Chair
- John E. Carlstrom

Professors
- John E. Carlstrom
- Fausto Cattaneo
- Hsiao-Wen Chen
- Wendy L. Freedman
- Joshua A. Frieman
- Michael D. Gladders
- Nickolay Y. Gnedin
- Doyal A. Harper, Jr.
- Craig J. Hogan
- Dan Hooper
- Wayne Hu
- Daniel E. Holz
- Edward W. Kolb
- Andrey V. Kravtsov
- Richard G. Kron
- Angela V. Olinto
- Paolo Privitera
- Robert Rosner

Associate Professors
- Jacob L. Bean
- Bradford A. Benson
- Daniel Fabrycky
- Jeffrey McMahon

Assistant Professors
- Damiano Caprioli
- Chihway Chang
- Clarence L. Chang
- Alex Drlica-Wagner
- Leslie Rogers
- Erik Shirokoff
- Irina Zhuravleva

Emeritus Faculty
- Kyle M. Cudworth
- Roger H. Hildebrand
- Lewis M. Hobbs
- Edward J. Kibblewhite
- Arieh Königl
- Donald Q. Lamb, Jr.
- Stephan S. Meyer
- Richard H. Miller
- Takeshi Oka
- Patrick E. Palmer
- Eugene N. Parker
Faculty in the Department of Astronomy and Astrophysics work on a wide range of topics at the frontiers of astrophysics: from understanding the beginning of the Universe to the search for habitable extrasolar planets; from the formation and evolution of the earliest galaxies to modeling the most energetic events in the modern Universe; from exploring our own solar system to the largest structures of the Universe. The department participates in major facilities that support the programs of our research groups. Many of these projects take advantage of connections with the neighboring national laboratories, Argonne and Fermilab, for both intellectual and technical resources. Research groups have access to leading telescopes worldwide, including the 6.5-m Magellan Telescopes at Las Campanas, Chile; the Dark Energy Survey at Cerro Tololo Inter-American Observatory in Chile; and the South Pole Telescope, with its ongoing development of powerful new imagers for measuring the Cosmic Microwave Background. Departmental researchers also make use of a number of telescopes (Hubble, Kepler, Chandra, Fermi, and others) and are actively developing new programs for EUSO, POEMMA, JWST, WFIRST, TESS, SOFIA and LSST. Chicago is an active participant in gravitational waves research as a member of LIGO, leading the development of the Holometer at Fermilab, and studying extreme cosmic particles at the Auger Observatory. We are a founding member of the world’s largest optical telescope, the 25-meter Giant Magellan Telescope, which is now under construction in the Chilean Andes with first light expected toward the end of the decade.

**PROGRAM REQUIREMENTS**

The requirements for the Ph.D. degree in Astronomy and Astrophysics are satisfied through the following steps:

- Completion of required core graduate courses
- Full-time scholastic residence of at least 300 units of coursework per quarter, including summer
- Completion of one to three pre-candidacy research projects
- Successful completion of a two-part Candidacy Exam
- Identification of a Thesis Advisor
- Formation of a Thesis Committee
- Thesis research and preparation
- Final Examination

**ADVISING/MENTORING**

Incoming students are assigned a faculty mentor who will advise and guide the student as they navigate the graduate program. Students are invited to seek out potential research supervisors as early as possible. Engagement with research is encouraged and supported by the program structure and through departmental events. Each week there are various talks, seminars, and colloquia highlighting current research by departmental members and visitors that bring together students, faculty, research scientists and post-docs as a vibrant intellectual community. These occasions help facilitate discovery of research areas and projects that may be of interest to incoming students.

**COURSE REQUIREMENTS**

During the first and second years, students complete one core course per academic quarter, and may choose to take elective courses. The core courses are:

- **ASTR 30100 Stars**
- **ASTR 30300 Interstellar Matter**
- **ASTR 30400 Galaxies**
- **ASTR 31000 Cosmology I**
In addition, first- and second-year students enroll in ASTR 35000 Order-of-Magnitude Astrophysics for one quarter and ASTR 49900 Graduate Research Seminar for up to five quarters.

RESEARCH
A significant fraction of time in the first two years is devoted to research projects. This work, organized as ASTR 37100 Precandidacy Research, is presented as part of the two-part Candidacy Exam taken in the Autumn and Spring Quarters of the second year. Advancement to candidacy is made when a student has successfully passed the two-part Candidacy Exam and established a Thesis Committee. After candidacy is established, students enroll in ASTR 49400 Post-Candidacy Research and may also take electives of advanced coursework.

DISSERTATION AND FINAL EXAMINATION
The Ph.D. thesis may be a single-author or multiple-author paper that is submitted to a research journal of high quality and judged to be suitable for publication by the student’s full Thesis Committee. This research is presented to the Thesis Committee in a Final Examination to engage in dialogue and debate, and receive constructive criticism. Final examinations are public events attended by the departmental community.

CONTACTS
For general information about application procedures, please contact the Student Affairs Administrator, Laticia Rebeles, lrebeles@astro.uchicago.edu, (773) 702-9808. Additional information regarding the academic program is available on the Department of Astronomy and Astrophysics (https://astrophysics.uchicago.edu/) website.

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.
Instructor(s): Daniel Fabrycky
Terms Offered: Autumn
Prerequisite(s): Open to advanced undergraduates by consent of instructor.

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.
Instructor(s): Hsiao-Wen Chen
Terms Offered: Autumn
Prerequisite(s): Open to advanced undergraduates by consent of instructor.

ASTR 30400. Galaxies. 100 Units.
The observed universe, the universe at high redshift, early universe microwave background radiation, relativistic homogeneous isotropic cosmologies, evolution of structure in the universe, primordial nucleosynthesis.
Instructor(s): Irina Zhuravleva
Terms Offered: Spring
Prerequisite(s): Open to advanced undergraduates by consent of instructor.

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.
Instructor(s): Brad Benson
Terms Offered: Spring
Prerequisite(s): Open to advanced undergraduates by consent of instructor.

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.
Instructor(s): Craig Hogan
Terms Offered: Winter
Prerequisite(s): Open to advanced undergraduates by consent of instructor.

ASTR 31100. High Energy Astrophysics. 100 Units.
This course covers a wide range of phenomena associated with the astrophysics of high energy photons, cosmic rays and neutrinos, including the processes of ionization, bremsstrahlung, synchrotron, pion production, Compton and inverse Compton scattering, as well as cosmic ray acceleration. Specific sources of high energy emission will also be discussed, including active galaxies, pulsars, gamma-ray bursts and supernova remnants.
Instructor(s): Damiano Caprioli
Terms Offered: Winter
Prerequisite(s): Open to advanced undergraduates by consent of instructor.
ASTR 31200. Computational Techniques in Astrophysics. 100 Units.
This course will introduce basic computational techniques most often used in astronomical research, such as interpolation, transforms, smoothing, numerical differentiation and integration, integration of ordinary differential equations, and Monte Carlo methods, and elements of basic computer algorithms, data structures, and parallel programming using Python as the main course programming language with heavy use of NumPy, SciPy, and Matplotlib packages. Practical examples where these numerical techniques are applied will be covered via homework and in class exercises using real-world astronomical problems and results of recent papers with emphasis on implementing the algorithms from scratch. The course will cover the access to astronomical archival data, and how to search it efficiently, focusing specifically on the Sloan Digital Sky Survey, but with introduction to other data sets. Machine learning methods will be introduced to illustrate how large data sets can be mined for interesting information.
Instructor(s): Andrey Kravtsov Terms Offered: Spring
Prerequisite(s): ASTR 20500 or CMSC 12100 or consent of instructor.
Equivalent Course(s): ASTR 21100

ASTR 31400. Creative Machines and Innovative Instrumentation. 100 Units.
An understanding of the techniques, tricks, and traps of building creative machines and innovative instrumentation is essential for a range of fields from the physical sciences to the arts. In this hands-on, practical course, you will design and build functional devices as a means to learn the systematic processes of engineering and fundamentals of design and construction. The kinds of things you will learn may include mechanical design and machining, computer-aided design, rapid prototyping, circuitry, electrical measurement methods, and other techniques for resolving real-world design problems. In collaboration with others, you will complete a mini-project and a final project, which will involve the design and fabrication of a functional scientific instrument. The course will be taught at an introductory level; no previous experience is expected. The iterative nature of the design process will require an appreciable amount of time outside of class for completing projects. The course is open to undergraduates in all majors (subject to the pre-requisites), as well as Master’s and Ph.D. students.
Instructor(s): Stephan Meyer and Erik Shirokoff Terms Offered: Winter
Prerequisite(s): PHYS 12200 or PHYS 13200 or PHYS 14200; or CMSC 12100 or CMSC 12200 or CMSC 12300; or consent of instructor.
Equivalent Course(s): CHEM 21400, PSMS 31400, ASTR 21400

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.
Instructor(s): Andrey Kravtsov Terms Offered: Not offered in 2020-2021.
Prerequisite(s): Open to advanced undergraduates by consent of instructor.

ASTR 35000. Order-of-Magnitude Astrophysics. 100 Units.
In physics and astrophysics, an approximate answer is often just as (if not more) useful than an exact answer. Making order-of-magnitude estimates is helpful to develop physical intuition, to verify numerical solutions, and to evaluate whether a research problem is worth pursuing. In this course, students will receive coaching and practice in physics-based reasoning, back-of-the-envelope estimation, and thinking on their feet. Students will be encouraged to take a broad perspective, to think critically, and to have fun using physics to understand the universe around them.
Instructor(s): Leslie Rogers Terms Offered: Autumn
Note(s): Open to 3rd and 4th year undergraduates in the Physical Sciences by instructor consent.
Equivalent Course(s): ASTR 25000

ASTR 35800. Astrophysics of Exoplanets. 100 Units.
Extrasolar planets, a.k.a. exoplanets, are planets orbiting other stars. First definitively detected in the mid 1990s, the planet count has rapidly expanded and their physical characterization has sharpened with improved observational techniques. Theoretical studies of planetary formation and evolution are now attempting to understand this statistical sample. The field also aspires to address questions about life in the universe. This course emphasizes hands-on activities, like working with real astronomical data to find and characterize exoplanets. Topics are the radial velocity, transit, and other discovery and characterization techniques; statistical distributions of known planets; comparisons among planet structure and planetary system types; formation in a protoplanetary disk and subsequent dynamical evolution; the goal of finding life on an exoplanet; colonization of exoplanets; and the Fermi paradox.
Instructor(s): Jacob Bean and Daniel Fabrycky Terms Offered: Spring
Prerequisite(s): ASTR 24100 and PHYS 23400 or PHYS 23410; or consent of instructor.
Equivalent Course(s): GEOS 32080, ASTR 25800
ASTR 35900. Physics of Planetary Interiors. 100 Units.
This course considers the physical processes governing the interior structure and evolution of planets, both those orbiting the Sun and exoplanets. Topics include an introduction to condensed matter physics relevant to planet interiors; properties of planetary materials; observational constraints; planet modeling; thermal histories; differentiation and core formation; connection to planetary atmospheres; and magnetic field generation.
Instructor(s): Leslie Rogers
Prerequisite(s): Open to third- and fourth-year undergraduate students majoring in Astrophysics, Physics or the Geophysical Sciences, or students who have completed two quarters of Calculus.

ASTR 37100. Precandidacy Research. 300.00 Units.
Students arrange with a faculty research supervisor to conduct a short-term independent research project lasting one or more quarters. Research completed in ASTR 37100 is presented as part of the student's candidacy exams.
Instructor(s): Rich Kron
Terms Offered: Autumn Spring Summer Winter

ASTR 38400. Gravitational Wave Astrophysics. 100 Units.
With LIGO's detection of gravitational waves from the merger of two black holes, the era of gravitational-wave astronomy has arrived. The detection of gravitational waves and photons from the merger of two neutron stars was similarly revolutionary. This class will explore the basics of gravitational-wave sources and detection. We will discuss recent results, and explore the future promise of gravitational-wave astrophysics and cosmology.
Instructor(s): Daniel Holz
Terms Offered: Winter

ASTR 40600. Gravitational Lensing. 100 Units.
Theory of bending of light by gravitational potentials followed by astrophysical and cosmological applications including: microlensing, planetary searches, strong lensing, and weak lensing. In different years, a subsample of these topics may be taught, based on interests of the instructor.
Instructor(s): Chihway Chang
Terms Offered: Autumn

ASTR 40800. The Perturbed Universe. 100 Units.
This seminar course will cover inflation as the source of structure in the universe and its observational signatures. Topics will include relativistic perturbation theory, canonical and general single field inflationary models, primordial non-Gaussianity, and gravitational waves.
Instructor(s): Wayne Hu

ASTR 43000. Plasma Astrophysics. 100 Units.
This course will give a general introduction to the theory of plasmas with particular emphasis on processes of astrophysical interest. Topics presented will include: Physical description of a plasma and plasma parameters: Debye length, plasma frequency, cyclotron frequency, Larmor radius; single particle motion and adiabatic invariants; kinetic theory and the Vlasov equation; magneto-hydro-dynamics and dynamo theory; plasma waves; waves in a cold and hot plasma/plasmas; Landau damping; collisional processes.
Instructor(s): Fausto Cattaneo

ASTR 44800. Cosmic Microwave Background. 100 Units.
The first half of the course will be lectures with the goal of establishing a common denominator, and the second half will be research. The course requires a final project to be presented in class.
Instructor(s): Wayne Hu
Terms Offered: Not offered in 2020-2021.
Prerequisite(s): Prerequisites are graduate-level cosmology and general relativity.

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 periodically preparing presentations based on papers in peer-reviewed journals and leading the discussion. This course is part of the College Course Cluster program: Climate Change, Culture and Society.
Instructor(s): Edwin Kite
Terms Offered: Winter
Equivalent Course(s): GEOS 32060, GEOS 22060

ASTR 46100. Dynamics of Exoplanets. 100 Units.
Exoplanets are planets that orbit other stars. As most detection methods are indirect, planets' orbital dynamics is key to basic characterization, and it was historically important to confirm their existence. Their surprising orbital properties challenged planet formation and evolution theories, prompting further development of dynamical theories. This course covers orbital mechanics of N-body systems from the short-term, relevant to observations such as transit-timing variations, all the way to billion-year timescales, relevant to the dynamical winnowing of unstable systems. It covers highly eccentric and inclined orbits, scattering and resonant dynamics, planetary orbits in binary star systems, the additional physics of tidal dissipation and orbital migration due to a gas disk, and current research topics.
Instructor(s): Daniel Fabrycky
Terms Offered: Not offered in 2020-2021.
ASTR 49400. Post-Candidacy Research. 300.00 Units.
Independent research undertaken towards completion of the dissertation.
Instructor(s): Rich Kron Terms Offered: Autumn Spring Summer Winter
Prerequisite(s): Completion of all candidacy requirements.

ASTR 49900. Graduate Research Seminar. 100 Units.
The instructor chooses a topic for the seminar and assigns papers that develop the topic from the earliest times to the most recent results. Students each present papers during the course, as assigned, and lead a discussion. The purpose is to give students practice in analyzing the literature and presenting to their peers, as well to assure exposure to a breadth in the topics in astronomy and astrophysics.
Instructor(s): Wayne Hu, Hsiao-Wen Chen Terms Offered: Spring Winter. Winter Quarter instructor Wayne Hu; Spring Quarter instructor Hsiao-Wen Chen.
Prerequisite(s): Intended for doctoral students in the Department of Astronomy and Astrophysics.

ASTR 50000. Theory and Practice of Science Education. 000 Units.
In this seminar, students examine their work as teaching assistants through activities that include self-reflection; investigating relevant educational literature; and engaging in in-depth discussions about their own teaching and learning. Readings and discussion topics include questioning techniques, learning theory, cooperative learning, growth mindset, metacognition, developing relationships with students, equity, and differentiation. Students will try out new ideas each week in their learning teams and report their results in class. In many cases, students provide guidance to one another regarding managing issues that typically arise in their learning teams. The seminar is intended for graduate students who are serving as teaching assistants for the first time, and is typically taken in the same quarter in which the student begins teaching.
Instructor(s): Brent Barker Terms Offered: Autumn Spring Winter
Prerequisite(s): Undergraduates serving as course assistants may enroll with instructor consent.
Note(s): Graduate students in Astronomy and Astrophysics and Geophysical Sciences enroll in ASTR 50000 the first quarter in which they will teach.
Equivalent Course(s): GEOS 39500

ASTR 70000. Advanced Study: Astronomy & Astrophysics. 300.00 Units.
Advanced Study: Astronomy & Astrophysics