Department of Astronomy and Astrophysics

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
• Alexei M. Khokhlov
• Edward W. Kolb
• Andrey V. Kravtsov
• Richard G. Kron
• Stephan S. Meyer
• Angela V. Olinto
• Paolo Privitera
• Robert Rosner
• Michael S. Turner

Associate Professors
• Jacob L. Bean
• Daniel Fabrycky

Assistant Professors
• Bradford A. Benson
• 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.
• 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 early in the next 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
- ASTR 31100 High Energy Astrophysics
- ASTR 30600 Detection of Radiation
First- and second-year students also take ASTR 49900 Graduate Research Seminar each quarter. A significant fraction of time in the first two years is devoted to research projects; this work, organized as ASTR 37100 Precandidacy Research, will be presented as part of the two-part Candidacy Exam. 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. Recent theses (http://astro.uchicago.edu/events/phd-thesis-defense.php) abstracts are published on the Department of Astronomy and Astrophysics (http://astro.uchicago.edu) website.

Contacts
For general information about application procedures, please contact the Student Affairs Administrator, Laticia Rebeles, lrebeles@oddjob.uchicago, 773-702-9808. Additional information regarding the academic program is available on the Department of Astronomy and Astrophysics (http://astro.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): Fausto Cattaneo 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: Winter
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 30500. Radiation Processes in Astrophysics. 100 Units.**
Most of what we know about the Universe comes from detection of electromagnetic radiation emitted by individual sources or by diffuse media. Once we understand the processes by which the radiation was created and the processes by which the radiation is scattered or modified as it passes through matter, we can address the physical nature of the sources. The physics of radiation processes includes electricity and magnetism; quantum mechanics and atomic and nuclear structure; statistical mechanics; and special relativity.
Instructor(s): Damiano Caprioli Terms Offered: Autumn
Prerequisite(s): PHYS 15400; ASTR 13300 and PHYS 15400 required for students majoring in Astrophysics.
Equivalent Course(s): ASTR 25400

**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: Autumn
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 32100. Cosmology II. 100 Units.**
Study of physical cosmology with emphasis on the standard big-bang model and its observational and experimental tests.
Instructor(s): Dan Hooper Terms Offered: Winter
Prerequisite(s): Open to advanced undergraduates who have taken Cosmology I by 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.
Instructor(s): Andrey Kravtsov Terms Offered: Not offered in 2019-2020.
Prerequisite(s): Open to advanced undergraduates by consent of instructor.
Note(s): Not offered in 2019-2020.

**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 Terms Offered: Winter
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 39900. Reading And Research: Astrononomy. 300.00 Units.**
Readings and Research for working on their PhD.
Note(s): This course has been replaced by ASTR 49400.

**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.
Prerequisite(s): Third- or fourth-year standing in the College and completion of intermediate-level courses in the Physical Sciences; or by consent of instructor.
Note(s): This course is aimed at undergraduate and graduate students in the Physical Sciences. Not offered in 2019-2020. Equivalent Course(s): ASTR 28500

**ASTR 41200. Science with Large Astronomical Surveys. 100 Units.**
The last several years have seen a veritable explosion of novel astronomical survey programs covering large areas of sky with unprecedented sensitivity. This course will explore the wide variety of science that can be done with surveys like the Sloan Digital Sky Survey, the Dark Energy Survey, the Gaia satellite, and the upcoming Large Synoptic Survey Telescope. Science topics will include our solar system, our Galaxy, the Local Group, distant galaxies, and cosmological measurements of our Universe. We will familiarize ourselves with the hardware and software components of astronomical surveys, before diving into hands-on analysis of public data sets. Students will learn computational and statistical techniques for analyzing large astronomical data sets.
Prerequisite(s): Third- or fourth-year standing in the College and completion of intermediate-level courses in the Physical Sciences; or by consent of instructor.
Note(s): This course is aimed at undergraduate and graduate students in the Physical Sciences. Not offered in 2019-2020. Equivalent Course(s): ASTR 28500

**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 Terms Offered: Spring
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 2019-2020.
Prerequisite(s): Prerequisites are graduate-level cosmology and general relativity.
Note(s): Not offered in 2019-2020.

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 22060, GEOS 32060

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 2019-2020.
Note(s): Not offered in 2019-2020.

ASTR 49400. Post-Candidacy Research. 300.00 Units.
Independent research undertaken towards completion of the dissertation.
Instructor(s): Rich Kron Terms Offered: Autumn Spring 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): Irina Zhuravleva, Erik Shirokoff, John Carlstrom Terms Offered: Autumn Spring Winter. Autumn Quarter instructor Irina Zhuravleva; Winter Quarter instructor Erik Shirokoff; Spring Quarter instructor John Carlstrom.
Prerequisite(s): Intended for doctoral students in the Department of Astronomy and Astrophysics.

ASTR 50000. Theory and Practice of Science Education. 300.00 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. This course will be offered for 0 credit hours in the 2019-2020 academic year.
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
Font Notice

This document should contain certain fonts with restrictive licenses. For this draft, substitutions were made using less legally restrictive fonts. Specifically:

- Times was used instead of Trajan.
- Times was used instead of Palatino.

The editor may contact Leepfrog for a draft with the correct fonts in place.