

ASTRONOMY & ASTROPHYSICS (Div III)

Chair: Professor Protik Majumder

- Marek Demianski, Visiting Field Memorial Professor of Astronomy
- Kevin Flaherty, Lecturer in Astronomy and Observatory Supervisor; affiliated with: Astronomy, Physics
- Anne Jaskot, Assistant Professor of Astronomy and Associate of the Hopkins Observatory; affiliated with: Astronomy, Physics
- Protik K. Majumder, Barclay Jermain Professor of Natural Philosophy, Chair of Astronomy; affiliated with: Physics, Astronomy
- Jason E. Young, Visiting Field Memorial Assistant Professor of Astronomy

How long will the Sun shine? How do we discover Earth-like planets among the many exoplanets circling other stars? How did the universe begin and how has it evolved over its 13.8-billion-year history? How do we detect not only light but also gravitational waves from afar? Astronomy is the science that asks and tries to answer questions like these. We have come a long way toward understanding what makes the sky appear as it does and how the Universe behaves. Williams Astronomy courses are for anyone who is interested in learning about the Universe, and who would like to be able to follow new astronomical discoveries as they are made. All courses in Astronomy satisfy the Division III requirement. The Astronomy major and the Astrophysics major, both administered by the Department of Physics and Astronomy, are described below.

The beginning astronomy courses are offered on two levels. Astronomy 101, 102, 104, and 330-range courses are intended primarily for non-science majors and have no prerequisite. Astronomy 111 is designed for students with some exposure to physics. It has a prerequisite of one year of high school physics or permission of the instructor, and a co-requisite of Mathematics 140 or equivalent background in calculus.

Most of the astronomy courses take advantage of our observational and computational facilities including a 24-inch computer-controlled telescope with sensitive electronic detectors, and our own computer network for image processing and data analysis. The Williams Astronomy site can be found at astronomy.williams.edu.

ASTRONOMY MAJOR

The Astronomy major is designed for students with an interest in learning about many aspects of modern astronomy, but who do not choose to take the most advanced physics and math courses of the astrophysics major. It is also appropriate as a second major for students concentrating in another field; in particular, combining an Astronomy major with a related major like Geoscience or Computer Science has been a fruitful path for some of our students. The Astronomy major emphasizes understanding the observed properties of the physical systems that comprise the known Universe, from the Sun and solar system, to the evolution of stars and star clusters, to the Milky Way Galaxy, to external galaxies and clusters of galaxies. Because some knowledge of physics and calculus is necessary to understand many astronomical phenomena, the Astronomy major requires the first two semesters each of the physics and calculus that are also required of Physics majors and Astrophysics majors.

There are several possible routes through the Astronomy major, depending on preparation and interest. Students considering a major in Astronomy should consult with members of the department early and often. A first-year student, if unsure about choosing between Astronomy and Astrophysics, may wish to take not only Astronomy 111 but also Physics 131, 141, or 151 and Mathematics 140 (if necessary) in the fall. Students who might place out of physics courses should read the section on placement under Physics.

Major Requirements for Astronomy

Astronomy 111 Introduction to Astrophysics OR Astronomy 101 Stars: From Suns to Black Holes and either Astronomy 102 The Solar System—Our Planetary Home OR Astronomy 104 The Milky Way Galaxy and the Universe Beyond

Two 200-level Astronomy courses (or additional 400-level Astronomy courses as substitutes)

Two 400-level Astronomy courses

Physics 131 Particles and Waves OR Physics 141 Particles and Waves—Enriched OR equivalent placement

Physics 142 Foundations of Modern Physics or Physics 151 Seminar on Modern Physics

Mathematics 140 Calculus II

Mathematics 150 Multivariable Calculus OR Mathematics 151 Multivariable Calculus OR equivalent placement

The total number of courses required for the Astronomy major is nine. A typical path through the major will begin with Physics 141, which is suitable for students with one year of high school physics and a background in calculus. However, students without high school physics may begin with Physics 131, and students entering with Advanced Placement in physics and/or math may obtain credit toward the major for the equivalent of

Physics 142 and/or Mathematics 150 or 151 taken elsewhere. There are some aspects of astronomy that are closely related to chemistry or geosciences. In recognition of this, certain advanced courses in those departments can be accepted for credit toward the Astronomy major.

THE DEGREE WITH HONORS IN ASTRONOMY

The honors degree in Astronomy will be awarded on the basis of a senior thesis presenting the results of an original observational, experimental, or theoretical investigation carried out by the student under the direction of a faculty member in Astronomy. There are no specific grade requirements (other than College-wide requirements for remaining in good academic standing) for entry into the thesis research program; however, a student wishing to do a thesis should have demonstrated both ability and motivation for independent work in previous courses and in any earlier research involvement. Students doing theses will normally choose a topic and an advisor early in the second semester of their junior year and usually begin their thesis work during the summer. During the senior year, those students whose proposals have been approved will elect two courses and a winter study project in addition to the minimum requirements for the major. Preparation for the thesis will occupy at least one course (Astronomy 493) and the winter study project (Astronomy 031). At the end of the winter study period, the department will decide, in consultation with each student, whether to admit that student to honors candidacy. Both a written thesis and an oral presentation to faculty and fellow students are required. The degree with honors will be awarded to those who meet these requirements with distinction. The degree with highest honors will be awarded to those who fulfill the requirements with unusually high distinction.

The department will be flexible with regard to the number and timing of courses devoted to thesis research within the general guidelines of two courses and a winter study project over and above the minimum major requirements and the written and oral presentations, especially in cases of students with advanced standing and/or summer research experience. Students considering unusual requests are urged to consult with potential advisors or the department chair as early as possible.

ASTROPHYSICS MAJOR

The Astrophysics major is designed for students who want a rigorous introduction to the field, and includes not only those who plan graduate study in astronomy, astrophysics, or a closely related area, but also those interested in a wide variety of careers. Astrophysics alumni are not only astronomers but also computer scientists, geologists, teachers, doctors, lawyers, business school professors, and so on. In recent years, many astrophysics majors have had a second major in fields as wide ranging as mathematics, computer science, geosciences, economics, English, and art history. This major emphasizes the description of the Universe and its constituents in terms of physical processes. Potential Astrophysics majors should consult early with members of the Department of Physics and Astronomy to determine their most appropriate route through the major. An essential ingredient in such students' undergraduate training is experience in physics and mathematics. Therefore, the major normally will begin in the first year a student is at Williams with Physics 131, 141, or 151 and Mathematics 140 or 150 or 151 in the fall. Physics 141 is recommended for students with one year of high school physics and a background in calculus. Students with very good background placing them out of Physics 142 and out of Mathematics 140 may choose to take Physics 201 and Mathematics 150 or 151 instead. Astronomy 111 will often be taken in the fall of the sophomore year; however, many students take it in the fall of their first year at Williams, along with physics and math. Students who might place out of physics courses should read the section on placement under Physics; those who place out of Physics 131 or 141 into Physics 142 or 151 should particularly consider taking Astronomy 111 in the fall of their first year.

In addition to the major courses described below, other courses in geosciences, mathematics, and computer science may also be appropriate.

Major Requirements for Astrophysics

Astronomy 111 Introduction to Astrophysics OR Astronomy 101 Stars: From Suns to Black Holes and either Astronomy 102 The Solar System—Our Planetary Home OR Astronomy 104 The Milky Way Galaxy and the Universe Beyond

Physics 131 Particles and Waves OR Physics 141 Particles and Waves—Enriched OR equivalent placement

Physics 142 Foundations of Modern Physics OR Physics 151 Seminar on Modern Physics

Physics 201 Electricity and Magnetism

Physics 202 Waves and Optics

Physics/Mathematics 210 Mathematical Methods for Scientists

Physics 301 Introductory Quantum Physics

Mathematics 150 Multivariable Calculus OR Mathematics 151 Multivariable Calculus

Three 400-level astronomy courses OR two 400-level astronomy courses and one of the following:

Astronomy 211 Astronomical Observing and Data Analysis

Physics 302 Statistical Physics

Physics 402T Applications of Quantum Mechanics

Physics 405T Electromagnetic Theory

Physics 411T Classical Mechanics;

Physics 418 Gravity

The total number of courses required for the Astrophysics major, an interdisciplinary major, is eleven. Students entering with Advanced Placement in physics and/or mathematics may obtain credit toward the major for the equivalent of Physics 141 and/or Mathematics 140 and/or 150 or 151 taken elsewhere, but at least 8 courses in astronomy, physics, and mathematics must be taken at Williams. There are some aspects of astrophysics that are closely related to chemistry or geosciences. In recognition of this relation, certain advanced courses in those departments can be accepted for credit toward the Astrophysics major on a two-for-one basis. It is not possible to double major in Astrophysics and Physics.

THE DEGREE WITH HONORS IN ASTROPHYSICS

The honors degree in Astrophysics will be awarded on the basis of a senior thesis presenting the results of an original observational, experimental, or theoretical investigation carried out by the student under the direction of a faculty member in Astronomy or Physics. There are no specific grade requirements (other than College-wide requirements for remaining in good academic standing) for entry into the thesis research program; however, a student wishing to do a thesis should have demonstrated both ability and motivation for independent work in previous courses and in any earlier research involvement. Students doing theses will normally choose a topic and an advisor early in the second semester of their junior year and usually begin their thesis work during the summer. During the senior year, those students whose proposals have been approved will elect two courses and a winter study project in addition to the minimum requirements for the major. Preparation for the thesis will occupy at least one course (Astrophysics 493) and the winter study project (Astrophysics 031). At the end of the winter study period, the department will decide, in consultation with each student, whether to admit that student to honors candidacy. Both a written thesis and an oral presentation to faculty and fellow students are required. The degree with honors will be awarded to those who meet these requirements with distinction. The degree with highest honors will be awarded to those who fulfill the requirements with unusually high distinction.

Honors candidates will also be required to attend departmental colloquium talks.

The department will be flexible with regard to the number and timing of courses devoted to thesis research within the general guidelines of two courses and a winter study project over and above the minimum major requirements and the written and oral presentations, especially in cases of students with advanced standing and/or summer research experience. Students considering unusual requests are urged to consult with potential advisors or the department chair as early as possible.

STUDY ABROAD

FAQ

Students **MUST** contact departments/programs **BEFORE** assuming study away credit will be granted toward the major or concentration.

Can your department or program typically pre-approve courses for major/concentration credit?

Yes, in some cases, if appropriate course information is available in advance (e.g. syllabi and/or course descriptions), though students should be sure to contact the department.

What criteria will typically be used/required to determine whether a student may receive major/concentration credit for a course taken while on study away?

Course title and description, and complete syllabus including readings/assignments.

Does your department/program place restrictions on the number of major/concentration credits that a student might earn through study away?

No.

Does your department/program place restrictions on the types of courses that can be awarded credit towards your major?

No.

Are there specific major requirements that cannot be fulfilled while on study away?

No.

Are there specific major requirements in your department/program that students should be particularly aware of when weighing study away options? (Some examples might include a required course that is always taught in one semester, laboratory requirements.)

Yes. PHYS 301, a required course for the Astrophysics major, is only taught in the fall, and is difficult to replicate abroad, especially regarding the lab component.

Give examples in which students thought or assumed that courses taken away would count toward the major or concentration and then

learned they wouldn't:

None to date.

ASTR 101 (F) Stars: From Suns to Black Holes

Have you ever wondered what makes the Sun and stars shine and what they are made of? Do they evolve, and if so, how do they change? What are black holes, and how can they form? How do we find planets around other stars? Astronomy 101, a non-major, general introduction to the part of contemporary astronomy that includes how stars form and die, will provide answers to these questions. We will pay special attention to exciting discoveries made in the past decade. Thousands of exoplanets have been discovered, with their atmospheres being studied in detail by the James Webb Space telescope. For the first time, gravitational waves from merging black holes have been detected. In this course we will discuss the basic methods and instruments used in these and other astronomical observations and what they can teach us about the life cycle of stars. We will discuss what happens at the centers of stars, how stars evolve, and why some stars explode and form neutron stars and black holes. This course is independent of and on the same level as ASTR 102 (solar system) and 104 (galaxies/cosmology); students who have taken these courses are welcome.

Class Format: lecture (two sessions per week), observing sessions (scattered throughout the semester), afternoon labs (five times per semester), and a planetarium demonstration. Planetarium and Roof-Observatory TAs will be available for consultation, in addition to the instructors, throughout the semester.

Requirements/Evaluation: two hour tests, a final exam, an observing portfolio, and lab reports

Prerequisites: none

Enrollment Limit: 48;12/lab

Enrollment Preferences: first and second-year students

Expected Class Size: 30/lec

Grading: yes pass/fail option, no fifth course option

Unit Notes: non-major course

Distributions: (D3)

Fall 2024

LEC Section: 01 TR 9:55 am - 11:10 am

LAB Section: 02 T 1:00 pm - 2:30 pm Kevin Flaherty

LAB Section: 03 T 2:30 pm - 4:00 pm Kevin Flaherty

LAB Section: 04 W 1:00 pm - 2:30 pm Kevin Flaherty

LAB Section: 05 W 2:30 pm - 4:00 pm Kevin Flaherty

ASTR 102 (S) Our Solar System and Others

What makes Earth different from all the other planets? What have NASA's Curiosity and Perseverance on Mars found about that planet's past running water and suitability for life? How has knowledge about Pluto and the outer solar system been transformed by NASA's flybys? Will asteroids or comets collide with the Earth again? What is the new James Webb Space Telescope revealing about exoplanets and their atmospheres? Astronomy 102, a non-major, general introduction to the part of contemporary astronomy that comprises the study of the solar system (and the systems of planets around other stars), will provide answers to these questions and more. We will cover the historical development of humanity's understanding of planetary systems, examining contributions by Copernicus, Galileo, Newton, Einstein, and others and the more recent discoveries of over 4000 exoplanets around stars other than the Sun. The course gives special attention to exciting discoveries of the past few years by space probes and space telescopes such as the Hubble, James Webb, and Kepler/K2/TESS missions. We regularly discuss the latest news briefs and developments in astronomy and relate them to the topics covered in the course. This course is independent of, and on the same level as Astronomy 101 (stars and stellar evolution) and 104 (galaxies and cosmology), and students who have taken those courses are welcome.

Class Format: lecture (two sessions per week), observing sessions (scattered throughout the semester), afternoon labs (five times per semester), and a planetarium demonstration. Planetarium and Roof-Observing TAs will be available for consultation, in addition to the instructors, throughout the semester.

Requirements/Evaluation: two hour tests, a final exam, an observing portfolio, and lab reports

Prerequisites: none

Enrollment Limit: 48;12/lab

Enrollment Preferences: first and second-year students

Expected Class Size: 30/lec

Grading: yes pass/fail option, no fifth course option

Unit Notes: non-major course

Distributions: (D3)

Spring 2025

LEC Section: 01 TR 9:55 am - 11:10 am

LAB Section: 02 T 1:00 pm - 2:30 pm Kevin Flaherty

LAB Section: 03 T 2:30 pm - 4:00 pm Kevin Flaherty

LAB Section: 04 W 1:00 pm - 2:30 pm Kevin Flaherty

LAB Section: 05 W 2:30 pm - 4:00 pm Kevin Flaherty

ASTR 104 (S) The Milky Way Galaxy and the Universe Beyond

How was the Universe created, and how has it evolved to its presently observed structure? This course will start at the Big Bang, the beginning of everything, and move forward from there. About five centuries ago Galileo Galilei used his own primitive telescope to make many astronomical discoveries: observing the moons of the Jupiter, craters on the Moon, and Sun spots to name a few. Galileo also noticed that stars are not spread on the celestial sphere at random but form a disk like structure, which we now call the Milky Way Galaxy -- our cosmic home. Almost a hundred years ago Edwin Hubble discovered that the Universe contains many galaxies and that they are moving away from each other. Hubble discovered that the Universe -- the largest physical object -- expands, so it had a beginning. In this course we will explore the tools and techniques that astronomers use to study stars and galaxies. From the discovery of the Milky Way to the expanding Universe, we will cover the key concepts and discoveries that have shaped our understanding of the cosmos. During recent decades astronomers have made exciting -- and unsettling -- new discoveries: it turns out that most of matter in the Universe does not emit light and most probably is composed of particles of unknown origin, and that the expansion of the Universe is now accelerating, pushed by a mysterious dark energy. At this point, astronomers have evidence to show that at early epochs the Universe was very dense and very hot. This early epoch is called the Big Bang. How the Big Bang happened is not known yet but there are several interesting hypotheses that our Universe could be one of many. This course will introduce important highlights in the observation and interpretation of remarkable astronomical phenomena and explore these many mysteries.

Class Format: lecture (two sessions per week), observing sessions (scattered throughout the semester), afternoon labs (five times per semester), and a planetarium demonstration. Planetarium and Roof-Observatory TAs will be available for consultation, in addition to the instructors, throughout the semester. Current astronomical discoveries will be discussed at the beginning of each class and by email throughout the semester.

Requirements/Evaluation: two hour exams, a final exam, lab reports, and an observing portfolio

Prerequisites: none

Enrollment Limit: 25

Enrollment Preferences: first-years

Expected Class Size: 15

Grading: yes pass/fail option, no fifth course option

Unit Notes: non-major course

Distributions: (D3)

Not offered current academic year

ASTR 111 (F) Introduction to Astrophysics (QFR)

The science of astronomy spans vast scales of space and time, from individual atoms to entire galaxies and from the universe's beginning to the future fate of our Sun. In this course, we will survey some of the main ideas in modern astrophysics, with an emphasis on the physics of stars and galaxies.

ASTR 111 is the first course in the Astrophysics and Astronomy major sequences. It is also appropriate for students planning to major in one of the

other sciences or mathematics and for others who would like a quantitative introduction that emphasizes the relationship of contemporary physics to astronomy. Topics include gravity and orbits, radiation laws and stellar spectra, physical characteristics of the Sun and other stars, star formation and evolution, black holes, galaxies, the expanding universe, and the Big Bang. Students will also use telescopes to observe stars, nebulae, planets, and galaxies and to make daytime observations of the Sun.

Class Format: The class has weekly afternoon laboratory sessions, which will alternate between 'hands-on' activities and problem-solving/discussion sessions. Nighttime observing sessions will occur throughout the semester.

Requirements/Evaluation: weekly problem sets, two hour-long tests, a final exam, lab reports, and an observing portfolio

Prerequisites: a year of high school Physics, concurrent college Physics, or permission of instructor, and MATH 140 or equivalent

Enrollment Limit: 28; 14/lab

Enrollment Preferences: potential Astronomy majors

Expected Class Size: 15

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Quantitative/Formal Reasoning Notes: The course requires regular problem sets and quantitative assignments. The course will emphasize how physical equations explain the observed properties of the universe.

Fall 2024

LEC Section: 01 TR 11:20 am - 12:35 pm Anne Jaskot

LAB Section: 02 M 1:10 pm - 3:50 pm Kevin Flaherty, Anne Jaskot

LAB Section: 03 R 1:10 pm - 3:50 pm Kevin Flaherty, Anne Jaskot

ASTR 206 (S) Astrobiology (QFR)

This course will focus on the development of complex life and its observational signatures, both on Earth and on other worlds. We will first investigate the conditions that have led to the development of complex life on Earth. We will view Earth over time from an outsider's perspective and challenge preconceptions about the basic requirements for life. We will also explore the 'hot spots' in the search for life beyond Earth in our Solar System. Observations in the next decade may reveal biosignatures in the atmospheres of exoplanets. We will learn about these future observations, while also interacting with current research-grade data for other planets and learning about the methods used to constrain the physical conditions on other worlds. Using quantitative models, we will test the stability of Earth-like planets to the variable and potentially hostile conditions of evolving solar systems.

Requirements/Evaluation: weekly problem sets, one paper, two mid-term exams, and a final exam

Prerequisites: Math 130 and at least one prior physical science course (either Astronomy, Physics, Geosciences, or Chemistry), or permission of instructor

Enrollment Limit: 20

Enrollment Preferences: Science majors, with preference given to students majoring in Astronomy, Astrophysics, or Geosciences

Expected Class Size: 12

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Quantitative/Formal Reasoning Notes: In this course students will make quantitative comparisons between environmental conditions on Earth, other planetary bodies, and models. The students will also examine observations regarding the detection and characterization of planetary bodies, including contemporary data.

Spring 2025

LEC Section: 01 MR 2:35 pm - 3:50 pm

ASTR 211 (S) Astronomical Observing and Data Analysis (QFR)

How do astronomers make scientific measurements for objects that are light-years away from Earth? This course will introduce the basics of telescopes and observations and will give students hands-on training in the techniques astronomers use to obtain, process, and analyze scientific

data. We will discuss observation planning, CCD detectors, signal statistics, image processing, and photometric and spectroscopic observations. We will begin by focusing on ground-based optical observations and will move on to non-optical observations, both electromagnetic (e.g., radio waves, X-rays) and non-electromagnetic (e.g., gravitational waves, neutrinos). Throughout the course, students will use computational techniques to work with real astronomical data, taken with our 24" telescope and from data archives.

Class Format: discussion, computer lab work, and observing

Requirements/Evaluation: weekly problem sets, lab work, and observing projects

Prerequisites: MATH 150 or 151; prior experience with Unix and computer programming is helpful, but not required

Enrollment Limit: 14

Enrollment Preferences: Astronomy or Astrophysics majors

Expected Class Size: 8

Grading: no pass/fail option, no fifth course option

Distributions: (D3) (QFR)

Quantitative/Formal Reasoning Notes: The course requires regular problem sets. Labs require computer programming and statistical and graphical analyses of data.

Not offered current academic year

ASTR 220 (S) New Discoveries with the James Webb Space Telescope

Launched in December 2021, the James Webb Space Telescope (JWST) has delivered new views of the universe and is reshaping our understanding of our solar system, planets around other stars, star formation, and galaxies in the early universe. The beautifully detailed images have also generated intense public interest and are often the subject of science articles in the news. Through JWST's new observations, this course will explore both cutting-edge astronomical science and science communication. We will focus on open questions in each of JWST's four themes: Other Worlds, Star Lifecycle, Galaxies Over Time, and Early Universe. We will discuss the science behind these questions, recent discoveries, and how astronomers are using JWST to learn more. We will also learn about astronomical observations, how JWST works, and how astronomers collect and evaluate scientific evidence. Students will discuss how discoveries are communicated to the public, analyze stories in popular media, and create their own versions of public astronomy communications.

Requirements/Evaluation: weekly homework questions and short writing assignments, class participation, mid-term written article, and final project

Prerequisites: none

Enrollment Limit: 20

Enrollment Preferences: Astronomy/Astrophysics majors and prospective majors, sophomores

Expected Class Size: 12

Grading: yes pass/fail option, yes fifth course option

Unit Notes: non-major course

Distributions: (D3)

Spring 2025

LEC Section: 01 MR 1:10 pm - 2:25 pm Anne Jaskot

ASTR 240 (F) Great Astronomers and Their Original Publications (WS)

Cross-listings: STS 240 / LEAD 240

Primary Cross-listing

In this course we will study some of the greatest figures in astronomy and consider their leadership in advancing progress in the field. We will consider their lives and works, especially as represented by original copies of their books and other publications. These great astronomers include: 16th century, Nicolaus Copernicus (heliocentric universe); Tycho Brahe (best pre-telescopic observations); 17th century, Galileo (discoveries with his first astronomical telescope, 1610; sunspots, 1613; *Dialogo*, 1632); Johannes Kepler (laws of planetary motion, 1609, 1619, Rudolphine Tables 1627); Johannes Hevelius and Elisabeth Hevelius (atlases of the Moon and of stars, 1647, and 1687); Isaac Newton (*Principia Mathematica*: laws of universal gravitation and of motion, 1687); 18th century, Edmond Halley (*Miscellanea curiosa*, eclipse maps, 1715, 1724); John Flamsteed and Margaret Flamsteed (*Atlas Coelestis*, 1729); and William Herschel and Caroline Herschel (1781, 1798). Also, from more recent times in which original works are

often articles rather than books: 20th century, Albert Einstein (special relativity, 1905; general relativity, 1916); Marie Curie (radioactivity); Cecilia Payne-Gaposchkin (hydrogen dominating stars, 1929), Edwin Hubble (Hubble's law, 1929); George Ellery Hale (Mt. Wilson Observatory 100" telescope, 1917; Palomar Observatory 200" telescope, 1948), Vera Rubin (dark matter, 1970s); Jocelyn Bell Burnell (pulsar discovery, 1968); and 21st century: Wendy Freedman (Universe's expansion rate, 2000s). First editions will be available in Williams' Chapin Library of rare books, where we will meet in an adjacent classroom. We will also consider how such original materials are collected and preserved, and look at examples from the wider world of rarities, such as a leaf from the Gutenberg Bible (c. 1453) and a Shakespeare First Folio (1623, with a discussion of astronomical references in Shakespeare's plays). The course will be taught in collaboration between an astronomer and a rare-books librarian, with remote lectures by experts from around the world.

Class Format: Meeting on campus in the Chapin Library classroom (Sawyer 452)

Requirements/Evaluation: class participation, two 5-page intermediate papers, and a final 15-page paper; student choice of additional readings from a provided reading list

Prerequisites: none

Enrollment Limit: 12

Enrollment Preferences: if overenrolled, preference by written paragraph of explanation of why student wants to take the course

Expected Class Size: 12

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (WS)

This course is cross-listed and the prefixes carry the following divisional credit:

ASTR 240(D3) STS 240(D2) LEAD 240(D2)

Writing Skills Notes: Comments on submitted papers will aid in writing skills

Attributes: LEAD Facets or Domains of Leadership

Not offered current academic year

ASTR 330 (S) The Nature of the Universe

This course is a journey through space and time from the first fractions of a second after the Big Bang to the ultimate fate of the Universe billions of years into the future. Topics include the Big Bang and its remnant cosmic background radiation, cosmic inflation, conditions during the first three minutes, creation of the elements, stellar and galactic black holes, relativity, the detection of gravitational waves, galaxies and quasars, dark matter, and the formation of the large-scale structure of the Universe. We will explore current ideas about the fate of our Universe, including the acceleration of its expansion, and its implications for the end of time. Finally, we will consider the fantastic but serious theoretical proposal that ours is but one of countless universes existing within a *multiverse*.

Class Format: lecture/discussion, three hours per week

Requirements/Evaluation: two midterm exams, a small observing portfolio, occasional quizzes, and a final exam

Prerequisites: none

Enrollment Limit: 48

Enrollment Preferences: open only to juniors and seniors; closed to students who have taken or are taking ASTR 104, and closed to ASTR, ASPH, and PHYS majors; preference given to seniors

Expected Class Size: 25

Grading: yes pass/fail option, no fifth course option

Unit Notes: non-major course; course in the 33X sequence are meant as general education courses for students in all majors

Distributions: (D3)

Not offered current academic year

ASTR 402 (S) Between the Stars: The Interstellar Medium (QFR)

The matter between the stars--the interstellar medium--tells the story of the evolution of galaxies and the stars within them. Stars are accompanied by diffuse matter all through their lifetimes, from their birthplaces in dense molecular clouds, to the stellar winds they eject as they evolve, and to their final fates as they shed their outer layers, whether as planetary nebulae or dazzling supernovae. As these processes go on, they enrich the interstellar medium with the products of the stars' nuclear fusion. Interpreting the emission from this interstellar gas is one of astronomers' most powerful tools to

measure the physical conditions, motions, and composition of our own galaxy and others. In this course we will study the interstellar medium in its various forms, from cold, dense, star-forming molecular clouds to X-ray-emitting bubbles formed by supernovae. We will learn about the physical mechanisms that produce the radiation we observe, including radiative ionization and recombination, collisional excitation of "forbidden" lines, collisional ionization, and synchrotron radiation. Applying our understanding of these processes, we will analyze the physical conditions and chemical compositions of a variety of nebulae. Finally, we will discuss the evolution of interstellar material in galaxies across cosmic time. This course is observing-intensive. Throughout the semester, students will work in small groups to design, carry out, analyze, and critique their own observations of the interstellar medium taken using the rooftop telescope.

Class Format: Tutorial meetings will be scheduled with the professor. Students will also complete observing projects using the rooftop telescope.

Requirements/Evaluation: weekly problem sets, 10-page final paper, and observing projects

Prerequisites: ASTR 111 and PHYS 201 or permission of instructor

Enrollment Limit: 10

Enrollment Preferences: juniors and seniors

Expected Class Size: 6

Grading: no pass/fail option, no fifth course option

Distributions: (D3) (QFR)

Quantitative/Formal Reasoning Notes: In this course, students will derive quantitative physical formulas, use these equations to calculate and compare physical properties, and generate and analyze graphical representations of data. They will also make and analyze measurements of astronomical data through observing projects.

Spring 2025

TUT Section: T1 TBA Anne Jaskot

ASTR 404 (S) Unsolved Problems in Galaxy Evolution

In this tutorial, we will learn about galaxies and their evolution by focusing on some of the key mysteries astronomers are trying to solve. Questions may include: How do galaxies turn their gas supply into stars? Is there a universal initial mass function for star formation? What is the origin of multiple stellar populations in globular clusters? Why do some galaxies cease star formation? Which galaxies reionized the universe? We will discuss the nature of each unsolved problem, debate the theories proposed to answer it, and consider how future progress might be made.

Requirements/Evaluation: student's papers, responses to the partner's papers, and problem sets

Prerequisites: ASTR 111 and PHYS 142 or 151 or permission of instructor

Enrollment Limit: 10

Enrollment Preferences: Juniors and Seniors

Expected Class Size: 6

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

Not offered current academic year

ASTR 410 (S) Compact Stellar Remnants: White Dwarfs, Neutron Stars and Black Holes

A star is a very interesting, very complicated physical object. Properties of stars and their evolutionary paths depend on an intricate interplay of different physical phenomena with gravity, nuclear interactions, radiation processes and even quantum and relativistic effects playing important roles. Using basic physics we will construct simple models of stars and discuss their evolution, concentrating on the key physical processes that play the dominant role at different evolutionary stages. We will discuss late stages of stellar evolution and concentrate on the basic properties of three possible remnants: white dwarfs, neutron stars and black holes. Radio and X-ray pulsars, supernovae including Type Ia and Gamma Ray Bursts will be discussed as well as observational confirmation of existence of black holes. We will explore extreme conditions existing near neutron stars and black holes and discuss their astrophysical consequences. We will also discuss the recent exciting detection of gravitational waves by the LIGO/VIRGO laser interferometric detectors.

Class Format: discussion three hours per week

Requirements/Evaluation: classroom participation, homework assignments, a midterm exam and a final exam

Prerequisites: PHYS 201 or permission of instructor

Enrollment Limit: 19

Enrollment Preferences: physics, astrophysics, and astronomy majors

Expected Class Size: 12

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

Not offered current academic year

ASTR 413 (F) Building Stars: A Physical Model of Stellar Structure (QFR)

How does the Sun shine? How does the Sun evolve with time? What physical processes determine the power output of the Sun? In this course we will explore our modern understanding of how stars work, and why they have a range of sizes, temperatures, and luminosities. As we go, we will discuss the laws of physics at work in our Sun and other stars. Over the course of the semester, we will build a working computer model of the Sun using the basic laws of nuclear fusion, radiative transfer, thermal mechanics, and hydrostatic equilibrium.

Class Format: Lectures will include time for computer programming work

Requirements/Evaluation: weekly problem sets, weekly coding homework assignments, two mid-term exams, and a final project

Prerequisites: PHYS 142 or 151, any prior class that makes use of programming, or permission of instructor

Enrollment Limit: 10

Enrollment Preferences: Astronomy, Astrophysics, or Physics majors, with first preference to Astronomy or Astrophysics majors

Expected Class Size: 6

Grading: no pass/fail option, no fifth course option

Distributions: (D3) (QFR)

Quantitative/Formal Reasoning Notes: In this course, students will use differential equations and numerical coding techniques to test and explore the relationships between physical laws using the Sun and other stars as examples. They will make quantitative comparisons between their calculations and observed stellar properties.

Fall 2024

LEC Section: 01 TR 11:20 am - 12:35 pm

ASTR 493 (F) Senior Research: Astronomy

An original experimental or theoretical investigation is carried out under the direction of a faculty member in Astronomy, as discussed under the heading of the degree with honors in Astronomy above. This is part of a full-year thesis (493-494).

Prerequisites: permission of department

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

Fall 2024

HON Section: 01 TBA David R. Tucker-Smith

ASTR 494 (S) Senior Research: Astronomy

An original experimental or theoretical investigation is carried out under the direction of a faculty member in Astronomy, as discussed under the heading of the degree with honors in Astronomy above. This is part of a full-year thesis (493-494).

Prerequisites: permission of department

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

Spring 2025

HON Section: 01 TBA David R. Tucker-Smith

ASTR 495 (F) Senior Research: Astrophysics

Cross-listings: PHYS 495

Primary Cross-listing

An original experimental or theoretical investigation is carried out under the direction of a faculty member in Astronomy or Physics, as discussed under the heading of the degree with honors in Astrophysics above.

Prerequisites: permission of department

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

This course is cross-listed and the prefixes carry the following divisional credit:

ASTR 495(D3) PHYS 495(D3)

Fall 2024

HON Section: 01 TBA David R. Tucker-Smith

ASTR 496 (S) Senior Research: Astrophysics

Cross-listings: PHYS 496

Primary Cross-listing

An original experimental or theoretical investigation is carried out under the direction of a faculty member in Astronomy or Physics, as discussed under the heading of the degree with honors in Astrophysics above.

Prerequisites: permission of department

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

This course is cross-listed and the prefixes carry the following divisional credit:

ASTR 496(D3) PHYS 496(D3)

Spring 2025

HON Section: 01 TBA David R. Tucker-Smith

ASTR 497 (F) Independent Study: Astronomy or Astrophysics

Astronomy independent study.

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

Fall 2024

IND Section: 01 TBA David R. Tucker-Smith

ASTR 498 (S) Independent Study: Astronomy or Astrophysics (QFR)

Astronomy/Astrophysics independent study, directed by one of the Astronomy faculty: Pasachoff/Jaskot/Flaherty

Requirements/Evaluation: Regular work with the instructor; submitted presentations and papers as agreed upon

Prerequisites: suitable Astronomy/Astrophysics/Physics/Math-Stats-Geosciences/Chemistry courses

Enrollment Limit: 10

Enrollment Preferences: research topic

Expected Class Size: 5

Grading: no pass/fail option, no fifth course option

Distributions: (D3) (QFR)

Quantitative/Formal Reasoning Notes: Substantial quantitative and formal reasoning are involved

Spring 2025

IND Section: 01 TBA David R. Tucker-Smith

ASTR 499 (F)(S) Physics and Astronomy Colloquium

Cross-listings: PHYS 499

Secondary Cross-listing

Physicists and Astronomers from around the country come to explain their research. Students of Physics and Astronomy at any level are welcome. Registration is not necessary to attend. A non-credit course.

Class Format: colloquium

Requirements/Evaluation: not a for-credit course

Prerequisites: none

Enrollment Limit: none

Enrollment Preferences: none

Grading: non-graded

Unit Notes: registration not necessary to attend

Distributions: No divisional credit

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 499No divisional credit ASTR 499No divisional credit

Fall 2024

LEC Section: 01 F 2:35 pm - 3:50 pm David R. Tucker-Smith

Spring 2025

LEC Section: 01 F 2:35 pm - 3:50 pm David R. Tucker-Smith

Winter Study -----

ASTR 31 (W) Senior Research: Astronomy

To be taken by students registered for Astronomy 493, 494.

Grading: pass/fail only

Not offered current academic year

ASTR 32 (W) Senior Research: Astrophysics

Cross-listings: PHYS 32

Primary Cross-listing

To be taken by students registered for Astrophysics 495, 496.

Class Format: independent study

Grading: pass/fail only

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 32ASTR 32

Not offered current academic year

ASTR 99 (W) Independent Study: Astronomy or Astrophysics

Open to upperclass students. Students interested in doing an independent project (99) during Winter Study must make prior arrangements with a faculty sponsor. The student and professor then complete the independent study proposal form available online. The deadline is typically in late September. Proposals are reviewed by the pertinent department and the Winter Study Committee. Students will be notified if their proposal is approved prior to the Winter Study registration period.

Grading: pass/fail only

Not offered current academic year