Astronomy and Astrophysics

Professor George Rybicki, Director of Undergraduate Studies

The science of astronomy and astrophysics involves the study of matter and radiation in the universe as understood through the laws of physics. Modern astronomical instruments reveal a great variety of objects scarcely imagined a few decades ago, including X-ray binary stars, pulsars, and quasars. Astronomical phenomena exhibit an extreme range of physical conditions, from superfluid neutrons in neutron stars, high-temperature nuclear reactions in supernovae, and strong gravitational fields near black holes, to the unique state of the universe during its earliest phases. Theoretical attempts to describe these and more familiar phenomena (such as stars and galaxies) have achieved a useful understanding in many cases. However, our overall knowledge of the universe is still woefully incomplete, and our contemporary physical knowledge is often stretched to its limits in attempting to understand physical conditions which cannot be reproduced in terrestrial laboratories.

The concentration in Astronomy and Astrophysics introduces students to a broad range of phenomena through a program of both observational and theoretical courses. This program builds from a foundation of modern physics to a general account of the known contents of the universe. The introductory and junior tutorials place students in close contact with the wide range of research activities at the Harvard-Smithsonian Center for Astrophysics. Undergraduates are strongly encouraged to pursue research projects (conducted under the supervision of members of the faculty), which culminate in their junior papers and senior theses. Since the emphasis of astronomy and astrophysics is on the explanation of phenomena in the universe in terms of physical theory, the initial stages of a concentration in Astronomy and Astrophysics closely resemble those of the Physics concentration, and the courses offered by the Department of Astronomy are readily accessible to any student with a good physics background. Our concentration offers avenues similar to Physics for future employment and research opportunities.

The concentration in Astronomy and Astrophysics offers three options: the basic concentration, the honors-eligible concentration, and the joint concentration. The basic concentration is intended for those students who have a strong interest in astronomy and astrophysics, but who do not wish to explore the subject to the same depth of physical theory as honors candidates. The specific course requirements for each track are described in the next section. Our gateway course, Astronomy 16, is encouraged for freshmen who would like to get a feel for what the concentration involves. The introductory tutorial (Astronomy 97hf) is taken as a fifth course running throughout the sophomore year and is optional but strongly encouraged of all concentrators. Both basic and honors candidates must enroll in the junior tutorial (Astronomy 98hf). The senior thesis (Astronomy 99) is required of honors candidates, but not of basic concentrators. Some flexibility in requirements is possible for late entrants to the concentration who have a suitable background in physics and mathematics.

Astronomy and Astrophysics offers joint concentrations with other departments. In general, such concentrations involve meeting requirements for honors candidates in both fields, although the Astronomy junior tutorial and senior thesis are not required of joint concentrators if they have not listed Astronomy and Astrophysics as their primary concentration. Joint concentrations combining Astronomy and Astrophysics with either Physics or with Earth and Planetary Sciences are particularly encouraged, although various other combinations are certainly possible. Students interested in joint concentrations are encouraged to contact the Director of Undergraduate Studies at 617-495-7452.

Students interested in completing a Master's degree in Astronomy and Astrophysics during their fourth year can find more detailed information in our section of the *Advanced Standing at Harvard College* booklet, and should contact the Astronomy Department early in their degree program.

REQUIREMENTS
Basic Requirements: 12 half-courses

1. *Required Courses:*
   a. Physics 15a, 15b, and 15c. Qualified students may replace 15a with 16, to be followed by 15b and 15c.
   b. Mathematics 1a and 1b, followed by 21a and 21b. Qualified students may start with Mathematics 21a.
   c. Astronomy 16.
   d. One half-course in Astronomy at the 100- or 200-level.
   e. Two other half-courses offered by the Department of Astronomy (except Astronomy 2). Astronomy 97hf is strongly encouraged. Only one of these half-courses may be chosen from among Science A-35, A-36, A-47, A-54, or Astronomy 5 or 7.
   f. Additional half-courses in Astronomy or a related subject to complete the requirement of at least twelve half-courses.
2. *Tutorials:*
   a. *Sophomore year:* Astronomy 97hf, optional but strongly encouraged, taken as a fifth half-course running throughout the year. Freshmen who have qualified for Advanced Placement in Physics, and especially those students who contemplate accepting Advanced Standing, may take Astronomy 97hf in their first year.
   b. *Junior year:* Astronomy 98hf, required, providing an introduction to contemporary astronomical research.
3. *Thesis:* None.
4. *General Examination:* None.
5. *Other information:*
   a. *Pass/Fail:* Two half-courses, not including the tutorials or Physics 15a, 15b, 15c, or 16, may be taken Pass/Fail.
   b. *Related subjects:* Physics, mathematics, applied physics, and applied mathematics courses are always admissible in this category. Appropriate courses in history of science, earth and planetary sciences, computer science, engineering sciences, and chemistry may be admitted by permission of the Director of Undergraduate Studies. Students interested in our graduate program should note that courses like Physics 151, 153, and 181 are generally expected of applicants to it.
   c. Astronomy 2 may not be taken for concentration credit.
   d. The twelve half-courses required for the basic concentration include the prerequisites for the courses listed above. For example, a student who begins with Mathematics 21a may count two half-courses for Mathematics 1a and 1b towards the required total of twelve half-courses.
   e. Students who intend further study in Astronomy and Astrophysics are strongly urged to complete the requirements for honors eligibility.

Requirements for Honors Eligibility: 16 half-courses

1. *Required courses:*
   a. Physics 15a, 15b, and 15c. Qualified students may replace 15a with 16, to be followed by 15b and 15c.
   b. Physics 143a.
   c. Two courses selected from Applied Mathematics 105a, 105b, or 111. Courses in Mathematics at the 100- or 200- level may be substituted by permission of the Director of Undergraduate Studies. Note that Mathematics 21a and 21b (or Mathematics 23a and 23b or 25a and 25b) are prerequisites for these courses, and hence should be taken early.
   d. Astronomy 145.
   e. Two additional half-courses selected from Astronomy 16 and Astronomy courses at the 100 or 200 level. Astronomy 191 is encouraged. One cross-listed course in Physics and in Earth and Planetary Sciences may be substituted by permission of the Director of Undergraduate Studies.
   f. Additional half-courses, if necessary, in astronomy or physics to complete the requirement of at least 16 half-courses including prerequisites. Courses in related subjects may be substituted by permission of the Director of Undergraduate Studies.
   g. Honors candidates are required to have an observational/instrumental component to their undergraduate studies. This requirement can be met by Astronomy 191 or Physics 191, or by a project in Astronomy 91, Astronomy 98, or Astronomy 99 that clearly has a strong observational/instrumental component. Such a project may be used to satisfy the requirement upon request of the student and approval by the student's project supervisor and the Astronomy Director of Undergraduate Studies.
2. *Tutorials:*
   a-b. Same as **Basic Requirements** (see item 5e for exceptions).
   c. *Senior year:* Astronomy 99, required, in which the student undertakes supervised research leading to the senior thesis (see item 5e).
3. *Thesis:* Required, and normally based upon research undertaken in Astronomy 99 (see item 5e).
4. *General Examination:* None.
5. *Other information:*
   a. *Pass/Fail:* At most, one Astronomy course at the 100- or 200-level may be taken Pass/Fail. Letter-graded credit is required for all physics and mathematics courses.
   b. *Related subjects:* Physics, mathematics, applied physics, and applied mathematics courses are always admissible in this category, and various earth and planetary sciences, computer science, engineering sciences and chemistry courses may be admitted (by permission of the Director of Undergraduate Studies). Students interested in our graduate program should note that courses like Physics 151, 153, and 181 are generally expected of applicants to it.
   c. Astronomy 2, 5, 7, and Science A-35, A-36, A-47, and A-54 may not be counted towards the concentration requirements for honors candidates.
   d. The 16 half-courses required for honors eligibility include the prerequisites for the courses listed above. For example, a student who begins with Mathematics 21a may count two half-courses for Mathematics 1a and 1b towards the required total of 16 half-courses.

e. Joint concentrators who have not listed Astronomy and Astrophysics as their primary concentration are not required to take any of the tutorials, but may be admitted upon request.

ADVISING

Upon joining the concentration, students are assigned a faculty adviser; students continue with the same adviser throughout their three years, unless there is a particular reason for making a change. Students meet with their adviser at least once per term and at other times as needed.

For up-to-date information on advising in Astronomy and Astrophysics, please see the Advising Programs Office website: *www.fas.harvard.edu/~advising/concentrations/Astronomy.html*.

RESOURCES

The Department of Astronomy is located within the Harvard-Smithsonian Center for Astrophysics, which also contains the Smithsonian Astrophysical Observatory and Harvard College Observatory, at 60 Garden Street and 160 Concord Avenue, Cambridge. The Center for Astrophysics has a large staff of scientists and is among the largest institutions devoted to astronomy and astrophysics in the world. A very broad range of astrophysical research is conducted by the many scientists at the Center, in its divisions of Atomic and Molecular Physics; High-Energy Astrophysics; Optical and Infrared Astronomy; Radio and Geoastronomy; Theoretical Astrophysics; and Solar, Stellar and Planetary Sciences. Scientists in these divisions encourage students to participate in their research. Full-time summer and part-time academic year employment is often available for Harvard undergraduates at the Center; please contact the Director of Undergraduate Studies for more information.

Through the Center for Astrophysics students may make use of a wide range of observational, experimental, and theoretical facilities. These include two 6.5-meter Magellan Telescopes in Chile; the Multiple-Mirror Telescope and the 60- and 48-inch reflecting telescopes of the Whipple Observatory on Mount Hopkins, Arizona; and the Submillimeter Array on Mauna Kea in Hawaii. Access to the 120-foot radome-enclosed radio telescope of the Northeast Radio Observatory Corporation at Westford, Massachusetts, is also possible. In addition, students may participate in the analysis of data from a number of national and international observatories, including X-ray data from the Chandra X-ray Observatory, ultraviolet and optical data from the Hubble Space Telescope, solar data from SOHO, radio data from the Very Large Array and the VLBI network, and infrared data from the Spitzer Space Telescope.

HOW TO FIND OUT MORE

The Director of Undergraduate Studies for the concentration is Professor George Rybicki. His Observatory office is 60 Garden Street, Room P-238 (617-495-7452); his email address is *grybicki@cfa.harvard.edu*. A map showing the location of the Observatory complex can be found at the Center for Astrophysics website, *cfa-www.harvard.edu*. The Astronomy Department Office is located at the same address in room C-25 (617-495-3752). On-line information about the Astronomy Department is available at *cfa-www.harvard.edu/ast*. If you are interested in study abroad, please contact the Director of Undergraduate Studies.

ENROLLMENT STATISTICS

Number of Concentrators as of November

Concentrators	2002	2003	2004	2005	2006
Astronomy & Astrophysics	6	8	10	9	8
Astronomy & Astrophysics + another field	6	7	3	8	4
Another field + Astronomy & Astrophysics	5	7	8	9	5