Scholars, Concepts and Discoveries
A 3 x 3 Silhouette

Rede uitgesproken door

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Remembering

Henk van de Hulst

and

Mayo Greenberg

PROLOOG

Mijnheer de Decaan, Familie, Vrienden, Collega's en Bestuurders, Dames en Heren,

Op deze catheder stond ik dertig jaar geleden, mijn vrouw Diane en kinderen van 10 en 6 plus mijn ouders in de voorste rijen. Nu sta ik hier en zie mijn vrouw Renate en twee kinderen van 9 en 7, met schoonouders in diezelfde rijen. In dezelfde toga, *none the worse for wear*, en ik hoor u denken: 'Harry jongen, je bent niet ver gekomen.', maar dat is een misverstand: waar het om gaat is de levensweg,
'Der Weg ist das Ziel' en bovendien zitten de kinderen van toen hier ook, met partners, en schitterende kleinkindertjes op schoot of bij de oppas! Dertig jaar ouder zijn we *allemaal* die vòòr 1971 werden geboren; dus weinig te treuren, veel te vieren, wat mij betreft.

Vanaf mijn geboorte in een gehucht bij een dorp in Westerwolde in 1936 tot 1943 toen ik eindelijk naar school mocht, heb ik mijn moedertaal geleerd en gesproken; dat is een prachtig, subtiel dialect. Mijn hele leven heb ik vooral in mijn tweede en derde taal moeten werken en dat doe ik vandaag ook. Mede omdat er veel collega's/gasten uit andere landen hier zijn, en omdat het Engels de *lingua franca* van de wetenschap is, gebruik ik dat voor mijn *drie bij drie* silhouet, doch Nederlands voor deze proloog en de epiloog.

Nadenkend over dit uur ontdekte ik al gauw dat er duizend verhalen zijn, van heel vaktechnisch tot praatjes bij plaatjes, filosofisch tot autobiografisch. Dertig jaar geleden heb ik afgezien van alle audio-visuele hulpmiddelen. De verleiding voor astronomen, u met prachtige beelden te boeien en eventueel te intimideren, wilde ik ook nu weerstaan.

Autobiografie is een riskant genre, terughoudendheid is geboden. Er blijven echter veel mensen en onderwerpen over die bij de formele afsluiting van een astronomisch professoraat aanlokkelijk zijn. Voor mij is dit niet het einde van mijn werkend leven, ik ben reeds jaren geleden begonnen met activiteiten waarmee ik nu gewoon verder kan. Dit verhaal is dan ook geen afscheid, maar eenvoudig een markering van een tijdstip waar de regelgeving een fase-verandering voorschrijft.

U hebt op een los blad in de symposiumfolder een overzichtje gekregen van de elementen van dat silhouet; u zult vanzelf merken welke hink-stap-sprong route ik kies, er zijn altijd nog meer dan 40 000 mogelijkheden wanneer ik linksboven begin.

And now from my second to my third language. What I wish to do is pay tribute to three great scholars to whom I owe very much; to refer very briefly to three concepts that played a major role during my working life and to describe three discoveries that were made when I was young and that worked wonders in astroscience ever since.

1.1 Herman Dooyeweerd

Philosophy, the love of wisdom and insight turned into theoretical thought, attracted me from an early age. I remember as an eighteen-year-old immigrant boy, in the lunch-break from work in a London Ontario shoe factory, reading Ernst Cassirer's *Philosophy of Man* on a park bench, a secondhand paperback I had bought for 75 cents, understanding little but fascinated by the grand ideas and the intricacy of the arguments.

In the Dutch Calvinist tradition of my family, the wisdom of the Gospels was considered applicable in all of life, including scholarship. Abraham Kuyper, the nineteenth-century theologian, institute builder, politician and statesman was a hero and Amsterdam's Free University philosopher Herman Dooyeweerd perceived to be the most incisive articulator of Kuyper's key concept of sphere sovereignty. I started to study Dooyeweerd's work while enrolled in a Canadian undergraduate math and physics programme; I continued struggling with him while a research student in Martin Ryle's group in Cambridge, but found that Ph.D. ambitions did not leave the time and freedom necessary to grasp Dooyeweerd's comprehensive theory of everything. That had to wait.

The plan for a philosophy postdoc period took hold; it was realized in the academic year '63-'64 by way of a Canadian appointment that began with a year's leave of absence at half salary. That year I ploughed through all of Dooyeweerd's three volume *New Critique of Theoretical Thought*, attended lectures by Dooyeweerd associates and rivals, participated in a seminar led by Dooyeweerd and professor Cees van Peursen from Leiden and became totally involved in philosophical debates. Wonderful intellectual vistas that rivalled Cambridge astronomy's.

Herman Dooyeweerd (* 1894) graduated in Law at the Free University at the age of nineteen and gained his doctorate with a major work on Constitutional Law five years later. After three years of crafting legislation in the Ministry of Labour he became deputy director of the thinktank of one of Kuyper's legacies, the ARP, a political party that right until its merger into today's Christian Democratic Appeal in the 1970s, had an influence out of all proportion to its size (typically 8 to 10 % of parliamentary seats). This influence it owed to the powerful intellectual culture to which Dooyeweerd made a major contribution, between the age of 26 and 32!

In 1926 Dooyeweerd was appointed to a full professorship at his alma mater, with the charge of legal philosophy, Dutch legal history and encyclopedia of law. He held this chair till his seventieth birthday, that is for nearly forty years.

Herman Dooyeweerd had incredible intellectual strength and corresponding physical stamina: he developed an entirely original ontology, a razorsharp epistemology and a rich anthropology, resulting in a three volume opus called *The Philosophy of the Cosmonomic Idea*, as early as 1936. At the same time writing prolifically on legal theory, tackling basic issues such as juridical causality and sources of law in their disciplinary technicalities as well as analysing them historically and philosophically. In addition to his writings of more than 200 books and scholarly papers, Dooyeweerd was an untiring lecturer in four languages, travelling widely in Europe and North America till his death in his 84th year. He was also a community builder in the prime fifty years of his life.

Most impressive about Dooyeweerd are his universal interest, his multidisciplinary competence and his respect for empirical data. I know no philosopher who laboured so hard to understand the essence of all disciplines in the whole spectrum of scholarly endeavours nor one who contributed so fundamentally to their foundations, from theology, history, law and the social sciences to biology, physics and mathematics. The explosion of knowledge after the 1950s has made it impossible in practice for even a genius to be such a *homo universalis* nowadays.

Dooyeweerd was a gentleman of style and refined aesthetic appreciation. He enjoyed intellectual debate and loved to be informed about specific scientific discoveries, always attempting to place them in the structured context where their interfaces have maximum richness. He was abundantly honoured and praised, e.g. by the onetime president of our Royal Academy, the famous jurist Langemeijer of this university, who wrote for Dooyeweerd's seventieth birthday that, while he himself comes from a totally different worldview, Dooyeweerd is the most original philosopher Holland has produced, even Spinoza not excepted. Giorgio Delvecchio, Italian neokantian philosopher of world repute, called Dooyeweerd the most profound, innovative and penetrating philosopher since Kant.
Dooyeweerd's insights have provided more perspectives and tools in my intellectual life than any others.

3.1 Nonthermal Radio Sources

In nature, sources of emission come in many kinds: the most common are warm bodies that radiate according to Planck's law, such as the body next to you or the sun-warmed wall in an English garden. They are sources of infrared and the *radio* emission is incredibly weak. Hot gasses, called plasmas, found for example on the surfaces of stars, radiate because their free electrons suffer from all sorts of agitation, accelerations which cause them to radiate by mechanisms that bear exotic names like Cerenkov radiation and bremsstrahlung and synchrotron radiation. When in the 1930s developments in radio communications and radar defense systems made highly sensitive radio receiver techniques available, it was not long before the Sun was found to be a strong source of radio emission, of radio *interference* as it was perceived mostly.

That there might be a population of *cosmic* sources was not predicted and when in the 1940s a few sources were found that were neither earth- nor sun-bound, but fixed on the celestial sphere, there was immediate excitement and the challenge of locating these sources precisely enough to identify them with something visible and known or knowable.

The first two were found to be located where stars in the Milky Way were known from optical flares, recorded in ancient chronicles, to have exploded as supernovae; but there was another, in the constellation of Cygnus, that found no such counterpart. This source, named Cygnus A, became a challenge for Martin Ryle's team at Cambridge to locate so precisely that among the thousands of stars and galaxies on a deep photograph, it could be identified uniquely with one of them. Graham Smith and associates met this challenge in 1951 and they and David Dewhirst identified Cygnus A with a nondescript faint galaxy, the first galaxy to be detected a radio source! Now you have to know the distance if you are to compute the power of any source from its measured signal. To know the distance of a galaxy you have to measure its recession velocity or redshift with respect to us, from which the distance then follows from the Hubble law which states that the universe expands uniformly so that the velocity of two galaxies with respect to each other is proportional to the distance they are apart. (That was the great leap forward in cosmology in the mid 1920s).Well, the big telescope on Mount Palomar could and did take spectra of Cygnus A and these spectra revealed to Baade and Minkowski a distance for Cygnus A so great that the computed power boggled even astrophysically informed minds.

With this single observation of Cygnus A, radio astronomers became cosmologists and Martin Ryle realised this instantly. The existence of even the one source Cygnus A implied that radio telescopes, with techniques of the mid fifties, could probe back to over half the vast reaches of cosmic time into the ancient past, to compare the *here and now* with the *there and then.* Radio cosmology was born with the identification and redshift measurement of Cygnus A.

The race was on, between Cambridge and teams in Australia, to count as many radio sources as possible as a function of their apparent radio magnitude, to measure their distribution on the sky, ultimately to measure their distribution in space and so to learn their distribution of power and get insight into, on the one hand their population statistics and on the other, their individual astrophysical character. A huge worldwide programme was born which continues to this day and has uncovered incredible phenomena, inspired spectacular theoretical astrophysics and set milestones in observational cosmology.

In 1960 Martin Ryle and his Cavendish team had the early reliable catalogues of radio sources that could be statistically analysed. It turned out that away from the plane of our own Milky Way this collection increased in number with decreasing flux more rapidly than a uniform distribution in space would yield: looking out in space =

looking back in cosmic time, the nonthermal radio source population was more numerous then than it is now. This was a fatal blow to the Steady State Cosmology invented and staunchly defended by two of Ryle's famous Cambridge colleagues Fred Hoyle and Hermann Bondi. I was there when they clashed in the RAS meeting and in the local and national press; I saw the raw emotions which are a far cry from the objective sterility the public often attribute to scientists ...!

In 1961 these objects, of which Cygnus A was the icon, were called *radio galaxies.* They are *nonthermal* radio sources because the distribution of their emission on the wavelength-scale is very different from that of a thermal source obeying Planck's law, with much more energy emitted at long wavelengths for equal intensity in, say, the infrared. This is because the emission comes from highly energetic electrons that have been lashed by swirling magnetized plasmas and whipped to enormous energies. This in turn is possible because the universe is full of local rotational energy: that's why we have planetary discs around stars, spiral galaxies as flat as pancakes, pulsars and stellar jets, massive black holes and accretion discs, jets a million light years long that feed particles into intergalactic space. Such rotational systems amplify seed magnetic fields to greater strengths and when you add some collisions and supersonic chaos, compression waves lash out some more and boost the electrons' energy as well as magnetic field strengths again. These fields in turn force the very energetic electrons into curved trajectories; and classical electromagnetic theory explains that a free electron that is forced to move in a curved path radiates waves whose emission and frequency characteristics depend on the particle's energy and the field's strength. This is the radiation that makes radio galaxies visible for radio telescopes. It is usually called synchrotron radiation.

It is miraculous that around 1960 it became clear that in the universe a whole lot of more or less independent circumstances had conspired to distribute throughout space-time a population detectable for twentieth century technology, at least the stronger fraction and that an improvement of that technology's sensitivity by a factor of 100.000 or so would complete the sweep-up. In the meantime that technological progress *has* been realized and now we see radio galaxies even of very modest strength right back to the kindergarten phase of the universe, the whole zoo of them and we can study the peculiarities of umpteen subtypes throughout cosmic history! That's the privilege of astronomers: imagine sociologists being able to interview housewives over the past twenty thousand years or historians grilling warlords from Babylonian to American empires ...

The pioneering role of radio astronomy in both cosmology and in high energy astrophysics is owed to the fortuitous population parameters of nonthermal radio sources and the achievements of WW II radar electronics ... !

2.1 Modal Structure

Dooyeweerd's ontology is in essence a theory of modal structure and of any individual entity's inevitable temporal functioning in that universal modal structure. Attempting the impossible, let me just give a four-minute glimpse of this best elaborated *theory of everything* that exists.

The population of nonthermal radio sources can be counted; its distribution over the sky mapped; its velocity or redshift distribution can be measured; the energetic processes that are their character can be analysed. We speak here successively of numerical, of spatial, of kinematic and of physical characteristics.

The whole of empirical reality, consisting of things, entities, individuals, subjects and objects, events, processes, contracts and emotions, theories and potatoes, hypotheses and stones, concerts and molecules, anything at all you can indicate with a noun, is subjected to *laws which obtain -wetten die gelden-*. This lawful texture which yields order, reliability, stability, integrity, is itself ordered and subtly structured, as can be learned from careful systematic observation. It can be logically thought of as a universal multilayered complex where one layer is founding the next, where each layer or mode, except the highest or last one, anticipates all the next and where each mode except the first or lowest one has retrocipations to all modes that precede.

These anticipations and retrocipations relate to *analogies* and come back even in our everyday- as well as in scientific language: the impact of an idea, the boundaries of a rule, the depth of an emotion, the growth of the economy, the power of a theater performance are examples of retrocipative expressions; a beautiful ratio, a living-space, a graceful swan, a just transition are anticipatory expressions.[1]
The modes are universal and irreducible, their order is one of increasing complexity and they are aspects of cosmic time *and* aspects of human experience which functions in all modes.

Dooyeweerd distinguishes fifteen modalities: in the foundational order of increasing complexity they are: the numerical or arithmetic, the spatial or geometric, the kinematical, the physical or energetic, the biotic, the psychical, the analytical, the formational, the lingual, the social, the economic, the aesthetic, the juridical, the ethical and the pistical. There are thousands of books and articles written by him and his school, in all disciplines, to analyse some of the rich complexity of an awesome array of subjects, structures and interactions in these terms. Once you penetrate the core of the approach, it

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[1] For example *emotion* is a psychic entity, *depth* is a geometric term: the entity in the higher mode is descibed by a notion from a lower mode by analogy. Similarly *ratio* is a numeric notion and *beautiful* an adjective that comes from the aesthetic mode.

also enables you, in any field, to more clearly structure a research proposal, a lecture course, a monodisciplinary meeting or an interdisciplinary workshop, a projectteam or an international organisation.

In basic physics the theory that is to unify electromagnetic forces, weak forces and strong or nuclear forces is called Grand Unified Theory, GUT for short. The ultimate step beyond GUT is to include gravity as well in what is called the "Theory of Everything". This latter name is a gross misnomer: it would be a physical foundation theory *for* everything but a theory *of* almost nothing. The common name is symptomatic of ultimate reductionism and reflects a positivist arrogance that impoverishes. The Dooyeweerdian theory of irreducible modalities is a true *Theory of Everything* that greatly enriches scientific endeavours and is very helpful in the analysis of i.a. increasingly complex social and legal problems and policy challenges posed by, for example, the need for sustainability.

Dooyeweerd's theory is neither well known nor widely mastered. This is due to its emergence in a religious context that is not widely shared by academics and that raises high barriers of subculture with an almost private terminology and personal attitudes. For me the concept of irreducible modalities is one that has deep meaning and strong operational effectiveness. It is an inheritance from my own Calvinian roots for which I am profoundly grateful.

3.2 Quasars

December 1962. A small conference in New York City at the Institute for Space Studies on Riverside Drive. Happily Martin Ryle had selected me to represent the Group; it enables me to visit my parents and family in Ontario before Christmas, first time since leaving Canada twenty-eight months earlier.

At the meeting, many aspects of the new field: *discrete radio sources* were discussed. Among the papers were those of Jesse Greenstein and of Maarten Schmidt, showing photographs and spectra of stars which were the best guesses for identifications with sources from the Third Cambridge Catalogue. 3C48 and 3C273; strange stars, totally puzzling spectra, they called them *radio stars*. When the book cameout more than a year later, those contributions were not in there. In the meantime Maarten Schmidt had his *Eureka experience*, suddenly saw that the spectrum of 3C273 became familiar if you blueshifted it by 36 000 km/sec. The implications were stunning, even for astrophysicists used to spectacular phenomena.

3C273, a very bright radio source, was redshifted to imply a distance of about 1 500 million lightyears, therewith was suddenly the most powerful object known in the universe, radiating from a region so incredibly compact that its image was that of a star, but an amount of energy per second equal to the power of ten entire Milky Ways or 1000 billion (10^{12}) suns or equivalently, radiating in one second what the sun radiated in over a million years! A new physical state, an entirely outrageous energy abundance, an altogether unheard-of concentration of power was manifestly staring us in the face right from our cosmic back yard ... Soon other identifications followed, spectra which were again and again shown to have huge redshifts, power houses all over the universe, never expected, never predicted, never dreamt of. The era of quasi-stellar radio sources, *quasars* had begun and so 1963 was the year of high energy astrophysics, of physical extremes that dwarfed all energy problems in physics that went before, that excited us extraordinarily: here we had objects intrinsically so bright that they could be detected over the entire immensity of space-time, even if they were near the horizon of the expanding universe.

If the realization of the existence of the extragalactic radio source population was exciting a few years earlier, its emergence was a little slower, although as we saw the identification and spectrum of Cygnus A was a peak event. Quasars sprang onto the scene like a bolt of lightning from a blue sky, it was more stunning even than Cygnus A, although closely related to it.

Not so much later it became clear that quasars were not always *radio* sources, more often than not a quasistellar object with the enormous optical power already seen in 3C273 and 3C48 had radio emission hundreds or even tens of thousands of times weaker than theirs. More likely the optical power was associated with X-ray emission. The real fire is X-ray and ultraviolet, the radio emission is but the smoke. But here as often elsewhere, the smoke led to the discovery of the fire.

Ever since 1962 quasars have been at centre stage in high energy astrophysics. Great efforts have been made to map their phenomenology in all wavelength domains, theoreticians find permanent employment in attempting to understand more and more of their physics. Only much later did it become clear that radio galaxies such as Cygnus A and the quasars have a common physical origin and their difference in appearance depends in part on their orientation. We have now an impressive range of arguments to undergird the hypothesis that every radio galaxy and quasar is a galaxy of stars that in its centre harbours a massive black hole, from a few million to several billions of solar masses. This monstrous mass concentration may hide, unseen from earth for eons, then flare with infernal intensity because matter, gas or even a whole hapless star (that was pulled off course by a chance encounter at a great distance a hundred million years earlier) is torn into its irresistable gravitational well, fiercely radiating as its demise is excecuted.

Quasars, weird and wonderful, subject to fierce controversies at astronomy conferences and cosmology workshops for decades, they have marked the scene of our work now for nearly forty years and they continue to serve as probes of physics extremes, as actors in wild scenarios, as stars forever imaged by astronomy paparazzi...whether they work in NASA or ESA, with Westerbork, the VLA or the EVN, at Palomar, Kitt Peak, La Palma, La Silla, Mauna Kea or Paranal. Jan Oort said once to me around 1970: " ... de sterrekunde was wel wat saai vòòr de jaren vijftig ..."/ " ... astronomy was kind of dull before the fifties ..."

2.2 Earth Rotation Aperture Synthesis (ERAS)

A landscape painter has more time than a portrait painter than a sport photographer. In astronomy most regions and objects to be imaged do not change in a week, in fact most do not change in an astronomer's lifetime.

When we image a scene, in our eye, with binoculars of with a radio telescope, the sharpness of the image is proportional to the diameter of the imaging element, lens or dish, divided by the wavelength: big dish, short wavelength, sharp image. In optical astronomy before the Hubble Telescope this was not so important: the turbulence in the atmosphere determined the image quality, which was always worse than the optics quality and lens size could achieve. In radio astronomy, where the wavelength is typically 100.000 times longer than in optical astronomy, this so-called diffraction limit is always the image sharpness limitation. You need a very big telescope, operating at the shortest radio wavelength you can manage.

These are of course two requirements that run counter to both engineering capabilities and economy. Short wavelenths can only be used if the reflecting surface is much smoother than that wavelength: smoothness costs engineering effort which costs money; it is the more difficult and expensive the larger the dish. The image sharpness of a 25m parabolic dish at a wavelength of thirty cm is about the diameter of sun or moon: a pretty fuzzy image for most purposes. For Jan Oort, who wanted to map the Milky Way using the 21cm line of neutral hydrogen, it was a good start and so the 25m Dwingeloo telescope proceeded with its pioneering work in 1956. For Martin Ryle, who wanted to resolve radio sources one from another or map the remnants of supernovae, he needed sharpness ten to one hundred times better and soon.

For spatial resolution purposes radio interferometry techniques were developed from the start of the post-war period. This development passed an important milestone when Ryle and Neville in 1961 used segments of an East-West cylindrical paraboloid near Cambridge to map a region centred on the North Pole; the next milestone was the completion of the Cambridge One Mile Telescope in 1962; then the opening of the Westerbork Synthesis Radio Telescope in June 1970 and the opening of the Very Large Array in New Mexico in October 1980. All these instruments were based on Earth Rotation Aperture Synthesis, a concept that was at the core of Ryle's instrumen-

tal effort and for which he received the Nobel Prize in physics in 1974.
Aperture Synthesis images little by little what the complete aperture, which you are unable to build for engineering and/or for budget reasons, would achieve all at once. It is possible because over the observing period taken, the object imaged does not change

What is the essence of the concept?
Without algebra to write or geometry to draw, I have to sketch in words.
The radiation from a very distant point source is seen by two detectors placed some distance apart at right angles to the line towards the source, as a plane wave. If the signal is detected at both and multiplied, there is constructive interference but when the source is off-axis the interference differs and at a certain angle is destructive. Thus you get a pattern of peaks and troughs, with amplitude and phase, called diffraction pattern, that can be written as a complex function and that depends on the point source's angular distance from the system axis. If you have two point sources the pattern becomes more complicated. If you move the detectors by rotation you get a different pattern, if you change their mutual distance you also change the pattern.

If the wavefront's statistical character is stable, i.e. the source does not change during the observing period, you do not need detectors all over the receiving area, or aperture, you can move two or more from one location to another, record the signals' products and combine them afterwards. Moreover, if you do not look at just one or two point sources but at any number of them, (and that is a good approximation of a continuous spatial distribution of brightness), then the very complex pattern of all the measurements plausibly contains all the information you would have had if you had seen the whole scene all at once.

An analogy: if I give you a puzzle of 1000 pieces and you work on it hard enough and complete it, the picture that emerges is very close to the whole picture on the front of the box (only the pieces' boundaries and a few missing ones spoil the perfection).

Moving devices of steel and aluminium with cables and electronics about is hard. But if you have enough elements in a line or several lines and you interconnect them in pairs, all possible ones or all uniquely distant ones and then look at the sky, the line between any two elements rotates w.r.t. the sky and goes through all orientations in twelve hours due to the earth rotation. So if you have twelve hours of patience and the capacity to store all signals recorded over the period, you have the information you would have had if the entire area projected by all pairs' elements on the rotating sky had been filled with appropriate detecting surface. I here skip the practical but solvable issue of delay lines to equalise radiation pathlengths during the rotation.

If now you also have the ability to calculate what you would have seen, by correctly calibrating and combining all the signals, then you can build the desired image, you have synthesized a large aperture using small elements and rather than move them all over the place you have used the rotation of the earth to which the elements are fixed. Earth Rotation Aperture Syntheses, thought of by several people in interaction in Australia and in England in the early fifties, was first successfully applied in the Cambridge group in 1957, perfected in the following five years or so by Martin Ryle and his team. (In the early sixties the computing power per unit cost was more than a million times less than it is today and in Cambridge only barely enough for ERAS to begin!)

It is this concept that gave radio astronomy its tremendous power and attraction: man wants images, images that are sharp, that are deep or sensitive, that show contrast or dynamic range. So in spite of the fact that the same law for sharpness applies to all imaging systems using electromagnetic radiation, to wit: two features can be distinguished if their separation is at least the wavelength divided by the diameter (in appropriate units) and radio astronomy has the tremendous handicap that its wavelenths are 100 000 times longer than those in optical astronomy, ERAS overcame the handicap, more: beat every other kind of astronomy, infrared, optical, ultraviolet, X-ray, in image sharpness or angular resolution. Radio astronomers built synthesis telescopes, incredibly thinned out but ultimately as big as the earth. That was the limit for some years, but then we put elements in space and overcame that too: we want to image all sorts of phenomena, especially to see the environments of the monstrous black holes in active galaxy nuclei even if that requires apertures the size of the earth-moon distance!

Nowadays ERAS is beginning to be applied in infrared and optical astronomy too and eventually their images will outrun the sharpness of radio astronomy's. But that's another story unfolding now and over the years to come.

1.2 Martin Ryle

When at the end of August 1960 I arrived in Cambridge, I had a Commonwealth Fellowship (first cohort of the programme) that said no more than that I was to do research in Mathematical Physics at Cambridge University. I took this to mean I could choose my own supervisor and subject. How to go about it? I got a list of all professors in the Cavendish Laboratory and in the Department of Applied Mathematics and Theoretical Physics. Speaking to a few research students and junior fellows at my College (Pembroke), I made a short list of some dozen eminent names and went about making appointments with somewhat sceptical secretaries. A Canadian lad with a strange Dutch name and his own money, looking for a thesis to do...

In two weeks' time I spoke to many interesting people, among others Mott and Polkinghorne, Batchelor and Sciama, Budden and Frisch, young Pippard and, yes, Martin Ryle. The radio astronomer Martin Ryle was last on my list. I had promised myself to make no decision before seeing everyone, so on a Friday afternoon I knocked on the secretary's door, strode in and said to the lady: " I'm here to see dr Ryle" to which Molly responded promptly "Profèssor Ryle if you please". Not a good start, I thought as I was ushered into a large low ceiling office with a huge tilted drafting table, piles of papers and a tall lean man who greeted me with a grin on his face and a very direct request: "Hello, tell me about yourself, what do you want to do?" It was soon clear that I knew what I wanted in general (an interesting Ph.D. problem) but had no idea what I wanted in particular (I admitted sheepishly that I knew nothing of radio astronomy except the term ...) "OK, we can change that. Look here, there are these enormous radio arcs on the sky, we think they are the remnants of supernovae you see, but we don't understand them, why they exist and why they radiate the way they do. You could work on them, they are a big challenge, come on, what do you say?" Professor Ryle was agitated, his eyes glowed, he looked at once impatient and very fond of these arcs on the large sheets with hand drawn contour maps. All his body language shouted about the importance of the problem, the fun we could have in solving it, the things we would show the world about these marvelous radio rings in the sky.
I promised I would decide in the weekend and drop by on Monday next. I was out on Free School Lane and onto Silver Street in twenty minutes and already I knew: "I'm going to work with Ryle. He loves what he does and he is prepared to share what he knows and what he enjoys..." On Monday I became a member of the Mullard Radio Astronomy Group, got a desk, was told where the so-called Philosophical Library was and went to work there, learning what was known about supernovae and their remnants. That week I walked by a dozen secretariats to tell: I am working with Professor Ryle, thank you.

Martin Ryle (* 1918) graduated in Oxford in physics with a First in 1939 and immediately joined J.A. Ratcliffe, the famous ionospheric physicist in Cambridge; he helped set up the university amateur radio station. In May 1940 the young Ryle joined the Air Ministry Research Establishment and began a five year period of intense development work in radar countermeasures. The Biographical Memoir of the Royal Society for Martin Ryle, written by Professor Graham Smith, documents the formidable achievements of the young Ryle and his group, achievements that played substantial, perhaps vital roles, e.g. in stopping precision V-2 bombardments of Britain and in deceiving Hitler's high command about the location of the great invasion, delaying the responses that could have jeopardised D-day. These achievements emerged in anxious circumstances and under tremendous pressure. When Ryle returned to Cambridge in 1945, not yet 27 years of age, he had made greater contributions to the common cause and endured more stress than most professional people do in a lifetime.

Ryle was a doer, with an acute sense of purpose and an extraordinary talent of grasping physical principles and turning them into instrumental practice. From 1946 onwards he worked with his team but also with his own bare hands at developing all aspects of radio interferometry. You could see him at the drawing board in his office and also with a soldering iron at the Lord's Bridge Radio Observatory. During our Saturday morning literature review sessions, obligatory for all research students, you felt Martin's tremendous interest in the study of radio sources and especially his passion for cosmology. The group already in the early sixties had a reputation of being anything but open towards the world outside: when prominent visitors, especially Americans, were coming to visit, Martin would say 'they have more money for a new canteen this year than we do for instrumentation..! So no need to tell all if they don't ask the right questions.' and we understood.

Inside, the group was completely open and very interactive. Martin Ryle's enthusiasm, his flashing temper, his outbursts (matched by sheepish apologies when they were seen to have been misdirected or clearly unfair), all this made for an exciting environment where new ideas were continually launched, immediately shot at and the few survivors followed up. The 1974 NOBEL prize in physics, for the development of aperture synthesis in radio astronomy, was the crowning acknowledgement for Ryle's combination of ingenuity and hard labour.

Martin Ryle had no easy life. He so identified with his work that critique was sensed as personal criticism and rivals perceived as abrasive competitors. At the same time he could be marvelously gentle and humourously ironic when at ease with his own people. It was an exceptional privilege to land in his group, become one of his junior associates and experience the ambition to be the best, the drive for ever deeper results and the pleasure of achieving tough goals. Martin Ryle died too young, in his sixty-sixth year. His candle always burnt at both ends, his soul was increasingly burdened by worries for mankind and this stress undermined his health. His legacy lives on in astronomy world-wide and in the Cavendish Laboratory, home to his famous group.

3.3 Cosmic Microwave Background (CMB)

In pre-Einsteinian physics there is an ether to mediate radiation propagation, there is an absoluteness to time, therefore a notion of what is simultaneous; there is no doubt about the meaning of size or scale. Special relativity swept this all aside and elegantly made the world fuzzy, pleasing to some, very disturbing if not irritating to others.

The 3 degree background radiation is one of the greatest discoveries of all time, no doubt it is the most important advance in observational cosmology since in the mid-twenties the expansion of the universe dawned on Hubble, an advance *cosmologically* more significant even than the discovery of the extragalactic radio source populations and than the discovery of quasars.

When Arno Penzias showed me around at their Bell Labs site in Murray Hill, New Jersey and explained where the pidgeon shit had masked the reality of the effect he and Robert Wilson had found in 1965: a persistent excess noise in their experimental communications receiver, I realized that here as in the Cambridge discovery of pulsars in1967, experimenters of integrity and persistence had been rewarded by nature first. The pulsar discovery was awarded the prize in physics by the NOBEL Committee in1974, the CMB discovery in 1978.

The experimental result would not so easily have gained recognition (since Thomas Kuhn we better understand the broad resistance to paradigm change) were it not for a theoretical prediction by George Gamow in 1948 that there ought to be a measurable microwave remnant of the radiation-dominated phase after the Big Bang and that due to multiple scattering prior to the lifting of the cosmic fog when the universe became transparent at age only 400 000 years, it should have a Planck spectrum. Also the proximity to Princeton and the corroborating work done there by Robert Dicke and his team was an important factor in favour of nearly instant acceptance in the physics and astronomy communities. Hundreds of measurements in the past 35 years have amply confirmed Gamow's expectations.

(By the way, the CMB discovery following the prediction by Gamow ranks with the 21cm-line of neutral hydrogen discovery following the prediction by Van de Hulst here in Leiden, as rare events where important findings are made *after* they are foretold on theoretical grounds: in most astronomy progress we use new techniques and technological advances and with instruments incorporating them, look around to find wonderful treasures, *like children wandering about Santa Claus' warehouse!!*)

The way I think of the microwave background radiation is as a kind of post-Einsteinian ether. The radiation has a perfect Planckian spectrum, so it provides a concept of simultaneity (two observers are coeval if they measure the same background radiation), yields a length standard (the wavelength of the peak), is a universal thermometer and defines a kind of reference frame for absolute motion that can be measured.

As if all that were not enough, the microwave background radiation promises to yield in the next decade or two, answers to vital but previously unanswerable cosmological questions. Already we know from background measurements over large areas of sky that the universe is homogeneous and isotropic. The smoothness of the radiation rivals that of the best billiard balls, it is one part in one hundred thousand. The departures from perfect smoothness contain all sorts of information about the very early universe and it is the challenge of the current breed of instrument designers/builders to map these departures as a function of angular scale on the sky and of wavelength. Various telescopes in the infrared and sub-mm domains will be launched by balloons and by rockets and space shuttles into orbit to perform these measurements, an experimental ambition beyond Penzia's and Wilson's wildest dreams after their amazing find in 1965.

The 3 degree background radiation has been a discovery of profound influence on observational cosmology as well as on our perception of the world. No greater contrast is conceivable than the one between the ultimate violence of the Big Bang and the most gentle rustle of the radiation it left for us and all of physical reality to bathe in. An altogether gentle outcome of an incomprehensible beginning.

2.3 Inflation; $\Omega \sim 1$

Cosmology, the discipline that deals with the universe at large, is an interest of the majority of astronomers, even though most of us do not master the intricacies of the physical arguments and the mathematical formulations. To contribute in some way to the methods or data of this trade gives great satisfaction.

The theory later known as Big Bang received its foundations with Einstein's General Relativity and was well developed in the 1920s. The discovery of the Hubble expansion gave it an empirical footing, the discovery of the extragalactic radio source population demonstrated the reality of cosmic evolution, the discovery and mapping of the CMB emboldened theorists to plunge back into the distant past before the first second was fulfilled and helium could begin to be cooked.

The Standard Model of cosmology has been very successful in standing up to many critical tests and surviving great scepticism to downright philosophical derision. By the early 1980s, radio galaxy and quasar populations were well counted and their space-time distributions calculated, as well as the CMB's rippling departures from smoothness measured to be about one part in 100 000. This does not mean there were no big question marks left.

On the contrary, these facts made older questions more pressing. Why is the universe so homogeneous on the large scale (while it is so lumpy from scales down from ~ 1% of the Hubble radius in the form of great supercluster sheets, then a whole range of clusters of galaxies, individual galaxies, spiral arms and stellar clusters, molecular clouds, dust sacks, interstellar matter, supernova remnants, supermassive black holes and their discs, red giant stars, sunlike stars, white dwarfs, neutron stars to Jovian planets, earthlike planets and stellar mass black holes)?

Why is the universe so isotropic, so you see exactly the same CMB, exactly the same source counts in totally different directions? The standard BB theory does not answer these questions, nor does it foretell that the expansion velocity is to be such that the universe seems flat, that is it neither accelerates nor decelerates, which implies totally puzzling finetuning between gravitation and kinetic energy long before the first second of time ended.

It turns out that the ultra high energy physics which rules prior to one second is preferably discussed on a logarithmic timescale that to base ten goes from at least –44 to 0 after which helium started to form from hydrogen, to +13 when matter and radiation decoupled, that is the fog lifted and the universe became transparent, to +17.3 which is now. On this scale the time before one second is much greater than the time since, for there are many more power of ten intervals to be considered.

This is not the place nor am I the person to discuss these issues: one must master a field to popularise it! But it was a grand concept, called cosmic inflation, that sprang onto the stage of the cosmology theater in 1981 with the American physicist Alan Guth, was refined by Russian Andrei Linde and American Paul Steinberg in the next couple of years and every since has held theoretical physicists *and* cosmologists spellbound.

Cosmic inflation is the plausible outcome of the conjecture that from about - 38 till about -30, the microscopic universe, thanks to the energy release of a phase change, was by an overwhelming acceleration of the universal expansion inflated, which homogenized all and balanced kinetic and gravitational energy to an inordinate precision. This concept gives a ground for many of the states just mentioned and does away with the seeming flukes and arbitrariness that are such unsatisfactory loose ends of the Standard Theory.

The Inflation concept makes predictions about the wavelength-dependence in the fine spatial structure of the CMB and it leads us to expect gravitational wave phenomena that are testable. So the concept, although it plays in a domain that is tens of orders of magnitude beyond scrutiny in man's accelerators, is not purely metaphysical because it makes predictions which inventive observational astronomers can conceivably measure. In fact, instruments are now on the drawing boards and even on the NASA and ESA testbeds, which can bring Inflation into the test range. Until we experience the contrary it is satisfying to have this concept as an undergirding of the Standard Model.

Jan Oort believed in $\Omega = 1$ exactly, although the observations said only that Ω is near unity within a factor of five or so. With Inflation at work this belief would be vindicated. A most articulate account about the role the Inflation concept plays in the perspective we have about the totality of the universe and our emergence in it, you find in the marvelous book called *Just Six Numbers*, published by Martin Rees two years ago.

1.3 Jan Hendrik OORT

About Professor Jan Hendrik Oort a great deal is known, especially in Leiden. Last year we celebrated the 100th date of his birth in 1900. (That's an easy birthyear, age goes with the calendar) and the University Library staged an exhibit on his life and work. My own life and work have been greatly influenced by Jan Oort, although I only met him for the first time in 1962, at a Herstmonceux Conference in the south of England.

In 1967 I had three job offers in Holland, left Canada and chose Leiden for Oort. I wanted to see for myself how Oort did things. I soon enough realised that he was inimitable but also that one could learn from him all the time. Today I do not wish to repeat what I have written about Oort, for example in a chapter *Meritus Emeritus* in the Liber Amicorum *Oort and the Universe* for his eightieth birthday and in an *In Memoriam* in the ESO Quarterly *The Messenger* of December 1992. What Oort achieved is unique and so splendid in quality and immense in quantity that it defies the imagination. The book I just mentioned as well as that by Jeanette Katgert-Merkelijn *The Letters and Papers of Jan Hendrik Oort* (1997) testify to and partly document these achievements. So do some *fifteen* independent obituary articles that appeared in astronomical publications after his death in 1992.

If Herman Dooyeweerd was fascinated by meaningful structure to be philosophically grasped and Martin Ryle was motivated by cosmological populations to be instrumentally resolved, then Jan Oort was propelled by a hunger for astronomical phenomena to be dynamically understood. I have met no other astronomer so boundlessly curious for anything any telescope might reveal! This hunger explains several features of his attitudes in research and his unashamed switching of viewpoints with new data.

Astronomical facilities are expensive and usually they are financed by public means. It is therefore natural for astronomers to worry that data gathered with expensive telescopes lie unprocessed in drawers or on tapes and computer disks. That would seem a waste, also of taxpayers' money. Well, Oort never seemed to have such worries: although not saying this very explicitly –maybe he felt a taboo is left well enough alone- by his behaviour it was clear to me what he thought: the real scarce item is creative capacity of astronomers, not quantities of data. Therefore an astronomer must always work on the very best data available or on systems enabling better data to be acquired; never waste time on data that are not the best to be had, let them gather dust!

An analogous lesson to be learned from Oort: you can spend as much time and energy on a minor problem as you can on a truly important one; therefore finding the issue deserving of your time, defining the problem to get your teeth into, that is of prime importance. It is the imperative for Ph. D. supervisors in the first few weeks of a new research student's time: find a problem that is of major substance and, in Russian astrophysicist Ginzburg's expression 'difficult but possible ...' After that, good students are self-propelled and learn far more from peers than from supervisors (to whom they can often only speak in quiet if they drive them to the airport ...).

His insatiable hunger for more data, greater vistas, deeper probes, sharper images, better spectra was sufficient for Oort to spend an incredible amount of energy on building instruments, building institutes, building alliances. He was kind, seemingly gentle to the point of shyness, but he was tenacious, persistent, unrelenting when it came to acquiring money for telescopes, governments' commitments for a European observatory, community support for a particular satellite. Jan's language gifts, his diplomatic skills, Mieke Oort's charming hospitality, all were brought to bear when it might advance the cause and course of astronomy.

I spoke of books and articles about Professor Oort and not wanting to repeat them. But poetry wants repeating. I will, to end, recall what the Oort family chose from Loren Eiseley's *Immense Journey* to announce his departure: it also expresses what an Amsterdam philosopher recently termed the tragic element in any ambitious human life:

"Down how many roads among the stars must man propel himself in search of the final secret! The journey is difficult, immense, at times impossible, yet that will not deter some of us from attempting it ...; we will travel as far as we can, but we cannot in one lifetime see all we would like to see or learn all that we hunger to know".

That silhouette you might read over once, in your own sequence ...
Dat silhouet kunt u wellicht nog eens nalezen, in uw eigen volgorde ...

EPILOOG

"Jij bent een geluksvogel" zegt mijn oudste zus nu en dan, en dat is ook zo, uit zich in kleinigheden zoals twintig jaar werken in Leiden en op 3 october geboren zijn. Dan in 1988 naar Duitsland verhuizen, het duurt even en het jaar daarop wordt een nationale feestdag verordoneerd, en wat wordt de datum ...? Juist. Altijd feest.

De mensen met wie ik werkte, ik besprak er drie, maar ik bofte met nog heel veel meer. Mijn promovendi, stuk voor stuk knappe jongelui die spoedig meer wisten over hun onderwerp dan ik en die mij bij de les hielden, geweldig. Collega's en medewerkers, hier op de Sterrewacht, te Dwingeloo en Westerbork, op La Palma en Mauna Kea, in München en Santiago, op La Silla en Paranal, op het Sterrenkundig Instituut te Utrecht, heel veel enthousiaste, begaafde mensen. (OK, ook een aantal ontzettende lastposten, maar die horen erbij ...). De Koninklijke Akademie, waar ik reeds meer dan twintig jaar van andere leden, veel vrienden, leer, over alles.

Dan de overheden, ministers, bestuurders, en ambtenaren. Bij ZWO/NWO kreeg ik altijd gehoor en heel veel steun. Dat gold in mijn ESO tijd ook voor vele ministeries overal in Europa. Ik heb heel veel gevraagd en erg veel gekregen. In die zin was ik een dure jongen. Maar dat geld heeft ook fantastische expedities opgeleverd en we hebben de gewone mensen die het opbrachten er alles over verteld; stel je voor, ontdekkingen bìnnen het wetenschapskringetje houden, nìet doorgeven, dòòdzonde!

De laatste negen jaar waren anders, ik werkte met een dozijn teams aan even zovele problemen of thema's, de meeste zeer aards. Meestal mocht ik die teams zelf samenstellen en leiden. Ik heb er enorm van genoten, die verscheidenheid aan mensen en velden. Dat die rapporten vaak echt gebruikt worden, vertaald en ook elders benut, dat geeft voldoening. Wij gaan daar mee door.

Gisteren en vandaag waren heel bijzonder, vrienden uit de hele wereld verzorgden meer dan twintig sprankelende voordrachten over bijna alles waarmee ik bezig was en ben. Ik dank hen van harte, evenals de Leidse vrienden die dit symposium organiseerden en de organisaties die e.e.a. betaalden.

Als ik namen zou noemen van allen die mijn professorale periode hebben verrijkt, is het einde weg. Ik noem er toch drie.

Wim Brouw. Wim heeft in een jaar of tien vanaf 1966 het onmogelijke gepresteerd en met anderen maar toch als de uniek onmisbare, de programmatuur ontwikkeld die de Westerbork telescoop echt bruikbaar maakte. Zonder Wims onvoorstelbare gaven èn zijn onbaatzuchtige inzet was dit instrument nooit het prachtige vehicle voor wereldklasse research geworden dat allerwegen is erkend.

George Miley, briljant onderzoeker, medewerker sinds 1971, mijn opvolger in 1987, beminnelijk mens en begaafd leider. George, in niemands handen had ik de Sterrewacht beter kunnen achterlaten!

Niek de Kort, astronoom in hart en nieren, ondernemer en adviseur, analist en schrijver. Met Niek als de spil bouwden wij een TELEAC cursus die moderne astronomie bij een kwart miljoen mensen bracht en de studenten-instroom structureel op een hoger peil. Niek en ik deden omstreeks twintig jaar later nog drie grote projecten, over ruimtetechnologie en milieu, over ruimtevaart en wetenschap, over remote sensing en geo-informatie infrastructuur. Niek, jouw onovertroffen productiviteit en je talent, bergen documentatie na enige uren brainstormen tot een coherente tekst te destilleren, daar bof ik mee. We zijn nog niet klaar!

Ik wil speciaal mijn collega's te Utrecht danken dat zij mij sinds voorjaar 1993 een wetenschappelijk *pied à terre* hebben gegund.

De Rector van de Universiteit Leiden en de Decaan van de Faculteit der Wiskunde en Natuurwetenschappen dank ik voor hun welwillendheid mijn professoraat, dat hier reeds jaren passief is, in Leiden te mogen afsluiten.

Ik heb gezegd.

Note: I considered adding an extensive reference list here, but decided against this convention. With the wonderful resources of the Internet, all possibly desired information is accessible with a few clicks of the mouse. The modern search engines are fast and comprehensive. Just type in any name or any word or phrase and the experience will be more rewarding than a trip (in practice oft not undertaken ...) to the library.

Some search engines:

www.altavista.com

www.HotBot.com

www.NorthernLight.com

www.google.com

www.AllTheWeb.com

Annex 1

PROLOGUE

Dean, Family, Friends, Colleagues and Boardmembers, Ladies and Gentlemen,

Here I stood 30 years ago, my wife Diane and children of 10 and 6 plus my parents in the front rows. Now I stand here and see my wife Renate and two children of 9 and 7 with parents-in-law in these same front rows. In the same gown, *non the worse for wear,* and I hear you thinking "Harry my boy, you haven't come very far ..." But that is a misunderstanding: what counts is the *route of life*, 'der Weg ist das Ziel' and moreover the children of that time are here also, with partners and beautiful grandchildren on the lap or with the babysitter! *All of us* born before 1971 are 30 years older; little to regret, much to celebrate, as far as I am concerned.

From my birth in a hamlet near a village in Westerwolde in 1936, until 1943 when finally I could enter school, I learnt and spoke my mothertongue; that is a beautiful, subtle dialect: my whole life I worked in my second and third language as I do today. Also because there are many colleagues and guests from other lands here today and because English is the *lingua franca* of scholarship, I use that for my 3 x 3 silhouette. For this Prologue and the Epilogue it is Dutch.

Reflecting upon this hour I soon discovered there are a thousand stories from very technical to comments with images, philosophical to autobiographical. 30 years ago I decided to forego all audio-visual aids. The temptation for astronomers to captivate you with beautiful images or even to intimidate you, I will also now resist.

Autobiography is a risky genre and reticence is advised. However, there remain many people and subjects attractive at the formal completion of an astronomical professorship. This is not the end of my working life, already years ago I started with activities which now simply continue. This story is not a farewell but rather the marking of an instant where the rules prescribe a phase-change.

On a loose leaf in the symposium folder you received an overview of that silhouette; as we go along you will note which hop, step and jump route I choose for there are still more than 40.000 options when I begin in the upper left corner.

And now from my second to my third language. What I wish to do is pay tribute to three great scholars to whom I owe very much; to refer very briefly to three concepts that played a major role during my working life and to describe three discoveries that were made when I was young and that worked wonders in astroscience ever since.

Annex 2

EPILOGUE

"You are a lucky so-and-so" my elder sister says now and then and that is true; it is manifest in small things such as working in Leiden for 20 years and being born on 3 October, then move to Germany in 1988, it takes a while and the next year a national day is decreed and what is the date ...? Right, always a party!

The people with whom I worked, I discussed three of them but I was fortunate with many more. My PhD-students, clever young people each one, who soon knew more about their subject than I and who kept me on my toes, wonderful. Colleagues and co-workers here at Leiden Observatory and Dwingeloo and Westerbork, on La Palma and Mauna Kea, in München and Santiago, on La Silla and Paranal, at the Astronomy Institute at Utrecht, many very enthusiastic talented people (O.K., also a number of pains-in-the-neck, but they are part of any story ...).

The Royal Academy, where for more than 20 years I learnt, about everything, from other members, many friends.

The Governments, ministers, administrators and civil servants. At ZWO/NWO I always met a willing ear and received a great deal of support. That also goes in my ESO time for many ministries all over Europe. I asked a lot and received very much. In that sense I was an expensive lad. But all that money resulted in phantastic expeditions and we told the ordinary people who paid for it all about it; just imagine, keeping discoveries within the science circle, not sharing, a downright shame!

The last nine years were different. I worked with a dozen teams on as many problems or themes, most of them very earthy. Usually, I could compose those teams myself and lead them. I have enjoyed this enormously, the variety of people and fields. That these reports are often really used, translated and also consulted elsewhere, is satisfying. We will continue.

Yesterday and today were very special, friends from all over the world delivered more than twenty sparkling lectures about nearly everything with which I was and am occupied. I thank them heartily, as well as the Leiden friends who organized this Sypmosium and the organizations that paid for it.

If I were to name all who enriched my professorial period, there is no end in sight. I mention but three:

Wim Brouw. Wim in 10 years or so from 1966 achieved the impossible and with others but nevertheless as the uniquely indispensable one developed the software that made the Westerbork telescope truly usable. Without Wim's unimaginable talents and his selfless effort this instrument would never have become the superb vehicle for worldclass research recognized everywhere.

George Miley, brilliant explorer, co-worker since 1971, my successor in 1987, amiable man and gifted leader. George, in no one's hands could I better have left the Sterrewacht!

Niek de Kort, astronomer in bone and marrow, entrepreneur and adviser, analyst and writer. With Niek as spill we built a television course that brought modern astronomy to a quarter million people and structurally raised the student influx. About 20 years later Niek and I did three more major projects, about space technology and environment, about spacecraft and science, about remote sensing and geo-information infrastructure. Niek, your unmatched productivity and your talent to destill a mountain of documentation after a few hours of brainstorming to a coherent text, they are my good fortune. We have not finished!

I specially want to thank my colleagues in Utrecht for granting me a scientific *pied-à-terre* since the spring of 1993. The Rector of Leiden University and the Dean of the Faculty for Mathematics and Natural Sciences I thank for their courtesy to let me conclude my professorship, here passive since several years, in Leiden.

I have spoken.