A New Universe to Discover

A Guide to Careers in Astronomy

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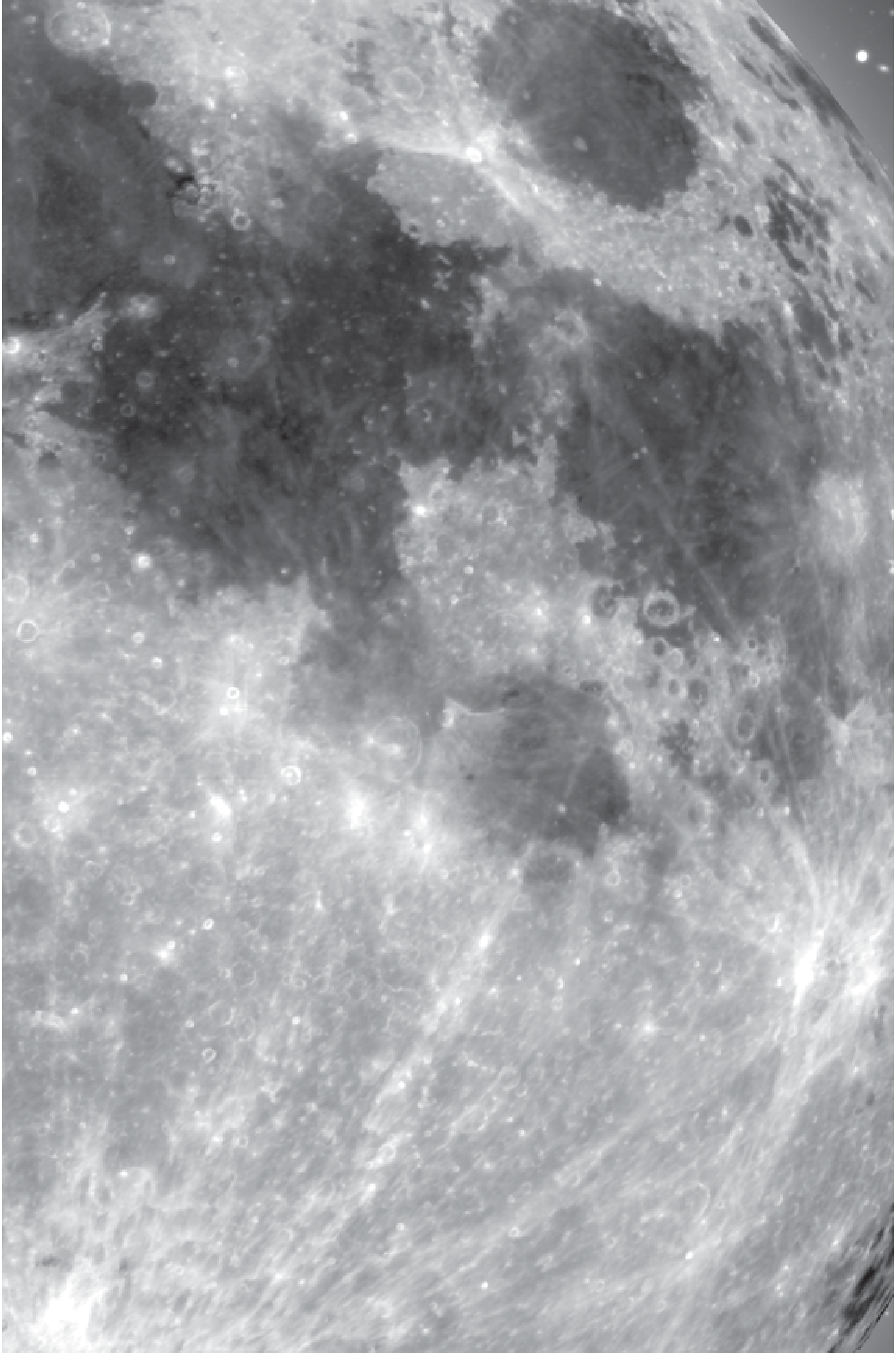


What are Astronomy and Astrophysics?

Ever since Galileo first turned his new-fangled one-inch "spyglass" on the moon in 1609, the popular image of the astronomer has been someone who peers through a telescope at the night sky. But astronomers virtually never put eye to lens these days. The main source of astronomical data is still photons (particles of light) from space, but the tools used to gather and analyze them are now so sophisticated that it's no longer necessary (or even possible, in most cases) for a human eye to look through them.

But for all the high-tech gadgetry, the 21st-Century astronomer is still trying to answer the same fundamental questions that puzzled Galileo: How does the universe work, and where did it come from?

Webster's dictionary defines "astronomy" as "the science that deals with the material universe beyond the earth's atmosphere." This definition is broad enough to include great theoretical physicists like Isaac Newton, Albert Einstein, and Stephen Hawking as well as astronomers like Copernicus, Johanes Kepler, Fred Hoyle, Edwin Hubble, Carl Sagan, Vera Rubin, and Margaret Burbidge. In fact, the words "astronomy" and "astrophysics" are pretty much interchangeable these days.

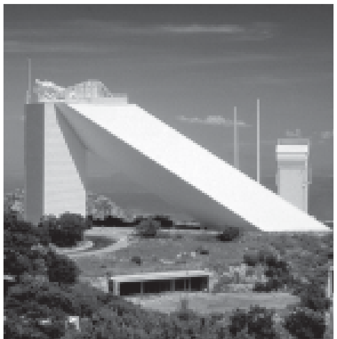
Whatever you call them, astronomers seek the answers to many fascinating and fundamental questions. Among them:

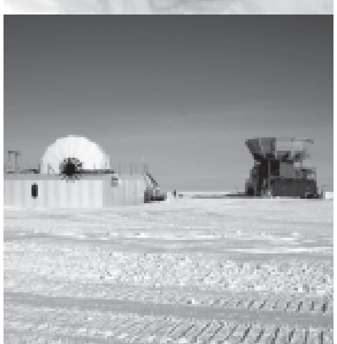
*Is there life beyond earth?
*How did the sun and the planets form?
*How old are the stars?
*What exactly are dark matter and dark energy?
*How did the Universe begin, and how will it end?

Astronomy is a physical (non-biological) science, like physics and chemistry. Astronomers use observations to collect data, and theory to make sense of it all. But unlike physicists and chemists, who can build laboratories and do experiments, astronomers must rely entirely on observation. Planetary astronomers are the lucky exceptions; they can send probes to touch and feel distant worlds like the Moon and Mars by remote control—and even bring back pieces of them.

The universe is so vast, and its mysteries so deep, that we're unlikely to run out of questions anytime soon. In just the last few years, astronomers have discovered dark energy, mapped the shape of the universe, plotted out its earliest few years, sent rovers to Mars, and launched a probe to orbit Saturn. These new discoveries reveal a universe richer and more varied than anyone had dreamed, and pose great new challenges for future astronomers.

What are the Tools of the Trade?





For much of the 20th Century, telescope technology advanced at a stately pace. Although some advances were made in radio telescopes, the technology of optical telescopes remained stagnant, with the 200-inch Hale telescope on Palomar Mountain reigning as the world's largest for 28 years, until 1976.

But an explosion of technology since then has dramatically increased the "seeing power" of today's telescopes, and changed the nature of the profession. These new tools have given astronomers new windows on the Universe.

On the Ground

Recent advances in materials, optics, and computers have triggered a surge of ever-larger and more powerful ground-based telescopes. Currently, the largest optical telescopes on earth are the twin 10-meter (400-inch) Keck telescopes in Hawaii. A dozen other optical telescopes around the world now have primary mirrors that measure more than five meters in diameter, larger than the once-mighty Hale. Gargantuan optical telescopes with mirrors 30 and 100 meters across are in the planning stages and expected to be operational in 10 to 20 years.

Adaptive optics increase the "seeing power" of these huge modern telescopes even more by compensating for blurring due to the earth's atmosphere. The day may not be far off when astronomers can directly see planets in other solar systems.

Meanwhile, astronomers who study the non-visible wavelengths—radio, infrared, and microwave—are forging ahead with new tools of their own. The largest ground-based astronomy project ever, the ALMA array of 64 12-meter radio dishes, is currently under construction in the high desert of Chile. The 100-meter Green Bank Telescope, the world's largest fully steerable radio telescope, has just been completed in West Virginia. The SOFIA infra-red telescope will soon take to the air in its own Boeing 747SP for ultra-clear views from the stratosphere. And buried a mile below the South Pole, the Ice Cube neutrino telescope, a network of 5,000 detectors arrayed through a cubic kilometer of ice, is slowly taking shape.

All of these new telescope projects will open up vast new frontiers of knowledge over the next couple of decades. Astronomers will use them to measure the chemical composition of stars, search for extrasolar planets, and probe the early history of galaxies. These cutting-edge telescopes will be brought to bear on some of astronomy's greatest unsolved mysteries. How did the first galaxies form? Why is most of the mass in the universe not directly observable? What exactly is this "dark matter"? Will the universe expand forever?

In Space

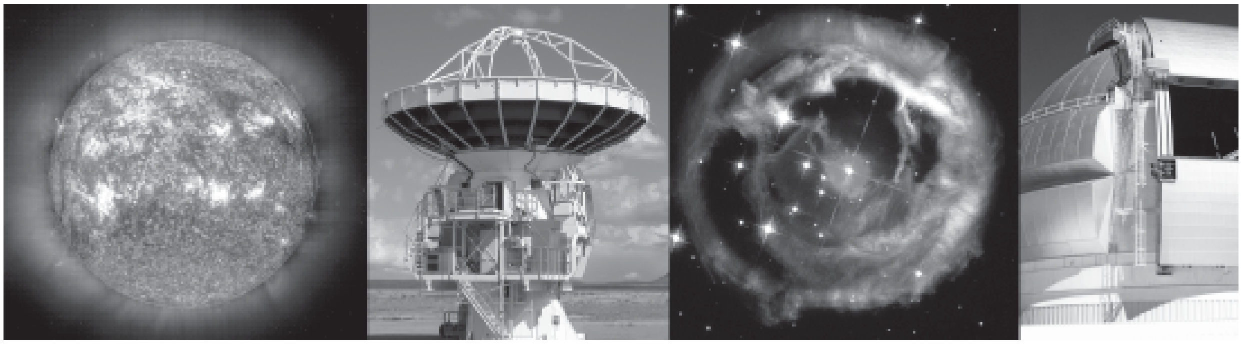
Space-based telescopes, because they orbit far above the earth's atmosphere, can see beyond the reach of ground-based instruments. We've all marveled at the extraordinary photographs from the Hubble Space Telescope. Other space-based telescopes study wavelengths that are mostly blocked by the atmosphere, such as ultraviolet, the far infrared, x-rays, and gamma rays.

The Hubble Space Telescope and its fellow NASA Great Observatories, the Chandra X-Ray Telescope and the Spitzer Space Telescope, have revealed the most distant supernova and shed new light on star formation, black holes, and the size of the universe. The Wilkinson Microwave Anisotropy Probe has revealed telltale signatures of the early universe. The Compton Gamma Ray Observatory detected photons from supernova eruptions and colliding galaxies, and shed new light on gamma ray bursters, the most powerful explosions in the universe. The Hipparcos Space Astrometry Mission has precisely mapped millions of stars. New space-based telescopes planned for the next 15 years will send back streams of data on galaxy formation, the age of the universe, dark matter and dark energy, and the Big Bang.

Computers

From Crays to laptops, computers have revolutionized the profession. Astronomers were among the first to embrace computers (both professionally and personally) back in the 1950s and 60s, and the typical astronomer today spends several hours a day at a computer screen analyzing data, controlling and monitoring telescopes, writing papers, reading journal articles, or researching databases.

Astronomers use powerful supercomputers to model cosmic jets and black holes, simulate galaxy collisions and supernova explosions, and determine how galaxies clustered together in the early universe. The popular Astrophysics Data Service provides instant on-line access to all astronomy and astrophysics journals. Data from space missions and ground-based telescopes are available over the web. The National Virtual Observatory will allow quick access to enormous troves of ground- and space-based data, including the Sloan Digital Sky Survey and HST images, which pinpoint more than 100 million celestial objects.



What do I have to do to Work in the Field of Astronomy?

Mostly it boils down to the type of education you pursue. And that depends on the specific job you're interested in.

To be a classic research astronomer who runs a telescope, analyzes data, and publishes papers, you'll need a PhD degree. Same for a college astronomy professor. Support positions in astronomy—for example, a telescope operator, observer, or software developer—typically require a Bachelor's or Master's degree. Specialized Master's degrees (in astrobiology, say) are growing in popularity.

Astronomy education is a fast-growing field these days. Pre-college teaching positions typically require a bachelor's degree, and public high school science teachers also need a teaching certificate. Positions in the up-and-coming field of astronomy education research require a PhD in either Astronomy, Physics, or Science Education. And no matter what your job in astronomy, you'll need good communication skills, both written and oral.

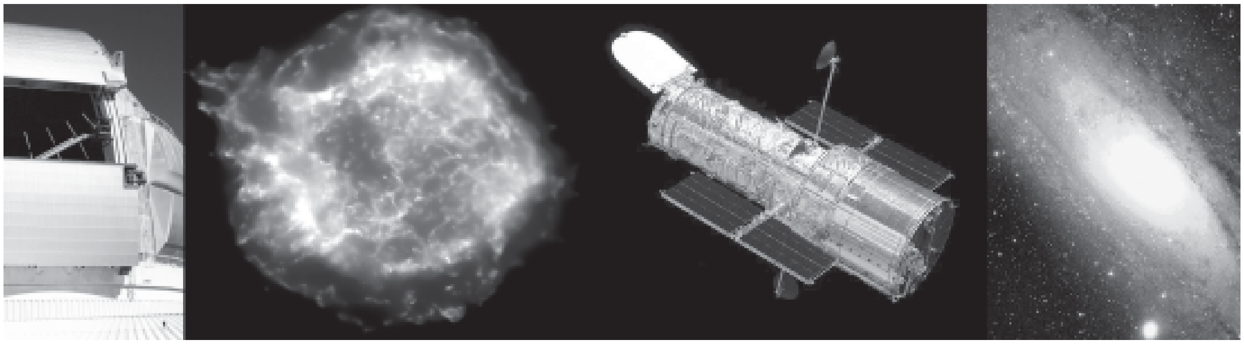
If you are in high school...

Take as many math and science courses as you can—physics, chemistry, biology, earth science, algebra, trigonometry, and calculus—as well as English, history and social studies. And don't forget to have some fun, too; extracurricular activities like sports, drama, music, and community service will make you a well-rounded person and help you get into the college of your choice.

Although few high schools teach courses in astronomy, you can learn on your own by reading astronomy magazines, joining a local astronomy club, or even buying a small telescope.

If you are in a two-year community college...

Again, take as many math and physics courses as you can, with an eye towards transferring to a four-year college. Most community colleges have credit-sharing and requirement agreements with a four-year school.



If you are in college...

The physics major is the typical undergraduate stepping stone to a PhD program and eventual astronomer's position.

To supplement the physics major, typical minors include math, astronomy, or chemistry, although some students choose humanities or social science minors. (In choosing a minor, be sure to check the admission requirements and preferences of graduate programs that interest you.)

Typical courses for a physics major include Introductory Mechanics, Electricity and Magnetism, Waves, Thermodynamics, Quantum Physics, Electrodynamics, Intermediate Mechanics, Intermediate Quantum Physics, one or two lab courses, plus one or two advanced physics courses.

Math courses required for the physics major typically include two semesters of Calculus, Linear Algebra, Several Variable Calculus, and Differential Equations.

What about an Astronomy major?

An astronomy major typically requires all of the same basic and intermediate physics and math courses, but replaces the advanced physics courses with introductory and advanced astronomy and astrophysics classes. Not all colleges and universities offer an astronomy major, however. Some institutions offer a "liberal arts" astronomy degree, with fewer physics and math courses which may be an option if you don't plan to go on to graduate sschool.

Many students opt for a double major in Physics and Astronomy. If you plan to go on to graduate school, the key is to meet the requirements of the doctoral program that interests you.

When should I start my major?

Most colleges require a full four-year physics sequence, so it's a good idea to start right away, in freshman year.

It may still be possible to switch to a physics major after freshman year, however. A few schools offer a three-year physics sequence, and others allow doubling up of courses to complete a four-year sequence in three. But in most cases, a late switch to a physics major will require an extra year.

What is Graduate School About, Anyway?

Choosing a Graduate School

There are a number of things to consider in choosing a graduate school program.

Physics or Astronomy Department?

Universities put varying degrees of emphasis on their Astronomy graduate programs. Their academic and research cultures can vary widely, so it's important to choose one that fits your aspirations. Typically, there are three scenarios.

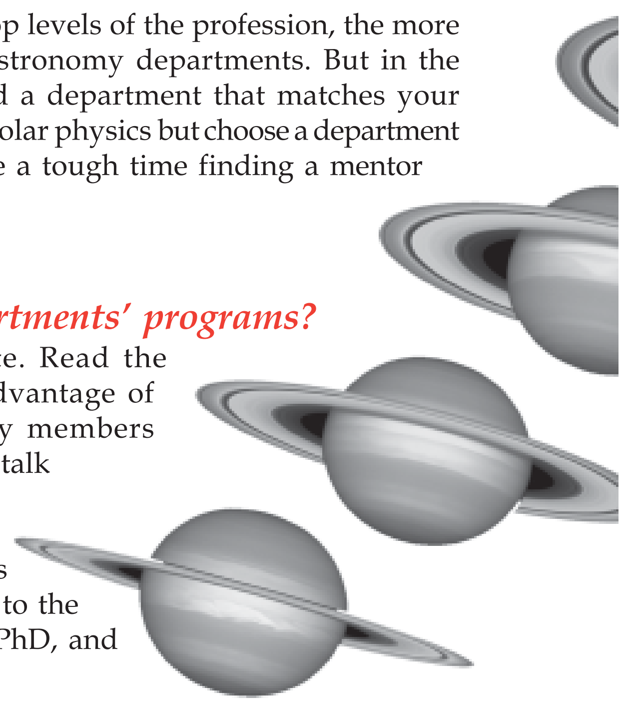
1. Astronomy as a subsection of the Physics Department. These programs usually offer only a handful of astronomy courses, and award physics degrees. Ten to twenty percent of the faculty may work in astronomy.

2. Combined Physics/Astronomy Department. In these combined departments, astronomers have more "clout." There are plenty of astronomy courses, degrees in astronomy are usually offered, and there may be a small telescope or observatory on campus.

3. Separate Astronomy Department. These offer many astronomy courses, degrees in astronomy, the largest number of astronomy faculty, and almost always have access to a telescope, either in their own observatories or through a consortium with other schools.

The largest astronomy departments have 30 graduate students and 20-30 faculty, research staff, and post-doctoral fellows. More typical astronomy departments are about half that size. Each has its own pros and cons; big departments have more opportunity for "cross-talk," and may have larger telescopes. Small departments offer closer faculty-student contact.

The more serious you are about reaching the top levels of the profession, the more you should look at schools with their own astronomy departments. But in the long run, the most important factor is to find a department that matches your research interests. If you have a fascination with solar physics but choose a department with an extragalactic emphasis, you may have a tough time finding a mentor or thesis advisor.



How do I evaluate the various departments' programs?

Start by checking the department's website. Read the research publications of the faculty. Take advantage of opportunities like colloquia to meet faculty members personally. If you can, visit the department and talk to both faculty and current graduate students. Ask them about their research, of course, but also quiz them about the more mundane aspects of life on campus: department policies, access to the telescope, graduate student stipends, time to PhD, and general quality of life.

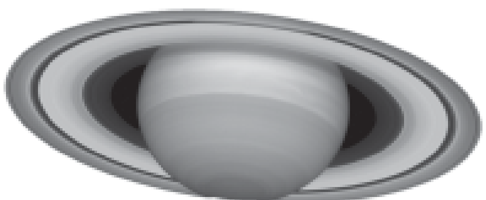
Applying to Graduate School

Most university astronomy departments evaluate the following for admission into a graduate program:

- Undergraduate grades.
- The most advanced physics and math courses taken.
- Undergraduate research projects. These can help enormously.
- Evidence that you've taken maximum advantage of local opportunities.
- The quality and reputation of the undergraduate physics and/or astronomy program.
- Standardized test scores, especially the GRE in physics.
- Letters of recommendation. They are most effective when they speak to independent thought and research.
- Personal essay. It should show a familiarity with the faculty and research facilities of the department.

Typical Graduate School Curriculum

The first two years of graduate school consist mostly of taking courses, typically eight courses in four semesters. Every graduate department requires a set of courses, and often offer additional elective courses. In a physics department, required courses include: classical mechanics, quantum physics, electrodynamics, and statistical mechanics. In an astronomy department, required courses typically include stellar structure and evolution, radiation processes in astrophysics, cosmology, extragalactic astronomy, and computational methods.



Many departments get students involved in research with a faculty member during the first two years, course load permitting. This may or may not lead to a research project for the PhD dissertation after finishing the coursework.

What about studying overseas?

Universities in English-speaking countries (Great Britain, Ireland, Australia) are quite a viable alternative. Others can be more challenging due to the language barrier, but are still do-able. Bear in mind that foreign universities are likely to have different requirements and philosophies. Make sure to research them thoroughly.

In the end, whether you go abroad or not is probably less important than finding a department whose research focus matches your interests.

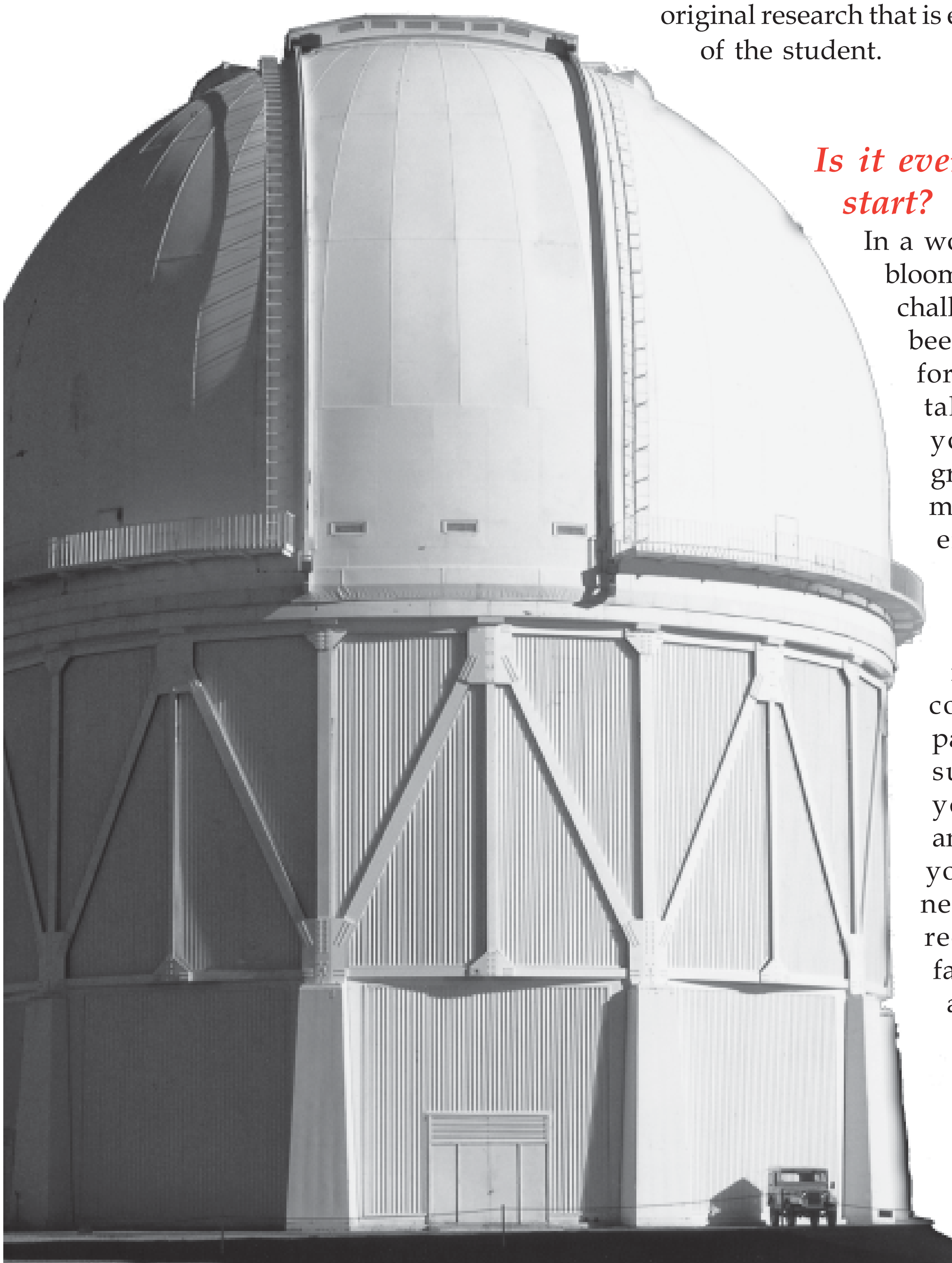
Starting in year three, you'll dive into your thesis research. Before you do, however, you'll have to survive a rite of passage called the "Qualifier," or "Prelim," which is a rigorous exam to make sure you're ready to proceed with your PhD thesis research. The Qualifier exam can take many forms: an oral exam, a written exam, a series of oral presentations, or a written thesis prospectus.

Some departments award a master's degree upon completion of the course work and qualifier exam. Others require a separate master's thesis.

If you decide to go on for your PhD allow 2-4 years to do your research and write your dissertation after finishing the coursework.

Some PhD research projects are based on theory, some on observation. Theorists spend a lot of time writing computer code and running simulations. Observers take data and analyze it. Theory-based dissertations, which may rely on easily available archived data, usually take less time than observation- or experiment-based projects, which are often subject to logistical delays (tight telescope time, bad weather, etc.)

The PhD degree is awarded upon completion of your dissertation. The dissertation may consist of a single monograph, a series of published papers, or a combination of monograph and papers. Each department has its own policy, but the one hard and fast rule is this: the dissertation must reflect original research that is entirely the work of the student.



Is it ever too late to start?

In a word, no. But late bloomers do face more challenges. If you've been out of school for a while, it can take time to find your student groove again. You may have to take extra courses to get back up to speed. Older students may not be able to count on their parents' financial support. And if you're working and raising kids of your own, you'll need to seriously reorganize your family's schedule and expectations.

What is the Profession like?

Professional lifestyle

Most astronomers feel very lucky in their jobs. Astronomy is a flexible, reasonably well-paid profession, with little or no clock-punching, strict vacation quotas, or other rigid work rules. An astronomer's value as an employee is measured not by the number of hours logged at the office, but by the quality of work, be it research, teaching, or support services. Most universities and research labs are reasonably accommodating when it comes to family issues like child care or elderly parents. Comments like this one from an astronomy professor/single dad are typical. "I can schedule doctor's appointments whenever I need to. I can take long lunches. People in other professions have demonstrably more difficult lives and far less freedom of choice."

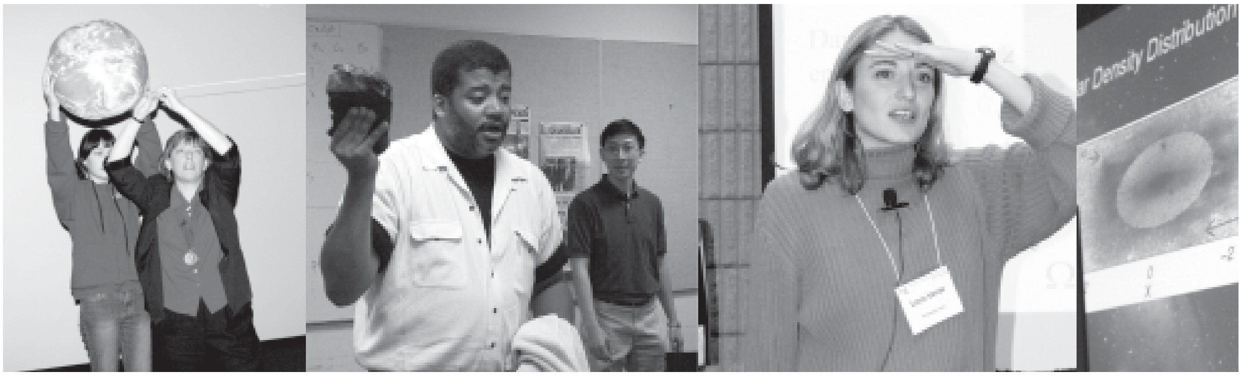
Perhaps the most common astronomy career hurdle is geography. Because the job market is so specialized and competitive, astronomers don't often get to choose their preferred area to live. They follow the job, whether it's in Paradise or Podunk. Moreover, your dream astronomy job may be in a lousy job market for your spouse.

Astronomy positions, especially on the lower rungs of the career ladder, are often temporary. (One to three years is typical.) Families need to be flexible and ready for a somewhat nomadic lifestyle in the beginning.

Historically, astronomy was a rich person's science, and before 1900 virtually all recognition for astronomical achievement went to white males. That's no longer the case, but in some institutions old attitudes still linger. Some women and minorities have reported what they consider unfair treatment in the profession. Age discrimination seems to be less of a problem, though; most astronomers work well past the traditional retirement age. On the other hand, despite laws against the practice, older applicants tend not to be favored for entry-level positions because of their perceived lack of "fresh" ideas, shorter career expectancy, and higher salary requirements.

Women and Minorities

In total, about 20 percent of astronomers are women. Among younger astronomers the percentage is higher, but it's much lower at the senior levels. In 2001, 25 percent of PhDs awarded by astronomy departments were earned by women, so it seems inevitable that the percentage of women in senior positions will eventually increase. Traditional minorities—African-Americans, Hispanics, and Native Americans—make up less than one percent of astronomy PhDs though this is changing.



What Jobs do Astronomers have?

As science professions go, astronomy is a relatively small field, with only about 7,000 professional astronomers in North America. (Compare that to the swarm of 40,000-odd physicists). Worldwide, about 11,000 astronomers are members of the International Astronomical Union, the world professional society. Because it's so small, the astronomy world is quite chummy, and it's easy to get to know and collaborate with colleagues around the world.

Although a few newly-minted PhDs jump straight into permanent positions, the usual astronomy career path starts with a temporary job as a post-doctoral scholar. After two to six years, post-docs typically move on to permanent positions at universities or government labs. (Thus, you may be in your mid-30s before landing your first permanent job.) By eight years past their PhD, 85 percent of astronomers have permanent jobs, half in research and half in other fields such as teaching or administration.

In a typical year, 200 to 300 jobs are advertised in the American Astronomical Society's *Job Register*. Roughly 150-200 of these are for temporary post-doctoral scholars. Considering that the number of astronomy/astrophysics PhDs awarded annually (by astronomy and physics departments) averages about 240, this adds up to a fairly competitive job market for aspiring post-docs.

Competition is also stiff for the other 50-100 permanent research and teaching positions that open up each year. In such a small and popular profesion, only people with smarts, a quality education, and a passion for the job are likely to land a permanent position in the field. But astronomy training prepares you for a wide variety of interesting and productive careers in related fields like industrial research, education, and public information. Virtually all astronomers eventually land a job of some sort; the overall employment rate for people with degrees in Astronomy and Astrophysics is an astonishing 99 percent.

Research Universities

Large research universities, both state and private, usually have the biggest astronomy departments. (Examples: Harvard University, University of California-Berkeley.) These departments typically have 15-20 professors, a research staff, and 20-30 graduate students. They usually have their own observatories, or share one with other colleges.

Astronomy faculty at large research universities pursue independent research, publish papers, support post-docs, train graduate students, teach classes, sit on academic committees, referee papers for publication, and write proposals to fund their research. Most of these positions are tenure-track, which means that after several years of satisfactory performance in scholarship, community service, and grantsmanship, the position becomes permanent.

Research staff at large university departments consist of three main categories:

- Post-docs are new astronomers only a few years out of graduate school. Their job is to help work on a senior astronomer's research project.
- Research professors work on their own projects, but must raise their own salaries and project expenses through grants. They are not required to teach.
- Research associates have jobs like operating telescopes or writing software. They typically work on other people's projects, but may do some research on their own. They do not teach or sit on academic committees.

Four-year Colleges

These are most likely to have joint physics/astronomy departments. Typical faculty size is 10-15 professors, perhaps a third of them astronomy professors. Research and support staff are limited.

The overall emphasis at smaller colleges is on teaching rather than research. While some professors may pursue independent research (often during the summer when classes are out), teaching is their main priority. If there's a telescope on campus, it's likely used for teaching, not research.

Two-year and Community Colleges

Two-year colleges can have physics departments, and often have physical science departments. Faculty teach five courses per semester, physics as well as astronomy. A PhD is not always required.

Industry and Business

Hundreds of astronomers are employed by private industry; many have PhDs. These contractors typically design and manufacture everything from telescopes to space probes, write software, and do many other tasks in support of NASA labs and space missions, ground-based observatories, and data processing/ management offices. These private companies need astronomers who understand and "speak the language" of the customer—be it a university, NASA, DOE, or other federal agency—and who can translate the customer's science requirements into technical requirements and specifications. Writing software is an especially fast-growing field for astronomers in private industry.

National Observatories and Research Centers

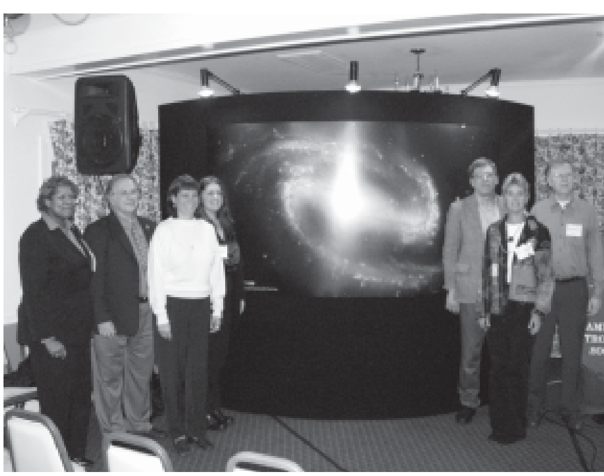
Many astronomers work at one of the National Observatories, which are government funded, and telescope time is open to any qualified astronomer.

The National Observatories include ground-based optical telescopes on Kitt Peak in Arizona, Sacramento Peak in New Mexico, and Cerro Tololo and Cerro Pachón near La Serena, Chile; and radio telescopes in Green Bank, West Virginia; Socorro, New Mexico, and Arecibo, Puerto Rico. The Gemini Observatory, with one telescope in Hawaii and one in Chile, is an international project.

In addition, NASA operates three space-based Great Observatories: the Hubble Space Telescope, the Chandra X-Ray Observatory, and the infra-red Spitzer Space Telescope. All of these, of course, are managed and controlled at ground-based centers.

These observatories are considered good places to work, with cutting-edge telescopes and a lively research atmosphere. Astronomers do their own research, but also support outside astronomers temporarily using the telescopes. Although many of these observatories are closely tied to universities, there are no teaching duties; the focus is purely on research. Some of the observatories offer a form of tenure. Salaries are comparable with industry and academia.

The NASA Research Centers employ many astronomers. Other government-funded research centers that focus on other fields such as energy research or particle



physics (e.g. Fermi National Accelerator Laboratory) employ a small number of astronomers.

The federal funding agencies themselves, such as the National Science Foundation and NASA, employ astronomers as administrators and overseers of the observatories and labs at their headquarters. Other astronomers work on high-level science policy in Congress or the Executive Branch.

Museums and Planetariums

Growing public interest in astronomy has spawned a number of jobs for astronomers at science museums and planetariums. The focus is primarily public education and outreach, although some larger institutions sponsor their own research. Degree requirements for these jobs range from bachelor's to doctorate degrees. More important are a broad range of astronomy knowledge and good communication skills with the public.

Public Relations and Journalism

Most astronomy research is supported by government funds, so it's vital to keep the taxpayers informed and interested. Astronomers with a knack for explaining complex ideas to the general public play a big role in this effort. Every NASA space mission, for example, has public relations, education and outreach staff with astronomy expertise. Organizations like the National Academy of Sciences and the American Association for the Advancement of Science hire people with astronomy backgrounds. Companies that manufacture telescopes and space probes need knowledgable public relations people. And for those with a talent for the written word, science journalism is a growing field.

Salary and Benefits

Although astronomers don't command CEO-level salaries and stock options, generally they're paid reasonably well. In the beginning, typical post-doc salaries range from $45,000 to $50,000 a year. Astronomy professors and research astronomers make between $50-100,000 a year, depending on school and seniority. Support positions pay a bit less. Government salaries are a bit higher.

Resources

There are many interesting books, newspaper articles, and websites on astronomy. Other sources of information are science museums, planetariums, and astronomy clubs. To help you get started here is a small list of resources.

Magazines

If you are interested in finding out more about astronomy and current research in astronomy these popular magazines are good places to start: Astronomy Magazine, Sky and Telescope, Scientific American, Science, and Nature. Many community libraries have subscriptions to them, and they are also available from newsstands and bookstores. The magazine publishers all have websites as well.

Undergraduate Schools

Your high school guidance counselor can help you find information about colleges and universities. The webpages of colleges and universities are also excellent sources. Books that describe colleges and universities are published every year; it's worth taking a look at these. Check with your local bookstore and library. Recent graduates can give you a wealth of information that you would not find in official publications. College alumni offices are more than willing to put you in contact with their alumni living in your area.

The Society of Physics Students is a professional organization explicitly designed for students, and has chapters at many schools with undergraduate astronomy and physics programs. Its web address is http://www.spsnational.org.

Graduate Programs

General information about graduate school in physics and astronomy is available from the American Institute of Physics at www.aip.org. The AIP annually publishes Graduate Programs in Physics, Astronomy, and Related Fields; this can be ordered from the AIP website. AIP's GradschoolShopper is an online site which provides both a graduate recruitment forum for graduate schools and a one-stop graduate-school shopping place for graduate-school-bound students at http://www.gradschoolshopper.com. Specific information about individual graduate programs is best obtained directly from the departments.

Careers and Jobs

Career and job information in astronomy is available on the website of the American Astronomical Society at http://www.aas.org/career. Education and employment trends are available from the American Institute of Physics at http://www.aip.org/statistics/. The Occupational Information Network's site at http://online.onetcenter.org/, developed for the United States Labor Department, has career and salary information for scientific professions.

Professional Organizations

These scientific societies advance and promote astronomy and astrophysics.
American Astronomical Society (http://www.aas.org)
Astronomical Society of the Pacific (http://www.astrosociety.org)
American Association of Variable Star Observers (http://www.aavso.org)

These organizations have sections or divisions that focus on astrophysical research.
American Physical Society (http://www.aps.org)
American Geophysical Union (http://www.agu.org)

Membership requirements for each society vary; all the societies publish peer-reviewed, scientific journals.

National Observatories, Facilities and US Federal Agencies

ALMA	Atacama Large Millimeter Array: http://www.alma.info/
CfA	Harvard-Smithsonian Center for Astrophysics: http://www.cfa.harvard.edu
CSC	Chandra Science Center: http://chandra.harvard.edu
IPAC	Infrared Processing and Analysis Center: http://www.ipac.caltech.edu/
Fermilab	Fermi National Accelerator Laboratory, a DOE facility: http://www.fnal.gov

Hipparcos	Hipparcos Space Astrometry Mission: http://www.rssd.esa.int/Hipparcos/
LANL	Los Alamos National Laboratory, a DOE facility: http://www.lanl.gov
NOAO	National Optical Astronomy Observatory: http://www.noao.edu
NRAO	National Radio Astronomy Observatory: http://www.nrao.edu
SDSS	Sloan Digital Sky Survey: http://www.sdss.org
SOFIA	Stratospheric Observatory for Infrared Astronomy: http://www.sofia.usra.edu
SSC	Spitzer Science Center: http://www.spitzer.caltech.edu/
STSCI	Space Telescope Science Institute: http://www.stsci.edu
DOE	Department of Energy: http://www.energy.gov
NSF	National Science Foundation: http://www.nsf.gov
NASA	National Aeronautics and Space Administration: http://www.nasa.gov

Glossary of Terms

BA - Bachelor of Arts, often awarded to majors in the arts and humanities. See Bachelor's Degree.
BS - Bachelor of Science, often awarded to majors in a science and engineering field. See Bachelor's Degree.
Bachelor's Degree - Degree awarded upon completion of college (undergraduate) requirements.
Dark energy - an unknown kind of matter-energy that accelerates the universe's expansion. It cannot be detected directly.
Dark matter - matter that cannot be detected directly with photons, but has mass and gravitational interactions.
Dissertation - A formal, written argument advancing a new point of view resulting from research; usually a requirement for an advanced academic degree.
Freshman - a person in the first year of study at an undergraduate college or university.
GRE - Graduate Record Examination. A required examination for admission to graduate school.
Liberal Arts - Studies in a college or university intended to provide general knowledge and intellectual skills (rather than occupational or professional skills). Traditional liberal arts fields include language, history, and science.
Major - main area of specialization, usually at the college level.
Master's Degree - an advanced degree. Requires a Bachelor's degree to be admitted into a masters program.
Minor - a secondary program of study.
Monograph – A scholarly work on a single subject. It may be a book, a journal article or paper.
Paper(s) - A scholarly article describing the results of observations and hypotheses.
PhD - Doctor of Philosophy, in the US it is the highest academic degree awarded.
Post-doc – see Post-doctoral scholar
Post-doctoral scholar - a person who has received a PhD and holds a temporary position. The position may be a fellowship (no obligation except to do one own's research) or a salaried position.
Post-doctoral student – see Post-doctoral scholar.
Thesis – used here as a synonym for dissertation.
Virtual Observatory - a "cyber" observatory that provides access to all data on celestial objects.

Names of People

Copernicus, Nicolaus. 15th century Polish physician and astronomer. Famous for his published heliocentric theory that challenged the geocentric view of his time.
Einstein, Albert. 20th century theoretical physicist of German origin. Einstein is perhaps best known for explaining the photoelectric effect, and his discoveries of special and general relativity.
Galilei, Galileo. 17th century scientist. First to use a telescope for astronomical observations, measurements of gravitational acceleration and the speed of light.
Hawking, Stephen. English physicist. Hawking's work showed that Einstein's General Theory of Relativity implied space and time would have a beginning in the Big Bang and an end in black holes, and, that is necessary to unify General Relativity with Quantum Theory.
Hipparcos - Second-century B.C. mathematician, philosopher and astronomer. He made the first catalog consisting of 1,080 stars.
Hoyle, Fred. 20th century English astronomer. Made seminal contributions to the theory of the structure of stars and on the origin of the chemical elements in stars, published over 40 books including popular science and science fiction.
Hubble, Edwin. 20th century American astronomer, determined that there are other galaxies in the

Universe beyond the Milky Way, and observed that the universe is expanding.
Kepler, Johanes. 17th century German scholar, First to correctly explain planetary motion, and principles of modern optics.
Newton, Isaac. 17th century English scientist and mathematician. Invented calculus and defined the laws of motion and universal gravitation which he used to predict precisely the motions of stars, and the planets around the sun. Constructed the first reflecting telescope.
Sagan, Carl. 20th century American astronomer. Sagan made major contributions to the study of planetary atmospheres and surfaces, the history of Earth and astrobiology, and was a successful popularizer of science.

Photo credits

Front cover, *Row 1*
a. David James, research faculty at Vanderbilt University (left) and Thompson LeBlanc, graduate student (right) in the control room of the SMARTS 1.5 meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. (Courtesy of FASST)
b. Astronaut and Astronomer John Grunsfeld presents AAS Past President and Professor at Indiana University Caty Pilachowski a page from Hubble's thesis that flew in the shuttle during the third HST servicing mission in 1999 (Photo by Richard Dreiser, © 2003 AAS)
c. Beth A. Brown, Astrophysicist, National Space Science Data Center (NSSDC), NASA/Goddard Space Flight Center, discussing an eclipse on CNN.
Row 2
d. Licia Verde, now an assistant professor at the University of Pennsylvania. speaking on combining microwave background observations with galaxy surveys to understand the nature of the universe. (Photo by Richard Dreiser, © 2003 AAS)
e. NGC3718 in Ursa Major (NOAO/AURA/NSF)
f. Carl Sagan Medalist Heidi Hammel (right, Space Science Institute) assisted by Seattle student Tori DeLung (left) in a demonstration comparing the size of the Earth with the distance to the Moon at the Pacific Science Center (Photo by Richard Dreiser, © 2003 AAS)
Row 3
g. Lisa Glukhovsky (Milford H.S., CT) at the 203rd AAS Meeting explaining the "Rapid, Accurate Method of Determining the Distance to Near Earth Asteroids" that won her the Intel Foundation Young Scientist Award (with a $50,000 scholarship) and the 2003 First Place Priscilla and Bart Bok Prize (with $5000 scholarship). (Photo by Kelley Knight, © 2004 AAS)
h. Neil deGrasse Tyson, Director of the Hayden Planetarium of the American Museum of National History, (left) holding a meteorite and Charles Liu, Associate at the Museum and Professor of Astrophysics at the City University of New York, (right) discussing solar system properties with middle school science teachers.
i. Astronomer Royal Sir Martin J. Rees (Cambridge University, England) receives a certificate from AAS President and Harvard Professor, Robert Kirshner, on the occasion of his being given the Henry Norris Russell Lectureship, a prize for lifetime achievement in Astronomy. (Photo by Kelley Knight, © 2005 AAS)

Page 1: Full Moon. Image taken by T.A. Rector and I.P. Dell'Antonio (NOAO/AURA/NSF)

Page 2: From Top to Bottom
a. McMath Solar Telescope on Kitt Peak, the largest solar telescope in the world. (NOAO/AURA/NSF)
b. Spitzer Space Telescope pointing its high gain antenna towards Earth. Artist's conception. (NASA/JPL-Caltech). Spitzer was launched in August, 2003.
c. Deployment of an optical module for AMANDA, a neutrino telescope at the South Pole. (AMANDA/NSF)
d. At the South Pole. The building on the left is the Antarctic Submillimeter Telescope and Remote Observatory and the structure on the right is MAPO, the Martin A. Pomerantz building where various astrophysics experiments are installed. (Photo courtesy of Robert Stokstad, Lawrence Berkeley National Laboratory)
e. Keck Telescope primary mirror is 10 meters in diameter (Photo by Robert van Green)

Pages 4-5: From left to right

a. He-II (NASA/NSSDC)
b. ALMA Prototype (NRAO/AUI and Photographer-Kelly Gatlin; Digital composite-Patricia Smiley)
c. Star V838 Monocerotis – December 17, 2002 (NASA/ESA and H.E. Bond {STScI})
d. Gemini North, Mauna Kea (NOAO/AURA/NSF)
e. Cassiopeia A: Chandra's Fireworks (NASA/CXC/SAO)
f. Hubble Space Telescope in orbit around the Earth as seen from the Space Shuttle. (NASA)
g. Andromeda Galaxy, T.A. Rector and B.A. Wolpa/ (NOAO/AURA/NSF)

Pages 6 and 7: A Change of Seasons on Saturn, NASA and The Hubble Heritage Team. (STScI/AURA) Acknowledgment: R.G. French. (Wellesley College)

Page 8: CTIO 4-meter Blanco telescope (NOAO/AURA/NSF)

Pages 10-11: From Left to Right
a. Heidi Hammel and Tori DeLung, see caption for Front Cover f.
b. Neil de Grasse Tyson and Charles Liu, see caption for Front Cover h.
c. Licia Verde, see caption for Front Cover d.
d. Daniel Zucker an astronomer at the Max Planck Institute in Heidelberg, Germany, found a giant clump of stars that could be a new satellite of the Andromeda galaxy. (Photo by Kelley Knight, © 2004 AAS)
e. David James and Thompson LeBlanc. See caption for Front Cover a.
f. Lynn Cominsky, Professor of Astronomy at Sonoma State University and AAS Deputy Press Officer in the press room at the 205th AAS Meeting. (Photo by Kelley Knight, © 2005 AAS)

Pages 12-13: From Left to Right
a. Moments after a spectacular Hubble Heritage image of a barred spiral galaxy was unveiled at the AAS meeting, it was transmitted to museum video display walls and posted on the internet. The team responsible included (l-to-r) Cheryl Gundy, Ray Villard, Patricia Knezek, Lisa Fratarre, Zolt Levay, Carol Christian and Howard Bond. Knezek is at WIYN Observatory; the others are with Space Telescope Science Institute. (Photo by Kelley Knight, © 2005 AAS)
b. Beth A. Brown, see caption for Front Cover c.
c. Middle school science teachers at an astronomy workshop held at the American Museum of Natural History in New York with Charles Liu, Museum Associate and Professor of Astrophysics at the City University of New York.
d. Sir Martin J. Rees, see caption for Front Cover i.

Credits

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Susana Deustua, PhD
Director of Educational Activities
American Astronomical Society
2000 Florida Avenue, NW #400
Washington, DC 20009-1231
202-328-2010
www.aas.org

Layout by Crystal Tinch

American Astronomical Society
2000 Florida Avenue, NW, Suite 400
Washington DC 20009-1231

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