian observatories. They have been asked to implement an emergency program. If there are gaps in the Astrographic Catalogue, this will harm the overall use of this valuable scientific instrument which has involved an enormous international effort, of which most of the work has already been provided.

The IAU would be grateful to Mr H. W. Wood, Government Astronomer of Sydney, New South Wales, to accept the management of the completion of the zones; and Dr Riet van Woolley, Director of the Commonwealth Observatory, Canberra, to provide the necessary assistance. The Commission of the Carte du Ciel undertakes to request financial assistance from the IAU for the publication of the last volumes when the manuscripts are ready for printing.

2. The Commission of the Carte du Ciel desires to complete the publication of the complete Astrographic Catalogue and requests the IAU to make available, in addition to the funds that have been allocated and not yet spent, a sum of twenty-one thousand gold francs to cover the cost of printing 5 volumes of the catalogue. These are for the zones which were undertaken by the Observatories of Potsdam, Perth and Rio de Janiero, whose manuscripts have been prepared by the Observatories of Oxford and Edinburgh, which could be printed by 1951.

Original text:
1. L'Assemblée Générale de l'U.A.r. et la Commission de la Carte du Ciel attirent l'attention des Gouvernements du Commonwealth et des Etats Australiens sur l'importance qui s'attache $. l'achèvement des zones du Catalogue Photographique du Ciel confiées aux observatoires australiens; elles leur demandent d'en favoriser l'exécution en programme d'urgence. Les dernières lacunes du Catalogue Photographique nuisent à l'utilisation globale de cet instrument scientifique précieux, qui a demandé tant d'efforts internationaux; elles sont d'autant plus regrettables que l'essentiel du travail a déjà été fourni. L'U.A.r. serait reconnaissante à Monsieur H. W. Wood, Government Astronomer, Sydney, New South Wales, d'accepter la direction de cet achèvement et à Monsieur le Dr R. v. d. R. Woolley, Direct,eurde l'Observatoire du Commonwealth, Canberra, de lui fournir les aides nécessaires. La Commission de la Carte du Ciel s'engage à demander l'aide financière de l'U.A.I. pour la publication des derniers volumes, lorsque les manuscrits seront prêts pour l'impression. 2. La Commission de la Carte du Ciel, désireuse de voir se terminer la publication du Catalogue Photographique, demande à l'U.A.r. de mettre à sa disposition, en plus des fonds qui lui ont été attribués et qui ne sont pas encore dépensés, une somme de vingt-et-un mille francs-or pour couvrir les frais d'impression de 5 volumes du Catalogue, appartenant aux zones laissées en souffrance par les Observatoires de Potsdam, de Perth et de Rio-deJaneiro et dont les manuscrits, préparés par les Observatoires d'Oxford et d'Edimbourg, pourraient être imprimés d'ici 1951.

XVIIIth General Assembly, Patras, Greece 1982

Resolution No. I0, Sydney Observatory Instruments

The International Astronomical Union

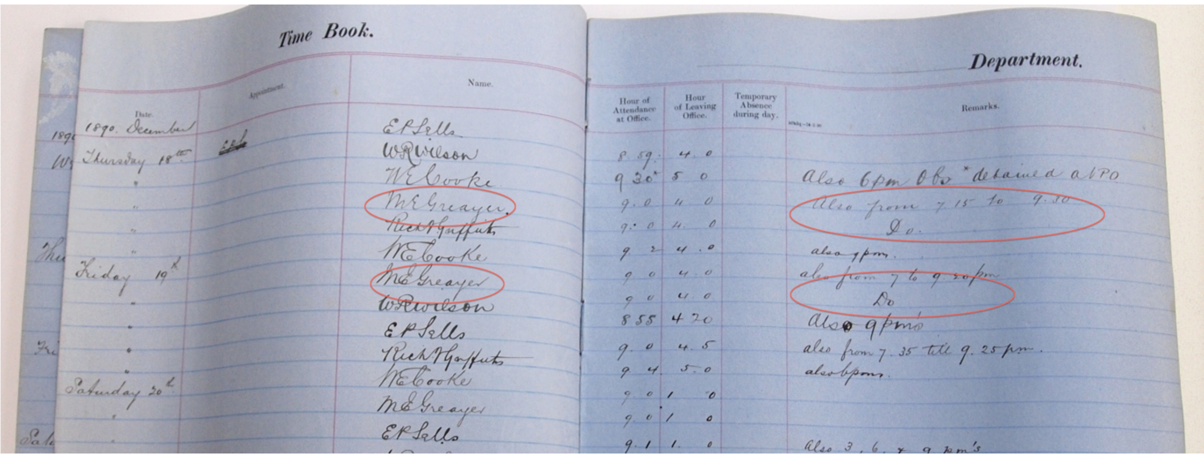
Noting: the decision to terminate scientific work of the Sydney Observatory, and

Recognising: the role of the Sydney Observatory in an international campaign for the improvement of the astrometric reference frame in the Southern Hemisphere,

Recommends: that the instruments now at Sydney continue to be made available for astronomical observations.

APPENDIX 9: LIST OF SELECTED ARCHIVAL RESEARCH RECORDS & SOURCES

The following list is of the primary research material which was difficult to identify as relevant to Adelaide Observatory's participation in the AC-CdC. It is not exhaustive but is intended to guide future researchers to investigate this topic, or associated topics, further. Mary Emma Greayer's Work is found in State Records South Australia GRG31. An example of the first listed entry, the Time Book GRG31/19, is illustrated below. I have electronically circled Greayer's working hours which substantiate her evening work.



State Records South Australia GRG31

Item No	Date	Description	Quotes and notes
GRG31/ 19	1890 to 1893	1890 to 1891 Time Book Observatory attendance book Greayer mainly seems to have been working alongside Cooke.	Greayer regularly worked 9am to 4pm, then 7:15pm to 9:30pm 18/12/1890 (Greayer, Cooke and Griffiths) 19/12/1890 (Greayer, Wilson Sells, Griffiths) 04/02/1891 (Greayer, Cooke, Griffiths) 7:25pm to 10:10pm 06/02/1891 (Greayer, Cooke, Sells, Wilson) ditto 09/02/1891 (Greayer, Cooke, Sells) 7:30pm to 9:45pm 11/02/1891 (Greayer, Cooke, Wilson) 8pm to 9pm 23/02/1891 (Greayer, Cooke, Wilson, Sells) 8pm to 9:45pm 25/02/1891 both Greayer and Cooke left at 1pm 'took this pm instead of tomorrow' 04/03/1891 (Greayer, Cooke, Sells) 8:15pm to 9:43pm 09/03/1891 (Greayer, Cooke, Sells, Wilson) 8:10pm to 9:58pm 13/03/1891 (Greayer, Sells, Griffiths, Cooke) 8:05pm to 9:45pm Then mainly Wilson, Griffiths, and Sells 27/04/1891 (Greayer, Cooke, Sells) 7:45pm to

			10:45pm 28/04/1891 (Greayer, Cooke, Griffiths, Sells) 7:32pm to 10:15pm 01/05/1891 (Greayer, Cooke, Wilson)
GRG31/ 19 with GRG31/ 52		1891 Alignment with Measurement of Zone Ledger Greayer Pittman	28 Aug 1891 (Greayer 7:15pm to 10pm) (Cooke 7:12pm to 10pm) (Sells notes that he observed Jupiter) (Griffiths 6pm to 9pm) Note: visit from a society also that evening. 07 Sept 1891 (Greayer and Cooke 7:10pm to 10:15pm) (Sells 7:46pm to 10:14pm) Both above noted clock stars observed by Cooke. Clock stars also observed 31 Aug 1891 when Greayer and Cooke worked from 7:15pm to 8:30pm. Observed Zone 3: RA 50 to 58 deg 26 Feb 1892 (Griffiths, Greayer and Cooke 7:50pm to 10:20pm) (Wilson until 9pm). Working in pairs: 02 Mar 1892 (Greayer and Cooke 7:50pm to 10pm) also (Griffiths and Wilson). 04 Mar 1892 (Greayer and Cooke 7:50pm to 10pm) also (Griffiths and Wilson). Same with May 4, 6 and July 11, 18 in 1892. 23 May 1982 (Greayer, Cooke and Wilson 7:15pm to 10:15pm) Pittman worked from 6pm to 10:15pm. Greayer worked every night that zone stars were taken in 1892 then through to Monday 3 July 1893 from 7:20pm to 10pm with Cooke. Note: A. Pittman (female) employed 1 April 1892 to 29 April 1893. Could be Adelaide Susan Pittman born 1871 to George Robert Pittman and Emma Jackson Daly or Annie Pittman who died in 1907.
GRG31/ 61	1893	Calculations, Nadir, Todd/Russell re positions.	Observer's initials: M & G on tables of observations using a micrometer could possibly be Griffiths and most likely Mary Emma Greayer because there is no other 'M' employed.
GRG31/ 01	1886 (Vol 3) from 1893 (Vol 4)	2 Letter books Todd	Vol 4: pp. 90–91 Date: 8 Aug 1894 Letter from Todd to Ellery about waiting for iron piers to stabilise temperature change in telescope. Compared Melbourne Catalogue with the Cape, movement of the Nadir? Asked how the photographic work is progressing and "I hope the government will not, in its economy, cut your wings."

GRG31/01	Vol 4	Letter Todd to Russell 3 Dec 1895	Vol 4: p167, 168, 169 Letter to Russell from Todd about using his slides.
GRG31/01	Vol 4	Letter Todd to Baracchi—3 Oct 1899	GRG31/01 Vol 4: p386 Todd to Baracchi:"Since Mr Griffiths marriage which has deprived me of Miss Greayer's services, we have been unable to observe any of your astrographic stars; but I hope soon to be able to take up the work again."
GRG31/02	1897	Letter Todd to Gill—16 Sept 1897	Todd to Gill, about drought: "I was glad to hear from my young friend Mr Cooke that he met you in England. He was, as you are probably aware, my first Assistant at the Observatory and was on my recommendation appointed as First Astronomer at the New Observatory Perth, which will probably be the best equipped astronomically in the Australian colonies."
GRG31/02	1897	Letters—26 Aug 1897	Employment of another 'junior' assistant and pay scales. Suitability of Mr Allen at £140 per annum and Mr Jennings accepting the position at £60 per annum.
	1897	Letter Baracchi to Todd—13 Mar 1897	Baracchi to Todd about the number of stars observed for reference stars by Adelaide Observatory and Todd's lack of success at finding staff since Cooke's departure. He thanks 'Sir Charles' and says he must again 'take advantage' of Adelaide Observatory: "According to the last decision of the Paris Conference (Astrographic) the places of some 7000 stars are to be determined by Meridian Observations, for the reduction of the Melbourne plates…this is my excuse for taking full advantage of your co-operation…I sympathise with you on the inexperience of your new assistant. The Government are trying to add to our professional staff a man from the Post office – a letter sorter…".
	1897	Letter Baracchi to Todd—19 Jan 1897	Baracchi to Todd asking when the rest of the stars will be observed.
GRG31/122		Melbourne Durchmusterang	Initials C and G—Cooke and Griffiths.
GRG31/56	1895 to 1897	Star reduction apparent to Mean RA and SPD	17 Jun 1895–9 Mar 1896 14 Sept 1896–7 Apr 1897 7 Apr 1897–20 Oct 1897 This could all be Greayer's work as indicated by the writing style. Requires further investigation.

GRG31/ 52	1891 to 1892	Magnitudes	28 Aug 1891 to 18 Jul 1892. This is a record of magnitudes for various zones. It may be Greayer's work. It can be matched with the Time Book and is worth further investigation.
GRG31/ 33	1914	Sydney zone Observations —51 deg to - 60 deg (1914) Two bound volumes connected to AC	Two bound volumes of AC reference stars pn typed pages bound together. This is Dodwell's work. The majority of this work was done in 1914. A number of observations date to Mar 1920.
GRG31/ 33	1914	Sydney zone— intermediates 51deg to - 65deg	Loose sheets once bound. May be the handwritten version of what was then typed. You can see calculation of how many times the star was observed. The observations go throughto the mid 1920s.
GRG31/ 13	1903 to 1904	Working Sub – estimates Observatory estimates	C. Todd—Government Astronomer R. F. Griffiths—Assistant Observer G. Dodwell—Assistant Observer J. W. Chettle—Assistant Observer J. Bromley, Esq—Assistant Observer VI Computer—this was a printer error G. Gray—Computer (may have replaced Greayer) J. Kelly—Porter and measurer
GRG31	1885 to 1934	Adelaide Observatory Visitors Book (Vol 1)	25/08/86 Visit by J. Greayer, A. Greayer, C. W. Greayer. 10/07/87 Visit by Jane Greayer (South Terrace East), J. L. Greayer, Philip C. Greayer, Jessie C. Greayer, Annie Greayer with Mary Brodie Myles and George Mowles (London). 15 /11/87 Jessie Greayer visited alone.

GRG31/51	1892 to 1893 (Vol 1)	Zenith Distances observed with the Transit Circle	Vol 1 First date 15 Aug, 1892 This appears to be all by Greayer (MG) and Cooke (C). The observers initials are: C and MG, with the initialled reductions by MG. The dates of observation align perfectly with the attendance time book for night work for both Cooke and Greayer. They worked until at least 10pm. There are 198 pages each with 5 stars over this period (est.) so approximately 990 star measurements in the book using the transit circle (sometimes the same star was measured using the east circle and west circle). Stars are remarked on if 'bad' or 'very bad' with occasional 'good' or 'very good' remarks by Greayer's (MEG) handwriting, or the occasional sign off by 'G' Griffiths. One example is 27 Feb 1893: 8 stars observed on east circle by C and S, but reduced by MEG. This was on a night when the three observed together, there were also 10 stars observed in the west by MEG and C on that same night. The three worked until 9:45pm.
GRG31/51	1893 to 1894 (Vol 2)	Zenith Distances observed with the Transit Circle	From the handwriting, these have been observed, noted and reduced by Cooke—no initials to suggest otherwise.
GRG31/51	1892 to 1892	Zenith Distances observed with the Transit Circle	From 6 May 1892, Greayer is noted as observing with Cooke and as reducing the zenith distances. On 12 Jul she observed with Griffiths, and on 13 Jul Greayer observed again with Cooke. On 27 Jul Cooke and Greayer observed together the stars from the Argentine general catalogue. Further observations to 12 Aug 1892.
GRG31/51	1896 to 1897	Zenith Distances observed with the Transit Circle	24 Jul 1896 to 28 Apr 1897 observations by G and MG, reductions by MG, examination by RFG. Also Nadir observations and notes by MG.
GRG31/51	1897 to 1897	Zenith Distances observed with the Transit Circle	30 Apr 1897 to 10 Dec 1897 observations by G and MG, reductions by MG, examination by RFG.
GRG31/51	1892 to 1892	Zenith Distances observed with the Transit Circle	5 Jan 1892 to 12 Feb 1892 observations by Cooke, reduction by MG. 5 Jan observation, 6 Jan reduction. Observation 6 Jan, reduction 7 Jan.

GRG31/ 54	1891 to 1892	Zone RA—4 volumes of zone and clock stars taken using micrometer.	29 Apr 1891 to 1892. Includes photo taken 10 Feb 1892 showing the wire measurements. The measurements recorded look like Greayer's writing.
GRG31/ 118		Lantern slides	Mainly eclipse trip to island of Tonga. Image of Perth Astrograph. Seismology, Lick Observatory.
GRG31/ 55	1890 to 1892	Zone working catalogue	01 Nov 1890 to 18 Jan 1892. No inscription but handwriting looks like MEG work throughout.

APPENDIX 10: TRANSCRIPTS OF INTERVIEWS

The University of Sydney Human Research Ethics Committee approved the interview research methodology undertaken for this thesis.
The approval protocol number is 02-20111/13399.
The Chief Investigator was Associate Professor Jennifer Barrett, Faculty of Arts Museum Studies.

The study, which began in March 2011, involved interviews with people who had a connection with Australia's participation in the Astrographic Catalogue and Carte du Ciel. The in-depth interview methodology was designed to gain insights into working life at Sydney (Melbourne/Perth) Observatory during the Carte du Ciel (Chart of the Sky) and the Astrophotography Catalogue projects, in particular the social history of working life and related material culture. Approval was given for deviation beyond a set list of questions in order to gain greater insight into the topic and so that the different connections which the interviewees had with the topic were taken into account. Approval was given for Irma Havlicek, Micro-Sites Manager for the Museum of Applied Arts and Sciences, to record the interviews.

Complying with the ethics standards adopted by the University of Sydney, a participant information statement was provided. Participation was voluntary and the subjects were not under any obligation to consent; they could withdraw or stop the interview at any time if they did not wish to continue. None of the interviewees withdrew or discontinued the interviews. The original list of interviewees was nine, but as the thesis progressed new findings from my research led to some of the people on the original list being interviewed and others replaced by people who could give different insights into the topic. This was in keeping with the qualitative aims of the research.

Consent was given for recording and use of the interview using the Participant Consent Form. The participants understood that the University of Sydney has kept a copy of the material. Participants understood that the thesis will be available to others in the public domain, and that presentations and papers prior to and after the final thesis will be available in the public domain. Copies of the transcripts were sent to the subjects on request.

The transcripts below have been selected to include only the information relevant to the topic but it is not discriminatory.

INTERVIEW WITH ROSAMOND MADDEN (RM) AND WINSOME BELLAMY (WB)

Date of Interview: 16 March 2011
Interviewer: Toner Stevenson, SID: 307199746
Recording: Irma Havliceck
Transcript: Casting Words
Location: Sydney Observatory

Rosamond Madden lived at Sydney Observatory with her parents Una and Harley Wood from 1945.
Winsome Lillian Bellamy worked at Sydney Observatory from 1948 to 1968 on the Astrographic Catalogue.

(In the Russell Room)
TS: … What attracted you to the Observatory?

WB: I worked at the observatory from 1948 to 1968… It's a long while since I've been working here and things have changed since then. You (RM) were only a small girl, and we got to know the family quite well while we worked here. It was like having a second family in my work. It was such a relaxed, easy life in those days, and Doctor Wood was so good to us. It's like having a second family…I finished my training as a children's nurse. And my mother got very sick and I had to be home decent hours. We had three small children at home. They were my sister's children and she couldn't look after them, so I needed to be home in the morning and in the evening. So, I got a job with the public service. They didn't tell me what I'd be doing. So, when I came to the Observatory, I found it very unusual. Nothing like I'd experienced before.

TS: …Why was that unusual?

The only office training I had had was at T and G insurance company, (Temperance and General Insurance Company) which was different work to the Observatory, where I was measuring star positions. I had not experienced anything to do with astronomy before and I found it boring.

RM: But you managed to alleviate the boredom?

WB: My word! There were four of us working on the micrometers. And two were measuring the star positions and two were writing down the details of the measurements. And in between times we were knitting, or doing crosswords to pass the time, because it was a very slow job. And not having any previous interest in astronomy, it was just routine work that we had been taught. And we just got on with it.

TS: Who taught you what to do?

WB: Dr Wood and Mr. Robertson taught us how to measure. There was nothing complicated about it. It was just centering a cross line, which was made of spider web. And the interesting part was that my father, who was a gardener, used to have a lot of spiders in the garden. And I would bring them in a little jar. They had to be garden spiders, because they spun the plainest web, and Mr. Pinnock would make the crossbars for the micrometers out of the spider webs, which I thought was rather great. It was an extra feather to my wing.

TS: And Ros, you were talking about Mr. Pinnock and what a character he was.

RM: He was one of those (interesting) people. He was a World War II veteran. And I just remember he always had stories to tell about his World War II experiences. And two things particularly I remember. He kept the workshop so beautifully. You'd walk in there and there'd be a nice smell of very clean machine oil. And all the bits and pieces, ball bearings, brass bits and pieces, were all neatly catalogued and nicely oiled so they wouldn't get destroyed. And he and dad did a lot of design and repair work together. It was one of the things that were mentioned when dad got the DSc - that he'd managed to do quite a lot with very few resources, because of his ability to make things. And the spider web is the classic example of where he and Horace Pinnock and Bill Robertson also did that ...

TS: … I know you were a young girl at the time but did you spend time with Winsome or the other measurers at all?

RM: We did have some interactions. When I was under ten, before my mother went back to school teaching, there'd sometimes be morning teas in the house. So, we did get to know, as much as a child gets to know, people. And we knew people's names. And we did know, despite what Winsome says, the women who worked in the observatory were very highly respected and relied on, obviously, for making all these accurate measurements. So, we had morning tea. And then as she was saying earlier, there was a period where there was lunchtime shuttlecock. And we'd get out on what we used to call the tennis court then I used to be allowed to have a hit occasionally, even though I was abysmal. Everybody would just have hits together, the staff and the families. And Christmas parties, I suppose.

WB: One of the men made the bats for us. We had an enlarged type of bats for shuttlecock, but we really enjoyed it. We looked forward to it. It was the highlight of the day…We started at nine in the morning. Nobody was supposed to sign the book after nine. And then there was a red line drawn across the book and my name was put in. And we finished at five. And in the lunchtime, which was three-quarters of an hour, I would run down to Medell's or one of the shops near Wynyard and I wasn't always back on time then either. I wasn't a really good public servant. We brought our lunch and we quite often had it in the park. It was a beautiful place to work. It was quiet, away from the main city. And the view was so beautiful. Nice surroundings, with the big Morton Bay figs in the grounds, outside the observatory.

TS: Your personal experience sounds very pleasant at the observatory. When you were doing your work, can you just describe how you worked?

WB: We had turns about to use the machine, because your eyes became very tired with looking through the micrometer. The other person would sit and write the figures down. We did about half an hour, or perhaps longer on the machine. And then we would swap places and the other one would have a turn. The four of us were working beside each other with the two different machines. But we talked all the time, while we were doing it, and swapped gossip and jokes. And we had a great time apart from work.

TS: And you were mainly doing that in the upstairs room we were talking about?

WB: Yes. We came up the little twisty stairs, through the library. And there was a room that was ours, which was a book-lined room, with two micrometers near the window. There was a second room where the typists sat and there was an office there as well.

TS: That building doesn't exist anymore, but from the photos it looks like it had quite big windows. Can you describe to me more what the room was like?

WB: The library that we came through first had bookcases around the room with glass doors with a lot of very old leather-bound volumes that were starting to wear. And our room was the same, but the bookcase had no glass doors on it. And the books were getting very broken and tattered, because we had a terrible lot of cockroaches in the building. So, we learned not to leave things around. But the books were never touched much, because there were so many of them. I can't tell you how many cupboards there were, but they were absolutely full of volumes, which were probably priceless.

TS: And did you ever use the library in that area? Ros, what do you remember of it?

RM: I remember the library more. I don't think I went into your room ever, but I certainly went into library. And I know when I was at university, when you're desperate at exam time you'll do anything for a change of scenery. I just remember there was a very brief period where I went in there just in desperation, I asked could I go in there at weekends and sit there with lovely volumes all around. And a beautiful big table in the middle with one of those leather tops with the polished wood around the edge.

WB: Which we used to play ping-pong on. We did that some days when it was raining. We'd play Ping-Pong instead of playing outside. You see, our life was pretty easy going; a lovely place to work.

TS: Winsome, you and Margaret Colville are both mentioned by Harley Wood, who picked out those who had made very important contributions. Did you have any awareness of that at the time?

WB: None at all.

RM: But I did. I knew that dad had a lot of respect for people like Winsome and Margaret. It's not that I remember specific things. It was the whole aura of how he talked about people. He had huge respect and appreciation for the work they did.

TS: (Shows image of WB at Hilger measuring machine)

WB: It was definitely viewed on that side. I don't remember those (points to eyepieces). There was viewing, but I don't know what that one was (points to eyepiece). It looks a bit modern. There seems to be more eyepieces than I remember. We did have a light box. When I think about it, the light box, as well as the windows.

TS: So, then you swapped with the other person. Who did you work with most?

WB: That would be Margaret, Lily and Verlie Maurice the lass that lives up near Macksville now. She and I worked together for as long as she was here.

TS: Why did she leave?

WB: She was getting married, so some of those pictures have got her either as a bridesmaid or as a bride, I forget which. I missed her. The other two lasses, one died working here. She had a brain tumour. They thought she was just nervy, but it turned out she was dying. And Margaret married. So, it was a big change.

TS: And could you imagine that women could have been doing astronomy work at all?

WB: None of the high-powered work was done by anyone but the men. So, we just gave what we measured to them and they did all the hard work. We wouldn't have known if it was unusual. It was just like little black spots. Some were bigger than others. But there were so many of them that if there'd been something really unusual, we'd have noticed. But I don't remember anything like that.

TS: And why did you leave, Winsome, after 20 years?

WB: Well, circumstances had changed at home. The children had gotten to an age where they could be independent. And my mother died, and I had always wanted to nurse, so, I just went back to nursing.

RM: Did you enjoy it?

WB: Very gladly, actually, because it was my field. And then until I retired I nursed. This was a very isolated place to work, being right away from the city. And we did miss the opportunities that we would have had to use the shops a lot. But we did have the privilege of having such a beautiful place to work. And the scenery was just magnificent. It looks altogether different now, when I see the skyline out there. But it was just lovely, a lovely spot. Even had the ships going out to sea through the harbour. We couldn't see them from inside the building. But we could if we were outside on the grounds, in the park.

INTERVIEW WITH DR NICK LOMB, SYDNEY OBSERVATORY

Date of Interview: 24 August 2011

Interviewer: Toner Stevenson, SID: 307199746

Recording: Irma Havliceck

Transcript: Casting Words

Location: Russell Room Sydney Observatory

Dr Nick Lomb worked as an astronomer at Sydney Observatory from 1979 and became Curator of Astronomy after the observatory became part of MAAS until 2009.

TS: (Shows NL the Southern Sydney Star Catalogue, Observatory Papers 96 and asks NL to explain his work at Sydney Observatory in this project).

NL: This is the Sydney Southern Star Catalogue. This was produced just after the Museum took over the Observatory in 1982. Over the next 12 months, the remaining astronomer here at the Observatory, David King, and myself produced this catalogue based on the measurements of 500 photographic plates of the night sky to measure the positions of something like 27,000 stars in the zone in the night sky as seen from the Southern Hemisphere. And this was published in 1983. It was published in the 'Journal and Proceedings of the Royal Society of New South Wales', and this is a reprint that's in the 'Observatory Papers No. 96'.

This is the star catalogue.... this is all the descriptions. These are some of the possible formulae being used. We've tried out lots of formulae to convert star positions – star positions on the plate to positions in the night sky – and these are some of the formulae that we tried out, and some errors that were calculated that we found out. Because always – no position is completely accurate, there is an error associated, and this is calculating the areas involved with these curves.

But the actual numbers were published with microfiche, which is the way in the 1980s of publishing large amounts of data. This could be used in certain devices like a microfiche scanner that was available in libraries that could then magnify – all these tiny pages would then become pages of numbers.

It was also published as a magnetic tape, a computer magnetic tape, which was sent to a data centre overseas. And today, the Sydney Southern Star, the stars from the Sydney Southern Star Catalogue, are available on the Internet through astronomical data sites as one of the catalogues that graph star positions in the southern sky. The predecessor catalogue to the Sydney Southern Star Catalogue was a huge project that Sydney Observatory was involved in, which was called the Astrographic Catalogue project, and Sydney Observatory took on that project back in 1887 and began work on this project in 1890.

And the idea of this project was to map the entire southern – matter of fact, to map the entire sky with identical telescopes at different observatories. There were 15 or 18 observatories involved in the project. The numbers varied as the project went on, but there were many observatories around the world, each allocated a particular zone.

TS: (Shows NL volumes 1 and 53 of the Astrographic Catalogue Sydney zones)
Sydney Observatory took on a very large zone in the southern sky as its project. It began taking the images in 1890, but the project was not finished until the 1960s. In fact, this last volume...it was published in 52 volumes, and then in 1971, the 53rd volume, this one, was published as basically giving the history and all the basic information about the project.

This was written by Dr Harley Wood, who was the Director of the Observatory at the time, back in 1971, and he wrote the explanation of the whole project the Observatory had been involved in for a period of 80 years previously. Can you imagine any organisation today taking on a project that would take 80 years? It's not…. of course, people didn't know when they took it on, it would take so long, but still, it was a huge project.

So, this was the very last volume, and this was the very first volume of the project, and as you can see, what it contains is positions, measurements of star positions on a plate. On each photographic plate, the stars are numbered, and their x-y-coordinates given. And there is an equation given, these numbers given for an equation. These numbers can then be calculated, could be converted to positions in the sky, and that's, of course, because lack of computing facilities in those days, even calculating these constants was a major difficulty, but today of course, we would publish in publishing machine-readable form the actual positions, the star coordinates in the night sky.

And I should explain that there is a coordinate system for stars in the night sky just like there's a coordinate system on Earth, the longitude and latitude on Earth, so you can say your position where you are on Earth, and the Observatory is roughly 151 degrees, 12 minutes, and 12 seconds east of Greenwich in London, and 33 degrees, 53 minutes to the south of the equator. Every position on Earth there is a longitude and latitude. Similar in the night sky, there is a system of coordinates. There are some coordinates, which are called right ascension at latitude. Right ascension is equivalent to longitude and declination is equivalent to latitude on Earth.

So, the two systems are very similar, and that's what the star catalogue does – is obtain star positions in their spherical coordinates, right ascension and declination. Declination that other people can find the same object or study its movement. If you do it back in the 1890s, and you compare its position to a position obtained in 1990s, or in 2000, or in 2009, 10, then you have a very long baseline to work out if there's been a slight change in the motion of the star, of the particular star that you're interested in.

TS: (Shows NL a photograph of the Melbourne Astrographic catalogue plates in timber boxes as stored at Macquarie University. Also an astrographic glass plate which was in its envelope)

Now, I mentioned photographic plates. They're the ones that are measured, but these are ones...these are astrographic catalogue plates in this nice lacquered plate box that you can't obtain now. In fact, I don't think you can obtain photographic plates any more. They've all gone to digital photography, but astronomers use to take images on glass plates which had a photo-sensitive emulsion on the back, and then they would expose it as in a camera, through a telescope and camera, and then end up with an image. So, there's an envelope which gets the basic information when this particular image was taken, 20th of January, 1893, made by a company called Marion, and tells you when it was...what time...six hours, three minutes, and twenty seconds. The time and date it was taken, how long it was exposed for, and the centre of the plate, the coordinates of the centre of the plate, which were nine hours, 24 minutes, two seconds, and right ascension at 56 degrees, seven minutes and 57 seconds in declination are written.

Here is what the plate looked like, and I'll try and hold it by the edges so as not to damage the plate itself. You can see that there is a grid, and the idea was to measure the positions of the stars with respect to the grid, and the stars on here are...this was a negative. The stars are little black points on this image, because it's a negative image. There's no need to convert it to a positive, so the plate was taken, it was developed, and then this was what was measured to present for the star Astrographic Catalogue project. So, there's the grid, and all positions are measured with respect to that grid.

INTERVIEW WITH VERLIE JUNE LEE (NEE MAURICE) (VM), SYDNEY OBSERVATORY

Date of Interview: 01 April 2013

Interviewer: Toner Stevenson, SID: 307199746

Recording: nil

Transcript: Toner Stevenson

Location: (by phone on request of interviewee)

Verlie June Maurice (VM) worked at Sydney Observatory from 1948 to 1954 on the Astrographic Catalogue, tides and other charts.

TS: What and when was your first experience and impression of the Observatory?

VM: When I began I didn't look to work at the Observatory. I had been working at the Education Department after the intermediate and leaving certificate, then moved into the Account section. They were looking for someone at the Observatory.

TS: Did you have to do a public service exam in the first place or show any special skills or talents in maths?

VM: No, I don't remember doing an exam. The government was employing a lot of public servants then. Myself, and Pat (Patricia Lawler) and Margaret (Colville) who also worked at the Observatory, they were young girls who had grown up in the Eastern Suburbs, I think they came straight from school. With Win (Winsome Bellamy), we all had a public school education and we found ourselves working together at the Observatory. It was like a big family, we had close friendships. The work was simply that, work.

TS: And why did you leave the Observatory?

VM: When I married Jack I left and we moved to Cowra to run a dairy farm. Jack introduced pasteurized milk into that town.

TS: Can you describe your work at the Observatory?

VM: We measured the photographic plates, first one side, and then we reversed the plate and measured the other side.

TS: How did you work out the magnitude of the stars?

VM: We assessed the size of the dots (stars); there must have been a scale we lined these up with. On the reverse side we compared position and size. The astronomers checked these and anything out of (error) range was done again. On a bad day there would be five out of the range, and on a good day none. We only worked on the glass plates in the mornings. There were four measurers (women) in the room and the windows faced south. In the afternoon we did the tide times and moon and sunrise, and perhaps even the time of planets rising.

TS: Do you remember where you worked in the Observatory?

VM: Yes in a room off the library. Winsome said it is not there now.

TS: That wing was removed in the 1980s. Were you mathematical?

VM: I had the intermediate certificate. We all had a basic education. When we left school at around 15 years old we straight away sought jobs, it was what girls did then. I did basic, or general maths. Margaret Wilson seemed to be very bright.

TS: Did you do any calculations or work with numbers?

VM: I did have to call out numbers for Harley Wood sometimes and I learnt how to memorise and check numbers. I must have been quite capable at that but I don't remember doing any complicated calculations. I did have to do tidal readings and the positions of the sun and, I think, also the planets. When we left Cowra we ran a post office and in those days it had a switchboard and I used to remember people's phone numbers. Jack said I could remember people's numbers better than their names.

TS: Can you tell me more about the other women who worked at the Observatory?

VM: We were all very good friends. We had a great social time, work was just that, work, but we all got on. When I arrived Win, Pat, Renee and Margaret were already there. After I left Pat died. She had a brain tumour.

TS: Yes I have read a letter Harley Wood wrote to her mother, it must have been very sad.

VM: Yes, she was so young. When Margaret Wilson (nee Colville) left she ran a pre-school I believe. And Win went into nursing, which she had started out doing before the Observatory.

TS: Do you remember much about Harley Wood?

VM: Yes he was a very busy man, often away looking for radio and other astronomy sites in Coonabarabran and Parkes. When he was here and saw something interesting in the telescope he would say come up and have a look at this! We always went up to the telescope in the dome above (in the main observatory). There was another dome on the site but it's not there now.

TS: That dome had the astrographic telescope in it.

VM: We never looked through that telescope; it was always the one in the main building.

TS: Do you think your work at the Observatory had any impact later on in your life?

VM: Work was work and we were not really interested in the astronomy. When I left we moved to the farm, then ran the post office and I taught scripture at school. Our son is a geophysicist, and our daughter is a school teacher, so perhaps some influence from Jack and myself. Now I am 81 and I have learnt to use computers. I am still a 'numbers' person. I have to remind my grandchildren not to change anything on my computer when they use it. We Skype our son in Germany and use the Internet.

INTERVIEW WITH RALPH MARTIN (RM), GREG LOWE (GL) & DR ANDREW WILLIAMS (AW) PERTH OBSERVATORY

Date of Interview: 14 November 2011

Interviewer: Toner Stevenson, SID: 307199746

Recording: Toner Stevenson

Transcript: Toner Stevenson

Location: Perth Observatory, Bickley

Ralph Martin was Acting Director of Perth Observatory

Andrew Williams worked as an astronomer at Perth Observatory Bickley

Greg Lowe worked as the Education Officer at Perth Observatory

(Inside the glass plate negative store in the Administration building, Perth Observatory Bickley)

RM: They (the AC plates) are rewrapped in non-acid paper. These are the standard (envelope) they used (holding up glass plate negative), it's got the date they were taken, 1904, the RA and Dec (declination) and the date they were accepted for the Perth Astrographic Catalogue. Perth was involved in the Astrographic Catalogue and if you look at them (the glass plates) here there are three different images of the same star on each. There are three centres on that one. That (method) gives you three different images of the same star.

Note: The Perth Observatory glass plate being inspected was plate number 971, taken August 7, 1904, by CN (Clive Nossiter). It has an RA (right ascension) of 18h 25m and Dec (Declination) -39°. This plate was listed in Volume II.

(In the Astrograph House)

GL: Understandably Cooke used to get really cheesed off allowing the public to have access to his main research telescope. Apparently too, Cooke wrote letters and pamphlets and gave great public lectures, so while he was a bit brusque, he really had the public's education in his interest.

RM:… It (the astrographic telescope) was in Perth and operating before 1900. The first plates are 1900.

AW: In the 1960s an electric motor replaced the battery

RM: If you look at the dome you can see that it is originally from that period.

TS: What do you use the dome for now?

GL: It's a Museum piece.

AW: We can do photography with high school students but we haven't actually got any students up here yet.

GL: It needs fixing. The drive corrector needs fixing or replacing, the mechanicals are okay but the electrics aren't quite right.

RM: How come you can't steer it in RA?

(GL demonstrated how the glass plates were fixed into the telescope)
GL: Ari (Arie Verveer) modified it (the dome) and (Dr) Markowitz came and patched in this offset guider so you can alter the angle and it has a little drive unit to control it with the box here, and the stepping motor here to move the plate at the right angle and right speed here, so you can track a fast moving object like an asteroid or a comet. The shutter used to be down here on the bottom end.

AW: It looks like the original shutter is in here. This is the darkroom for processing the negatives. It looks like the camera might be in here.

GL: Yes the shutter used to be down here on the bottom end.

(GL rotated the astrographic telescope).
(AW provided a paper listing Perth Observatory permanent staff from 1896 to 2010).

INTERVIEW WITH DR BARRY CLARK

Date of Interview: 10 September 2012

Interviewer: Toner Stevenson, SID: 307199746

Recording: Toner Stevenson

Transcript: Toner Stevenson

Location: Melbourne Observatory within the Royal Botanic Gardens, Melbourne.

Dr Barry Clark is a member of the Astronomical Society of Victoria, Melbourne Observatory. He has researched and written about Melbourne Observatory and its collections extensively.

(Inside the Astrograph House)

TS: We are looking at an interesting display about the human computers; the women who were involved in the Astrographic Catalogue in Melbourne.

BC: The idea of using young women was to do the tedious work of astronomy; young women did the measurement of the photographic plates in the late 1800s. It seemed like a good idea here, you could pay them about half of what they had to pay the men and they were good workers and they cost less. These were the first attempts to get the local Colonial government to agree to have women on the public service. I think the initial approach was made in 1892 and it was not until 1899 that the project started. They had enough money to employ initially six women. One was so good at her work that after two years she was transferred to the permanent staff.

TS: Was that Miss Peel?

BC: Yes that was Miss Peel. Accordingly she was Australia's first female astronomer.

TS: I have been wondering who Miss Peel was, from my understanding she started here in 1898 and worked to 1918.

BC: There was another one who worked for a long time and she eventually became the librarian for the Astronomical Society of Victoria. You can see the glass plate there with the image of the stars on it. This is a microscope and it's got little gadgets which can move very precise distances, which you can actually read off. It was a tedious business, maybe you had

10,000 stars to measure and once you had done that you had to turn the plate 180 degrees and do all measurements again to check that the measurements gave the same answer. So it was a way of double-checking for arithmetic, transcription errors. You can see (BC pointed to the photograph of a woman using the Repsold machine) from the ergonomics it was very poorly arranged. This is a terrible pose, no backrest.

TS: The table in that image has always fascinated me with its brick base and stone table top.

BC: It's a slate table top and we still have some on site the same.

TS: Presumably that was to make sure the machine was very stable and didn't vibrate.

BC: Well when you were working to that precision the last thing you would want is the desk moving around because someone had bumped into it.

TS: There was Repsold 1 and Repsold II then the Comb, and Henry Chamberlain Russell, from my research, designed, or had his machinist make, two machines using old Troughton and Simms eyepieces that he took out of other instruments. I have never seen them used here although he sent them to Baracchi. That's one of many mysteries about this project.

BC: You might be interested to know that Charles Merfield worked at Sydney Observatory for a while and then became one of the active astronomers at Melbourne. Merfield was a very active photographer, and he was killed in a car accident in 1931 and his estate included 220 odd kilograms of photographs he had taken, none of them sorted or identified.

The Melbourne photographic club now has those plates on loan and they are going through them to identify what topics they are. But we have found pictures of Merfield using the great Melbourne Telescope in the 1930s, which has been a revelation because we thought it was out of use.

(Inside the astrograph dome)
BC: Ellery designed this (pointing to the dome's opening device); it's a copy of David Gill's.

(Barry Clark rotated the dome)

BC: I did quite a lot of work on this about ten years ago because it kept jamming. Because it had no bottom part of the bearing so I put in these wooden blocks. I had to put the same in the other side using hardwood, Jarrah and Red gum. It's been good for ten years since then.

BC: I got interested in astronomy when I was a primary school student and the teachers were away and we got to go to the local library in the state school, which had about 40 books, I was the last in the queue and the only book left that had even the slightest interest for me was about astronomy. I had not ever seen a book about astronomy and I was hooked from that moment on. By sixteen, or even younger, by fifteen, I was making telescopes. By seventeen I was doing nightly demonstrations in the front lawn of the guy who was the president of the ASV.

(In the ASV collection store looking at boxes of Astrographic Catalogue collection glass plates)
BC: Alan Vaughan said he was interested to see what these plates have on them.

TS: What can you see on that one?

BC: That is plate number 23 and it is a beautiful one.

INTERVIEW WITH DR. RICHARD GILLESPIE

Date of Interview: 13 September 2012

Interviewer: Toner Stevenson, SID: 307199746

Recording: Toner Stevenson

Transcript: Toner Stevenson

Location: Richard Gillespie's office, Melbourne Museum Carlton Gardens.

Dr Richard Gillespie is Head of the Humanities Department for Museum Victoria. He has undertaken specialist research on Melbourne Observatory over a number of years.

TS: Could you please explain your connection with Melbourne Observatory?

RG: When the Observatory closed in 1945, the Museum, what was then the National Museum of Victoria, a natural history museum, was gazetted to take control of that site, because the plan was to establish the Museum down there. They moved collections down there, a lot of the wet specimens; the marine specimens were stored down there. There was even a plaque saying that this would be the site of the future site of the National Museum. That was there for about thirty years while the Museum looked out for other sites.

So there has been a long-standing connection. The Museum looked after the heritage aspects of the buildings. It oversaw members of the Astronomical Society who continued to run public viewings utilizing some of the historic as well as some of their own telescopes that had been there since the 1930s. So the people could book through the planetarium in the city to go and do night viewings down there.

The volunteers were listed as volunteers through the Museum's books and this close association continued for 40 years until it gradually dissipated, essentially when the Museum moved out to Science works, the Science Museum, and the planetarium in the city closed. There were objects in the Museum collection that related to Melbourne Observatory, but the observatory site was handed over to the Botanic Gardens around 1990 or thereabouts and the link was broken.

Coincidentally I had started doing the observatory history. I was interested in the artefacts we had in the Museum that related to the history of the Observatory. When the Observatory closed, we actually have the book in the collection, in our archives, of a detailed list of all the instruments from the telescopes all the way through to the computing equipment, arithmetic calculators and thermometers, recording where everything went. A lot of the clocks went to Mt Stromlo because Mt Stromlo took over the timekeeping responsibilities that were being run from Melbourne Observatory. As you know, the Astrographic Telescope went up to Sydney. The Great Melbourne telescope and some of the smaller telescopes went to Mt Stromlo.

The 4 1/2-inch equatorial telescope, the main small equatorial telescope, went to the Physics Department of Melbourne University where it still is. A lot of other old scientific material went to high schools. A lot of the historical material came to the Museum. Over the years the Astronomical Society would rescue equipment it saw Public Works Department throwing, or it would find its way to the Museum. So we have gradually acquired archival material that was rescued in that fashion as well.

All of the archival records of the Great Melbourne Telescope went to Mt Stromlo with the telescope and a lot of that material got destroyed in the 1950s fire. The astrograph records went to Sydney, and then the main administrative files went to Public Records Office and then there were remnants that got rescued subsequently, and I have got involved in those types of rescues as well.

There is not much that relates to the astrograph that remains. Not the least because the Astrograph House was pretty much cleaned out to put in a new telescope, the ASV Astronomical Society members put their own telescope in there in the late 50s/60s. There was the darkroom in the bottom of the Astrograph House and so some odds and sods came out of that darkroom at some point or other during the 60s and 70s to the Museum.

TS: I know you have a lot to do with the GMT, and it, like the astrographic project, isn’t necessarily considered a major success story from an astronomical point of view. Why do you think it is important to preserve to re-examine or have available this heritage?

RG: It is true the Great Melbourne telescope did not result in major discoveries that changed the course of astrophysics or understanding of the nature of nebulae, which it was intended to do when it was designed and brought to Melbourne. But that, I think, in itself is really interesting and fascinating. Scientific dead-ends are just as interesting as scientific success stories. William Herschel's 40-inch telescope was pretty unsuccessful when he built it and he went back to using his 20-inch telescope. That's the nature of the beast.

The Leviathan telescope in Birr in Ireland was successful briefly but then it didn't do a lot of major work subsequently, after discovering spiral galaxies in the 1840s. The GMT is important for a number of reasons. Firstly, it was one of the first international telescopes, and in that way it has a relationship to the astrograph project. Secondly, it is really the first telescope that can rightly claim an international and national committee of astronomers and major scientific bodies designed it. These included the Royal Society and the British Association. This is a period when telescopes were essentially commissioned by individual government astronomers or by wealthy amateurs interested in doing cometry work or nebulae searching.

So it is a really interesting transition in the nature of the organisation of science. That was part of what participating in the Astrographic Catalogue and Carte du Ciel meant and why that resonates within Melbourne at a time when Melbourne is a wealthy colony, indeed one of the wealthiest cities in the world in terms of land values. There was an extraordinary kind of vigour and an interest in exploration, but in reality in a much more practical form. The notion of doing this type of astronomy, which is more theoretical, sits problematically and uneasily with Melbourne culture and its priorities at that time.

TS: How did social factors such as the Depression impact projects do you think?

RG: One needs to remember the extent of the Great Melbourne Telescope represented the start of astrophysics research in Australia, certainly mid-nineteenth century. It was an unusual circumstance that resulted in that through the interest of the Royal Society and the wealth of Melbourne and the people of Melbourne at the time.

The function of the State Colonial Observatories was timekeeping, navigation, weights and measures and meteorology, and that remained their predominant role. Federation in 1901 takes away meteorology. But it was not until 1908 when it (meteorology) is organised and goes to the Federal Government and after that the State Governments are pretty much disinterested and have certainly lost interest in funding, or indeed expanding, any of the State

Observatories. And it's just an ongoing battle after that, certainly at Sydney Observatory, then Adelaide and equally Melbourne Observatory.

They continued to do research at Melbourne, they keep the time series going and their geomagnetic, geophysical research, timekeeping, and star charting with the Astrograph Catalogue data reduction. Plus the other major focus is the reduction and processing of data and publication because they are sitting on all this research that goes back to the 1860s and hasn't been published. That becomes a major priority and most of the funds go into the Astrographic Catalogue. All this work is funded relatively cheaply by the State Government, a lot of this is cheaply funded because a lot, not all, of the workers were women, very cheaply paid and there were young men, recent graduates, also poorly paid but the actual contingent of astronomical staff is very modest indeed. Everybody was really waiting for the Federal Government to step up to the mark and, as we know, it is not until the mid-1920s when Mt Stromlo really starts getting off the ground. So I find it hard to think that the Astrographic Catalogue in any way interferred with the development of research physics. It was always seen that research astronomy was not going to occur in any great way in the State Observatories.

TS: I would like to finish off with, and I am interested in, what we were discussing earlier about where 'things' belong. Is the (Observatory) site important in actually interpreting the instrument? I am interested in a perspective, in your point of view on that, whether the site is important, particularly to do with observatories.

RG: I think it is. I know the Sydney Observatory site and obviously Melbourne Observatory I know well. Both of these are significant sites and interpreting the history on the site is much more powerful than trying to do this in the abstract. The same goes for Mt Stromlo because it makes sense to talk about Mt Stromlo and the type work that goes on there in situ. Although Mt Stromlo is different, having so many off-site telescopes as well. There is a disconnect as it were now between astronomers and their observing sites because of the nature of technology and so forth that makes it quite different from the past, still that sense of the relationship between the instrument and place is an important one, especially in nineteenth, twentieth and up to mid-twentieth century astronomy.

TS: What would you say to astronomers today about their work and what/how they should be considering the future heritage of the work they are doing today?

RG: It’s an interesting question and not something I have really thought about. Obviously the telescope sites are significant, at least the earth based ones. It’s also about the type of instrumentation that people use; the telescopes and all the instruments on site, and the off-site instrumentation and imaging technology, as well as the processing that the astronomers may do. But one supercomputer looks like another supercomputer. It doesn’t have the same character as an astrographic plate reader and a human computer from the Astrographic Catalogue era. So how do you capture that? I think perhaps you get more into oral history and programs and so forth and we have other techniques for capturing history and exploring historical significance.

INTERVIEW WITH BILL NEAL ABOUT VICKI NOONAN, MELBOURNE OBSERVATORY

Date of Interview: 23 November 2013

Interviewer: Toner Stevenson, SID: 307199746

Recording: Nil

Transcript: Toner Stevenson

Location: Bill Neal's apartment, Melbourne

TS: Thank-you Bill for agreeing to meet me in your home and for the information you have sent me about your grandmother, Vicki Noonan.

BN: I wanted you to see some of the things I have of hers and particularly the album with autographs and drawings. I remember going to her place as a child, she had these framed cartoons on the wall, and I knew that she worked at Melbourne Observatory. Her grandfather was Patrick Hanna MLA (1819–1890) and her father was John Noonan, and her mother Elizabeth Hanna. Sarah Victoria was born in 1887 and as a child she grew up in a house called 'Leura', which is still standing on 37 Jackson Street, St Kilda. It is substantial. They must have been reasonably well-off. Her father, John Noonan, died in June 1892 when my grandmother was only five years old. So she never really had a father.

(Note from Bill Neal sent later: Patrick Hanna (1819–1890) established his wealth through engineering works, a ferryboat on the Yarra and tolls. He owned a house called 'La Trobe' on William Street.)

TS: Do you know what type of education your grandmother had and what led her to work at the Observatory?

BN: My grandmother and her sisters were educated at the Presentation Convent. She always liked to be called Vicki, but her name was Victoria Sarah. My grandmother and her two sisters went to school at the Presentation Convent in Windsor; it is still there in Dandenong Road. Below is an excerpt I copied from their records some years ago now. The numbers are the enrolment numbers. On the 3rd of February 1896, the three Noonan girls were enrolled. They had previously been at a private school and were enrolled by their mother, Elizabeth Noonan, Lady, Jackson Street St Kilda.

660	Mary	10.10
661	Victoria	8.10
662	Agnes	5.7

TS: Why and how do you think she came to work at Melbourne Observatory?

(BN shows TS an autograph album)
BN: I have an album she used for social events and autographs between 1906 and 1910; this was also during her time at Melbourne Observatory. My grandmother worked at Melbourne Observatory from the 1st of May 1907 and she resigned 14th of April 1909, as described in the 41st and 43rd Reports to the Board of Melbourne Observatory, information provided by Barry Clark. She was 20 when she commenced work at Melbourne Observatory.

The US Navy Fleet on a good will mission came into Melbourne in August 1908 and it must have been a trend to get autographs from the sailors. There are also sketches and short poems and sayings. She seems to have been having a very good time. Her sister, Mary, wrote in the book:

> ‘This world that we're a livin' in
> Is mighty hard to beat
> You get a thorn with every rose
> But ain't the roses sweet’

TS: There are entries in her album by her most regular astrographic partners: Eileen Sheldon and Evelyn V Hockin and Muriel Heagney who started just before she did.

BN: The pages from Eileen Sheldon and Muriel Heagney both have the same date: 28th May 1907 (E Hockin's picture of the cat is undated). She must have made friends quickly because most of these entries by the Melbourne Observatory workers were made not long after she started there.

TS: During her two years of employment, Vicki Noonan was measuring the stars on glass plates and doing logarithmic calculations. She was known as ‘N’ in the Astrographic Catalogue. Do you have any idea of why she worked at the Observatory?

BN: Perhaps she worked at the Observatory in order to earn some money when the family was not doing very well, or in order to support a very active social life. Perhaps it was to be a modern woman and go out to work in an interesting field.

Regarding the line: *love many, trust a few but always paddle your own canoe*; it was written in the book by my grandmother's sister and the idea it expresses appeals to me, which is why I brought it to your attention but can't really say it sums up my grandmother. I can certainly clearly remember her but I was only thirteen when she died. In fact she could not paddle her own canoe. When her husband died in 1939 his estate remained in the hands of trustees and I can remember my mother talking about how frustrating it was to go into the city and get these patronising men to agree to any expenditures. But Thomas Murphy left his family very well provided for; his estate was valued at nearly £50,000 and included twelve real estate properties in Melbourne.

In 1912, after she left the Observatory, Vicki married Thomas Murphy (1866–1939), a doctor many years her senior. They had ten children together, the eldest, Isla Victoria (was born in 1913 and she attended university) was an outstanding army officer and lawyer. The youngest, Enid, was born in 1930, and is my mother. Vicki Noonan died on the 26th of May 1973, aged 86. Two of her children, Alison McInnes and Brendan Murphy, are still living.

APPENDIX 11: PERTH ZONE AC MAGNITUDE SCALES

The page below outlines the determination of magnitude for the Perth zone of the Astrographic Catalogue (Cooke 1912, p. 9). It demonstrates the three scales which were used on this zone and is an example of the eventual lack of consistency in the determination of magnitude for the Melbourne, Perth and Sydney zones of the Astrographic Catalogue.

The Perth Catalogue was mainly measured in Perth, but some sections were measured at the Royal Observatory Edinburgh (ROE). At both locations an alphabetical system was adopted to indicate the magnitude or star brightness. The Perth measurers were instructed to match the magnitude scale used in the Cape Photographic Durchmusterung (CPD). When Turner reviewed the Perth Catalogues (1915), he noted the uniformity of the magnitude scale measurement but advised that the values assigned to the letters needed to be adjusted. This was done for the zones not already started.

When the measurements from ROE returned to Perth for printing, Curlewis noticed a further discrepency in the way the magnitudes were measured, as he described in volume thirty-three:

> "The investigation between the measures of the diameters shows that the Edinburgh measurers had quite a different method of dealing with the star images to that adopted by Perth … the Perth Measurers confined their attention to what may be called the purely umbral portion or black centre of the star image, while the Edinburgh measurers included a considerable part of the penumbral or faint extension of the image."
>
> (Curlewis 1922, p. ii).

The comparison between Perth Observatory's initial magnitude scale (the scale adopted after 1915) and Edinburgh Observatory's magnitude scale are shown by the inserts in the figure below. From 1918, Edinburgh Observatory commenced a program of re-measuring the magnitudes using the Perth method (Sampson 1918, p. 266).

At present the exact value for each letter is not known, but a comparison of a few plates, taken at random, with the C.P.D. gives the following mean relative values:—

A = 8.39 magnitude in C.P.D.
B = 8.67 magnitude in C.P.D.
C = 8.81 magnitude in C.P.D.
D = 9.31 magnitude in C.P.D.
E = 9.65 magnitude in C.P.D.
F = 9.97 magnitude in C.P.D.
G = 10.17 magnitude in C.P.D.
H = 10.25 magnitude in C.P.D.

The limiting magnitude of the C.P.D. is practically 10. There are a few running down to 10.5, but they are scattered between G and M, and are either variable or apparently unreliable. In the scale used at Perth each separate image is distinctly larger or darker than the next below it, and various observers never differ in their estimate by more than the one unit. The gradation is therefore fairly accurate, as it should be from the mode of formation of the images, and it seems legitimate to extend the curve corresponding to the brighter stars down to the lowest limits. A straight line can be drawn which represents fairly well the graph of the magnitudes A to G on the C.P.D. scale, and by extending this to N we obtain the following values:—

Edinburgh Scale

A= 7.7
B = 8.3
C= 8.6
D = 9.1
E = 9.5
F = 9.9
G = 10.1
H = 10.2

A = 8.4 magnitude.
B = 8.7 ,,
C = 9.0 ,,
D = 9.3 ,,
E = 9.6 ,,
F = 9.9 ,,
G = 10.2 ,,
H = 10.4 ,,
J = 10.7 ,,
K = 11.0 ,,
L = 11.3 ,,
M = 11.6 ,,
N = 11.9 ,,

New Perth Scale (from 1916)

A = 8.5
B = 9.0
C = 9.5
D = 10
E = 10.5
F = 11
G = 11.5
H = 12

which are provisionally adopted.

VI.—MEASURES OF POSITION.

Personality of Measures.

Professor Turner's remarks as to the negligibility of personality (Oxford *Astrographic Catalogue* XXVIII) have been accepted as correct, so that beyond a few experiments as a test no notice of it has been taken. The same observer measures any one plate completely, in both the direct and reversed positions; so it is difficult to see how any error can be introduced.

Probable error of the Measures.

A careful operator, using the same kind of instrument, probably has an accidental error of about the same magnitude wherever situated; and a comparison of a number of measures at Perth practically corroborates the results obtained at Oxford. It may be taken for granted then that the probable error of a catalogued measure is $\pm$ 0″·20 or a trifle less.

Figure 87: Perth Astrographic Catalogue, Volume Three (Cooke 1912).

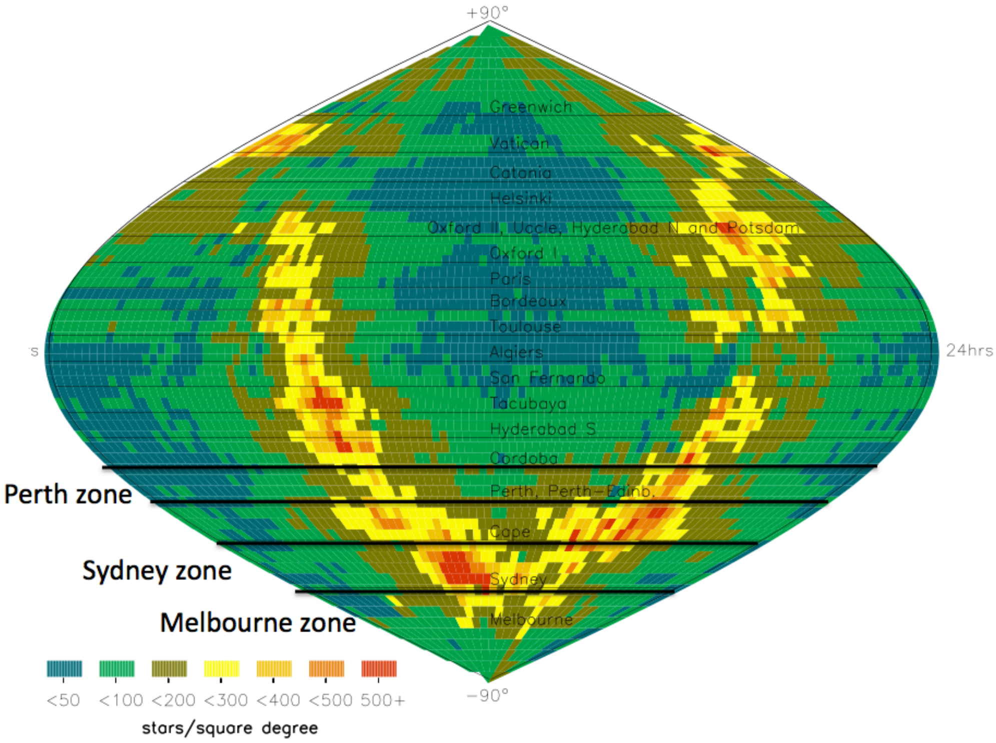
At Sydney Observatory, two different magnitude scale indicators were applied depending on whether Sydney A or Sydney B machines were used, as shown in the list below .

Sydney A	Sydney B
a = 7.5	1 = 8.0
b = 8.0	2 = 8.5
c = 8.5	3 = 9.0
d = 9.0	4 = 9.5
e = 9.5	5 = 10.0
f = 10.0	6 = 10.5
g = 10.5	7 = 11.0
h = 11.0	8 = 11.4
i= 11.5	9 = 11.8
j = 12.0	10 = 12.2

APPENDIX 12: DIAGRAMS ILLUSTRATING RECENT ANALYSIS OF THE AC

The following three charts use as a base the AC2000 and AC2002.2 proper motion charts produced by Sean Urban et al (1998, pp. 1220–1221) of the United States Naval Observatory, using Hipparcos Star Catalogue data. They are made available online at http://ad.usno.navy.mil/ac/.

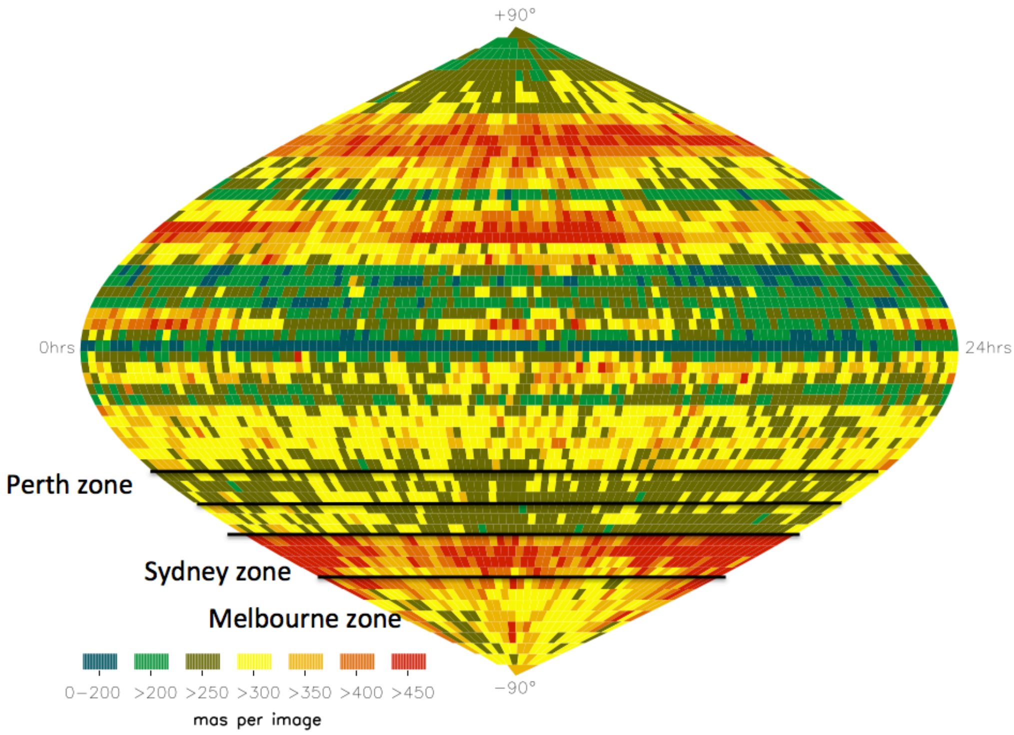
The richest section of the sky: Star distribution per square degree



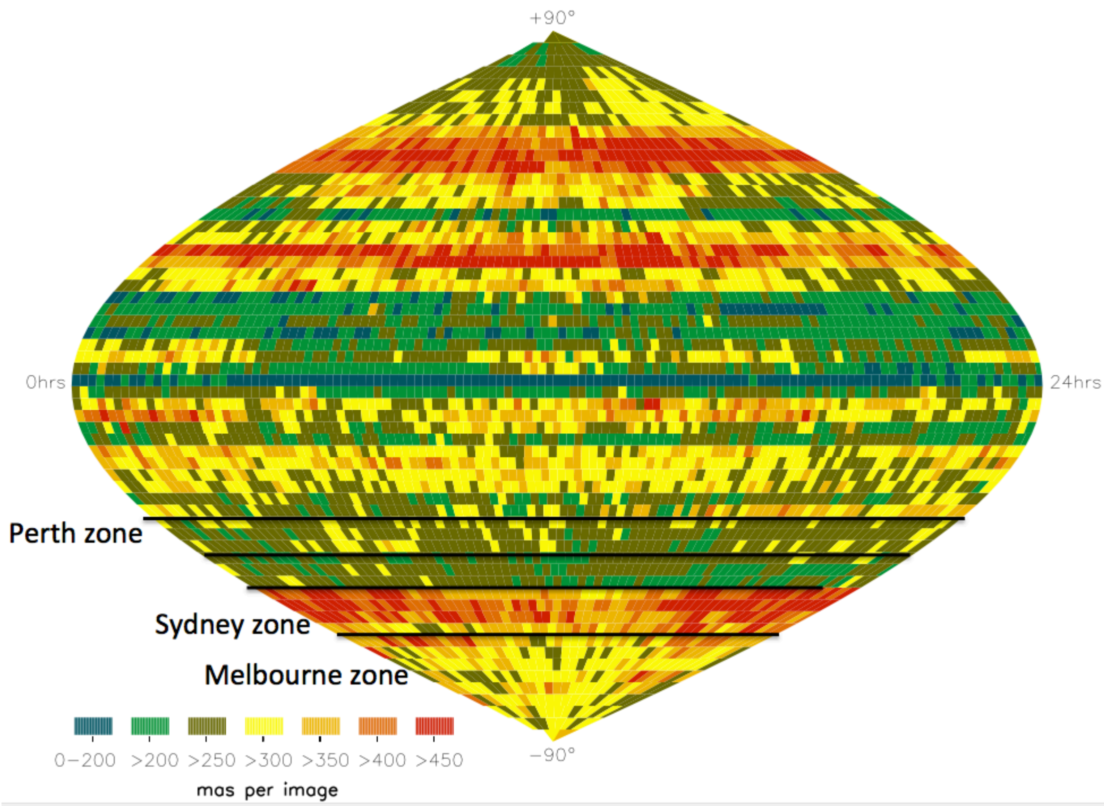
The chart above was produced using the AC2000. This was created from the AC data which was converted into digital form and verified (Urban et al 1998 p. 1220). The x–y co-ordinates were then mathematically reduced. Results indicated that Sydney Observatory had the highest number of sky segments with the highest concentration of stars per square degree, as shown in red and orange.

The following charts were produced when the AC2000 was combined with other star charts to show proper motion in the AC2002 (Urban, Corbin & Wycoff 1997). There were three bands (zones) which included Sydney Observatory, the Vatican and Potsdam Observatory, which were high in errors, as indicated by the red and orange shading.

Standard proper motion errors in right ascension



AC Mean error of declination compared to position on the sky



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Papers of William Christie: papers on overseas observatories (RGO 7/161)

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(RGO 9/606)

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Baracchi to Christie 12 March 1898, RGO 7/161

Ellery to Christie, 16 April, 1892, RGO 7/162.

Ellery to Christie, 5 May, 1892, RGO 7/162.

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Curlewis to Dyson, 17 Sept 1912, RGO 8/95

Dyson to Gill, 12 Oct 1912, RGO 8/95

Gill to Dyson 17 Oct 1912, RGO 7/157

Baillard to Dyson 5 Nov 1912, RGO 8/95

Ross to Dyson 10 Mar 1913, RGO 8/95

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<u>Letters</u>

Lindsay Sharp to Evan Williams, 29 Feb 1984 (Archive MRS 342)

Gareth Roberts to Lindsay Sharp, 20 Feb 1985 (Archive MRS 342)

Letter Harley Wood to Nick Lomb 30 Jan 1984 (Harley Wood Archive, Box 4, viii)

Alan Ventress to Dawn Casey, 17 January 2011 (Records DIR/11/0015)

Documents

'Record of Star Photographs' James Short logbook (uncatalogued)

The Astrographic Catalogue (Harley Wood Archive, Box 2, FVI, f.9)

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Astrograph House, Red Hill 1922, James Short (2005/124/1-7).

Astrograph House, Melbourne Observatory, c1893 (P32549–P11)

Astrograph House, Sydney Observatory, interior view (P3548-798)

Astrograph House, Sydney Observatory, exterior view c1900 (P3548–791).

Astrograph House, Sydney Observatory, construction c1951 (P3549-219).

James Short at Red Hill during the test phase of the site.(2005/124/1-1 (detail)).

Harley Wood using the Melbourne astrograph at Sydney Observatory, 1969 (David Mist Archive 96/44/1-5/5/19/1).

Perth Observatory foundation stone celebrations, 29 Sep 1896. Photograph Clarke and Son, Royal Studios, Perth (P3549-189).

Sydney Observatory, exterior c1968, showing the 1906 extension (P3549-216).

James Short using the Sydney astrograph at Red Hill (uncatalogued).

Ethel Wilcocks and Mary Allen using the measuring machine, Sydney Observatory (P3549-130; 00554923)

Winsome Bellamy and the Hilger measuring machine, c.1954 (00224689).

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Harley Wood using the Melbourne Astrograph, 1958 (P3549-220), Harley Wood Archive, Box 8, xiii (c).

Winsome Bellamy at the launch of Sydney Observatory East Dome, 28 Jan 2015. Photograph Ryan Hernandez (uncatalogued).

Collection Objects

1888 Medal from Centennial Melbourne International Exposition awarded to H. C. Russell (91/221)
Reaseau plate printer, 1895 – 1915, Melbourne or Sydney Observatory (H10373 1:2)
Box of fifteen réseaux by Gautier from Melbourne Observatory (H10270)
Réseaux plate no. 16, 1892, used at Sydney Observatory (H10271)
Reseau plate in case, ordered by Wood for Sydney Observatory, maker Hilger and Watts 1952 (H10272).
Micrometer maker Repsold and Sohne, Hamburg Germany (H10066).
Micrometer 'Sydney A', 1915 (H10139)
Micrometer 'Sydney B', 1919 (H10140)
Box of magnitude scales for comparative use (uncatalogued).
'The Millionaire' Calculating Machine, 1905 – 1915 (K969).
Sydney Zone Glass Plate Negatives: Astrographic Catalogue (uncatalogued)
Sydney Zone Glass Plate Negatives: Carte du Ciel (uncatalogued)
Melbourne Zone Glass Plate Negatives: Astrographic Catalogue (uncatalogued)
Melbourne Zone Glass Plate Negatives: Carte du Ciel (uncatalogued)
Logbooks and papers associated with AC-CdC (uncatalogued)

MAAS records located at Sydney Observatory

Documents

Ida Digby's employment card (uncatalogued).

Publications

Astrographic catalogue, Sydney Zone (MRS 209)
Astrographic catalogue, Melbourne Zone (MRS 209)

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Photograph of (L to R, F to B) Verlie Lee, Renee Day, Margaret Colville, Patricia Lawler, Margaret Brown. Photograph W. Bellamy, 1947 (uncatalogued).
Sydney Observatory Astrographic Bureau (LtoR) Roslyn Logan, Yvonne Donohue, Shirley Wall (front), Winsome Bellamy (back), c1960 (uncatalogued).

Photographs

Photograph Melbourne Observatory star measurer using the 'Repsold' micrometer (MM 059414)

Astrographic reseau testing equipment, Melbourne Observatory (MM 059418)

Astrograph House, Melbourne Observatory, 1969 (MM 059399)

PERTH OBSERVATORY

Photographs

Adelaide Observatory staff c1895 (L to R) Charles Todd, William Ernest Cooke and Mary Emma Greayer, donated B. Minchin (uncatalogued).

Demolition of the old astrograph house, 1964 (uncatalogued).

Collection

'Greenwich' micrometer ordered for Perth Observatory from Troughton and Simms in 1906 (uncatalogued).

Perth Zone Glass Plate Negatives: Astrographic Catalogue

Perth Zone Glass Plate Negatives: Carte du Ciel

Logbooks

Magnitude, computation and double star identification by Prudence Valentine Williams at Perth Observatory for Plate 3365 (uncatalogued)

Library

Astrographic Catalogue Perth Zone

Astrographic Catalogue Perth Zone, measured by ROE

Astrographic Catalogue, Sydney Zone

Astrographic Catalogue, Melbourne Zone

Astrographic Catalogue Oxford Zones (I and II)

Astrographic Catalogue Paris Zone

Astrographic Catalogue, Hydrabad Zones (North and South)

Astrographic Catalogue Toulouse Zone

Astrographic Catalogue Greenwich Zone

Astrographic Catalogue, Vatican Zone

Astrographic Catalogue Catania Zone
Astrographic Catalogue Helsingfors Zone
Astrographic Catalogue, Uccle Zone
Astrographic Catalogue Potsdam Zone
Astrographic Catalogue Algiers Zone
Astrographic Catalogue, San Fernando Zone
Astrographic Catalogue Cordoba Zone
Astrographic Catalogue Cape of Good Hope Zone

PUBLIC RECORDS OFFICE VICTORIA (PROV)
Melbourne Observatory
Letters and Letterbooks (VPRS 866, 867)

Letterbook (Outward) 1898 to Oct 1903 000867/P/0000 vol. 1, Box 73
Letterbook (Outward) Oct 1903 – Nov 1910 (000867/P/0000 vol. 2, Box 73
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Baracchi to Cooke, 7 Oct 1898 (000867/P/000, pp. 73-74)
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Baracchi to Russell 28 Oct 1898 (000867/P/000, pp. 76–77)
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Baracchi to Gill, 5 Dec 1898 (000867/P/0000, pp. 100-105)
Baracchi to Cooke, 5 Dec 1898 (000867/P/0000, pp. 100-105)
Baracchi to Cooke, 16 Jan 1899 (000867/P/0000, pp. 130–137)
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Cooke to Dyson, 18 Feb 1910 (A44.330)
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Sampson to Dyson 16 Aug 1919 (52.447)

Documents

Staff Absence Records (A44.382)
Staff Records (A44.382/ 52.448)

STATE LIBRARY NEW SOUTH WALES (SLNSW)

Chart of Southern Circumpolar Stars made at Sydney Observatory under the direction of H.C. Russell, 1894. Mitchell Library (082-49)

STATE LIBRARY WESTERN AUSTRALIA

Photograph: Perth Observatory, astrograph house in the foreground (008471D)

STATE RECORDS AUTHORITY NEW SOUTH WALES (SRNSW)

Agency A3003, unless otherwise specified.

Note all archives are in boxes and the box numbers are the main identifier.

Letters and Letterbooks

Russell to Mouchez, 25 July 1889 (Box 37A, R20, pp. 12-13)

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Russell to Ellery, 20 Jan 1891 (Box 37A, R20, pp. 112–115)

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