

# DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

---

## Chair

- Joshua A. Frieman

## Professors

- Jacob L. Bean
- John E. Carlstrom
- Fausto Cattaneo
- Hsiao-Wen Chen
- Daniel Fabrycky
- Wendy L. Freedman
- Joshua A. Frieman
- Michael D. Gladders
- Nickolay Y. Gnedin
- Daniel E. Holz
- Daniel Hooper
- Wayne Hu
- Edward W. Kolb
- Andrey V. Kravtsov
- Jeffrey McMahon
- Paolo Privitera
- Robert Rosner
- Abigail G. Viereg

## Associate Professors

- Bradford A. Benson
- Damiano Caprioli
- Clarence L. Chang
- Alex Drlica-Wagner
- Leslie Rogers

## Assistant Professors

- Chihway Chang
- Alex Ji
- Austin Joyce
- Harley Katz
- Gordan Krnjaic
- Jamie Law-Smith
- Diana Powell
- Irina Zhuravleva

## Emeritus Faculty

- Kyle M. Cudworth
- Doyal A. Harper, Jr.
- Lewis M. Hobbs
- Craig J. Hogan
- Edward J. Kibblewhite
- Arieh Königl
- Richard G. Kron
- Donald Q. Lamb, Jr.
- Stephan S. Meyer

- Takeshi Oka
- Angela V. Olinto
- Patrick E. Palmer
- Michael S. Turner
- Donald G. York

#### Research Faculty

- Thomas Crawford
- Cosmin Deaconu
- Vikram Dwarkadas
- Richard Kessler
- Eric Oberla
- Alexandra Rahlin

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 EUROS, 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 scheduled for completion in Chile in the 2030s.

### PROGRAM REQUIREMENTS

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

- Satisfactory completion of graduate courses
- Full-time scholastic residence of at least 300 units of coursework per quarter, including summer
- Completion of 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.

### PRE-CANDIDACY REQUIREMENTS

During the first and second years, students complete the following courses:

- ASTR 30100 Stars
- ASTR 30400 Galaxies
- ASTR 31000 Cosmology I
- ASTR 30600 Detection of Radiation
- ASTR 31100 High Energy Astrophysics
- ASTR 35000 Order-of-Magnitude Astrophysics

- ASTR 37100 Precandidacy Research
- ASTR 49910 Graduate Seminar: Colloquium

ASTR 37100 Precandidacy Research is taken every quarter. In this course, students arrange with a faculty supervisor to conduct a short-term independent research project lasting one or more quarters. Research completed in ASTR 37100 is presented in the two-part Candidacy Exam, which is held prior to the start of Autumn Quarter in the second and third years of the program.

In addition to required courses, students complete five electives. Sample electives include:

- ASTR 32100 Cosmology II
- ASTR 33100 Astrophysical Fluid Dynamics
- ASTR 34000 Statistical Methods in Astrophysics
- ASTR 44700 The Hubble Constant
- ASTR 49920 Graduate Seminar: Fellowship and Proposal Writing
- ASTR 49930 Graduate Seminar: Candidacy Preparation

Graduate-level courses offered by other departments in the Physical Sciences Division may be taken as electives, subject to approval by the Deputy Chair for Academic Affairs.

Advancement to candidacy is made when a student has successfully passed the two-part Candidacy Exam and formed a Thesis Committee. After candidacy is established, students enroll in ASTR 49400 Post-Candidacy Research and may also take advanced coursework. Ph.D. candidates are expected to meet with their committees at least twice per year to review progress on the thesis project. (Current students should refer to the Graduate Student Handbook, or contact the Student Affairs Administrator, for complete details on procedures and regulations required in the graduate program.)

#### PLAN OF STUDY

First Year							
Autumn Quarter	Units	Winter Quarter	Units	Spring Quarter	Units	Summer Quarter	Units
ASTR 30100		100 ASTR 31000		100 ASTR 30400		100 ASTR 37100	300.00
ASTR 35000		100 ASTR 49910		100 ELECTIVE		100	
ASTR 37100		100 ASTR 37100		100 ASTR 37100		100	
		300			300		
Second Year							
Autumn Quarter	Units	Winter Quarter	Units	Spring Quarter	Units	Summer Quarter	Units
ELECTIVE		100 ASTR 31100		100 ASTR 30600		100 ASTR 37100	300.00
ELECTIVE		100 ELECTIVE		100 ASTR 37100		100	
ASTR 37100		100 ASTR 37100		100 ELECTIVE		100	
		300			300		

Total Units: 2400

#### FINANCIAL SUPPORT

All students admitted to the Ph.D. program are offered full financial support. Generally this takes the form of a teaching assistantship that provides a full tuition scholarship and pays a competitive monthly stipend. Teaching assistants are typically assigned to one of the undergraduate laboratory courses in the general education program. The department requires a minimum of two quarters of teaching, after which students may continue to be supported through teaching assistantships, research assistantships, or fellowship funding. Students are urged to compete for the many national and other fellowships available. Incoming students who hold a fellowship may defer the teaching assignment requirement.

#### GRADING POLICY

All required courses are taken for a quality grade (3.0 on a scale of 4.0). ASTR 37100 Pre-Candidacy Research and ASTR 49400 Post-Candidacy Research are typically taken as P/F, but a letter grade may be requested by the student.

Graduate students are expected to maintain an average grade of B (3.0 on a scale of 4.0) or better. If a student falls below this average, the Deputy Chair for Academic Affairs, in consultation with the student and other faculty, will identify appropriate actions for enhancing academic progress.

## DISSERTATION AND FINAL EXAMINATION

The Ph.D. thesis may be a single-author or long-form paper (a collection of multiple-author papers) 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](mailto: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): Harley Katz Terms Offered: Autumn

Prerequisite(s): Open to 4th year 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): Hsiao-Wen Chen Terms Offered: Spring

Prerequisite(s): Open to 4th year 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): Clarence Chang Terms Offered: Spring

Prerequisite(s): Open to 4th year 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): Dan Hooper Terms Offered: Winter

Prerequisite(s): Open to 4th year 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 4th year 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: Winter

Prerequisite(s): ASTR 20500 or CMSC 14100 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): Scott Wakely (Autumn), John Carlstrom (Winter), Stephan Meyer (Spring) Terms Offered: Autumn Spring 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): CMSC 21400, PSMS 31400, CHEM 21400, ASTR 21400, PHYS 21400

#### **ASTR 32060. 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.

Instructor(s): E. Kite Terms Offered: Winter

Equivalent Course(s): ASTR 22060, GEOS 22060, GEOS 32060

#### **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): Wayne Hu Terms Offered: Autumn

#### **ASTR 33100. Astrophysical Fluid Dynamics. 100 Units.**

This course will cover selected topics of fluid dynamics that are most relevant to astrophysics. We will intuitively derive the Euler equations that describe inviscid fluids and apply them to classical problems of sound and gravity waves, instabilities, and shocks. We will start with a basic understanding of these problems and gradually increase the level of complexity to bring them to more realistic environments of the interstellar, circumgalactic, and intergalactic media. We will finish the course by discussing the motion of viscous fluids and examples from computational fluid dynamics. Selected astrophysical examples will be discussed throughout the course. This course is tailored for graduate students and senior undergraduates in physics and astrophysics. No previous exposure to fluid dynamics is required.

Instructor(s): Irina Zhuravleva Terms Offered: Autumn

#### **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.

Instructor(s): Chihway Chang Terms Offered: Winter

#### **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

Equivalent Course(s): ASTR 25000

#### **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): Various Terms Offered: Autumn Spring Summer Winter

#### **ASTR 39000. Counterhistories of Mathematics and Astronomy. 100 Units.**

Mathematics and astronomy are often taught as packaged universal truths, independent of time and context. Their history is assumed to be one of revelations and discoveries, beginning with the Greeks and reaching final maturity in modern Europe. This narrative has been roundly critiqued for decades, but the work of rewriting these histories has only just begun. This course is designed to familiarize students with a growing literature on the history of mathematics and astronomy in regions which now make up the global south. It is structured as a loosely chronological patchwork of counterexamples to colonial histories of mathematics and astronomy. Thematic questions include: How were mathematical and astronomical knowledge conjoined? How were they

embedded in political contexts, cultural practices, and forms of labor? How did European scientific modernity compose itself out of the knowledges of others? Where necessary, we will engage with older historiographies of mathematics and astronomy, but for the most part we will move beyond them. No mathematics more advanced than highschool geometry and algebra will be assumed. However, those with more mathematical preparation may find the course especially useful.

Instructor(s): Prashant Kumar Terms Offered: Spring

Equivalent Course(s): CHSS 39001, SALC 39000, KNOW 39000, ASTR 29000, HIPS 27010, HIST 35305

**ASTR 39900. Reading And Research: Astronomy. 300.00 Units.**

Readings and Research for working toward their PhD.

Terms Offered: Autumn Spring Summer Winter

**ASTR 44700. The Hubble Constant. 100 Units.**

The Hubble constant is the cosmological parameter that sets the absolute scale, size and age of the universe; it is one of the most direct ways we have of quantifying and constraining how the universe evolves. In recent years, a tension has arisen in measurements of the Hubble constant that come from using Cepheid variables to tie into the Hubble expansion based on Type Ia supernovae (~74 km/sec/Mpc), and those inferred from measurements of fluctuations in the cosmic microwave background (~67 km/sec/Mpc). Yet a third method, using red giant branch stars (the Tip of the Red Giant Branch or TRGB) give results that lie between the Cepheids and CMB (~70 km/sec/Mpc). This discrepancy raises the interesting possibility that there is physics missing from our standard (Lambda) Cold Dark Matter cosmological model. In this course we will cover the history of recent measurements of the Hubble constant, delve into how current measurements are made, examine the theoretical ideas for explaining the current tension, and look forward to the future and prospects for either supporting or refuting the case for new physics.

Instructor(s): Wendy Freedman Terms Offered: Spring

**ASTR 49400. Post-Candidacy Research. 300.00 Units.**

Independent research undertaken towards completion of the dissertation.

Instructor(s): Various Terms Offered: Autumn Spring Summer Winter

Prerequisite(s): Completion of all candidacy requirements.

**ASTR 49910. Graduate Seminar: Colloquium. 100 Units.**

In this course for first-year Ph.D. students in Astronomy and Astrophysics, students will become acquainted with the research of the weekly colloquium speakers and prepare for active participation in the colloquia.

Instructor(s): Hsiao-Wen Chen Terms Offered: Winter

**ASTR 49920. Graduate Seminar: Fellowship and Proposal Writing. 100 Units.**

In this course for first-year Ph.D. students in Astronomy and Astrophysics, students will identify prospective fellowship or research funding opportunities and learn how to prepare strong applications, with the goal of producing completed examples as final projects.

Instructor(s): Austin Joyce Terms Offered: Spring

**ASTR 49930. Graduate Seminar: Candidacy Preparation. 100 Units.**

In this course for second-year Ph.D. students in Astronomy and Astrophysics, students will prepare for part two of the candidacy examination through presentations, board work, discussion, and questions.

Instructor(s): Wayne Hu Terms Offered: Spring

