

ASTRONOMY AND ASTROPHYSICS

haverford.edu/astronomy

The range of astronomical phenomena is vast—from the Big Bang origin of the universe, to the death throes of collapsing stars, to the rings of Saturn. The 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. Our curriculum is shaped to provide both astronomy and astrophysics majors with 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 major is through a pair of courses that survey all major areas of modern astrophysics: ASTR 205 and 206. These are typically taken in the sophomore year, to allow students to build a foundation in physics (our majors require physics courses, as explained below). We also offer as number of more focused, upper level courses on specific topics in astronomy, including one on observational techniques. Some of these 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 computer facilities. Other opportunities lie off-campus through the department's alliances with national and private observatories, including Kitt Peak in Arizona and the Simons Observatory in Chile.

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.
- 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.

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.

ASTR/PHYS 152, is a half-credit course for first-year students who are considering a physical science major and wish to study some of the most recent developments in astrophysics early in their college education.

Major Programs

Our department offers two majors: astronomy and astrophysics. Both majors provide substantial training in quantitative reasoning and independent thinking through work in and out of the classroom.

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The department also offers a minor in astronomy.

- 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.
- The astrophysics major is appropriate for students who wish to pursue the study of astronomy with additional attention to the physical principles that underlie astrophysical phenomena. The depth of the physics training required for a degree in astrophysics will prepare students who wish to pursue a career in astronomy or astrophysics, or to do graduate study in astronomy or astrophysics.

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

- study physics (PHYS 105 or 115 and 106, or PHYS 101 and 102, or Bryn Mawr equivalents). beginning in their first year.
- enroll in ASTR 205/206 and PHYS 213/214 in their sophomore year.
- take ASTR/PHYS 152 in the second semester of their first year.

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.

MAJOR REQUIREMENTS

Astronomy Major Requirements

The astronomy major is appropriate for students that 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.

- PHYS 105 (or 101 or 115), PHYS 106 (or 102), PHYS 213, PHYS 214.
- Two mathematics courses; MATH 121 and all 200-level or higher mathematics courses can be used to satisfy this requirement.
- ASTR 205, ASTR 206, 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.

- ASTR 404, which may be replaced by approved independent research either at Haverford or elsewhere.
- Written comprehensive examinations.

Bryn Mawr equivalents may be substituted for the non-astronomy courses. ASTR/PHYS 152 is recommended but not required.

Astrophysics Major Requirements

The astrophysics major is appropriate for students who wish to pursue the study of astronomy with additional attention to the physical principles that underlie astrophysical phenomena. The depth of the physics training required for a degree in astrophysics will prepare students who wish to pursue a career in astronomy or astrophysics, or to enter graduate study in astronomy or astrophysics.

- PHYS 105 (or 115 or 101), PHYS 106 (or 102), PHYS 213, PHYS 214, PHYS 211 (usually taken concurrently with PHYS 213).
- Two mathematics courses. MATH 121 and all 200-level or higher mathematics courses can be used to satisfy this requirement.
- ASTR 205, ASTR 206, and any two 300-level astronomy courses. Majors can substitute 100-level Swarthmore astronomy seminars for 300-level astronomy courses.
- PHYS 302, PHYS 303, and PHYS 309.
- The Senior Seminar, PHYS 399, 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. ASTR/PHYS 152 and PHYS 308 are recommended but not required.

MINOR REQUIREMENTS

- PHYS 105 (or 115 or 101); PHYS 106 (or 102).
- ASTR 205; ASTR 206; one 300-level astronomy course. Minors may substitute a 100-level Swarthmore astronomy seminar for the 300-level astronomy course.

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We strongly recommend (but do not require) ASTR/PHYS 152.

SENIOR PROJECT

As noted above, we offer two majors: astronomy and astrophysics. The senior project and requirements differ for the two.

Astronomy Major

For many decades, the capstone work for seniors majoring in astronomy (not astrophysics) has been a set of three, three-hour, comprehensive examinations covering all of astronomy. Students are given some choice in which questions to answer. We emphasize that the questions on these written examinations are likely to address topics of current prominence or interest in the field, whether or not they have been covered in our courses. In a year marked by new discoveries about a particular planet, for instance, we might ask for a summary of the scientific findings even though our curriculum barely touches planetary science.

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 341 (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 in the astrophysics major, students are required to participate in a year-long seminar course, PHYS 399. 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 (typically 25-50 pages, including figures and references), written in the form of a scientific paper. Frequently, this leads to a publication in a peer-reviewed journal.

Senior Project Learning Goals

As noted above, we offer two majors: astronomy and astrophysics. While the senior year work differs for the two, the learning goals are closely similar.

Astronomy Major

The goal of the comprehensive exams in astronomy is primarily to assess seniors' grasp of the full extent of their chosen field of study, and secondarily to provide a summary reminder of the field. For students, the comprehensive exams are thus both an evaluative assessment, and to a lesser extent a formative experience. The exams offer the departmental faculty a last chance to lay out the nature of astronomy, both for students planning further study in the field or for those leaving astronomy behind.

As the capstone experience for senior majors in astronomy, the comprehensives are entirely separate from a student's research experience—unlike the case for majors in astrophysics. Both astronomy and astrophysics majors, however, are required to undertake senior research either on campus or off campus, perhaps in a summer REU experience. For *astrophysics* majors, this research is central to the senior experience (see below). For *astronomy* majors, on the other hand, senior research and the comprehensives are decoupled: the former stresses depth; the latter breadth.

Astrophysics Major

The Haverford astrophysics 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 astrophysics, and to develop technical expertise in one of the analysis techniques common to that field (often computational data analysis).

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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

As noted above, we offer two majors: astronomy and astrophysics. Assessment of the senior year work differs for the two.

Astronomy Major

The comprehensives are read and graded by all astronomy faculty. They are graded on a numerical 1-10 scale for each problem, not the usual Haverford 4.0 scale. While performance on astronomy comprehensive exams is not recorded on a student's transcript, students must pass the exams in order to graduate with an astronomy major.

Comprehensive results are also the primary determinant of departmental honors for astronomy majors. High honors are awarded to students who:

- demonstrate clear mastery of the field, including both topics central to our curriculum and those not.
- are able to situate their responses in a wider context of astrophysics or science in general.
- show an understanding of research fields not covered in our curriculum.
- display some originality in their responses, evidence that they "own" the material.

Regular departmental honors again require mastery and a sense of context, with less emphasis on originality.

While the emphasis of comprehensives is on the first two of the departmental learning goals ("knowledge of the extraterrestrial universe" and "problem-solving skills"), we also look for evidence that other goals have been met, including "scientific intuition" and written communication skills.

Astrophysics Major

As noted, 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. For astronomy majors, the award of honors will additionally be based on performance on the comprehensive examinations, with consideration given for independent research. For astrophysics majors, the award of honors will additionally be based on the senior thesis and talk.

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

We offer all Haverford astrophysics majors the opportunity to obtain astronomical observations at a research facility, e.g. Green Bank

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Observatory and other observatories at which our faculty conduct research.

Haverford is also part of the KNAC eight-college consortium (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.

FACILITIES

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

FACULTY

Scott Engle

Visiting Assistant Professor

Andrea Lommen

Professor

Karen Masters

Associate Professor

Bruce Partridge

Bettye and Howard Marshall Professor of Natural Sciences and Professor of Astronomy Emeritus

Paul Thorman

Laboratory Instructor in Physics

COURSES

ASTR H101 ASTRONOMICAL IDEAS

Scott Engle

Natural Science (NA), Quantitative (QU)
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. At least 30 spaces will be reserved for freshmen, perhaps more as space dictates. (Offered Spring 2018)

ASTR H152 FIRST-YEAR SEMINAR IN ASTROPHYSICS

Staff

Natural Science (NA)

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). (Offered Spring 2018)

ASTR H205 INTRODUCTION TO ASTROPHYSICS I

Scott Engle

Natural Science (NA)

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):
Prerequisite(s): MATH H118 or equivalent; PHYS H105 or PHYS B121; Co-requisite(s): PHYS H106 or B201. (Offered Fall 2017)

ASTR H206 INTRODUCTION TO ASTROPHYSICS II

Andrea Lommen

Natural Science (NA)

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. (Offered Spring 2018)

ASTR H304 COMPUTATIONAL PHYSICS

Daniel Grin

Natural Science (NA)

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): CMSC H105 (or equivalent) and either PHYS H213 or PHYS H306. (Offered Spring 2018)

ASTR H341 ADVANCED TOPICS: OBSERVATIONAL ASTRONOMY

Staff

Natural Science (NA)

ASTRONOMY AND ASTROPHYSICS

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 H206. (Typically offered every other fall)

ASTR H344 ADVANCED TOPICS IN ASTROPHYSICS

Andrea Lommen

Natural Science (NA)

Topics drawn from one of the following areas in current astrophysics: stellar structure and evolution, galaxy structure and evolution, extragalactic astronomy and cosmology, radio astronomy, x-ray astronomy, and gravitational wave astronomy. Prerequisite(s): ASTR H205 and ASTR H206. (Offered Fall 2017)

ASTR H404 RESEARCH IN ASTROPHYSICS

Andrea Lommen

Natural Science (NA)

Intended for those students who choose to complete an independent research project in astrophysics under the supervision of a faculty member. Prerequisite(s): Instructor consent. (Offered Fall 2017 and Spring 2018)