ASTRONOMY

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M.S., M.Phil., Ph.D.

Chair
Priyamvada Natarajan

Director of Graduate Studies
Héctor Arce (203.432.3018, hector.arce@yale.edu)

Professors
Héctor Arce, Charles Bailyn, Charles Baltay (Physics), Sarbani Basu, Paolo Coppi, Pierre Demarque (Emeritus), Debra Fischer, Marla Geha, Larry Gladney (Physics), Jeffrey Kenney, Richard Larson (Emeritus), Gregory Laughlin, Priyamvada Natarajan, C. Megan Urry (Physics), William van Altena (Emeritus), Frank van den Bosch, Pieter van Dokkum, Robert Zinn

Associate Professors
Reina Maruyama (Physics), Daisuke Nagai (Physics), Nikhil Padmanabhan (Physics)

Assistant Professor
Laura Newburgh (Physics)

FIELDS OF STUDY

Fields include observational and theoretical astronomy, solar and stellar astrophysics, exoplanets, the interstellar medium and star formation, galactic astronomy, extragalactic astronomy, radio astronomy, high-energy astrophysics, and cosmology.

SPECIAL REQUIREMENTS FOR THE PH.D. DEGREE

A typical program of study includes twelve courses taken during the first four terms, and must include the core courses listed below:

The Physics of Astrophysics (ASTR 500), Computational Methods in Astrophysics and Geophysics (ASTR 520), Observational Astronomy (ASTR 555), Interstellar Matter and Star Formation (ASTR 560), either Stellar Populations (ASTR 510) or Stellar Astrophysics (ASTR 550), and either Galaxies (ASTR 530) or The Evolving Universe (ASTR 565). ASTR 620 or PHYS 678 may be substituted for ASTR 520 with the permission of the director of graduate studies (DGS).

Students require the permission of the instructor and the DGS to skip a core class if they think that they have sufficient knowledge of the field. Students will be required to demonstrate their knowledge of the field before they are allowed to skip any core class.

Two of the twelve courses must be research credits, each earned by working in close collaboration with a faculty member. Of the two research credits, one must be earned doing a theoretical research project and one doing an experimental research project. The students need to present the results of the project as a written report and will be given an evaluation of their performance.

The choice of the four remaining courses depends on the candidate’s interest and background and must be decided in consultation with the DGS and/or the prospective
Astronomy thesis adviser. Advisers may require students to take particular classes and obtain a specified minimum grade in order for a student to work with them for their thesis. Students must take any additional course that their supervisors require even after their fourth term. In addition, all students, regardless of their term of study, have to attend Professional Seminar (ASTR 710 and ASTR 711) every term, unless registered in absentia. Students must also take Responsible Conduct in Research for Physical Scientists (PHYS 590), which discusses ethics and responsible conduct in scientific research and fulfills the requirement stipulated by the National Science Foundation for all students and for all postdoctoral researchers funded by the NSF. Note that ASTR 710, ASTR 711, and PHYS 590 may not be used to fulfill the twelve-course requirement.

Students are encouraged to take graduate courses in physics or related subjects. On an irregular basis, special topic courses and seminars are offered, which provide the opportunity to study some fields in greater depth than is possible in standard courses. To achieve both breadth and depth in their education, students are encouraged to take a few courses beyond their second year of study.

There is no foreign language requirement. A written comprehensive examination, normally taken at the end of the fourth term of graduate work, tests the student’s familiarity with the entire field of astronomy and related branches of physics and mathematics. Particular attention will be paid to the student’s performance in the field in which the student plans to do research. An oral examination, held a few weeks after the written examination, is based on the student’s chosen field of research. Satisfactory performance in these examinations, an acceptable record in course and research work, and an approved dissertation prospectus are required for admission to candidacy for the Ph.D. degree. The dissertation should present the results of an original and thorough investigation, worthy of publication. Most importantly, it should reflect the candidate’s capacity for independent research. An oral dissertation defense is required.

Teaching experience is an integral part of graduate education in astronomy. All students are required to serve as teaching fellows for four terms. Both the level of teaching assignments and the scheduling of teaching are variable and partly determined by the needs of the department. Most students will teach in each of their first three terms and complete their fourth teaching assignment sometime after the qualifying exam. Students who require additional support from the Graduate School must teach additional terms, if needed, after they have fulfilled the academic teaching requirement.

**HONORS REQUIREMENT**

Students must earn a grade of Honors in at least three classes by the end of the fourth term of full-time study and have a grade average of High Pass or better.

**MASTER’S DEGREES**

**M.Phil.** Upon application, the department will recommend for the award of the M.Phil. degree any student who has completed all the requirements of the Ph.D. degree except the Ph.D. dissertation. These requirements include taking and passing the qualifying exam and submission of the research projects’ final written reports (one for each of the two ASTR 580 projects).
M.S. Students who withdraw from the Ph.D. program may be eligible to receive the M.S. degree if they have met the requirements and have not already received the M.Phil. degree. For the M.S., students must successfully complete at least nine courses (not including ASTR 710 and ASTR 711) and at least one research project (ASTR 580). The student should have a grade average of High Pass in the courses and a grade of High Pass or above in the research project.

Program materials are available upon request to the Director of Graduate Studies, Department of Astronomy, Yale University, PO Box 208101, New Haven CT 06520-8101.

COURSES

ASTR 500b, The Physics of Astrophysics  Sarbani Basu
Primarily for incoming students in the Ph.D. program in Astronomy. The basic physics and related mathematics needed to take the advanced graduate courses. Topics in mechanics, thermodynamics and statistical mechanics, fluid mechanics, special relativity, and electrodynamics with applications to astrophysical systems are covered. Open to undergraduates with permission of the instructor.

ASTR 501a, Dynamics of Astrophysical Many-Body Systems  Frank van den Bosch
This course presents an in-depth treatment of the dynamics of astrophysical systems, including gases, plasmas, and stellar systems. The course starts with a detailed formulation of the theoretical foundations, using kinetic theory and statistical physics to describe the dynamics of many-body systems. Special emphasis is given to collisional processes in various astrophysical systems. Next, after deriving the relevant moment equations, we focus on specific topics related to (1) stellar dynamics, (2) hydrodynamics, and (3) plasma physics. Related to stellar dynamics we cover potential theory, orbit theory, Jeans modeling, gravitational encounters, and secular evolution (bars and spiral structure). In the field of (non-radiative) hydrodynamics we study, among others, the Navier-Stokes equation, vorticity, transport coefficients, accretion flow, turbulence, fluid instabilities, and shocks. We end with a cursory overview of plasma physics, including the Vlasov equation and the two-fluid model, Langmuir waves, Alfvén waves, Landau damping, ideal vs. resistive magnetohydrodynamics (MHD), and dynamos. Throughout the course, we focus on specific astrophysical applications. Prerequisites: undergraduate degree in physics or astronomy and basic knowledge of classical, Hamiltonian dynamics.

ASTR 510b, Stellar Populations  Robert Zinn
The stellar population of our galaxy and the galaxies of the local group. The properties of stars and star clusters, stellar evolution, and the structure and evolution of our galaxy.

ASTR 520a / EPS 538a, Computational Methods in Astrophysics and Geophysics  Paolo Coppi
The analytic and numerical/computational tools necessary for effective research in astronomy, geophysics, and related disciplines. Topics include numerical solutions to differential equations, spectral methods, and Monte Carlo simulations. Applications are made to common astrophysical and geophysical problems including fluids and N-body simulations.
ASTR 550a, Stellar Astrophysics  Sarbani Basu
An introduction to the physics of stellar atmospheres and interiors. The basic equations of stellar structure, nuclear processes, stellar evolution, white dwarfs, and neutron stars.

ASTR 555b, Observational Astronomy  Pieter van Dokkum
The design and use of optical telescopes, cameras, spectrographs, and detectors to make astronomical observations. The reduction and analysis of photometric and spectroscopic observations.

ASTR 570b / PHYS 570b, High-Energy Astrophysics  Paolo Coppi
A survey of current topics in high-energy astrophysics, including accreting black hole and neutron star systems in our galaxy, pulsars, active galactic nuclei and relativistic jets, gamma-ray bursts, and ultra-high-energy cosmic rays. The basic physical processes underlying the observed high-energy phenomena are also covered.

ASTR 580a, Research  Staff
By arrangement with faculty.

ASTR 585b, Radio Astronomy  Hector Arce
Introduction to radio astronomy, theory, and techniques. Includes radiation fundamentals, antenna theory, and an introduction to radio interferometry. Discussion of spectral line radio emission and of thermal and nonthermal radio emission mechanisms in the context of galactic and extragalactic astronomical observations.

ASTR 600a / PHYS 600a, Cosmology  Nikhil Padmanabhan
A comprehensive introduction to cosmology at the graduate level. The standard paradigm for the formation, growth, and evolution of structure in the universe is covered in detail. Topics include the inflationary origin of density fluctuations; the thermodynamics of the early universe; assembly of structure at late times and current status of observations. The basics of general relativity required to understand essential topics in cosmology are covered. Advanced undergraduates may register for the course with permission of the instructor.

ASTR 610b, The Theory of Galaxy Formation  Frank van den Bosch
This astronomy course focuses on the physical processes associated with galaxy formation. Topics include Newtonian perturbation theory, the spherical collapse model, formation and structure of dark matter haloes (including Press-Schechter theory), the virial theorem, gravitational interactions, cooling processes, theory of star formation, feedback processes, and numerical simulations. The course also includes a detailed treatment of statistical tools used to describe the large-scale distribution of galaxies and introduces the student to the concepts of galaxy bias and halo occupation modeling. During the final lectures we discuss a number of outstanding issues in galaxy formation.

ASTR 710a and ASTR 711b, Professional Seminar  Staff
A weekly seminar covering science and professional issues in astronomy.