



# Handbook for Undergraduate Students in Astronomy 2020-2021

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University of Wisconsin-Madison

# Department of Astronomy

## Location:

University of Wisconsin-Madison  
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<http://www.astro.wisc.edu/>

**Department of Astronomy Directory** <http://www.astro.wisc.edu/our-people/directory/>

## Undergraduate Faculty Advisor

Prof. Snezana Stanimirovic  
4514 Sterling Hall, 608-890-1458, [ssanimi@astro.wisc.edu](mailto:ssanimi@astro.wisc.edu)  
Prof. Elena D'Onghia  
3504 Sterling Hall, 608-890-1458, [edonghia@astro.wisc.edu](mailto:edonghia@astro.wisc.edu)

Not sure which courses you should take? Would you like to get involved in a research project? Do you have an academic problem that you need assistance with? Have you met the Astronomy Major course requirements and you are ready to declare a major?

## Undergraduate Advisor

Eric Schueffner  
2508 Sterling Hall, make an appointment via Starfish

## Undergraduate Coordinator

Heather Sauer  
2554 Sterling Hall, 608-890-3775, [hsauer@wisc.edu](mailto:hsauer@wisc.edu)

Please feel free to come me for assistance. I am always more than happy to answer your questions, provide information, or be a listening ear. I am also the Astronomy Timetable Representative, so please contact me if you require assistance to add independent study credits (be sure to include the Course Number and Section, the Professor's Name, and your Campus ID). I look forward to meeting you!

**Department of Physics Undergraduate Website** <http://www.physics.wisc.edu/undergrads/>

# *Welcome to the University of Wisconsin-Madison Department of Astronomy!*



Department Chair: Richard Townsend

The UW-Madison Astronomy Department's mission is to conduct cutting edge research and to offer students and postdocs the highest quality of education. We conduct research in diverse areas of astronomy, from the physics of stars to cosmology, in observation and theory, and through the construction of cutting-edge instruments for our complement of telescopes. We pride ourselves in an inclusive, diverse, and friendly scientific environment.

Research Universities like the UW-Madison offer undergraduate students the unique opportunity to become involved in forefront research at the cutting edge of science. Beyond developing technical and scientific writing skills, the immersion in a research program in the Astronomy Department at UW-Madison gives students the opportunity to develop a genuine understanding of the process and culture of modern science.

Apart from purely academic matters, we value your personal well-being. If there is anything you think we can help with, contact the department office, located on the second floor of Sterling Hall.

Diversity is a source of strength, creativity, and innovation for UW-Madison. We value the contributions of each person and respect the profound ways their identity, culture, background, experience, status, abilities, and opinion enrich the university community. We commit ourselves to the pursuit of excellence in teaching, research, outreach, and diversity as inextricably linked goals.

The University of Wisconsin-Madison fulfills its public mission by creating a welcoming and inclusive community for people from every background — people who as students, faculty, and staff serve Wisconsin and the world.



**Department of Astronomy**  
UNIVERSITY OF WISCONSIN-MADISON



At present, we have eleven faculty members in the Department, all of whom teach undergraduate courses and carry on programs of research. Wisconsin astronomy is famous for technological advances in instrumentation and major astronomical discoveries. Historically, Washburn Observatory, which opened on campus in 1878, pioneered the development of photoelectric astronomy. Later, Wisconsin led the nation into space astronomy, building the first Orbiting Astronomical Observatory and then the Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE), which flew aboard the Space Shuttle. Wisconsin astronomers also served on the teams responsible for four Hubble Space Telescope instruments, including the current Cosmic Origins Spectrograph. Today, UW is the lead institution in a major infrared survey of the Milky Way galaxy using the Spitzer Space Telescope.

Examples of Wisconsin's continuing technological innovation are the Wisconsin H- $\alpha$  Mapper (WHAM) that has discovered a new major component of the Milky Way Galaxy; the Star Tracker 5000 which has become the premier guidance system for astronomical rocket and balloon flights; and the Wide-field Imaging Spectro-Polarimeter, a rocket payload. The University of Wisconsin-Madison is also a major partner in both the WIYN and SALT observatories. The WIYN 3.5-meter telescope is located on Kitt Peak in Arizona and is fully operable by undergraduates in Sterling Hall. Wisconsin faculty and students are in the process of building fiber optic "integrated field units" to advance WIYN spectroscopy. The Robert Stobie Spectrograph, the primary first-light instrument for SALT, an 11m telescope located outside Sutherland, South Africa, was designed and built in Chamberlain Hall. Currently, its sibling spectrograph for near-infrared observations is also being designed and built on campus. The Department recently established a 5-year partnership with IRAM (Institute de Radioastronomie Millimetrique) to obtain access to two radio telescopes: The Northern Extended Millimeter Array (NOEMA) in French Alps and the 30-m single-dish telescope in the south of Spain. In addition, the Department operates two 2.3-m Small Radio Telescopes (SRTs) for educational purposes. One SRT is located on the roof of Sterling Hall, while the second one is in Pine Bluff. Both are extensively used for undergraduate and graduate classes, as well as public outreach.

Wisconsin's research interests range from studies of the large-scale structure of the Universe through observations of galaxies and clusters of galaxies to work on the formation of stars and the interstellar medium out of which they form. We also carry out theoretical research into the dynamics of galaxies, the nature of interstellar gas and dust, the internal structure out to the winds of hot stars, and the origins of stars. The Department operates a powerful network of image processing workstations for the analysis and interpretation of astronomical data, using both national high-performance computing facilities and several large departmental computer clusters. Most importantly, undergraduates are welcome to join us in any of these research programs.

To understand the techniques and ideas of modern astronomy requires a thorough background in physics and mathematics. This is particularly important for the student who plans a career in astronomy. For this reason, the Astronomy Department offers the Astronomy-Physics major to provide undergraduates with the opportunity to develop an appreciation of our current understanding of the physical universe. The Astronomy-Physics major includes core courses in astronomy that are taken while the student obtains the necessary comprehensive background in physics and mathematics. This booklet describes the Astronomy-Physics major in greater detail.

We look forward to joining you in your adventure at the University of Wisconsin and are excited that you are interested in majoring in astronomy. If you have any questions, please don't hesitate to contact us.

## Department of Astronomy & Associated Faculty

### Amy Barger

Ph.D. University of Cambridge, 1997

Observational cosmology, distant galaxies and supermassive black holes, observations at X-ray, optical, near-infrared, submillimeter and radio wavelengths, star formation and accretion histories of the Universe.

### Matthew A. Bershadsky

Ph.D. University Of Chicago, 1994

Extragalactic Astronomy and observational cosmology; galaxy kinematics, image structure, stellar populations; galaxy and quasar evolution; optical and IR observations and instrumentation.

### Elena D'Onghia

Ph.D. University of Milan, 2003

Cosmology, nature of dark matter, large scale structure formation, dynamics and galaxy formation.

### Sebastian Heinz

Ph.D. Univ. Of Colorado, BOULDER, 2000

Relativistic jets, black holes, AGN, X-ray binaries, galaxy clusters, gamma ray bursts, interstellar and intergalactic medium.

### Alex Lazarian

Ph.D. University Of Cambridge, 1995

Magnetohydrodynamic turbulence, interstellar dynamics and statistics, magnetic reconnection, generation of magnetic field, interstellar polarization, dust-grain dynamics/alignment, microwave emissivity of dust, molecular clouds and star formation.

### Robert D. Mathieu

Ph.D. Univ. of California-Berkeley, 1983

Observational studies of star formation, binary stars, and open star clusters with an emphasis on the formation and evolution of binary stars. Involves extensive high-precision stellar radial-velocity surveys, and study of optical, infrared and

submillimeter spectral energy distributions and variability.

### Snezana Stanimirovic

Ph.D. University of Western Sydney, 1999

Galactic disk/halos, dust properties in low-metallicity environments, physics of the ISM, radio techniques and applications.

### Richard H. Townsend

Ph.D. University College London, 1997

Stellar astrophysics, magnetic fields, stellar winds, massive stars.

### Christy Tremonti

Ph.D. Johns Hopkins University, 2003

Galaxy and AGN co-evolution, galactic chemical

### Andrew Vanderburg

Ph.D. Harvard, 2017

Observational studies of exoplanets focusing on planet detection (developing new observational/data analysis techniques) and characterization of planet properties/system architectures.

### Eric M. Wilcots

Ph.D. University of Washington, 1992

Radio astronomy; observations of H I in galaxies and dynamics of galaxies; galaxy evolution; H II regions.

### Ke Zhang

Ph.D. California Institute of Technology, 2015

Planet formation, extrasolar planets, astrochemistry.

### Ellen Zweibel

Ph.D. Princeton University, 1977

Theoretical astrophysics, especially plasma astrophysics. Generation and evolution of astrophysical magnetic fields, interstellar astrophysics, star formation, stellar physics.

## Associated Faculty

The Department works closely with the members of the Department of Physics. Active researchers and programs include Baha Balantekin, neutrino astrophysics; Daniel Chung and Peter Timbie, cosmology;

Francis Halzen and the Ice Cube team, neutrino astronomy, cosmic rays and active galaxies; James Lawler, laboratory measures of atomic transition probabilities; and Dan McCammon, X-ray astronomy, soft X-ray background, the hot interstellar medium.

## **Professor Emeriti on Campus**

**Edward B. Churchwell**

Ph.D. University of Indiana, 1970

Radio and infrared observations of massive star formation regions; atomic abundances and chemical evolution of the galaxy; chemistry and structure of interstellar molecular clouds.

**John S. Gallagher, III**

Ph.D. University of Wisconsin, 1972

Multi-wavelength observational investigations of physical processes that shape galaxies; the evolutionary states of galactic stellar populations and interstellar matter; relationships between stellar populations and the interstellar medium in actively star forming galaxies.

**Kenneth Nordsieck**

Ph.D. Univ. of California-Santa Cruz, 1972

Instrumental, observational, and analytical applications of astronomical polarimetry; optical studies of supergiants and the polarization that arises from scattering by interstellar dust.

**Blair D. Savage**

Ph.D. Princeton University, 1968

The properties of the interstellar medium in the Galaxy and in the halos of other galaxies; the intergalactic medium.

## **Senior Scientists**

**Marina Orio**

Ph.D. Technion, Haifa, Israel, 1987

Transients' populations, interacting binaries, accreting and hydrogen burning white dwarfs.

**Jeffrey W. Percival**

Ph.D. University of Wisconsin, 1979

Instrument control software, telescope control systems, guidance and navigation for suborbital rockets.

**Bart Wakker**

Ph.D. Groningen, 1990

The interstellar medium in the Galactic halo, high-velocity clouds, nearby galaxies, circumgalactic and intergalactic medium, absorption-line spectroscopy, radio astronomy.

**Marsha Wolf**

Ph.D. University of Texas-Austin, 2005

Galaxy evolution, stellar populations in galaxies, merging galaxies, post-starburst galaxies, quasar host galaxies, and astronomical instrumentation.

## Research Areas

### Stars & Stellar Systems

Stellar astrophysics studies the building blocks of galaxies – stars – both individually and in associations ranging from binary systems up to clusters, in order to understand the complex lifecycle of these remarkable objects.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/STARS-STELLAR-SYSTEMS/](http://www.astro.wisc.edu/our-science/research-areas/stars-stellar-systems/)

### Galactic Astronomy

Galactic astronomy studies the composition and structure of the Milky Way Galaxy, including the statistical properties of its stellar populations, and the global properties of the interstellar medium.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/GALACTIC-ASTRONOMY/](http://www.astro.wisc.edu/our-science/research-areas/galactic-astronomy/)

### Theory & Computation

Astrophysical theory attempts to understand the universe, or aspects thereof, through the methods of physics and mathematics.

Computational astrophysics uses numerical simulation to test and develop theoretical models, taking the place of experiments.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/THEORY-AND-COMPUTATION/](http://www.astro.wisc.edu/our-science/research-areas/theory-and-computation/)

### Plasma Astrophysics

Plasma astrophysics studies how plasmas behave in order to understand the detailed birth, evolution, and death of the wide variety of structures we can see in the universe: from stars and planetary systems, to galaxies and clusters of galaxies.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/PLASMA-ASTROPHYSICS/](http://www.astro.wisc.edu/our-science/research-areas/plasma-astrophysics/)

### Extragalactic Astronomy & Cosmology

Extragalactic Astronomy studies the structure and evolution of other galaxies, including their stellar populations, active galactic nuclei, and interstellar media, and the clustering of galaxies. Cosmology studies the structure and evolution of the universe as a whole.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/EXTRAGALACTIC-ASTRONOMY/](http://www.astro.wisc.edu/our-science/research-areas/extragalactic-astronomy/)

### Observational Astronomy

Observational Astronomy studies the visible universe by detecting photons and particles. Depending on wavelength, observers use a wide range of detection methods and a broad variety of skills to extract quantitative information from images, spectra, and light curves of cosmic objects.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/OBSERVATIONAL-ASTRONOMY/](http://www.astro.wisc.edu/our-science/research-areas/observational-astronomy/)

### Interstellar & Intergalactic Media

The interstellar and intergalactic media consist of gas, dust, magnetic fields, interstellar radiation, and energetic cosmic rays. The UW-Madison Astronomy program has a long, pioneering history in ISM/IGM and continues to lead a rich array of research in this area.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/INTERSTELLAR-INTERGALACTIC-MEDIA/](http://www.astro.wisc.edu/our-science/research-areas/interstellar-intergalactic-media/)

### High Energy Astrophysics

High energy astrophysics studies the universe at its most extreme. Its focus is the understanding of compact objects and the processes occurring in their vicinity, the properties of ionizing cosmic radiation, and the acceleration of non-thermal particle distributions.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/HIGH-ENERGY-ASTROPHYSICS/](http://www.astro.wisc.edu/our-science/research-areas/high-energy-astrophysics/)

### Instrumentation

Astronomical Instrumentation constructs the cameras and spectrographs that collect the data astronomers use to analyze astrophysical processes and test theories. Instruments can be designed to provide high spatial, spectral or time resolution.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/INSTRUMENTATION/](http://www.astro.wisc.edu/our-science/research-areas/instrumentation/)

### Astrophysics in Physics

The Physics department hosts a number of groups working actively on astrophysical topics, ranging from cosmology to high-energy astrophysics.

[HTTP://WWW.ASTRO.WISC.EDU/OUR-SCIENCE/RESEARCH-AREAS/ASTROPHYSICS-IN-PHYSICS/](http://www.astro.wisc.edu/our-science/research-areas/astrophysics-in-physics/)

## Astronomy Requirements for the Major

The major requires a minimum of 34 credits in the field of specialization, with at least 6 of these credits in astronomy and at least 28 credits in physics.

Before declaring the major, students must have a cumulative GPA of 2.5 and complete the first two of the three intro sequence physics classes: Physics 247, 248, and 249, or 207, 208, and 241, or Physics 201, 202, 205. We encourage students to declare their major as early as possible. In addition, the specific course requirements for the major are (these also count toward the 15 credits of upper-level courses as required by the College of Letters and Science):

### Astronomy:

At least two of the following (but note that 310 is a prerequisite for 330, 335, and 500):

1. 310 Stellar Astrophysics, 3 cr
2. 320 The Interstellar Medium, 3 cr
3. 330 Galaxies and Cosmology, 3 cr
4. 335 Cosmology, 3 cr
5. 340 Solar System Astronomy, 3 cr
6. 500 Techniques of Modern Observational Astrophysics, 3 cr

Students wishing to take a survey course should take Astronomy 200.

### Physics:

1. 247-248-249 A Modern Introduction to Physics (or 201-202-205; or 207-208-241) 14 cr
2. 311 Mechanics, 3 cr
3. 322 Electromagnetic Fields, 3 cr
4. 415 Thermal Physics, 3 cr
5. 448 Atomic and Quantum Physics, 3 cr
6. 449 Atomic and Quantum Physics, 3 cr
7. 531 Introduction to Quantum Mechanics (3) may be substituted for the 448-449 sequence.

**A 300-level or higher laboratory course must be taken;** Astronomy 510 or Physics 308 (Intermediate Laboratory- Electromagnetic Fields and Optics) or 321 (Electric Circuits and Electronics) are recommended to satisfy this requirement.

### Recommended Additional Courses:

**MATH:** Mathematics courses other than those required as prerequisites for physics courses are not required for the major, but the following courses are recommended:

1. Math 319 (Ordinary Differential Equations)
2. Math 321 and 322 (Applied Analysis)

If a student plans to work toward the PhD degree the student should also take:

1. Math 320 (Linear Mathematics) or Math 340 (Matrix and Linear Algebra)

**Note:** Additional math (or statistics) courses should be chosen after consultation with the undergraduate advisor.

**Computing:** Computers are fundamental to astronomical research. An introduction through Comp Sci 302 or short courses run by the computing center should be considered.

**Chemistry:** A college course in physical or organic chemistry is useful for astronomy students. Physical

chemistry is particularly valuable for those interested in the interstellar medium, comets, and planets.

**Statistics:** A background in statistics is valuable, particularly for students interested in observational astronomy. Statistics 301, or Statistics 309/310 for a more solid foundation, are suggested.

**Languages:** Spanish, French, German, and Russian are the most useful foreign languages for astronomy students but are not required.

## Honors in the Major

Students wishing to receive Honors in the Major must satisfy the following requirements:

1. Completion of four 300 or higher-level astronomy courses with a minimum grade point average of 3.5 at UW-Madison at the time of graduation.
2. Completion of a Senior Honors Thesis (Astron 681/682) with a grade of AB or better (for a total of 6 credits), or a submitted publication of a lead-author paper in the professional astronomy journal.

Students wishing to pursue Honors in the Major should contact a faculty advisor to seek guidance about planning the Honors in the Major curriculum that best reflects their special interests.

## Thesis of Distinction

This award is granted at graduation, upon recommendation of a department to the dean, to any student not earning the Honors Degree who has written an exceptionally good or original thesis, without consideration of the student's record in other work. The faculty advisor appoints another faculty member to read the thesis and make an appropriate recommendation. These theses are retained in the department. The award is noted on the student's transcript.

## Distinction in the Major

This award is granted at graduation, upon the recommendation of a department to the dean, to any student not earning the Honors Degree who has done outstanding work in the major and who has passed a comprehensive examination on that work. The comprehensive examination may be omitted for the student with a 3.5 grade point average in the major who successfully completes special work prescribed by the department. The award is noted on the student's transcript.

## Declaring a Major in Astronomy

Before declaring the Astronomy major, all students must complete Physics 247, 248, and 249 (recommended sequence), or 207, 208, and 241, or Physics 201, 202, 205. Email one of the Undergraduate Faculty Advisors to schedule an appointment to declare the major. Feel free to reach out to either of them if you need advising.

## Regularly Check the Degree Audit Reporting System (DARS)

The Degree Audit Reporting System (DARS) is part of UW-Madison's commitment to academic advising. A DARS report is particularly helpful when combined with the wisdom of skilled advisors. Always review the DARS report with the transcript. DARS reports become increasingly important as a student first decides on a particular college, then determines a major or combination of majors, and finally approaches graduation. DARS shows which requirements have been completed and which remain unsatisfied. It can offer suggestions about appropriate courses that may be taken to meet specific requirements. DARS is not intended to replace contact with academic advisors. Students can print their DARS report through My-UW. 'What If' DARS reports may be helpful in showing how completed or in-progress courses may be used in different degree programs.

**Astronomy-Physics Undergraduate Catalog website:** [http://pubs.wisc.edu/ug/lis\\_astron.htm](http://pubs.wisc.edu/ug/lis_astron.htm)

## Course Descriptions

**Astronomy 103: The Evolving Universe. I, II; 3 cr (P-E).** The universe is vast and ever changing. The topics covered in this course include lifecycles of stars; supernovae and creation of elements; white dwarfs, pulsars and black holes; the Milky Way and galaxies; distances of stars and galaxies; quasars; expansion of universe; open and closed universes; the big bang. *Pre-requisites:* Open to all undergrads. Not open to students who meet prerequisites for Astronomy 200

**Astronomy 104: Exploration of the Solar System. I, II; 3 cr (P-E).** Humanity is linked to the solar system in countless ways. Topics covered in this course include the sky and celestial motions; ancient astronomy; the Copernican revolution; gravity, orbits, and interplanetary travel; formation of the solar system; a survey of the sun, planets and moons; asteroids, meteors and comets; origin of life, and exoplanets. *Pre-requisites:* Open to all undergrads.

**Astronomy 150: Topics in Astronomy. I or II; 2 cr (P-E).** This course will intensively study selected topics of modern astronomy. Examples include missions to the planets, formation of stars and planets, end states of stellar evolution (supernovae, white dwarfs, pulsars, black holes), origin and evolution of the universe. *Pre-requisites:* Open to all undergrads. Astronomy 103, 104, as appropriate for the topic, or instructor consent.

**Astronomy 160: Life in the Universe. Alt yrs; 1; 2 cr (P-E).** An examination of the origin and evolution of life in the universe based on our knowledge of astronomy, biology, and geology. Includes discussions on the search for extraterrestrial life and the history of life in our solar system. *Pre-requisites:* Open to all undergrads.

**Astronomy 200: The Physical Universe. II; 1; 2 cr (P-E).** Modern astrophysics involves applying physical principles to understand astronomical phenomena. Includes the solar system, stars, nebulae, galaxies, and cosmology, with emphasis on origins and evolution. Some nighttime observation with telescopes required. *Pre-requisites:* Physics 202 or 208 or 248 or cons inst. Not open to students who have taken Astron 103. Simple calculus required.

**Astronomy 310: Stellar Astrophysics. I; 3 cr (P-I).** Properties of normal and peculiar stars as found from an analysis of the radiation they emit; introduction to radiation transfer. Theory of stellar atmospheres, interiors, and evolution. *Pre-requisites:* Math 222 and Physics 205, 241, or 249

**Astronomy 320: The Interstellar Medium. Alt yrs; II; 3 cr (A).** Properties of neutral and ionized interstellar gas, giant molecular clouds, the warm and hot inter-cloud medium, supernova remnants, and interstellar dust. Physical processes in low-density gases including radiation transfer, excitation and ionization of interstellar atoms and molecules, and the interaction between gas and dust. *Pre-requisites:* Astronomy 310

**Astronomy 330: Galaxies: Alt yrs; II; 3 cr (A).** Distribution of stars, gas, and dust within our Milky Way, and their motions. Nearby galaxies: our Local Group. Optical, radio, and other techniques for observing galaxies. Composition and motions of other galaxies; galaxies with active nuclei; galaxy formation. *Pre-requisites:* Astronomy 310

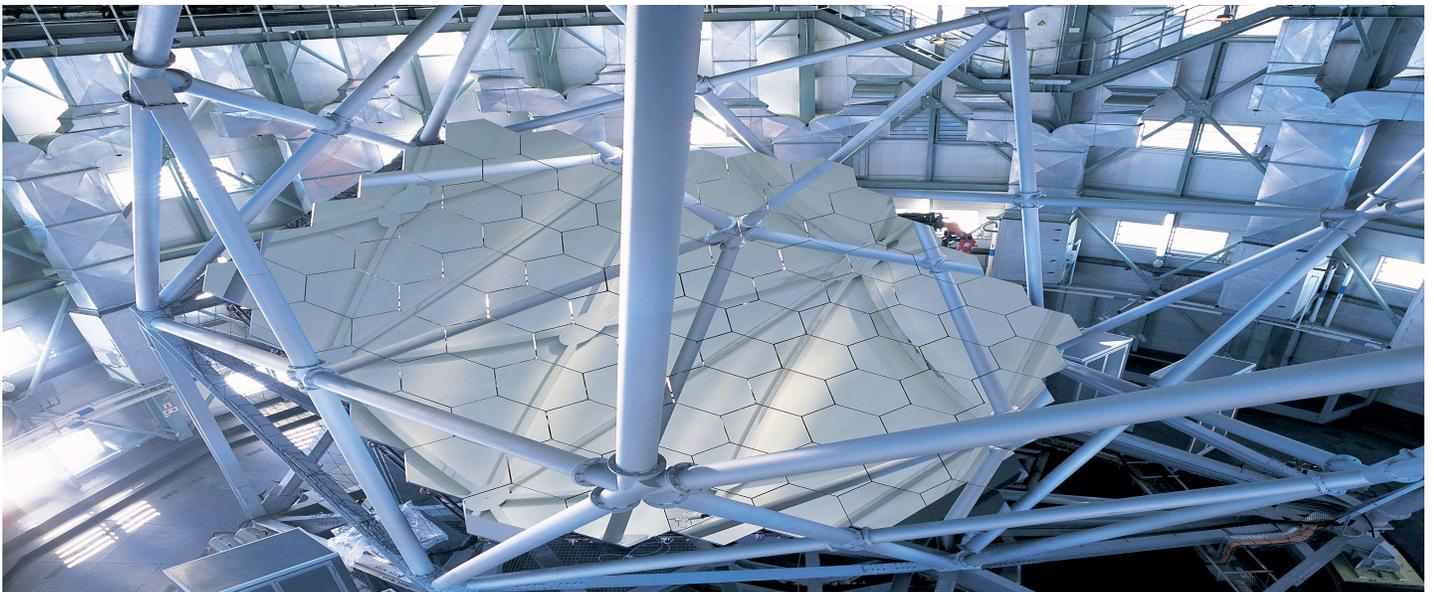
**Astronomy 335: Cosmology: Alt yrs; II; 3 cr (A).** Introduction to the study of our Universe as a whole. Distribution of matter on the largest scales. Equations for cosmic expansion; making observations in an expanding curved spacetime. Nucleosynthesis and other tests of the Big Bang hypothesis. Gravitational collapse and the growth of structure. *Pre-requisites:* Astronomy 310

**Astronomy 340: Solar System Astrophysics: Alt yrs; I; 3 cr (P-I).** Properties of solar system objects, solar atmospheric phenomena, physics of planetary atmospheres, results of recent planetary missions, comets, origin of the solar system. *Pre-requisites:* Math 222 and Physics 205, 241, or 249

**Astronomy 460: Experiences in Astronomical Observing: I or II; 1 cr (D).** A basic introduction into astronomical research by undertaking a small observing project with optical and/or radio telescopes. Topics covered are: understanding the astronomical literature, observing and data reduction, writing scientific reports and papers, presenting scientific results, and basics of scientific ethics. *Pre-requisites:* Cons Inst. One of Astron 310, 320, 330, or 500 advised.

**Astronomy 500: Techniques of Modern Observational Astrophysics: I or II; 1; 3 cr (A).** An introduction to astrophysics data collection. Students will be familiarized with the concepts, techniques, skills and resources needed to plan, obtain, reduce and interpret observations of astronomical objects. *Pre-requisites:* Graduate student or Astron 310 and instructor consent.

**Astronomy 510: Techniques of Modern Observational Astrophysics: Irr.; 1-2 cr (A).** An introduction to the techniques of modern observational radio astronomy. The course covers fundamentals of radio astronomy, modern radio instrumentation, and observing techniques, through a mixture of classroom lectures, discussions, and hands-on observational projects with a small radio telescope. *Pre-requisites:* Graduate student or instructor consent.



## 4-Year Plan

| Four Year Plan                   |                | Astro-Physics Degree                |                | BS |
|----------------------------------|----------------|-------------------------------------|----------------|----|
| <b>Fall 1</b>                    | <b>Credits</b> | <b>Spring 1</b>                     | <b>Credits</b> |    |
| Math 221 (QR-B)                  | 5              | Math 222                            | 4              |    |
| Biological Science               | 3              | Biological Science                  | 3              |    |
| Humanities                       | 3              | Astronomy 200 (non-majors take 103) | 3              |    |
| Language                         | 4              | Language                            | 4              |    |
|                                  |                | Comm A                              | 2              |    |
| <b>Total</b>                     | <b>15</b>      | <b>Total</b>                        | <b>16</b>      |    |
| <b>Fall 2</b>                    | <b>Credits</b> | <b>Spring 2</b>                     | <b>Credits</b> |    |
| Physics 247                      | 5              | Physics 248                         | 5              |    |
| Math 234                         | 4              | Literature                          | 3              |    |
| Social Science                   | 3              | Social Science                      | 4              |    |
| Language                         | 4              | Math 320 (or 319 and 340)           | 3              |    |
|                                  |                |                                     |                |    |
| <b>Total</b>                     | <b>16</b>      | <b>Total</b>                        | <b>15</b>      |    |
| <b>Fall 3</b>                    | <b>Credits</b> | <b>Spring 3</b>                     | <b>Credits</b> |    |
| Physics 249                      | 4              | Physics 311                         | 3              |    |
| Astronomy 310                    | 3              | Astronomy 300 level                 | 3              |    |
| Math 321                         | 3              | Social Science                      | 3              |    |
| Comm B                           | 3              | Literature                          | 3              |    |
|                                  |                | Math 322                            | 3              |    |
| <b>Total</b>                     | <b>13</b>      | <b>Total</b>                        | <b>15</b>      |    |
| <b>Fall 4</b>                    | <b>Credits</b> | <b>Spring 4</b>                     | <b>Credits</b> |    |
| Physics 322                      | 3              | Social Science                      | 3              |    |
| Physics 448                      | 3              | Physics 449                         | 3              |    |
| Ethnic Studies                   | 3              | Physics 415                         | 3              |    |
| Astro 510 (or any 300 level lab) | 2              | Humanities                          | 3              |    |
| Elective                         | 4              | Astro 300 level (optional)          | 3              |    |
|                                  | <b>15</b>      |                                     | <b>15</b>      |    |
|                                  |                | <b>Total</b>                        | <b>120</b>     |    |

*Students are strongly encouraged to consider doing a Senior Thesis research project during their senior year (Astro 691/692). It is recommended that you start exploring possible topics with faculty prior to the senior year.*

## Strategies for Choosing Math Courses

There are specific math courses listed as prerequisites for physics courses. (Math courses other than those required as prerequisites for physics courses are not required for the Astronomy major, but Math 321 and 322 are recommended. If you plan to work toward the PhD, you should also take Math 320 or 319 and 340.) Please consult with an advisor when choosing your Mathematics course.

1. **Math 221/222:** Standard Introductory calculus sequence. Math 221 is a prerequisite to Physics 247, 207 and 201.
2. **Math 234:** Calculus of Several Variables, typically taken to complete the sequence Math 221/222/234. This course could be taken simultaneously with Math 319.
3. **Math 319:** Techniques in Ordinary Differential Equations. You are strongly advised to take this or Math 320 before or with Physics 311 (Mechanics).
4. **Math 340:** Elementary Matrix and Linear Algebra. This course is a bridge between concrete and abstract math. The next step for students interested in more abstract math is Math 521/522 (Advanced Calculus). Many physics students find this course to be particularly useful and we strongly suggest taking it or Math 320, Math 320 Linear Mathematics. Math 320 is a "light" version of Math 319 and 340 and can be taken as a one-semester alternative to those if you are short on time.
5. **Math 321:** Applied Mathematical Analysis. Techniques for solving problems in the physical sciences, engineering, and applied mathematics, using advanced calculus and analytic function theory. It is recommended that Math 321 be taken before taking Physics 322. Requires a significant time commitment.
6. **Math 322:** Applied Mathematical Analysis. Techniques for solving partial differential equations, with an emphasis on practical problems in the physical sciences. Also covers special functions, Fourier Transformations, etc.

## Physics Department Suggested Curricula

The appropriate program for your goals should be established with the help of your advisor. The introductory program consists of Physics 247-248-249/307. Students are encouraged to take this sequence.

Note, however, that Physics 247 is offered only in the fall semester. Alternatively, 207-208-241 or 201-202-205 (or 241 or 244) may be substituted. The remainder of the physics core for the Astronomy Major program is Physics 311, 322, 415, 448, 449 (531 may be substituted for the 448-449 sequence) and a 300-level or higher laboratory course (Astronomy 510 or Physics 308 or 321 are recommended to satisfy this requirement).

Also Math 221-222-223 or equivalents are necessary since they are prerequisites for other courses. It is possible to enter the core program in either semester since 201, 202, 205, 207, 208, 241, 244, 311, and 322 are given each semester. Students are urged to start the recommended sequence of courses as soon as they have the calculus prerequisite (Math 221 or equivalent). However, no important obstacle is met if the student does not begin until the sophomore year.

## Events, Involvement & Awards

Undergrads are sometimes shy about attending events they see advertised around, even though the subjects may sound quite interesting. Don't be— seminars and colloquia are open events and **we welcome you to attend**.

The percentage of a talk that anyone will likely be able to understand varies widely from one seminar to another, and from one speaker to another. If the title sounds interesting, then there's a fair chance you'll be able to keep up for a while. (Keep in mind that most people there will not generally follow the whole talk.)

### Undergraduate Lounge

We have a lounge JUST for undergraduate students to use, study, chat, have lunch, and relax. The undergraduate lounge for astronomy-physics majors is in Sterling Hall room 3527. If you need access to the room, visit the undergraduate coordinator, Heather Sauer, in room 2554-Sterling Hall.

### Astronomy Club

Get involved: organize and host movies, talks, study groups, or anything you think is of interest. Visit their Facebook page: <https://www.facebook.com/astroclubuw/>

### Astronomy Science Lunch

The astronomy science lunch is held on Mondays at noon in Sterling Hall room 4421.

### Astronomy Colloquium Information

The Astronomy Colloquia on Thursday at 3:45 PM in 4421 Sterling is highly recommended for our undergraduate majors. The event begins at 3:30 with a social period while enjoying coffee and cookies, allowing you to meet and converse with Astronomy Department faculty and graduate students. The talk is presented to a group with widely varying interests; therefore, the material is conveyed in a more general fashion, with questions encouraged. Those with astrophysical interests at all levels of experience can enjoy an informative and supportive interaction in an environment of academic inquiry. <http://www.astro.wisc.edu/talks/>

### Physics Colloquium Information

The Physics Department hosts a large number of colloquia and seminars each year. Check the web for Colloquium & Seminar Notices ([www.physics.wisc.edu/seminars/](http://www.physics.wisc.edu/seminars/)). The Physics Colloquium at 3:30 PM on Friday afternoon in 2241 Chamberlin Hall is intended to be a broad-based presentation that physicists in all subfields have a chance to enjoy. <http://www.physics.wisc.edu/seminars/index.html>

### Awards

Lowell Doherty Aware for Excellence in Astronomy – is awarded in recognition of a graduating senior's exceptional performance in astronomical research and in the classroom as an Astronomy-Physics major. The criteria are: graduating senior undergraduate student, outstanding academic performance, and outstanding research performance. Students are nominated by Astronomy faculty and research scientists, and the award decision is made by the Department's awards committee every spring.

**Fay Ajzenberg-Selove Scholarship Fund:** This fund supports undergraduate **women** majoring in or planning to major in astronomy or physics. The fund was established in May 1996 by Professor Ajzenberg-Selove. Professor Selove received her MS in 1949 and Ph.D. in 1952 in Physics, both from the University of Wisconsin. Interested students should apply at: <https://www.physics.wisc.edu/awards>

**Bernice Durand Undergraduate Research Scholarship:** Established in 2003, this undergraduate research scholarship will be giving preference to women or to ethnic minorities in Physics and Astronomy who show research potential, motivation and interest in the discipline. This award will

typically be given to 1 student per year after the completion of the three-semester introductory classical and modern physics sequence or equivalent and will enable the student to work with the research group of her or his choice. The intent is that the amount of the award shall be at least one third of the coming academic year's resident full year tuition. Interested students should apply at:  
<https://www.physics.wisc.edu/awards>

**Research stipends and internships:** Students should consider applying for several UW and national scholarships and awards listed at:  
<https://research.wisc.edu/information-for-undergraduate-students/>

The Hilldale undergraduate fellowship in particular provides a stipend for undergraduate research in collaboration with a faculty member. In addition, the Wisconsin Space Grant Consortium provides several possibilities for fellowships, internships and scholarships:  
<https://spacegrant.carthage.edu/funding-programs/undergraduate/>

Interested students should contact faculty advisors for further information.

# Undergraduate Research Opportunities

## REU

REU ([Research Experience for Undergraduates](#)) programs are a way for undergraduates to get some research experience, make contacts and become more involved in their academic community. They're funded by the NSF ([National Science Foundation](#)) and sites are located all over the country, as well as some NSF-funded sites abroad.

There are programs in [astronomy](#), [physics](#) and [many other fields](#), Atmospheric Sciences, Engineering, etc., as well.

Any US citizen or permanent resident who has not graduated prior to the start of the REU program is eligible to apply. A few of the programs (NRAO and NOAO) accept recent graduates. Check with the individual programs about eligibility.

Applicants are traditionally Sophomores or Juniors, although Freshmen are welcome to apply to most programs. Applications are typically due at the end of January. It's a good idea to start working on them no later than early December (see the checklist).

## University of Wisconsin Programs

The University of Wisconsin provost's office offers research fellowships in a variety of fields. These fellowships will provide you with funding to do a research project with a UW faculty member.

The UW also sponsors an [undergraduate symposium](#), which is a wonderful venue to get some experience presenting your research. Applications will be available through the Symposium website.

The [Undergraduate Research Scholars Program](#) has some projects in the physical sciences which provide opportunities for younger undergraduate students to do research with a faculty mentor.

## Other Internships and Sources of Funding

The Wisconsin Space Grant Consortium offers research awards, up to \$3,500, to fund research related to space-studies. Application materials and deadlines have not been posted for the 2009-2010 award year, but last year's deadline for applications was February 4th.

[NASA](#) funds many summer schools and institutes to prepare undergraduates for careers in science. This year the Exploration System Mission Directorate is offering the opportunity for students to gain work experience at one of the NASA centers in support of the Vision for Space Exploration.

The [NASA Academy](#) is a unique experience for people with not only an interest in astronomy, but also earth science, manned space flight, engineering, or space policy and administration. It is a prestigious program with a dedicated Alumni Association. The application deadline is in January.

Arecibo Observatory offers a summer REU program at the telescope facilities in Puerto Rico. Their deadline is typically in early February.

Google is offering the [Anita Borg Scholarship](#) to women in computing and science fields.

[The nucleus](#) has many summer internships in physics, astronomy and other physical sciences (both domestic and abroad) listed in the [summer research section](#) of their website.

### **Conferences for Undergraduate Research**

The UW's Undergraduate Symposium [undergraduate symposium](#).

National Conferences on Undergraduate Research [NCUR](#)

[National Society of Black Physicists](#)

### **Useful Links**

The AAS ([American Astronomical Society](#)) has a list of REU sites. If you scroll down, this has a good summary of application deadlines and program details. Note that the list is incomplete and there are more sites listed at the [NFS REU page](#).

The Journal of Undergraduate Science and Technology (JUST)

[Aaron Geller's links for undergrad researchers](#).

[Snezana Stanimirovic's links for undergrad researchers](#).

### **Final Notes**

All of these opportunities can help you get a feel for what it's like to do research in the "real world" of academia and can really help you get your foot in the door. Not only will the contacts that you make help you in your future career, but you'll also have experiences which will speak well for you in job and graduate school applications. For research opportunities in the Astronomy Department students are encouraged to contact individual professors and research scientists or get in touch with the faculty advisors.

# What's Next? After Completing an Astronomy-Physics Degree

## Skills Gained with an Astronomy-Physics Major

You will have gained an overall view of both classical and modern physics along with problem-solving ability and the flexibility to continue learning. Your training can:

1. Prepare you for employment in industrial or governmental laboratories.
2. Prepare you for graduate study in astronomy, experimental or theoretical physics.
3. Provide a broad background for further work in other sciences, such as materials sciences, astronomy, geophysics, meteorology, radiology, medical physics, biophysics, engineering, and environmental studies.
1. Provide a science-oriented liberal education. This training can be useful in some areas of business administration, law, or other fields where a basic knowledge of science is useful.
2. Provide part of the preparation for secondary school teaching.

## Additional Career Options

The professions and professional organizations listed below illustrate the types of positions you might qualify for if you complete this major. *This list also illustrates that employment possibilities are often enhanced by selecting employment-related courses, enrollment in a second major, or by selecting a minor that can augment your major.* Bachelor's degree holders in Astronomy may work as research assistants or in other physics-related occupations as technicians. They may find jobs in support positions at national observatories, national laboratories, federal agencies, and sometimes in large astronomy departments at universities or for jobs in other fields where a physics background is good preparation, such as engineering and technology. An undergraduate astronomy degree is excellent preparation for science teachers, laboratory technicians, computer programmers, and science journalists. It can also serve as the basis for graduate degrees in other fields, such as law or medical school.

- |  |                                      |
|--|--------------------------------------|
| 1. Astronomer                                | 2. Community College Instructor      |
| 3. Natural History Museum Staff              | 4. Planetarium Staff                 |
| 5. Spacecraft Operations Specialist          | 6. Spacecraft Researcher             |
| 7. Teacher of Earth Science                  | 10. Teacher of Physics and Chemistry |
| 8. National Observatories & Research Centers | 11. Software/IT                      |
| 9. Finance                                   | 12. Business                         |

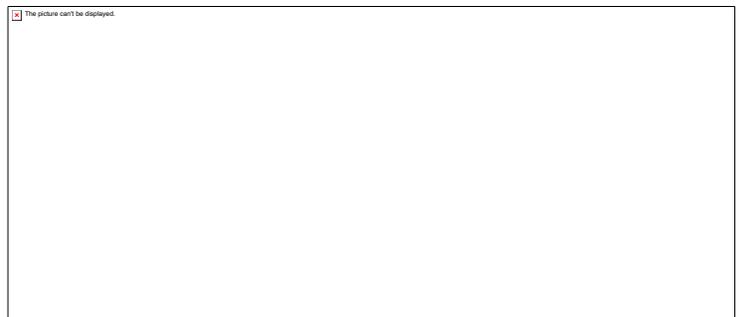
**Careers in Astronomy:** <http://www.jobsforastronomers.com/careers>

## American Institute of Physics Career Guide

<http://www.aip.org/statistics/trends/career.html>

## Careers Using Physics

<http://www.spsnational.org/cup/>



## Wisconsin Employers that have Hired Astronomy Majors:

Broadcast Interactive Media  
Epic Systems Corporation  
GEA Process Engineering, Inc.  
Harley-Davidson Motor Company  
SolidWorks Corporation  
King Pharmaceuticals  
Kleiss Gears, Inc.  
Mad City Labs



Mead & Hunt, Inc.  
Modine Mfg. Co.  
Pronto Progress  
HG Weber  
US Chemical  
Trane, Inc.  
TCS Basys Controls

### AIP State-By-State Listing: Who is Hiring Physics Bachelor's?

Employment opportunities for recent physics bachelor's degree recipients exist in all areas of the economy. At the link below, you will find a state-by-state listing of only a portion of the employers who recently hired new physics graduates to fill science and engineering positions. The many high schools, colleges, universities, and branches of the military that hire physics bachelors are not included. These listings will be useful to recent graduates by illustrating the diversity of employers who hired Astronomy/physics bachelor's:

<http://www.aip.org/statistics/trends/states/state.html>

### Median Salary Range for Astronomy Careers

Actual expected salaries will vary depending on your chosen career path, experience, and even your geographic location. Are you interested in detailed information about the forecasted demand for a particular profession or in the estimated salaries such positions are likely to pay? This government web site allows you to search on a particular job: <https://www.bls.gov/bls/blswage.htm>

### Graduate School: Skills Astronomers Need to Succeed

**Astronomers need to be good at physics and math;** that's what they do! Don't fall into the trap of thinking that astronomy is one of the "easier" sciences!

**Astronomers work with computers, so good computer and programming skills are helpful.**

**Some astronomers build their own instruments,** learning about electronics, materials fabrication and machining, and other skills.

**Astronomers need good teaching skills,** since they teach as much as they learn.

**Astronomers also need good writing skills** to write grant proposals for money and telescope time, and to share their research by writing articles for journals.

**Astronomers must have good communications skills** to convey their research results.

**Astronomers generally work in teams with various colleagues, so they need to be able** to share information and get along with different people.