ASTRONOMY AND ASTROPHYSICS

Department Website:
https://www.haverford.edu/astronomy

Astronomy and astrophysics apply physical principles to understand the properties of objects in space. The range of scales of phenomena to be investigated is vast—from neutron stars the size of cities, to galaxies containing billions of stars, or even the entire Universe as a single system. The Haverford astronomy and astrophysics curricula are based on the study of these systems and of their evolution. Any study of astronomy and astrophysics is enriched by a firm understanding of the physics underlying these phenomena, and as such astronomy and astrophysics majors share many similarities with physics. Our curriculum is shaped to provide a solid foundation in the basic principles of both astronomy and physics, an understanding of the most recent developments in astronomy and cosmology, and the inspiration to pursue further learning in the sciences.

Entry to either the astronomy or astrophysics major comprises foundational courses in physics and mathematics during the first two years as well as ASTR 204 (typically taken in the sophomore year), which surveys all major areas of modern astrophysics. We also offer a number of more focused, upper level courses on specific topics in astronomy and astrophysics, including one on modern observational techniques. These courses usually reflect the research interests of our faculty.

Student research is a vital part of both majors. Our faculty work at the cutting edge of modern astronomy and cosmology, creating exceptional research opportunities for majors. Some of those opportunities are based on campus, within the College's William J. Strawbridge Observatory, equipped with telescopes and powerful computational facilities. Other opportunities lie off-campus, and we also encourage students to apply for summer research experience in other departments (as well as our own).

Learning Goals

The courses offered in the astronomy and astrophysics program address a variety of learning goals:

- Knowledge of the contents of the extraterrestrial universe, including planets, stars, galaxies, and the large-scale structure of the universe itself, and understanding the formation and evolution of all of these.
- Problem-solving skills: like physics, astronomy emphasizes the understanding the physical world in terms of physical laws, an endeavor that is validated by applying these mathematical laws to a variety of astrophysical phenomena and then solving the resulting mathematical problem in order to verify the subsequent predictions with observations.
- Constructing models: the construction of models to describe natural phenomena and astronomy represents the most creative aspect of any science.
- Developing physical intuition: the ability to look at a complicated system and know what's important.
- Computer programming: a cornerstone of modern astronomy, from data analysis to modeling.
- Observing skills in using a variety of astronomical instruments and techniques.
- Research experience, which involves:
  - confronting the unknown and tolerating its ambiguity.
  - generating new science with which to understand new observations.
  - analyzing data.
  - the art of scientific collaboration.
  - oral and written communication of new results.
  - designing new experiments/observations, and networking with other scientists to possibly generate new collaborative efforts.

Haverford's Institutional Learning Goals are available on the President's website, at http://hav.to/learninggoals.

Curriculum

Introductory Courses

The department regularly offers courses that require no prerequisites or prior experience in astronomy. These are intended primarily for non-science students.

Major Programs

Students can choose to major in either astronomy or astrophysics. Both majors provide substantial training in quantitative reasoning and independent thinking through work in and out of the classroom.

The department also offers a minor in astronomy.

- The astrophysics major is the same as a physics major, but with an astronomical emphasis. This major is appropriate for students who wish to pursue the study of astronomy with attention to the physical principles that underlie the observed phenomena. The depth of the physics training required for a degree in astrophysics will prepare students who wish to pursue graduate study in

astronomy or astrophysics, or to make use of their physics training for a wide range of other careers.
- The astronomy major is appropriate for students who desire an in-depth education in astronomy that can be applied to a wide-range of career trajectories, but who do not necessarily intend to pursue graduate study in astronomy.

Although a variety of pathways can lead to a major in the department, we advise prospective astronomy or astrophysics majors to:

- study physics (PHYS H105 or PHYS H115 and PHYS H106, or PHYS H101 and PHYS H102, or Bryn Mawr equivalents). beginning in their first year.
- enroll in ASTR204 and PHYS H213/PHYS H214 in their sophomore year.

For students with little or no prior computer programming experience, and who do not intend to take CMSC105, we advise (but do not require) taking ASTR 104 / PHYS 104 in the first or second year. (Students who do well in this course can, if desired, go on to take CMSC107.)

Students may major in astronomy or astrophysics, but not both. Astrophysics majors may not double major in either physics or astronomy, nor can they minor in either physics or astronomy. Astronomy majors may pursue a double major or a minor in physics, however we encourage students considering that option to look more closely at being an astrophysics major.

For either major, students may count courses taken outside the Quaker Consortium toward the major with advanced permission; typically two to three courses may be granted credit in this way. Students interested in this option should discuss this point with their major/pre-major advisor in advance.

Major Requirements

Astrophysics Major Requirements

- PHYS H105 (or PHYS H115 or PHYS H101), PHYS H106 (or PHYS H102), PHYS H213, PHYS H214, PHYS H211 (usually taken concurrently with PHYS H213).
- Two mathematics courses; MATH H121 and all 200-level or higher mathematics courses can be used to satisfy this requirement.
- ASTR H204 and any two 300-level astronomy courses. Majors can substitute 100-level Swarthmore astronomy seminars for 300-level astronomy courses.
- PHYS H302, PHYS H303, and PHYS H309.
- The Senior Seminar, PHYS H399F and PHYS H399I, including a talk and senior thesis on research conducted by the student. This research can be undertaken in a 400-level research course with any member of the Physics and Astronomy Department or by doing extracurricular research at Haverford or elsewhere, e.g., an approved summer research internship at another institution. The thesis is to be written under the supervision of both the research advisor and a Haverford advisor if the research advisor is not a Haverford faculty member.

Bryn Mawr equivalents may be substituted for the non-astronomy courses.

Astronomy Major Requirements

- PHYS H105 (or PHYS H101 or PHYS H115), PHYS H106 (or PHYS H102), PHYS H213, PHYS H214.
- Two mathematics courses; MATH H121 and all 200-level or higher mathematics courses can be used to satisfy this requirement.
- ASTR H204, four 300-level astronomy courses, one of which may be replaced by an upper-level physics course. Majors can substitute 100-level Swarthmore astronomy seminars for 300-level astronomy courses.
- PHYS H399F and PHYS H399I, which may be replaced by approved independent research either at Haverford or elsewhere.
- The Senior Seminar, PHYS H399F and PHYS H399I, including a talk and senior thesis on research conducted by the student. This research can be undertaken in a 400-level research course with any member of the Physics and Astronomy Department or by doing extracurricular research at Haverford or elsewhere, e.g., an approved summer research internship at another institution. The thesis is to be written under the supervision of both the research advisor and a Haverford advisor if the research advisor is not a Haverford faculty member.

Bryn Mawr equivalents may be substituted for the non-astronomy courses.

Senior Project

The senior project and requirements are the same for the Astronomy major and the Astrophysics major:

Coursework prior to the senior year provides students' primary preparation for their thesis work. As outlined in our program's educational goals, this coursework emphasizes: knowledge of the extraterrestrial universe, problem solving skills, constructing models, developing physical intuition, computer programming, observing skills, and research-like inquiry. Students also gain experience with oral and written communication of complex scientific topics in their introductory physics labs

and in upper level coursework, including ASTR H341 (Observational Astronomy). During group research meetings, students provide weekly oral reports to each other on their thesis progress and receive ongoing support and instruction from faculty.
To pull together the many elements that make up the senior year, students are required to participate in a year-long seminar course, PHYS H399. At the approximately biweekly meetings, students and some departmental faculty gather around a table to discuss topics running the gamut from scientific ethics to how to give a scientific talk or write a scientific research paper. Further details on this course are contained in the description of senior year work in physics.
The most important part of the senior seminar remains the senior paper and the senior presentations. We assess students by their performance on a short talk and the draft of the background section of their thesis during the fall semester, a comprehensive talk or poster presentation in the spring semester and a senior thesis written in the form of a scientific paper.

Senior Project Learning Goals

The senior thesis project extends through at least an entire academic year, with many students starting their thesis research during the summer before their senior year. The thesis thus requires students to engage in focused work, towards a single goal, for a substantial time period. We aim for students to develop deep topical expertise in a single subfield of astronomy or astrophysics, and to develop technical expertise in one of the analysis techniques common to that field (often computational data analysis).

Students learn to ask good questions of others and themselves, in pursuit of a deeper understanding of a previously unsolved question about the natural world.

Students are expected to place their senior research work in the context of the scientific literature in their field of study, and to present their results to an audience of professionals (for their thesis) and their peers (for the talk or poster). They are given training in searching and reading the scientific literature by each research supervisor, as well as specific materials through the senior seminar course.

More than is the case in any other undergraduate curricular engagement, students must learn how to be independent and self-motivated to complete their thesis work. This style of scientific inquiry also imbues a realistic sense of professional scientific research in students and increases their grit.

Senior Project Assessment

Each senior's thesis culminates in both a written and an oral component. The written thesis is carefully read and evaluated by two faculty readers.
The thesis research itself is evaluated for (i) a demonstrated understanding of the context and content of the research (including a review of the relevant scientific literature), (ii) independent problem solving and synthesis, and (iii) success in understanding the forward looking implications of the research.
The written and oral presentations of the research are evaluated for (i) a clear and appropriate writing style and (ii) well-curated and well-presented visual displays of the research results.

Requirements for Honors

All astronomy and astrophysics majors are regarded as candidates for honors. For both majors, the award of honors will be made in part on the basis of superior work in the departmental courses and in certain related courses. The award of honors will additionally be based on the senior thesis and talk. High honors carries the additional requirement of demonstrated originality in senior research.

Minor Requirements

• PHYS H105 (or PHYS H115 or PHYS H101); PHYS H106 (or PHYS H102).
• ASTR H204; one 300-level astronomy course.
Minors may substitute a 100-level Swarthmore astronomy seminar for the 300-level astronomy course.

Concentrations and Interdisciplinary Minors

Astronomy and astrophysics majors can pursue concentrations in scientific computing and education, while astrophysics majors with interdisciplinary interests in biophysics may also qualify for the biophysics concentration.

Each of these concentrations is described in its relevant section of the Catalog.

Special Programs

Haverford is part of the KNAC eight-college consortium (https://astro.swarthmore.edu/knac) that provides research assistantships for a summer student exchange program, grants for student travel to outside observatories, and a yearly symposium at which students present their research.

Study Abroad

Astronomy and astrophysics majors can and do pursue studies abroad. There are a number of programs, mostly in English-speaking countries, that

allow astronomy and astrophysics majors to continue and broaden their studies in the field while abroad. Majors may count courses taken abroad toward the major with advanced permission; typically two to three courses may be granted credit in this way. Students interested in studying abroad should discuss this point with their major/pre-major advisor in advance.

Facilities

See the departmental web page for a description of laboratories, equipment and other special facilities for this program.

Faculty

Suzanne Amador Kane
Professor of Physics and Astronomy

Ted Brzinski
Assistant Professor of Physics and Astronomy (On Leave 2020-2021)

Daniel Grin
Assistant Professor of Physics and Astronomy (On Leave 2020-2021)

Saki Khan
Visiting Assistant Professor of Physics and Astronomy

Natalia Lewandowska
Visiting Assistant Professor of Astronomy

Andrea Lommen
Professor and Chair of Physics and Astronomy

Karen Masters
Associate Professor of Physics and Astronomy (On Leave Spring 2021)

Bruce Partridge
Professor Emeritus of Physics and Astronomy

Walter Smith
The Paul and Sally Bolgiano Professor of Physics; Professor of Physics and Astronomy

Paul Thorman
Physics Laboratory Instructor and Observatory Coordinator

Affiliated Faculty

David Wonnacott
Associate Professor of Computer Science

Courses

ASTR H101 ASTRONOMICAL IDEAS (1.0 Credit)
Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
Fundamental concepts and observations of modern astronomy, such as the properties of planets, the birth and death of stars, and the properties and evolution of the Universe. Not intended for students majoring in the physical sciences.
(**Offered:** Spring 2021)

ASTR H104 TOPICS IN INTRO PROGRAMMING: PHYSICS AND ASTRONOMY (1.0 Credit)
Andrea Lommen, David Wonnacott
Division: Natural Science; Quantitative
Domain(s): C: Physical and Natural Processes
Topics in Introductory Programming is designed to give a general introduction to programming as related to data analysis across many fields. Students will be introduced to standard introductory programming imperative and object oriented techniques as well as data structures necessary to create efficient and understandable algorithmic solutions to problems. This course satisfies the prerequisite for CMSC 107. Antirequisite(s): Students who have taken a semester of college-level computer science (e.g.,CMSC105) or placed into CMSC107 are ineligible to take this course. It is intended for students with little or no background in computer programming. This course is equivalent to CMSC 104.
(**Offered:** Spring 2021)

ASTR H152 FIRST-YEAR SEMINAR IN ASTROPHYSICS (0.5 Credit)
Karen Masters
Division: Natural Science
Domain(s): C: Physical and Natural Processes
This half-credit course is intended for prospective physical science majors with an interest in recent developments in astrophysics. Topics in modern astrophysics will be viewed in the context of underlying physical principles. Topics include black holes, quasars, neutron stars, supernovae, dark matter, the Big Bang, and Einstein's relativity theories. Crosslisted: Astronomy, Physics Prerequisite(s): PHYS H101 or H105 and concurrent enrollment in PHYS H102, H106 or B121 (or Bryn Mawr equivalents)

ASTR H204 INTRODUCTION TO ASTROPHYSICS (1.0 Credit)
Natalia Lewandowska
Division: Natural Science
Domain(s): C: Physical and Natural Processes
General introduction to astronomy including: the structure and evolution of stars; the properties and evolution of the solar system including planetary surfaces and atmospheres; exoplanets; and observational projects using the Strawbridge Observatory telescopes. Prerequisite(s): MATH H118 or equivalent; PHYS H105 or PHYS B121; Co-requisite(s): PHYS H106 or B201

(**Offered:** Fall 2020)

ASTR H206 INTRODUCTION TO ASTROPHYSICS II (1.0 Credit)
Division: Natural Science
Domain(s): C: Physical and Natural Processes
Introduction to the study of: the structure and formation of the Milky Way galaxy; the interstellar medium; the properties of galaxies and their nuclei; and cosmology including the Hot Big Bang model. Prerequisite(s): ASTR H205A and MATH H118 or equivalent.

ASTR H304 COMPUTATIONAL PHYSICS (1.0 Credit)
Daniel Grin
Division: Natural Science
Domain(s): C: Physical and Natural Processes
An introduction to the methods and problems of computational physics, including matrix methods, ordinary differential equations, integration, eigensystems, Monte Carlo techniques, Fourier analysis, and iterative methods. Course will include a substantial independent project. Crosslisted: Physics, Astronomy, Computer Science Prerequisite(s): PHYS 213 or BMC PHYS 306 or instructor consent

ASTR H341 ADVANCED TOPICS: OBSERVATIONAL ASTRONOMY (1.0 Credit)
Karen Masters
Division: Natural Science
Domain(s): C: Physical and Natural Processes
Observing projects that involve using a CCD camera on a 16-inch Schmidt-Cassegrain telescope. Projects include spectroscopy; variable star photometry; H-alpha imaging; imaging and photometry of galaxies and star clusters; instruction in the use of image processing software and CCD camera operation. Students work in groups of two with minimal faculty supervision. Formal reports are required. Prerequisite(s): ASTR H204
(**Offered:** Fall 2020)

ASTR H344 ADVANCED TOPICS IN ASTROPHYSICS: GRAVITY WAVES (1.0 Credit)
Andrea Lommen
Division: Natural Science
Domain(s): C: Physical and Natural Processes
This course will explore the creation and detection of gravitational waves (GWs) across the spectrum, from the speculative universe-sized GWs that may someday be detected from the epoch of inflation, to the kHz waves that LIGO did indeed detect last year! In the course you will investigate theoretical, observational, and computational aspects of GWs across the spectrum, culminating in a final investigative project of your own choosing. Prerequisite(s): ASTR H205 and ASTR H206

ASTR H404 RESEARCH IN ASTROPHYSICS (0.5 Credit)
Andrea Lommen, Karen Masters
Division: Natural Science
Intended for those students who choose to complete an independent research project in astrophysics under the supervision of a faculty member.
(**Offered:** Spring 2021)

ASTR H480 INDEPENDENT STUDY (1.0 Credit)
Andrea Lommen
Division: Natural Science
Intended for students who want to pursue some topic of study that is not currently offered in the curriculum. In order to enroll, a student must have a faculty sponsor. Prerequisite(s): Instructor consent
(**Offered:** Fall 2020)