ACADEMIC REVIEW / SELF-STUDY: EDUCATION COMPONENT

1. UNDERGRADUATE EDUCATION

1.1. THE ASTROPHYSICS MAJOR

1.1.1. Course Requirements

The Astrophysics Major program consists of:

- One lab class: either Astro 120 (Optical), 121 (Radio), or 122 (Infrared)
- Two upper division classes, drawn from Astro 160 (Stellar Physics), C161 (Relativistic Astrophysics and Cosmology), and C162 (Planetary Astrophysics)
- About five additional upper division electives (for a total of 30 units of upper division coursework. These 30 units *include* the three Astronomy classes just mentioned.)

In addition, Majors are encouraged—but not required—to take the two lower division classes, Astro 7A and 7B (Introduction to Astrophysics), as preparation for the above courses. The overwhelming majority of our Majors do take 7A/7B.

The complete list of electives is listed at http://astro.berkeley.edu/academics/undergraduate/electives.html. Electives include:

- Physics 110A and 110B, Electromagnetism and Optics
- Physics 111, Modern Physics and Advanced Electrical Lab
- Physics 112, Statistical and Thermal Physics
- Physics 137A and 137B, Quantum Mechanics
- Math 121A and 121B, Math Methods for Physical Sciences

These electives are typical of those taken by Physics double majors, who constitute ∼50% of Astrophysics Majors (see §1.1.3). Sample curriculum sequences can be found at http://astro.berkeley.edu/academics/undergraduate/curriculum.html.

Honors Thesis. Majors who maintain a GPA higher than 3.5 in courses in astronomy and related fields, and a GPA higher than 3.3 overall, are eligible for the Honors Program. Candidates for graduation with Honors take at least 3 units of Astro H195 while carrying out and writing up a research project with a departmental advisor (§1.1.5).

1.1.2. Philosophy and Rationale of the Major Program

The Astrophysics Major is designed to ground students in the theory and practice of modern astrophysics. Students are exposed to a rich phenomenology spanning the birth and fate of stars, the origin and evolution of planetary systems, high-energy processes in the vicinity of black holes and neutron stars, structure formation in the universe at large, and the geometry and evolution of spacetime. They are taught the fundamental physics underlying these diverse phenomena. They are trained to reason quantitatively and from first principles. Furthermore, they acquire extensive hands-on experience collecting and analyzing astronomical data.

A primary goal is to prepare students for graduate work in astrophysics and related fields (see §1.1.7 Placement). Another goal is to train a scientific and technically literate workforce (e.g., teachers, field engineers, hardware/software developers, and science writers). An effort to formally distinguish between these two career goals was made in the 1990s by creating two tracks, "focussed" (for future astrophysics Ph.D.'s) and "broad" (for everyone else). Focussed majors had a more demanding program than broad majors. Ultimately, however, virtually all majors adopted the focussed program, leaving the broad courses poorly enrolled and maintained. The Department has since eliminated the broad program, and streamlined and upgraded the major courses to reflect both students' and faculty's appetites for rigor (§1.1.4). The Department believes that the focussed program serves the needs of both future astronomers and future non-astronomers equally well by providing a uncompromisingly first-rate science education.

Close ties with Physics and Math. The required load of 3 "in-house" Astronomy classes (§1.1.1) is light by design, to encourage students to study more physics and math. The rationale is that Astrophysics is, to large extent, a field of applied physics: astronomers use physics and math to quantitatively understand astronomical phenomena. Double majoring in Physics is encouraged, and a large fraction of Astrophysics Majors follow this recommendation (§1.1.3).

Labs. A key feature of the Major program is its heavy emphasis on laboratory work, as detailed in §1.1.4. This emphasis reflects the nature of astronomy as an empirical, observation-driven science. Each lab is extremely demanding (median of ∼20 hours per week) and teaches the full complement of skills in observational astronomy: instrument design, data acquisition, data analysis, technical writing, and oral presentation. The instructional techniques employed by the labs adopt educational "best practices": peer instruction and inquiry-based learning. The rewards of the lab classes are commensurate with the intensity of the experience; though only one lab is required, some students take two and a few even take three. The skills learned in hardware/software development and error analysis are directly portable to a variety of technical fields other than astronomy. The most capable and motivated undergraduates matriculate from the lab classes into research groups (§1.1.5).

Planetary science track. In recent years, the increasing cross-talk between astrophysicists and geophysicists, spurred by spacecraft missions, the discovery of extrasolar planets, and the possibility of detecting life on other worlds, has motivated the Major program to develop a "Planetary Science Track." The electives of this track are chosen from Physics, Earth and Planetary Sciences (EPS), and Chemistry (http://cips.berkeley.edu/major.html).

Order-of-magnitude thinking. Finally, a hallmark of a degree in Astrophysics is the ability to make order-of-magnitude estimates. The utility of this skill—which is necessary in astronomy partly because the systems of interest cannot be manipulated and are too remote to permit detailed characterization—extends far beyond the confines of astronomy (e.g., consultants must routinely make educated guesses about complex markets). Here the Astronomy Department arguably fills a gap left open by a traditional education in Physics. The latter usually stresses technical ability: physics students are trained to perform long, extended derivations and symbolic manipulations concerning highly idealized systems. Gains in the ability to think abstractly and perform analytic calculations are made at the expense of connecting concepts to everyday experience and reality (e.g., a student can calculate exactly the entropy of a set of N harmonic oscillators as a function of the total quantum number n, but can fail to estimate, and explain in plain terms, the specific heat of a potato). By contrast, students of astrophysics are taught to characterize the gross properties of any system to within factors of 10. Astrophysics Majors live day-to-day with actual numbers.

1.1.3. Enrollment

Figure 1 displays both the number of Astrophysics single majors and the number of Astrophysics double/triple majors from 1993–2007, as recorded in the Cal Profiles database. Note that the numbers plotted in any given academic year include the entire cohort of sophomores, juniors, and seniors (for the alternative metric of bachelor's degrees granted per year, see next paragraph). In 2000–2001 (about the same time the Department hired 5 new faculty members), enrollment increased markedly, from ∼20 to ∼45. The proportion of double majors also grew; in recent years it has held steady at about 50%. In 2007, the breakdown of multiple majors was as follows: 18 double majors in physics, 2 triple majors in physics and math, 1 double major in mechanical engineering, 1 double major in microbial biology, and 5 double majors in the humanities. Thus, $27/44 = 61\%$ of our current crop of Astrophysics Majors are planning to receive a degree in at least one other field, with most choosing physics.

The actual numbers of bachelor's degrees granted per year, both single and multiple, are plotted in Figure 2. The number of bachelor's multiple degrees has approximately doubled in the past five years compared to the typical output prior to 2000.

The fraction of female majors is plotted in Figure 3. As with Figure 1, the sample comprises

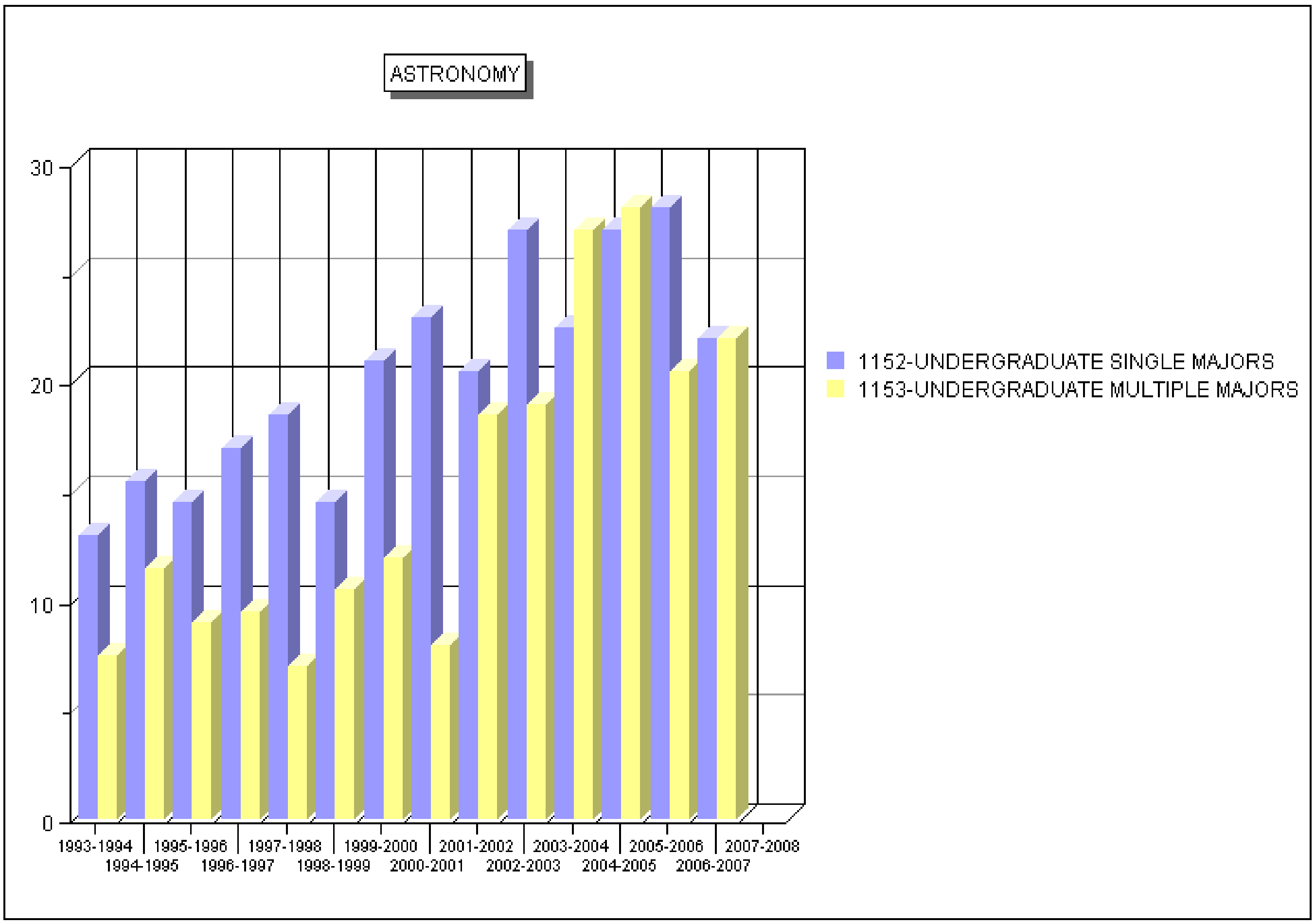

Fig. 1.— The number of astrophysics single majors, and the number of students double majoring in astrophysics and another subject (primarily physics; see text), versus time. The number plotted in any given year includes sophomores, juniors, and seniors. Data collected from CalProfiles (https://secure.vcbf.berkeley.edu/calprofiles/login.aspx).

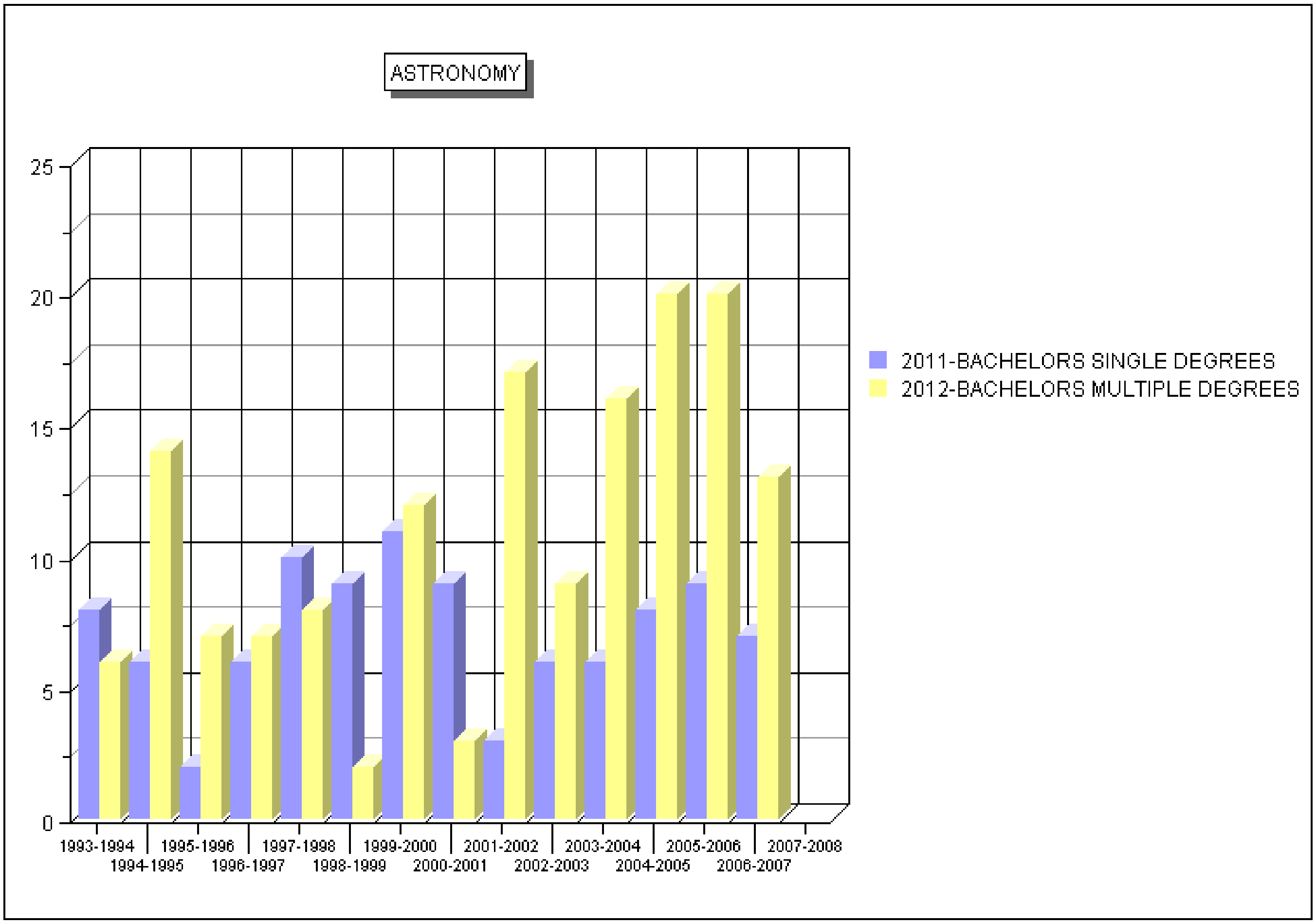

Fig. 2.— The number of bachelor's single degrees in astrophysics, and the number of bachelor's multiple degrees in astrophysics and another subject (primarily physics), awarded per year, versus time. Data collected from CalProfiles (https://secure.vcbf.berkeley.edu/calprofiles/login.aspx).

all majors—sophomore, junior, and senior—in any given academic year. With the exception of 2006–2007, the female:male ratio in recent years is about 40:60—respectable though still not ideal. Women majors are supported in part by the Society of Women in the Physical Sciences (SWPS; see §1.1.6). Furthermore, our lab classes adopt educational "best practices" that have been shown to encourage women to pursue careers in engineering and science (see §1.1.4). For a sampling of successful female alumnae, see §1.1.7. Percentages of various self-identified ethnicities are given in Figure 4.

1.1.4. Innovations and Improvements in Undergraduate Major Curriculum in Past Decade

The past decade 1997–2007 has witnessed substantial progress in the teaching of Astrophysics Majors. Many improvements involve raising the level of rigor with which courses are taught.

The Undergraduate Labs (Astro 120, 121, 122).

The Berkeley Astrophysics Major reflects a range of educational goals. One target population includes students who wish to acquire broad technical training without necessarily having graduate school as a goal. One lab class is a requirement for all Astrophysics Majors.

The Leuschner Observatory is the setting for the upper division undergraduate lab classes and operates three student-built radio telescopes (Figure 5), an array of small optical telescopes for visual observations, a solar echelle spectrograph, and a 30-inch robotic telescope that is equipped with optical and infrared cameras (Figure 6).[1]

The lab classes share the common goal of developing extensive capabilities in data gathering and statistical analysis. Students achieve expertise in these areas because the labs include the complete range of activities normally encountered in observational/experimental research. Students use lab gear to measure the fundamental parameters of telescopes, spectrographs, and detectors, make astronomical observations with these systems, and write software to control equipment and analyze the results. We avoid "black box" equipment and "cookbook" procedures and instill a deep skepticism of such approaches by illustrating the pitfalls of using such tools.

Each semester comprises four to five experiments. Many lab courses in physical sciences favor offering a roster of experiments that can be executed in any order. By contrast, our investigations are structured so that students are presented with challenges of increasing sophistication and com-

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[1]Heiles 1999, "Berkeley's Advanced Labs for Undergraduate Astronomy Majors," Bull. Am. Astr. Soc., 193, 5902; Graham & Treffers 2001, "An Infrared Camera for Leuschner Observatory and the Berkeley Undergraduate Astronomy Lab," 2001, Pub. Astr. Soc. Pacific, 111, 607.

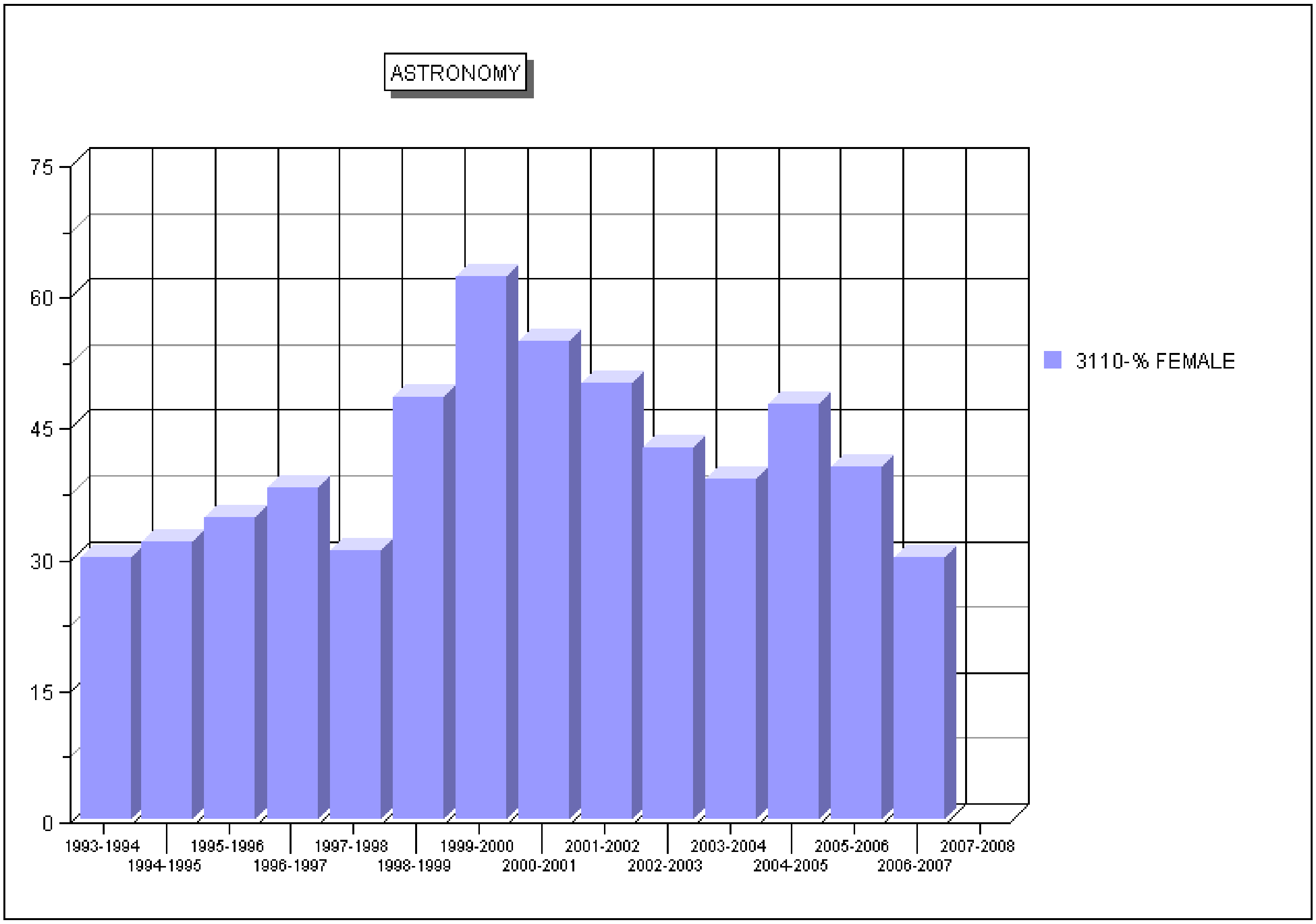

Fig. 3.— The percentage of astrophysics majors—sophomore, junior, and senior—who are female, versus time. Data collected from CalProfiles (https://secure.vcbf.berkeley.edu/calprofiles/login.aspx).

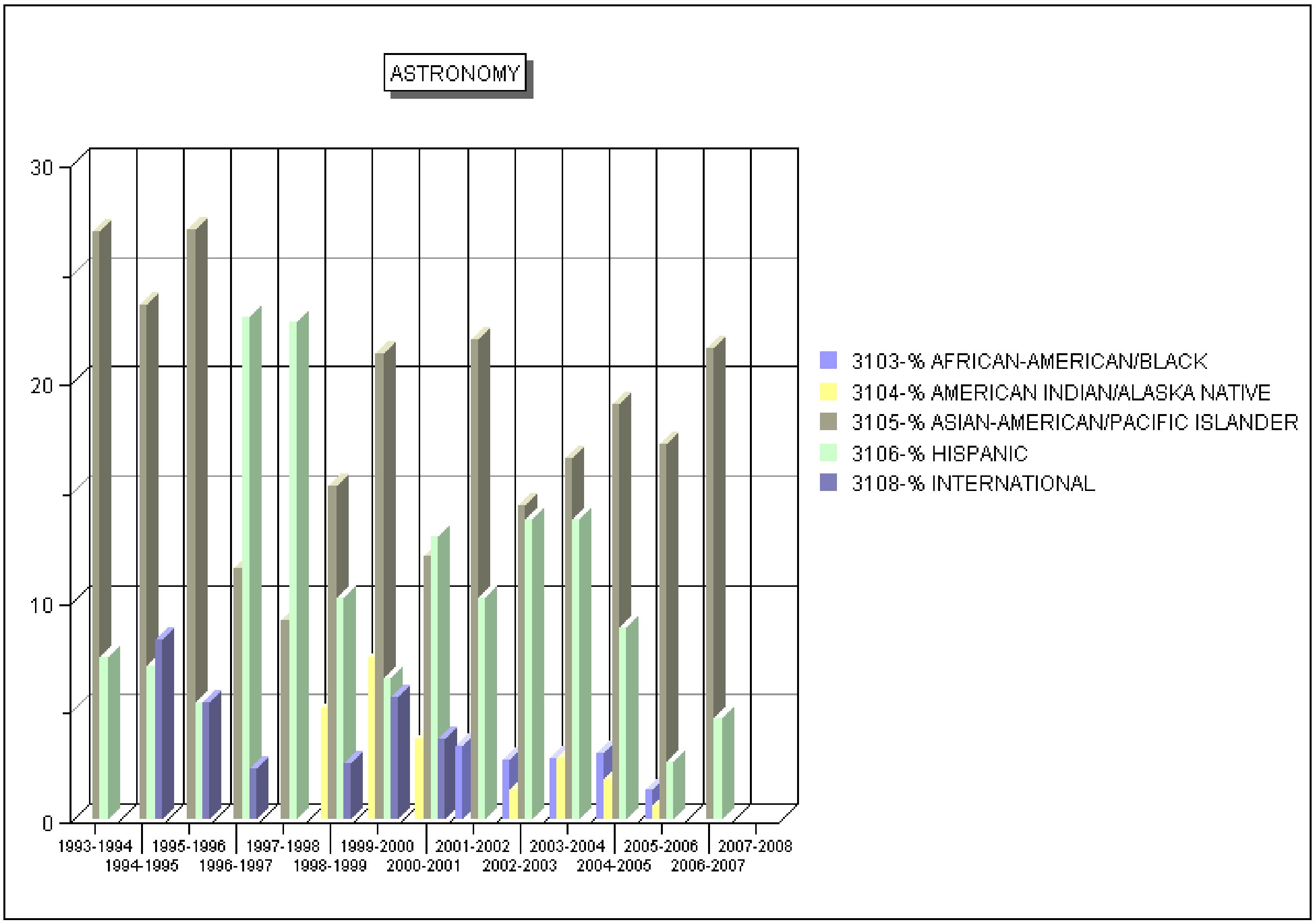

Fig. 4.— The distribution of non-white/caucasian ethnicities of astrophysics majors, versus time. Data collected from CalProfiles (https://secure.vcbf.berkeley.edu/calprofiles/login.aspx).

Fig. 5.— Astronomy undergrad Rick Kirian adjusts a 12 GHz radio dish on the roof of Campbell Hall.

Fig. 6.— The robotic 30-inch reflector at Leuschner Observatory (Lafayette, CA). An infrared camera is installed at the Cassegrain focus.

plexity: for example, the optical lab begins with the detection of individual photons and concludes by measuring the Doppler shift from the ensemble of photospheric absorption lines in the solar spectrum by invoking the convolution theorem. While the superficial purpose is to teach an array of technical skills, the broader goal is to build confidence by allowing students to tackle problems that at the beginning of the semester would appear utterly daunting.

Students are held to exacting standards in the reporting and presentation of their work. The lab offers good opportunities for developing an understanding of effective techniques for the visualization of quantitative information. For example, once a week each lab group makes a ten-minute presentation describing their failures and successes. Writing skills are emphasized by requiring that each student write up results of the lab at the end of an experiment. These reports are graded using many of the criteria that a referee would use to evaluate an article for a peer-reviewed journal, including accuracy, completeness, and clarity and quality of presentation.

The students leave the course having gained experience for how to proceed when faced with recalcitrant equipment and imperfect data. We are familiar with educational "best practices": the techniques employed comprise an eclectic mix of peer-instruction, inquiry-based learning, the Socratic method, and traditional lectures. There is ample research in the education literature that suggests that adopting techniques that encourage cooperation and collaboration are especially important to encourage women to enroll in and sucessfully complete classes in the physical sciences.[2]

The Labs are the most over-subscribed (20–30%) classes offered in the Astrophysics Major. Student evaluations repeatedly report that the Undergraduate Astronomy Lab experience is the definitive part of their undergraduate education, providing the motivation and skills to pursue broad technical career goals. This success has been recognized three times by the award of Berkeley's Noyce Prize to the Lab's instructors (D. Cudaback 1994; C. Heiles 2002; J. Graham 2007). In addition, the Educational Initiatives Award was given in 1995 to the Undergraduate Astronomy Lab in recognition of its cooperative and interactive nature.

These accomplishments are well summarized by Heiles' prize citation: "The 2002 Noyce Prize for Excellence in Undergraduate Teaching has been awarded to Carl Heiles of the Department of Astronomy, in recognition of his dedication to and inspired leadership of undergraduate laboratory courses in astronomy. ... Prof. Heiles leads his students on a rigorous, demanding, and rewarding 'hands on' exploration of the scientific process, from formulating and refining a research problem, to constructing and using measurement devices, to analyzing and interpreting data, and writing and presenting results. Heiles' laboratory courses are now recognized throughout the astrophysics community as an exceptional model for undergraduate education. Many undergraduates from

[2]E.g., Brainard & Carlin 1998, "A six-year longitudinal study of undergraduate women in engineering and science," Journal of Engineering Education, 87(4), 369–375.

Heiles' laboratory course have gone on to become graduate students in the premier physics and astronomy departments around the nation. His former students testify eloquently to his impact on their scientific development. As one former undergraduate put it, 'I credit Prof. Heiles for serving as a role model of how one can be an inspiring and innovative teacher while maintaining a commitment to research excellence... . Wherever I go, I wear my badge as a Cal alumnus with honor. I am proud to say that Prof. Heiles' influence as a teacher and mentor gives that badge an added shine that reflects well on me, on him, and on UC Berkeley as leaders in undergraduate science teaching.' "

Introduction to Astrophysics (Astro 7AB). Starting in 1999, Marcy, and later Graham and Quataert, raised the bar substantially higher for Astrophysics Majors' first serious introduction to their chosen discipline. A decade ago, the distinction between the lower division classes Astronomy 7 and Astronomy 10 was unclear. Astronomy 7 was in many cases taught as merely a slightly more technical version of Astronomy 10, using modest amounts of algebra but no calculus. Now students make extensive use of math and elementary physics at the Math 1 (calculus) and Physics 7 levels to understand astronomical phenomena quantitatively. Emphasis is placed on physical understanding, order-of-magnitude estimates, and detailed quantitative calculations. The higher level of the course was accompanied by a change in textbook to Carroll & Ostlie's *An Introduction to Modern Astrophysics*. Astronomy 7 now regularly has 50–55 registered students each semester, including a large number of physics and engineering majors. The higher standards and improved teaching are also manifesting themselves in the greater number of physics double majors since 2000–2001 (§1.1.3; Figures 1 and 2).

The Astronomy Learning Center (TALC). Graduate student John Johnson is credited with establishing what is now a Department institution: The Astronomy Learning Center (TALC), where students meet with teaching assistants (TAs) to solve problems. Unlike traditional office hours, however, students who attend TALC are expected to solve problems mostly by themselves, at the blackboard and in real time, in groups of 3–6. A hard and fast rule of TALC is that the TA does not give out answers and does not check papers for correctness. Instead the TA engages the students in a Socratic dialogue, meeting their questions with questions designed to spark further thought. The philosophy here is that students learn best by doing rather than by merely listening, and that lessons are reinforced by students thinking out loud to one another. See Johnson's award-winning essay on "TALC: Individualized Assistance Through Collaborative Learning" at http://astro.berkeley.edu/resources/campbell/talc.

TALC is now firmly embedded in Astro 7 and Astro 10. It has also been introduced in the upper division course Astro 160 (Stellar Physics), to excellent effect. In the latter case, TALC essentially replaces the regular office hours of the TA, and thus there is no major additional time burden. TALC has the further advantage that the lecturer can also be present and engage with the students informally. It is recommended that TALC be adopted in the other upper division courses, Astro C161 and C162 (§3.1.3).

Astro C162 Planetary Astrophysics. In the most recent upgrade to the planetary science curriculum, Chiang replaced Astro 149—a former 3-unit "broad" course—with Astro C162, a 4-unit "focussed" course on planetary physics. The course is now taught at the same level as Astro 160 and C161. When de Pater teaches C162, she uses the textbook, "Planetary Science," which she co-authored with Dr. Jack Lissauer and which is replete with extensive problem sets. Together, the 160, C161, and C162 series comprise the streamlined upper division non-lab classes from which majors select two to fulfill their degree requirements. Instructors have noted that since this upgrade, the quality of students learning planetary science has improved.

While each instructor naturally places different emphases on different topics in a subject as mature and wide-ranging as planetary science, it is worth mentioning that C162 is an excellent venue for teaching order-of-magnitude thinking: how to estimate—from first principles, scaling arguments, and everyday experience—any quantity under the Sun to within a factor of 10. Planetary science is particularly suited to the teaching of order-of-magnitude physics because students can check their estimates against their own terrestrial experiences. In addition to weekly problem sets, multiple, high-quality written and/or oral presentations involving quantitative calculations are also required. Several graduating seniors reported in their Exit Interviews (§1.1.7) that the order-of-magnitude skills they learned in C162 were among the most useful they had acquired in their undergraduate careers. For a sample course website, see http://astro.berkeley.edu/˜echiang/planet/planet.html.

1.1.5. Opportunities for Undergraduate Research

One of the goals of the Major program is to prepare students for graduate research (§1.1.2). The Department supplies several resources to help guide students through their first research experiences, from start to finish.

The Department maintains an Astronomy Undergraduate Research Resources website (http://astro.berkeley.edu/˜julie/aurr) where students can find links to research opportunities, both off-campus (National Science Foundation REUs and other internships) and on-campus (academic year fellowships, summer programs, and travel grants). Astronomy professors also post undergraduate research positions to this website, as Bloom, Bower, Davis, and Filippenko have done, in addition to advertising through the campus program URAP (Undergraduate Research Apprenticeship Program).

After students have undertaken a research project, they learn to write a scientific paper about their results and practice giving talks about their work in **Astro 199 (Research Presentation in**

Astronomy), a class invented and taught by graduate student Julie Comerford for the past 3 years. Student accomplishments are documented on the class website (http://astro.berkeley.edu/˜julie/astro199). For her successes with the class, Comerford received an Outstanding Graduate Student Instructor award and an American Association of Physics Teachers Outstanding Teaching Assistant award. Responsibility for teaching Astro 199 has now been passed to a younger graduate student; the class should remain an integral part of the undergraduate experience for Majors.

In 2007, Astrophysics Majors joined the Physics Undergraduate Poster Session to showcase their research results. In this same year the Astronomy Department also offered the first Astronomy Department Poster Award, a cash prize presented to the best undergraduate astronomy research poster at the Poster Session. Several Majors have given posters at American Astronomical Society (AAS) meetings, and Comerford accompanied 3 students to the 21st National Conference on Undergraduate Research. In 2007, undergraduate Ferah Munshi received the 2007 AAS Chambliss Astronomy Achievement Student Award, which was established to recognize, at a national level, exemplary research by undergraduate and graduate students who present posters at the semi-annual AAS meetings.

Undergraduate research projects mature into honors theses and into published papers in the refereed literature. A sampling of these, supervised by Blitz, Chiang, de Pater, and Marcy, can be found under http://astro.berkeley.edu/˜julie/aurr/courses.htm.

1.1.6. Mentoring

Undergraduate mentoring is currently informal and loosely structured. Student Affairs Officer Dexter Stewart talks to the undergraduates about which courses to take to satisfy the Major requirements. The students then consult with one of the two faculty members designated as undergraduate advisors if they have any additional questions. The faculty members are required to sign off on the proposed list of courses, but this is nearly always *pro forma*. A more significant mode of mentoring is that students receive extensive guidance from the faculty via the upper division laboratory classes and in one-on-one interactions at TALC.

In addition to the informal one-on-one advising described above, the Department also runs two question-and-answer sessions each fall: one devoted to graduate school and the application process, and one to REUs and undergraduate research. Women majors may sign up for additional mentoring with the Society for Women in the Physical Sciences (SWPS; http://socrates.berkeley.edu/˜swps/mentoring.htm). Typically one graduate student and one postdoc act as mentors to a group of $\sim$5 undergraduates. Each group meets 2–4 times a year. In 2007–2008, 10 women Astrophysics Majors participated in this mentoring program.

More concrete advice about electives needs to be given (§3.1.1).

1.1.7. Placement of Graduates

Graduating seniors are asked to fill out an Exit Interview form to inform the Department of their immediate plans and to collect feedback regarding their overall undergraduate experience. Based on the ∼25% who return the form, we learn that roughly half go on to graduate school in astrophysics or related fields. A recent sampling of schools that accept our majors includes the University of Colorado at Boulder, Columbia University, San Francisco State University, Stanford, San Jose State University, and Caltech. The other half plan to teach, write, or travel.

Graduates serve the nation's spectrum of educational needs from high schools to the Ivy League, in high-tech industry (e.g., Microsoft and Tinsley Labs), and a broad array of technical fields. Some examples of women alumnae: Amber Miller ('95) is an associate professor of physics at Columbia University, where she pursues experimental cosmology. Pimol Moth ('98) is a faculty member at Hartnell College in Salinas, CA, which serves 9300 students of which 52% are Latino. Amy Jordan ('03) teaches physics, chemistry, and math at Evergreen High School in Boulder, CO.

Without exception, the Astro lab series (120, 121, 122) are declared the "most useful" courses taken by majors. Other courses praised include Physics 110A (Electromagnetism and Optics), Physics 111 (Modern Physics and Advanced Electrical Lab), Astro 162 (Planetary Astrophysics / Order-of-Magnitude Physics), and Astro 250 (Special Topics in Astrophysics).

Plans are afoot to enforce completion of the Exit Interview (§3.1.6). Furthermore, a wiki-based polling of 2002–2007 alumni is ongoing (§3.1.7; go to http://ugastro.berkeley.edu/wiki).

1.2. SIGNATURE "DISCOVERY" CLASSES

1.2.1. Astro 10: General Astronomy

This course is designed to provide, for both non-science and science majors, a description of the fantastic Universe in which we live. It is a special "Discovery Course" in the College of Letters and Science. We cover the structure and evolution of planets, stars, galaxies, and the cosmos as a whole, providing insights into amazing objects like quasars, exploding stars, neutron stars, and black holes. Recent newsworthy events such as the detection of planets around other stars, the possible evidence of primitive life on Mars, and the discovery of gravitationally repulsive "dark energy" are also featured.

Major themes include our origins (such the origin of the chemical elements, stars, planets, and life), the methods by which astronomers investigate and eventually understand various aspects of the Universe, the scientific unification of many seemingly disparate phenomena, and the excitement felt by astronomers doing ground-breaking research on some of the most far-reaching topics imaginable. This course inspires students to become more inquisitive about the natural world, and develops their skills in arriving at conclusions based on physical reasoning and on logical, quantitative arguments. It also kindles the Socratic flame, providing a foundation for more extensive studies in astronomy.

Astronomy is based on physics, and during the semester we present many of the physical principles that govern the Universe. No formal prerequisites are required for this course, and reliance on mathematics is not excessive. However, it is assumed that students are familiar with simple high-school algebra and geometry (including squares and square roots, scientific notation, ratios, proportions, etc.). We stress that astronomy is more than just stargazing, and that we have set out to explore a physical science.

The lectures attempt to present, in simple and understandable terms, explanations of how the Universe "works," as well as the interrelationships between its different components. We do not ask students to memorize lots of trivial facts, such as the exact surface temperature or diameter of the Sun. Of course, in every subject there is terminology to learn, and important points to remember. Students are, for example, expected to know that the Sun is a garden-variety star, primarily composed of hydrogen, and that nuclear fusion is producing its energy. Moreover, they should understand the fundamental ways in which the Sun differs from very massive stars, and the consequences of these differences. We emphasize *thinking* about new concepts and being able to figure things out.

One of the major goals of this course is to help non-science majors develop a better appreciation of *how* science is used to explain natural phenomena. Also, we hope that their perception of and curiosity about the world around them will become more fully developed. For example, we would like them to notice that the sky is blue, and then wonder about *why* it is blue; some students will also relate this to concepts they learned in the course, such as the color of reflection nebulae. When they go outside and examine the night sky, we hope they will quantitatively estimate the distances to stars, assuming their intrinsic power rivals that of the Sun.

The class consists of three 50-minute lectures per week. Questions are encouraged, but only a few can be entertained during lecture. Students also convene for one 50-minute discussion section each week with a Graduate Student Instructor (GSI). The relatively small group setting (at most 32 people per section) allows students to ask more questions and participate in a more hands-on manner (group activities, demos, and discussions).

1.2.2. Astro C12: The Planets

The Center for Integrative Planetary Science has promoted a course for undergraduates titled, simply, "The Planets." This course is designed for non-science majors and covers the science of our solar system and planetary systems in general. It is normally jointly taught by two professors, one from Astronomy and one from Earth & Planetary Science.

The course has several goals. One is to expose students to the variety and depth of different science disciplines. The course covers physics (of light, gravity, atoms), chemistry (of atmospheres, planetary interiors; the greenhouse effect is highlighted), and geophysics (tectonics, differentiation, volcanism, seismic waves), all with a modest level of algebra (but not calculus). The hope is to present to students the principled and predictive nature of science.

Another goal is to draw attention to uncertainty as a normal part of careful thinking. Embracing uncertainty in model predictions, such as in the rate of global warming or the existence of liquid water inside Enceladus, lends credibility to the scientific process. The students also learn to estimate quantities approximately, such as the relative thermal fluxes from a planet and its host star or the rise in ocean levels in the upcoming century. The overarching goal is to imbue the student with predictive powers in their endeavors even outside the nominal realms of science. Another goal is to learn that careful observations reveal order in the universe. The students in "The Planets" must track the motion of Mars relative to the stars during the semester, to note and understand its orbit.

For many students, seeing planets and the Moon in our campus 12-inch telescope looms as the most memorable part of the course. Somehow, we must find ways to capture this exciting telescope experience and channel it into a richer learning experience. Similarly, "The Planets" is designed to reveal the grand beauty and connectedness of our Solar System, both in pictures of astronomical objects and in the simplicity of a few physical concepts that bind so many disparate phenomena.

The course ends with a comparison of other planetary systems to our own, and a summary of the origin of life on Earth. This springboards naturally to a discussion of the possible existence of extraterrestrial life, especially intelligent life, and the quest to detect it.

Currently, "The Planets" is taught with a traditional lecture style, but with encouragement for questions and discussion. The traditional lecture style is demonstrably inadequate to achieve maximal learning and engagement by the students. We are exploring ways to spend more class time in a question-and-discussion mode. Such a format is, however, fully implemented in the discussion sections that meet once per week with a Graduate Student Instructor.

1.2.3. Summer Sessions

Campus administration encourages the offering of summer classes to meet the need for state-mandated enrollment growth. For the past six years, the Department of Astronomy has responded by offering both Astro 10 and Astro C12 every summer. The number of students enrolled in Astro 10 (including both sessions 1 and 2) in any given year ranges between $\sim$40 and 90, while $\sim$30 to 70 have enrolled per year in Astro C12 (session 2).

Students taking the class include UC-registered non-science majors seeking to fulfill degree requirements, as well as "summer-session only" students seeking enrichment. Thus the summer sessions provide an important means of outreach. Each class lasts only 6 weeks (by contrast to the 13-week semester) and as a result is extremely intensive.

The Department has a long-standing policy of having graduate students and postdocs teach summer sessions—despite campus encouragement to "regularize" the sessions by having regular faculty teach regular classes to regularly registered students during the summer months. But there is wide if not unanimous support within the Department for continuing our policy because of the unique opportunity afforded to graduate students and postdocs in constructing their own large-scale classes. Those who have taught summer sessions report gaining extensive and invaluable experience teaching students with diverse backgrounds. They strongly endorse summer teaching to any of their peers pursuing academic careers.

The main area of improvement lies in offering more resources to the summer instructor. Currently the instructor, upon stepping up to serve, is left practically entirely to their own devices. It is recommended (§3.1.9) that the Department formalize an initiation process by having the instructor meet, before the course begins, with the Student Affairs Officer (currently Dexter Stewart), the Chair, a previous summer session instructor, and a faculty member who has taught the regular semester-version of the course. The purpose of these initial meetings would be to orient the instructor, to pass on information and advice. Subsequent meetings can be scheduled to review the planned syllabus and to answer additional questions that arise. The main goal of this action item is to make sure summer instructors have several knowledgeable people—including faculty members—who they can turn to for assistance throughout the summer. A further recommendation would be to have graders available, as the burden of teaching these large classes single-handedly, often for the first time, has been heavy on the instructors, who have the added pressure of conducting research.

1.3. QUALITY OF UNDERGRADUATE INSTRUCTION IN FORMAL COURSEWORK

1.3.1. Evaluation of Faculty

Quality of instruction is primarily assessed by standard end-of-semester course evaluations. The instructor and the course are rated separately. Ratings are requested on a 7 point scale, with 1 representing an “ineffective” instructor or “poor” course, 4 representing a “moderately effective” instructor or “fair to good” course, and 7 representing an “extremely effective” instructor or “excellent” course.

The Department regularly collects and reviews these data (but see §3.1.4). Results averaged over the four semesters from Fall/Spring 2006 and Fall/Spring 2007 are as follows (see Figures 7, 8, and 9):

Astro 10. Instructor average: 5.5 (min 5, max 7). Course average: 5.4 (min 5, max 6).

All Lower Division Courses Excluding Seminars. Instructor average: 5.8 (min 5, max 7). Course average: 5.5 (min 4, max 7).

All Upper Division Courses Exclusing Seminars. Instructor average: 6.1 (min 4, max 7). Course average: 5.9 (min 4, max 7).

Here are sample comments attending the ratings:

Astro 7B / Instructor Rating: 5 / Strengths: “Good quality lectures. Clear explanations.” / Weaknesses: “Homeworks weighted too heavily so there was no opportunity for error. Homeworks did not follow from material taught in class.”

Astro 7B / Instructor Rating: 6 / Strengths: “Amazingly intelligent. Very willing to answer questions, very fun. Available enough that I could probably contact him at any point in time. Tests are very fair. Extremely creative.” / Weaknesses: “Talks rather fast sometimes and flies through derivations.”

Astro C12 / Instructor Rating: 5.5 / Strengths: “Clear lectures. Well prepared slides and examples. Answered all questions thoroughly.” / Weaknesses: “Sometimes felt as if we were being babied.”

Astro C12 / Instructor Rating: 6 / Strengths: “Enthusiastic. Brings slides and movie clips that explain concepts better. Willing to answer questions.” / Weaknesses: “Too much information on slides, was sometimes overwhelming.”

Astro 121 / Instructor Rating: 7 / Strengths: “Did his best to teach us his trade. Handouts had a ton of information.” / Weaknesses: “Sometimes things would be a little over my head.”

Astro 121 / Instructor Rating: 6 / Strengths: “Preparation and organization. Great availability. Constructive comments on papers. Friendly and approachable. Understanding and kind. Brings us cookies. Makes plenty of helpful resources available.” / Weaknesses: “Voice in lecture is so deep and monotonous that it puts everyone to sleep.”

Astro C161 / Instructor Rating: 5 / Strengths: “Good preparation, good attitude. Doesn’t cover anything too quickly.” / Weaknesses: None stated.

Astro C161 / Instructor Rating: 6 / Strengths: “Prepared effective notes and problem sets. Clear lectures allowed for strong understanding. Personable, energetic, enthusiastic.” / Weaknesses: “Sometimes slightly elitist about cosmology.”

Astro C161 / Instructor Rating: 6.5 / Strengths: “Very prepared. Answers questions well when asked. Excellent professor.” / Weaknesses: “Sometimes skips over steps that may seem trivial but are not.”

The consensus is that the Department boasts highly effective instructors at the undergraduate level. As previously noted, Heiles and Graham were each awarded the Noyce Prize for excellence in undergraduate teaching in the physical sciences, including curriculum development. In 2006, Filippenko was named “Professor of the Year” by the Carnegie Foundation for the Advancement of Teaching, to acknowledge his “dedication to teaching, commitment to students, and innovative instructional methods.” For details on how Filippenko has engineered Astro 10 into a class that about 1/6 of all Cal undergraduates take, see http://www.berkeley.edu/news/media/releases/2006/11/16_case.shtml.

1.3.2. Evaluation of Graduate Student Instructors (GSIs)

The popular non-majors class and the large size of the undergraduate program ensure a constant, heavy demand for GSIs in the Department. Nearly all graduate students teach during their first semester, and come to campus aware that teaching is recognized as an important responsibility, not just a backup job for students who cannot get research funding or fellowships. Incoming students typically teach for Astronomy 10 their first semester, but may go on to teach for different courses later. Sometimes teaching beyond the two-semester requirement is done for funding reasons, but more often than not students choose to continue teaching because they enjoy it, for the experience, or out of a sense of responsibility. Still, almost every semester, undergraduate students and students from other departments must be recruited to fill a large number of unfilled section instructor positions (typically 3–5 per semester) in the non-majors classes.

The Department invests in significant training of incoming graduate students. A two-credit

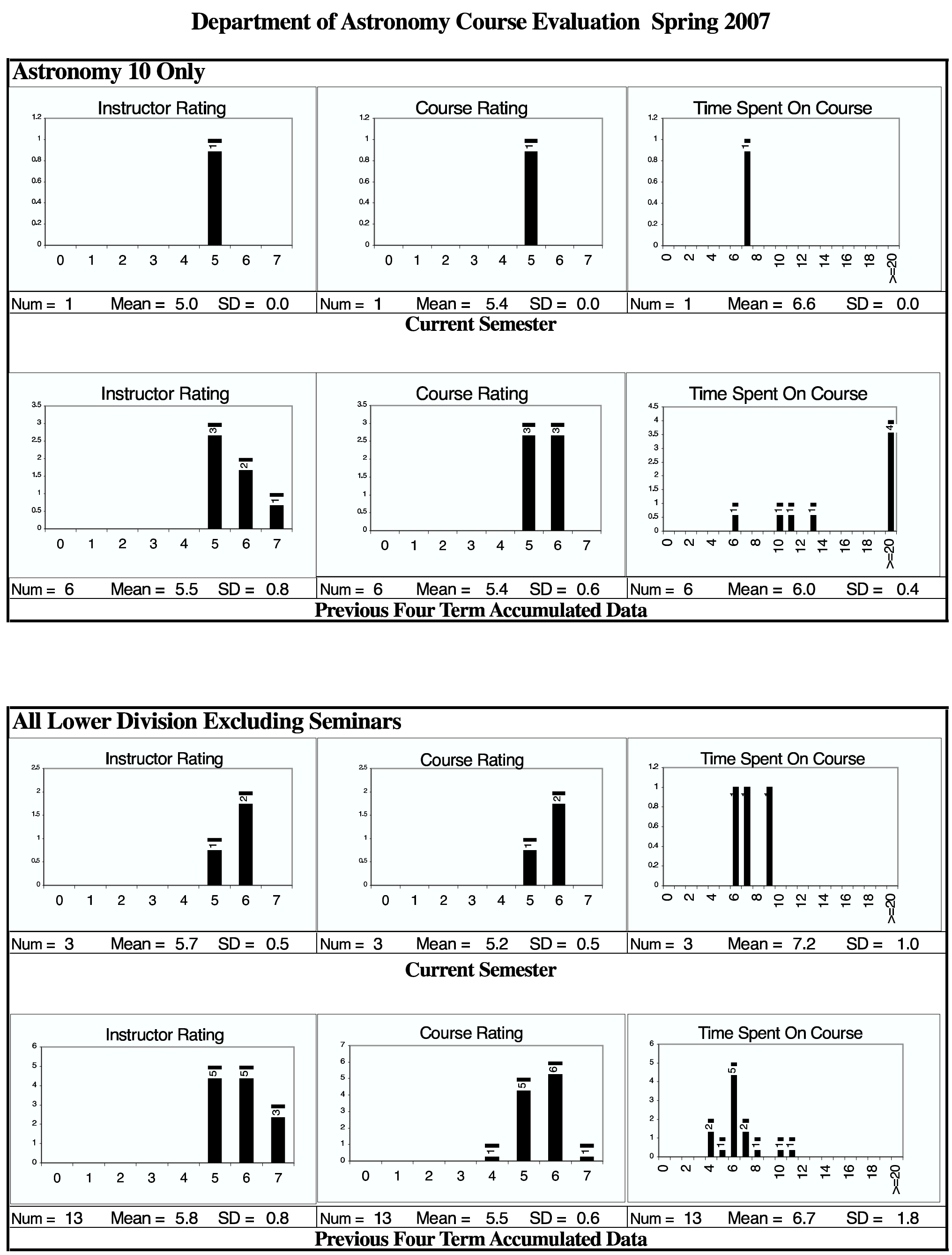

Fig. 7.— A recent snapshot of class-averaged student course evaluations, for our Signature Discovery class Astro 10 for non-science-majors (top) and lower division undergraduate classes (bottom). Data exclude seminars (e.g., weekly lunchtime seminars). Data for Spring 2007 are shown together with data accumulated from Fall/Spring 2006 and Fall/Spring 2007.

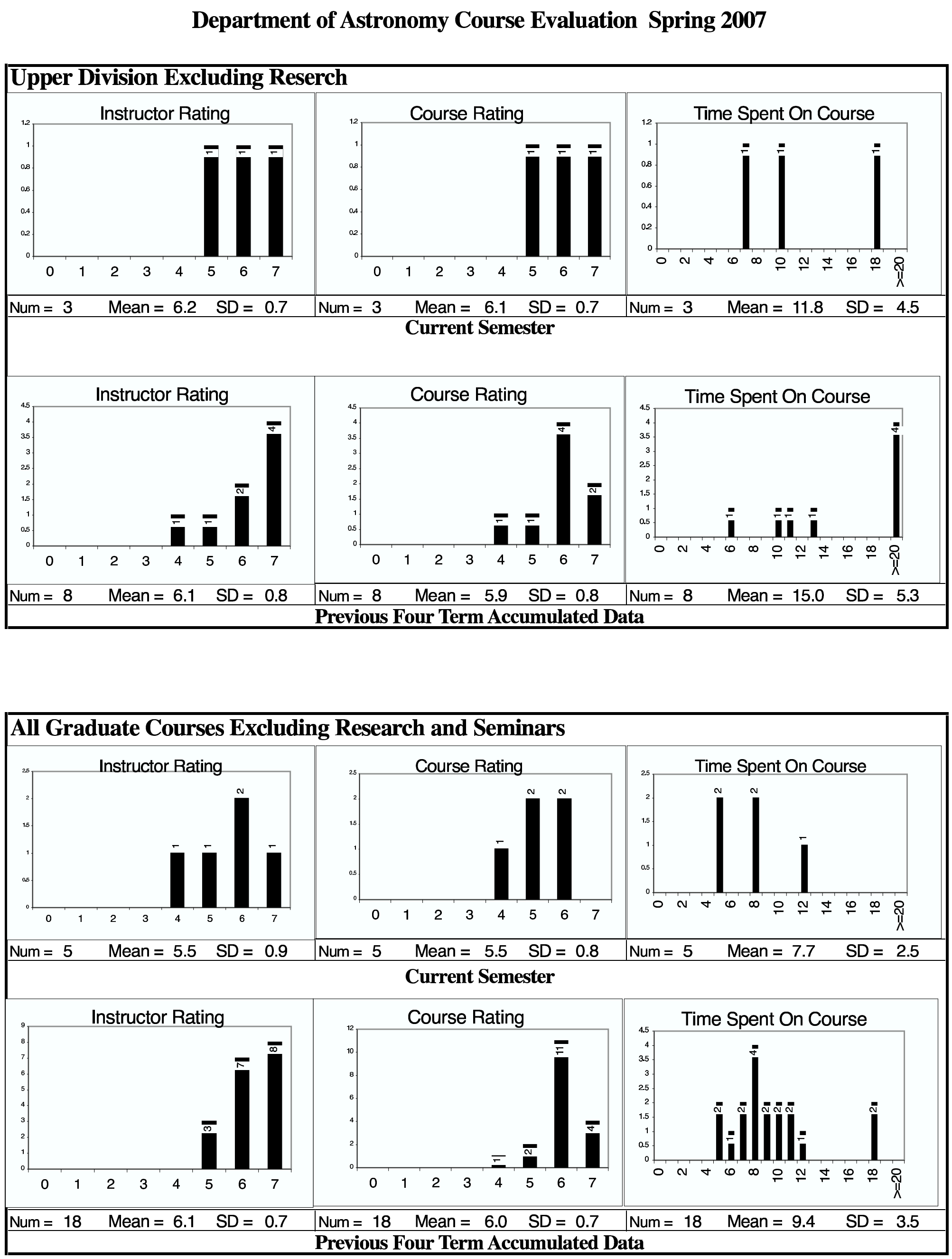

Fig. 8.— A recent snapshot of class-averaged student course evaluations, for upper division undergraduate classes (top) and graduate classes (bottom). Data exclude seminars (e.g., weekly lunchtime seminars) and research (e.g., honor's thesis credits). Data for Spring 2007 are shown together with data accumulated from Fall/Spring 2006 and Fall/Spring 2007.

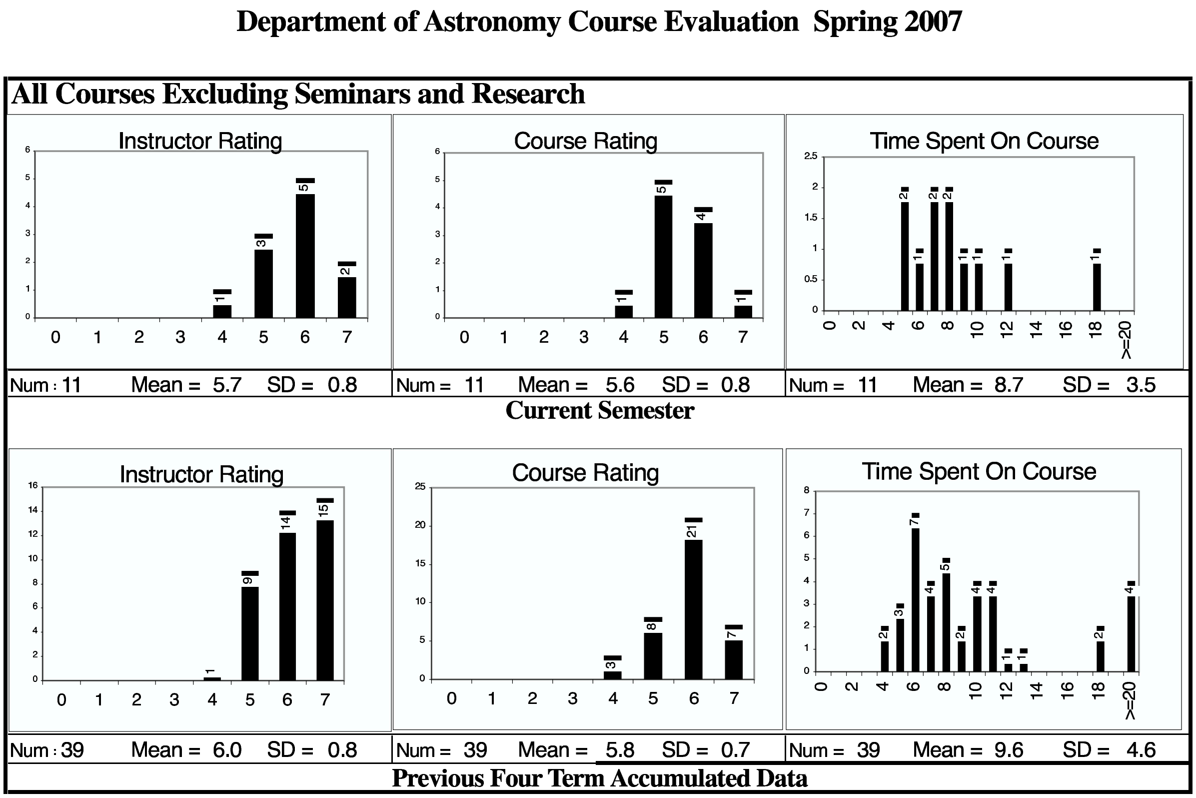

Fig. 9.— A recent snapshot of class-averaged student course evaluations, for all courses excluding seminars (e.g., weekly lunchtime seminars) and research. The bottom three panels show data accumulated from Fall/Spring 2006 and Fall/Spring 2007.

class ("Astronomy 300") devoted to instructional techniques for new GSIs was founded by Andrea Somer in 1997 with assistance from Jon Arons; it has since become a model for similar courses across the entire campus. It is typically taught each fall semester by one or two graduate students with extensive teaching experience and is taken by all incoming first-year students (as well as, in some cases, graduate students in other departments and astronomy undergraduates). The content of Astro 300 is generally biased towards immediately practical advice, though general pedagogy principles are also discussed.

GSIs typically have full control over what to teach and how to teach in section each week. GSIs innovate, experiment, and often excel under this freedom: Astronomy GSIs have won the campus-wide Teaching Effectiveness Award a total of six times over the past ten years, more than nearly every other department. The award is given each year to "honor a small number [typically less than 15] of outstanding Graduate Student Instructors who have made a significant contribution to teaching and learning in their departments."

Several resources are in place to help ensure that the most outstanding ideas developed each year propagate freely between GSIs and between years, helping alleviate the need for new instructors to reinvent the wheel. A large archive binder of successful lesson plans, worksheets, and activities is kept on file to be freely borrowed by any GSI; its contents have recently also been digitized and put online as a student-editable wiki.

On the other hand, the fact that faculty usually give GSIs near-total responsibility for planning their own sections means there is minimal control, or even awareness, of sections that are not taught well by GSIs—particularly when the GSIs in question do not seek assistance. However, course evaluations seem to indicate that this is a relatively rare occurrence: on the same seven-point scale on which instructors are rated, only four GSIs out of nineteen received an average rating of less than 5.0 in the academic year 2005–2006. One of the four was an undergraduate and another was from outside the Department.

Some other relevant evaluation statistics, averaged over the four semesters from Fall/Spring 2005–2006 and Fall/Spring 2006–2007:

All Courses. GSI average: 5.75 (min: 3.3, max: 6.8)

Lower Division Courses. GSI average: 5.73 (min: 4.5, max: 6.7)

Upper Division Courses. GSI average: 6.00 (min: 3.3, max: 6.8)

Some sample comments from undergraduates:

Astro 7B / Rating: 7 / Strengths: "The best discussion I've had in a science class here." / Weaknesses: None listed.

Astro C12 / Rating: 6 / Strengths: "The GSI was active, enthusiastic, and clearly incredibly knowledgeable... . She put a lot of time into class demos and worksheets, which were very useful when taking the midterms and completing the homework." / Weaknesses: None listed.

Astro 10 / Rating: 6 / Strengths "Constantly changing her approach to teaching. I learned more in section than in lecture." / Weaknesses: "Disconnect between lecture and section."

Astro 10 / Rating: 5 / Strengths: "Always prepared with an organized plan... . Answers questions well." / Weaknesses: "Sections... did not vary much from week to week, and most... [involved] just the GSI talking."

Astro C162 / Rating: 5 / Strengths: "Good attitude, responsiveness, and knowledge of the course." / Weaknesses: "Needs to more clearly convey the important information with greater brevity."

In general, the GSI program in the Department is in very good health. The great heterogeneity among different GSIs makes it difficult to generalize a single set of recommendations. However, some global recommendations for ways to further improve the quality of section instruction include:

1. More discussion between faculty and students about the content of section, and faculty awareness of what GSIs are doing in section on a week-by-week basis. While the general freedom of GSIs to control their own sections is on balance a positive feature, GSIs new to a course sometimes have difficulty determining the best way to distribute the very limited amount of time available to them each week, and are likely to benefit from guidance about what specific subjects to bring up each week and what content to emphasize. This guidance need not be binding.

2. A more even distribution of the introductory courses between Fall and Spring semesters. The demand for Fall GSIs is much higher than in the Spring, and inevitably a large fraction of the GSI positions must be filled by undergraduates and students from other departments, who are not as well suited to the job (less background in the subject, have not taken Astro 300, are not familiar with TALC procedures, etc.; of course, often these students excel despite these handicaps.) However, additional section instructors are occasionally necessary even in the Spring, so it is unclear how spreading the demand will improve the overall situation.

3. Consideration of a higher uniform pay baseline. The GSI monthly salary is significantly lower than the GSR monthly salary, in effect requiring students who teach voluntarily beyond their first year to accept a pay cut, even though by that point they will likely also be doing research (unpaid) in addition to teaching. The minimum annual financial guarantee only partially compensates for this difference.

4. Improved facilities. All sections are currently taught in a single room in Evans Hall that is not well-suited for the purpose (unusual room shape, limited whiteboard space, in a different

building from Campbell Hall, often very crowded.) GSIs are encouraged to make heavy use of demos and group activities, which work best in a large, open room with boards on all four walls.

5. Continued support and recognition of teaching excellence, both formally (through the Department's Outstanding GSI award) and informally.

2. GRADUATE EDUCATION

2.1. REQUIREMENTS FOR Ph.D.

The requirements for a Ph.D. in Astrophysics include:

- 6 graduate courses, 3 of which are taught by the Astronomy Department (§2.1.1)
- Astro 290AB: seminar to introduce students to research opportunities
- Teaching: 2 semesters, whether compensated or not (§2.1.2)
- Exams, Preliminary (§2.1.3) and Qualifying (§2.1.4)
- Thesis, signed by committee

See http://astro.berkeley.edu/academics/graduate/requirements.html for technical details.

2.1.1. Course Requirements

Ph.D. candidates must complete at least 6 courses, 3 of which must be taken in the Department. Except in unusual circumstances, first-year students take

- Astro 201, Radiative Processes
- Astro 202, Astrophysical Fluid Dynamics

These two courses are more physics classes than they are astronomy classes. Together they lay down the basic ways in which matter emits and interacts with radiation, and how matter moves in response to pressure, viscous, gravitational, and magnetic forces. See http://astro.berkeley.edu/academics/courses for course websites.

Equipped with an understanding of the physics of astrophysics, graduate students go on to take ∼3 classes drawn from the following list:

- Astro 204, Numerical Techniques in Astronomy
- Astro 216, Interstellar Matter
- Astro 218, Stellar Dynamics and Galactic Structure

- Astro C228, Extragalactic Astronomy and Physical Cosmology
- Astro C249, Solar System Astrophysics
- Astro 252, Stellar Structure and Evolution
- Astro C254, High Energy Astrophysics
- Astro 255, Computational Astrophysics
- Astro 267, Plasma Astrophysics

Students may also take Astro 250 (Special Topics in Astrophysics). The material in Astro 250 varies from year to year, reflecting current trends and hot topics in astrophysics. Topics in the last decade have included gamma-ray bursts, planetary dynamics, supermassive black holes, star formation, and order-of-magnitude physics (§2.4).

Though the Department no longer requires that graduate courses be taken outside of Astronomy, it nonetheless encourages students to do so. Popular choices include Physics 231 (General Relativity) and Physics 221AB (Quantum Mechanics). More possibilities can be found at http://astro.berkeley.edu/academics/graduate/outside.html.

In recent years Astro 218 (Stellar Dynamics and Galactic Structure) has not been offered as regularly as students would like, in part because the department is diverting FTE effort towards the construction of the Allen Telescope Array. In 2007 this shortcoming was partly remedied by the offering of an Astro 250 reading seminar on galactic dynamics (http://cymric.berkeley.edu/wiki).

Confronted with perennial student dissatisfaction regarding the low frequency with which certain core classes (Astro 218 and 252) are taught, the faculty are newly resolved to offer these and other core classes—i.e., Astro 216, C228, C249, and C254 (all subjects eligible for topics in the preliminary exam)—at least once every two years (§3.2.2). Ensuring that this promise is fulfilled should be a consideration for future hires—the Department must hire people motivated to teach graduate core classes so as to lighten the somewhat strenuous load currently shouldered by faculty.

There has also been discussion of introducing a second cosmology class that covers more advanced topics and better prepares graduate students for research. The effort to create this class is being led by M. White through the Physics department (§3.2.9). Such a class would be cross-listed with the Astronomy Department and would enable graduate students in Astronomy exposure to a wider variety of perspectives (from, e.g., Ma, White, Seljak).

2.1.2. Teaching Requirements

Regardless of whether the student is supported by a fellowship or a research assistantship, every student must acquire two semesters of teaching experience during their graduate career. Practically all students fulfill this requirement in their first year, as TAs for the popular lower division classes Astro 10 and Astro 7. *However, students are not required to fulfill this requirement in their first year.* If they receive funding through a Research Advisor, or if they hold a fellowship, students can defer a portion of their teaching duties to after their first year. Making this possibility clear to prospectives should be an action item, so that they are not dissuaded from attending Berkeley because of a perception that the teaching load is excessive (§3.2.5).

Many of our students go above and beyond the call of duty when teaching. The most capable of teaching assistants are asked in their second years (and in some cases, third years) to serve as Head TA for Astro 10. It is not uncommon for students to TA a third and even a fourth semester, mostly for upper division courses. While in many instances this is done out of financial need, in some cases graduate students TA simply because they enjoy teaching and/or wish to learn a subject better. A few graduate students have spearheaded major curriculum developments (§1.1.4, under TALC; §1.1.5). Excellent teaching is rewarded annually by our Department through the Outstanding Graduate Student Instructor Award and the Teaching Effectiveness Award (http://astro.berkeley.edu/academics/awards.html).

The teaching load for Astronomy graduate students at UCB is heavier than for their counterparts elsewhere in the country. Partly this is due to the enormous enrollment in our flagship service class, Astro 10. Equally important is the passion that many of our graduate students have for excellent teaching. But the emphasis on teaching has its downsides: Students do not start research as early as they would otherwise, and some prospective students decline to attend Berkeley because they want to start research early and do not want to be burdened with a teaching load (see also §2.2; for a countermeasure, see §3.2.5).

Nonetheless, the consensus is that the advantages—the fostering of good teaching values, plus satisfying the very real need to service ∼1000 students in Astro 10, plus giving our graduate students a competitive advantage in applying for postdoctoral fellowships such as the NSF which require significant education components—outweigh the disadvantages. One distinguished alumnus of our department, Michael Brown of Caltech (discoverer of the "10th" planet Eris), reports that he appreciated serving as TA for the lower division classes because he "actually learned a lot of astronomy."

2.1.3. Preliminary Exam ("Prelim")

The prelim is an oral examination conducted by three faculty members on three topics. Normally the topics are selected by the student from the list of core graduate courses (see §2.1.1). If an Astro 250 (Special Topics class) covers a subject that is considered by the faculty to be sufficiently fundamental and wide-ranging, then that subject may also be used as a prelim topic. Recent examples include "Planetary Dynamics" and "Star Formation." To ensure that students develop some breadth, however, certain combinations of topics are disallowed, e.g., both "Star Formation" and the "Interstellar Medium" cannot be used at the same time. Nor can "Radiative Processes" and "Astrophysical Fluid Dynamics" be used at the same time, on the grounds that the student is not tested on enough phenomenology. The student is tested orally for about 40 minutes per topic.

The prelim must be taken before the end of a student's second year. Most students comply with this rule. About 1 in every 30 students does not pass the exam the first time, takes it again, and passes the second time. Performance ranges from marginal (about 1 in 10) to exemplary (about 1 in 10). The consensus is that this exam is functioning well in helping students to reinforce what they learn in class, to acquire greater command of phenomenology, and to develop the skill of thinking on one's feet. Some classes (e.g., Astro 201/202) offer oral mid-terms and oral final exams as a way to practice for the prelim.

2.1.4. Qualifying Exam ("Qual")

The Department website states the following regarding the qualifying exam:

"The purpose of the Qualifying Exam is to show that the student is ready to begin thesis work. The qual is an oral examination in which a committee of four faculty members examines the student in depth on three topics pertinent to the student's intended thesis topic. The customary format is that the student speaks for [a total of] 40 min on the three topics. This presentation is typically interrupted by questions, and is followed by questioning of the student's general knowledge. The three topics are often chosen to lead the discussion from a broad subject foundation to the specific area of proposed investigation. One intent of the exam is to explore the student's readiness to tackle a thesis and the feasibility of the proposed research: Are the questions and methods well defined and is there enough time for completion? More broadly, the exam also serves to test the student's mastery of topics, ability to present the material concisely and coherently, and ability to respond to probing questions.

"...The Qualifying Exam is required by the University in order to receive the Ph.D. degree—no exceptions are allowed. Department policy is that the Qualifying Exam be taken no later than the end of four calendar years of graduate study, unless a specific exemption is granted by the

Chair/Head Graduate Advisor."

Despite these seemingly clear rules, there remains some confusion about the purpose of the qual. Some regard the exam as an opportunity to receive constructive feedback on a proposed thesis topic, at an early and formative stage of the project. This is close to the stated intent of the qual. But others consider the exam a *de facto* defense. They postpone the taking of the exam because they wish to fend off all questions and criticisms of the examiners.

Many students conform to the four-year rule. Many do not. Some statistics:

- Of the current graduate students in Campbell Hall who have taken their qual, 5/9 took it before the end of their fourth year, and 4/9 did not (taking it instead in their fifth, seventh, and ninth years).
- Of the current class of fifth-year students, numbering four students, none has taken their qual.
- Of the current class of sixth-year students, numbering nine students, one has yet to take their qual.

In and of itself, the spotty compliance with the four-year rule may not be such a big problem. In the end, all students take the exam (they must to receive their PhD—no exceptions are allowed); the adoption of four years as a time limit is somewhat arbitrary (but six-month extensions can be granted); and extenuating circumstances in research are commonplace. But the data do reflect some deeper issues: (i) confusion regarding the purpose of the exam (is it a proposal, or is it a defense); (ii) weak methods of enforcement; (iii) a graduate advising system whose current laissez-faire character allows students to go unadvised for long stretches of time. For proposals on how to improve the situation, see §2.7 on Advising, and §3.2.6 and §3.2.7 for Action Items.

2.1.5. Exit Seminar: None Currently Required

Berkeley does not require a final defense. The reasons for not having a defense seem natural enough: Often, the presentation of one's thesis research seems a purely formal exercise, especially if the defense occurs after the research has already been published.

Yet there may be advantages in requiring a defense, or an "exit seminar": (i) closure and celebration; (ii) the entire department, not just the advisor and committee members, learns what the student has accomplished; (iii) practice and incentive in delivering a professional-grade research seminar; and (iv) a clear distinction between this "final defense" and the qual.

To avoid having to schedule an extra series of talks and an extra demand on people's time, we might schedule these exit seminars as part of the weekly research seminars (RAL, CIPS, TAC), or even the weekly Journal Club (§2.6).

2.2. ADMISSIONS

A decade ago, the entire faculty participated in the admissions process and selected the final list of admitted students from a pre-screened list composed by the Graduate Admissions Committee. In recent years, to save time and to eliminate "noise" introduced by non-committee faculty who naturally did not possess the in-depth perspective and knowledge of committee members, all decisions have made by the committee alone, a subset of about 5 faculty.

Data on the last 7 years of admissions is given in Table 1. Class size is determined by the quality of the applicant pool and by University enrollment caps. All criteria are judged with roughly equal importance in the selection process: grades, rigor of coursework, GRE scores, prior research experience, letters of recommendation, and maturity of statement. Roughly speaking, we offer about 10 positions for every 100 domestic applicants, and 1 position for every 50 international applicants.

Averaged over the last 7 years, 44% of those offered positions ultimately accept—an excellent rate given fierce competition from several top-tier schools across the nation. In no small part our success can be attributed to our graduate students who host prospective students with generosity and enthusiasm. The male:female ratio of incoming students, averaged over the last 7 years, is 55:45.

There is enough uncertainty in the process of identifying future outstanding scientists that the Department errs on the side of being inclusive, as it should. One new strategy that the committee tried in 2006–2007 was to conduct phone interviews with both international candidates (whose records are difficult to calibrate against U.S. standards, and whose speaking abilities cannot be reliably assessed on paper) and "borderline" candidates. The phone interviews proved very informative, as one could sense the level of seriousness and maturity of the candidate. Phone interviews should become an integral component of the selection process in future years.

Berkeley has a long tradition of attracting top-flight talent. Maintaining this tradition requires vigilance and renewed effort. Several challenges loom at present: (1) satisfying the needs of the large number of theorists hired within the last 6 years onto the faculty in Astronomy, Physics, and Earth and Planetary Sciences; (2) raising more funds to better tap into the enormous and still largely unexploited pool of talented non-U.S. citizens; and (3) ensuring that astrophysics remains an attractive subject when other fields such as biophysics are currently enjoying tremendous growth.

Productive measures include:

1. Increasing the graduate student stipend to at least match those offered at other institutions (§3.2.3);
2. Making sure incoming students understand that they can defer their teaching duties to after their first year, so as to make our program more attractive to students eager to start research immediately (§3.2.5);
3. Raising funds and working with campus administration to increase the number of non-U.S. citizens the Department can afford. Eliminating the non-resident tuition required of foreign students before the passing of their quals (§2.3) would be a step in the right direction.
4. Having the faculty advertise the graduate program in Astronomy when giving talks and colloquia at other institutions;
5. Ensuring that theory faculty give talks to graduate student audiences in both Astro 290 and Physics 290 (Introduction to Current Research);
6. Advertising our theory-oriented graduate classes—Astro 201, 202, 218, C228, 252, C254, and 255—to all Physics students.

2.3. FINANCIAL SUPPORT

All first-year students are supported by fellowships, Graduate Student Instructor (GSI) positions (§2.1.2), and the Graduate Division's Block Grant. Support covers both fees (tuition) and a living stipend. The Department is proud to routinely host recipients of the following fellowships: the Berkeley Fellowship (campus), the Chancellor's Science Fellowship (campus), the Diversity Fellowship (campus), and the NSF Graduate Research Fellowship.

For graduate students in their second year and beyond, support comes from the following sources: fellowships (18%), graduate student research (GSR) positions (PI grants of individual faculty) (54%), graduate student instructor (GSI) positions (22%), and the Graduate Division's Block Grant (6%). The way an individual graduate student secures funding is very advisor-specific.

The high cost of living in the Bay area, exacerbated by escalating warfare with competing graduate programs, motivated the faculty to vote to raise graduate student salaries in Fall 2006. In 2007, the salary for incoming students was $25.8K. The Department also agreed to provide $2K per first-year student for research expenses (computers, travel, page charges, textbooks). Despite these improvements, we still lag institutions such as Harvard, which in 2007 paid $27.6K salary to its graduate students.

There is also ongoing concern about the extra burden shouldered by foreign students, who must pay substantially more tuition because they are non-residents.[3] While most international students and their Research Advisors simply comply with this rule and find the extra money to pay for non-resident tuition through grants, this requirement is considered by some students to be unfair.

Finally, there has been in recent years lack of communication between faculty and students regarding the source of students' funding. Responsibility for such discussion must ultimately rest with the Research Advisor. The advisor should state clearly how much funding they have to support a graduate research assistantship, and for how long, and whether the student's pay will need to be supplemented by teaching (§3.2.4). To ensure that funding situations are unambiguous for every student, we propose that the student describe as part of their Annual Progress Report (§2.7.3; §3.2.6) the source of their funding and what their future prospects are.

2.4. INNOVATIONS AND IMPROVEMENTS IN GRADUATE CURRICULUM IN PAST DECADE

Astro 204. Numerical Techniques in Astronomy. Astro 204 was initiated by Heiles because our graduate students were asking our undergraduate lab students how to do basic numerical techniques such as least-squares fitting. Our incoming graduate students tend to be either (1) adept with these techniques already; or (2—the majority) nearly completely uninitiated. At a minimum, Astro 204 serves to remove this shortcoming. It was taught in 2002, 2004, and 2005 as a special topics course (Astro 250), and then as the numbered course Astro 204. Since 2002, 23 Astronomy grads took it (about 70% of students who entered since 2002); in addition, 7 undergrads and 8 physics grads took it. The class typically gets good ratings.

Astro 204 emphasizes practical application of classical statistics to the analysis of real-life observational data and/or numerical results from simulations. It covers algorithms and techniques, model fitting, and data display. The course breaks down into broad sections: (1) Image display, processing, use of color; (2) Probability density functions, transformations, tests, Monte Carlo generation; (3) Fitting of all kinds, including non-Gaussian statistics, highly covariant and almost-degenerate problems, and problems having more than one variable with uncertainties; (4) Fourier techniques, discrete issues, convolution, filtering, irregular sampling, clean, maximum entropy; (5) Wavelets, the common continuous and discrete ones; (6) Principal components analysis.

[3] The penalty is reduced substantially after the student passes their qualifying exam.

With the pending retirement of Heiles, one of the remaining faculty will need to carry the torch. Whatever new "Computing/Statistics" courses materialize in the future (see 3.1.10) will need to account for the fact that many graduate students enter Campbell Hall unequipped to perform some basic statistical analyses.

Astro 252. Stellar Structure and Evolution. Astro 252 was initiated by Quataert because our graduate students were asking for a graduate course on stellar physics, which had not been taught for 6 years since the departures of Shu and Bildsten. In the Fall of 2006, the first year it was taught by Quataert, Astro 252 was attended by 10 registered graduate students—7 in Astronomy and 3 in Physics—plus several auditors. It received outstanding ratings. Astro 252 will now be offered every other year (§3.2.2).

Astro 252 covers hydrostatic equilibrium, energy transport by conduction, radiation, and convection, energy losses by neutrinos, energy generation by thermonuclear fusion, and the physics of chemical equilibria (e.g., ionization balance and nuclear statistical equilibrium). These basic physical principles are used to understand (1) the pre-main sequence evolution of stars (e.g., the Hayashi line), (2) the H-burning main sequence, (3) stellar spectral types, (4) the evolution of low mass stars to form white dwarfs, (5) the evolution of massive stars prior to core-collapse, (6) core-collapse supernovae and explosive nucleosynthesis, (7) the synthesis of heavy elements, (8) neutron star structure, and (9) stellar seismology as a precision probe of stellar structure.

Astro 252 emphasizes physical understanding and order-of-magnitude estimates. For example, rather than have the students write a stellar structure code to solve for the properties of the main sequence, they are instead required to analytically derive the basic scaling relations that describe steady hydrogen fusion (and to improve on such estimates using polytropic models). Although stellar structure is one of the most established areas of astrophysics, Astro 252 emphasizes that it also an active area of research! Towards this end, the students are required to give a 20-minute oral presentation on a current research problem. Topics have included solar neutrinos, the solar wind, stellar "feedback," and the connection between long-duration gamma-ray bursts and core-collapse supernovae.

Astro 250. Order-of-Magnitude Physics. In this class, inspired by one taught successfully for many years at Caltech, students are trained in the art of estimating any quantity under the Sun to within a factor of 10. We cover material properties (elastic moduli, thermal expansion coefficients, electrical conductivities), fluid mechanics (aerodynamic drag, boundary layers, turbulence), biophysics (locomotion by air, sea, and land; energy usage), wave physics (gravity waves in water, acoustic waves, normal modes), and magnetism (dynamos, hard disk densities), among other topics. The applications deliberately emphasize terrestrial phenomena so that students learn how to be maximally resourceful: they can draw upon their own experience and perform home experiments.

When Chiang introduced this course in Spring 2006, the class was attended by more than 20 graduate students in Physics (40%), Astronomy (55%), and Earth and Planetary Science (5%). Rating were very high; students noted that the course was "empowering" and recommended it be offered regularly. The current plan is to offer this course as an Astro 250 (Special Topics class) every two or three years, and to make sure it is advertised widely to Physics and EPS graduate students.

2.5. QUALITY OF GRADUATE INSTRUCTION IN FORMAL COURSEWORK

Quality of instruction is primarily assessed by standard end-of-semester course evaluations. The instructor and the course are rated separately. Ratings are requested on a 7 point scale, with 1 representing an "ineffective" instructor or "poor" course, 4 representing a "moderately effective" instructor or "fair to good" course, and 7 representing an "extremely effective" instructor or "excellent" course.

The Department regularly collects and reviews these data (but see §3.1.4). Results averaged over the four semesters from Fall/Spring 2006 and Fall/Spring 2007 are as follows:

All Graduate Courses Excluding Seminars and Research Courses. Instructor average: 6.0 (min 5, max 7).

Here are sample comments attending the ratings:

Astro 202 (Astrophysical Fluid Dynamics) / Instructor Rating: 7 / Strengths: "Originally I did not plan on taking this class. I assumed that since this was [the instructor's] first time teaching the class it would be better to wait a year. However, by lecture one I was sold. Lectures offer great physical insight into a class which could easily be obscured by equations. Lectures were always well-organized, coherent, and often exciting." / Weaknesses: "It would be nice if the problem set due dates were more flexible."

Astro 202 (Astrophysical Fluid Dynamics) / Instructor Rating: 6 / Strengths: "Well-prepared. Usually has intuition to back up equations/relations." / Weaknesses: "We saw about a half-dozen linear perturbations for various phenomena. It would have been good to spend less time on the algebra after the first perturbation example and more time discussing phenomena."

Astro C228 (Extragalactic Astronomy and Physical Cosmology) / Instructor Rating: 7 / Strengths: "Very clear lectures. Well organized. Clearly interested in material. Assignments were challenging and relevant to the course and helped solidify material from lecture. Available during office hours as well." / Weaknesses: None stated.

Astro 216 (Interstellar Matter) / Instructor #1 Rating: 6 / Strengths: “Very thorough, presents material objectively. Organized. Thorough at answering questions.” / Weaknesses: “Sometimes lectures can get over-detailed, although sometimes this was a virtue. Lectures which involve mostly mathematical derivations would more usefully be done on the board because mathematics on Powerpoint is sometimes difficult to follow and the subtle points of the derivation are not always apparent.”

Astro 216 (Interstellar Matter) / Instructor #2 Rating: 6 / Strengths: “Thorough, well-prepared lectures are well-focussed with a clear outline of the main points. Helpful answers to questions. Excellent lecture notes.” / Weaknesses: “A few graphs or images when describing data would be useful. Assigning an article to read prior to given series of lectures might be helpful; definitely getting the lecture notes to the students early (even if they are not the final, complete draft) would be very helpful.”

Astro 218 (Stellar Dynamics and Galactic Structure) / Instructor Rating: 5 / Strengths: “Wonderful when [the instructor] keeps class qualitative. Knows all the literature, all the history, and really understands the big physical picure. Great at conveying this understanding. I really like the laid-back atmosphere... . I feel totally comfortable asking questions (not true in my other classes)...” / Weaknesses: “Not as good at conveying quantitative info... . Often mistakes in the derivations and his description of [mathematics] is sometimes vague. I think that the problem is pacing. Just copies notes straight onto board without thinking. Mis-copies and goes too fast... . Not available for office hours.”

Astro 218 (Stellar Dynamics and Galactic Structure) / Instructor Rating: 4 / Strengths: “Leads great discussions! Motivates subject well, provides very interesting historical context. Challenges students to reason out problems, to discuss, to think creatively and deductively.” / Weaknesses: “Any and all board work, especially any math... . Numerous mistakes, poor explanations of derivations, random notation, stands in front of board, goes far too quickly at times. Lack of preparation is obvious at times. Avoid derivations! They are in the textbook! Focus on discussions!”

The consensus is that the quality of graduate instruction in formal coursework is—with a few perennial exceptions—very good. A principal criticism is that not all graduate courses are offered with sufficient frequency to meet student demand (see §2.1.1; for the planned correction, see §3.2.2).

2.6. JOURNAL CLUB

Journal Club (Astro 292-001) plays an important role in the life of the Department. Lately a typical session of Journal Club consists of two speakers each delivering a 30-minute oral presentation on a paper that is usually taken from the recent astrophysical literature. Most speakers are graduate students, though occasionally postdocs, faculty, and outside visitors step forward. The aims of Journal Club are to:

1. Develop every speaker's ability to analyze and critique modern research efforts;
2. Enable exploration of topics outside one's immediate research interests;
3. Hone presentation skills, including the ability to field questions from the audience.

Journal Club is distinguished among the seven weekly Department seminars (not counting Colloquium) in attracting the broadest attendance and covering the greatest diversity of topics. It is one of the few venues where the entire Department—students, postdocs, and faculty—can participate profitably. The utility of Journal Club in enhancing graduate school education is hard to overestimate.

In recent years Journal Club has had difficulty filling slots for speakers. At 2 slots per meeting and 13 meetings per semester, Journal Club demands 52 speakers per year. The number of graduate students in Campbell Hall, even including those from Physics, is only about 40.

The problem can be alleviated in a few ways:

1. Schedule the number of talks per meeting based on the number of people who sign up to give them. Demand only that at least one speaker present each week, but still allow for the possibility of having two speakers.

   A historical note: When Heiles ran Journal Club, he enforced a uniform policy of one 30-minute talk per meeting, with the remainder of the hour used for relaxed discussion. He reports that students and faculty alike enjoyed this format. One drawback of this approach is that it may not encourage enough participation from students, many of whom can slip by without regularly giving Journal Club talks. By contrast, under the present proposed format, we expect that some weeks will feature one talk while others will have two. This represents a hybrid strategy that hopefully combines positive aspects of both the Heiles format and the current two-talk format.

2. Record on a Department website whether a student has given a Journal Club talk in any given semester, and encourage those who are lagging their peers to catch up. A reasonable goal is to have every student give a Journal Club talk at least once per year for every year that they are registered—though pressure can be lessened for first-year students (who are burdened with teaching and taking classes) and final-year students (who are busy applying for jobs and finishing theses). This record ("Wall of Fame/Shame") is currently maintained by Journal Club organizer Kalas at http://astro.berkeley.edu/~kalas/pages/kalas_journal_club_08a.html.

Encouragement to give talks should be given not only by the Journal Club organizer, but also by the Research Advisor, Academic Advisor, Class Shepherd, and Head Graduate Advisor. The message that Journal Club is an integral part of graduate school education and should be taken seriously needs to be better communicated to students.

3. Provide immediate feedback to every speaker after their talk on the quality of their presentation, and supply suggestions for improvement. Feedback can be given by anyone in attendance, but should at a minimum be given by the organizer of Journal Club. Here again the student's various advisors (Research Advisor, Academic Advisor, Class Shepherd, and Head Graduate Advisor) can chime in.

4. Actively invite postdocs to give Journal Club talks. Of course, the venue is open to all (including faculty and outside visitors), but students and postdocs should be especially encouraged to give talks.

These action items are reiterated in §3.2.8.

2.7. ADVISING

2.7.1. The First Year

Prior to 2007, incoming students were welcomed primarily through campus-wide orientations organized by the Graduate Division: an orientation for all new graduate students, an orientation for international students, and an orientation for Graduate Student Instructors. The Department Chair met with first-years to discuss classes for the fall and beyond. The students received a folder of administrative information and met as a group with staff members during the first week of classes.

In 2007, several older graduate students (Maness, Shapiro, and Strubbe, also known as the "Mentor Masters"; see §2.7.4) took the initiative to develop a day-long orientation specifically for incoming Astronomy graduate students. Such a department-specific orientation is actually standard practice in other departments on campus. Staff members introduced themselves and helped the new students get settled. Four faculty members described graduate academics and made recommendations regarding coursework and starting research. The new students went out for lunch with their mentors, and later participated in a scavenger hunt around the Department to encourage them to meet other students and postdocs. The orientation was well-received by this year's first-year class and lauded by the faculty. The Mentor Masters intend to organize this event annually.

The Chair serves as Academic Advisor (§2.7.2) to all first-year students. The rationale here is that the Chair has a broad view of the activities in the Department. A downside is that the Chair's busy schedule does not easily permit the Chair to initiate meetings with students.

First-year students are required to take the year-long course Astronomy 290, Introduction to Current Research, organized by the Chair. Various faculty from Astronomy, Physics, and Earth & Planetary Sciences, as well as researchers from Lawrence Berkeley National Lab and the Space Sciences Lab, give hour-long, usually fairly formal presentations of their research. This format has recently come into question. Some students are frustrated that the colloquium-style talks are not tailored to a first-year audience, that many speakers do not explicitly spell out first-year projects, and that not all faculty in the Astronomy Department participate. In response, the Department is now having Astro 290 taught in a more free-form style that emphasizes informal discussion, and ensuring that all Astronomy faculty sign up to give a talk. At the same time, the Academic Advisors (§2.7.2) and Student Mentors (§2.7.4) need to encourage students more strongly to take the initiative and "knock on doors" to inquire about specific research opportunities. As one graduate student put it, "...[It's] the student's job to go talk to professors one-on-one...Professors can encourage students to do this (or not, if they don't want grad students...) but for the most part any to-the-whole-class presentation can only be so personable. It's the student's job to note those talks which seem especially interesting and take the initiative to go talk to those faculty...the main thing is that (some) faculty need to give better talks and students need to start banging on doors."

2.7.2. The Head Graduate Advisor, Class Shepherd, and Academic Advisor

Traditionally the Berkeley Astronomy Department has adopted a laissez-faire doctrine regarding how graduate students conduct research. The advantages of such an approach are many. Students left to their own devices think "outside the box." As such they are more likely to innovate and make significant advances in the field. They develop their own set of tools and rely less on hand-me-down black boxes. The lessons they learn from their own mistakes tend to be driven home more powerfully. Unencumbered by bureaucratic requirements, they can and do devote long uninterrupted blocks of time to research. In short, neglect is benign insofar as the young scientist learns what it takes to be a principal investigator. Many students graduate while operating at least at the level of a postdoc.

Nevertheless, there can be too much of a good thing. Some students are unable to identify worthwhile projects, and do not find the guidance they seek from senior personnel. These students can work for a year or two—in a few cases, considerably longer—on unfruitful projects. Students enter graduate school with a dispersion in skill, knowledge, and motivation; the laissez-faire approach works outstandingly for some but not for all. In addition, if the relationship between a student and their Research Advisor is not working out for whatever reason, there needs to be a system whereby parties can seek assistance. Finally, a few perennial inefficiencies—including delays in taking the qualifying exam (§2.1.4), a less-than-100% acceptance rate for our top-ranked candidates (§2.2), and students who take an inordinate amount of time ($\geq$ 8 yr) to graduate (§2.7.5) and who thereby divert resources from more deserving students—may be attributed, in part, to lack of attention paid by faculty to students.

To bring out the greatest good out of the greatest number of graduate students, the Department must advise in a way that is neither too intrusive nor too neglectful. Here the faculty is aiming to do better by taking a page from the graduate students (§2.7.4) and spreading the responsibility of advising to more people other than the "Head Graduate Advisor" (HGA).

Just what does the role of HGA entail? In the narrowest of senses, the duties of the HGA include signing off on prelim/qual completion forms and authorizing special requests. Special requests include cases when a student wishes to regain entry to our graduate program after an extended leave of absence; or when a student wants to have on their qual committee someone who is not a member of the Academic Senate; or when a student wants to work more than the standard number of hours per week as a teaching assistant. In each case, the request must be, and usually is, approved by the HGA. In recent memory, the HGA has served more-or-less solely in this rubber-stamping capacity.

But looking towards the future, we envision the HGA performing a more active and holistic role as overseer of the graduate advising system. The HGA should read every Annual Progress Report (§2.7.3) written by students; identify systemic problems and bring them to the attention of the Chair and faculty; provide intelligent advice when solicited regarding coursework and teaching opportunities; make sure students are completing their prelim and qual exams in a timely fashion; and offer solutions when asked about any and all problems related to graduate school life, especially those concerning research and career development.

In addition to the HGA, plans are afoot to introduce "Class Shepherds (CSs)." Every class would be assigned one faculty member who would follow that class from entry through graduation. The CS would ensure compliance with timelines for taking the prelim and qual; read all the Annual Progress Reports (§2.7.3) for their class and initiate dialogue as necessary; and, if asked, serve to mediate problems that arise between Research Advisor and student. Note the large redundancy between the CS and the HGA; more on this below.

The Class Shepherd would work in parallel with the student's individual "Academic Advisor" (AA). The AA is a faculty member assigned to follow the progress of an individual student. The student and their AA may share some research interests. The AA shoulders all the duties carried by the CS, only at an individual level. The AA reads and offers feedback on the student's Annual Progress Report; ensures the student is on track with regards to the prelim and qual; offers a third party perspective on research problems; and provides advice about classes and teaching opportunities. The student and their AA would touch base at least twice per academic year—once at the start of the fall term, and again during the spring term.

The large overlap in duties (redundancy) between the HGA, CS, and AA is intended. If one of these three advisors lapses in carrying out their responsibility towards a particular student (as will almost certainly occur, given the time pressures on faculty), the slack should be taken up by the remaining advisors. The main goals of the advising system are to identify and address students' problems while they are still small and manageable, and to get students talking to more than just their Research Advisor.

This advising system is new. The newly appointed HGA (Chiang) is only now beginning to appreciate how the position can be made more active. Currently only the second-year students have an active CS (Chiang). Every graduate student has an AA, but many do not communicate with their AAs. The future success of the advising system will rest in large part with the faculty, who will need to make conscious efforts towards extending, on a regular and periodic basis, invitations to students to discuss their progress and problems. The HGA will need to regularly check that these invitations are being delivered.

2.7.3. Annual Progress Report

Starting in 2004 at Chair Backer's request, each graduate student is required to write a 1–2 page Annual Progress Report (APR). The report summarizes and reflects back on the year's activities, and charts the future. Currently the APR is due at the start of each fall semester, the better to review the preceding summer's accomplishments and to engage the Department when it is well-rested and energized.

While the faculty agree that the APR is a useful tool to take the pulse of graduate student life, the students themselves have been less than impressed. Student discontent stems from lack of reciprocation: many who take the time to thoughtfully compose their APRs receive no feedback from the faculty. Some corrective action is being taken. For example, the Class Shepherd (Chiang) for the current crop of second-year students has written them a formal note to acknowledge having read through all their APRs. His letter to them noted their concerns, and reminded and encouraged them to take their prelim before the end of their second summer. In the one case where an APR signalled a need for further communication, meetings were established between the student and the CS, and the student and their AA. These meetings were acknowledged by all parties to be helpful.

Such examples of feedback are today more the exception than the rule. Several action items seem in order: (1) Each student's submission of the APR in early Fall should be followed soon thereafter (say within a month) by a face-to-face meeting between that student and their AA.

The APR should be used as a launching point for discussion. Final responsibility for scheduling a meeting to give feedback on the APR must rest with the faculty member serving as AA. (2) Each Class Shepherd should acknowledge having read through all the APRs for the students under their watch. In the majority of cases, such acknowledgements will be mere formalities. Nevertheless, written or oral acknowledgement to the students should still be made to maintain good will between the faculty and the students and to keep communication lines as open as possible. (3) The Head Graduate Advisor should be entrusted to read every APR, and to identify, in consultation with the Chair, system-wide problems and students in apparent need of special attention. (4) The Research Advisor is strongly encouraged to read the APRs of their graduate student researchers.

2.7.4. Student-Student Mentoring

At least since 1998, there has existed a system for graduate students to mentor each other. In the past, the system was overseen by one graduate student referred to as the Mentor Master. In 2006, the mentor system was overhauled to make it more effective. The number of Mentor Masters was increased to at least two. Graduate students interested in mentoring must now attend a meeting to discuss expectations. Mentors are assigned to incoming students during the summer prior to the first-years' arrival. Mentors agree to meet with their mentees when they arrive in Berkeley, to be present at the first-year orientation, and to meet one-on-one at least several times per semester throughout the mentee's first two years. The Mentor Masters periodically remind the mentors and mentees when they ought to meet, and check that the meetings have taken place. In response to suggestions from students, the Mentor Masters now organize group sessions for entire classes and their mentors to discuss topics of general relevance, such as how to choose a Research Advisor. This new student mentor system has been positively received, but it is only in its second year; more input from younger students will help to improve it further.

2.7.5. Time to Graduate

From 2000–2007, 24/27 graduate students received their Ph.D. in 5–7 years; see Table 2. The other 3/27 students finished in 8–10 years.

Indications are that in the near future, graduating in 5 years will be a rare occurrence. The last time this happened was in 2003. Few if any of the students currently in their fourth and fifth years are prepared to finish in 5 years. We can expect 6–7 years to be the norm for the forseeable future.

The Department has never imposed a hard and fast rule for the time to Ph.D., preferring instead to “output a mature product,” as former faculty member Ivan King was known to say. There is no indication that the lengthened gestation time is putting recent graduates at a disadvantage at competing in the postdoc market. Nevertheless the Department should maintain an eye on the steady upward creep, and to attempt corrective action on a case-by-case basis through the advising system.

2.8. Placement of Graduates

The Department is proud of being home to young astronomers who have gone on to secure permanent positions at research institutes, research universities, and four-year colleges worldwide. A partial but continually updated list of recent alumni is located at http://badgrads.berkeley.edu/doku.php?id=alumni.

It is the norm for freshly minted Berkeley Astronomy PhDs to secure postdoctoral positions around the world. Many receive fellowships; in the year 2007 alone, Berkeley Astronomy PhDs were recipients of an NSF Fellowship, a Spitzer Fellowship, and a Michelson Fellowship.

Many graduates trained in Campbell Hall—this group includes both Astronomy and Physics PhDs—hold tenure-track jobs today, either as research staff (at, e.g., the Institute for Astronomy in Hawaii; Lowell Observatory; NOAO; Space Telescope Science Institute; Space Sciences Laboratory) or as faculty (at, e.g., San Francisco State University; Cornell; San Diego State University; UC Berkeley; Princeton; UC Santa Cruz; UC Irvine; UNAM; Caltech; MIT).

Table 1. Graduate Admissions

Academic Year	Domestic Apps	Int'l Apps	Domestic Offers	Int'l Offers	Accept[a]	Female	Int'l
2000–2001	68	26	19	3	6	2	1
2001–2002	85	61	11	1	5	1	1
2002–2003	98	33	11	1	4	3	0
2003–2004	107	42	8	1	8	3	2
2004–2005	88	38	11	1	5	2	0
2005–2006	79	52	10	1	7	4	0
2006–2007	94	42	9	1	4	2	1

[a]Includes students who defer entry.

Table 2. Time to Ph.D. in Astrophysics (2000–2007)

Number of years	5	6	7	8	9	10
Number of students	7	10	7	1	1	1

3. ACTION ITEMS

3.1. Undergraduate Students

3.1.1. Guidance in Choosing Electives

A long list of possible electives (numbering ∼50!) is posted at http://astro.berkeley.edu/academics/undergraduate/electives.html. But students desire more guidance in selecting electives. Faculty need to get involved in offering undergraduates specific advice about specific courses. More specific recommendations should be placed on the Department website.

3.1.2. Possibility of Taking Graduate Courses

Only for sufficiently prepared undergraduates can Astro 252 (graduate-level Stellar Structure and Evolution) substitute for Astro 160 (upper division Stellar Physics). Similarly, Astro C228 (graduate-level Extragalactic Astronomy and Cosmology) can substitute for Astro C161 (upper division Relativistic Astrophysics and Cosmology) in exceptional circumstances. Permission must be granted on a case-by-case basis, and presumably rarely.

3.1.3. Introduce TALC into Astro C161 and C162

The successful implementation of TALC (§1.1.4) into Astro 160 calls for its introduction into the other upper division non-lab classes, Astro C161 and C162. TALC sessions can substitute for conventional GSI office hours. Lecturers are encouraged to drop in on TALC to interact with students informally.

3.1.4. Improved Collection, Analysis, and Storage of Course Evaluations

Currently course evaluations are (a) collected by front desk personnel (a position with a relatively high turnover rate), (b) analyzed by Physics Emeritus Professor L. Kerth, and (c) kept by the Chair's Assistant. This unnecessarily complicated system has led to data being incorrectly analyzed, and difficulties in recovering past records. Processing course evaluations is important because the Department and campus administration regularly review course evaluations for promotion cases. It would be ideal to have one staff member in charge of this task.

3.1.5. Awards at Graduation

All student awards (Klumpke-Roberts, Department Citation, AAS research prizes, Astronomy Department Poster Award, etc.) should be acknowledged during the Commencement ceremony. The graduate student instructor for Astro 199 and the faculty chair in charge of Prizes should collate all this information for the Chair in time for Commencement.

3.1.6. Exit Interview: 100% Participation

Our Student Affairs Officer (D. Stewart) plans to enforce completion of the Exit Interview when graduating seniors visit her to review their completion of degree requirements.

3.1.7. Undergraduate Alumni Wiki: Where Are They Now?

Systems administrator D. Logan created in November 2007 an Undergraduate Alumni Wiki (http://ugastro.berkeley.edu/wiki) whereby our alumni can post their current occupation and any reflections on the pros and cons of their undergraduate education in Astrophysics. Of the 137 alumni who have been notified by e-mail of our request for this information, 15 have logged onto the wiki as of Jan 5 2008. D. Stewart, E. Chiang, and student work-study assistants now plan to phone remaining alumni to encourage them to participate in the survey.

3.1.8. Teach Galaxies in Astro 160/C161

Students have complained that galaxies are treated inadequately in their upper division coursework: By their own description, Astro 160 (Stellar Physics) focuses on the internal physics of stars and more-or-less ignores the environment which gives birth to stars, while Astro C161 (Relativistic Astrophysics and Cosmology) concentrates on cosmology and treats stars as point particles. The instructors for these classes should meet and discuss their respective syllabi to ensure that students are exposed to an appropriate range of material that includes galaxies.

3.1.9. Provide Human Resources for Summer Session Instructors

The main area of improvement lies in offering more resources to the summer instructor. Currently the instructor, upon stepping up to serve, is left practically entirely to their own devices.

The Department should formalize an initiation process by having the instructor meet, before the course begins, with the Student Affairs Officer (currently D. Stewart), the Chair, a previous summer session instructor, and a faculty member who has taught the regular semester-version of the course. The purpose of these initial meetings would be to orient the instructor, to pass on information and advice. Subsequent meetings can be scheduled to review the planned syllabus and to answer additional questions that arise. The main goal of this action item is to make sure summer instructors have several knowledgeable people—including faculty members—who they can turn to for assistance throughout the summer. A further recommendation would be to have graders available, as the burden of teaching these large classes single-handedly, often for the first time, has been heavy on the instructors, who have the added pressure of conducting research.

3.1.10. New Computing/Statistics Course

Few could argue that hands-on experience with modern computing tools is not a requirement for success in the physical sciences. Yet there is a growing disconnect between what computational capabilities exist (and what computational power the data demands for analysis) and what is being taught in the classroom. The problem is pervasive not just for undergraduates who opt to join industry but also for students who attend graduate school in the physical sciences. The Astronomy Department, represented by Bloom, is co-sponsoring a campus-wide proposal to begin a Designated Emphasis (DE) in Computational Science and Engineering (CSE) for our graduate students, building upon the explicit recognition that:

> Computation is now regarded as an essential third component of the scientific method, complementing the traditional methods of theory and experiment, to advance scientific and engineering practice.[4]

Indeed training in computation and statistics should ideally happen *before* starting the graduate career — the tools provided by such a framework are immediately beneficial and would serve as the foundation for all research endeavors. Important is the recognition that the lines between fundamental astrophysical research and fundamental advancement in computational sciences are blurring. It is on this basis that we feel formal instruction in the computation and statistical arts must be part of a robust undergraduate program in the 21st century.

Our undergraduates already receive instruction in basic programming and statistics through the laboratory classes (Astro 120, 121, 122) but the focus in those classes is on providing hands-on

[4]http://www.cs.berkeley.edu/∼demmel/CSE_DE_Proposal_25Oct07.pdf

connections to astrophysical data collection and analysis. Computational tools, such as IDL, are introduced to bootstrap students quickly into visualization and basic analysis (usually at the level suitable for doing introductory research in the summer months). There is little time available for building foundations in computer science, teaching modern computing languages that will scale well within the impending parallel CPU paradigm, and teaching the skills required for dealing with massive datasets.

The main goal is to provide our undergraduates with a class focused on programming and statistics with astronomical applications. We are proposing to develop and teach a semester-long course aimed at exposing undergraduates to basic concepts in analysis and data management with state-of-the-art software tools. The format would be roughly thirty 1.5-hour lectures, weekly discussion sections and extensive coding problem sets to give hands-on experience with the concepts introduced in lectures. Some published textbooks which may be useful include Miller & Ranum's *Problem Solving with Algorithms and Data Structures Using Python* and Kiusalaas' *Numerical Methods in Engineering with Python*. Prerequsites could include a prior Computer Science (CS) class. We provide an example curriculum:

- Building Data Analysis Tools
  - Statistical analysis
    - Implementing frequentist hypothesis testing on large datasets
    - Bayesian approach to signal extraction with noisy data
  - 2-D Imaging analysis and visualization (Python and VTK)
- Data Management
  - Database creation (single and multi-processor architectures)
  - Intelligent indexing and fast spatial queries on large datasets
  - Cross-matching and data mining
  - Interacting with web-based archives
- Computing Techniques
  - Strategies for parallel computing
  - Integrating with Virtual Observatory webservices
  - Grid computing and cluster hardware

Example relevant computer science classes include:

- Computer Science 226 (Algorithms and Data Structures): Princeton University
  URL: http://www.cs.princeton.edu/courses/archive/fall07/cos226/lectures.html
- Computer Science 50 (Introduction to Computer Science): Harvard University
  URL: http://www.courses.fas.harvard.edu/∼cs50/
- CS 170 (Introduction to CS Theory): UC Berkeley
  URL:http://www.eecs.berkeley.edu/Courses/Data/210.html
- CS 174 (Computers and Discrete Probability): UC Berkeley
  URL: http://www.eecs.berkeley.edu/Courses/Data/212.html

Example relevant astronomy and physics classes:

- Astro 303 (Observing and Modeling the Universe): Princeton University
  URL: http://www.astro.princeton.edu/ strauss/AST303/
- Phys 18.330 (Introduction to Numerical Analysis): MIT.

3.2. Graduate Students

3.2.1. Exit Seminar Requirement

We reiterate the advantages in requiring an "exit seminar": (i) closure and celebration; (ii) the entire Department, not just the advisor and qual committee members, learns what the student has accomplished; (iii) practice and incentive in delivering a professional-grade research seminar; and (iv) a clear distinction between this "final defense" and the qual.

To avoid having to schedule an extra series of talks and an extra demand on people's time, we might schedule these Exit Seminars as part of the weekly research seminars (RAL, CIPS, TAC), or even the weekly Journal Club.

3.2.2. Regularly Offer Core Courses

The faculty are resolved to offer the "core" classes other than 201 and 202—i.e., Astro 216, 218, C228, C249, 252, and C254 (all subjects eligible for prelim topics)—at least once every two years. (Meanwhile, Astro 201 and 202 should be offered every year—as they have been.)

3.2.3. Increase Graduate Salary

An increase in incoming graduate student salary from the current \$25.8K to \$27.6K would match at least one of our competitors (Harvard).

3.2.4. Unambiguous Communication Regarding Funding

Responsibility for initiating discussion about a student's salary must ultimately rest with the Research Advisor. The Research Advisor should state clearly how much funding they possess to support a graduate research assistantship, and for how long, and whether the student's pay will need to be supplemented by teaching. To ensure that funding situations are unambiguous for every student, the student should describe as part of their Annual Progress Report (§3.2.6) the source of their funding and what their future prospects are.

3.2.5. Students Can Fulfill 50% of Teaching Requirement After the First Year

All graduate students must teach at least two semesters during their career at Berkeley. But they are not required to teach those two semesters during their first year. If they receive funding through a Research Advisor, or if they hold a fellowship, students can defer 50% of their teaching duties to after their first year. Everyone—the Chair (who serves as AA for all first-year students), the faculty, and current students—should make this possibility clear to incoming graduate students and prospectives as part of the recruitment process.

3.2.6. Enforcing the Advising System

The main goals of the advising system are to identify and address students' problems while they are still small and manageable, and to get students talking to more than just their Research Advisor.

We envision a three-tiered approach to advising, with many responsibilities shared between the three levels.

1. At the top is the Head Graduate Advisor, who oversees the entire system. The Head Graduate Advisor reads every Annual Progress Report (§2.7.3) written by students; identifies systemic problems and brings them to the attention of the Chair and faculty; provides intelligent advice

when solicited regarding coursework and teaching opportunities; makes sure students are completing their prelim and qual exams in a timely fashion; and offers solutions when prompted about any and all problems related to graduate school life, especially those concerning research and career development.

2. At the intermediate level is the Class Shepherd, a faculty member assigned to track the progress of all students in their n^{th} year. The Class Shepherd works to ensure compliance with timelines for taking the prelim and qual; reads all Annual Progress Reports (§2.7.3) for their class and initiates dialogue as necessary; and, if asked, serves to mediate problems that arise between Research Advisor and student.

3. At the most specific level is the Academic Advisor, a faculty member who may share some research interests with a particular student. The Academic Advisor reads and offers feedback on the student's Annual Progress Report; ensures the student is on track with regards to the prelim and qual; offers a third party perspective on research problems; and provides advice about classes and teaching opportunities. The Academic Advisor must touch base with the student at least twice per academic year—once at the start of the fall term, and again during the spring term.

The envisioned advising system follows the engineering philosophy of redundancy: critical components of the system are duplicated to increase reliability.

With regards to the Annual Progress Report:

1. Each student's submission of the Annual Progress Report in early Fall should be followed soon thereafter (say within a month) by a face-to-face meeting between that student and their Academic Advisor. The Annual Progress Report should be used as a launching point for discussion. Final responsibility for holding a meeting to give feedback on the Report must rest with the Academic Advisor.

2. Each Class Shepherd should acknowledge having read through all the APRs for the students under their watch. In the majority of cases, such an acknowledgement will be a mere formality. Nevertheless, written or oral acknowledgement should still be made to maintain good will between the faculty and the students, and to keep communication lines as open as possible.

3. The Head Graduate Advisor should be entrusted to read every Annual Progress Report, and to identify, in consultation with the Chair, system-wide problems and students in apparent need of special attention.

4. To ensure that funding situations are unambiguous for every student, the student should describe as part of their Annual Progress Report the source of their funding and what their future prospects are. There can be a standard template for the Report that has as one of its sections "Funding".
5. On this template, there should places for the AA and CS to provide written comments and to sign off.

3.2.7. The Qual is a Thesis Proposal and Should Be Taken Before Calendar Year 4

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The definition of the qual is given in §2.1.4, taken verbatim from the Department website. It is a proposal, not a defense. The examinee is called upon to make a "*reasonable* (not an *airtight*) case" for the science to be done.[5] The examiners are called upon to scale their expectations accordingly. The examiners are also charged with providing constructive feedback on the proposed work, with the goal of improving the work while it is still at a formative stage.

The qual should be taken before the end of a student's fourth calendar year. Now it is recognized that the imposition of four years as a deadline is somewhat artificial. Nevertheless, setting a definite deadline seems reasonable insofar as it (1) encourages students to complete their degrees in a timely manner and (2) provides a concrete goal for students to work towards during the early stages of their research explorations. Exceptions to the four-year rule can be requested by writing a letter to the Head Graduate Advisor (currently Chiang) stating the reasons for the delay and setting a target date for the exam during the ninth semester. Presumably such exceptions will be requested rarely. And if the Advising system is working, the need for such an extension for any given student should become apparent to them and to their various advisors (Research Advisor, AA, CS, HGA) well in advance (months, at least) of the deadline.

Ideally, the qual will serve as a goad to sharpen the focus of young researchers. If the qual compels students to continually ask themselves during their first four years, "What are the most interesting and important questions in my chosen field, and what can I do to answer them?"—then it will have fulfilled one of its main purposes, which is to teach students how to develop their own game plans and chart their futures.

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[5]As stated by (then) Chair Arons, in a message to students and faculty dated January 24, 1997.

3.2.8. Improving Journal Club

1. Schedule the number of talks per meeting based on the number of people who sign up to give them. Demand only that at least one speaker present each week, but still allow for the possibility of having two speakers.

   A historical note: When Heiles ran Journal Club, he enforced a uniform policy of one 30-minute talk per meeting, with the remainder of the hour used for relaxed discussion. He reports that students and faculty alike enjoyed this format. One drawback of this approach is that it may not encourage enough participation from students, many of whom can slip by without regularly giving Journal Club talks. By contrast, under the present proposed format, we expect that some weeks will feature one talk while others will have two. This represents a hybrid strategy that hopefully combines positive aspects of both the Heiles format and the current two-talk format.

2. Record on a Department website whether a student has given a Journal Club talk in any given semester, and encourage those who are lagging their peers to catch up. A reasonable goal is to have every student give a Journal Club talk at least once per year for every year that they are registered—though pressure can be lessened for first-year students (who are burdened with teaching and taking classes) and final-year students (who are busy applying for jobs and finishing theses). This record ("Wall of Fame/Shame") is currently maintained by Journal Club organizer Kalas at http://astro.berkeley.edu/~kalas/pages/kalas_journal_club_08a.html. Encouragement to give talks should be given not only by the Journal Club organizer, but also by the Research Advisor, Academic Advisor, Class Shepherd, and Head Graduate Advisor. The message that Journal Club is an integral part of graduate school education and should be taken seriously needs to be better communicated to students.

3. Provide immediate feedback to every speaker after their talk on the quality of their presentation, and supply suggestions for improvement. Feedback can be given by anyone in attendance, but should at a minimum be given by the organizer of Journal Club. Here again the student's various advisors (Research Advisor, Academic Advisor, Class Shepherd, and Head Graduate Advisor) can chime in.

4. Actively invite postdocs to give Journal Club talks. Of course, the venue is open to all (including faculty and outside visitors), but students and postdocs should be especially encouraged to give talks.

3.2.9. Graduate Cosmology Curriculum

M. White is leading the effort to develop a new graduate-level cosmology course in Physics (referred to here as C229), to be cross-listed in Astronomy. This course would follow on the heels of the current graduate-level introduction to cosmology, Astro C228. Physics C229 would cover more advanced topics and would better prepare students for doing research in cosmology. Ma, Seljak, White, and others would take turns teaching C228 and C229, enabling graduate students in Astronomy and Physics to learn from their various perspectives.