Department of Astronomy and Astrophysics

Chair
- Angela Olinto

Professors
- John Carlstrom
- Kyle Cudworth
- Wendy Freedman
- Joshua A. Frieman
- Doyal A. Harper, Jr.
- Stephen Kent
- Alexei Khokhlov
- Edward W. Kolb
- Arieh Königl
- Andrey Kravtsov
- Richard G. Kron
- Donald Q. Lamb, Jr.
- Stephan Meyer
- Angela Olinto
- Robert Rosner
- Noel M. Swerdlow
- Simon P. Swordy, Physics
- James W. Truran, Jr.
- Michael Turner

Associate Professors
- Fausto Cattaneo
- Scott Dodelson
- Nickolay Y. Gnedin
- Dan Hooper
- Wayne Hu

Assistant Professors
- Jacob Bean
- Bradford A. Benson
- Hsiao-Wen Chen
- Daniel Fabrycky
- Michael Gladders
- Erik Shirokoff
Emeritus Faculty

- James W. Cronin
- Roger Hildebrand
- Edward Kibblewhite
- Richard H. Miller
- Takeshi Oka, Chemistry
- Patrick E. Palmer
- Eugene Parker
- Peter O. Vandervoort
- Donald G. York

The Department of Astronomy & Astrophysics awards the Ph.D. degree, and carries on programs of research and graduate instruction on the quadrangles of the University; at Adler Planetarium, Chicago; at Apache Point Observatory, Sunspot, New Mexico; and at the Yerkes Observatory, Williams Bay, Wisconsin.

ADMISSION

Students seeking admission to the department for graduate study should have the training in physics and mathematics that is represented by the conventional bachelor's degree. Applicants must submit recent scores on the Graduate Record Examination Aptitude and Advanced Physics tests.

PROGRAM OF STUDY

The program leading to the Ph.D. degree in Astronomy & Astrophysics has four parts: a program of six required and elective courses, a research project, the candidacy examination, and research leading to a dissertation. The program and the requirements for graduate degrees are summarized below. This additional information is also available online (http://astro.uchicago.edu/gradprogram/prospective.php). The application is also available online (https://apply-psd.uchicago.edu/apply).

During the first and second academic years, students normally take the course sequence:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 30100</td>
<td>Stars</td>
<td>100</td>
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<tr>
<td>ASTR 30300</td>
<td>Interstellar Matter</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 30400</td>
<td>Galaxies</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 31000</td>
<td>Cosmology I</td>
<td>100</td>
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<tr>
<td>ASTR 31100</td>
<td>High Energy Astrophysics</td>
<td>100</td>
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<tr>
<td>ASTR 30600</td>
<td>Detection of Radiation</td>
<td>100</td>
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<tr>
<td>ASTR 30700</td>
<td>Prep: Summer Research Project</td>
<td>100</td>
</tr>
</tbody>
</table>

The normal program of courses in the first two-years of graduate student in Astronomy and Astrophysics consist of 6 required courses. The courses are scheduled as follows:
• **Year 1.** Autumn quarter - Stars; Winter quarter - Interstellar Matter; Spring quarter - Galaxies.

• **Year 2.** Autumn quarter - Cosmology; Winter quarter - High Energy Astrophysics; Spring quarter - Detection of Radiation.

First and second year students, will conduct a summer research project and participate in research activities, or courses of their choice, in all quarters. Weekly activities include Faculty Research Seminars, Graduate Student Research Seminars, and Department Colloquia.

Students will report on their cumulative research activity and participate in a candidacy examination at the end of **Year 1** and **Year 2**. Admission to candidacy depends on faculty approval of the students’ performance in coursework and the above mentioned activities. A student is officially admitted to research on the basis of a satisfactory performance on the Candidacy Examination, upon which, the student should arrange with a faculty member to have that faculty member serve as sponsor for the students research. Information is as follows:

**STEP I: FALL AFTER 1 YEAR IN DEPARTMENT**
The student makes an oral presentation (~20 minutes) to the committee on a minor research project (one that took 1 or 2 quarters). This will be followed by questions about the project and about more general issues in astronomy, with aim of determining whether the student is making sufficient progress towards the goals listed at the bottom of this page. Based on the exam, courses, and feedback from advisor[s], the committee will provide feedback to the student. In rare cases this may include the requirement to re-take a course. The Candidacy Committee will provide written reports to the student, Academic Chair, and Advisor.

**STEP II: JUNE OF THE 2ND YEAR**
Student makes an oral presentation on a major project (3-4 quarters of research) accompanied by written report. The report should include a full bibliography of all relevant work (as in a standard scientific publication). If the student played a major role in writing a paper, this can be used in lieu of the written report. The presentation will be followed by questions about the work and the broader context, so that the entire oral exam will typically last between 90-120 minutes.

**Scope of Exam:** Questions are likely to begin with motivations for the research, history, and references and then extend to courses related to the work. For example, a report on Gravitational Lensing in the Dark Energy Survey will likely be followed by questions about cosmology (31000) and detection of radiation (30600). The committee will also probe the students knowledge in any core course in which a grade lower than B was obtained.

**THE DEGREE OF DOCTOR OF PHILOSOPHY**

Students who enter the department intending to proceed toward the degree of Doctor of Philosophy are normally required to complete the 3xx level program of lecture courses described above. With the approval of the student’s dissertation committee, modifications of this requirement may be made. Students are expected to maintain a grade point average of at least 3.0 in their course work.
At the end of the second year, after completing the basic 3xx level program courses, students who wish to begin research for the degree of Doctor of Philosophy must pass both the written and oral portions of the candidacy examination, which includes the subject matter of the basic 3xx level astronomy courses. The candidacy examination will be given towards the end of the Summer quarter of the student's second year. A student whose performance on this examination does not merit continuation in the program may retake the examination once. Ordinarily, students who do not proceed toward the Ph.D. are given the opportunity to complete the master's degree. Graduate students who are permitted to proceed toward the degree of Doctor of Philosophy may elect to receive an incidental Master of Science degree after having passed the candidacy exam.

The requirements for the degree of Doctor of Philosophy include the divisional requirements. In particular, a student who is permitted to begin research for the dissertation based on a satisfactory performance on the candidacy examination must still formally establish candidacy for the degree according to divisional requirements. A degree candidate must fulfill a two quarter teaching requirement, which is explained in detail in the departmental graduate program document. A candidate for the degree must submit a dissertation. The dissertation shall consist of a paper, or papers, submitted for publication in a recognized scientific journal, and the student may be the sole author, or a member of multiple authors by a group who will be determined by a faculty committee. A dissertation shall be accepted as satisfying the requirements of a Ph.D. in the Department of Astronomy and Astrophysics only if it has been approved by the Dissertation Committee and has been submitted for publication in a recognized scientific journal.

Facilities for Research

A student may perform the research for the doctoral dissertation on the quadrangles of the University or Yerkes Observatory. A student working at either location has access to the complete facilities of the department.

Moreover, there exists in the other departments and in the institutes of the Division of the Physical Sciences a variety of research programs which bear on modern astrophysics. Contact with persons working in these programs is possible and is encouraged. In fact, students' research programs may be carried out under the direction of faculty members in these departments and institutes.

Computing resources for the department include a multiprocessor SUN SPARC server, networked printers, and a multitude of workstations and PCs, with Ethernet and LocalTalk (AppleTalk) connections in every room. This equipment is linked via ethernet with the computation facilities of the Division of the Physical Sciences, which include SUN and SGI servers, and a high speed line links them to the super computer facilities of the National Center for Supercomputer Applications at the University of Illinois at Urbana and of the Argonne National Laboratory (operated by the University of Chicago). These resources form a powerful facility for computational astrophysics.

The principal instruments at the Yerkes Observatory are the 40 inch refracting telescope and the 41 inch and 24 inch reflecting telescopes, all of which are used for both instrument testing and research. The department's adaptive optics group has
actively used the 41 inch reflector in recent years, and the astrometric program uses the refractor extensively. The Yerkes Observatory also houses an excellent library as well as engineering facilities and shops that are heavily used in developing instrumentation for the department's wide ranging activities.

The University of Chicago is a member of the Astrophysical Research Consortium, a consortium of several universities that has built and operates a 3.5 meter new technology telescope on Sacramento Peak in Sunspot, New Mexico. This remotely operated facility was designed to permit rapid changes in instrumentation and in observing mode.

The University is also a key partner in the Sloan Digital Sky Survey (SDSS). The SDSS is a project for which a 2.5 meter new technology telescope is mapping the Northern Galactic sky cap with five band photometry and obtaining redshifts of approximately one million galaxies and one hundred thousand QSOs.

By arrangement, facilities of the Argonne National Laboratory may be used by students in the department. These include unique facilities for experimental nuclear astrophysics, and a computation center equipped with vector and parallel processing computers.

Students also may take advantage of the resources of the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, including the computational facilities, through its Institute for Cosmology and Particle Physics, funded by the National Aeronautics and Space Administration, or through the program in Experimental Astrophysics.

In recent years, some students have also used national facilities such as the National Radio Astronomy Observatory, the National Optical Astronomy Observatories, and the NASA Ames Research Center.

ASTRONOMY AND ASTROPHYSICS COURSES

ASTR 30100. Stars. 100 Units.
Introduction to stars (physical and observational), hydrodynamics of self-gravitating fluids, statistical mechanics and equations of state, energy transport, astrophysical nuclear reactions, stellar models, advanced topics.

Terms Offered: Winter

ASTR 30300. Interstellar Matter. 100 Units.
Interstellar medium, collision-less systems, distribution of stars in the solar neighborhood, stellar kinematics/dynamics, observations of galactic large-scale structure, theory of galactic structure and evolution.

Terms Offered: Spring
ASTR 30600. Detection of Radiation. 100 Units.
Radiation as a random process, optical coherence, and signal analysis in spatial and temporal domains, along with the detection and measurement of radiation with astronomical instruments.
Terms Offered: Spring

ASTR 31000. Cosmology I. 100 Units.
This course presents an introduction to the principles of cosmology. The first part introduces homogeneous, relativistic cosmologies and covers the Robertson-Walker metric, dynamics in the presence of matter, radiation, and dark energy, the universe as a function of time and redshifts, and techniques for calculating observable quantities. The next part covers the growth and evolution of structure in the universe including the formation of clusters and voids, correlation functions, and the mass spectrum. The next part covers the physics of the early universe, including inflation, primordial nucleosynthesis, and recombination. The final part covers current topics in cosmology, including analysis of the cosmic microwave background and tests for detecting and measuring dark matter and dark energy.
Terms Offered: Autumn
Prerequisite(s): Graduate Standing and ASTR 30100 - 30600; or Consent of Instructor

ASTR 31100. High Energy Astrophysics. 100 Units.
No description available.
Terms Offered: Winter

ASTR 31300. Extragalactic Studies. 100 Units.
When, where, and how stars formed in galaxies is central to understanding many other aspects of large stellar systems: baryons streaming into dark-matter haloes, large-scale outflows, patterns in chemical abundances, and how all these processes have changed with time. This class will look at what is known empirically about star formation in nearby galaxies across a wide range of conditions, identifying those that are most significant for building up the mass in stars and most significant energetically for the local interstellar medium. The range of conditions includes strong dynamical interactions on large scales, and high-density regions and regions exposed to intense radiation on small scales. Our approach will study prototype galaxies from relevant classes (e.g. starburst, ultra-luminous infrared emitters, ultraviolet-luminous, etc.), exploring what is known about the recent history of star formation in these systems from multi-wavelength data.
Prerequisite(s): Graduate Standing; or 30100 - 30600; or Consent of Instructor

ASTR 31500. Dynamics of Fluids. 100 Units.
Prerequisite(s): Graduate Standing; or 30100 - 30600; or Consent of Instructor

ASTR 31600. Dynamics Particles. 100 Units.
Dynamics of collision-less plasmas and stellar systems. Stochastic processes and kinetic equations. Dynamics of galaxies and star clusters. Astrophysical plasmas.
Prerequisite(s): Graduate Standing; or 30100 - 30600; or Consent of Instructor
ASTR 32000. Relativistic Astrophysics. 100 Units.
Special and General relativity and the experimental tests, with applications to astrophysical problems such as super-massive stars, black holes, relativistic star clusters, and gravitational radiation.
Prerequisite(s): Graduate Standing; or 30100 - 30600; or Consent of Instructor

ASTR 32100. Cosmology II. 100 Units.
Study of physical cosmology with emphasis on the standard big-bang model and its observational and experimental tests.
Prerequisite(s): Graduate Standing; or 30100 - 30600; or Consent of Instructor

ASTR 33000. Computational Physics and Astrophysics. 100 Units.
Basic computational methods useful for astrophysics, supplemented by specific examples drawn primarily from astrophysics. Starting with basics (e.g., precision, errors and error analysis) and basic computational methods (differentiation, integration/quadrature, Monte Carlo, numerical linear algebra), and then discussing solution of problems posed in terms of ordinary and partial differential equations.
Prerequisite(s): Graduate Standing; or 301 - 30600; or Consent of Instructor

ASTR 34000. Statistical Methods in Astrophysics. 100 Units.
An exploration of the variety of statistical methods used in modern astrophysics. We discuss the frequentist (hypothesis tests, confidence intervals) and Bayesian (explicit priors, model-choosing, parameter estimation) approaches. Other topics include: Markov Chain Monte Carlo and other computational statistics; multi-dimensional likelihood space; Fischer information matrices; time series analysis. Assignments draw from examples in the astronomical literature.
Prerequisite(s): Graduate Standing; or 301 - 30600; or Consent of Instructor

ASTR 37100. Precandidacy Research: Astron. Var Units.
For course description contact Astronomy and Astrophysics.

ASTR 38000. History of the Telescope. 100 Units.
The history of the idea of telescopes, and of telescopes as working devices, is covered. Following a short discussion of the ideas of "seeing at a distance" in the pre-telescopic world, Galileo's astronomical discoveries are noted. The evolution of the telescope through the 17th, 18th, 19th and 20th centuries are then described. The key developments in telescope systems in each century are highlighted. These include optics, platforms and clocks, structures, rockets, computers, instruments, detectors and observatory sites. The roles of amateur astronomers, wealthy patrons, wealthy entrepreneurs and governments in bringing about these developments are emphasized, and the impact on society of the discoveries made with telescopes is outlined. Serendipitous discovery, personal stories of the main actors on the stage and the feedback between the development of modern civilization and the tools of astronomy are features of the story.
Prerequisite(s): Graduate Standing; or 30100-30600; or Consent of Instructor

ASTR 38100. General History of Astrophysics. 100 Units.
No description available.
ASTR 38800. Galileo's Astronomy and Conflicts with the Church. 100 Units.
This course is devoted to Galileo's work in astronomy, above all the Dialogue on the Two Great Systems of the World, and his conflicts with the Church concerning the interpretation of Scripture and the attempt to prove the Copernican theory.

ASTR 40100. Practice Data Analysis. 100 Units.
No description available.

ASTR 40200. Particle Astrophysics. 100 Units.
No description available.

ASTR 40300. Structure Formation in the Universe. 100 Units.
No description available.

ASTR 40400. QSOs in the SDSS. 100 Units.
No description available.

ASTR 40600. Gravitational Lensing. Units.
Theory of bending of light by gravitational potentials followed by astrophysical and cosmological applications including; microlensing, planetary searches, strong lensing, and weak lensing.

ASTR 40700. AstroPolitics. 100 Units.
No description available.

ASTR 40800. The Perturbed Universe. 100 Units.
No description available.

ASTR 40900. Topics in Observational Cosmology. 100 Units.
No description available.

ASTR 41100. Science of the Dark Energy. 100 Units.
No description available.

ASTR 41300. Topics in Stellar Astronomy. 100 Units.
No description available.

ASTR 41400. Advanced Fluid Dynamics. 100 Units.
No description available.

ASTR 41500. Astrophysical Jets. 100 Units.
No description available.

ASTR 41600. Intergalatic Medium. 100 Units.
No description available.

ASTR 41800. Introduction to Intergalatic Medium Studies. 100 Units.
Introduction to intergalactic medium studies. The course will begin with a historical overview of absorption-line studies and proceed with in-depth discussion of ongoing research topics. These include the re-ionization epoch, chemical enrichment of the universe, and association between luminous matter traced by galaxies and gaseous clouds probed by absorption-line observations.

ASTR 42200. Early Universe Cosmology. 100 Units.
No description available.
ASTR 42700. Atomic Structure and Spectra. 100 Units.  
No description available.

ASTR 43000. Plasma Astrophysics. 100 Units.  
No description available.

ASTR 43100. Ultra-High Energy Cosmic Rays. 100 Units.  
No description available.

ASTR 43200. High Energy Cosmic Particles. Units.  
This graduate level course will focus on high energy particle astrophysics from basic facts to recent discoveries in the study of cosmic rays, gamma-rays, and neutrinos. The course will introduce the main concepts of proposed mechanisms for generating these particles, the past and current detections techniques and observatories, and recent observations. Some particle physics and cosmology will be covered including models of dark matter particles and the effect of cosmic backgrounds on high energy cosmic particles.

ASTR 43300. Accretion Disks. 100 Units.  
No description available.

ASTR 43600. Theory of Supernovae. 100 Units.  
No description available.

ASTR 44200. Topics in Astrophysical Fluid Dynamics. 100 Units.  
No description available.

ASTR 44800. Cosmic Microwave Background. 100 Units.  
No description available.

ASTR 45000. Extreme Optics. 100 Units.  
Frontiers in optics will be a review of the state of the art in optics as it applies to astronomy. Topics to be covered will include  
(1) Single dish optics: adaptive optics, building large telescopes and coronography  
(2) Interferometers using multiple telescopes  
(3) Lasers for guide stars and wavelength control  
(4) LIGO and LISA

ASTR 45100. High Resolution Imaging. 100 Units.  
No description available.

ASTR 45200. Primer on the SDSS. 100 Units.  
No description available.

ASTR 45300. Computational Cosmology. 100 Units.  
No description available.
ASTR 45400. Image Processing (Analysis) 100 Units.
Many key results in current research rely on the inner workings of codes that operate on pixels. Examples are measuring the weak lensing shear field, measuring precise light curves for supernovae in the presence of contaminating light from a host galaxy, high-precision relative photometry (e.g. to detect transits), reliable morphological star/galaxy classification to faint flux limits, reliable color measurements (e.g. for photometric redshifts), crowded-field photometry, and detection of diffuse light to very low surface brightness levels. This course will explore some of the ideas that have been developed to address these and other problems of interest, illustrated by CCD detectors. The format of the class will be first to consider what goes into the pixels (e.g. ingredients of the point-spread function), followed by the techniques for unwinding the instrumental effects, concluding with what extracted parameters are optimal for some particular application (what comes out of the pixels).

ASTR 45800. Exoplanets. 100 Units.
The study of exoplanets, planets associated with stars other than the Sun, has become one of the most exciting and rapidly evolving areas of modern astronomy. This new course will address general questions concerning the detection and characterization of exoplanets and of what we have already learned about the origin and properties of exoplanetary systems and of how they compare with those of the Solar System. This discussion will be placed in the context of models of planet formation in protoplanetary disks, their structure and composition, and their dynamical interactions with the natal disk, the parent star, and other planets. The course will make use of seminal papers on these topics and will encourage active participation by the students.

ASTR 45900. What Makes a Planet Habitable? 100 Units.
This course explores the factors that determine how habitable planets form and evolve. We will discuss a range of topics, from the formation of planets around stars and the delivery of water, to the formation of atmospheres, climate dynamics, and the conditions that allow for the development of life and the evolution of complex life. Students will be responsible for reading and discussing papers in peer-reviewed journals each meeting and for periodically preparing presentations and leading the discussion.
Instructor(s): E. Kite Terms Offered: Winter
Equivalent Course(s): GEOS 32060, GEOS 22060

ASTR 46400. Nuclear Astrophysics. 100 Units.
No description available.

ASTR 46500. Atomic Spectra. 100 Units.
No description available.

ASTR 47100. Evolution of Galaxies. 100 Units.
No description available.

ASTR 47200. Star Clusters. 100 Units.
No description available.
ASTR 47300. Distant Galaxies. 100 Units.
No description available.

ASTR 48000. Current Topics in Astrophysics (Graduate) 100 Units.
No description available.

ASTR 48100. Advanced Computational Techniques. 100 Units.
No description available.

ASTR 48200. Dark Energy and Cosmic Acceleration. 100 Units.
No description available.

ASTR 49400. Post-Candidacy Research. Var Units.
No description available.

ASTR 49900. Graduate Research Seminar. 100 Units.
No description available.