



## HARVARD UNIVERSITY DEPARTMENT OF ASTRONOMY

60 GARDEN STREET MS16 CAMBRIDGE MA 02138  
TEL 617 496 6515 FAX 617 495 7049  
[DCHARBONNEAU@CFA.HARVARD.EDU](mailto:DCHARBONNEAU@CFA.HARVARD.EDU)

20 March 2009

Dear Students,

Over the past year, our department has been hard at work designing our revised concentration requirements as well as our new secondary field. I am delighted to report that the new requirements and course offerings will go into effect in September 2009.

The key changes relating to the concentration are as follows:

1. The number of requirements has been reduced from 16 to 12 half courses. Note that in the old system we counted Math 1a and 1b, whereas these will not be counted under the new requirements, so the effective change is to reduce the number of required half courses by 2.
2. The senior thesis is no longer required for honors consideration.
3. We are introducing a set of 5 new courses as follows:
  - a. Astronomy 16 and 17 (which may be taken in either order), providing an overview of astrophysics using single variable calculus and mechanics.
  - b. Astronomy 110, 120, 130, each of which treats one of the most exciting topics in astrophysics today, including exoplanets, stellar physics, and cosmology.
  - c. Astronomy 100, a course in observational astronomy that includes a week-long trip to gather observations with telescopes at a world-class observatory.
4. There are no longer separate tracks for "basic" and "honors". This means that you don't need to decide whether to pursue the requirements for honors at the time that you declare your concentration; rather, this decision can be made as late as the start of your senior year.
5. The concentration will be named simply "Astrophysics".

Our new secondary field, which will also be named "Astrophysics", will provide you with an understanding of the physical universe beyond the Earth that is firmly rooted in introductory physics and single-variable calculus. It emphasizes the interplay between the remote observation of astrophysical phenomena and the construction of models to describe them, and the required courses will include the use of various observatories. In order to ensure that you can fulfill the requirements while pursuing a concentration in another field, we have held our secondary to 4 courses, which include the physics requirement.

The Harvard-Smithsonian Center for Astrophysics is one of the world's preeminent institutes for the study of astrophysics, and operates many of the leading observatories around the globe and off of it. Our department is very excited about these changes to our curriculum, and I look forward to discussing them with you whenever you like. Please email, call, or drop by my office to chat.

Best regards,

David Charbonneau  
Thomas D. Cabot Associate Professor of Astronomy  
Director of Undergraduate Studies, Astronomy and Astrophysics

**Concentration:     *Astrophysics***

**REQUIREMENTS: 12 half-courses**

1. *Required courses:*
  - a. Astronomy 16 and 17. (2 half courses)
  - b. Physics 15a, 15b, and 15c. (3 half courses; see note 7e. and 7f. below)
  - c. Mathematics 21a and 21b, or Mathematics 23a and 23b, or Mathematics 25a and 25b, or Applied Mathematics 21a and 21b. (2 half courses; see note 7d. below)
  - d. Astronomy 98, Research Tutorial, generally taken in the spring semester of the junior year. (1 half course)
  - e. Two additional courses in Astronomy. (2 half courses; see note 7c. below)
  - f. Two additional courses in Astronomy or related fields to complete the requirement of 12 half-courses. (2 half courses)
2. *Tutorial:* Required, see item 1d. above.
3. *Honors Eligibility:* Students who wish to be considered for honors must satisfy requirements 1e. and 1f. by completing Astronomy 99 and/or courses at the 100-level or above. None of the courses satisfying 1e. or 1f. may be taken pass/fail. Courses that meet this requirement include:
  - i. Astronomy 99, a full-year course leading to the senior thesis. The Department of Astronomy is located within the Harvard-Smithsonian Center for Astrophysics, one of the world's largest astrophysical research institutes. The Center for Astrophysics offers significant undergraduate research opportunities, which students are encouraged to pursue through the senior thesis.
  - ii. Any 100-level or 200-level course in Astronomy.
  - iii. Astronomy 97.
  - iv. Physics 143a, 143b, 151, 153, 175, or 181.
  - v. Earth and Planetary Sciences 100, 121, 132, or 150.
  - vi. Applied Mathematics 105a, 105b, 111, or 115.
4. *Thesis:* Optional. See item 3. above.
5. *Joint concentrations:* Joint concentrations are permitted to enable students to pursue study at the interface of Astrophysics and another field such as Physics or Earth and Planetary Sciences. Students must meet with the Director of Undergraduate Studies to develop the plan of study.
6. *General Examination:* None.
7. *Other information:*
  - a. *Pass/Fail:* At most one of the courses counted for concentration credit may be taken Pass/Fail.
  - b. *Related fields:* Includes all departmental courses offered in Physics, Earth and Planetary Sciences, Mathematics, and Applied Mathematics that count towards the respective concentration requirements. Appropriate courses in Applied Physics, Computer Science, Chemistry, Engineering Sciences, Mathematics, and Statistics may be counted for concentration credit with permission from the Director of Undergraduate Studies.
  - c. Students may count one half course selected from the following list for concentration credit, provided the course is completed prior to enrolling in other courses offered by the Department of Astronomy.
    - i. Astronomy 1 or Astronomy 2,
    - ii. a freshman seminar in Astronomy, or,
    - iii. a course offered through Science of the Physical Universe element of the General Education program that focuses on astronomy.

- d. Math Xa, Xb, 1a, and 1b normally do not count toward concentration credit.
- e. Physics 11a may be substituted for Physics 15a provided students follow Physics 11a with Physics 15b and 15c. This option is intended for students with no previous exposure to Physics, or students who complete Physics 11a prior to deciding to concentrate in Astrophysics.
- f. Qualified students may replace Physics 15a with Physics 16, to be followed by 15b and 15c.
- g. Students considering graduate study should contact the Director of Undergraduate Studies to prepare a study plan to meet this goal.

---

**Secondary Field:    *Astrophysics***

**REQUIREMENTS: 4 half-courses**

1. Physics 11a, or 15a, or 16, providing an introduction to mechanics. This course serves as the co-requisite for Astronomy 16 and Astronomy 17.
2. Astronomy 16, providing an introduction to stellar and planetary astronomy.
3. Astronomy 17, providing an introduction to galactic and extragalactic astronomy.
4. One additional course in Astronomy, either Astronomy 98, or any course in Astronomy at the 100-level.
5. *Other information:*
  - a. Courses taken at other institutions may be substituted for substantially equivalent Harvard courses with the permission of the Head Tutor.
  - b. *Pass/Fail:* No course may be taken Pass/Fail.

---

*Relevant course listings as they would appear in the 2009 – 2010 Courses of Instruction:*

**Astronomy 16. Stellar and Planetary Astronomy**

*Half course (spring term)*

This course provides an introduction to the physical principles describing the formation and evolution of stars and their planetary companions. Topics include thermal radiation and stellar spectra; telescopes; energy generation in stars; stellar evolution; orbital dynamics; the Solar system; and exoplanets. This course includes an observational component: Students will determine the distance to the Sun, and use the Clay Telescope atop the Science Center to study stellar evolution and detect exoplanets.

*Prerequisite:* An introductory course in mechanics, which may be taken concurrently, satisfied by Physics 11a, or Physics 15a, or Physics 16.

**Astronomy 17. Galactic and Extragalactic Astronomy**

*Half course (fall term)*

This course provides an introduction to the physical principles describing galaxies and the composition and evolution of the Universe. Topics include the interstellar medium; star clusters; the structure and dynamics of the Milky Way; other galaxies; clusters of galaxies; active galaxies and quasars; cosmology; and the early universe. This course includes an observational component: In addition to observing galaxies with the Science Center Clay Telescope, students will use the millimeter-wavelength telescopes at the Harvard-Smithsonian Center for Astrophysics to determine the mass of the Milky Way.

*Prerequisite:* An introductory course in mechanics, which may be taken concurrently, satisfied by Physics 11a, or Physics 15a, or Physics 16.

### **Astronomy 91r. Supervised Reading and Research**

*Half course (fall term; repeated spring term)*

Supervised reading and research in a subject of astrophysics that is not normally included in the regular course offerings of the department.

*Note:* Students must arrange for course supervision with an individual member of the Department. The course may be counted only once toward the concentration requirements, and may not be taken more than twice.

*Prerequisite:* Astronomy 16 or Astronomy 17

### **Astronomy 98. Research Tutorial in Astrophysics**

*Half course (spring term)*

This tutorial introduces students to research at the forefront of astrophysics, and provides opportunities for students to meet with research scientists and individuals active in science policy, education, and journalism. Students meet weekly for a lecture and discussion over dinner with a guest speaker, preceded by a reading and a preparatory seminar. Students will be mentored throughout the term on a research project of their choosing. The Harvard-Smithsonian Center for Astrophysics is home to one of the largest groups of astronomers in the world, providing extensive opportunities for undergraduate research.

*Prerequisite:* Astronomy 16 or Astronomy 17

### **Astronomy 99. Senior Tutorial in Astrophysics**

*Full course*

For honors candidates in Astrophysics. Individually supervised reading and research leading to the senior thesis. The Harvard-Smithsonian Center for Astrophysics is home to one of the largest groups of astronomers in the world, providing extensive opportunities for undergraduate research.

*Prerequisite:* Astronomy 98.

### **Astronomy 100. Methods of Observational Astronomy.**

*Half course (spring semester)*

In this course we will learn the basic tools of modern astronomical research, including telescopes, detectors, imaging, spectroscopy, and common software. Emphasis will be placed on both the theory behind telescopes and their use, and hands-on experience with real data. Using this basic knowledge we will analyze science-level astronomical data from a wide range of telescopes and review the basic properties of stars, galaxies, and other astronomical objects of interest. The course includes a trip to the F. L. Whipple Observatory on Mount Hopkins, Arizona, to gather data with various telescopes.

*Prerequisite:* Astronomy 16 or Astronomy 17, either of which may be taken concurrently.

*Note:* This course is similar in content to Astronomy 97. Students who have taken Astronomy 97 may not take Astronomy 100 for credit.

### **[Astronomy 110. Exoplanets]**

*Half course (fall semester)*

A survey of the rapidly-evolving field of the detection and characterization of planets orbiting other stars. Topics includes proto-stellar collapse and star formation; comets, meteorites, and protoplanetary disk structure; models of planet formation; methods of detecting extrasolar planets; composition and physical structure of planets; planetary atmospheres; habitable zones; greenhouse effect; biosignatures.

*Note:* Offered in alternate years.

*Prerequisite:* Astronomy 16.

### **[Astronomy 120. Stellar Physics]**

*Half course (spring semester)*

Stars are the basic building blocks of galaxies and are responsible for the nucleosynthesis of most of the elements. Topics include the structure of self-gravitating objects; energy transport in stars; stellar atmospheres; asteroseismology; nuclear fusion in stars; stellar evolution; nucleosynthesis of the elements; the degenerate remnants of stars; black holes. This course will make use of thermodynamics, statistical mechanics, and quantum mechanics, but will review these subjects as necessary.

*Note:* Offered in alternate years.

*Prerequisite:* Astronomy 16. Physics 15c strongly recommended.

### **Astronomy 130. Cosmology**

*Half course (spring semester)*

The physical model describing the initial conditions, evolution, and ultimate fate of the Universe. Topics include cosmic dynamics; the Robertson-Walker Metric; curvature; estimating cosmological parameters; the accelerating universe; dark matter; gravitational lensing; the cosmic microwave background; nucleosynthesis; inflation and the very early universe; formation of structure.

*Note:* Offered in alternate years.

*Prerequisite:* Astronomy 17 or Physics 15c.

### **Astronomy 150. Radiative Processes in Astronomy**

*Half course (fall semester)*

This course offers a survey of radiative processes of astrophysical importance from radio waves to gamma rays. Topics include thermal and non-thermal processes, including bremsstrahlung, synchrotron radiation, and Compton scattering; radiation in plasmas; and atomic and molecular spectra.

*Prerequisite:* Physics 15c or equivalent.

### **Astronomy 191. Astrophysics Laboratory**

*Half course (spring term)*

Laboratory and observational projects in astrophysics. Students choose two projects from a selection including: observational studies of the cosmic microwave background radiation, molecules in interstellar clouds, the rotation of the galaxy, galactic molecular sources with the submillimeter array (SMA), stars and clusters with the Clay Telescope; and laboratory experiments including super-conducting submillimeter detectors, x-ray CCDs, and hard x-ray imaging detectors and telescopes.

*Note:* Primarily for concentrators in astrophysics. Students with physics as their primary concentration but who have demonstrated a serious interest in astrophysics may take this to satisfy their laboratory requirement (in place of Physics 191) upon petition to the Head Tutor of Physics.

*Note:* Expected to be omitted in 2010 – 2011. Given in alternate years.

*Prerequisite:* Astronomy 16 or 17, or Physics 15c or equivalent.

*Other 100-level courses that may be of interest to undergraduates:*

### **Astronomy 151. Astrophysical Fluid Dynamics.**

### **Astronomy 192. Tools and Techniques of Astronomical Measurements.**

### **[Astronomy 193. Noise and Data Analysis in Astrophysics.]**