The American Astronomical Society's Examination of Graduate Education in Astronomy

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EXECUTIVE SUMMARY	1426
1 INTRODUCTION	1428
2 COMPONENTS AND STRUCTURE OF THE AAS STUDY	1429
2.1 Initiating the Dialog	1429
2.2 Structured Community Workshops.....	1429
2.3 Seeking Further Community Input	1430
3. SUMMARY OF WORKSHOP ISSUES.....	1430
3.1 Charge to the Graduate Curriculum Working Group.....	1430
3.2 Charge to Graduate Admissions and Support Modes Working Group	1430
3.3 Master's Degrees.....	1431
4 DISCUSSION OUTCOMES	1431
4.1 General Conclusions.....	1431
4.2 Broadening Academic Options: Conclusions.....	1432
4.3 Creative and Rewarding Teaching Experiences Should Be Provided	1433
4.4 Graduate Student Support Modes: Conclusions.....	1433
4.5 The Master's Degree: Conclusions.....	1434
5 RECOMMENDATIONS	1435
5.1 Action Items	1435
5.2 Additional Recommendations	1436
ACKNOWLEDGMENTS.....	1436
REFERENCES	1436
APPENDIX	1436
A. Participants in AAS Regional Graduate Education Workshops.....	1436
A.1 Keynote Speakers.....	1436
A.2 PhD Granting Graduate Departments	1436
A.3 Others.....	1437
A.4 AAS	1437
B. Keynote Addresses	1438
B.1 The Obvious and the Overlooked	1438
B.2 Reshaping Graduate Education in Science and Engineering.....	1441
B.3 Fostering Breadth in Graduate Education in Astronomy	1445
B.4 The Changing Graduate Educaiton and Research Environment.....	1445
C. Career Trends for New Doctorates in Astronomy and Astrophysics	1449
C.1 Statistical Trends in Astronomy and Physics	1449
C.2 Summary	1454
D. Additional Statistics	1455
D.1 The AAS Job Register	1455
D.2 Support of Graduate Students.....	1455

EXECUTIVE SUMMARY

Astronomy is entering an era which promises unprecedented discovery enabled by powerful new observational and computational tools undreamed of 20 years ago, and an enthusiastic cadre of recent PhDs eager to exploit these new capabilities. At the same time, long-term prospects for funding basic research are more uncertain than in recent decades. While it is dangerous to predict future funding patterns, there is near unanimous agreement that the growth astronomy and other sciences have enjoyed over the past 40 years cannot be sustained. As a consequence women and men who aspire to careers in basic scientific research will exceed the number of available long-term positions traditionally sought by young people following receipt of the PhD. These projections have led many to urge that the nation and its graduate schools take steps to decrease the PhD production rate.

Other participants in the national debate argue that "birth control" is far too simplistic a response. Their major concern is that adopting this approach will discourage young people from pursuing graduate education in the sciences and consequently decrease the pool of technical talent vital to the nation's future. They view graduate schools as a national resource which for more than 50 years have trained the scientists and engineers who have developed ideas and technologies which have been central to the economic health and survival of the United States. Rather than decreasing the number of entering students, they urge that graduate schools be challenged to re-examine their goals, to devise curricula and cultures which continue to attract first rate students, and to prepare students not only for research in a particular discipline, but for a broader range of post-graduate careers.

In response to the unpredictable climate for support of basic research and the sometimes conflicting visions of the role of US graduate programs in society today, the scientific community has organized a number of studies aimed at re-examining the goals of graduate education in science. In 1995, the AAS Council charged its Astronomy Education Policy Board to structure a series of activities directed specifically at examining graduate education in astronomy.

This report summarizes the results of those activities, which included both society-wide discussions of the issues confronting graduate education in astronomy, and three focused regional workshops attended by astronomy department chairs and graduate students from 59 PhD granting institutions, along with representatives from other professional societies, the industrial community, the science education community and the funding agencies which provide the bulk of support for astronomy.

The discussions were focussed on the following questions:

- Should some/all graduate schools continue to focus solely on producing the next generation of research astronomers and if so, how can we match PhDs produced to “traditional” career opportunities?
- Should some/all graduate schools examine ways to broaden academic options or restructure current degree options to prepare students for both traditional research *and* alternative careers?
- Could enhanced MSc or professional Master’s programs play a more significant role in graduate training today? If so, what is the appropriate relationship between Master’s and PhD programs?
- Are changes in the “academic culture” and the current reward structure required in order to facilitate desirable changes in graduate education?
- Are there changes in funding patterns which would facilitate desirable changes in the goals and content of graduate education?

The discussions were both lively and thoughtful, and perhaps surprisingly, reflected or developed consensus on a number of points, among which the following are particularly noteworthy:

- While there was agreement that graduate education in astronomy should retain a primary focus on producing the next generation of research scientists, there was a clear commitment to exploring curricular changes that would prepare students not only for research careers, but for a broad range of post-graduate jobs.
- Both student and faculty participants were near-unanimous in their view that it would be unwise for either graduate schools or funding agencies to adopt practices aimed at matching graduate admissions to perceived “traditional” (academic) job opportunities.

The AAS Education Policy Board and its Graduate Education Advisory Committee developed from the discussions a series of recommendations which they and the Society believe will enable the astronomical community to shape graduate programs which are responsive to the needs of students, the discipline, and the society which supports us. The full set of recommendations is included in the body of the report.

Key Recommendations

Three recommendations merit particular note:

Define and Support Experiments to Enrich Graduate Education

Federal and state resources should be allocated to develop pilot programs aimed at providing students with structured opportunities to gain broader experience and exposure to cultures outside academia during their careers. Example programs might include (1) developing new curriculum options involving partnerships between astronomy and other university departments, with industry, or with local schools; (2) developing enhanced MSc or specialized professional Master’s programs which provide students with exposure to additional “hard” (e.g. high speed computing and visualiza-

tion techniques; instrumentation; teaching) and “soft” skills (communication; team problem solving) in addition to basic training in physics and astrophysics; and (3) providing fellowships/traineeships targeted at exposing students to instrumentation development, formal and informal science education and curriculum development, and the demands, expectations, and culture of industry and national laboratories.

This recommendation is made with the understanding that in times of constant or declining budgets, funding such experiments—even at a modest level—comes at the expense of other more traditional programs. The long-term gains, however, will likely outweigh potential short-term displacements. To ensure that limited resources are invested wisely, the community and the funding agencies must work together to subject any experiments to rigorous peer-review and evaluation.

Re-examine the Master’s Degree in Astronomy

The astronomical community should carry out a national review of the merits and liabilities of (1) enhancing Master’s degree programs to ensure they provide the broad and thorough training necessary for students either to pursue a PhD, or to leave graduate school armed with the skills necessary to embark successfully on a variety of career paths; and (2) requiring an MSc for admission to a PhD program. Central to this recommendation is a commitment to ensuring that a Master’s degree would represent a desirable and “marketable” outcome for many students, and would come to be recognized widely as a mark of significant academic achievement rather than a “failed PhD.”

Enhanced MSc degree programs would incorporate rigorous course work, research experience, a range of technical skills and exposure to the scientific world outside of academia, through internships or local partnerships. Such degrees—of duration 2 to 3 years—would provide a mix of academic and “real-world” experience that would benefit both students who pursue an astronomy PhD, and those who choose other careers.

Several arguments persuade us to recommend further discussion of the possibility of admitting *all* entering students to an MSc rather than a PhD program: (1) it would allow institutions to recruit more widely and take greater risks in admitting potentially talented individuals; (2) it would provide both students and faculty with an opportunity to “pause and reflect” prior to making a commitment to pursue a PhD or to choose a different career path; (3) it would allow institutions to be more selective in admitting students to a PhD program; and (4) it would allow graduate programs to grow in stimulating and potentially beneficial new directions, by forging links and partnerships with a wider scientific community.

Provide Students with the Information and Experience Necessary to Make Informed Career Decisions

Both graduate departments individually, and the AAS collectively, should (1) develop comprehensive databases

which summarize employment histories of astronomy Master's and PhD recipients and (2) develop mechanisms to expose students to a variety of career options. Together these actions would provide prospective and current students with the background needed to make informed choices among graduate schools and realistic assessments of their post-graduate career options. These might include short-term activities, such as sponsoring career seminars featuring astronomy PhDs engaged in challenging and stimulating non-academic careers, and longer term investments, such as developing graduate curricula which incorporate "real-world" skills and/or off-campus experiences.

1 INTRODUCTION

Astronomy as a field and as a profession has never been more exciting. The discoveries of the past few decades—unseen dark matter which comprises more than 90% of the material in the universe; coherent filamentary structures traced by galaxies and extending for hundreds of millions of light years; massive black holes which power energetic outbursts during the lifetimes of most luminous galaxies; jets of exquisitely collimated hot plasma, extending over tens of light years and signaling the birth of stars and planetary systems; mature extra-solar planetary systems orbiting both sun-like stars and pulsars—have captured the imagination of scientists and the public alike. The next decades promise even greater change in our understanding of the universe as astronomers begin to exploit the power of a new generation of ground-based optical/infrared and radio telescopes, space-based observatories, and high-speed computing capability nearly unimaginable even a decade ago.

At the same time, the scientific community in the United States is entering a period of great uncertainty as the nation and its leaders debate the role of basic research in the post cold war era. While neither the ultimate outcome of this debate nor the resulting shape of a new "social contract" between scientists and the society that supports them is yet clear, there is near-unanimous agreement that the growth in numbers of scientists and funding levels enjoyed by astronomy and other sciences over the past 40 years cannot be sustained.

Moreover, many universities are in the process of re-examining their mission and structure in response both to financial pressures and questions regarding their role in society. Federal laboratories are engaged in a similar process, while the industrial sector has already taken steps to alter or downsize major research laboratories. The anticipation of slower growth or a real decline in support for basic research, combined with the possibility of a decrease in the number of "traditional" permanent research positions, has led some to argue that the nation should take steps to reduce the rate at which graduate programs produce PhDs.

Others express deep concern that taking such steps will discourage talented young people from pursuing graduate education in the sciences – leading both to a decrease in the pool of technically-trained individuals vital to the nation's economic future, and to erosion of the world leadership the US has enjoyed in most research areas over the past half century.

Still others add yet another element to the on-going national debate by arguing that many students currently emerging from PhD programs develop too narrow a range of skills, and as a result are unable to adapt readily to the rapidly changing needs of a technology-driven global economy. Moreover, because students are embedded within a culture which values academically-based fundamental research often to the exclusion of other, equally challenging pursuits, they reject or ignore career options outside academia. These participants in the national debate conclude that society can no longer afford generous support for "graduate education" narrowly defined as "the process by which the next generation of research scientists is trained." Instead, they urge that graduate schools be challenged to re-examine their goals, revise their curricula and develop a "culture" which broadens the definition of "graduate education" and encourages students to explore and eventually pursue a much broader range of post-graduate careers.

The rapidly changing environment for support of basic research coupled with the multiple, sometimes conflicting political forces pulling on the nation's graduate schools, have combined to motivate the scientific community to organize a number of studies aimed at (1) examining and better understanding the goals of graduate education as we enter the next century; and (2) ensuring that they are aligned not only with discipline aspirations, but the long term needs of the nation and our graduate students. Two prominent recent examples develop a number of proposals aimed at effecting change in graduate education for a wide range of scientific and engineering disciplines (NAS/COSEPUP Report, Griffiths 1995; NSF/MPS Report, Armstrong 1996). Both reports urge that graduate programs in science be reshaped to (1) offer a broader range of academic options to enhance student versatility, (2) develop alternate methods for federal support of graduate students to encourage and enable students to gain broader experience during their graduate careers, and (3) re-examine the role of the Master's degree in light of both student aspirations and projected needs of the private sector.

In 1995, the AAS Council authorized the Astronomy Education Policy Board to structure a series of activities aimed at re-examining the goals of graduate training in astronomy. While informed and given initial focus by the seminal Griffiths and Armstrong reports, the activities were directed toward developing an understanding of whether and how changes in graduate education in astronomy might best be made in light of the following factors, many of which are specific to our community:

- the inherently multi-disciplinary nature of astronomy and the breadth built implicitly into graduate training.
- the small size of the field (AAS membership is ~ 6000 astronomers), and the relatively small number of PhDs granted (less than 1% of science and engineering disciplines);
- the rising number of PhDs awarded (up from an average of 120 per year in the early 1990s to 173 in 1995);
- the astronomy PhDs awarded annually come from a relatively small number of institutions (80% of PhDs come from approximately 30 universities; 50% from 11);
- the large fraction of astronomy students supported by

federal funds (approximately half of all enrolled students of whom more than 80% are supported by PI-directed research assistantships);

- the close match between the number of PhDs granted annually and the number of available post-doctoral positions; by contrast, the number of long-term positions made available per annum in academia and national laboratories is smaller by more than a factor of three.

- the typical time to degree (median of 7 years), combined with time spent in postdoctoral “holding” positions (4 to 8 years) which require the “average” graduate to wait for 11–15 years before learning whether s(he) will secure a job as a professional astronomer.

The outcome of the AAS examination of graduate education is reported here. The following sections (1) describe the format of the study, (2) summarize the key points raised in discussions held in the course of three regional workshops in November, 1996, and (3) set forth recommendations aimed at strengthening our ability to succeed in carrying out one of our fundamental missions as a community—to educate the next generation of scientists.

2 COMPONENTS AND STRUCTURE OF THE AAS STUDY

2.1 Initiating the Dialog

As a first step, the Society devoted a significant fraction of its January, 1996 meeting in San Antonio to plenary and special sessions designed to alert the community to the importance of re-examining the goals of graduate education, and to initiate discussion of these issues among a broad cross-section of the membership. These sessions included: addresses by NSF Director Neal Lane and National Academy of Sciences President Bruce Alberts; a summary by John Armstrong of the NSF/MPS study on graduate education; a panel discussion involving astronomy faculty from representative graduate programs from throughout the country; and an open dialog eliciting comments from a cross-section of the society.

2.2 Structured Community Workshops

In June, 1996 the AAS received financial support from the National Science Foundation, which in combination with Society funding enabled the AAS to continue this dialog via a series of three, 1½ day regional workshops held during November, 1996. These workshops were designed by the Society’s Astronomy Education Policy Board and its Graduate Education Advisory Committee to encourage detailed and structured discussion in three areas:

- *graduate curricula*: the content and breadth of graduate curricula appropriate to preserving excellence in training for research careers, while taking cognizance of the current environment for post-graduate employment as well as the broader societal need for effective and imaginative technically-trained people;

- *graduate admissions and support modes*: the admissions policies changes which might be necessary to address the mismatch between the number of entering students and available “traditional” academic positions, the appropriate

balance among support modes for graduate students (PI-supported RAs; fellowships; traineeships), and possible new funding opportunities which might stimulate desirable changes in graduate admissions patterns, curricula and the academic culture;

- *Master’s degree in astronomy*: the desirability of developing Master’s degree programs which provide broadened training aimed at enhancing success both in traditional research and “alternative” careers; the advantages and liabilities of requiring an MSc as for admission to PhD candidacy

Workshop participants included representatives from 59 PhD granting institutions (most institutions sent both a faculty member—typically the department or graduate program chair—and a graduate student); and 31 representatives from the following communities: funding agencies, national observatories, institutions which grant only a Master’s degree in astronomy, or a joint physics/astronomy MSc; 4 year colleges, community colleges, university administration, other scientific fields, industry, education. The full list of participants is included as Appendix A.

Each meeting was initiated by a keynote address aimed at framing issues from a national perspective. Keynote speakers at the three workshops were Neal Lane, Director of the National Science Foundation: Eastern/Southern Region; Phillip Griffiths, Director of the Institute for Advanced Study: Midwestern Region; and Marye Anne Fox, Vice President for Research the University of Texas at Austin: Western Region. The speeches from our first two keynote speakers, plus an invited talk at the western region workshop from Eugene Levy, Dean of Sciences at the University of Arizona, are included as Appendix B. An additional invited talk at the western region workshop by Judy Franz, Executive Director of the American Physical Society, summarizing the findings from a workshop on graduate education for physics department chairs, is not reproduced here (Franz, 1995).

In addition, statistical material was prepared and presented by representatives from the Office of Scientific and Engineering Personnel (OSEP) of the National Research Council and by the AAS Executive Office. Speakers from the OSEP presented data on PhD recipients in Astronomy and in Physics from 1973–1995, culled from the annual *Doctoral Records File* survey and from the longitudinal *Survey of Doctoral Recipients*. A manuscript summarizing this data, prepared by the OSEP, is included as Appendix C. To supplement the OSEP data, the AAS Executive Office examined the trends in availability of jobs advertised in the AAS *Job Register* and assembled statistics on federal support of graduate students in Astronomy and in Physics from the NSF data release of *Selected Data on Graduate Students and Postdoctorates in Science and Engineering*. These statistics are presented in Appendix D.

Discussions of graduate curricula, funding issues and Master’s programs took place in three separate working groups, each of which comprised senior departmental representatives, graduate students and individuals from outside the astronomical community; all participated vigorously. In addition, the graduate students structured presentations sum-

marizing their concerns to a plenary session at each meeting, while outside participants provided additional perspectives in the course of a panel discussion.

The organizers made a deliberate attempt not to inform participants in later workshops of the conclusions reached by earlier groups, in order that the degree of consensus (or lack thereof) on each of the key issues be assessed from the conclusions reached through independent discussions.

While each workshop developed its own distinctive “flavor,” there was in the end considerable overlap regarding the merits and liabilities of various possible approaches to restructuring and funding graduate education.

2.3 Seeking Further Community Input

The results of the three community workshops were summarized in a presentation made at a special session at the January 1997, Toronto AAS meeting which was organized with the goal of eliciting further community dialog and commentary. In addition, a summary of preliminary workshop conclusions was posted on the Web and members were encouraged to post comments using the AAS website.

3 SUMMARY OF WORKSHOP ISSUES

In this section, we summarize the charges to the three workshop breakout sessions focussed on (1) broadening academic options, (2) graduate admissions and support modes, and (3) the role of the Master’s degree in astronomy.

3.1 Charge to the Graduate Curriculum Working Group

The changing environment for support of scientific research has led the scientific community to re-examine the goals of graduate education. Two recent reports (see Introduction) urge significant reshaping of graduate curricula in order to provide students with a broader mix of skills and experience, and thus the training and background necessary for pursuing a variety of challenging post-graduate careers. They specifically recommend that graduate programs in science and engineering provide options:

- to develop expertise in state-of-the-art technical areas, such as high speed computing or instrumentation;
- to expose students to training and research experience which crosses traditional disciplinary boundaries;
- to develop communication, project management and team problem solving skills to complement traditional emphasis on focused individual research;
- to develop classroom teaching, curriculum development and/or public outreach skills which would find application in improved communication skills with the public and for some, in K-14 classrooms.
- to provide experience outside the classroom and laboratory (e.g. internships in industry; in schools)

Workshop participants were asked to discuss the relevance of these proposed new approaches to the astronomical community and assess their potential merits and liabilities as viewed from the perspective of: students; universities; the astronomical research enterprise and its goal of sustaining world-leading research; and the broader needs of US society in the United States which must develop the

human resources to compete successfully in a rapidly changing, technology-based world economy. They were also asked to identify experiments which might stimulate desirable change.

3.2 Charge to Graduate Admissions and Support Modes Working Group

The anticipated downsizing of the scientific research enterprise has led some to suggest that admissions policies and the level and character of federal support for graduate students be re-structured with the goal of reducing the student population. If zero or negative population growth were the goal, departments might deliberately restrict admissions to graduate school; concomitantly, federal research dollars devoted to graduate training might also be reduced.

Some suggest the possibility that a decreased number of graduate students and the aggregate federal investment in graduate student support might be balanced by an increase in the number of postdoctoral fellowships, thereby ameliorating the potentially negative effects of a decrease in the graduate student population on the health of the research enterprise.

A variant of this proposal would involve both reducing aggregate federal support for graduate students, and directing such support to the “best” students, through (1) portable fellowships awarded at entry to graduate school (analogs of the Hubble Fellowships) or (2) “dissertation fellowships” awarded following completion of pre-thesis PhD requirements. Such changes would in effect endorse a “birth-control” policy and might alter significantly the balance of enrollment among institutions.

An alternative approach would be to view graduate education not simply as a means for producing the next generation of research scientists, but as part of a process essential to meeting a critical societal goal—preparing talented individuals for a range of careers which require creative approaches to solving challenging technical problems. Rather than attempting to tailor admissions to a fluctuating and uncertain job market, graduate admissions would be kept at near current levels, and advanced graduate training in science would be broadened in its intellectual content—to the benefit of both future researchers and those that pursue “alternative” careers. Federal support for students would then be provided with the implicit understanding that these dollars represent an investment not only in the future of the discipline but in the future of society.

While following this path need not require a shift in federal funding patterns, some have suggested that the balance of federal support for graduate students should shift—away from traditional research assistantships supported through PI grants, and towards fellowships, traineeships or block grants.

Proponents of this approach argue that students supported via traditional PI-supported RAs carry with them obligations to carry out specific research tasks which in some cases can conflict with the goal of seeking knowledge beyond traditional discipline boundaries or working outside of their advisor’s research specialty. Increasing the fraction of students supported via fellowships would, following this ar-

gument, “free” such students to shape a more balanced research experience.

Others see block grants as a mechanism for providing strong incentives for graduate schools to develop a dual—rather than singular—focus to their programs. By providing funding to institutions which propose imaginative new approaches to graduate training—including a variety of broadening options—a strong message regarding national priorities would be sent, and the intellectual energies of some departments would almost certainly be invested in developing such approaches.

Participants were asked to assess merits and liabilities of (1) altering graduate admissions policies; (2) developing a dual focus to graduate education; and (3) proposed changes in the balance and character of federal funding for graduate students and graduate education. They were also asked to identify appropriate “experiments” which might enable evaluation of different approaches or stimulate desirable change.

3.3 Master’s Degrees

There is a widespread perception that a Master’s Degree in Astronomy is a less than worthy achievement, offered to those who did not meet the criteria for admission to PhD candidacy. Are there advantages to restructuring the traditional path through graduate school so that a Master’s degree is not a “failed” PhD? Should Master’s programs be designed to provide a broader more “applied” approach to scientific training, with possible specialties in instrumentation, computing, or science education? An enhanced Master’s degree programs of 2–3 years duration might incorporate some or all of the following:

- training in state-of-the-art technical areas, such as high speed computing or instrumentation;
- training and research experience which crosses traditional disciplinary boundaries;
- communication, project management and team problem solving skills
- experience outside the classroom and laboratory in science education, in an industrial research laboratory; in the business or corporate world.

An enhanced Master’s degree would represent a desirable and “marketable” outcome for many students, and would come to be recognized widely as a mark of significant academic achievement.

Workshop participants were asked to examine the merits and liabilities of (1) developing enhanced MSc programs; and (2) requiring an MSc for admission to PhD candidacy.

4 DISCUSSION OUTCOMES

This section synthesizes the principal findings which emerged from the working group discussions at the regional meetings, those reached in plenary sessions by all participants at the three regional meetings, as well as those expressed in our open dialogs with Society members.

4.1 General Conclusions

4.1.1 *Create a climate of experimentation to foster necessary changes*

Workshop participants and AAS members recognize that we are entering an era when the assumptions underlying academic research which developed during the cold war decades are being challenged. As US society positions itself to compete successfully in the emerging global economy, funding levels and patterns, as well as the structure and size of the research enterprise, are bound to change.

Members recognize that adapting to change and shaping creative responses to political and economic realities will require flexibility and a willingness to experiment—with the intendant understanding that experiment entails risks and results in failures as well as successful new structures. They were nevertheless clear in their commitment (1) to undertake a critical re-examination of graduate education and the underlying assumptions of the academic culture in which it takes place; and (2) to urge the community and its funding agencies to develop and support experiments aimed at stimulating healthy change and finding new approaches to better serve both our students and society—fully recognizing that funds directed towards enabling such experiments, may decrease the number of dollars available to support other desirable programs.

Indeed, participants remarked that given the will to experiment expressed in the regional meetings, the small size of the astronomical community represents an advantage: lower community “inertia” can enable relatively rapid response to a changing environment. Despite its modest numbers, astronomy could in principle play a leadership role in exploring new approaches to graduate education.

4.1.2 *Retain primary focus on producing first rate research scientists*

Participants urged that in selecting and funding experiments, great care be taken (1) to minimize risks to a structure which has proven enormously successful in training scientists who have carried out world-leading research in astronomy for more than 50 years; (2) to subject experiments in graduate education reform undertaken with federal support to the same rigorous standards of peer-reviewed evaluation that inform selection of first-rate research proposals.

4.1.3 *Deliberate reduction of the population of graduate students or of graduate departments is not wise*

Past trends and current predictions suggest that of those presently enrolled in graduate school, no more than 30% will assume permanent positions in academia or national laboratories. Despite these predictions and the recent rise in astronomy PhD production, workshop participants—including students—felt strongly that neither graduate schools nor funding agencies should adopt practices aimed at matching graduate admissions to perceived “traditional” job opportunities.

First, it was agreed that the admissions process is imperfect; identifying college seniors with the combination of intelligence and temperament matched to a research career is,

with few exceptions, extremely difficult. Practicing “birth control” at this stage would result in premature evaluations based more on “objective” criteria than on assessment of a student’s performance in a graduate research department. Moreover, “birth control” at this early stage would almost certainly compromise the ability of graduate departments to meet their stated goal of enhancing diversity in the physical sciences.

Second, birth control via elimination of departments was also deemed both unwise and impractical both (1) because astronomers in small, recently-formed departments make significant and imaginative contributions to training productive MScs and PhDs; and (2) even were one to adopt implicit or explicit strategies to eliminate or curtail support for the “lower” half of the 74 degree-granting institutions, the current PhD production rate would be decreased by only 20%.

Furthermore most participants believed that graduate training in astronomy provides students with a strong background in physics, and experience in posing and solving problems—two critical components of the skill mix needed for success in a wide range of careers. It was felt that if changes were to be made, they should be directed toward expanding the goals of graduate education. This would allow us to improve our preparation of individuals able to contribute creatively to the economic well-being of the nation rather than to retrench in order to avoid “overproducing” PhDs for the academic market.

4.1.4 Provide students with accurate and up to date career statistics and clear information regarding alternative careers

The mismatch between PhD and “traditional” job production rates places a special obligation on graduate departments to provide students with accurate information regarding career trends and the career paths taken by past graduates. Participants agreed that departments should assume responsibility for longitudinal tracking of their graduates and for making such information available both to applicants and to the AAS. In turn, the AAS should use these data (with specific linkage between names, departments and outcomes omitted) along with corresponding NRC information for the physical sciences to compile an up-to-date statistical picture of short- and long-term job trends.

4.1.5 The combined median time-to-degree of 7 years followed by 2 postdoctoral fellowships is unreasonably long

Participants were unanimous in the belief that the current norm—spending 7 years in graduate school and 6 or more years in post-doctoral positions before determining whether a career in astronomy represents a realistic option—is unacceptable. While some argued that placing a hard 4 to 5 year limit on time-to-degree would be a desirable first step in reducing the “time to career decision,” there was no consensus, and in fact considerable reluctance, to commit to a specific set of guidelines or to mandatory federal funding caps aimed at reducing time-to-degree. Others argued that imposing mandatory statutes might have the undesirable goal of reducing the population of women and mi-

norities in our field. Moreover, many participants remarked that a recommendation to broaden graduate education and to reduce the time to degree might well be inconsistent.

This critical area is one which would benefit from additional structured discussion both within the community and with our funding agencies, perhaps in the context of the next decadal survey. The discussion should have the goal of recommending community guidelines that would address reducing both the time-to-degree and the time young PhDs must wait to postpone long term career decisions.

4.1.6 Changing the academic culture

Participants acknowledged that a realistic re-examination of graduate education requires that departments and institutions look critically at the “cultural” assumptions which inform their actions. In particular, the current system primarily (or exclusively) rewards those who pursue academically-based fundamental research. Often, pursuit of alternative intellectual challenges—for example, those focussed on the educational missions of the institutions—are discouraged either actively or passively, sending clear messages to young faculty and students alike.

Many participants lamented the constraints of the present system but were unable to develop consensus recommendations regarding mechanisms for escaping its “traps.” As a first, relatively painless step, it was recognized that modest readjustments in attitude by graduate faculty could make a significant difference in the self esteem of students who wish to pursue broader educational goals. There was also agreement that in the long run institutional and federal incentives aimed at stimulating cultural change will be critical.

However, it was impossible in the time available to develop consensus regarding desirable changes, and the institutional and federal funding and review practices required to effect them. The subject is complex, and developing consensus regarding sound community guidelines for change will be difficult. However the issues are central to the future of the community and merit additional careful discussion, perhaps in the context of the next decadal survey.

4.2 Broadening Academic Options: Conclusions

4.2.1 Emphasize basic scientific training and problem solving skills

The regional working groups were unanimous in urging that astronomy graduate education remain focussed primarily on providing basic scientific training and problem solving skills, through coursework and research experience. Many argued that because astronomy is by nature highly interdisciplinary, this approach—thoughtfully applied—would ensure that students are prepared to address a broad range of problems in the physical sciences, even absent any additional curricular changes. Some participants expressed the belief that it might be timely to re-examine extant departmental offerings to ensure that courses continue to emphasize fundamental skills as opposed to increasingly specialized content.

There was unanimous agreement that curricula should stress early research experience to enable students to begin as soon as possible to develop the skills required to pose and solve problems, both independently and in groups.

4.2.2 Broaden graduate education

Despite the interdisciplinary training inherent in astronomy graduate programs, there was resonance with the Griffiths and Armstrong recommendations to complement sound basic training and problem solving skills with curricula that encourage increased exposure to both “hard” (e.g. numerical simulation and visualization techniques, astronomical instrumentation, database management) and “soft” (e.g. communication, team problem solving, management, teaching) skills during their graduate careers. Each group believed that broadening academic options in this way would benefit students both by enhancing their potential effectiveness as researchers in astronomy and their ability to secure rewarding, “non-traditional” jobs.

Very modest levels of federal funding directed toward supporting curricular changes incorporating the above elements would, in our view, stimulate experiment and healthy change throughout the community. We strongly urge the funding agencies to work with the community to develop programs that would enable departments to propose innovative approaches aimed at providing opportunities for graduate students to develop broader skills. We believe that investments aimed at encouraging (1) partnerships with other departments within their institutions, with local industry, with local schools, and (2) development of enhanced MSc programs would be particularly efficacious.

4.2.3 Achieving broadening goals must not add new courses to graduate curricula

However, broadening the graduate experience was deemed best accomplished by restructuring extant courses and pre-dissertation research experience rather than by requiring students to take additional specific classes; current requirements have already driven the median time to degree to 7 years—a time which was deemed unacceptably long.

4.3 Creative and Rewarding Teaching Experiences Should Be Provided

Participants were unanimous in their belief that graduate curricula should be structured to provide mentored classroom teaching experience, and to encourage development of a wide range of teaching skills (e.g. communication of physical concepts to non-scientists, developing interactive course modules). Developing these skills will serve students well in a variety of careers: in traditional academic research positions, in teaching positions at all levels, and in a wide range of private sector jobs. Again, participants believed that integrating teaching experience within extant curricula would be far preferable to requiring students to enroll in specialized courses focussed on teaching methods. Developing approaches—including federal funding incentives aimed at encouraging curricular changes to enhance student teaching

experiences (for example, through award of federally-funded “science education fellows”)—was deemed to have high priority.

4.4 Graduate Student Support Modes: Conclusions

4.4.1 Increase the opportunity for training in instrumentation

There was near-universal agreement that NSF and NASA be urged to initiate or expand programs to identify, encourage and support individuals who have the inclination and aptitude to pursue careers related to astronomical instrumentation and technology development.

A number of participants urged initiation of short term internships of 2–4 months duration—modeled after the NSF REU programs and targeted at a broad cross-section of students just beginning their graduate careers. Such programs would be hosted by labs in academic, national observatory, or industrial settings, and would provide intensive exposure to astronomical instrumentation to students in their first or second year of graduate school. For some, such a program might act as a catalyst to choosing instrumentation development as a career path. For most, the experience of working in a laboratory environment would represent an important addition to their graduate training by providing exposure to a broad range of skills (instrumentation design and development; team research; project management) which have wide applicability in both the academic and private sectors. Indeed, observatory graduate internships may be essential for the future of astronomical research, in that they may be the only way that a sizable fraction of future researchers gain hands-on experience with the complex instrumentation of the next generation telescopes.

There was also considerable support for increasing the number of longer term internships or traineeships at industrial, national or major university laboratories, aimed at students desiring a career in instrumentation. This would require targeting additional NSF or NASA fellowships toward individuals with strong potential for careers in instrumentation development.

4.4.2 Increase the availability of fellowships after 2–3 years

A consensus view emerged from all 3 workshops: (1) competitively awarded fellowships represent an important mechanism for supporting first rate students and enabling them to structure successful graduate careers, and (2) that their number should be increased. Participants urged that more emphasis be given to awarding such fellowships not at entry to graduate school, but rather after 2 to 3 years when a student’s competence, aptitude and temperament for research had been evaluated. Some were in favor of offering the fellowships after competitive review of dissertation proposals, citing as advantages: (i) developing early “focus” for a dissertation through the discipline of preparing a structured proposal; (ii) providing “real world” experience in competitive proposal writing; (iii) enabling students to chart and follow a brisk timetable for completing their research independently of the demands often placed by requirements to meet deadlines/requirements of funded research programs; (iv) the

opportunity to structure mentoring relationships with a broader range of faculty, including those whose research support may already be committed to other students.

4.4.3 Do not abandon traditional research assistantships

The traditional model in which most graduate students are supported via research assistantships administered by individual investigators is, however, considered basically sound and should remain the preferred mechanics for supporting PhD students. Participants argued strongly that this approach represents a demonstrated means of ensuring that graduate students are closely mentored, and work on cutting edge science selected for support via competitive peer review.

As a result, workshop participants and other members of the community urged caution in shifting the balance of federal support away from RAs and towards fellowships/traineeships—with the exception of urging “full speed ahead” on the recommended programs to increase opportunities for training in instrumentation.

They argued instead that the community would be well served by a careful, structured community discussion regarding funding patterns and practices that will best meet the needs of students, the discipline and society. The upcoming decadal survey provides an appropriate and timely forum for developing such recommendations.

4.4.4 Do not adopt policies which disadvantage foreign nationals

While endorsing experiments to somewhat alter the balance of funding support toward the fellowship/traineeship modes, participants at the same time expressed deep concern that effecting these experiments might have the unwanted consequence of decreasing support opportunities for foreign students (at present, federally-funded fellowships can be awarded only to US citizens). There was near-unanimous agreement that astronomers should avoid implementing practices which implicitly or explicitly erect barriers to access by foreign nationals to US graduate programs. It was emphasized that astronomical research in the US has benefitted enormously from the vigor and imagination of foreign nationals, and that construction of large ground- and space-based research facilities increasingly depends on cooperative efforts with multiple international partners. The effectiveness of these partnerships depends significantly on establishing close personal collaborations and mutual understanding of cultural differences—both of which develop naturally in a system which is open and financially accessible to foreign nationals.

4.4.5 Do not move to block grants

All three regional workshops considered the possible merits of block grants awarded competitively to departments who propose experiments aimed at reshaping their graduate programs to take advantage of unique circumstances (e.g. linking with industrial partners; linking with a school of education to develop a focussed program in science education). There was considerable skepticism regarding both the

mechanisms and review criteria that might be used for block grant evaluation. Moreover, participants felt that block grants historically have not typically met the same quality standards typical of peer-reviewed individual investigator grants.

However, the reluctance to adopt the block grant mechanism *per se* should *not* be interpreted as a lack of enthusiasm for providing a variety of opportunities for funding experiments aimed, for example, at comprehensive curricular reform, partnerships with industry, or imaginative Master's programs. There was, instead, near-unanimous support for encouraging such experiments, provided that they were designed by first rate investigators and subject to rigorous peer review.

4.5 The Master's Degree: Conclusions

4.5.1 Consider developing enhanced MSc programs

There was interest in encouraging departments to develop enhanced Master's degree programs designed to provide the broad and thorough training necessary for students to either continue with a PhD in astronomy or a related field, or to leave graduate school armed with the skills necessary to embark successfully on a variety of career paths.

Schools embarking on this path would offer a MSc program of 2–3 years duration with a core curriculum providing (1) basic scientific training via thorough introduction to the physical principles underlying astronomy and astrophysics; (2) mentored, creative teaching experience; and (3) mentored research experience. In addition to this curricular core, MSc students would also develop expertise in both “hard” skills, such as high speed computing, visualization techniques, and instrumentation, and “soft” skills, such as effective written and oral communication and team problem solving through structured research projects, either in the classroom, in national or industrial laboratories, or with local facilities.

4.5.2 Consider the merits of requiring an MSc for entry to a PhD program

Perhaps the most surprising and potentially far-reaching outcome was the groundswell of support in advance of the workshops expressed for requiring all students to complete an enhanced MSc prior to admission to a PhD program.

While there was not uniform support for this idea, proponents argued that this path would (1) allow institutions to recruit more widely and take greater risks in admitting potentially talented individuals; (2) provide both students and faculty with an opportunity to “pause and reflect” prior to making a commitment to pursue a PhD or to choose a different career path; (3) allow institutions to be more selective in admitting students to a PhD program; and (4) allow graduate programs to grow in stimulating and potentially beneficial new directions, by forging links and partnerships with a wider scientific community.

The notion of an interlude to “pause and reflect” before committing to a PhD dissertation was particularly appealing to our graduate student participants. Many of them acknowledged that with no clear understanding of careers available to Master's Degree recipients, pursuing a PhD often seems the simplest path to follow. Some students even acknowledged

that they continued graduate study past the Master's level, knowing that a research career in astronomy was not their ultimate goal.

Other participants were deeply wary of this approach because:

- a required Master's program of 2–3 years duration might increase the time to PhD, and might in particular slow the progress of the very best students—those who are poised to complete a PhD program within 4–5 years.
- without a national consensus to adopt a required MSc, institutions might use the absence of such a requirement as a tool to gain a recruiting advantage.
- an implicit national policy to require an MSc as *sine qua non* for admission to a PhD program might intrude on the rights of an institution to set policies and practices best suited to its strengths and aspirations.

The issues raised by the proposal of an enhanced, required MSc require far more time for thoughtful dialog than was available during the workshops. Further discussion of this issue in the course of the upcoming decadal survey would allow the community to discuss more fully the advantages and disadvantages of this proposal.

4.5.3 Potential niche for professional Master's degree in astronomy instrumentation

Participants noted the potential of a relatively small but still significant niche for specialized Master's degrees in astronomy-related instrumentation. Such programs might be tailored to develop the skills required to work on academic/industrial teams that will design and operate the sophisticated instruments and detectors required for present and future ground- and space-based facilities. There were felt to be advantages to having people with some astronomy background in these important positions.

4.5.4 Potential niche for professional Master's degree in astronomy education

A potentially larger role for Master's students might involve participation in formal or informal education programs (museums; planetaria; outreach programs linked to observatories or large projects). Some participants suggested the possibility of developing a joint Master's programs with schools of education, with the aim of bringing the excitement of astronomy to the classroom and to K-12 curricula. To effect such programs would realistically require developing incentives—in the form of funding opportunities—to overcome the barriers to cooperation between traditional academic and education departments.

4.5.5 Potential niche for professional Master's degree in astronomy and related fields

Several participants reported success in developing Master's programs involving collaboration with departments of engineering and computer sciences. In some cases, these programs involve internships with local industries. They appear to provide strong cross-disciplinary training for students and effective research collaborations for faculty, particularly at institutions with relatively small departments. Participants

urged developing mechanisms—including seed funding opportunities—to encourage and support such programs where local conditions are favorable.

5 RECOMMENDATIONS

Recommendations stemming from discussions carried out during the past year fall into two general categories. The first comprises actions to be undertaken over the next two years by individual departments, the AAS, and the funding agencies. The second includes additional recommendations that should be considered carefully as part of a continuing effort to improve graduate education in astronomy.

5.1 Action Items

5.1.1 Support experiments to enrich graduate education

- Federal and state resources should be allocated to develop pilot programs aimed at providing students with structured opportunities to gain broader experience and exposure to cultures outside academia during their careers. Example programs might include (1) developing new curriculum options involving partnerships between astronomy and other university departments, with industry, or with local schools; (2) developing enhanced MSc or specialized professional Master's programs which provide students with exposure to additional “hard” (e.g. high speed computing and visualization techniques; instrumentation; teaching) and “soft” skills (communication; team problem solving) in addition to basic training in physics and astrophysics; and (3) providing fellowships/traineeships targeted at exposing students to instrumentation development, formal and informal science education and curriculum development, and the demands, expectations, and culture of industry and national laboratories. The investments in such experiments could be quite modest, but in our view would provide an important—perhaps essential—stimulus to developing a climate in which change is encouraged and valued.

- The AAS should provide a forum for publicizing ongoing curricular experiments, and for critical discussion of both successful and failed experiments.

5.1.2 Provide students with information and opportunities for a broad range of career decisions

- All astronomy departments should develop complete databases of employment histories of recent graduates, both Master's and PhD recipients, in order to provide the basis for student evaluation of departmental success in placing students in challenging positions/careers, and to enable “networking” between currently enrolled students and past graduates.

- The AAS should compile and publish electronically a database synthesizing national statistics on employment trends for doctoral recipients.

- All departments should develop mechanisms to expose their students to individuals engaged in a variety of challenging, non-academic careers which make use of skills acquired in the course of graduate education in astronomy.

- The AAS should develop programs aimed at providing students with realistic information regarding non-academic

careers, via career seminars. The Society should also develop a list of potential speakers for departmental career seminars.

- The AAS should work with astronomy PhDs currently pursuing non-academic careers with the aim of developing sessions at Society meetings that will appeal to such individuals. The Society's goal should be to sustain long term relationships with astronomers involved in a wide variety of careers.

- The AAS should coordinate closely with other scientific societies currently developing similar programs—in particular, the American Physical Society, the American Chemical Society, and the Joint Policy Board for Mathematics.

5.1.3 Re-examine the structure and role of the Master's degree in astronomy

- The astronomical community should carry out a structured national review of the merits and liabilities of (1) developing an enhanced Master's degree program designed to provide the broad and thorough training necessary for students either to pursue a PhD, or to leave graduate school armed with the skills necessary to embark successfully on a variety of career paths; and (2) requiring such an enhanced MSc for admission to a PhD program.

The proposed review might be incorporated as part of the next decadal review, perhaps following additional discussion organized by the AAS to better frame the key issues.

5.2 Additional Recommendations

5.2.1 Provide students with better experience in real world skills

- proactively incorporate team problem solving, written/oral presentation, proposal writing and management skills into graduate curricula in order to better prepare students for a wide range of careers, including traditional academic research.

5.2.2 Provide students with creative and rewarding teaching opportunities

- provide mentored classroom teaching experience and involve students in curriculum and courseware development.
- provide non-traditional TAs such as partnerships with local school teachers, planetaria, etc.
- provide AAS teaching workshops for graduate students led by science educators.

5.2.3 Expand opportunities for students to gain exposure to related disciplines and technologies

- Encourage graduate minors in related fields.
- Develop and evaluate models of Master's degree programs which involve cross-disciplinary training and collaborations with local partners, such as industry or education departments.

5.2.4 Critically examine the current "academic culture"

- Work consciously to change attitudes reflecting an overly narrow (and unrealistic) definition of success.
- Review the reward structure which informs promotion, tenure and merit recognition to ensure that it is aligned with

"messages" a department wishes to transmit to faculty and students regarding the goals of graduate education and the definition of a "successful" graduate.

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APPENDIX A: PARTICIPANTS IN AAS REGIONAL GRADUATE EDUCATION WORKSHOPS

A.1 Keynote Speakers

Marye Anne Fox, Vice President for Research, U. Texas at Austin
 Phillip Griffiths, Director, Institute for Advanced Study
 Neal Lane, Director, National Science Foundation

A.2 PhD Granting Graduate Departments

(N=59)

University of Alabama
 Arizona State University
 University of Arizona
 Brigham Young University
 University of British Columbia
 Caltech
 Carnegie Mellon University
 Case Western Reserve

University of Chicago
 University of Colorado
 Columbia University
 Cornell University
 UC Berkeley
 UC Davis
 UC Irvine
 UC Los Angeles
 UC Riverside
 UC Santa Cruz
 University of Delaware
 University of Florida
 Georgia State University
 University of Georgia
 Harvard University
 University of Hawaii
 University of Illinois
 Indiana University
 Iowa State University
 Johns Hopkins University
 University of Kentucky
 Louisiana State University
 University of Maryland
 University of Massachusetts
 Universidad Nacional Autonoma de Mexico
 University of Michigan
 Michigan State University
 University of Minnesota
 University of Nebraska, Lincoln
 University of New Mexico
 New Mexico State University
 University of North Carolina
 Ohio State University
 Pennsylvania State University
 University of Pittsburgh
 Princeton University
 Rice University
 Rutgers University
 University of Rochester
 San Diego State University
 Stanford University
 Suny, Stony Brook
 University of Texas
 Texas Christian University

Vanderbilt University
 University of Virginia
 Virginia Tech
 University of Washington
 University of Wisconsin
 University of Wyoming
 Yale University

A.3 Others

Mark Adams, McDonald Observatory
 Cindy Blaha, Carleton College
 Marc Davis, CAA
 Roger Davis, NM Science and Technology Company
 Judy Franz, Executive Director, APS
 Howard French, Honeywell Corporation
 Richard Greene, NOAO
 George Greene, Dean of Graduate School, UMN
 Karen Greif, National Research Council
 Bill Herbst, Wesleyan University
 William Harris, Biosphere II Center
 Patricia Keller, Education Department, UMN
 Charlotte Kuh, National Research Council
 Louis Lanzerotti, Lucent Technologies
 Susan Lea, SFSU
 Bernard McDonald, NSF
 John Neithammer, MN Technology Inc.
 Stephan O'Neil, Technology Transfer, U Colorado
 Leonid Ozernoy, George Mason University
 Ted Poehler, Provost, Johns Hopkins University
 Jeffrey Rosendahl, NASA
 Russ Ritenour, Radiology, UMN
 Andrea Schweitzer, Honeywell Corporation
 James Schuder, Sun Microsystems
 Hugh Van Horn, NSF
 Paul Vanden Bout, NRAO
 Kim Venn, Macalaster College
 Jim Voytuk, National Research Council
 Sidney Wolff, NOAO
 James Wright, NSF
 Charlie Wu, STScI

A.4 AAS

(N = 11)

Doug Duncan, Education Coordinator
 Andrea Dupree, President
 Suzan Edwards, AEPB

Andy Fraknoi, AEPB
 Alex Filippenko, AEPB
 Katy Garmany, AEPB
 Len Kuhi, Treasurer
 Gene Levy, AEPB
 Bob Milkey, Executive Officer
 Michal Simon, AEPB
 Steve Strom, AEPB

APPENDIX B: KEYNOTE ADDRESSES

B.1 The Obvious and the Overlooked

Neal Lane, Director, National Science Foundation
 1 November 1996
 Washington, D.C.

Good evening. It is truly a pleasure and an honor to join you as keynote speaker for this first in a series of workshops on graduate education in Astronomy. My thanks go out to Andrea Dupree and Bob Milkey and the AAS's education policy committee for giving me this opportunity.

I appreciate that we have the full spectrum of the astronomy community represented here today. We know the success of our efforts hinges on hearing from everyone—students, faculty, recent graduates, industry employers, funding agencies, societies, and others. The fact that all of us are here and have taken time to participate in these workshops sows the seeds of success for our collective efforts.

For me personally, it is also especially gratifying to know that I share the marquee for this series with good friends and outstanding leaders like Marye Anne Fox and Phil Griffiths. I can't tell you how fortunate I feel that my talk comes first in this series. Following Phil and Marye Anne would be like being asked to apply a second coat after Michelangelo painted the ceiling!

As I was preparing for this talk, I stumbled across a story that underscored one of the ironies of life in today's world. It seems an assistant high school track coach had set up a make-shift office in the team's equipment shack. His job was to record the runners' times and distribute them to other coaches. The shack had no electricity, so computers and copiers weren't an option for data entry and communicating the results—not unlike some observatories I've heard about.

For this reason, the coach ended up relying on the tried and true system of a manual typewriter and carbon paper to produce multiple copies of his tabulations. One of the student-athletes saw him lining up the carbon paper and pecking away and said, "Wow. That's amazing stuff. Soon we won't need copier machines anymore."

This story, in addition to highlighting a modern-age generation gap, also reminds us of the astounding pace of progress in our world today—which brings me to the subject of my talk today.

My remarks are entitled, *The Obvious and the Overlooked*. I want to focus on two topics—one obvious, and one that we often overlook. The obvious and sometimes obsessive topic is change—specifically changes in the so-called compact between science and society. We need to approach

these changes in a thoughtful manner, recognize they are real and probably irreversible, and appreciate their implications for graduate education.

The second topic I will address—the one we often overlook—is the opportunity presented by this period of change, specifically the opportunities brought by the advent of a new age of information and knowledge, an age of advanced computation, communication, and information technologies. These have immense implications for all fields of science and engineering, astronomy in particular, and engineering and their role in our society.

My message today is that we must explicitly factor both of these topics into our thinking and our recommended course of action. Far too often, our instincts are to focus too narrowly on responding and adapting to change. As important as this is, it is not enough. The greater challenge—less distinct but certainly more rewarding—is to position ourselves to pursue the opportunities emerging at this, the dawn of the 21st Century.

I have a particular interest in these issues as they relate to astronomy. Throughout my career, in my own work and experience, I have seen time and again that astronomy is a source of inspiration, motivation, methods, and technologies, and insights for much of science and engineering. Astronomy is, without question, a key to progress for our entire enterprise. Our innate desire as humans to understand the cosmos has fired the creative genius of our brightest minds for generations. That will certainly always be true.

I once had the honor of writing a chapter on the contributions of my long-time mentor, Alex Dalgarno of the Harvard-Smithsonian Center, to atomic and molecular physics—structure, collisions, and interactions with light. The experience was very pleasant but at the same time frustrating given the enormity of the contributions Alex has made and the paucity of pages I had been allotted to describe them.

As I was reviewing all this work and, more generally, the many connections between the atomic, molecular, and optical sciences and astrophysics, I was once again struck by the power of astronomy and astrophysics in motivating and stimulating scientific discovery across the broad sweep of time and virtually all fields.

Equally striking examples of these connections were highlighted just two weeks ago at a major event here in Washington. The five Americans awarded the 1996 Nobel prizes in physics and chemistry came here to spend a day in the media spotlight. It gave them the chance to showcase their achievement and discuss the value of science and the role of NSF and other Federal support in their success.

Hugh Van Horn, NSF's Division Director for Astronomy, reminded me of an interesting storyline that emerged from their presentations. The breakthroughs that earned them the Nobels were inspired in large part by questions emerging from astronomy.

Rick Smalley and Bob Curl of Rice University, who shared the Chemistry award with Harry Kroto of the University of Sussex, made this very point. They told of how Kroto's interest in the long-chained carbon molecules detected by radio astronomers first led them to apply their laser-

supersonic cluster beam apparatus to carbon. That led them to the buckyball, and the rest is history.

The physics laureates, David Lee and Robert Richardson of Cornell and Douglas Osheroff of Stanford had a similar story to tell. They described how their initial interest in the superfluidity of Helium 3 was inspired by questions about the behavior of Fermi liquids within neutron stars.

These examples underscore the importance of our gathering here today and of this series of workshops. It is vital that we sustain and nourish the astronomical and astrophysical sciences, and ensure that they remain rewarding and inspiring fields of scientific endeavor and education. As these examples show, this works to the benefit of the entire science and engineering enterprise and our nation as a whole.

Our workshop planners may not have known this, but it is highly appropriate that November 1 was chosen as the opening day for this session. Forty-four years ago today, the first H-Bomb test was conducted. That's an anniversary that may trouble some of us, while reassuring others. It nevertheless also provides an indelible reminder of the role science has played in our national security, and conversely of the role national security has played in justifying public support for science. That brings me to the subject of change.

All of us here today know better than most that the Federal government's significant role in the support of science grew from the contribution American scientists made during World War II—not just in applications of nuclear science but in countless other areas as well. Although in many nations the scientific community has been called upon to help with a war effort, only the United States, through the articulation of Vannevar Bush, adopted a genuine pact between science and the rest of society.

The agreement outlined by Bush was reinforced, especially in our attitudes and rhetoric, by the significant demands of forty years of Cold War. It is debatable, and hotly debated, how important the Cold War was to Federal support of science. But, most would agree that Bush's agreement garnered much of its legitimacy and sense of irreversibility from the nation's overarching national security needs.

Since the end of the Cold War six years ago, many in our community have been debating the tenets of the compact between science and society. Does it need to be revisited, reformed, reconstructed? The implication being that a simple rewrite and update of the compact could usher in a new golden era.

Reality, of course, is not so simple. In a very real sense, this debate was eclipsed before it began. A more divergent perspective on science and technology has taken hold—a perspective that I believe we need to understand and articulate. It seems to me something very different from the “compact” that has been emerging in practice over the last 10–15 years while many of us have remained wedded to the old rhetoric. The initial compact of the Vannevar Bush era has evolved, perhaps without our conscious attention.

What has taken shape, I believe, is a more expansive and multifaceted arrangement that encompasses the larger R&D enterprise in the nation, both public and private. This includes, of course, industry, small business, national laboratories, mission agencies, research universities, and state and

local economic development councils. These, and others I have not named, are critical components of the new, and as yet unbaptized, arrangement that has grown from the original compact.

And so, as we continue to speak with reverence about the compact between science and the federal government, we are, in fact, thinking of the past more than the present. I want to emphasize strongly that I am not suggesting we lessen or eliminate the Federal role in support of fundamental research, primarily in our universities. I believe just the opposite. Rather, I am suggesting that this new perspective is a way to recharacterize the roles and positions of all participants in the national research and development system, as the system has evolved and matured. It is accurate to say that our once narrow compact has blossomed into a cornucopia.

And so for those who are threatened by imminent changes in the old compact, I would comfort them with reality—the reality that those changes have been in play for some time. The current R&D enterprise that has evolved from the old compact is not now, and never will be, a cemented set of dogma. Rather, time and events have fashioned a dynamic and sometimes even spontaneous system. There will be no reversal of this momentum.

The reality of these changes—and their irreversibility—is most apparent in the focus of our discussion today: graduate education. There was a time, not very long ago, when newly minted PhDs were often considered disappointments if they had to venture beyond academe or a small set of eminent research labs to secure employment. Today, it is folly to try to turn back the clock and ask whether there will be enough faculty openings and traditional research positions for tomorrow's PhDs. That is too narrow a way to think about graduate education.

I noticed that the background materials prepared for these workshops included a number of references to what's commonly called the “COSEPUP report on graduate education.” This report does deserve our attention, in part because it makes clear that a structural change has occurred. It notes that, “Among recent PhDs, there is a steady trend away from positions in education and toward applied research and more diverse, even non-research employment.”

We see this trend in virtually all of science and engineering. It is perhaps most acute in the mathematical and physical sciences, though no fields are immune. Where 20 years ago, the majority of PhDs embarked on academic careers after graduation, today a majority pursue careers outside the academy.

Our friends at the American Chemical Society and the American Mathematical Society tell us that a sizable fraction of new PhDs are encountering prolonged and increasingly frustrating job searches. Over 20 percent of PhD chemists report being unemployed up to six months after graduation. Over 10 percent of new PhDs in mathematics report being unemployed a full year after graduation.

The situation is virtually the same in astronomy. The Survey of Earned Doctorates sponsored by NSF's Division of Science Resources Studies testifies to this.

• In the early 1970's, a PhD astronomer had a roughly 50/50 chance of landing a permanent position upon gradua-

tion. That figure has since dropped to 20 to 25 percent.

- The great majority of the remainder continue their education in one way or another. Forty percent of the class of 1995 received postdoctoral research associate positions. Another one-third chose the route of additional study in other fields.

The bottom line is that 7 out of 10 recent PhDs in astronomy have not obtained what most of us would consider stable or satisfactory career positions.

We've all witnessed this feed a vicious cycle of frustration and even resentment for many of America's best and brightest. You may have seen the *New York Times Magazine* article that ran in late September entitled, "How to Make a PhD Matter." The author is a professor of English, but his opening observation matches much of what we are seeing in the physical sciences. He writes: "Getting a PhD today means spending your 20's in graduate school, plunging into debt, writing a dissertation no one will read—and becoming more narrow and more bitter each step of the way."

Most of us find more than a small measure of irony and incongruity in this state of affairs. We all recognize that the frustrations are real and the discouragement profound. But, we also know that the research itself remains a hotbed of excitement and amazement. Everything that attracted us and continues to attract young people to research remains as abundant as ever.

In just the past year, we have witnessed the discovery of planets orbiting stars beyond our solar system, gained new insights into dark matter, and viewed images of the birth of galaxies. We have even been tantalized by the prospect of ancient microbial life on another planet. While the jury is still out on that last finding, it nevertheless helps to fortify and elevate the sense of optimism and opportunity surrounding astronomy.

Indeed, I believe this sense of optimism and opportunity belongs at the center of our deliberations on the future of graduate education. We cannot afford to have it otherwise—or to overlook these opportunities. We may be witnessing the emergence of a new era of discovery and progress for science and engineering in America. Leadership from the research community—astronomy in particular—will determine whether we realize the opportunities it offers.

Consider, for example, the data on U.S. economic growth since World War II. Our GDP has grown by a factor of six over the past five decades, thanks in large part to scientific and technological progress. Economists have concluded that innovations emerging from science and technology account for roughly one-third of all economic growth over the past half-century. That's an amazing accomplishment—one in which we should all take great pride.

But I would argue that the best is yet to come for science and technology. Our role and our contribution will be even greater in the future. We have now entered what many are calling "the information age," and it promises to be an age where progress and success are shaped by scientific and technological endeavors.

This potential for progress emerges in large part from advanced computing, communications, and information technologies, such as those related to the World Wide Web. This

has revolutionized physics, astronomy, and virtually every field of research. It's changed how we conduct research, post results, access data and images, develop and debug code, and search for jobs and explore career options. We can even read *Ap.J. Letters* weeks before it arrives in printed form.

All of this, as powerful and revolutionary as it is, represents just one small hint of the potential impact of these emerging technologies on our society. This impact is so profound that it may well redefine how we view terms like "school," "classroom," "laboratory," "university," and "career in science and engineering."

In a trilogy of speeches delivered in February of this year, Vice President Gore suggested the metaphor, "distributed intelligence," to describe this new age of intelligent systems. It is a complicated metaphor, based on applying the principles of parallel processing and networking to social challenges and economic progress. It is noteworthy in and of itself for the Vice President of the United States to discuss things like massive parallelism and broad bandwidths. That's almost certainly a first in our history.

Distributed intelligence rests upon one key concept: shifting information and control away from centralized systems to the individual. It's a notion we've been discussing at NSF for some time, even before the Vice President introduced the metaphor.

One could say that this involves all of society getting wired, except that it won't always involve wires. This may yield an age in which the sharing of information is instantaneous and ubiquitous. We are already gaining a few glimpses of its potential impact on both science and society:

- We can now buy plane tickets without a travel agent, just as we can now access the most advanced software for cosmology simulations without a programmer.

- It applies to activities as simple as pumping our own gas or banking through an ATM, and as complex as remote observation and distance learning.

- It has also given us new ways to open the frontiers of science to the widest possible audience. JPL's Shoemaker/Levy home page has been visited over 7.5 million times, and Internet watchers also reported a flurry of use when Comet Hayakutake graced our skies.

At NSF, we are exploring how to approach this concept in ways that maximize both its scientific potential and its benefit to society, and we are still grappling with some of the basic terminology. We are currently developing approaches that come under headings like "learning and intelligent systems" and "knowledge networks." These include such activities as data mining, visualization, pattern recognition, improved human/computer interfaces, and learning technologies. We believe all of these hold immense benefit both from a scientific standpoint and as drivers of economic growth and social benefit.

When we view graduate education in the context of these activities, it points out the fundamental dilemma we face.

- On the one hand, we know that the knowledge and skills our students acquire are well suited for tomorrow's opportunities and challenges—not just in research but in a wide array of careers. Students learn to master and often invent cutting edge technologies; they tackle deep and complex

problems, and they hone their talents for creativity and ingenuity at every step of the way.

- On the other hand, we also are beginning to understand that the traditional goals, attitudes, and approaches of our system may belong to a different era. The workshop hosted by NSF's MPS directorate in June of 1995 stressed this in its summary report: "...students are unaware not only of the options available to them outside of academia, but also of the applicability of [their] skills...to fields other than the one they have trained to enter."

Fortunately for all of us, countless efforts are underway to remedy this dilemma. Most of these are department and discipline-based. At NSF, we have developed a number of mechanisms designed to encourage these grass-roots efforts.

- We are exploring new forms of traineeships that by design will give students a wider array of experiences during their studies. This extends directly from one of the recommendations of National Science Board Task Force on Graduate Education, co-chaired by Marye Anne Fox and Eve Menger.

- We have also launched an effort to review the criteria used in our Merit Review process. Given the role of research funding in graduate education, this is especially relevant to our gathering here today. We'll be setting up mechanisms to get your input via NSF's web pages. This should all begin around Thanksgiving. I encourage all of you to follow this effort closely and send us your views.

- We've also established new programs, such as GOALI—short for Grant Opportunities for Academic Liaison with Industry. This makes it easier for faculty and their students to collaborate with industrial colleagues. Thus, students can get a better idea of the culture, opportunities, and intellectual demands of industry.

- To cite one specific example, the University of Rochester and the Rockwell International Science Center are working together with help from GOALI to develop long-wave focal plane detector arrays. It's the kind of collaboration that has evolved into a true win-win-win situation. Rockwell gets valuable input from astronomers. The university community gets access to devices that are otherwise prohibitively expensive. And, students gain valuable experience working with the private sector.

None of these efforts provides the magic bullet for the challenges we face. We know that. It will take much more—and most important of all it will take a commitment to working together and testing and exploring new approaches.

To conclude my remarks this evening, let me first say that I know I am asking a lot of you. I am asking you to do more than just respond to change, but also to exercise leadership that will help position the entire science and engineering community for new opportunities. That is a tall order, but I can't help but to recall the last time I spoke to an AAS gathering—last January in San Antonio.

Those who were there caught the full throttle of my frustration over the government shutdown and prolonged budget battles. I called upon the astronomy community to lead and help spread word about the importance of stable funding for research. You delivered, and the entire science and engineering community followed your lead. I believe it is no coinci-

dence that this year NSF's budget was in place prior to the start of the fiscal year.

Today, while I don't quite bring the same feelings of frustration or messages of immediate demise, we still face an uncertain future. The long-term threat to science is just as real as I described to you last January. We know that the drive to balance the budget will bring some rocky times. This gives all of us good reason to feel apprehensive about the future.

But as I've said throughout my talk today, we can't let this apprehension slow us down. I believe we will have a future golden age of science. It just won't be the same as in past years.

I believe that scientific research will continue to explore the most fundamental questions of nature. Clearly, this includes astronomy. And, doctoral-level graduate education will continue to prepare the nation's brightest and most capable students to make the major discoveries of tomorrow.

I nevertheless predict our system of research—including university research—and education will do much more than this. In a future golden age, research will also emphasize the integration and dissemination of knowledge beyond publishing in journals and presenting papers. We will rely on yet-to-be established networks of discoverers and users. This new partnership will make the benefits of research more apparent and, at least some of the time, more immediate.

Graduate education at the doctoral and masters level will include valuable knowledge and skills, such as communication, teamwork, management, and leadership, that will enable scientists and engineers to excel in a wide range of professions. Why is this important? One reason is to ensure better jobs for science graduates.

But perhaps more important is the fact that future leaders in the world of business, law, medicine, and politics will need to understand science and technology to a degree society has never recognized and certainly not required before.

Will all of this come to pass? I don't know. But it will not come to pass unless we expand our views of research, of the university, of connections and partnerships involving the doers and users of science, and of graduate education.

This is why, as in January, I bring high expectations for leadership from all of you. Your efforts can once again show the way for the entire science, engineering, and technology community. We know that dramatic change is upon us, necessitating a thoughtful and appropriate response. We also know, but sometimes overlook, that even more dramatic and rewarding opportunities await us as well.

Your efforts through this series of workshops hold the key to success on both of these scores, and I once again have full confidence that you will deliver.

Thank you and thanks again to the AAS for inviting me to join you this evening.

B.2 Reshaping Graduate Education in Science and Engineering

Phillip Griffiths, Director, Institute for Advanced Study
8 November 1996
Minneapolis, MN

Today I'd like to speak to you about the way we prepare our students for careers in science and engineering, especially at the graduate level. This topic sounds somewhat mundane compared to thinking about quasars, dark matter, and the cosmos. And some of what I say may refer more to science in general than astronomy in particular. But most of you know how many young scientists—including astronomers—are having difficulty finding the secure careers they dreamed about in graduate school. And you also know that any scientific community needs a steady flow of bright graduate students. So I would suggest that the shape of graduate education has a powerful bearing on all of you, both as researchers who want the intellectual stimulation of younger colleagues and as educators who want to attract talented students to science.

This is a complex topic, and I owe a great deal to those who have helped to educate me. I've had the privilege of chairing COSEPUP, which is the National Academy of Sciences' Committee on Science, Engineering, and Public Policy, and over the past few years we've been talking with students, postdocs, faculty, and members of professional societies from all over the country about graduate education. As a result of these conversations and our own deliberations, COSEPUP released a report on graduate education about a year and a half ago, and this is a good time to reflect on what we learned in preparing the report and on what has taken place since then.

One thing we learned is how difficult it is to initiate the changes we want without causing changes we don't want. We certainly don't want to jeopardize the high quality of our present system. Also, my personal opinion and that of COSEPUP is that we don't want the level of graduate enrollment to drop off significantly. Any good research program needs a community of interactive faculty, postdocs, and graduate students; we count on the students to bring fresh perspective and to pose the original questions that are raised only by those who see a subject for the first time. We also need graduate students to staff research programs and to teach undergraduates. There is evidence that the influx of foreign students we saw in the late 80s and early 90s may be dropping off, and universities face a major challenge in attracting talented American students to science.

We've heard many informed people call for a reshaping of graduate education, and for good reasons. There are more graduates than there are academic positions and jobs in basic research, and recent graduates are finding the transition to other types of jobs difficult. More than half of new graduates with PhDs—and much more than half in some fields, such as chemistry and engineering—are now finding work in non-academic settings. From this we can see that even PhDs who begin their careers in academia will probably make at least one career change—a move to an adjacent field, to a position in academic or industrial management, or to a new career altogether. And I don't mean a new career in taxi driving. In spite of the anecdotes, there are very few PhDs in science working the graveyard shift at Yellow Cab. But there are many of them engaged in work that is not research. The job of our graduate schools is to equip them for challenging positions they have prepared for—not just jobs they settle

for. And today this preparation should include a range of options better aligned with the realities of employment.

One new reality of employment is that more graduates go to work in new kinds of scientific organizations. We're mainly familiar with two kinds of organizations: we might call them small science and big science. Small science operates on a kind of "Mom and Pop" scale, with an individual investigator, a small number of researchers, and little need for management skills. Big science, which is typified by the national laboratories of defense and energy and large industrial facilities, employs many more researchers and promotes the development of its own managers to a degree not usually seen among university scientists.

Today we still have big and little science, but we're seeing growth in mid-sized organizations, such as engineering research centers, science and technology centers, and small to mid-sized companies. The most successful of these organizations are run by people who are closely tied to the science and who can also organize and run programs. This is a combination of abilities that is not addressed by the traditional graduate curriculum.

In preparing our report, COSEPUP talked with employers from both the academic world and industry, and asked them to critique the abilities of recent graduates. The employers praised their scientific ability, but they also reported difficulty in taking these talented graduates and developing the communication, leadership, and management skills that allow them to become administrators, directors, and managers.

COSEPUP also evaluated the Science and Technology Center programs that the NSF runs and found virtually the same condition. The level of science was almost uniformly high; the scientific community knows very well how to evaluate the quality of science in a proposal. But the selection process failed to evaluate the managerial aspects of proposals, and subsequent problems have been attributed to poor management. This is a challenge that is familiar to the astronomy community, which has traditionally managed telescopes and other facilities.

So when we think about the relationship between graduate education and careers in science, we see three things: a continuing tendency of departments to steer their students toward academic careers, a shortage of traditional academic research positions, and a feeling among employers that more non-research skills are needed. If we put these three things together, we see the need for a better alignment between the way scientists and engineers are educated and the way they are likely to spend their professional careers. So COSEPUP has recommended that universities offer a broader range of academic options to produce scientists and engineers who are more versatile and adaptable.

When we say "broader range," we don't mean that students should ignore the importance of the dissertation experience or chase after too many subjects. Instead, we envision a modified graduate program that is a richer variant of the current experience. We will always need the researchers who dive deeply into their subject and bring us the new discoveries and insights that underpin science and technology. Some people, especially those who are absolutely committed to academic research, will continue to best use their graduate

years to focus deeply on their area of research, and then use postdoctoral time to broaden their understanding of the context of their work and perhaps of adjacent fields.

All students, however, should be offered more options. They should be able to prepare themselves to work across fields and to communicate and collaborate with people in other disciplines. Some of the most exciting problems in science today are found at the edges or interfaces of disciplines. We can think of problems in biophysics, neuroscience, computational chemistry, and of course astrophysics. A biologist working in biophysics needs not only expertise in biology, but also a true feel for physics. Getting a feel for another subject is hard to describe. It includes being able to communicate in the language of the other field, and most especially to gain a deep working awareness of how people in that field approach a problem and frame their questions.

For example, at the Institute for Advanced Study, we have a group of mathematicians and physicists working together on quantum field theory. In one very exciting development, the physicists, using ways of thinking that are more intuitive and less formal than those of traditional mathematics, have suggested that two models of quantum field theory should at a certain level be the same. Expressing this idea mathematically has led to certain mathematical predictions which seem to be true and that were unlike anything the mathematics community had ever seen. So this program is really being driven by the effort of the mathematics community to get inside the heads of the physicists and better understand how they think.

We can also think, for example, about a collaboration between mathematicians and geophysicists. Mathematicians know things about the relevant differential equations that can be helpful, but that's only part of the issue. They also have to know how one formulates geophysical problems and sets up the right equations. Differential equations are always approximate; they make certain assumptions. And those assumptions may give us an equation that doesn't really model what we're interested in. So the mathematician has to have an intuitive knowledge of the mind set of the geophysicist if the collaboration is to be a success.

One of the things that makes it difficult for students to gain insight into other disciplines is our tradition of organizing graduate departments by discipline. We do need to keep enough of this disciplinary organization so students have a firm foundation to work from. But many of the emerging areas of science lie between the traditional disciplines. So the challenge is to make modifications that allow graduate students to at least dip their toes into these emerging areas. We're not suggesting these modifications in response to a bureaucratic or organizational theory, but in response to the way science is being done today.

There are a number of steps departments can take to offer a wider range of options. They can offer academic options, such as minors, electives, and internships in adjacent or related fields. And they can help students sharpen more general career skills, such as the ability to express technical matters to nonspecialists and to work as members of a team. Faculty advisers can play an especially important role. By helping a

student understand the shape of the scientific enterprise, they help the student make better career choices.

Another way to think about the need for breadth is suggested by Linda Wilson, president of Radcliffe College, who chairs the Office of Scientific and Engineering Personnel at the National Research Council. Linda points out that scientists are expected to perform many tasks during the course of their careers, including the following: synthesis of knowledge across disciplinary boundaries, follow-up of new discoveries, organization of new knowledge, transmission of new knowledge, transfer of technology, thinking about ethics, and educating the public about science. Students must learn to do these tasks just as they learn to do research.

There is some very good news about graduate education, and that is that faculty and students at many institutions have already initiated a variety of curricular modifications. Just a few examples: At Penn State there is an MBA/PhD concurrent degree program, and other programs that cross disciplinary boundaries. Ohio State has reorganized its departments and schools, and encouraged departments to broaden their master's programs and offer summer internships in industry. The University of Colorado has added multidisciplinary certificate programs in such areas as cognitive science, environmental policy, and biotechnology. Last June, COSEPUP hosted a National Convocation on Doctoral Education to bring together people who have tried strategies like these. A summary of this meeting is presented on the home page of the National Academy of Sciences (<http://www2.nas.edu/convo>).

One way to encourage the kinds of modifications we've been talking about is to adjust the way the federal government supports graduate education. For the last two decades, about 85% of federal support for students has taken the form of research assistantships. These are awarded to a principal investigator to support a research program. Graduate students who receive support on that grant are expected to do research related to the grant. This apprenticeship method has, on the whole, worked marvelously. But as we go into the future, the overwhelming concentration of resources in research assistantships may not be the best method of support.

Let me suggest two alternatives. The first is to increase the proportion of traineeships, which have been used very successfully at the National Institutes of Health, especially for emerging or interdisciplinary areas such as cell biology and neuroscience. Training grants can be used in either emerging or traditional areas, where part of the grant's purpose is to encourage institutions to offer more curricular options and to provide more effective student guidance.

The other alternative is to give more student money in the form of graduate fellowships. My personal opinion is that fellowships offer a specific advantage: they allow students the maximum degree of choice. Students know which program is most attractive to them, and fellowships let them vote with their feet.

My own feeling is that we don't yet know which alternatives will work best. So instead of making radical reforms to the current system, we can experiment with incremental changes. Instead of putting 5/6 of our federal money into research assistantships, we could shift the proportion to 2/3

and see what happens. By making small shifts in the direction of fellowships and training grant mechanisms, we may get a feeling for what works best.

Another modification COSEPUP has looked at has to do with what we could call the “problem of the queue.” Many new graduates are “lined up,” waiting for tenure-track jobs, and this backup creates a tendency to spend more time in school and in postdoctoral positions. Over the last three decades, the time to degree has increased steadily—in some fields by about 30%. According to the NSF, the median number of years between receipt of the bachelor’s degree and the doctorate in science and engineering increased from 7.0 years during the 1960s to 8.7 years in 1991.

It may seem contradictory to suggest both a broader educational experience and a shorter time to degree, but I believe the key is to give students more of the information they need to plan their careers.

When I say information, there are several things I do not mean.

I do not mean we can predict where science is going to be in the future. We have a general sense of areas of science where activity is increasing and employment is growing—such as information science, environmental science, and neuroscience. But that’s not a prediction, or futurism; it’s a projection based on what is known.

The second thing I do not mean by more information is trying to predict the job market. Many of us remember the famous prediction of a shortage of PhDs that the NSF put out in the late 1980s. No one could have known about the recession which followed that prediction and led to shrinking budgets for states and reduced numbers of tenured faculty at the state universities. There was no way to predict that, or many of the other factors that affect job markets.

What I mean by good information is information that can make students more aware of what their options might be once they have their PhD. One example of useful information is that everyone seems to agree that small to mid-size companies represent a growth area for the near to mid future. And these companies have certain employment needs that students should know about.

We had a number of people from these kinds of businesses talk to COSEPUP, and we asked them about the kind of people they like to hire. The first thing they’re looking for is people who have a PhD—people who have done an independent research project and know one area of science really well. The second thing they’re looking for is people who are adaptable. They know that they can’t hire a new scientist each time there’s a breakthrough in a new technology; they have to use the people they already have. Graduate students who know this can see that they’ll need to be versatile and flexible if they want such a job. So our second major recommendation is that universities and other institutions provide graduate students and their advisers with more up-to-date and accurate information about careers. Students need a much more realistic picture of what’s out there.

Many universities have initiated public discussions of these issues and disseminated excellent career information. Brown University and Cal Tech’s career service offices now assign a counselor specifically to graduate students. Johns

Hopkins, Stanford, and other institutions hold career days, when students can learn how well their career goals match the needs of employers. The National Academy of Sciences has set up an on-line Career Planning Center for Beginning Scientists and Engineers. Earlier this year COSEPUP prepared a guidebook entitled “Careers in Science and Engineering: A Student Planning Guide for Grad School and Beyond.”

We hope that modifications like this will bring the supply of graduates most closely into balance with the demand of employers. Students with good guidance and information will be better prepared to find the careers they want.

In the meantime, many institutions are grappling with the question of whether there should be limits on student populations. It’s difficult to envision a good mechanism to limit numbers of students without being unfair or disrupting the educational process. And our country clearly benefits from attracting the best scientific talent, both from the U.S. and from abroad. However, some people have called for limits on international students, for two quite different reasons. One is that many of them remain in this country after graduation to compete for scarce jobs. The other is that many foreign graduates now return to their home countries, many of which offer rapidly improving opportunities for research. In Washington, this is beginning to raise the issue of whether we should be training and supporting citizens of other nations who eventually compete with us.

Whatever universities do about enrollment policy, the fiscal pressures for change are powerful. Some researchers believe that federal and state cuts in research funding over the next several years may be as high as 30%. Such enormous reductions would force institutions to go back to first principles and ask a basic question: How can we do excellent research and education in times of constricted external resources, and how can we treat students fairly in these times?

Too often we’ve lost sight of the educational aspect of our mission. As indicated earlier, one way to enhance this aspect is to shift resources from research assistantships to education and training grants. We can also provide better information so students can make wise decisions about their educational and professional careers. Certainly there are other ways to shift the balance, and this is where we rely on yourselves and others who have recognized the need for discussion and action.

I want to close with a thumbnail sketch of the kind of environment where more and more of our science graduates will be working. We’ve all read about the downsizing at Bell Labs, IBM, DuPont, and other major corporate laboratories. And we’re generally aware of the shortening time horizons for R&D in industry. If industry is doing less of its own research, and doing it farther downstream, how will they retain access to the frontiers of science? The answer seems to be that they will have to rely on access to university research communities.

No one is sure how this will be done, but it will certainly include various kinds of consortia. Industries have a need to see what’s coming down the road, and universities have a need to broaden their funding base as well as provide more educational options for their students. For example, we may

see a “semiconductor research corporation” which will give grants to campus-based researchers in much the same way NSF gives research grants today. We’ll see more people moving back and forth between the universities and the research corporations, receiving and transferring new knowledge. Industry will put up money, as will universities, and the government will serve, among other roles, as advocate for long-term research and be an “honest broker” between industry and the universities. The Fraunhofer consortia are examples of this kind of effort.

There remain many problems of the structure and operation of consortia, because the objectives of universities and industries are quite different. Universities are interested in education and in knowledge for its own sake, while industries must apply the results of research to earn profits. For example, frequently the two parties disagree strongly over the control of patent rights to intellectual property. The universities would like to publish new results openly and to receive a portion of financial benefits, while industry would like to hold exclusive patent rights long enough to maximize their return on investment. Agreement on issues such as this will require a significant blending of two quite different cultures.

As these consortia become more common, the process of graduate education will have to take them into account. One way graduate students can prepare for them is to become familiar with industrial culture through internships and exchange of personnel. The graduate experience for a scientist who will work in a mixed research culture should be different from the experience of someone who will work as a university professor.

The last few decades have been an extraordinary period in the development of science and in the public support for science. We can see now that the coming decades will be different, but they need not be less interesting, or less fruitful for science. It’s important for the scientific community to see this now and to take positive steps to strengthen our system of education in appropriate ways.

We don’t want to tamper with the essential soundness of graduate education, but we want to bring it into better alignment with the employment universe. This is especially important if we are going to attract the talented students we need to maintain our strength in science. With good cooperation among universities, industry, government, and the professional societies, we can maintain the level of excellence and world leadership we have all worked so hard to achieve.

Thank you very much.

B.3 Fostering Breadth in Graduate Education in Astronomy

Marye Anne Fox, Vice President for Research, U. Texas at Austin

22 November 1996

Tucson, AZ

Published in *The American University: National Treasure or Endangered Species?*, ed. R.G. Ehrenberg, Cornell University Press, 1997, p. 100.

B.4 The Changing Graduate Education and Research Environment

Eugene Levy, Dean of Sciences, University of Arizona

22 November 1996

Tucson, AZ

The changing shape of graduate education in science is a subject that is occupying a place of increasing national prominence. Signals abound: for example, over the past months prominent newspaper articles have appeared, even in the *Arizona Daily Star*, describing the allegedly shrinking career opportunities for scientists, and elaborating on the putative negative implications of this for today’s cohort of students. This shrinking of opportunities is apparently driven by the reduction of support for basic research in the private sector—especially in physical science—and by the apparent petering out—and threatened reversal—of what had been, for a full half century, a sustained, high impulse thrust in growing governmental support for basic science.

It is my impression that the primary response of the academic community specifically—has been to adopt a posture of studied denial . . . and thus I want to try to cast my remarks in a rather broad context, pertaining both to the changing research-support environment and to potential changes in the academic environment . . . even independently of the threats to research funding.

Beyond threatened reductions in support for scientific research, the situation in academic science is exacerbated by independent developments in university demographics and economics. For several decades in the middle part of the century, universities and colleges underwent an extraordinary expansion, as the bachelor’s degree has displaced the high school diploma as the basic job certificate in much of the American workplace, and as the opportunity for college education was extended to a much larger fraction of the population than had previously been the case. This accelerated growth of universities seems more or less to be saturating out. It is not obvious that college will soon be the destination for a much larger fraction of the population than is already the case. While it is likely that the college population will continue to grow along with the general population growth, without continued increase in the fractional college enrollment, future expansion of the college/university population is likely to be much slower than it has been in recently past decades. I think we all are aware that the far-greater-than-replacement level of PhD production in the past was absorbed in significant measure by the expansion of higher education, as well as by expansion in the national laboratories and by a vigorous commitment to research and development in many private corporations.

On top of the change in demographics, significant public attention is being focused on the costs of universities and on the sources of funding for higher education and for research. During the past several years, cost consciousness and cost competition have started to become significant issues in the economics of higher education. I anticipate that this dynamic will accelerate, and that we will see increasing cost competition within the traditional community of colleges and universities. It seems clear, even as universities expand to accommodate a growing population, that expansion will not be

funded as lavishly as has been the case over the past five decades.

Moreover—and perhaps more importantly—I anticipate the possibility of significant competition from alternative “education providers” in an expanding and increasingly cost-competitive educational marketplace. Today we are confronted with the appearance of for-profit, private “education providers,” named as universities... even with investors and stock-market listings... and already penetrating some constituencies that had previously been the exclusive province of traditional colleges and universities. It is as yet unclear how much of this competition will take place on the Internet, or whatever follows the Internet. This expanded competitive environment will likely continue to translate into an increasingly sharp focus on the ways in which funds are allocated and used within universities. The similarity between this developing situation and the dislocations currently occurring the health-care industry should not escape you. A substantial part of the U.S. academic research enterprise is supported by an implicit social contract that supports research—largely through faculty salaries—in an environment built largely for education. In the health-care industry, it has traditionally been the case that the cost of medical research was partly underwritten by hospital charges to patients and their insurance companies. In the past, health care was not a cost-competitive enterprise in the United States. In the current cost-competitive health-care environment, some of the biggest impacts are falling on medical research and education. It remains to be seen just how cost-conscious and cost-competitive higher education will become... but I believe that the potential threat to the current social/economic compact between education and research in the United States could be large and profound as they are becoming in medicine.

I want to remind you that I am not prescribing or advocating these changes and threats. I am merely describing what already has started to take place or what looms as potential threat to the prevailing social-economic-academic compact. I do not want to be shot as a messenger with grim tidings... nor do I want to play the role of Chicken Little crying about a falling sky. But rather I believe it is important for us to try to understand the changes that threaten to overtake us... and to consider, deliberately, how we preserve high value academic research environments and educational programs in a changing world.

These changes within universities and within the scholarly enterprise are being driven by social, economic and perceptual changes outside of universities. I have already mentioned the petering out of momentum in Federal support for basic research, and the possible development of a highly cost-competitive environment. But, at the same time, it is important to realize that there has been a substantial erosion in public confidence in major institutions of all kinds... not only universities, but governmental institutions, the Congress, legislatures and so on. While we in the university and research community feel mistreated by government institutions and funding sources, it is well to keep in mind that the people in those institutions, who will most directly affect our future, are running scared themselves.

In thinking about the challenges we currently face, it is well to try to maintain a reasoned and balanced historical perspective. We are not at the end of history. The particular challenges that we face today are not going to last forever; history is somewhat cyclic. Good times are likely to roll again. In any case, research is not threatened with devastation, only with retrenchment. And even the retrenchment is not being visited on all disciplines equally.

However, the main reason I make this point about historical cyclicality is to preempt the issue. In some respects it is irrelevant. It is not enough to assert—as I have heard many of my colleagues do—that times will get better, and that we need only tough out the temporary downturn. Time scale is a central issue... some changes are indeed secular... and other changes are of sufficiently indeterminate and long time scale that they are indistinguishable from secular changes in terms of their impact on planning.

Indeed, I have already tried to make the case that at least part of the challenge we confront is of a secular nature—the near saturation of the fraction of our population that will attend college. I think it is important to realize that the world has changed in other ways as well.

Although we are focused here on astronomy, it is important to realize that similar discussions are going on more broadly, in other disciplines and in other forums. The recent studies of science graduate education carried out by the National Academy of Sciences and by the NSF Division of Mathematical and Physical Sciences mark the fact that there is growing anxiety about how our graduate programs fit into changing national needs and priorities. Much of the motivation for our most immediate anxieties derives from what we see as a discordancy between the supply of graduate students—especially PhD students—and the capacity of our disciplines, and our society more broadly, to absorb those students into jobs and careers that we—and they—regard as matching their skills, educations and ambitions in meaningful ways.

Not only is it the case that most, if not all, scientific disciplines are faced by similar challenges, but it is also important to keep in mind that changes important to the structure of the academic enterprise—and to the assumptions and values that currently drive it—are occurring broadly in our society. This past Monday (November 18), the front page of the *New York Times* carried an article worth glancing at. The article is entitled “Publisher’s Squeeze Making Tenure Elusive.” In a direct sense, this problem is hardly relevant to the scientific disciplines; but it is very important to academic disciplines in the social sciences and humanities. Despite the fact that these other disciplines have for a long time confronted problems similar to the ones that we are now beginning to grow alarmed about, and despite the fact that our colleagues in these disciplines feel a certain amount of unavoidable satisfaction over the potential of eroded support for science, these disciplines too are facing new challenges in the changing academic environment.

We all are convinced that astronomy departments constitute an undeniable social good... manifestly deserving of every resource society throws their way because of the spiritual reward that comes from delving into some of the deepest and

oldest questions that humans have asked. And the reality is that astronomy, as a discipline, has become accustomed to a lot of resources. Astronomers are fond of citing how important an educational vehicle astronomy is for exciting the imaginations of students and for communicating scientific concepts...indeed, we astronomers frequently treat ourselves to the illusion that astronomy is unique in those respects. I want to tell you from my perspective having responsibility for the University of Arizona's College of Science that your colleagues in every one of the scientific disciplines believe their disciplines to be equally blessed with similar unique qualities. I am fond of an aphorism attributed to Richard Feynman...

The first principle is to not fool yourself, and you are

I think that we have too much tendency to overlook—even to deny—the magnitude of the change that is overtaking us, and the pervasiveness with which that change may affect all that we do...including life within our academic departments. The thrust of my remarks is that we are in need of much more substantial response to impending changes than to merely tune our graduate programs at the margins. We need to be concerned with how, as institutions, we adapt to changing circumstances. The issues involved are money, values and culture...within our disciplines and within our academic departments.

In my remarks at the AAS meeting in San Antonio last winter, I likened the scientific community (and particularly the astronomical community) to a person driving an open convertible on a beautifully maintained road, through a gorgeous landscape, and headed directly at a precipice where the road ends...kind of like a Road Runner cartoon. And in this cartoon, the driver of the car has not a care in the world he (or she) has one arm thrown over the seat and is happily proclaiming: "The world is great; everything is fine; look where I have come from; look at all that wonderful road and landscape behind me."

Perhaps the biggest impediment that our universities confront in responding to changing circumstances is the pervasive denial—among faculty and administrators—that real change is actually upon us. The major manifestation of denial in the university research community is the fantasy that we are experiencing only a transient political and fiscal aberration, and that, if we just wait it out, the aberration will pass and "normalcy" will return. One aspect of the putative "normalcy"—the return of which eagerly we await—is a steady, year-after-year real growth in funding for higher education and for scientific research. Another aspect of the "normalcy" for which we long is a relaxation of the tense, critical scrutiny that both higher education and research have been subjected to during the past several years. We long for the happy days of past decades, during which higher education was held in unquestioned esteem, world leadership in every area of scientific research was deemed to be of strategic importance and a national objective, and every dollar directed into scientific research programs—all research, basic and applied, however esoteric—was considered a dollar somehow well spent. It is not surprising, and probably healthy, that we long for the return of such circumstances.

Indeed, scientific research is extraordinarily valuable to modern society, both in the way it drives the technological economy and for the spiritual expansion it provides by investigating deep questions of long-standing human interest. Such happy circumstances may one day return; if we wait long enough, they surely will. However—given that our nation is feeling such an intense need for financial stringency, given the broadscale disillusionment with institutions that wracks our society, and given the political environment within which spending decisions are being made—it may be unrealistic to expect a return to such happy circumstances on any temporal horizon useful for today's planning.

Especially since the end of World War II, scientific research has occupied a privileged position of declared strategic national importance. The current generation of scientists has lived its entire life in this environment of expansive support for scientific research. We have integrated into our personalities that this environment is the norm. I am not sure that it is. The past fifty years of post-Manhattan-Project, post-Cold-War-and-Sputnik scientific euphoria may be the anomaly...and we may be on the brink of relaxing back the more stringent and more retrenched norm.

To me, this is something of a paradoxical situation. Science and basic research are fundamental and at the heart of the technological economy in which we now live. One need only look around and ask how much of what we now take for granted on a daily basis and how much of what our economy (from plants growing in silicate soil, to "bits" flying around silicon chips) is grounded in deep scientific understanding that did not exist as recently as 75 years ago. In my view, the 21st century is likely to see even greater advances in deep scientific technology.

Nonetheless, we are confronted with the possibility of serious retrenchment in scientific research. It is not a rational situation, either in terms of the importance of the endeavor or in terms of the amount of money involved.

"Basic" scientific research is hard to define uniquely, but...

- basic research accounts for about \$35 billion per annum in the Federal budget (very broadly construed);

- this amounts to about 2% of the Federal budget, or about 0.5% of GDP...one half of one percent of the overall social and economic activity of our society...*the one half of one percent* that gives rise to nearly everything else...and we propose to cut it (in some scenarios—admittedly very unlikely scenarios—by as much as 30%).

In my view the fact that our society proclaims inability to support this small level of activity in the face of its manifest importance is indicative of non-rational thinking. But the nonrationality makes it harder to deal with the problem...not easier. As scientists, we too frequently dismiss that nonrational as being beneath attention. As citizens in the larger society, frequently it is the nonrational that must occupy us.

I want to describe two personal experiences, one of which is intended to emphasize that we are confronting secular—or quasi-secular—change in the research-support environment...and that this change has been gathering steam for a time. The second is intended to raise a flag—in

the spirit of Feynman's aphorism—about the ability of the scientific community to fool itself.

As many of you know, I have been pretty active in space science policy and program planning for twenty years, from very early in my career...indeed starting in 1976 (so this is an anniversary year for me in that respect). Though I do it far less now, I have spent a great deal of time in Washington in connection with these issues...with nontrivial amounts of interaction both in the Congress and in Executive offices. I want to share a very well-founded perception with you: During the first part of those twenty years, it was an unquestioned article of faith in the Congress that the health and vigor of the U.S. university research enterprise was a matter of strategic national importance. In 1986, I was invited to testify as part of a series of science policy hearings in the House of Representatives Science, Technology and Space Committee, focused on ensuring the continued vigor of our nation's research enterprise in the universities. In the context of those hearings, in 1986, it still was an axiom that the health of the scientific enterprise in universities was of strategic national importance. The main question was to determine what was necessary to ensure that health. That article of underlying faith did not divorce the wrangling over science funding from the usual politics...but it modulated the politics in important ways.

By the early 1990s, to the best of my ability to perceive it in Washington, that notion, while not entirely dead, was extraordinarily diminished and diluted. I was told explicitly by key congressional staff in 1992 that the health of university research, *per se*, was no longer an explicit and widely accepted priority in the Congress. Events since then have only solidified the impression that times have changed...and that the next several decades are likely to be modulated by forces and perception different from those of the past five decades.

The second personal observation that I want to recount is addressed to what I worry is the level of self-fooling and denial of which the scientific community is capable. We are in a golden age in astronomy. The Hubble Space Telescope, AXAF (or rather its parts), gamma-ray observations, infrared astronomy, new ground-based telescopes and so on. And now we are talking seriously about the "next generation space telescope" and ambitious interferometer arrays in space to discover and study other planetary systems. Looking at this conceptual agenda, and looking at what seems to be coming down the pike—at least if the advisory studies and reports can serve as prophecy—I detect no reason whatever to worry about the future.

In the late 1970s and early 1980s I served on the National Academy's Space Science Board, and chaired its Committee on Planetary and Lunar Exploration. I was first appointed to the committee—a young assistant professor—at almost exactly the time—almost to the month—of the 1976 Mars Viking landing...right in the midst of the rush of excitement and all of the expansive thinking about the future that the Viking success at Mars engendered.

In the committee we spent the next several years formulating an extraordinarily exciting terrestrial planets initiative...Venus, Earth and Mars, life in the Solar System, cata-

strophic planetary climate change...including a detailed, staged prescription for cooperating with the Soviet Union that was enthusiastically accepted by the Soviets as the basis for a possibly accelerated agenda of cooperation in planetary exploration. The intensive robotic presence on Mars, specifically planned to begin in 1984 was very exciting...the broader technological benefits of the planned robotics development were understood and laid out. It was a very satisfying, almost a monumentally sound, piece of scientific advice. The report was published by the NRC Press, and duly distributed and enthusiastically received by all the appropriate units of government...it was very widely read and very well known. You can read it...but you have to find a copy...it is out of print now.

I do not have enough time to compare those plans, expectations and recommendations with the eventual realities...but, take my word for it, the plans, expectations and recommendations were not isomorphic with the eventualities.

The role of my remarks at the beginning of this conference is to try to provoke your thinking about the problems of astronomy in a broader context...a context that I believe is likely to have a profound affect on the overall academic research environment during the next couple of decades. Confining our attention narrowly within our own academic disciplines, and focusing solely on the details of this year's Federal budget battle (fooling ourselves into believing that what is "postponed" this year will likely be funded next year) and not raising our eyes a little bit to look at the broader social scene...that narrow focus, I think, is hazardous and shortsighted.

I think that we confront some real changes in the next years to several decades...changes that will challenge the current structure of academic enterprise, both in teaching and research...and especially in what has been the implicit symbiotic social and economic contract between teaching and research.

According to a recently released Government Accounting Office report (hot off the Internet in Robert Park's weekly APS diatribe, so it must be true)...according to that report, while household incomes rose 82% (clearly that is in unadjusted dollars) in the years 1980–1994, tuition at public colleges and universities rose 234% in the same interval. Research expenditures rose—also in the same interval—157%.

Predicting the future is hard—I would never try to do it—but you might ask yourself whether you think that trajectory is likely to be continued during the next decade and a half...and, as you contemplate that question, again keep in mind that the most recent specific discussions about the future of research support project a 30% real decline over a half dozen years. That 30% decline will almost certainly not come to pass...but the talk about it helps define the environment, and set the expectations.

I did not intend to come across negatively or pessimistically in these remarks. Indeed, I am very optimistic:

- I am optimistic that the worst-case scenarios will not come to pass.
- I am optimistic that science will continue to be valued

and supported, though I suspect that the environment will be less expansive in the next decade or two than it has been in the recent past.

- And I am optimistic that creative, insightful and clever people will be able to find ways to meet the challenges I have described...and meet them in ways that preserve the integrity of our scientific agenda and aspirations, while, at the same time, responding to the pressures that will continue to be imposed on the academic world.

Indeed, I think there are sensible—even exciting—responses to the challenges that we confront. I have my own ideas about that, and some of you have heard me speak about those ideas. But my role at the beginning of this conference is not to hold forth on my ideas, but rather to challenge you on this subject. To find the answers, we will need to look within ourselves and examine some of the most basic assumptions that now shape the academic enterprise.

I hope this meeting can be a step in that direction. Thank you very much.

APPENDIX C: CAREER TRENDS FOR NEW DOCTORATES IN ASTRONOMY AND ASTROPHYSICS

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When career trend data are reported for new PhD's, it is common to find that data for new doctorates in Astronomy and Astrophysics (henceforth referred to as Astronomy) are grouped with that for Physics. Although many graduate departments offer training in both Physics and Astronomy, it has been difficult to ascertain whether the employment situation for the two groups is the same. It is widely recognized that a crisis in overproduction of Physics PhDs occurred in the late 1970's, and that the persistence of a poor job market has reduced enrollments in graduate programs in Physics. What is not known is whether similar conditions also exist for new doctorates in Astronomy. The data presented in this report summarize trends in degree production and career paths for new doctorates in Astronomy, and demonstrate that significant differences exist between trends for Astronomy and Physics.

Data were derived from two sources collected by the National Research Council for the National Science Foundation (NSF) and other government agencies: the annual Survey of Earned Doctorates (whose records are summarized in the Doctoral Records File (DRF)) and the biennial Survey of Doctoral Recipients (SDR). A third source, the Survey of Graduate Students and Postdoctorals in Science and Engineering (GSESP), is collated by the NSF. All three databases examine different segments of the population, and data are constrained by differing survey methods.

The DRF is statistically the most complete, containing information on every individual earning a doctorate in a given year; however for this study its accuracy is limited by *self-reporting* of degree fields. For example a student receiving a PhD from a Department of Physics and Astronomy would have the option of selecting one of either Physics or Astrophysics or Astronomy for a field of study. Thus if a

student considers his degree to be in physics he will be included in the physics DRF database, but if he selects either Astronomy or Astrophysics, he will be included as an astronomer.

The SDR is a longitudinal study which follows a sample population for an extended period and is the best source for employment trend data, but it is limited by the fact that only 8% of degree recipients in a given discipline are followed. The number of individuals tracked in the field of astronomy is low, and small numbers may compromise the results. However, the sample population in physics is statistically significant, and thus trends seen in both fields are likely to be real. In addition, since the SDR tracks only those who earned the doctorate in the United States, it will miss all PhDs who earned a degree abroad and who join the U.S. workforce after earning the degree.

The GSESP is an annual survey of graduate enrollments and postdoctoral appointments that is completed by academic departments, and includes those postdoctoral appointees with foreign degrees. Postdoctoral appointments outside of academia will not be counted by this survey, and postdoctoral appointees in centers and laboratories not directly connected to a department may not be known to the department providing the data. By piecing together data from these sources, it is possible to construct a picture of educational and employment patterns. We report here on major trends found for Astronomy and Physics for the decade 1985–1995.

C.1 Statistical Trends in Astronomy and Physics

C.1.1 Declining graduate enrollments after a period of growth

After a boom in graduate enrollments in the 1960's, enrollment plummeted in the 1970's in the physical sciences. Graduate enrollment in both Astronomy and Physics increased in the late 1980's but once again, graduate enrollments are on the decline. Enrollment has been dropping in Physics since 1992, but only began dropping in Astronomy in 1995 (Figs. 1 and 2, Table 1). There were approximately 870 graduate students in Astronomy enrolled full-time in 1995, and 11,000 in Physics. The number of graduate students in both Astronomy and Physics declined by about 9% between 1994 and 1995.

C.1.2 PhD production is on the rise

Astronomy PhD degree production dipped during the 1970's and early 1980's, partially in response to reduced federal support for graduate education in the physical sciences but rose steadily since the late 1980's (Fig. 3, Table 2a). 173 degrees were awarded in 1995. After a large dip in the late 1970's and early 1980's, the number of degrees awarded in Physics increased since the mid-1980's, and has recovered to levels similar to those in the early 1970's. 1479 degrees were awarded in 1995 (Fig. 4, Table 2b). The recent declines in graduate enrollment have not yet been felt at the level of degree production, because of the long period of training required prior to degree.

Astronomy PhD production is unequally distributed across institutions and is dominated by a small number of institutions (Fig. 5). Of the 719 degrees awarded from 1991–

FIG. 1. Full-time Graduate Enrollment in Astronomy and Physics 1985–95.

95, 316 (or 44%) were awarded by 11 institutions. These institutions make up only 10% of the PhD-granting institutions awarding Astronomy degrees. However, of the 105 institutions that awarded at least one Astronomy degree during the period from 1973–1995, 20 did not award a degree from 1986 to 1995, and 26 did not award a degree from 1991 to 1995. There are a number of very small graduate programs that award the doctorate in Astronomy only rarely.

C.1.3 The demographics of new PhDs

Women represent about 16–17% of new doctorates in Astronomy, compared with 10–12% for Physics (Fig. 6, Tables 2a, 2b for details). Little increase in the representation of women in Astronomy has occurred since the 1980's, although the fraction has varied from year to year. Efforts to encourage women to pursue advanced study in both Astronomy and Physics have apparently met with limited success.

There are frequently-voiced concerns about large influxes of non-US citizens into graduate programs in the US, and fears that these foreign students are depriving US citizens of graduate opportunities. This does not appear to be the case in Astronomy. The percentage of US citizens and permanent residents earning the doctorate is higher in Astronomy than in Physics. About 85% of degrees in Astronomy were earned by US citizens and permanent residents in 1995, as compared to 73% in Physics (Fig. 7). Unlike in Physics, there has not been a noticeable increase in the number of non-US citizens earning degrees in Astronomy. The fraction of recipients of degrees in Physics with temporary visas has risen steadily since the mid-1980's (Fig. 8).

C.1.4 Graduate students are taking longer to earn the PhD

The time to degree has lengthened in both Astronomy and Physics since the 1970's by approximately one year,

FIG. 2. Full-time Graduate Enrollment in Astronomy 1985–95.

FIG. 3. New PhDs in Astronomy and Physics.

FIG. 4. New PhDs in Astronomy.

FIG. 5. Doctorates in Astronomy by Number of Degrees Conferred 1991–95. Numbers above data bars represent the number of institutions in each category. Of the 105 institutions awarding degrees in Astronomy from 1973–95, 20 did not award a degree from 1986–1995 and 26 did not award a degree from 1991–95.

TABLE 1. Graduate Enrollment in Astronomy and Physics.

Full-time Graduate Students in all Institutions 1985-95											
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Physics	10287	10957	11304	11638	12040	12191	12442	12689	12397	11747	11054
Astronomy	635	654	681	705	762	790	810	840	848	953	871

reflecting a trend observed broadly across the sciences. However, Astronomy PhDs have a slightly shorter median time to degree (from the time of first enrollment in a graduate program to awarding of the PhD) than do Physics PhDs; 7.25 years compared to 7.5 years in 1995 (Fig. 9).

C.1.5 A growing pool of Postdoctoral Fellows

Disturbingly, the fraction of new PhDs in both Astronomy and Physics without definite commitments at the time of degree has increased since the early 1980's (Figs. 10–13). However, the proportion with definite commitments

TABLE 2a. Characteristics of Astronomy/Astrophysics Doctorates (1973–1995).

	Phd Year 1973	Phd Year 1974	Phd Year 1975	Phd Year 1976	Phd Year 1977	Phd Year 1978	Phd Year 1979	Phd Year 1980	Phd Year 1981	Phd Year 1982	Phd Year 1983	Phd Year 1984
Total Phds	131	133	131	150	120	138	115	121	109	102	115	98
Males	125	127	119	139	111	131	107	108	98	86	100	86
Females	6	6	12	11	9	7	8	13	11	16	15	12
US citizens	110	118	105	128	106	123	97	104	96	91	101	80
Male US citizens	106	113	95	119	98	119	90	94	89	76	86	71
Female US citizens	4	5	10	9	8	4	7	10	7	15	15	9
Perm residents	2	1	5	3	3	4	4	5	4	1	2	1
Male Perm Res	2	1	5	3	2	3	4	3	2	1	2	
Female Perm Res					1	1		2	2			1
Temp Visa	19	12	20	17	10	11	13	11	8	10	12	15
Male Temp Visa	17	12	18	15	10	9	12	10	7	9	12	13
Female Temp Visa	2		2	2		2	1	1	1	1		2
Minorities		2	1			1	3	4	3	2	1	1
Planning Postdocs	57	63	57	68	64	89	64	62	59	65	67	59
Planning Acad Appoint	21	17	19	22	15	14	11	17	13	11	20	10
Planning Gov Appoint	11	12	15	8	7	4	2	9	11	5	6	6
Planning Indust Appoint	10	5	9	9	6	6	12	11	9	11	5	4
Median Time to Degree	6.00	5.96	5.92	6.00	6.50	6.17	6.50	6.63	6.59	7.17	6.91	6.79
Median Age at Degree	28.17	28.33	28.41	28.75	29.25	28.92	29.46	29.25	29.25	29.58	29	29.17
Number of Inst Awarding PhDs	43	46	47	44	40	47	43	45	44	41	41	37
	Phd Year 1985	Phd Year 1986	Phd Year 1987	Phd Year 1988	Phd Year 1989	Phd Year 1990	Phd Year 1991	Phd Year 1992	Phd Year 1993	Phd Year 1994	Phd Year 1995	Total
Total Phds	100	109	100	130	113	128	125	134	145	144	173	2864
Males	89	100	87	114	96	108	111	115	120	119	143	2539
Females	11	9	13	16	17	20	14	19	25	25	30	325
US citizens	82	88	72	97	78	92	84	100	106	103	120	2281
Male US citizens	73	82	63	84	67	76	77	87	86	83	99	2033
Female US citizens	9	6	9	13	11	16	7	13	20	20	21	248
Perm residents	2	3	1	7	4	4	2	6	5	9	21	99
Male Perm Res	2	2	1	6	2	2	2	4	2	8	17	76
Female Perm Res		1		1	2	2		2	3	1	4	23
Temp Visa	14	17	23	20	26	30	37	28	34	32	28	447
Male Temp Visa	13	15	19	18	22	28	30	24	32	28	24	397
Female Temp Visa	1	2	4	2	4	2	7	4	2	4	4	50
Minorities		2	2	2	4	3	1	5	5	2	5	49
Planning Postdocs	64	69	67	84	78	79	78	97	100	95	96	1681
Planning Acad Appoint	8	10	5	8	6	9	12	8	7	9	19	291
Planning Gov Appoint	1	4	3	4	5	7	3	2	4	8	3	140
Planning Indust Appoint	12	11	6	7	6	10	8	3	4	4	5	173
Median Time to Degree	7.00	7.00	6.67	6.92	7.00	7.17	7.00	7.00	7.00	7.00	7.25	
Median Age at Degree	29.71	29.83	29.33	29.42	29.96	29.87	29.83	29.55	29.58	29.92	29.83	
Number of Inst Awarding PhDs	48	40	38	40	43	43	48	46	45	47	55	105

TABLE 2b. Characteristics of Physics Doctorates (1973–1995).

	Phd Year 1973	Phd Year 1974	Phd Year 1975	Phd Year 1976	Phd Year 1977	Phd Year 1978	Phd Year 1979	Phd Year 1980	Phd Year 1981	Phd Year 1982	Phd Year 1983	Phd Year 1984
Total Phds	1458	1206	1169	1087	1030	929	993	862	906	912	928	982
Males	1408	1155	1111	1043	975	884	928	808	844	844	869	915
Females	50	51	58	44	55	45	65	54	62	68	59	67
US citizens	1078	838	820	783	727	681	703	611	625	615	608	659
Male US citizens	1049	817	785	760	694	656	666	576	587	575	572	614
Female US citizens	29	21	35	23	33	25	37	35	38	40	36	45
Perm residents	124	97	104	73	83	60	66	46	49	34	49	35
Male Perm Res	114	86	94	69	74	52	56	40	43	29	43	31
Female Perm Res	10	11	10	4	9	8	10	6	6	5	6	4
Temp Visa	229	218	224	211	197	170	194	178	195	232	244	251
Male Temp Visa	219	204	211	195	185	159	180	166	177	209	227	235
Female Temp Visa	10	14	13	16	12	11	14	12	18	23	17	16
Minorities	14	11	19	11	27	16	20	12	11	21	16	25
Planning Postdocs	538	442	450	421	397	366	403	363	353	328	350	404
Planning Acad Appoint	163	119	105	105	108	74	73	51	53	60	68	53
Planning Gov Appoint	150	116	92	75	85	74	68	64	62	60	59	76
Planning Indust Appoint	151	128	134	111	112	161	181	173	200	191	160	154
Median Time to Degree	6.5	6.67	6.91	6.5	6.75	6.92	6.5	6.67	6.59	7	7	7
Median Age at Degree	29.34	29.42	29.5	29.17	29.59	29.59	29.17	29.5	29.08	29.66	29.58	29.67
	Phd Year 1985	Phd Year 1986	Phd Year 1987	Phd Year 1988	Phd Year 1989	Phd Year 1990	Phd Year 1991	Phd Year 1992	Phd Year 1993	Phd Year 1994	Phd Year 1995	
Total Phds	980	1078	1137	1172	1161	1265	1286	1403	1399	1548	1479	
Males	889	978	1030	1058	1060	1135	1144	1236	1230	1373	1297	
Females	91	100	107	114	101	130	142	167	169	175	182	
US citizens	616	606	627	626	597	660	671	709	704	789	764	
Male US citizens	563	556	571	582	549	613	605	636	633	703	677	
Female US citizens	53	50	56	44	48	47	66	73	71	86	87	
Perm residents	46	37	55	55	57	65	68	81	102	255	295	
Male Perm Res	40	32	49	39	47	50	58	60	79	204	239	
Female Perm Res	6	5	6	16	10	15	10	21	23	51	56	
Temp Visa	276	348	376	403	401	507	525	581	550	471	399	
Male Temp Visa	247	308	344	354	365	441	460	510	477	433	360	
Female Temp Visa	29	40	32	49	36	66	65	71	73	38	39	
Minorities	18	21	18	26	22	18	28	38	35	42	37	
Planning Postdocs	397	453	548	566	566	616	670	686	655	706	643	
Planning Acad Appoint	66	55	54	56	59	56	55	56	47	57	72	
Planning Gov Appoint	59	61	49	54	42	35	38	42	34	37	35	
Planning Indust Appoint	178	156	134	128	117	110	105	85	94	112	141	
Median Time to Degree	7.09	7	7	7	7	7.09	7.24	7.41	7.5	7.5	7.5	
Median Age at Degree	29.83	30	30.08	30.08	30.09	30.25	30.16	30.08	30.5	30.66	30.58	

for postdoctoral appointments at the time their degree was granted is increasing. This proportion is higher in Astronomy than in Physics, where a declining but still significant proportion plan to take permanent positions in industry. About 65% of Astronomy doctorates earning the degree from 1991–95 had definite plans at graduation to assume postdoctoral appointments compared to 38% of new Physics doctorates.

Not surprisingly, the number of individuals holding postdoctoral appointments has risen in both Physics and Astronomy (Figs. 14 and 15, Table 3). Over 260 Astronomy PhDs held postdocs in academia in 1995, double that of 1987. This is approximately 50% of those 1–4 years post-degree. The numbers also increased in Physics, but not as dramatically.

In both Astronomy and Physics, women are represented proportionately to their fraction in the PhD pool: about 20% in Astronomy and 10% in Physics in 1995 (Fig. 16).

In contrast, the fraction of non-US citizens in postdoctoral appointments in Physics rose from 47% in 1987 to close to 56% in 1995, while falling in Astronomy from 40% in 1987 to 33% in 1995 (Fig. 17). These numbers do not include individuals holding postdocs in other sectors, such as industry or government labs, but do include individuals who earned their degrees outside of the US. Since the fraction of non-US citizens in the postdoc pool far exceeds their representation in the pool of new PhDs earned in the US, these data suggest that a significant number of foreign-trained individuals come to the US for further training as postdoctoral

FIG. 6. Fraction of Women Earning PhDs in Astronomy and Physics.

fellows. Whether they opt to stay in the US following completion of their postdoc is unknown.

- Changing career paths for young scientists

Career opportunities for new PhDs in Astronomy are changing from those in the past. However, these changes are not as dramatic as that for new Physics PhDs, where uncertainties in employment impact on a much larger group. Because of the predominance of postdoctoral training for new PhDs in both disciplines, we examined the career paths of individuals 5–8 years post-degree, at a time when it seems reasonable to assume that most should have achieved stable employment. Because the numbers of individuals in a given employment sector are based on weighted estimates from the sample drawn in the SDR, and because the population of astronomers overall is small, changes in a small number of actual respondents may produce apparently large weighted changes from year to year. These variations should be viewed with caution. For detailed breakdowns, see Data Tables 4–8.

C.1.6 Recent growth in tenure-track faculty positions

By far the largest employer of PhD astronomers is academia, and 50–60% of astronomers (not including postdocs) are employed there. This fraction has remained relatively stable over the last 20 years. For Astronomy PhDs 5–8 yrs post-degree, both the number and fraction holding tenure-track positions declined until 1989, but has increased slightly since then (Figs. 18 and 19, Table 4). About one-third of the

FIG. 7. Citizenship Status of New Physics Doctorates.

FIG. 8. Citizenship Status of New Astronomy Doctorates.

cohort held tenure-track faculty positions in 1995. As the number of tenure-track faculty positions declined there was a corresponding increase in those holding non-tenure-track positions in academia, and high numbers have persisted. This shift may reflect changes in university hiring patterns that are also seen in other disciplines.

The academic employment for physicists 5–8 years post-PhD is not as robust. Only 25% held tenure-track faculty positions in 1995, and the overall percentage holding positions in academia is somewhat lower (see Table 5).

C.1.7 Changing opportunities outside of academia

The fraction of Astronomy PhDs 5–8 years post-degree holding positions outside of academia has remained relatively stable at around 35–40% over the past 20 years, although the number holding such positions rose in the 1980's (Figs. 20 and 21, Table 4). The most notable trend was the increase from the early 1980's until 1993 in positions held in federal labs and other government agencies. This growth might have been the result of increases in space-based astronomical research supported by the federal government. However, the number holding such positions dropped sharply in 1995. At the same time, the number of those employed in other positions in science and engineering (S&E) increased markedly. This sector includes, for example, those who are self-employed, work in museums or planetaria, or teach at the junior college or pre-college levels. Employment in in-

FIG. 9. Median Time to Degree: Astronomy and Physics 1973–95.

FIG. 10. Career Plans for Doctorates in Astronomy/Astrophysics 1981–1985.

dustry represents only 10–12% of positions overall; this percentage has not changed markedly over the past 20 years.

In Physics, in contrast, the majority of those employed outside of academia hold positions in industry, although the fraction of those 5–8 years post-degree working in industry has fallen since 1985 (see Table 5). Comparatively fewer Physicists hold positions in federal labs or other employment in S&E.

C.1.8 No evidence for growing unemployment

The SDR permits an estimate of the number of individuals who are unemployed and seeking positions, as well as those working outside of S&E. At least some of the latter might be viewed as under-employed, since their training and expertise are not fully utilized. Unemployment for the 5–8 year cohort in Astronomy appears to be very low (<1%), particularly in recent years. However, considerable variability is seen for other cohorts across the survey period, probably as a result of very low reporting numbers. Similarly, low reporting numbers made it impossible to accurately estimate the population working outside of S&E. Examination of the entire Astronomy workforce, however, also indicates that both unemployment and employment outside of S&E remain low (see Table 8).

Unemployment in Physics, based on SDR data, ranges from 1–5%, depending on the age cohort examined. In ad-

FIG. 12. Career Plans for Doctorates in Physics 1981–1985.

dition, a higher proportion of Physics PhDs report employment outside of S & E, particularly among older cohorts, where levels reach 8% in recent surveys.

C.2 Summary

- Graduate enrollments in Astronomy, after a period of slow growth during the 80's and early 90's, declined by 9% in 1995.

- The number of PhDs awarded in Astronomy grew to 173 in 1995, but represents only 12% of those awarded in Physics. Representation of women is higher in Astronomy than in Physics, but has not changed significantly since the 1980's. Time to degree has lengthened for both fields by about one year since the 1970's, to a median of over 7 years since first enrollment in a graduate program.

- A decreasing percentage of new Astronomy PhDs have definite plans for employment at the time of the degree, but the proportion planning postdoctoral work has increased.

- The number of postdoctoral fellows in Astronomy has doubled since 1987, to over 250 in academia alone.

- About 50% of Astronomy PhDs 5–8 years post-degree are employed in academia. After a period of decline, both the number and fraction with tenured or tenure-track academic positions has increased in recent years; about 33% held such positions in 1995 5–8 years after earning their degree.

- About 40% of Astronomy PhD's 5–8 years post-degree are employed in a scientific field outside of academia. The proportion employed in industry, a major employer of physicists, is on the order of 10%. The remainder fluctuate between holding positions in federal labs and "other jobs."

FIG. 11. Career Plans for Doctorates in Astronomy/Astrophysics 1991–1995.

FIG. 13. Career Plans for Doctorates in Physics 1991–1995.

FIG. 14. Postdoctoral Astronomy and Physics Appointments in PhD-Granting Institutions 1987–95.

The proportion with positions in federal labs and other government positions declined sharply in 1995, to approximately 5%.

APPENDIX D: ADDITIONAL STATISTICS

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This appendix contains charts with some additional statistical information concerning employment opportunities and methods of financial support for graduate students in astronomy, and a comparison of these with support for physics students.

D.1 The AAS Job Register

Since 1986 the AAS has operated its *Job Register*, for posting of open positions in astronomical research, education, and technology. While a large fraction of the jobs available in these fields are posted in this service, it is by no means a complete sample of the open positions, and one must be wary of conclusions drawn from an incomplete sampling, especially with regard to the type of positions available. Nevertheless, it is instructive to look at the trends in total job listings as compared to the total PhD production rates (as reported by the NAS).

Figure 22 shows the total jobs listed each year since 1986 compared with the number of PhD degrees awarded in US institutions. A more detailed categorization of each job

FIG. 15. Postdoctoral Astronomy Appointments in PhD-Granting Institutions 1987–95.

advertised was obtained beginning in 1991, and the number of postings for tenure-track faculty positions and postdoctoral research positions are indicated for those years. In a typical year between one-third and one-half of the total postings have been for post-doc positions. It is important to realize that many of the postings for post-doc positions are repostings of the same position as the incumbent's term runs out (typically two or three years) and the sponsor seeks another person to fill the position. The remaining jobs making up the total are in the areas of research support, management, and student positions.

Since 1991 the number of non-U.S. positions posted in the *Job Register* has averaged about 20% of the total number, and has been steadily growing. We have no way of knowing whether this indicates an increase in available positions overseas, or whether it reflects an increasing usage of the *Job Register* by foreign institutions.

The most notable trends from this data are (1) that the number of postdocs plus visiting professor positions advertised each year in the job register are well matched to the number of astronomy PhDs awarded each year, with 200 such jobs corresponding to 172 new PhDs in 1995, and (2) the number of tenure track positions advertised each year is approximately 30% of the number of PhDs awarded.

D.2 Support of Graduate Students

The data reported in this section were gathered by the NSF (National Science Foundation, Selected Data on Gradu-

TABLE 3. Postdoctoral Appointments in Physics and Astronomy in Doctorate-Granting Institutions 1987–95.

	1987	1988	1989	1990	1991	1992	1993	1994	1995
Physics	1552	1584	1683	1723	1813	1984	1823	1841	1821
Astronomy	124	147	186	184	210	206	219	246	263

Fraction of Women in Postdoctoral Positions in Physics and Astronomy 1987-95

	1987	1988	1989	1990	1991	1992	1993	1994	1995
Physics	0.08	0.08	0.08	0.09	0.09	0.08	0.09	0.09	0.1
Astronomy	0.13	0.13	0.14	0.14	0.16	0.12	0.16	0.15	0.2

Fraction of U.S. Citizens/Permanent Residents in Postdoctoral Positions in Physics and Astronomy 1987-95

	1987	1988	1989	1990	1991	1992	1993	1994	1995
Physics	0.53	0.51	0.46	0.44	0.42	0.43	0.40	0.42	0.46
Astronomy	0.60	0.61	0.59	0.61	0.60	0.61	0.65	0.72	0.67

Fraction of Non-U.S. Citizens in Postdoctoral Positions in Physics and Astronomy 1987-95

	1987	1988	1989	1990	1991	1992	1993	1994	1995
Physics	0.47	0.49	0.54	0.56	0.58	0.55	0.60	0.58	0.54
Astronomy	0.40	0.39	0.41	0.39	0.40	0.39	0.35	0.28	0.33

TABLE 4a. Career Progression Matrix for Astronomy/Astrophysics Doctorates—All Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	6	2	2	17		17	2	1	18		1	
(2) Part-time employed	14	15	38	1	4	7	6	5	3		13	16
(3) Working outside science and engineering			20				2	47	3			15
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	120	133	182	180	133	95	95	101	93	48	46	78
(5) Postdoc appointments (in any sector)	102	151	141	158	164	143	146	163	169	97	195	227
(6) Other academic position	66	63	31	33	46	65	51	36	70	38	44	108
(7) Industry	10	29	67	52	43	68	56	57	41	42	34	58
(8) Federal labs and other government	57	55	49	5	39	59	35		48	2	2	30
(9) Other jobs (including self-employed)	43	4	46	5	43	7	2	76	26		61	
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	275	337	394	280	379	375	286	398	407	201	242	381
(11) Supported by federal grants/contracts	247	226	372	305	324	263	282	385	n/a	235	266	333
Panel B: Number in 5-8 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position			5		1			3	21			
(2) Part-time employed	13	6	14	8	3	4	3	7	3	7		
(3) Working outside science and engineering	9	14			2	22		25		3		
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	126	142	145	191	207	154	167	156	94	151	120	123
(5) Postdoc appointments (in any sector)		10	36	3	3	26	15	16	16		29	30
(6) Other academic position	18	46	50	96	57	83	65	65	110	87	92	75
(7) Industry	10	42	38	30	101	53	54	62	60	68	64	37
(8) Federal labs and other government	58	86	43	78	45	12	23	22	55	90	58	17
(9) Other jobs (including self-employed)	9	32	47	36	26	68	85	138	54	41	38	90
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	136	258	228	270	333	248	250	187	220	319	279	171
(11) Supported by federal grants/contracts	133	202	249	218	316	383	290	401	n/a	365	196	255
Panel C: Number in 9-12 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	2				2		2					
(2) Part-time employed		1	3	3	9	9	1	4	9	9	9	
(3) Working outside science and engineering	7	22	1	2	1	23	25	41		20	14	
(4) Tenure-track Faculty (4-yr institutions)	65	73	149	152	189	167	160	151	178	141	169	166
(5) Postdoc appointments (in any sector)			2	1	22	21	1					
(6) Other academic position	10	20	21	29	92	63	44	35	43	43	88	113
(7) Industry	9		21	48	22	34	97	44	82	102	73	95
(8) Federal labs and other government	7	7	53	51	47	80	53	23	2	40	32	55
(9) Other jobs (including self-employed)			10	26	25	17	24	64	110	134	35	30
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	27	36	163	245	191	228	240	218	227	206	220	202
(11) Supported by federal grants/contracts	60	68	131	247	324	266	250	308	n/a	302	259	311
Panel D: Number in 13-16 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position					2			1	2		12	30
(2) Part-time employed	1				1	3	9	9	2			
(3) Working outside science and engineering			18	24	26	1	1	22			57	44
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	30	27	66	28	114	113	179	230	128	119	126	210
(5) Postdoc appointments (in any sector)				1				20				
(6) Other academic position	2	8	33	2	3	4	96	96	85	23	49	82
(7) Industry					24	45	74	48	59	69	36	15
(8) Federal labs and other government	1	17	8		78	50	50	72	58		15	15
(9) Other jobs (including self-employed)	9	9			24	24	27	49	47	62	87	61
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	20	9	26	2	194	230	226	260	236	133	157	247
(11) Supported by federal grants/contracts	20	35	84	25	99	186	255	344	n/a	198	245	300
Panel E: Number in 17-20 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position		1							26			
(2) Part-time employed			1				3	7	9		15	
(3) Working outside science and engineering						24	28	54	25			31
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	66	70	25	23	72	72	77	101	208	169	110	148
(5) Postdoc appointments (in any sector)												
(6) Other academic position		2		23	25		23	66	76	69	80	70
(7) Industry						1	1	55	53	20	7	33
(8) Federal labs and other government	12	12		46	23		56	62	49	92	67	21
(9) Other jobs (including self-employed)	2		11	23			27	59	28	54	24	35
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	35	36	36	23	3	1	102	260	154	189	161	184
(11) Supported by federal grants/contracts	44	38	26	69	50	46	150	237	n/a	207	176	231

TABLE 4b. Career Progression Matrix for Astronomy/Astrophysics Doctorates—All Doctorates.

	Survey Year											
Panel A: Number in 1-4 Year Cohort	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.01	0.00	0.00	0.04		0.04	0.01	0.00	0.04		0.00	
(2) Part-time employed	0.03	0.03	0.07	0.00	0.01	0.02	0.02	0.01	0.01		0.03	0.03
(3) Working outside science and engineering			0.03				0.01	0.10	0.01			0.03
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.29	0.29	0.32	0.40	0.28	0.21	0.24	0.21	0.20	0.21	0.12	0.14
(5) Postdoc appointments (in any sector)	0.24	0.33	0.24	0.35	0.35	0.31	0.37	0.34	0.36	0.43	0.49	0.43
(6) Other academic position	0.16	0.14	0.05	0.07	0.10	0.14	0.13	0.07	0.15	0.17	0.11	0.20
(7) Industry	0.02	0.06	0.12	0.12	0.09	0.15	0.14	0.12	0.09	0.19	0.09	0.11
(8) Federal labs and other government	0.14	0.12	0.09	0.01	0.08	0.13	0.09		0.1	0.01	0.01	0.06
(9) Other jobs (including self-employed)	0.10	0.01	0.08	0.01	0.09	0.02	0.01	0.16	0.06		0.15	
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.69	0.77	0.76	0.65	0.81	0.86	0.74	0.92	0.91	0.89	0.63	0.76
(11) Supported by federal grants/contracts	0.62	0.52	0.72	0.70	0.69	0.60	0.73	0.89	n/a	1.04	0.70	0.66
Panel B: Number in 5-8 Year Cohort	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position			0.01		0.00			0.01	0.05			
(2) Part-time employed	0.05	0.02	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.02		
(3) Working outside science and engineering	0.04	0.04			0.00	0.05		0.05		0.01		
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.52	0.38	0.38	0.43	0.47	0.36	0.41	0.32	0.22	0.34	0.30	0.33
(5) Postdoc appointments (in any sector)		0.03	0.10	0.01	0.01	0.06	0.04	0.03	0.04		0.07	0.08
(6) Other academic position	0.07	0.12	0.13	0.22	0.13	0.20	0.16	0.13	0.27	0.19	0.23	0.20
(7) Industry	0.04	0.11	0.10	0.07	0.23	0.13	0.13	0.13	0.15	0.15	0.16	0.10
(8) Federal labs and other government	0.24	0.23	0.11	0.18	0.10	0.03	0.06	0.04	0.13	0.20	0.14	0.05
(9) Other jobs (including self-employed)	0.04	0.08	0.12	0.08	0.06	0.16	0.21	0.28	0.13	0.09	0.09	0.24
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.62	0.72	0.64	0.62	0.76	0.63	0.61	0.41	0.57	0.73	0.70	0.46
(11) Supported by federal grants/contracts	0.60	0.56	0.69	0.50	0.72	0.97	0.71	0.87	n/a	0.84	0.49	0.69
Panel C: Number in 9-12 Year Cohort	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.02				0.00		0.00					
(2) Part-time employed		0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.02		0.02	
(3) Working outside science and engineering	0.07	0.18	0.00	0.01	0.00	0.05	0.06	0.11			0.03	
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.65	0.59	0.57	0.49	0.46	0.40	0.39	0.42	0.42	0.44	0.40	0.36
(5) Postdoc appointments (in any sector)			0.01	0.00	0.05	0.05	0.00					
(6) Other academic position	0.10	0.16	0.08	0.09	0.22	0.15	0.11	0.10	0.10	0.08	0.21	0.25
(7) Industry	0.09		0.08	0.15	0.05	0.08	0.24	0.12	0.19	0.25	0.17	0.21
(8) Federal labs and other government	0.07	0.06	0.20	0.16	0.11	0.19	0.13	0.06	0.00		0.08	0.12
(9) Other jobs (including self-employed)			0.04	0.08	0.06	0.04	0.06	0.18	0.26	0.23	0.08	0.07
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.30	0.36	0.64	0.80	0.48	0.60	0.63	0.69	0.55	0.49	0.55	0.44
(11) Supported by federal grants/contracts	0.66	0.68	0.51	0.80	0.82	0.70	0.66	0.97	n/a	0.73	0.65	0.68
Panel D: Number in 13-16 Year Cohort	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position					0.01			0.00	0.01		0.03	0.07
(2) Part-time employed	0.02				0.00	0.01	0.02	0.02	0.01			
(3) Working outside science and engineering			0.14	0.44	0.10	0.00	0.00	0.04			0.15	0.10
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.70	0.44	0.52	0.51	0.42	0.47	0.41	0.42	0.34	0.44	0.33	0.46
(5) Postdoc appointments (in any sector)				0.02				0.04				
(6) Other academic position	0.05	0.13	0.26	0.04	0.01	0.02	0.22	0.18	0.22	0.08	0.13	0.18
(7) Industry					0.09	0.19	0.17	0.19	0.15	0.25	0.09	0.03
(8) Federal labs and other government	0.02	0.28	0.06		0.29	0.21	0.11	0.13	0.15		0.04	0.03
(9) Other jobs (including self-employed)	0.21	0.15			0.09	0.10	0.06	0.09	0.12	0.23	0.23	0.13
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.48	0.15	0.24	0.06	0.80	0.97	0.53	0.50	0.63	0.49	0.5	0.64
(11) Supported by federal grants/contracts	0.48	0.57	0.79	0.81	0.41	0.79	0.60	0.67	n/a	0.73	0.78	0.78
Panel E: Number in 17-20 Year Cohort	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position									0.05			
(2) Part-time employed		0.01	0.03				0.01	0.02	0.02		0.05	
(3) Working outside science and engineering						0.25	0.13	0.13	0.05			0.09
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.83	0.82	0.68	0.20	0.60	0.74	0.36	0.25	0.43	0.42	0.37	0.44
(5) Postdoc appointments (in any sector)												
(6) Other academic position		0.02		0.20	0.21		0.11	0.16	0.16	0.17	0.26	0.21
(7) Industry						0.01	0.00	0.14	0.11	0.05	0.02	0.10
(8) Federal labs and other government	0.15	0.14		0.40	0.19		0.26	0.15	0.10	0.23	0.22	0.06
(9) Other jobs (including self-employed)	0.03		0.30	0.20			0.13	0.15	0.06	0.13	0.08	0.10
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.44	0.43	1.00	0.20	0.03	0.01	0.55	0.76	0.37	0.47	0.56	0.60
(11) Supported by federal grants/contracts	0.55	0.45	0.72	0.60	0.42	0.63	0.82	0.69	n/a	0.51	0.61	0.75

TABLE 5a. Career Progression Matrix for Physics Doctorates—All Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	108	134	62	41	42	49	23	53	32	73	195	116
(2) Part-time employed	120	50	104	26	40	10	8	30	97	99	105	139
(3) Working outside science and engineering	241	271	207	75	63	132	93	191	53	50	120	176
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	1279	905	662	568	440	382	533	487	384	591	585	531
(5) Postdoc appointments (in any sector)	644	782	857	640	525	857	791	780	1022	709	1432	1963
(6) Other academic position	438	256	160	286	218	243	282	270	534	712	542	287
(7) Industry	1044	1185	1183	4318	1098	925	1186	1153	1137	799	683	905
(8) Federal labs and other government	872	705	318	342	311	264	167	257	306	255	173	97
(9) Other jobs (including self-employed)	291	229	185	166	257	160	58	87	147	282	91	208
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	2605	2590	2321	1892	1982	1792	1935	2223	2551	2578	2271	2530
(11) Supported by federal grants/contracts	2370	2295	2044	1914	1569	1464	1580	1986	n/a	2137	1952	2217
Panel B: Number in 5-8 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	53	87	91	39	19	17	16	25	50	147	91	45
(2) Part-time employed	99	68	22	64	36	18	31	9	37	88	82	178
(3) Working outside science and engineering	165	261	429	261	196	220	180	214	105	56	157	119
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	1780	1954	1706	1221	938	763	599	690	699	743	986	922
(5) Postdoc appointments (in any sector)	63	103	142	61	105	71	52	66	45	114	233	305
(6) Other academic position	121	187	215	370	399	328	267	265	500	139	351	571
(7) Industry	881	1276	1274	1592	1662	1352	1420	1494	1288	1304	1063	953
(8) Federal labs and other government	551	459	663	859	392	325	337	310	317	286	323	287
(9) Other jobs (including self-employed)	250	286	368	338	290	242	217	134	195	108	227	255
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	1609	1984	2037	1850	1806	1912	1687	1702	1922	1529	1701	1965
(11) Supported by federal grants/contracts	1743	2102	2239	2140	1942	1830	1329	1513	n/a	1683	1653	1821
Panel C: Number in 9-12 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	43	15	20	53	44	26	10	33	25	75	103	
(2) Part-time employed	24	45	26	97	61	12	61	21	10	36	77	38
(3) Working outside science and engineering	107	164	265	253	446	460	320	174	135	115	34	85
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	1168	1358	1597	1610	1496	1179	951	855	627	525	804	860
(5) Postdoc appointments (in any sector)		23	38	98		17	12				66	93
(6) Other academic position	20	39	61	287	412	235	252	270	313	95	300	370
(7) Industry	568	796	1043	1342	1698	1670	1644	1727	1568	1433	1307	1375
(8) Federal labs and other government	368	369	476	671	680	650	390	397	355	196	318	275
(9) Other jobs (including self-employed)	215	224	265	364	328	348	319	297	240	357	208	180
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	806	1220	1365	1657	1985	1768	1517	1541	1446	1449	1285	1493
(11) Supported by federal grants/contracts	1103	1484	1751	1815	2091	2034	1628	1957	n/a	1353	1224	1450
Panel D: Number in 13-16 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	18	21	33	2	25	46	26	28	25	24	30	30
(2) Part-time employed	22	12	11	60	32	85	42	55	34	88	77	91
(3) Working outside science and engineering	52	57	161	180	145	451	489	470	259	255	281	179
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	828	891	1071	1526	1643	1773	1503	1138	1053	603	678	582
(5) Postdoc appointments (in any sector)	1	5	6	1	48	22		3			28	15
(6) Other academic position	14	62	52	71	148	302	326	248	472	101	373	321
(7) Industry	412	472	595	579	1114	1190	1704	1919	1447	1464	1314	1321
(8) Federal labs and other government	166	267	251	443	514	548	668	604	442	389	366	407
(9) Other jobs (including self-employed)	52	82	214	166	239	149	254	297	399	290	179	182
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	442	579	868	1135	1520	1560	1632	1735	1413	1301	1301	1107
(11) Supported by federal grants/contracts	861	891	1176	1202	1650	1849	1988	2538	n/a	1596	1329	1150
Panel E: Number in 17-20 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	23	1		24		1	2	4	25	20	80	46
(2) Part-time employed	5	52	2	50	27	27	38	88	39	50	73	92
(3) Working outside science and engineering	66	24	135	212	241	135	279	304	469	405	320	327
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	695	791	828	821	945	1394	1747	1866	1367	1179	952	917
(5) Postdoc appointments (in any sector)					1	1			24			
(6) Other academic position	34	36	16	85	150	107	81	222	600	106	278	271
(7) Industry	496	466	351	345	477	760	1070	1744	1850	1772	1468	1509
(8) Federal labs and other government	279	156	142	69	190	405	474	542	594	627	460	432
(9) Other jobs (including self-employed)	45	27	38	48	196	183	195	279	404	369	578	436
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	538	495	544	483	878	1301	1101	1662	1809	1359	1170	1218
(11) Supported by federal grants/contracts	868	862	814	769	844	1418	1418	2490	n/a	2053	1658	1720

TABLE 5b. Career Progression Matrix for Physics Doctorates—All Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.02	0.03	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.05	0.03
(2) Part-time employed	0.02	0.01	0.03	0.01	0.01	0.00	0.00	0.01	0.03	0.03	0.03	0.03
(3) Working outside science and engineering	0.05	0.06	0.06	0.02	0.02	0.05	0.03	0.06	0.01	0.01	0.03	0.04
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.25	0.20	0.18	0.16	0.14	0.14	0.17	0.15	0.10	0.17	0.15	0.12
(5) Postdoc appointments (in any sector)	0.13	0.17	0.23	0.18	0.18	0.21	0.25	0.24	0.28	0.20	0.36	0.44
(6) Other academic position	0.09	0.06	0.04	0.08	0.07	0.09	0.09	0.08	0.14	0.20	0.14	0.06
(7) Industry	0.21	0.26	0.32	0.38	0.37	0.34	0.38	0.35	0.31	0.22	0.17	0.20
(8) Federal labs and other government	0.17	0.16	0.09	0.10	0.10	0.10	0.05	0.08	0.08	0.07	0.04	0.02
(9) Other jobs (including self-employed)	0.06	0.05	0.05	0.05	0.09	0.06	0.02	0.03	0.04	0.08	0.02	0.05
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.57	0.64	0.69	0.57	0.70	0.70	0.64	0.73	0.72	0.77	0.65	0.63
(11) Supported by federal grants/contracts	0.52	0.56	0.61	0.58	0.55	0.57	0.52	0.65	n/a	0.64	0.56	0.56
Panel B: Number in 5-8 Year Cohort												
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.01	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.02	0.05	0.03	0.01
(2) Part-time employed	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.03	0.02	0.05
(3) Working outside science and engineering	0.04	0.06	0.09	0.05	0.05	0.07	0.06	0.07	0.03	0.02	0.04	0.03
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.44	0.42	0.35	0.25	0.23	0.23	0.20	0.22	0.22	0.25	0.28	0.25
(5) Postdoc appointments (in any sector)	0.02	0.02	0.03	0.01	0.03	0.02	0.02	0.02	0.01	0.04	0.07	0.08
(6) Other academic position	0.03	0.04	0.04	0.08	0.10	0.10	0.09	0.08	0.15	0.05	0.10	0.16
(7) Industry	0.22	0.27	0.26	0.33	0.41	0.41	0.46	0.47	0.40	0.44	0.30	0.26
(8) Federal labs and other government	0.14	0.10	0.14	0.18	0.10	0.10	0.11	0.10	0.10	0.10	0.09	0.08
(9) Other jobs (including self-employed)	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.04	0.06	0.04	0.06	0.07
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.44	0.47	0.47	0.42	0.48	0.62	0.58	0.58	0.63	0.57	0.53	0.60
(11) Supported by federal grants/contracts	0.48	0.49	0.51	0.48	0.51	0.59	0.46	0.51	n/a	0.62	0.52	0.55
Panel C: Number in 9-12 Year Cohort												
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.02	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.03	0.03	
(2) Part-time employed	0.01	0.01	0.01	0.02	0.01	0.00	0.02	0.01	0.00	0.01	0.02	0.01
(3) Working outside science and engineering	0.04	0.05	0.07	0.05	0.09	0.10	0.08	0.05	0.04	0.04	0.01	0.03
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.47	0.45	0.42	0.34	0.29	0.26	0.24	0.23	0.19	0.19	0.25	0.27
(5) Postdoc appointments (in any sector)		0.01	0.01	0.02		0.00	0.00				0.02	0.03
(6) Other academic position	0.01	0.01	0.02	0.06	0.08	0.05	0.06	0.07	0.10	0.03	0.09	0.11
(7) Industry	0.23	0.26	0.28	0.28	0.33	0.36	0.42	0.46	0.48	0.51	0.41	0.42
(8) Federal labs and other government	0.15	0.12	0.13	0.14	0.13	0.14	0.10	0.00	0.11	0.07	0.10	0.08
(9) Other jobs (including self-employed)	0.09	0.07	0.07	0.08	0.06	0.08	0.08	0.09	0.07	0.13	0.06	0.05
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.34	0.43	0.39	0.38	0.43	0.43	0.43	0.43	0.47	0.56	0.43	0.47
(11) Supported by federal grants/contracts	0.47	0.53	0.50	0.42	0.45	0.50	0.46	0.55	n/a	0.52	0.41	0.46
Panel D: Number in 13-16 Year Cohort												
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
(2) Part-time employed	0.01	0.01	0.00	0.02	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.03
(3) Working outside science and engineering	0.03	0.03	0.07	0.06	0.04	0.10	0.10	0.10	0.06	0.08	0.08	0.06
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.53	0.48	0.45	0.50	0.42	0.39	0.30	0.24	0.25	0.19	0.21	0.18
(5) Postdoc appointments (in any sector)	0.00	0.00	0.00	0.00	0.01	0.00		0.00			0.01	0
(6) Other academic position	0.01	0.03	0.02	0.02	0.04	0.07	0.07	0.05	0.11	0.03	0.11	0.1
(7) Industry	0.26	0.25	0.25	0.19	0.29	0.26	0.34	0.40	0.35	0.46	0.40	0.42
(8) Federal labs and other government	0.11	0.14	0.10	0.15	0.13	0.12	0.13	0.13	0.11	0.12	0.11	0.13
(9) Other jobs (including self-employed)	0.03	0.04	0.09	0.05	0.06	0.03	0.05	0.06	0.10	0.09	0.05	0.06
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.30	0.33	0.40	0.41	0.41	0.39	0.37	0.41	0.37	0.46	0.44	0.39
(11) Supported by federal grants/contracts	0.58	0.50	0.54	0.43	0.45	0.46	0.45	0.60	n/a	0.56	0.45	0.41
Panel E: Number in 17-20 Year Cohort												
Not in Full-time S&E Work Force												
(1) Unemployed and seeking position	0.01	0.00		0.01		0.00	0.00	0.00	0.00	0.00	0.02	0.01
(2) Part-time employed	0.00	0.03	0.00	0.03	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02
(3) Working outside science and engineering	0.04	0.02	0.09	0.13	0.11	0.04	0.07	0.06	0.09	0.09	0.08	0.08
Full-time employed in S&E field												
(4) Tenure-track Faculty (4-yr institutions)	0.42	0.48	0.55	0.50	0.43	0.46	0.45	0.37	0.26	0.26	0.23	0.23
(5) Postdoc appointments (in any sector)					0.00	0.00			0.00			
(6) Other academic position	0.02	0.02	0.01	0.05	0.07	0.04	0.02	0.04	0.11	0.02	0.07	0.07
(7) Industry	0.30	0.30	0.23	0.21	0.21	0.25	0.28	0.35	0.34	0.39	0.35	0.37
(8) Federal labs and other government	0.17	0.10	0.09	0.04	0.09	0.13	0.12	0.11	0.11	0.14	0.11	0.11
(9) Other jobs (including self-employed)	0.03	0.02	0.03	0.03	0.09	0.06	0.05	0.06	0.08	0.08	0.14	0.11
Research Involvement (in full-time S&E position)												
(10) Engaged primarily in research	0.35	0.34	0.40	0.35	0.45	0.46	0.31	0.36	0.37	0.34	0.31	0.34
(11) Supported by federal grants/contracts	0.56	0.58	0.59	0.56	0.43	0.50	0.40	0.54	n/a	0.51	0.44	0.48

FIG. 16. Fraction of Women Holding Postdoctoral Appointments in PhD-Granting Institutions 1987–95.

TABLE 6a. Career Progression Matrix for Astronomy/Astrophysics Doctorates—Citizen/Permanent Resident Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	6	2	2	17		17			18		1	
(2) Part-time employed	14	15	38	1	4	7	6	5	3		13	16
(3) Working outside science and engineering			15					2	47	3		15
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	120	121	182	180	109	95	95	75	67	2	46	78
(5) Postdoc appointments (in any sector)	90	146	139	106	108	141	146	136	169	92	163	172
(6) Other academic position	66	63	31	33	22	65	51	36	70	38	28	81
(7) Industry	10	27	67	52	43	68	56	57	41	42	18	18
(8) Federal labs and other government	57	55	49	5	39	59	35		48	2	2	30
(9) Other jobs (including self-employed)	43	4	46	5	43	7	2	47			38	
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	263	330	392	230	275	373	286	316	355	150	178	280
(11) Supported by federal grants/contracts	247	224	372	286	220	261	282	303	n/a	184	202	230
Panel B: Number in 5-8 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position			5		1			3	21			
(2) Part-time employed	13	6	14	8	3	4	3		4			
(3) Working outside science and engineering	9	14				22		25		3		
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	116	121	133	169	203	127	131	156	94	119	89	109
(5) Postdoc appointments (in any sector)		10	36	3	3	2	15	16	16		29	30
(6) Other academic position	18	36	50	96	57	83	65	65	110	87	92	75
(7) Industry	10	42	38	28	101	50	51	62	60	68	64	37
(8) Federal labs and other government	58	86	43	78	45	12	23	22	55	58	42	17
(9) Other jobs (including self-employed)	9	32	47	36	26	68	85	138	54	41	38	90
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	117	248	228	270	333	196	211	187	220	287	248	157
(11) Supported by federal grants/contracts	124	181	249	218	312	329	287	401	n/a	333	179	241
Panel C: Number in 9-12 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	2				2		2					
(2) Part-time employed		1	3	3	9	9	1	4	9	3		
(3) Working outside science and engineering	7	22	1	2	1	22	25	41		20	14	
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	56	63	127	108	167	167	147	127	136	141	169	129
(5) Postdoc appointments (in any sector)			2	1	22	21	1					
(6) Other academic position	10	20	21	29	92	63	44	35	43	43	88	113
(7) Industry	9		21	48	22	34	97	41	78	102	73	80
(8) Federal labs and other government	7	7	53	51	47	80	53	23	2	40	32	55
(9) Other jobs (including self-employed)				26	25	17	24	64	110	134	35	30
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	27	36	152	201	191	228	230	197	181	206	220	183
(11) Supported by federal grants/contracts	51	58	121	247	302	266	240	281	n/a	302	259	296

FIG. 17. Fraction of Non-US Citizens Holding Postdoctoral Appointments in PhD Granting Institutions 1987–95.

TABLE 6b. Career Progression Matrix for Astronomy/Astrophysics Doctorates—Citizen/Permanent Resident Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	0.01	0.01	0.00	0.04		0.04			0.04		0.00	
(2) Part-time employed	0.03	0.03	0.07	0.00	0.01	0.02	0.02	0.01	0.01		0.04	0.04
(3) Working outside science and engineering			0.03				0.01	0.12	0.01			0.04
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.29	0.28	0.32	0.45	0.29	0.21	0.24	0.19	0.16	0.01	0.15	0.19
(5) Postdoc appointments (in any sector)	0.22	0.34	0.24	0.27	0.29	0.31	0.37	0.34	0.40	0.52	0.53	0.42
(6) Other academic position	0.16	0.15	0.05	0.08	0.06	0.14	0.13	0.09	0.17	0.22	0.09	0.20
(7) Industry	0.02	0.06	0.12	0.13	0.12	0.15	0.14	0.14	0.10	0.24	0.06	0.04
(8) Federal labs and other government	0.14	0.13	0.09	0.01	0.11	0.13	0.09		0.11	0.01	0.01	0.07
(9) Other jobs (including self-employed)	0.11	0.01	0.08	0.01	0.12	0.02	0.01	0.12			0.12	
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.68	0.79	0.76	0.60	0.76	0.86	0.74	0.90	0.90	0.85	0.60	0.74
(11) Supported by federal grants/contracts	0.64	0.54	0.72	0.75	0.60	0.60	0.73	0.86	n/a	1.05	0.68	0.61
Panel B: Number in 5-8 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position			0.01		0.00			0.01	0.05			
(2) Part-time employed	0.06	0.02	0.04	0.02	0.01	0.01	0.01		0.01			
(3) Working outside science and engineering	0.04	0.04				0.06		0.05		0.01		
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.49	0.35	0.36	0.40	0.46	0.35	0.35	0.32	0.23	0.32	0.25	0.30
(5) Postdoc appointments (in any sector)		0.03	0.10	0.01	0.01	0.01	0.04	0.03	0.04		0.08	0.08
(6) Other academic position	0.08	0.10	0.14	0.23	0.13	0.23	0.17	0.13	0.27	0.23	0.26	0.21
(7) Industry	0.04	0.12	0.10	0.07	0.23	0.14	0.14	0.13	0.15	0.18	0.18	0.10
(8) Federal labs and other government	0.25	0.25	0.12	0.19	0.10	0.03	0.06	0.04	0.13	0.15	0.12	0.05
(9) Other jobs (including self-employed)	0.04	0.09	0.13	0.09	0.06	0.18	0.23	0.28	0.13	0.11	0.11	0.25
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.55	0.76	0.66	0.66	0.77	0.57	0.57	0.41	0.57	0.77	0.70	0.44
(11) Supported by federal grants/contracts	0.59	0.55	0.72	0.53	0.72	0.96	0.78	0.87	n/a	0.89	0.51	0.67
Panel C: Number in 9-12 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	0.02				0.01		0.01					
(2) Part-time employed		0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.02	0.01		
(3) Working outside science and engineering	0.08	0.19	0.00		0.00	0.05	0.06	0.12		0.04	0.03	
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.62	0.56	0.56	0.40	0.43	0.40	0.37	0.38	0.36	0.29	0.41	0.32
(5) Postdoc appointments (in any sector)			0.01	0.00	0.06	0.05	0.00					
(6) Other academic position	0.11	0.18	0.09	0.11	0.24	0.15	0.11	0.10	0.11	0.09	0.21	0.28
(7) Industry	0.10		0.09	0.18	0.06	0.08	0.25	0.12	0.21	0.21	0.18	0.2
(8) Federal labs and other government	0.08	0.06	0.23	0.19	0.12	0.19	0.13	0.07	0.01	0.08	0.08	0.14
(9) Other jobs (including self-employed)				0.10	0.06	0.04	0.06	0.19	0.29	0.28	0.09	0.07
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.33	0.40	0.68	0.76	0.51	0.60	0.63	0.68	0.49	0.45	0.55	0.45
(11) Supported by federal grants/contracts	0.62	0.64	0.54	0.94	0.81	0.70	0.66	0.97	n/a	0.66	0.65	0.73

TABLE 7a. Career Progression Matrix for Physics Doctorates—Citizen and Permanent Resident Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	102	126	61	36	9	16	23	44	6	68	106	46
(2) Part-time employed	120	50	97	26	40	7	8	6	79	99	54	94
(3) Working outside science and engineering	230	271	207	73	63	132	93	162	51	30	106	61
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	1209	869	609	531	432	316	415	307	307	439	396	450
(5) Postdoc appointments (in any sector)	586	651	741	549	382	367	436	514	574	428	924	1226
(6) Other academic position	407	254	121	252	194	243	253	243	323	463	352	230
(7) Industry	1003	1152	1132	1210	1009	853	1035	1003	1002	492	411	512
(8) Federal labs and other government	853	691	300	342	311	232	167	257	302	223	155	97
(9) Other jobs (including self-employed)	261	229	185	166	205	122	44	84	94	146	65	178
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	2443	2418	2123	1764	1704	1377	1427	1730	1810	1597	1432	1682
(11) Supported by federal grants/contracts	2192	2109	1852	1754	1416	1203	1261	1555	n/a	1369	1295	1515
Panel B: Number in 5-8 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	45	83	78	36	19	1	16	2	23	109	91	34
(2) Part-time employed	85	67	22	61	36	18	27	7	37	41	58	158
(3) Working outside science and engineering	158	253	416	261	196	207	178	214	105	24	110	51
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	1582	1782	1594	1061	826	668	541	583	582	548	604	586
(5) Postdoc appointments (in any sector)	58	103	136	61	94	47		49	45	45	123	97
(6) Other academic position	112	185	215	326	357	319	265	211	420	79	247	433
(7) Industry	823	1198	1179	1520	1521	1195	1212	1299	1080	1014	822	706
(8) Federal labs and other government	544	448	627	837	392	325	309	283	285	286	298	268
(9) Other jobs (including self-employed)	234	252	347	338	269	242	190	101	115	76	126	208
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	1484	1864	1896	1699	1683	1792	1443	1414	1590	1187	1142	1261
(11) Supported by federal grants/contracts	1590	1923	2077	1900	1798	1683	1224	1284	n/a	1371	1102	1287
Panel C: Number in 9-12 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	37	14	20	49	44	24	4	33		43	103	
(2) Part-time employed	24	43	25	94	61	12	61	21	10	36	60	18
(3) Working outside science and engineering	101	162	265	251	424	455	320	174	135	63	25	85
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	1052	1211	1457	1518	1398	1058	841	727	550	462	610	619
(5) Postdoc appointments (in any sector)		23	38	98		17	12				44	93
(6) Other academic position	20	32	61	287	374	219	218	270	313	81	282	316
(7) Industry	528	740	970	1179	1473	1507	1471	1517	1432	1161	1033	1084
(8) Federal labs and other government	347	345	460	627	622	628	390	394	330	167	283	260
(9) Other jobs (including self-employed)	210	218	239	321	306	309	317	287	213	213	88	131
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	764	1137	1228	1541	1745	1461	1362	1437	1313	1215	1006	1128
(11) Supported by federal grants/contracts	1030	1391	1634	1680	1823	1823	1517	1773	n/a	1209	983	1250

FIG. 18. Number of Astronomy PhDs Employed in Academia 5–8 Years Post-degree.

FIG. 19. Fraction of Astronomy PhDs Employed in Academia 5–8 Years Post-degree.

TABLE 7b. Career Progression Matrix for Physics Doctorates—Citizen and Permanent Resident Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
Panel A: Number in 1-4 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	0.02	0.03	0.02	0.01	0.00	0.01	0.01	0.02	0.00	0.03	0.04	0.02
(2) Part-time employed	0.03	0.01	0.03	0.01	0.02	0.00	0.00	0.00	0.03	0.04	0.02	0.03
(3) Working outside science and engineering	0.05	0.06	0.06	0.02	0.02	0.06	0.04	0.06	0.02	0.01	0.04	0.02
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.26	0.20	0.18	0.17	0.16	0.14	0.17	0.12	0.11	0.18	0.16	0.16
(5) Postdoc appointments (in any sector)	0.12	0.15	0.21	0.17	0.14	0.16	0.18	0.20	0.21	0.18	0.36	0.42
(6) Other academic position	0.09	0.06	0.04	0.08	0.07	0.11	0.10	0.09	0.12	0.19	0.14	0.08
(7) Industry	0.21	0.27	0.33	0.38	0.38	0.37	0.42	0.38	0.37	0.21	0.16	0.18
(8) Federal labs and other government	0.18	0.16	0.09	0.11	0.12	0.10	0.07	0.10	0.11	0.09	0.06	0.03
(9) Other jobs (including self-employed)	0.05	0.05	0.05	0.05	0.08	0.05	0.02	0.03	0.03	0.06	0.03	0.06
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.57	0.63	0.69	0.58	0.67	0.65	0.61	0.72	0.70	0.73	0.62	0.62
(11) Supported by federal grants/contracts	0.51	0.55	0.60	0.58	0.56	0.56	0.54	0.65	n/a	0.62	0.56	0.56
Panel B: Number in 5-8 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	0.01	0.02	0.02	0.01	0.01	0.00	0.01	0.00	0.01	0.05	0.04	0.01
(2) Part-time employed	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.06
(3) Working outside science and engineering	0.04	0.06	0.09	0.06	0.05	0.07	0.07	0.08	0.04	0.01	0.04	0.02
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.44	0.41	0.35	0.24	0.22	0.22	0.20	0.21	0.22	0.25	0.24	0.23
(5) Postdoc appointments (in any sector)	0.02	0.02	0.03	0.01	0.03	0.02		0.02	0.02	0.02	0.05	0.04
(6) Other academic position	0.03	0.04	0.05	0.07	0.10	0.11	0.10	0.08	0.16	0.04	0.10	0.17
(7) Industry	0.23	0.27	0.26	0.34	0.41	0.40	0.44	0.47	0.40	0.46	0.33	0.28
(8) Federal labs and other government	0.15	0.10	0.14	0.19	0.11	0.11	0.11	0.10	0.11	0.13	0.12	0.11
(9) Other jobs (including self-employed)	0.06	0.06	0.08	0.08	0.07	0.08	0.07	0.04	0.04	0.03	0.05	0.08
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.44	0.47	0.46	0.41	0.49	0.64	0.57	0.56	0.63	0.58	0.51	0.55
(11) Supported by federal grants/contracts	0.47	0.48	0.51	0.46	0.52	0.60	0.49	0.51	n/a	0.67	0.50	0.56
Panel C: Number in 9-12 Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.01		0.02	0.04	
(2) Part-time employed	0.01	0.02	0.01	0.02	0.01	0.00	0.02	0.01	0.00	0.02	0.02	0.01
(3) Working outside science and engineering	0.04	0.06	0.07	0.06	0.09	0.11	0.09	0.05	0.05	0.03	0.01	0.03
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.46	0.43	0.41	0.34	0.30	0.25	0.23	0.21	0.19	0.21	0.25	0.24
(5) Postdoc appointments (in any sector)		0.01	0.01	0.02		0.00	0.00				0.02	0.04
(6) Other academic position	0.01	0.01	0.02	0.06	0.08	0.05	0.06	0.08	0.10	0.04	0.11	0.12
(7) Industry	0.23	0.27	0.27	0.31	0.36	0.40	0.44	0.48	0.48	0.52	0.41	0.42
(8) Federal labs and other government	0.15	0.12	0.13	0.14	0.13	0.15	0.11	0.12	0.11	0.08	0.11	0.1
(9) Other jobs (including self-employed)	0.09	0.08	0.07	0.07	0.07	0.07	0.09	0.08	0.07	0.10	0.03	0.05
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.35	0.44	0.38	0.38	0.42	0.39	0.42	0.45	0.46	0.58	0.43	0.45
(11) Supported by federal grants/contracts	0.48	0.54	0.51	0.42	0.44	0.49	0.47	0.55	n/a	0.58	0.42	0.5

FIG. 20. Number of Astronomy PhDs Employed Outside of Academia 5–8 Years Post-degree.

FIG. 21. Fraction of Astronomy PhDs Employed Outside of Academia 5–8 Years Post-degree.

FIG. 22. AAS Job Register Listings.

FIG. 23. Support of Astronomy Grad Students.

FIG. 25. Federal Support—Astronomy Students.

FIG. 24. Support of Physics Grad Students.

FIG. 26. Non-Federal Support—Astronomy Students.

TABLE 8. Career Progression Matrix for Astronomy/Astrophysics Doctorates—All Doctorates.

	Survey Year											
	1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993	1995
All-Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.03		0.00	0.01
(2) Part-time employed	0.04	0.02	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
(3) Working outside science and engineering	0.02	0.03	0.02	0.02	0.02	0.05	0.03	0.08	0.03	0.02	0.03	0.03
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	0.48	0.45	0.46	0.44	0.43	0.41	0.40	0.35	0.34	0.41	0.36	0.35
(5) Postdoc appointments (in any sector)	0.10	0.13	0.11	0.11	0.10	0.10	0.08	0.08	0.07	0.04	0.08	0.09
(6) Other academic position	0.09	0.11	0.09	0.13	0.12	0.12	0.13	0.13	0.18	0.11	0.19	0.20
(7) Industry	0.03	0.06	0.08	0.08	0.10	0.11	0.14	0.10	0.11	0.13	0.10	0.09
(8) Federal labs and other government	0.15	0.15	0.11	0.12	0.13	0.11	0.12	0.07	0.10	0.11	0.08	0.09
(9) Other jobs (including self-employed)	0.07	0.04	0.08	0.07	0.08	0.08	0.10	0.17	0.13	0.17	0.14	0.11
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	0.56	0.63	0.61	0.61	0.64	0.66	0.62	0.62	0.59	0.58	0.53	0.56
(11) Supported by federal grants/contracts	0.61	0.56	0.67	0.66	0.66	0.76	0.69	0.80	0.70	0.62	0.60	0.65
All-Year Cohort												
<u>Not in Full-time S&E Work Force</u>												
(1) Unemployed and seeking position	8	4	7	17	5	20	4	5	67		13	30
(2) Part-time employed	40	30	84	29	21	27	28	37	33	48	56	50
(3) Working outside science and engineering	24	44	39	29	31	84	56	215	73	43	89	90
<u>Full-time employed in S&E field</u>												
(4) Tenure-track Faculty (4-yr institutions)	496	573	721	676	831	765	824	916	921	1010	956	1043
(5) Postdoc appointments (in any sector)	102	161	179	163	189	190	162	199	185	97	224	275
(6) Other academic position	97	139	135	199	240	215	279	344	476	260	498	583
(7) Industry	36	78	126	130	190	201	282	269	298	322	270	276
(8) Federal labs and other government	152	185	168	185	258	203	240	181	271	260	209	269
(9) Other jobs (including self-employed)	75	54	124	106	159	156	204	444	350	410	370	334
<u>Research Involvement (in full-time S&E position)</u>												
(10) Engaged primarily in research	541	754	890	895	1197	1139	1239	1468	1484	1366	1340	1551
(11) Supported by federal grants/contracts	580	663	968	961	1235	1315	1371	1891	1790	1700	1525	1814

ate Students and Postdoctorates in Science and Engineering: Fall 1995, Supplementary Data Release Number 3: by Source of Major Support) and are publically available on the World Wide Web.

Figures 23 and 24 show the sources of major support for Astronomy and Physics students respectively. It is interesting to note that Astronomy students are more dependent on funding by Federal funds than are Physics students, with Federal funding roughly equaling institutional funding for Astronomy students in recent years. It is also true that the

number of students funded for graduate study in physics has been declining since 1992, as has the total enrolment of Physics graduate students. The first year with a downturn in the number of supported Astronomy students was 1994, and it is too soon to tell if that indicates a trend.

Figures 25 and 26 show the types of Federal and non-Federal support received by Astronomy students in the years 1986 through 1994. Note that research assistantships dominate the Federal support while teaching assistantships dominate the non-Federal support.