The Department of Astronomy offers two undergraduate degrees, a Bachelor of Science and a Bachelor of Arts. The BS provides a rigorous sequence of subject-specific courses, while the BA degree provides somewhat more flexibility in the choice of courses. The department also offers a minor in astronomy.

The curriculum emphasizes a broad and substantial education in astronomy, physics, and mathematics. A faculty actively engaged in research provides first-rate instruction and opportunities for undergraduate involvement in research.

A bachelor’s degree in astronomy can prepare students for graduate study in astronomy (about 50% of our graduates take this path), but those who seek employment in other fields can fill the same jobs as physics and computer science majors.

A faculty actively engaged in research provides first-rate instruction and opportunities for undergraduate involvement in research.

The Department of Astronomy operates the Kitt Peak Station of the Warner and Swasey Observatory near Tucson, Ariz., home of the Burrell Schmidt telescope. This telescope is used for surveys and ultra-deep imaging with a large format CCD. Observatory operations are managed by Dr. Paul Harding and Charles Knox. Dr. Harding also leads departmental efforts in instrumentation for the Observatory.

On the Case Western Reserve campus, a 9.5-inch refractor permanently mounted on the roof of the A. W. Smith Building is available for use by students. The department also houses a research and instruction computer laboratory and has access to the university’s high-performance computing cluster.

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The curriculum emphasizes a broad and substantial education in astronomy, physics, and mathematics. A faculty actively engaged in research provides first-rate instruction and opportunities for undergraduate involvement in research.

A bachelor’s degree in astronomy can prepare students for graduate study in astronomy (about 50% of our graduates take this path), but those who seek employment in other fields can fill the same jobs as physics and computer science majors.

The department offers a graduate program leading to the degree of Doctor of Philosophy in astronomy. Current research provides opportunities in observational and theoretical studies of galaxy formation and evolution, galaxy cluster evolution, astronomical instrumentation, and cosmology.

Facilities
The Department of Astronomy operates the Kitt Peak Station of the Warner and Swasey Observatory near Tucson, Ariz., home of the Burrell Schmidt telescope. This telescope is used for surveys and ultra-deep imaging with a large format CCD. Observatory operations are managed by Dr. Paul Harding and Charles Knox. Dr. Harding also leads departmental efforts in instrumentation for the Observatory.

On the Case Western Reserve campus, a 9.5-inch refractor permanently mounted on the roof of the A. W. Smith Building is available for use by students. The department also houses a research and instruction computer laboratory and has access to the university’s high-performance computing cluster.

Department Faculty
Stacy S. McGaugh, PhD
(University of Michigan)
Professor and Chair, Director, Warner and Swasey Observatory
Galaxy formation and evolution; low surface brightness galaxies; cosmology; dark matter and gravity

William F. Janesh, PhD
(Indiana University)
Instructor
Searches for dwarf galaxies; development of software tools

R. Earle Luck, PhD
(University of Texas, Austin)
Worcester R. and Cornelia B. Warner Professor of Astronomy
Stellar and galactic chemical evolution; stellar spectrophotometry

J. Christopher Mihos, PhD
(University of Michigan)
Professor
Galaxy evolution; interacting and merging galaxies; galaxy clusters; computational and observational astronomy

Adjunct Faculty
Jeffery R. Kriessler, PhD
(Michigan State University)
Adjunct Assistant Professor
Substructure in galaxy clusters

Secondary Faculty
John Ruhl, PhD
(Princeton University)
Connecticut Professor, Department of Physics
Experimental astrophysics and cosmology

Glenn D. Starkman, PhD
(Stanford University)
Distinguished University Professor, Department of Physics
Theoretical cosmology; particle physics; astrophysics

Bachelor of Science in Astronomy
The Bachelor of Science in astronomy requires 122 credit hours, including 23 hours in astronomy, 40 hours in physics, 14 hours in math, 3 hours in computer programming and 12 hours in technical electives.

Major courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 221</td>
<td>Stars and Planets</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 222</td>
<td>Galaxies and Cosmology</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 306</td>
<td>Astronomical Techniques</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 309</td>
<td>Astrophysics Seminar I</td>
<td>1</td>
</tr>
<tr>
<td>ASTR 310</td>
<td>Astrophysics Seminar II</td>
<td>1</td>
</tr>
<tr>
<td>ASTR 311</td>
<td>Stellar Physics</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 323</td>
<td>The Local Universe</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 328</td>
<td>Cosmology and the Structure of the Universe</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 333</td>
<td>Dark Matter</td>
<td>3</td>
</tr>
</tbody>
</table>

Additional required courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
<td>4</td>
</tr>
<tr>
<td>or MATH 124</td>
<td>Calculus II</td>
<td></td>
</tr>
<tr>
<td>MATH 223</td>
<td>Calculus for Science and Engineering III</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 227</td>
<td>Calculus III</td>
<td></td>
</tr>
<tr>
<td>MATH 224</td>
<td>Elementary Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>or MATH 228</td>
<td>Differential Equations</td>
<td></td>
</tr>
<tr>
<td>PHYS 121</td>
<td>General Physics I - Mechanics</td>
<td>4</td>
</tr>
</tbody>
</table>
Department of Astronomy

or PHYS 123 Physics and Frontiers I - Mechanics
PHYS 122 General Physics II - Electricity and Magnetism 4
or PHYS 124 Physics and Frontiers II - Electricity and Magnetism

PHYS 203 Analog and Digital Electronics 4
PHYS 204 Advanced Instrumentation Laboratory

PHYS 221 Introduction to Modern Physics 3
PHYS 250 Computational Methods in Physics 3
PHYS 310 Classical Mechanics 3
PHYS 313 Thermodynamics and Statistical Mechanics 3

PHYS 324 Electricity and Magnetism I 3
PHYS 325 Electricity and Magnetism II 3
PHYS 331 Introduction to Quantum Mechanics I 3
PHYS 332 Introduction to Quantum Mechanics II 3
ENGR 131 Elementary Computer Programming 3

Approved technical electives (these can be from the Departments of Astronomy; Chemistry; Mathematics, Applied Mathematics, and Statistics; Physics; or Earth, Environmental, and Planetary Sciences. Check with advisor for complete list.)

MATH 201 Introduction to Linear Algebra for Applications
EEPS 345 Planetary Materials
PHYS 316 Introduction to Nuclear and Particle Physics
PHYS 349 Methods of Mathematical Physics I
PHYS 326 Physical Optics
PHYS 350 Methods of Mathematical Physics II

Total Units 92

Six hours of mathematics and natural science (physics) are double counted towards the SAGES breadth requirements, and one required math course is double counted towards the SAGES Quantitative Reasoning requirement.

Sample Plan of Study: Bachelor of Science in Astronomy

First Year

<table>
<thead>
<tr>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Fall</td>
</tr>
<tr>
<td>Spring</td>
</tr>
</tbody>
</table>

Calculus for Science and Engineering I (MATH 121) 4
General Physics I - Mechanics (PHYS 121) 4
PHED (2 half semester courses) 0
SAGES First Seminar 4
Social Science I 3
Calculus for Science and Engineering II (MATH 122) or Calculus II (MATH 124) 4
General Physics II - Electricity and Magnetism (PHYS 122) 4
PHED (2 half semester courses) 0
Elementary Computer Programming (ENGR 131) 3
Doing Astronomy (ASTR 151) 1

Year Total: 15 15

Second Year

<table>
<thead>
<tr>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
</tr>
<tr>
<td>Spring</td>
</tr>
</tbody>
</table>

Stars and Planets (ASTR 221) 3
Calculus for Science and Engineering III (MATH 223) or Calculus III (MATH 227) 3
Introduction to Modern Physics (PHYS 221) 3
Analog and Digital Electronics (PHYS 203) 4
SAGES University Seminar 3
Galaxies and Cosmology (ASTR 222) 3
Elementary Differential Equations (MATH 224) or Differential Equations (MATH 228) 3
Advanced Instrumentation Laboratory (PHYS 204) 4
Computational Methods in Physics (PHYS 250) 3
SAGES University Seminar 3
Year Total: 16 16

Third Year

<table>
<thead>
<tr>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>Fall</td>
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<tr>
<td>Spring</td>
</tr>
</tbody>
</table>

Cosmology and the Structure of the Universe (ASTR 328) 3
Thermodynamics and Statistical Mechanics (PHYS 313) 3
Technical Elective 3
Arts & Humanities II 3
Social Science II 3
Stellar Physics (ASTR 311) 3
Electricity and Magnetism I (PHYS 324) 3
Classical Mechanics (PHYS 310) 3
Quantitative Reasoning 3
Technical Elective 3
Year Total: 15 15

Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
</tr>
<tr>
<td>Spring</td>
</tr>
</tbody>
</table>

Astronomical Techniques (ASTR 306) 3
Astrophysics Seminar I (ASTR 309) 1
The Local Universe (ASTR 323) 3
Electricity and Magnetism II (PHYS 325) 3
Introduction to Quantum Mechanics I (PHYS 331) 3
Astronomy Capstone Project (ASTR 351) 1-3
Technical Elective 3
Astrophysics Seminar II (ASTR 310) 1
Dark Matter (ASTR 333) 3
Introduction to Quantum Mechanics II (PHYS 332) 3
Astronomy Capstone Project (ASTR 351) 1-3
Technical Elective 3
Global and Cultural Diversity 3
Year Total: 17-19 14-16
Total Units in Sequence: 123-127

a. Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics, PHYS 124 Physics and Frontiers II - Electricity and Magnetism, in place of PHYS 121 General Physics I - Mechanics, PHYS 122 General Physics II - Electricity and Magnetism.

b. ASTR 306 Astronomical Techniques, ASTR 311 Stellar Physics, ASTR 323 The Local Universe, ASTR 328 Cosmology and the Structure of the Universe, and ASTR 333 Dark Matter are taught every other year only.

c. A SAGES Capstone Experience is required of all students. The BS does not require the astronomy capstone but only that a capstone be taken. The number of hours shown assumes the astronomy capstone with 1 hour in the senior fall semester and 3 hours in the senior spring semester. If another capstone is taken, the number of hours may be different.

Bachelor of Arts in Astronomy

The Bachelor of Arts in astronomy requires 120 credit hours, including 20 hours in astronomy, 26 hours in physics, 14 hours in math, 3 hours in computer programming, and 6 hours in technical electives.

Required 200 Level Courses

- ASTR 221 Stars and Planets
- ASTR 222 Galaxies and Cosmology

Required 300 Level Courses

- ASTR 306 Astronomical Techniques
- ASTR 309 Astrophysics Seminar I
- ASTR 310 Astrophysics Seminar II

Additional 300 Level Courses—3 of 4 Required

- ASTR 311 Stellar Physics
- ASTR 323 The Local Universe
- ASTR 328 Cosmology and the Structure of the Universe (Additional required courses)
- ASTR 333 Dark Matter

Additional required courses

- MATH 121 Calculus for Science and Engineering I
- MATH 122 Calculus for Science and Engineering II
- or MATH 124 Calculus II
- MATH 221 Introduction to Modern Physics
- or MATH 223 Calculus III
- MATH 224 Elementary Differential Equations
- or MATH 227 Calculus III
- MATH 228 Differential Equations
- PHYS 121 General Physics I - Mechanics
- or PHYS 123 Physics and Frontiers I - Mechanics
- PHYS 122 General Physics II - Electricity and Magnetism
- or PHYS 124 Physics and Frontiers II - Electricity and Magnetism

PHYS 221 Introduction to Modern Physics
PHYS 250 Computational Methods in Physics
PHYS 310 Classical Mechanics
PHYS 313 Thermodynamics and Statistical Mechanics
PHYS 324 Electricity and Magnetism I
PHYS 331 Introduction to Quantum Mechanics I
ENGR 131 Elementary Computer Programming

Total Units 69

Six hours of mathematics and natural science (physics) are double counted towards the SAGES breadth requirements, and one required math course is double counted towards the SAGES Quantitative Reasoning requirement.

Sample Plan of Study: Bachelor of Arts in Astronomy

First Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
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<td>15</td>
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</table>

Year Total: 15

Second Year

<table>
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<tr>
<th>Units</th>
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<th>Spring</th>
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<tbody>
<tr>
<td>12</td>
<td>12</td>
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</table>

Year Total: 12

Six hours of mathematics and natural science (physics) are double counted towards the SAGES breadth requirements, and one required math course is double counted towards the SAGES Quantitative Reasoning requirement.
Classical Mechanics (PHYS 310) 3
SAGES University Seminar 3
Year Total: 12 15

### Third Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>Cosmology and the Structure of the Universe (ASTR 328)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Thermodynamics and Statistical Mechanics (PHYS 313)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Arts &amp; Humanities I</td>
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<td></td>
</tr>
<tr>
<td>Arts &amp; Humanities II</td>
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<td></td>
</tr>
<tr>
<td>Technical Elective</td>
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<td></td>
</tr>
<tr>
<td>Stellar Physics (ASTR 311)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Electricity and Magnetism I (PHYS 324)</td>
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<td></td>
</tr>
<tr>
<td>Quantitative Reasoning</td>
<td>3</td>
<td></td>
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<tr>
<td>Technical Elective</td>
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<tr>
<td>Year Total:</td>
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### Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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</thead>
<tbody>
<tr>
<td>Astronomical Techniques (ASTR 306)(^a)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Astrophysics Seminar I (ASTR 309)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Introduction to Quantum Mechanics I (PHYS 331)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Astronomy Capstone Project (ASTR 351)(^b)</td>
<td>1 - 3</td>
<td></td>
</tr>
<tr>
<td>Global and Cultural Diversity</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Astrophysics Seminar II (ASTR 310)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Dark Matter (ASTR 333)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Astronomy Capstone Project (ASTR 351)(^b)</td>
<td>1 - 3</td>
<td></td>
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<tr>
<td>Year Total:</td>
<td>11-13</td>
<td>5-7</td>
</tr>
</tbody>
</table>

Total Units in Sequence: 100-104

\(^a\) 300-level astronomy courses: three of the following five are required: ASTR 306, ASTR 311, ASTR 323, ASTR 328, ASTR 333.

\(^b\) A SAGES Capstone Experience is required of all students. The BA in astronomy does not require the astronomy capstone but only that a capstone be taken. The number of hours shown assumes the astronomy capstone with 1 hour in the senior fall semester and 3 hours in the senior spring semester. If another capstone is taken, the number of hours may be different.

\(^*\) Suggested, but not required for the major.

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**Graduate Program**

The PhD degree in astronomy is granted to those students who have shown an extensive knowledge of advanced astronomy and the ability to do original research. The student is required to pass a general qualifying examination in astronomy, usually taken at the end of the second year. The student must then prepare a dissertation based on the results of independent research. A PhD candidate must also satisfy the general requirements of the School of Graduate Studies.

Full-time graduate students who maintain satisfactory academic performance while pursuing the PhD degree in astronomy normally receive a stipend for teaching and/or research, which includes full tuition and a monthly amount sufficient to cover living expenses.

**Courses**

**ASTR 101. Introduction to the Sun and Its Planets. 3 Units.**

This introductory astronomy course describes our solar system of planets and how astronomers develop our physical understanding about the universe. Topics include the properties of the Sun and planets; the formation of the solar system and how the planets have evolved over time; asteroids, comets, and dwarf planets; and a comparison of our solar system with new planetary systems being found around other stars. This course has no pre-requisites.

**ASTR 103. Introduction to the Stars, Galaxies, and the Universe. 3 Units.**

This introductory astronomy course describes the universe we live in and how astronomers develop our physical understanding about it. Topics covered include: the properties of stars; the formation, evolution, and death of stars; white dwarfs, pulsars, and black holes; spiral and elliptical galaxies; the Big Bang and the expansion of the Universe. This course has no pre-requisites.

**ASTR 105. Introduction to Einstein’s Universe. 3 Units.**

This course is a descriptive introduction for the non-science major to Einstein’s Special and General Theories of Relativity and how these theories have fundamentally altered our understanding of the universe. Topics discussed will include: time dilation, length contraction, the twin paradox, the warping of space-time, white dwarf stars, neutron stars, black holes, the structure and evolution of the universe. No mathematical background beyond simple algebra is needed. This course has no pre-requisites.

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**Minor in Astronomy**

The requirements for the minor in astronomy are as follows:

One of the following: 4

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>PHYS 115</td>
<td>Introductory Physics I</td>
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<tr>
<td>PHYS 121</td>
<td>General Physics I - Mechanics</td>
<td></td>
</tr>
<tr>
<td>PHYS 123</td>
<td>Physics and Frontiers I - Mechanics</td>
<td></td>
</tr>
</tbody>
</table>

One of the following: 4

| PHYS 116 | Introductory Physics II |

---

**Graduate Program**

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ASTR 107. Introduction to Life in the Universe. 3 Units.
This course is intended to introduce the non-scientist to the field of astrobiology - the interdisciplinary study of, and the search for, extraterrestrial life and the conditions for extraterrestrial life in the Universe. This course has no pre-requisites.

ASTR 151. Doing Astronomy. 1 Unit.
This course is intended to introduce students to how astronomy is done. The course will focus on the astronomical research process, the scientific community, and on career paths in astronomy. Course activities will include readings and class discussions focusing on various topics in modern astronomy, including ongoing research activity in the department. This course is largely intended for first- and second-year students considering majoring or minoring in astronomy, or pursuing a career in astronomy. Prereq: First- or second-year academic standing.

ASTR 221. Stars and Planets. 3 Units.

ASTR 222. Galaxies and Cosmology. 3 Units.

ASTR 306. Astronomical Techniques. 3 Units.
This course covers the techniques astronomers use to conduct research, including observations using ground- and space-based telescopes, computer simulations and other numerical methods, and statistical data mining of large on-line astronomical datasets. Offered as ASTR 306 and ASTR 406. Counts as SAGES Departmental Seminar. Prereq: ASTR 222.

ASTR 309. Astrophysics Seminar I. 1 Unit.
Selected topics in astronomy not covered ordinarily in courses. Presentation of talks by the students. Prereq: ASTR 222 or Requisites Not Met permission.

ASTR 310. Astrophysics Seminar II. 1 Unit.
Selected topics in astronomy not covered ordinarily in courses. Presentation of talks by students. Prereq: ASTR 222 or Requisites Not Met permission.

ASTR 311. Stellar Physics. 3 Units.
Radiative transfer, atomic and molecular opacities, and the observable properties of stars. Stellar interiors, nuclear processes, and energy generation. The evolution of stars of varying mass and production of the elements within supernovae explosions. Offered as ASTR 311 and ASTR 411. Prereq: ASTR 222.

ASTR 323. The Local Universe. 3 Units.

ASTR 328. Cosmology and the Structure of the Universe. 3 Units.

ASTR 333. Dark Matter. 3 Units.
This course will systematically explore the evidence for dark matter in the universe. Necessary physical theory and astronomical concepts will be developed as appropriate. Topics to be covered include gravitational dynamics, gravitational lensing, and hydrostatic equilibrium as probes of the gravitational potentials of extragalactic systems. Examples include the rotation curves of spiral galaxies, the Oort discrepancy in the local Galactic disk, the dynamics of pressure supported dwarf and giant elliptical galaxies, and the Local Group timing problem. In clusters of galaxies, the mass discrepancy is illustrated separately by measured velocity dispersions, the hydrostatic equilibrium of the hot intracluster medium, and both strong and weak gravitational lensing. On cosmic scales, the course will address evidence from the gravitating and baryonic mass content of the universe, the growth of large scale structure from the initially smooth cosmic microwave background, and the existence of large voids and large scale bulk flows. The course will describe the various dark matter halo models commonly employed and introduce the techniques of mass modeling. We will examine hypotheses for the nature of dark matter, both baryonic and non-baryonic, and discuss strategies for experimental detection of plausible dark matter candidates. Theories that seek to explain the observed mass discrepancies by means of modifying the Law of Gravity rather than invoking dark matter will be explored. Offered as ASTR 333 and ASTR 433. Prereq: PHYS 310 or requisites not met permission.

ASTR 351. Astronomy Capstone Project. 1 - 3 Units.
A two semester course (1 hour in the Fall Semester and either 2 or 3 hours in the Spring Semester) for students desiring a Capstone Experience in astronomy. Students pursue a project based on experimental, theoretical or teaching research under the supervision of an astronomy faculty member. A departmental Capstone Project Committee must approve all project proposals (by the end of the Fall Semester) and this same committee will receive regular oral and written progress reports. Final results are presented at the end of the semester as a paper in a style suitable for publication in a professional journal as well as an oral report in a public symposium. Counts as SAGES Senior Capstone. Prereq: ASTR 222.

ASTR 369. Undergraduate Research. 1 - 3 Units.
Supervised research on topics of interest. Can be used as a thesis course if desired. Students may register more than once for a maximum of 9 credits overall (1-3 credits each semester).

ASTR 406. Astronomical Techniques. 3 Units.
This course covers the techniques astronomers use to conduct research, including observations using ground- and space-based telescopes, computer simulations and other numerical methods, and statistical data mining of large on-line astronomical datasets. Offered as ASTR 306 and ASTR 406. Counts as SAGES Departmental Seminar.

ASTR 411. Stellar Physics. 3 Units.
Radiative transfer, atomic and molecular opacities, and the observable properties of stars. Stellar interiors, nuclear processes, and energy generation. The evolution of stars of varying mass and production of the elements within supernovae explosions. Offered as ASTR 311 and ASTR 411.

ASTR 423. The Local Universe. 3 Units.
ASTR 428. Cosmology and the Structure of the Universe. 3 Units.

ASTR 433. Dark Matter. 3 Units.
This course will systematically explore the evidence for dark matter in the universe. Necessary physical theory and astronomical concepts will be developed as appropriate. Topics to be covered include gravitational dynamics, gravitational lensing, and hydrostatic equilibrium as probes of the gravitational potentials of extragalactic systems. Examples include the rotation curves of spiral galaxies, the Oort discrepancy in the local Galactic disk, the dynamics of pressure supported dwarf and giant elliptical galaxies, and the Local Group timing problem. In clusters of galaxies, the mass discrepancy is illustrated separately by measured velocity dispersions, the hydrostatic equilibrium of the hot intracluster medium, and both strong and weak gravitational lensing.
On cosmic scales, the course will address evidence from the gravitating and baryonic mass content of the universe, the growth of large scale structure from the initially smooth cosmic microwave background, and the existence of large voids and large scale bulk flows. The course will describe the various dark matter halo models commonly employed and introduce the techniques of mass modeling. We will examine hypotheses for the nature of dark matter, both baryonic and non-baryonic, and discuss strategies for experimental detection of plausible dark matter candidates. Theories that seek to explain the observed mass discrepancies by means of modifying the Law of Gravity rather than invoking dark matter will be explored. Offered as ASTR 333 and ASTR 433.

ASTR 497. Special Topics in Astronomy. 1 - 3 Units.

ASTR 601. Research. 1 - 18 Units.
Original research under the guidance of the staff.

ASTR 651. Thesis M.S.. 1 - 18 Units.
(Credit as arranged.)

ASTR 701. Dissertation Ph.D.. 1 - 9 Units.
(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.