

ASTRONOMY

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<http://astronomy.yale.edu>
 M.S., M.Phil., Ph.D.

Chair

Priyamvada Natarajan

Director of Graduate Studies

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

Assistant Professor Earl Bellinger, Laura Newburgh (*Physics*), Chiara Mingarelli (*Physics*), Malena Rice

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.

Core Courses

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| ASTR 5000 | The Physics of Astrophysics | 1 |
| ASTR 5100 | Stellar Populations | 1 |
| or ASTR 5500 | Stellar Astrophysics | |
| ASTR 5200 | Computational Methods in Astrophysics and Geophysics ¹ | 1 |
| ASTR 5300 | Galaxies | 1 |
| or ASTR 5650 | The Evolving Universe | |
| ASTR 5550 | Observational Astronomy | 1 |
| ASTR 5600 | Interstellar Matter and Star Formation | 1 |

¹ ASTR 6200 or PHYS 6780 may be substituted for ASTR 5200 with the permission of the 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 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 7100 and ASTR 7110) every term, unless registered in absentia. Students must also take Responsible Conduct in Research for Physical Scientists (PHYS 5900), 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 7100, ASTR 7110, and PHYS 5900 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. An oral qualifying exam, normally taken at the end of the fourth term of graduate work, tests the student's familiarity with the field in which the student plans to do research, and on the material covered in three thesis work-relevant taught courses taken by the student during the first two years.

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 5800 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 7100 and ASTR 7110) and at least one research project (ASTR 5800). 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 5000b, 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 5010a, 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 5100b, 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 5200a / EPS 5380a, 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 5550a, 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 5560a, Astrostatistics and Data Mining Earl Bellinger

Introduction to the statistical tools used to analyze and interpret astrophysical data, including common data mining techniques for finding patterns in large data sets and data-based prediction methods. Use of publicly available high-quality astronomical data from large surveys such as SDSS and 2MASS, and from space-based observatories such as Spitzer, Herschel, and WISE. Coding with the Python programming language.

ASTR 5650b, The Evolving Universe Pieter van Dokkum

Overview of cosmic history from the formation of the first star to the present day, focusing on direct observations of the high-redshift universe.

ASTR 5700b / PHYS 570 / PHYS 5700b, 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 6000b / PHYS 6000b, 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 7100a and ASTR 7110b, Professional Seminar Staff

A weekly seminar covering science and professional issues in astronomy.

ASTR 7460a / MATH 7460a / PHYS 7460a, Global Properties of Nonlinear Relativistic Fields Vincent Moncrief

Many relativistic field equations of interest in mathematical physics, astrophysics and cosmology are intrinsically nonlinear. Notable examples are various nonlinear wave equations, the Maxwell-Klein-Gordon equations, the Yang-Mills-Higgs equations and the Einstein field equations of general relativity. Techniques for analyzing their global solutions on various manifolds include (higher order) energy estimates and so-called light-cone estimates. An interesting question for the Einstein equations is whether the so-called “cosmological principle,” according to which only the very special manifolds admitting (spatially) homogeneous and isotropic metrics need be considered for cosmology, is firmly established or whether this principle can be relaxed to allow for much more general manifolds and still be consistent with observations. Another issue is how the Thurston geometrization theorem, established by Hamilton and Perlmán via Ricci flow, relates to the “cosmic censorship conjecture” of Roger Penrose, often regarded as the main open mathematical problem of general relativity.