Status of the Profession

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KEY POINTS ON THE STATUS OF THE PROFESSION

- The number of astronomers has grown by about 40% over the past decade. While the number of women entering the field has increased substantially, minorities are under-represented.
- The number of astronomers with jobs in industry, or with long term, non-tenured, jobs has increased dramatically compared with traditional faculty positions.
- The increase in the number of astronomers and the declining share of the NSF budget going to astronomy has led to extreme difficulties in the NSF grants program and in the support of the National Observatories.
- In 1989, direct NASA support of astronomers through the grants program exceeds that of NSF, although the total of the NSF grants program over the decade far exceeds that of NASA.
- Access to major new telescopes will be an important issue for the 1990s. US astronomers, who once had a monopoly on telescopes larger than 3 meters, will, by the year 2000, have access to just half of the world's optical telescope area.

INTRODUCTION

Astronomy in the 1990s is on the threshold of a great revolution with the advent of NASA's Great Observatories and with the promise of several ground-based optical telescopes that will exceed the light gathering power of the Palomar 5 m telescope. Dramatic progress will be made at other wavelengths as well, with the operation of the VLBA radio array scheduled for 1992 and the flights of the gamma ray, X-ray and infrared Great Observatories planned for the coming decade. The excitement generated by astronomy has resulted in a growth of the number of astronomers by 42 percent over the 1980s. However, the growth of the number of astronomers, the failure to keep pace with funding levels attained by other branches of science and the expense of new instruments has caused significant difficulties for several parts of astronomy. Problem areas include:

- Funding from the National Science Foundation, traditionally the patron of ground-based astronomy, has failed to keep up with the needs for grants to individual researchers, for maintenance of existing observatories, and for development of innovative techniques such as optical and infrared interferometry.
- The US is danger of losing its pre-eminence in astronomy as other countries undertake major new initiatives to build major new ground based and orbiting observatories.

- NASA's focus on large projects that take 10 to 20 years to complete has eliminated many more modest efforts that span the career of graduate students or postdoctoral fellows.

This chapter raises a number of issues without recommending any solutions, for this is the purview of the report of the Policy Panel. Topics discussed below include the demographics of the profession, the impact of the previous survey report, trends in the funding of research by NASA and the NSF, the access to major research facilities, a snapshot of the employment record of astronomers, the productivity of research astronomers, and the status of women and minorities in the field.

THE DEMOGRAPHICS OF ASTRONOMY

How Many Astronomers Are There?

The number of astronomers is important when we consider whether there will be enough astronomers available in the next decade to replace the number of expected retirements from astronomical faculties and to analyze the data from new instruments. A significant number of scientists trained in other fields, particularly physics, are attracted to the science of astronomy. Therefore our definition of who is an astronomer must include people who have migrated into the field and are doing astronomy as well as those who have been specifically trained as astronomers. To maintain consistency with the Field Committee Report, we use an operational definition of an astronomer as a scientist with a PhD, or equivalent, who is either teaching or performing research in astronomy. Although a broad definition, this set represents the pool of qualified astronomers in the U.S. capable of using astronomical data.

One of the best ways of estimating the number of astronomers, and of establishing the characteristics of the astronomical community, is to use the membership of the American Astronomical Society. The American Institute of Physics periodically surveys a sample of the AAS Membership, so their characteristics as to age, employer, primary work activity, etc., are known.

Before examining the results of those surveys, we must first confirm that the AAS membership fairly represents the astronomical community. At the time of the Field Committee report, it was found that about 80 percent of working astronomers were AAS members. Recent estimates by AIP and a spot check in the Washington, DC area indicate this number is the same today. We assume that the AAS membership is representative of the community and that information about the AAS membership is valid for the community as a whole.

Figure 1 shows that the membership of the AAS has grown steadily over the last decade. The size of the pool of astronomers can be estimated from the AAS membership by applying various correction factors to account, for example, for the number of foreign members, incompleteness of the AAS membership etc. An estimate of these factors by the Field committee led to an estimate of the nation's pool of astronomers to be 0.82 times the membership of the AAS. Now, ten years later, a similar factor still seems to be appropriate, and we estimate that the U.S. has a pool of nearly 4200 astronomers, up by 42 percent since 1980.

The pool of astronomers is not, however, the same as the number of active research astronomers. If the latter is defined as someone who at least co-authors one paper year, then a survey by Abt (1990a) indicates there are about 2800 active researchers. However, research activity is limited both by available funding and time, particularly for faculty who work at institutions which are oriented primarily toward teaching. Given modest support, astronomers at smaller institutions oriented toward teaching can, and do, make significant contributions to astronomical research. These astronomers can readily involve students in their work and thus make even greater contributions to the educational process. With additional resources the pool of research astronomers could increase significantly.

The Solar and Planetary divisions of the AAS provide an initial indication of the numbers of solar system astronomers. The Solar Physics division numbers about 350 U.S. members, or approximately 6 percent of the AAS membership. This value is considerably lower than similar ratios reported for other countries, e.g. France with 15 percent, West Germany with 8 percent and Japan with 12 percent. The Division of Planetary Sciences has 700 members, about 13 percent of the total AAS membership.

How Active Are the Astronomers?

The number of papers published in astronomy is a measure of research activity. Abt (1989a,b) has

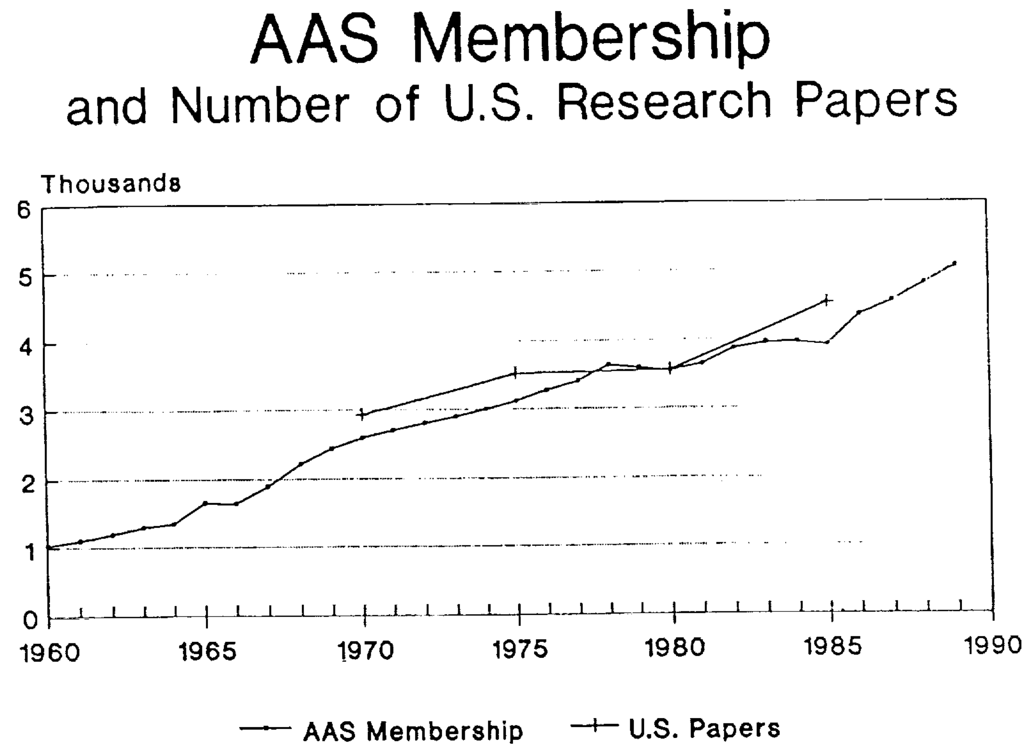

FIGURE 1 The membership of the AAS has increased by 42 percent in the last decade. The number of scientific papers by US authors has increased by roughly the same proportion.

studied the publication practices of astronomers. Over the past two decades the number of research papers produced by U.S. astronomers has grown significantly, just about as rapidly as the AAS membership. U.S. astronomers published 4527 papers in 1985, a growth of 28 percent in ten years. Over the same time, the AAS membership grew by 26 percent (Figure 1). However, the growth of U.S. papers has lagged behind the rest of the world. The number of non-U.S. papers grew by 57 percent over those ten years, and now they account for a dominant 68 percent of all astronomy papers.

Abt also finds that the average full member of the AAS publishes 3.3 items per year, of which about half are refereed papers describing original research. Correcting for multiple authors, Abt concludes that the average AAS member produces the equivalent of one-half of an original research paper per year. However, about a quarter of the AAS members are more than twice as productive as the average, producing the equivalent of one single-author research paper per year.

Astronomy is rapidly becoming more international. Nowhere is this more evident than in the growth in the number of papers from foreign authors in astronomical journals around the world. Abt (1989b) has examined the statistics of foreign authorship in astronomy by defining four categories of papers: 1) solely American authorship; 2) lead US authorship but significant foreign participation; 3) lead foreign author but significant American participation; and 4) solely foreign authorship. If foreign papers are defined as half of those in categories 2) and 3), plus all of those in category 4), then Figure 2 shows a dramatic increase in foreign papers since 1970 in the *Astrophysical Journal*; similar numbers apply to the *the Astronomical Journal* as well.

The number of papers with international collaboration (categories 2 and 3) are becoming much more common than they were before the 1960s when they represented less than 5 percent of the total. Starting in the early 1970s, the *Astrophysical Journal, Astronomical Journal, the Monthly Notices of the Royal*

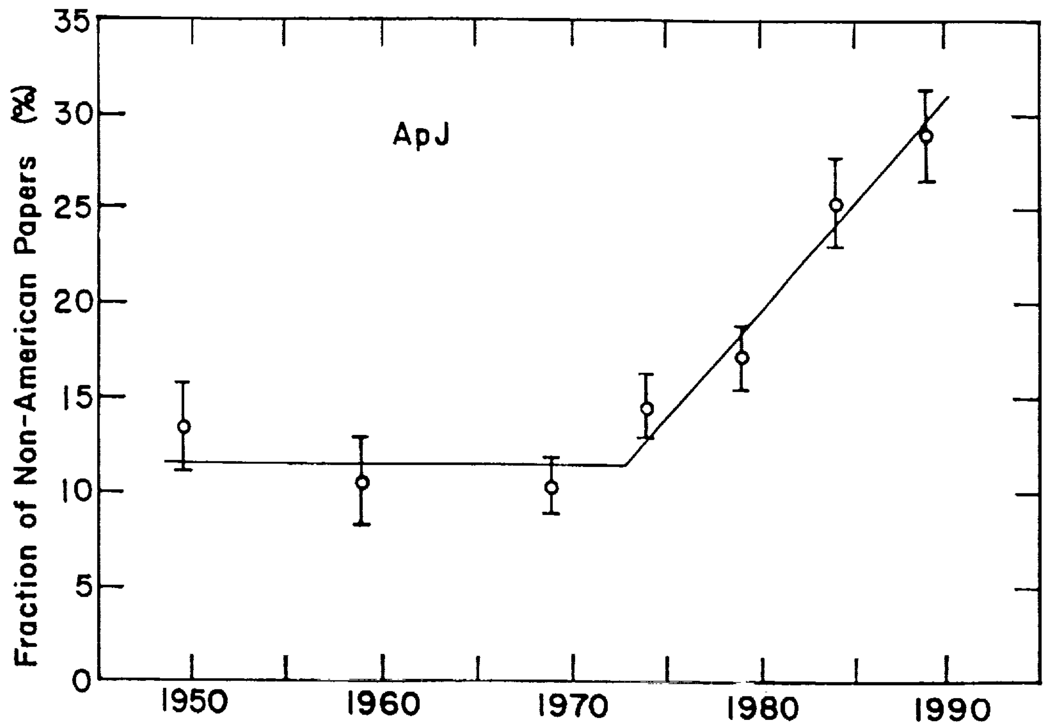

FIGURE 2 The number of papers with significant foreign participation appearing in the Astrophysical Journal has increased dramatically in the last 20 years (1990b). Courtesy of the H. Abt and the Astronomical Society of the Pacific

Astronomical Society and *Astronomy and Astrophysics*, all showed a shift from purely national papers to the current percentage of 25 percent multi-national papers. International cooperation is quickly becoming the standard way of doing research, just as before 1970, papers by a sole author were the norm, but thereafter papers by multiple authors became usual.

How Can We Characterize the Astronomical Community?

Astronomy is being carried out by a young and growing community. Traditionally concentrated in academic institutions, astronomers are now employed by an increasingly diversified group of institutions. One-half of U.S. astronomers now work outside of academe. The number of astronomers working with industrial or commercial companies is showing the most rapid growth, a factor of three over the past decade.

In 1987, the median age of U.S. astronomers was 42, the youngest for all the societies sampled by the American Institute of Physics (Figure 3). Half the U.S. astronomers were between the ages of 35 and 50. In contrast, in 1973 astronomers were, on the average, eight years younger, with a median age of 34. In those days, half the astronomers were concentrated in the ten year age group of 27 to 37. Given a continuation of present trends, we would expect the median age to move up by another five years in the coming decade. The profession will not suffer any serious effects due to retirement in the coming decade.

The percentage of women in astronomy has grown by almost fifty percent during the last decade; from eight percent to twelve percent. Examination of the graduate student population shows signs of a slow, continuing growth in the number of women in astronomy.

Recent surveys show that twelve percent of the doctoral degrees awarded by astronomy departments in 1987 went to women, and that twenty percent of the total astronomy graduate population is female. These

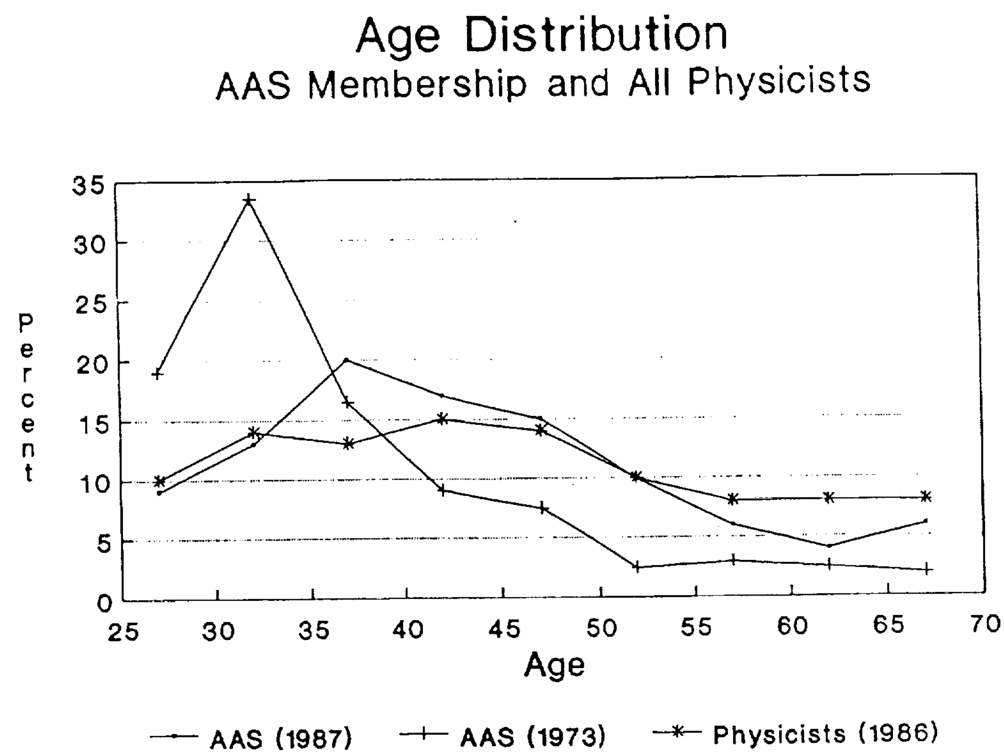

FIGURE 3 The average age of astronomers and physicists as determined by membership surveys by the AIP. In general, a astronomers are younger than physicists.

fractions are similar to or higher than the female membership of the AAS and lead us to expect that the percentage of women in astronomy will continue to rise slowly over the next decade.

Ethnic minorities are significantly under-represented in astronomy. Preliminary results from a survey of the AAS membership show that 93 percent of the AAS members classify themselves as white, 4 percent as Asian and 1 percent as Hispanic. Afro-Americans comprise less than 0.5 percent of the AAS membership.

Results of the Field Committee Report on Personnel Issues

The previous Astronomy Survey Committee, chaired by George Field, emphasized that successful basic research is dependent upon an active and vigorous community which can only be maintained through adequate funding of the research infrastructure. The Field committee made two important recommendations with regard to providing long-term, federal funding in astronomy. First, they recommended an increase in the money for theory and data analysis. Second, anticipating increased retirements in the 1990s, the Committee also recommended that ten to twenty competitive five-year positions, funded by NSF, be established for young astronomers.

Partly in response to these recommendations, NSF established the Presidential Young Investigator awards designed to encourage young scientists, and NASA initiated a specific program for supporting astrophysics theory groups. NASA also recognized the need for longer term funding for young astronomers and has recently converted 10 percent of their growing data analysis funding into a program of five-year awards.

THE FUNDING OF ASTRONOMICAL RESEARCH

Although astronomy has a long tradition of private and state support, federal funding continues to provide the bulk of the funding for astronomical research. The NSF provides the major share of funding for ground-based astronomy, while NASA provides nearly all the funding for space astronomy. Historically, ground-based optical astronomy has attracted additional private and state support; radio astronomy has depended heavily upon federal funding; and space astronomy has been entirely federally supported.

Observational astronomy depends heavily upon modern, effective instrumentation. The faintness of the objects being studied requires massive and expensive telescopes which, in turn, limits the number of research instruments that can be built. Since their establishment nearly three decades ago, the national observatories, funded by NSF, have provided unrestricted access to first class research telescopes and facilities on the basis of merit. NASA, likewise, has adopted the general policy that observing time should be accessible to anyone in the astronomical community and that use of the space facilities should be awarded on the basis of scientific proposals which are reviewed by a panel of scientific peers.

But it takes more than instruments to make a strong and vital scientific program: it takes people to do the research. Programs of competitive research grants for individual astronomers have been one of the most important components of U.S. astronomy. In combination with telescopes and instrumentation available to the entire community, these grant programs make possible the broad geographical distribution which characterizes U.S. astronomical research. Both NSF and NASA have such programs. In addition, the Departments of Energy (DoE) and Defense (DoD) have grant programs for basic research, and both award some grants that are astronomical in nature.

The impact of private and state funding upon the total competitive research grant picture is small. There is a substantial amount of private and state money in various institutions that supports astronomical research by the staff and faculty of the institution. However, the NSF and NASA grant programs are of paramount importance to the health of the field. Thronson has tabulated the credits for funding which appear in articles by U.S. researchers in the *Astrophysical Journal* in 1989. He finds that NASA and NSF are each cited about 40 percent of the time and other federal agencies (especially DoD and DoE) are credited in about 10 percent of the papers.

We will, therefore, analyze the funding trends in the two largest grant programs in which the entire program is restricted to astronomy projects, the NSF program of astronomy grants and the various grant programs in NASA's Astrophysics Division (Figure 4). Measuring trends in the two major programs will suffice to give an indication of the health of astronomy funding in the two agencies. All references to budgets and amount of support have been converted to 1989 dollars using the OMB correction factors for basic non-military research, which are very close to the standard cost-of-living index.

Support from the National Science Foundation

The Grants Program Funding from the NSF Division of Astronomical Sciences, which supports most astronomy from the ground, goes into two major programs: the national observatories and the program of individual research grants. This latter category includes both grants to individual astronomers and grants to universities to support various facilities.

The NSF grants program funds projects that range widely in size, from small grants for various supplements, publication of meeting proceedings, etc. up to grants of over a million dollars for the operation of entire university observatories (Figure 6a). The bulk of the NSF grants falls between these extremes and supports individual research projects. These grants are critically important to the individual researchers, particularly in the area of theory. Figure 6b shows a steady erosion in the grants to individuals and which account for about 2/3 of the overall grants program; excluded are major grants to university observatories. Another measure of the erosion in support to individual astronomers is the decrease in the average size of grants in the $25-250k range. With typical costs of summer salary, publications and a graduate student salary plus overhead now exceeding $70,000 per year, the grants program has dropped below a critical threshold. While an individual can, and often must, have more than one grant, such a system of support suffers from inefficiencies and often produces more proposals than papers.

Overall, the picture is rather bleak within the NSF grants budget, except for a 24 percent increase in

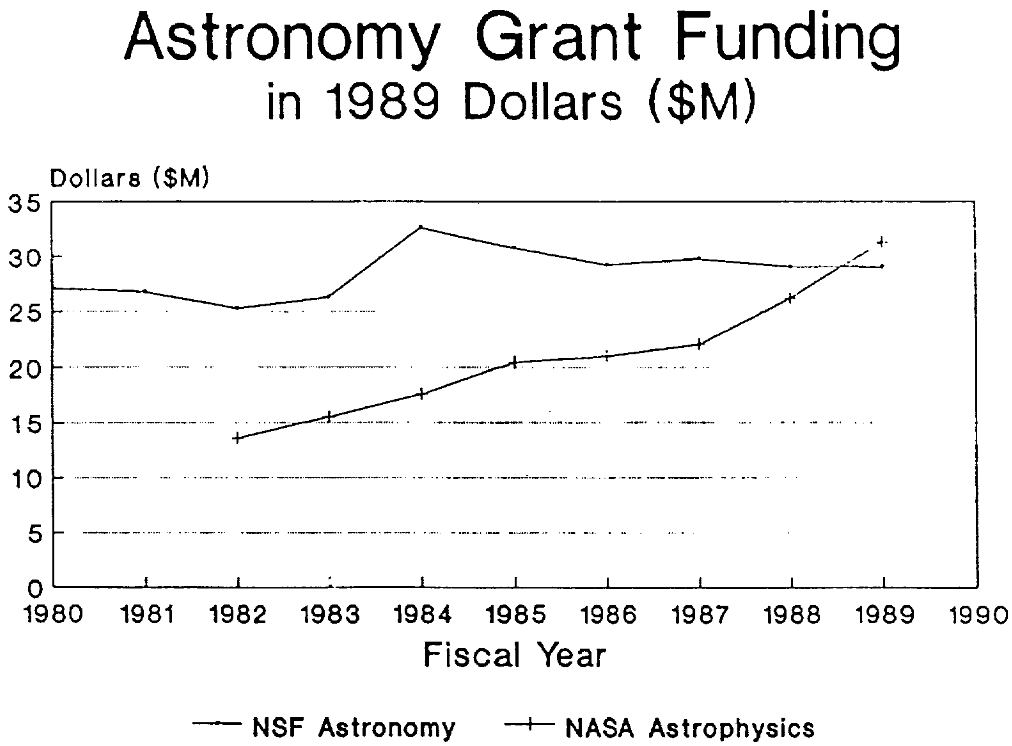

FIGURE 4 Overall funding of astronomy grants by NASA and the NSF in constant collars. In the case of NSF, funding of university observatory facilities is included.

1984 that was eaten away in subsequent years. While all the indicators of activity within astronomy were rising with the number of publications up by 27 percent in the first five years of the decade and the number of astronomers increasing by 40 percent since 1980, the 1989 grants budget is only 11 percent above the 1980 level in constant dollars. The number of grants awarded has risen from about 250 in 1980 to 372 in 1989, but the average size of grants to individuals is down by almost one-half in 1989 dollars, from just over $90k in 1981 to $55k.

The increase in 1984 appears to have resulted from the publication of the Field Committee Report, which noted the sad state of the infrastructure that enables astronomical research to proceed, and recommended an augmentation. Unfortunately, after 1984, the research base at NSF has been eroded year by year. In fact, Figure 7 shows that the construction funds for building the VLBA have come from the research base, a move that leaves the research infrastructure as poorly funded as it was a decade ago.

Support for Facilities Support for national facilities has deteriorated during the last decade. Data for NRAO are representative of the problem (Figure 7). The integrated shortfall in the operations budget between 1984-1989 is almost $15 million, with drastic, adverse effects in staff compensation and morale, telescope and receiver maintenance, development of new receivers, computing capabilities and cutbacks in critical educational and postdoctoral programs.

Support from NASA

In marked contrast to NSF, the NASA grant programs in astrophysics over the decade have more closely tracked the growth in the number of astronomers and the publication activity. The NASA programs were reorganized several times during the decade, and it is not possible to derive comparable numbers for years before 1982. However, from 1982 to 1989, the total of the various NASA grant programs has grown from $17.5M to $31.3M, or 79 percent. The average grant size has remained stable at about $40,000 throughout this time. The number of grants awarded per year rose from 336 in 1981 to 574 in 1989. The small grant size is caused by the fact that NASA gives grants to pay for the expenses associated with observing with IUE.

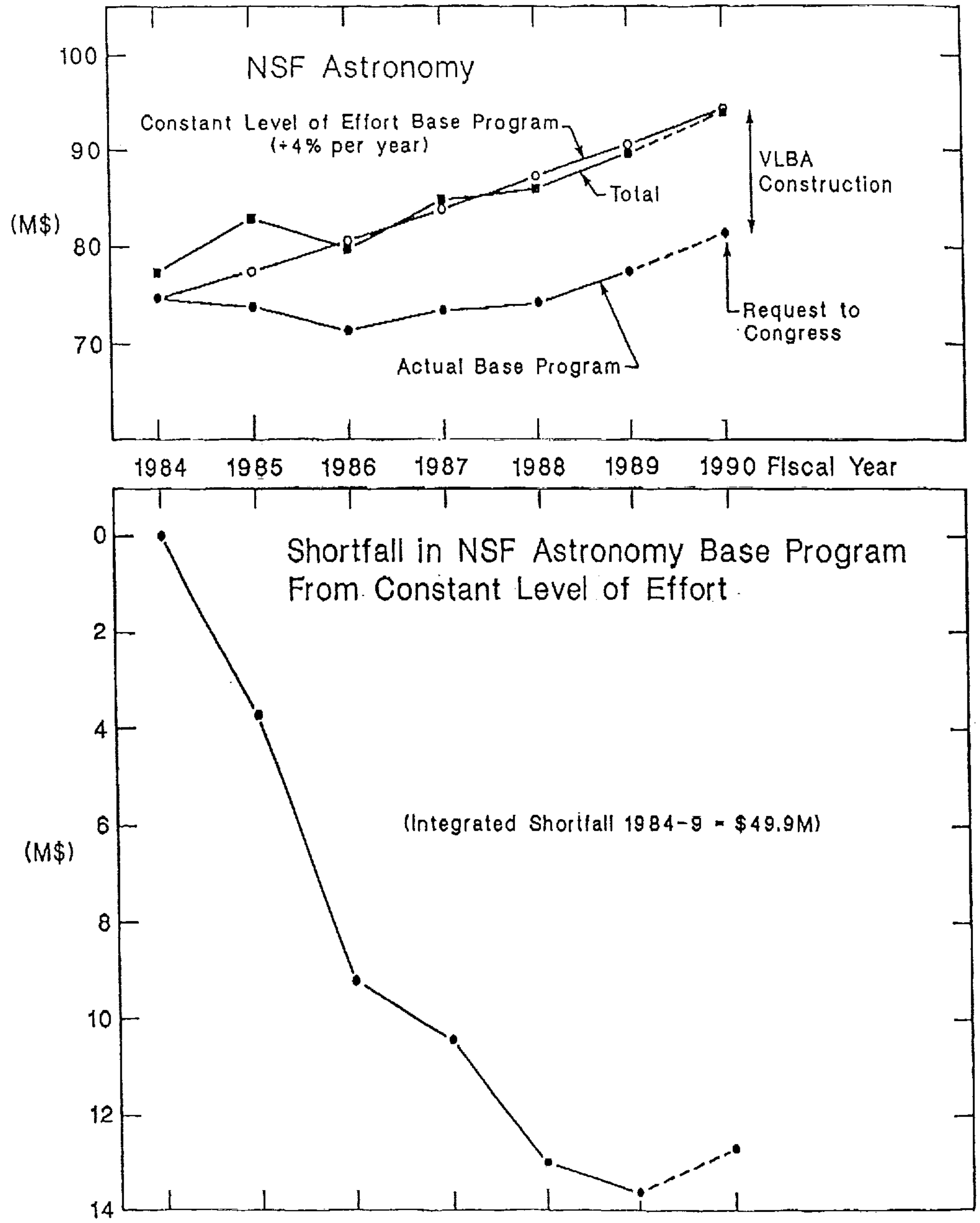

FIGURE 5 The NSF astronomy program has not received adequate funding to maintain a constant level effort of program over the last five years. Construction of the VLBA has had a marked impact on the support available for research grants.

It should be pointed out, however, that the average grant is too small to support a post-doctoral fellow or, in some cases, even a graduate student. Many IUE researchers have to write multiple proposals to support themselves and their postdocs and graduate students. In the rest of the Astrophysics Data Program the grant sizes are significantly larger, but still often low enough that multiple grants are required to support a researcher.

Behind the rise in the number of grants by NASA is a specific new policy to provide sufficient resources to analyze adequately the data from their space science missions. This policy includes setting up multi-wavelength data archives, provision of data analysis funding long after missions have ceased operation, and the establishment of senior fellowships. Nor has theory been neglected. There is now a strong program that

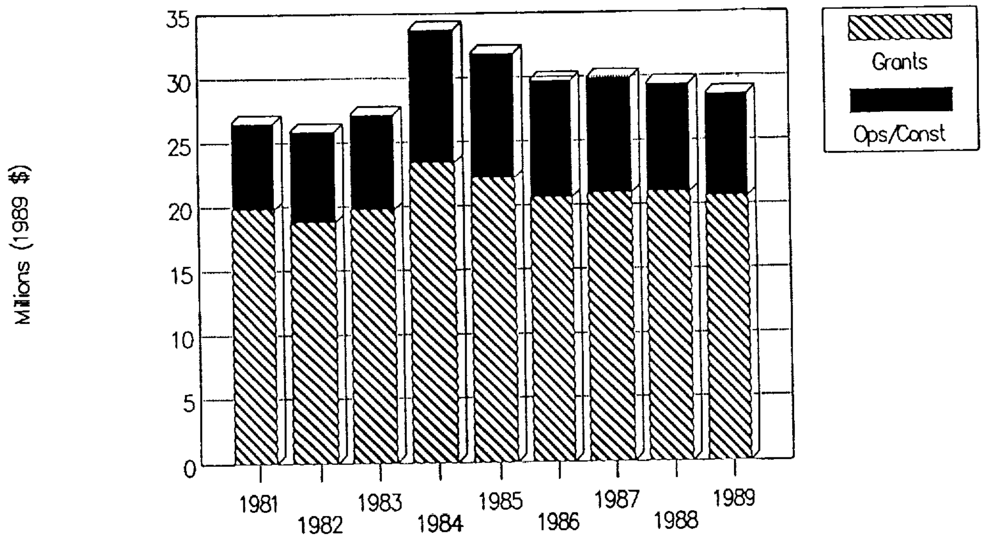

FIGURE 6a The division between funding of research grants and the operation and construction of university observatories over the last decade.

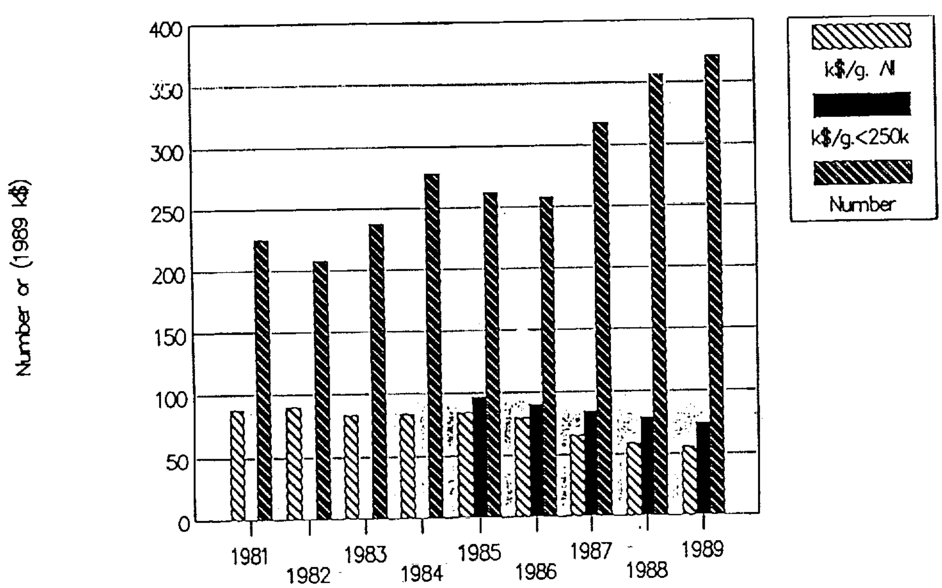

FIGURE 6b The numbers and average size of NSF research grants, corrected for the portion of the research budget devoted to operation and construction of facilities. The middle bar shows the decreasing size of grants in the $ 25-250 thousand range.

supports work on theoretical astrophysics, a vital component needed for the interpretation of astronomical data.

One important trend to emerge from this analysis of the grants program is the emergence of NASA as the dominant agency in astronomy grant funding. In 1982, NSF provided almost 60 percent of the grant money, but in 1989 NASA, for the first time, provided more money for astronomy grants than did the NSF. Since several large, long-lived missions will be launched in the early 1990s, NASA's future spending plans call for a major increase in the amount of data analysis money which will go the community in the form of grants. If present plans come to pass, NASA will be providing two-thirds of all the astronomy grant money by 1995.

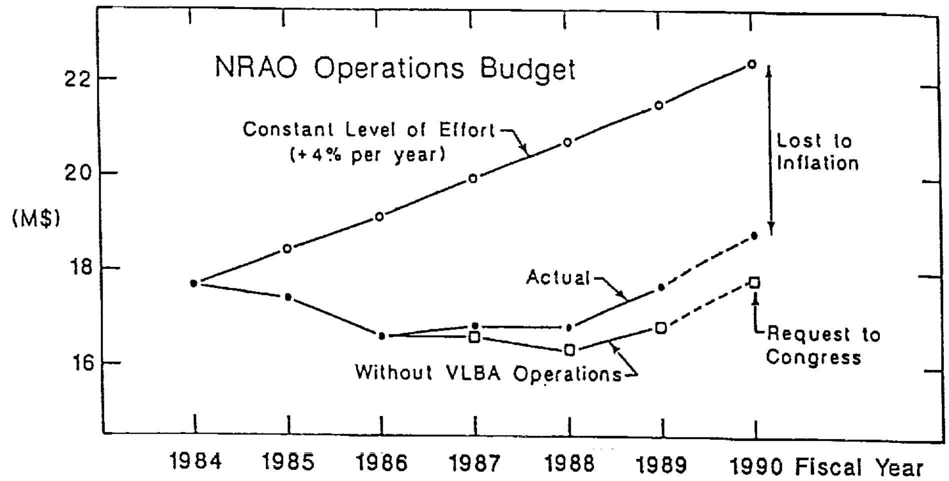

FIGURE 7 The funding of the National Radio Astronomy Observatory shows that funding has fallen significantly short of maintaining a constant base program with concomitant impact on all aspects of observatory operation.

ACCESS TO MAJOR TELESCOPES

Astronomy is, more than almost any other physical science, an observational science. Two aspects are of critical importance for maintaining American leadership in the field. First, we must build the best telescopes and equip them with the best instruments. Second, we must guarantee broad access by US astronomers to those instruments. The US faces serious challenges to its long-standing pre-eminence in optical astronomy. Since the 1950s, the US had almost all of the collecting area in telescopes larger than 3 m (Figure 8 and Table 1). By the end of the century the US fraction will drop to about 50 percent with Japan and a united Europe making major national commitments to large, 7-8 m, optical telescopes. Without the *privately* funded instruments like Keck, Columbus and Magellan, and without the proposed (shared) NOAO 8 m telescopes, the U.S. fraction would drop to about 35 percent of the world's collecting area.

Different branches of astronomy have similar problems:

- In the fifteen years between Einstein and AXAF, American X-ray astronomers will have relied solely on foreign telescopes to make advances in a field they invented.
- In centimeter wavelength radio astronomy, the aging VLA is still the supreme instrument, but in the rapidly growing field of millimeter radio astronomy, the IRAM 30 m telescope and the new millimeter arrays in Europe and Japan challenge our leadership in another field we developed.
- The US led the development of infrared astronomy, based in large part on the strength of our detector technology, and opened space infrared astronomy with the IRAS satellite. Leadership in infrared astronomy will pass to the Europeans when they launch the ISO mission and we wait until 2000 or later for the flight of NASA's infrared Great Observatory, SIRTF.
- The US pioneered neutrino astronomy, but the major facilities in particle astronomy are now in Europe, Japan and the Soviet Union with a major new Canadian observatory expected soon.

The competition for observing time on major new telescopes will be severe. For instance, the Hubble Space Telescope (HST) made initial time assignments in response to proposals for the first year of operation. Nine times as much observing time was requested as was available and in the first year only one proposal in five was assigned time. This is a remarkably high demand for an instrument whose launch date was two years in the future at the time of proposal submission and whose launch had frequently been postponed. Even with reduced capabilities due to the flaw in its primary mirror, HST will be oversubscribed by a factor of about five to one for ultraviolet imaging and spectroscopy where its powers are unequaled by other facilities. Another less extreme case is the four meter telescopes at the National Observatories, which are

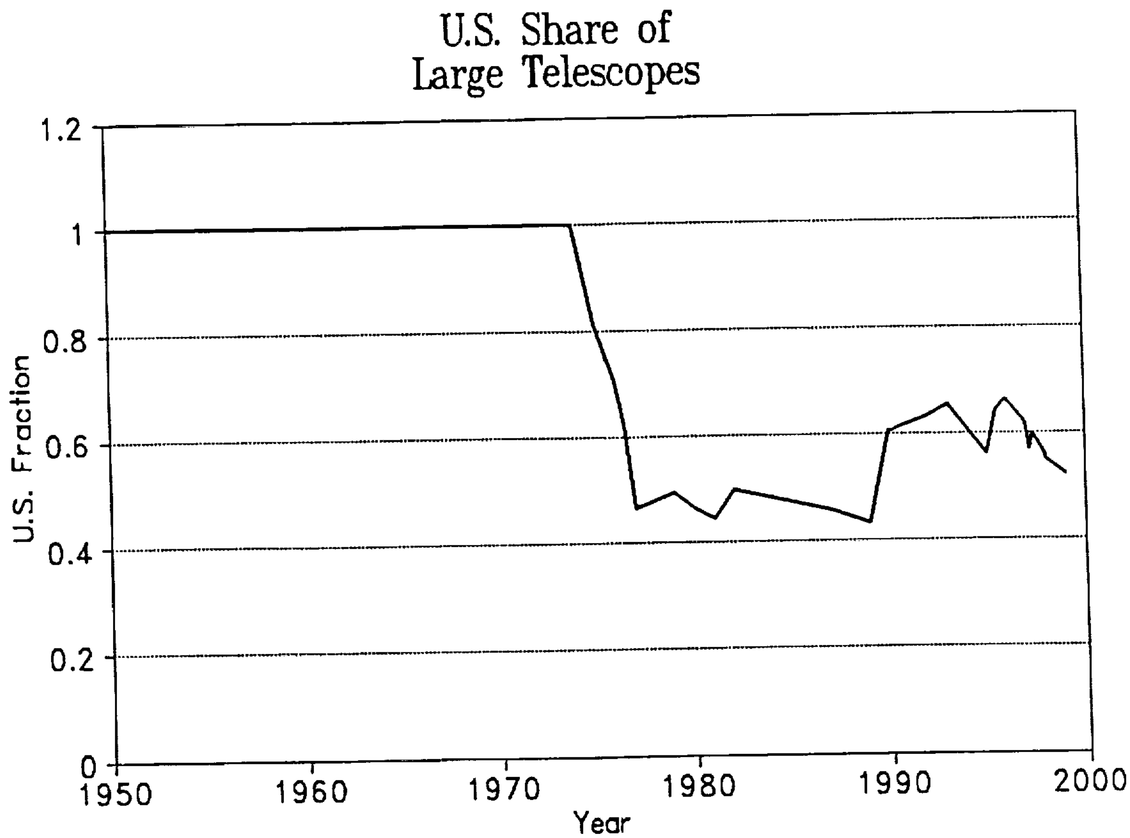

FIGURE 8 The fraction of the world's telescope area accessible to US astronomers, for optical telescopes larger than 3m. The figure assumes all the telescopes described in Table 1 are built.

more than ten years old, but where the demand typically runs four times more than time available. Requests for observing time on other U.S. telescopes typically exceed the number of available hours by factors of two or more.

ASTRONOMY AS A PROFESSION

The Growth of "Firm Money" Positions

The types of jobs that astronomers now occupy have changed over the last decade. Traditionally, an astronomer achieved a permanent job on the tenured faculty at a university or college. Industrial and academic research jobs, with their perceived impermanence and lack of academic freedom, were considered less desirable. However, as predicted in the Field Committee Report, the rapid growth of astronomy in the late 1960s and the concomitant youthful age of the astronomical faculty has meant that faculty retirements have been few and far between. This has, in turn, severely limited the number of tenured faculty jobs that opened up during the last ten years. Industrial and national research facilities have taken up much of the slack by employing increasing number of astronomers who still carry out astronomical research.

Academic institutions still provide jobs for half of the AAS members (Figure 9a), but other types of employment have become more important. Nearly 75 percent of the employed in academia hold permanent, tenured jobs (Figure 9b). Exclusive of astronomers holding postdoctoral appointments, 17 percent of the academic astronomers have positions as research associates.

Table 1. U.S. Share of Large (≥ 3m) Telescopes

Telescope Name	US Share	Mirror Diam (m)	# Mirrors	Date	World Telescope Area (m^2)	US Fraction
Palomar	1	5	1	1950	19.6	1.00
Lick	1	3	1	1959	26.7	1.00
NOAO-KPNO	1	4	1	1974	39.3	1.00
CTIO	1	4	1	1975	51.8	1.00
AAT	0	3.9	1	1975	63.8	0.81
Calar Alto	0	3.5	1	1976	73.4	0.71
ESO	0	3.6	1	1976	83.6	0.62
USSR	0	6	1	1976	111.9	0.46
IRTF	1	3	1	1979	118.9	0.50
UKIRT	0.15	3.8	1	1979	130.3	0.47
MMT	1	1.8	6	1980	145.5	0.52
CFHT	0.15	3.6	1	1980	155.7	0.50
Herschel	0	4.2	1	1987	169.6	0.46
ESO NTT	0	3.6	1	1989	179.2	0.43
Keck-1	1	10	1	1991	257.7	0.61
ARC	1	3.5	1	1991	267.3	0.62
WIYN	1	3.5	1	1992	277.0	0.63
MMT-upgrade	1	6.5	1	1994	294.9	0.65
VLT-1	0	8	1	1995	345.2	0.56
Keck-2	1	10	1	1996	423.7	0.64
Columbus	0.75	8	2	1996	524.2	0.66
Japan	0.1	7.5	1	1997	568.4	0.62
VLT-2	0	8	1	1997	618.7	0.57
Magellan	1	8	1	1997	668.9	0.60
VLT-3	0	8	1	1998	719.2	0.56
NOAO	0.5	8	2	1997	819.7	0.55
VLT-4	0	8	1	1999	870.0	0.52

In contrast to postdoctoral appointments, which are normally awarded for a short, fixed term, usually two or three years, the research associate position, while still dependent upon outside funding, is available for a longer term. In some cases it may be continued as long as money is available. A significant number of universities are showing a willingness to guarantee some degree of permanence for their research associates, typically by guaranteeing a year or two of support to weather the loss of a grant or contract until new support can be found. The emerging importance of this type of job as a long-term career choice for astronomers deserves highlighting. We refer to such jobs, that carry a degree of permanence which exceeds the normal three year postdoc position, as "firm money" positions.

Industrial jobs, though often dependent upon a company's ability to obtain outside funding, also have a degree of permanence. Although companies may shift employees from one contract to another, the larger salaries and the challenges of the corporate world are attracting more astronomers than ever before. The percentage of U.S. astronomers who work in a corporate setting has nearly doubled over the last decade. In 1987, the number of astronomers who work for industry or are self-employed exceeded the number who work in Federally Funded Research and Development Centers, such as the national observatories. Corporate positions, which have no guarantees but which do have a reasonable degree of permanence, would also be

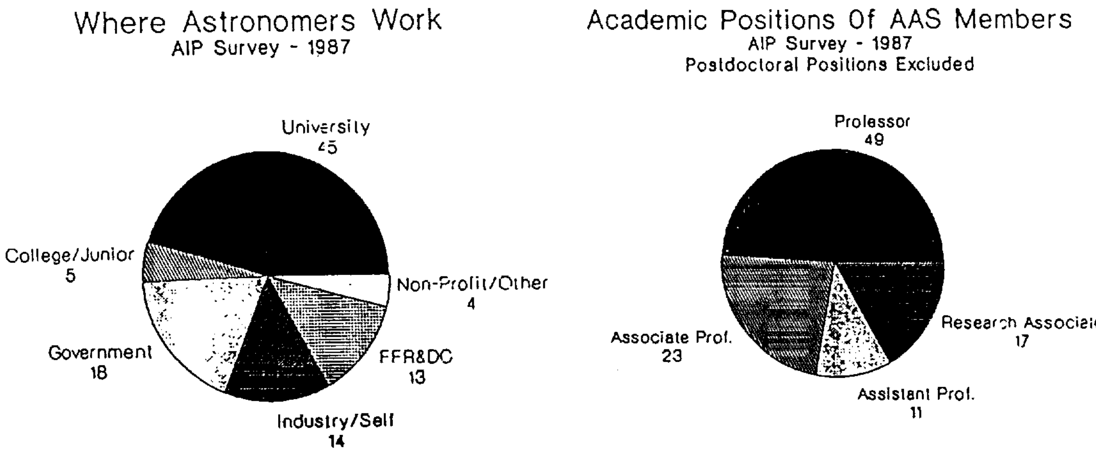

FIGURE 9 a) The fraction of astronomers in various types of jobs. FFR&DC refers to federally funded research and development centers; b) The fraction of astronomers holding different ranks within universities and colleges.

classified as "firm money" positions. Interestingly, it is not exclusively the young astronomers who are choosing careers outside of academia. The median ages of academic and non-academic astronomers are identical.

Trends in employment become particularly apparent when a tabulation is made of the type of position astronomers hold ten years after receiving their Ph.D. A survey was made of the 117 astronomers who received their Ph.D. in 1980. In comparison with the class of 1970 surveyed ten years later two conclusion can be drawn. First, there has been a significant decrease in the number of graduates who are working in universities, particularly true for tenure-track faculty positions. Only 32 percent of the class of 1980 are now in universities, 22 percent are in tenured or tenure track positions. The numbers for 1970 are 42 percent and 30 percent respectively. Second, there has also been a substantial growth in the number of people who are working in industry and some growth in the percentage working in Federally Funded R&D (FFR&D) Centers. 12 percent of the class of 1980 work in industry, up from 1 percent for the class of 1970. 15 percent now work in FFR&D Centers, up from 11 percent. Finally, the number of people who have left the field is a roughly constant 30 percent for both the 1970 and 1980 classes.

Research is an important part of the life of the average U.S. astronomer. Not only is this fact manifested through the large number of papers produced every year, more than one for each member of the astronomical community, but it also emerges from direct surveys of the community. Over half of all AAS members surveyed claim to work primarily on basic research and only 9 percent cite teaching as their primary activity, but another 25 spend a substantial amount of their time in teaching. The other three major activities at which astronomers work are administration, applied research and design, development or engineering.

The records of the Solar Physics Division of the AAS show that solar astronomers are not well represented on university faculties. Approximately 45 out of the 350 members of the solar physics division are found in academic environments, or roughly 10-20 percent. Most of the remainder of the solar astronomers are found in industry of national facilities. This value contrasts with the roughly 50 percent of astronomers who hold university jobs. In contrast to solar astronomers, the distribution of planetary astronomers mirrors that for U.S. astronomers as a whole. Fifty-one percent of the members of the AAS Division of Planetary Sciences are employed by universities. Thirty percent of the planetary astronomers say they work in government labs, comparable to the percentage of all astronomers which work in government labs and federally funded research centers.

What Can We Say About the "Typical" Astronomer's Career?

In order to understand the workforce in astronomy we have to know where people who work as

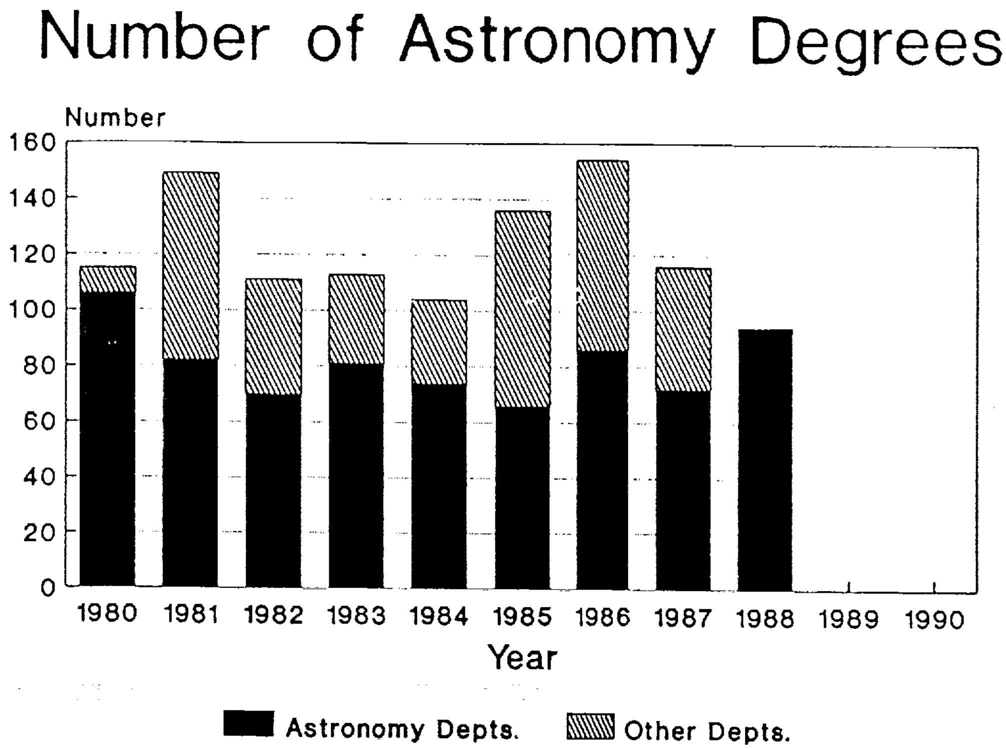

FIGURE 10 The number of PhDs granted in astronomy has been relatively steady over the decade. The number of scientists entering astronomy from other fields has increased since 1980.

astronomers are trained, what the progression of jobs is in an "average" career, and how and when they leave the field.

The rate of production of astronomers has remained virtually constant over the past two decades. The number of doctoral degrees awarded for dissertations in astronomical topics over the last decade has averaged 125 degrees per year (Figure 10). Of these, 81 degrees come from the 69 institutions that grant astronomy degrees. The other 44 are degrees in physics, or some other science, where the thesis topic is clearly identified as astronomy or astrophysics.

What undergraduate institutions do astronomy graduate students come from? AIP surveys show that 57 percent come from PhD granting institutions, whereas 15 percent are produced by the 4-year colleges and foreign institutions account for 24 percent. What did astronomy graduate students major in as undergraduates? Generally it was physics (52 percent), followed by astronomy (28 percent), mathematics and other (16 percent), and engineering (4 percent).

The flow of new people into the AAS has been twice the rate of degree production, averaging 250 per year. Thus, half the people entering astronomy in the past decade were trained in a science other than astronomy and migrate into the field later in their career. In the recent survey of the AAS membership, 1/3 of the respondents held their degree in a field other than astronomy. Such a high fraction of scientists coming in from outside the field is quite unusual and attests to the intellectual excitement of astronomy.

The other critical factor regulating the size of the pool of astronomers is the flow out of the field. Many people who were trained in astronomy or who once worked as astronomers and have, for personal or economic reasons, moved into another field typically tend to continue their membership in the AAS for some time after they leave the field. Under our definition such people continue to be counted as astronomers for a few additional years, only disappearing from our counts when they drop their AAS membership. Over time, this effect will average out and should not introduce a significant error into our estimates.

Specific studies done for the Field Committee ten years ago found that the attrition rate was greatest immediately after the postdoctoral period. Similar studies have not been carried out recently. However, the number of people dropping their AAS membership each year has remained unchanged during the past decade, about 50 persons per year.

What is the Job Situation for Astronomers?

One critical question is how closely the number of astronomers matches the number of available jobs. Since astronomy is a small and relatively well defined field, it is possible to get fairly comprehensive information about the employment situation. The American Astronomical Society publishes a monthly listing of jobs of interest to people trained in astronomy. The AAS Job Register was started in 1977, and in the early eighties a successful effort was made to ensure that it provided a complete listing of astronomy jobs. Since then, the AAS Job Register has provided an excellent indication of the astronomy job market, listing most astronomy-related jobs likely to be filled by Ph.D. astronomers. Of course, it also includes some jobs for people with Bachelors and Masters degrees, as well as jobs that involve primarily engineering, computer work, administration, and other non-astronomy work that may be of interest to astronomers. However the great majority of listed jobs are for Ph.D. level scientists.

The total number of jobs advertised each year in the AAS Job Register has risen steadily from fewer than 200 per year in the early 1980s to about 280 per year in the late 1980s, a net increase of about 30 percent over the decade. While these are not all new jobs, they do indicate an increased opportunity to find or switch jobs. The largest single increase came at the time the Space Telescope Science Institute was established and clearly represents a growth in the number of jobs in astronomy.

Two-thirds of the listed jobs are non-permanent, either post-doctoral positions or work on contracts expected to be of limited duration. These jobs serve an important role in providing transitional positions between graduate school and permanent work, but they do not contribute to the permanent job market. Instead permanent and semi-permanent jobs provide the long-term location and job security sought by most astronomers as their careers advance. These include academic and observatory jobs that are described as tenured or tenure-track, civil service positions at government labs, and jobs that have no definite duration and have a high expectation of continuing for several years.

Excluding tenured or senior jobs that are not open to young astronomers, the number of new, permanent and semi-permanent jobs has risen only slightly from about 60 per year in 1980-1982 to just over 70 per year in 1986-1988. Because this number is only about one-half the number of new Ph.D. astronomers, the competition for permanent jobs in astronomy has remained high.

As confirmed by the growth in the number of astronomers working in the commercial sector, it is apparent that substantial numbers of Ph.D. astronomers have joined a pool of people not employed in traditional permanent astronomy jobs. While some people have left astronomy altogether, most have maintained employment in astronomy-related jobs of various types. They are often doing applied research, hardware design or construction, and computer system or software development, often on contracts for particular projects. Many of these jobs are funded by federal sources, either directly by NASA or NSF grants, or less directly by contracts for NASA projects.

Projections of the job situation into the next decade are clouded by uncertainty in several areas. First, the recent lifting of mandatory retirement ages may change the normal retirement patterns, particularly for academic astronomers. Second, the trend toward longer term, more stable research funding by NASA coupled with the growing acceptance of "firm money" jobs by astronomers makes the job situation particularly sensitive to federal research funding. Third, when half the practicing astronomers come from physics, which has ten times the number of people, the field is particularly susceptible to changes in the migration pattern. These changes might be small in terms of the other field, but could severely disrupt the projections of growth in astronomy.

EDUCATION AND HUMAN RESOURCES

What Can Astronomers Do About Improving General Science Education?

According to all the experts, including the Presidential Commission that wrote the report entitled *A Nation at Risk*, the U.S. is facing a technical manpower shortage. A major effort is under way to improve the technical competence of the U.S. workforce before Halley's Comet returns in 2061. What part can astronomy play in this effort? With its broad public appeal, astronomy often attracts students at all levels into science courses, and it is only these students who are able to go into careers in science and engineering. Astronomers can work with local schools and with science museums and planetariums to provide up-to-date, interesting, and scientifically accurate materials. They can cooperate with local reporters to see that exciting advances in astronomy are brought to the attention of the public.

The astronomical community has a responsibility to help at all levels, from working with local schools to encouraging the federal government to take action. The supply of new scientific talent, both for the benefit of our country and for maintaining excellence in U.S. astronomy, will depend, in part, on our efforts in this important task. The diverse issues of astronomy and education are discussed in the report of the Policy Panel, in Chapter 7 of the Volume I of this report, and in *An Educational Initiative in Astronomy*, edited by R. A. Brown.

What Can Astronomers Do About Improving Pre-College Science Education?

Though almost all students take science courses in the junior high-school years, few students choose to take more advanced high-school science courses. Contributing to this drastic sieve is the content of high-school physics courses and the reputation among high-school students of the courses and their teachers. If more high-school students took courses in the physical sciences, then the colleges and universities would have more chance to train students technically in astronomy, physics, mathematics, and geology. Astronomers could help high schools include contemporary astronomical topics in their courses, as is done in biology and other science courses, rather than limiting astronomical discussion largely to the important historical origins of astronomical thought in centuries past.

On the elementary-school and junior-high levels, science courses are usually taught by teachers with little science training. Astronomers can provide up-to-date information about current astronomy projects to local teachers and schools, and offer to assist in presenting current and exciting science topics to young students. Astronomers can encourage local schools to take their students to local facilities such as science museums and planetariums, or to visit telescopes at the astronomers' institutions.

On all secondary levels, astronomers can offer to cooperate with local school boards or state adoption committees, as appropriate, to see that textbooks and other materials have extensive and accurate information about astronomy. Astronomers can work with publishers and other providers of educational material to see that astronomy is well represented in the materials available.

What Can Astronomers Do About Improving College Education?

Astronomers can take active roles in their own institutions' teaching of both non-science-major and science-major undergraduates. They can see that personnel and equipment are devoted to providing the best possible environment for undergraduate courses in astronomy. They can make available courses for all academic levels of undergraduates, with particular attention to providing courses beyond the beginning survey not only for astronomy or physics majors but also for majors in other sciences and in non-science fields.

Astronomers can improve the status of astronomy teaching by making certain that the best professors take their turns in teaching lower-level courses. They can provide rewards for good teaching among graduate students. At present, most first-year students (60 percent) are supported on teaching assistantships, while research assistantships are provided later. Astronomers could try, instead, to provide structure in which the most qualified and experienced graduate students work as teaching assistants for part of their time. This would not only assist the undergraduate students in obtaining an interesting introduction to astronomy but also provide better training in teaching for the future astronomy professors. Providing the best education to liberal-arts college majors is a way of influencing the country's future lawyers, businessmen, and politicians, who can eventually play important roles in governmental and private funding of science.

The national agencies, including NSF and NASA, can extend and improve their programs that involve in research professors who have heavy time commitments involving teaching. Such programs as NSF's *Research in Undergraduate Institutions* can be expanded to increase the exposure of undergraduate students to contemporary astronomical research. During fiscal 1988, seven new awards were made under this program for a total of $369,000 plus three supplemental grants for $170,000. From regular research awards, an additional 6 grants were awarded to undergraduate institutions for $287,000 plus 8 continuing awards for $185,000 totaling $472,000.

Programs of liaison between research universities and surrounding colleges and universities can be extended. Regional informal meetings of astronomers are valuable ways of keeping members of the astronomical community, and their students, in touch with modern astronomical research.

Programs at observatories and research institutes to involve undergraduates in summer or term-time programs can be enlarged. Such programs tend to be prominent candidates for cutting at times of fiscal stress.

Astronomers can be active in incorporating recent research, including not only optical astronomy but also non-optical astronomy, into laboratory work for students at all levels.

What education issues face the astronomical community?

Training of instrumentalists. Based on anecdotal opinions there seems to be a falloff in the number of astronomers being trained in the design and construction of astronomical instruments. A questionnaire to all astronomy department chairs as part of this survey revealed that half of them them feel that their departments do not have enough faculty and staff who specialize in the development of astronomical instrumentation. More than half also foresee the need for an increase in the number of faculty who specialize in instrumentation during the next five years.

Problems of couples in astronomy. As the number of women in astronomy grows, the hiring of qualified applicants is more and more dependent upon finding employment for the applicant's spouse. Since women astronomers are more likely to be married to other astronomers than are their male colleagues, this problem is much more severe for the female members of the profession.

The survey of department chairs shows that 60 percent of the departments have tried to hire an academic couple during the past decade. None of the departments had anti-nepotism policies which would prevent them from hiring both persons, and there were a fair number of successful arrangements where both parties were accommodated. However, there were a larger number of cases where substantial difficulties were encountered. In the majority of cases all parties made a good faith effort to make things work out, but, in a few cases, the department or the central administration was simply unwilling to bend.

The most common difficulty was that making a spousal arrangement took time. Some spouses had to accept distinctly second-class positions such as adjunct faculty appointments. The number of cases reported indicate that this is a substantial problem which requires sensitivity, good faith and time to work out. With the rising number of women in astronomy it is important that all astronomy departments and university administrations increase their efforts to find adequate solutions to the problem of hiring astronomy couples.

Women and minorities in astronomy. Issues of equality, under-representation, role models, etc. are important. The growing percentage of women in astronomy will bring these issues into sharper focus in the next decade. The AAS has surveyed its membership on the question of discrimination. On the basis of answers to the survey, which had a response rate in excess of forty percent, the incidence of discrimination is not large. 10 percent of the respondents report having seen or experienced discrimination against women in the areas of hiring practices, pay and promotions. 16 percent report having seen discrimination in the general social treatment of women.

It is important to follow up on these data with a more detailed investigation. In 1979 the AAS Committee on the Status of Women made a detailed study of the perceptions of female members. This study should be repeated so a comparison can be made with the attitudes and perceptions of the previous decade. It is important to pinpoint areas in which progress has been achieved as well as areas in which more needs to be done. We owe it to our profession to see that the study of astronomy is equally accessible both males and females. We owe it to our colleagues to ensure that jobs at all levels are, likewise, equally accessible to everyone.

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