Training the Next Generation of Astronomers*

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Abstract

While both society and astronomy have evolved greatly over the past fifty years, the academic institutions and incentives that shape our field have remained largely stagnant. As a result, the astronomical community is faced with several major challenges, including: (1) the training that we provide does not align with the skills that future astronomers will need, (2) the postdoctoral phase is becoming increasingly demanding and demoralizing, and (3) our jobs are increasingly unfriendly to families with children. Solving these problems will require conscious engineering of our profession. Fortunately, this Decadal Review offers the opportunity to revise outmoded practices to be more effective and equitable. The highest priority of the Subcommittee on the State of the Profession should be to recommend *specific, funded* activities that will ensure the field meets the challenges we describe.

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1 Introduction

The collective self-examination made possible in astronomy by the Decadal Review process is a prime opportunity to engineer the incentives and institutions that shape our profession. We need not simply accept as inevitable the institutional framework that we've inherited.

The standard trajectory of the American academic career has been essentially fixed since the mid-20th century, when postdoc appointments started becoming common [1]. However, the practice of astronomy has changed since the 1950's: we now deal with increasingly enormous telescopes, collaborations, and data sets. The lack of similar evolution in graduate training has resulted in Ph.D. recipients who are no longer optimally trained for the skills and new positions required by modern astronomical research. In §2, we discuss these issues in detail and identify inefficiencies in the current structure for funding and training new professionals.

The practical structure of academic astronomy has also changed significantly. While the Ph.D. overproduction rate compared to faculty spots has remained approximately steady over the past two decades, there were many fewer postdoc positions in the past [2]. In recent years, however, increased federal funding has led to a boom in graduate student and postdoc positions without a concomitant expansion in the number of permanent faculty positions [3]. In §3, we explore the implications of these realities in our field.

Additionally, the past half-century has witnessed a dramatic change in the workforce. The opportunity to gain the contributions of many excellent astronomers is currently missed. In §4, we consider only one example of this phenomenon: how the resulting rise in the demand for "child-friendly" careers has been borne by our field. Progress to date has been minimal, and the evidence is that this situation systematically selects against women.

There is thus a good case to be made that the institutional framework of academic astronomy is suboptimal and disserves both the practitioners of astronomy and the public that ultimately funds it. Fortunately, this is an issue that we, the astronomical community, can solve. We argue that the Subcommittee on the State of the Profession (SSP) should direct its attention toward improving the structure of our instutional framework. We outline below the evidence for a few outstanding problems, describe their costs to the community, and provide some suggestions that we hope will prove useful to those charged with charting the course of astronomy over the next decade.

2 Allocation of Training Resources

The training of professional astronomers is integral to the discussion of what science will be done in the coming ten years. In this section, we discuss the current state of astrophysics training and propose that adaptations to this process will be necessary in order to best use financial resources and personnel to produce the best science.

2.1 The Cost, Training, and Employment of Astronomy Ph.D.s

Significant financial resources are currently invested in the training of the next generation of astronomers. A typical astronomy Ph.D. candidate may earn \$20K annually, with an additional \$20K spent by the PI or department to pay tuition and university fees. Assuming that the average student spends 5 years in graduate school and requires an additional \$50K over the course of this time to support equipment, travel, and miscellaneous expenses, every graduate student will cost the profession a quarter of a million dollars. Each year in the past decade, there have been $\gtrsim$170 astronomy Ph.D.s awarded in the United States [4, 5], *for a total of over $43M spent annually to produce new professionals* (see also the Seth *et al.* Position Paper on "Employment & Funding in Astronomy"). This is almost quadruple the annual operations budget of the Keck Observatory [6].

Graduate students are typically funded through research grants and are typically expected to devote the vast majority of their time to pure research. This policy is even expressly stated in some graduate student guides (*e.g.* [7]) and is pervasive in the professional culture. Few programs offer any incentives to broaden coursework beyond astronomy and physics to include computer science, engineering, public policy, business, or education. While many astronomy graduate programs mandate that students spend one or more semesters as teaching assistants, training in teaching skills is generally minimal, although there are laudable exceptions [8, 9]. Development of the skills needed for teaching at the non-university level and public outreach is typically absent from the curriculum.

There is only room in the field for $\sim$50% of Ph.D. recipients to become faculty at colleges and universities [3]. In fact, self-reporting of the careers of 651 astronomy Ph.D. recipients from 1980-2000 at eight universities reveals that 34% currently hold tenure-track faculty positions at research universities[1]. The remaining two-thirds of Ph.D. astronomers are employed at teaching colleges as tenure-track faculty (10%), at K-12 schools as educators or elsewhere as education researchers (2%), at observatories and national laboratories as permanent support/research staff (38%), and within business and industry (17%). That is, almost one third of Ph.D. recipients are not primarily employed in research.

An informal survey of UC Berkeley faculty indicates that they spend approximately 25% of their work time on research (excluding student and postdoc interaction), 25% on teaching, 19% on administrative duties (including committee participation and large-scale project management), 14% on advising students and postdocs, 12% on securing funding (for personal research as well as observatories/organizations/departments as a whole), and 5% on public outreach[2]. Despite the small sample size we feel that it is fair to say that **even "research university" faculty spend the majority of their time on activities other than research**.

Overall, we find that **training is a significant expenditure in the field of astronomy** and that **a majority of astronomy Ph.D. recipients spend a significant fraction of their time on activities other than research**.

2.2 The Needs of the Field Now and in the Coming Decade

Although the critical problem-solving skills obtained via research training are unarguably used by all astronomy Ph.D.s, regardless of career, there are other, equally valuable skills that these Ph.D.s will need that are not currently included in graduate training. This mismatch between the training

[1]From the websites of astronomy departments at Harvard University, the Ohio State University, Princeton University, UC Berkeley, UCLA, UC Santa Cruz, UT Austin, and the University of Virginia. Note that these departments are highly-ranked and likely have above-average tenure-track placement rates compared to the field as a whole. Data available in ASCII format online at `http://astro.berkeley.edu/~pkwill/ay2010_training/careers.txt`.

[2]Data available in ASCII format online at `http://astro.berkeley.edu/~pkwill/ay2010_training/factime.txt`.

of young professionals and the skills required in their future employment will only continue to grow in the coming decade. The increasing size and scope of projects in astronomy (*e.g.* Keck, VLA, ALMA, TMT, supercomputing and data management facilities) are creating increasingly large collaborations in which diverse skills are needed [10].

Obviously, the success of these projects depends critically on the $\sim\frac{1}{3}$ of Ph.D.s who become faculty and PIs. Such success is, however, dictated by much more than the PI's ability to do excellent science. Lead scientists within collaborations must also excel at managing funding and personnel, communicating science needs and results to the public (including the general public, government agencies, private investors, and industrial partners), and instructing and mentoring junior members of the group. Many of the requisite skills for these tasks are, in general, completely ignored during graduate and postdoctoral training and developed only later through trial and error. The lack of these skills in PIs can result at best in inefficiencies and at worst in misuse of funding and failure of strong scientific programs.

About two-fifths of Ph.D. astronomers find employment in permanent support or research staff positions, which require skills in areas such as data management and the construction, operation, and maintenance of hardware and software. This proportion will likely increase with the increasing scope of planned facilities. Despite this fact, Ph.D. programs generally do not have formal structures that encourage candidates to develop sophisticated programming or engineering skills.

Even more critically, the funding of the field and influx of talented individuals into it rely on education and outreach at all levels. This is the explicit career of 11% of Ph.D. astronomers (K-12 educators, education researchers, and professors at teaching colleges), but it is also an important role of university faculty ($\sim$30% of whose time is devoted to teaching and public outreach) and, to varying extents, of support astronomers. The importance of this part of astronomy cannot be understated: in the notable case of the Hubble Space Telescope (HST), public enthusiasm for the field directly led to the continuation of NASA support and congressional funding that would have otherwise been cut [11]. Nevertheless, education and outreach typically have minimal roles in astronomy training (§2.1).

Finally, $\sim\frac{1}{6}$ of Ph.D. astronomers leave the field entirely. While, as argued by the Seth *et al.* Position Paper on "Employment & Funding in Astronomy", there are not enough permanent positions in the field for all astronomy Ph.D.s, there is no reason to believe that those who leave are uniformly less excellent astronomers than those who stay. **The training that Ph.D.s receive creates expectations about the profession and signals what it values. The mismatch between that training and actual employment opportunities may drive talented young scientists to leave the profession.**

2.3 The Role of the Decadal Review

The above breakdown of job outcomes is a statistical reality. Graduate mentors need to both support and provide training for a number of possible employment opportunities. We suggest that the SSP investigate ways in which funding structures and associated directives to universities can be altered to support this realignment. In particular, **we suggest the following**:

(A) That the definition of a career in astronomy be broadened to include the true assortment of potential careers in astronomy that Ph.D.s eventually have; that this be assessed via rigorous tracking of the employment statistics of all Ph.D. recipients from graduate school through postdoc positions and culminating only when permanent positions are attained; and that updated statistics be regularly disseminated within the academic community. This is also one of the main points of the Seth *et al.* Position Paper on "Employment & Funding in Astronomy".

(B) That the training given at universities granting astronomy Ph.D.s reflect this paradigm shift, such that graduate students are trained for the jobs they will eventually hold.

(C) That communication and leadership skills be emphasized in a meaningful and substantial way in Ph.D. programs, helping the next generation to garner support from non-scientists, lead successful scientific projects and collaborations, and attract, educate, and mentor future generations of scientists.

Creative thinking will obviously be necessary to effect such a change in the astronomy education system at the graduate level. Here we list some means through which this might be achieved, which we intend not to be exhaustive but rather to initiate discussion: new Ph.D. programs could be funded to provide the breadth of knowledge and specialization now required by many careers in astronomy, *e.g.*, joint programs between astronomy and computer science, engineering, business, public policy, or education (dual Ph.D., Ph.D./masters, Ph.D. with a "minor"); federally-funded astronomy Ph.D. students could be required to spend a semester away from research in, *e.g.*, government agencies, student teaching positions, or internships within industry; quantifiable mentoring, teaching, and outreach requirements could be attached to federal grants (expanding on the latest NSF Proposal and Award Policies and Procedures Guide[3]) such that young professionals are required to devote part of their time to improving their leadership and communication skills. Most likely, a combination of many changes and initiatives will be needed to ensure that the training of young astronomers is best-suited to the positions that will need to be filled in the next ten years and beyond.

3 Postdocs

The structure of the traditional academic career has not kept up with the realities of the modern university. The postdoctoral position, once a short stopping point between Ph.D. and the tenure track, has evolved into a substantial phase of the academic career, with recipients holding 2–3 postdoc positions (*i.e.*, 4–9 years) until a permanent job is obtained [3]. Along with the increasing duration of this phase, it is also becoming increasingly and unneccessarily demanding and demoralizing.

3.1 The Postdoctoral Experience

Three fundamental factors are responsible for the transformation of the character of the postdoc phase: (1) the boom in Ph.D.s granted, (2) the lack of a similar expansion in permanent academic positions, and, importantly, (3) the failure of most Ph.D. training programs to adapt to this discrepancy, as described in §2. The interaction of these factors results in a situation where there are many people competing for few spots. While intense competition for prestigious jobs is natural, the incentives of the field encourage maximization of the amount of work extracted from trained astronomers, *i.e.*, the attrition of Ph.D.s out of the running for those jobs as late as possible. This situation does not select for higher-quality faculty — it merely places unneccessary burdens on those who do not end up attaining faculty jobs. The explicit recommendation of the previous

[3] http://www.nsf.gov/pubs/policydocs/pappguide/nsf09_1/index.jsp

Decadal Review committee to increase federal funding for postdoctoral fellowships has played a role in this effect [12, p. 198].

The consequences of this situation are acute. **Current postdocs endure a period of intense competition, prolonged job insecurity, multiple relocations with little or no choice in destination, and the prospect of a forced late-stage (mid-30's) career change.** As we discuss in the following section, the implications for those who also wish to start a family are particularly dire. This situation will not change as long as the three factors described above hold. Because our field is vibrant and competitive and academic jobs are very attractive to many, it would be incorrect to suggest that the difficulty of the postdoc phase will lead to unfilled tenure-track positions. However, the simple fact is that *we can do better*.

3.2 The Role of the Decadal Review

The problems of the postdoc system are not limited to astronomy, nor can they be solved overnight. One advantage that our field has, however, is relatively small size and the importance that federal funding plays within it. **We recommend that the SSP**:

(D) Re-evaluate postdoctoral and pre-tenure positions and recommend funding changes to remove the "arms race" incentives of the current system.

We hope that the SSP discusses a wide range of approaches to meeting this challenge, such as: eliminating the plethora of federally funded postdoctoral fellowships in favor of funding more diverse permanent positions; completely reconceptualizing the postdoctoral process and the transition from graduate school to permanent positions; encouraging the creation of a more fluid workforce in which early-career jobs can be held for longer periods of time and transitions between positions flow naturally with project timescales rather than in rigid (typically 3-5 year) timescales. It is worth noting that the tenure system plays a fundamental role in shaping the current postdoctoral system. Finally, in this topic, academic systems outside of the United States can provide examples, both good and bad, from which to learn.

4 Retaining Excellent Astronomers

The lack of adaptation in our professional institutions to social change has dramatic effects on the retention of excellent astronomers, with particular impact on underrepresented groups. Lengthy reports can be (and have been) written on this topic; we will focus on one example, the area of "child-friendliness" within astronomy and its effect upon women in our field. We will treat it briefly and consider again how the structure of our institutions affects the profession; we hope that other position papers will deal with this, and the other ways in which our field loses excellent astronomers, much more fully.

4.1 Child-Friendliness

In the past, most couples had one working spouse and one spouse who performed virtually all childcare duties. In such situations, it is viable for the working spouse to have an extremely time-demanding job. The modern norm is for families to be dual-income, and professional couples with children increasingly expect that both partners will work hard, pursue a fulfilling career, and share in childcare duties [13]. In this situation time-demanding and relatively low-paying jobs are much more difficult to accommodate.

The increase in demand for careers that accommodate two-income families has occurred more-or-less simultaneously with the severe lengthening of the postdoc phase. All of the difficulties mentioned in §3 are particularly problematic for parents; moreover, the postdoc stage usually happens at the exact age — in the late 20's and early 30's — in which most families are started. The hardship of multiple relocations is especially trying for those with long-term partners — let alone those with long-term partners *and* children — who therefore need to solve the "two-body problem" not once but several times over the course of only a few years. The reality of these concerns is well-established in our field and others. In a survey of University of California graduate students in all disciplines, 74% of the male respondents and 84% of the female respondents reported being "somewhat" or "very concerned" about the family-friendliness of their career paths [14]. (Here, we treat issues relating to family-friendliness as a superset of those relating to child-friendliness.) Exacerbating the problem is the difficulty of re-entering the field after any significant time away from it, discouraging would-be parents from leaving the field temporarily to care for young children. In fact, even junior faculty are uncomfortable with lessening their workload for maternity/paternity. According to the UC Faculty Work and Family Survey [15], less than a third of eligible faculty used the University's tenure "clock stoppage" option for new parents; of the survey respondents who did not, a significant fraction ($\sim$30%) cited "It might have hurt my career" as a reason for not invoking it.

4.2 Impact of Child-Unfriendliness on Excellence

While the difficulties of raising a family affect all academics, there is no question that they disproportionately impact the careers of women, regardless of their level of talent. In [14], 46% of the female respondents who began graduate school with the goal of becoming faculty but shifted their goals cited "issues related to children" as a major factor, while only 21% of the male respondents did. The results of [15] make for sobering reading: in virtually every aspect, female faculty find more of a tension between their careers and their families than their male counterparts. **We emphatically reject the notion that a prioritization of family life over career necessarily implies a lack of excellence in the field.** Improving the representation of women in astronomy depends upon addressing the child-friendliness of academic careers, though **the status of women in astronomy depends on far more than this one factor**. Conversely, **genuine efforts in this direction will make it a better field for all of its members, not just women.**

4.3 Impact on Legitimacy of the Field

We believe that the inequities alluded to in this section are all serious and worthy of correction on their own merits. However, they also have a damaging effect on the field by injuring its legitimacy in the public eye. Legislators and other funders may question — justifiably — whether they should direct spending towards a field that is only sluggishly addressing its glaring inequalities [16, 17]. This is especially true for a field which generally aspires to be a meritocracy in which individuals succeed purely based on the quality of their contributions. While astronomy is not the only offender, other fields, notably biology, do a better job of retaining excellent scientists [18, 19].

Significant federal effort is now directed towards rectifying gender inequalities in STEM (Science, Technology, Engineering, and Mathematics) professions. In [17], the National Academies stated that in order to "maintain scientific and engineering leadership amid increasing economic and educational globalization, the United States must aggressively pursue the innovative capacity of *all* of its people," regardless of gender (emphasis original). In October 2008, Barack Obama responded to a query from the Association for Women in Science with the following statement of policy [20]:

> We will need to significantly increase our STEM workforce, and to do that we will need to engage not just women and minorities but also persons with disabilities, English language learners, and students from low income families... We also support improved educational opportunities for all students, increased responsibilities and accountability for those receiving federal research funding, equitable enforcement of existing laws such as Title IX, continuation and strengthening of programs aimed at broader engagement in the STEM disciplines...

There has, in fact, been formal federal investigation into forcing university science programs to begin addressing inequalities by applying Title IX to them (*e.g.* [21, 22]).

4.4 The Role of the Decadal Review

It will take concerted effort across many sectors of academia, government, and society to enable us to attract and retain the best astronomers from all demographics. Nevertheless, the Decadal Review is an opportunity to begin implementing necessary policies. We **suggest that the SSP**:

(E) Mandate that job ads and offer letters at *all* levels in the field include information on the hiring institution's family-friendly policies.

(F) Identify model programs that have demonstrated positive impacts on the demographics and family-friendliness of astronomy and recommend that funding be allocated for duplications, expansions, and improvements of these programs.

(G) Identify policies that help retain the most talented astronomers and recommend that required implementation of these policies be attached to federal funding. Study the examples of other fields for lessons, both positive and negative.

(H) Consider any changes to the postdoctoral system in the light of the effect they will have on family-friendliness and the retention of excellent astronomers.

We reiterate that **many of the current challenges in astronomy careers are due to institutional structures than can be changed**. Some ideas to initiate discussion are: establishing opt-out minimum tenure "clock stopping" or parental leave policies; issuing comprehensive employer childcare assistance standards. A community approach to the enforcement of Title IX, should it be mandated, should be discussed.

5 Conclusion

The Decadal Review provides an invaluable opportunity to affirm *and revise* our values as a community and set priorities accordingly. This process has been tremendously successful in establishing support for instruments that have been the basis for ground-breaking science: the Very

Large Array, HST, and Spitzer were all made possible in large part due to recommendations of past Decadal Review committees. The Decadal Review process has also won support in Washington for the field of astronomy and indirectly led other fields to establish their own similar review processes [23].

However, while past reviews have been extremely successful in shaping the technologies used to pursue the next generation of science, less attention has been directed towards properly training and maintaining the astronomers who perform the science. Still less has been focused on training the next generation of astronomy educators, public policy experts, and project managers. While the needs of the profession and the labor market have evolved significantly since the astronomy Decadal Review process was established, the overall academic structure of the field has remained largely unchanged. Many of our current practices are outmoded, resulting in misallocated resources and attrition patterns that cause us to lose the contributions of excellent scientists.

The failure of past Decadal Review processes to allocate sufficient time and funding to revising these practices represents an undervaluation of the field's human resources. In a time of economic downturn and budget shortfalls, it is in our best interest to put stock in the ability of talented individuals to develop creative new solutions to outstanding problems in our field, whether those problems be in basic research, education, public outreach, or policy. We urge the Subcommittee to develop strong, concrete recommendations tied to funding which acknowledge and support the important role human contributions make to the scientific endeavor.

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