# STEWARD OBSERVATORY
*Established in 1916*

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The University of Arizona’s (UA) Department of Astronomy currently has 47 Ph.D. students, making it the largest astronomy graduate program in the country. The program is extremely high quality, with admission of approximately 8-10 students per year from among 120-130 applicants. Incoming astronomy graduate students have the highest mean GRE scores among over 100 graduate programs on campus. We compete with Caltech, Harvard, Santa Cruz, Berkeley, and Chicago for the best students in the country. The graduate program is diverse, with 40% women (compared to the national average of 30%) and 26% international. Two thirds of the graduating Ph.D. students move into permanent astronomy positions in academia, government, or other research institutes.

According to the American Institute of Physics’ statistics, the Department of Astronomy runs the largest undergraduate majors program in the country. In 2005, 24 students graduated, and the best of these were accepted in the Ph.D. programs at Caltech, UC Berkeley, Harvard and Chicago, which are in the top echelon of astronomy departments nationwide. Over two thirds of the majors have formal research experience during their time as undergraduates, drawing on the full expertise of about 28 faculty members in theory, observation, and instrumentation. The program has excellent gender equity, with 45% women, above the national average for astronomy, which is far above the national average in physics. (Many of our students are double majors in physics and astronomy.)

One in four UA students takes a General Education course taught by the Department of Astronomy. Despite their major commitments to research, astronomy faculty members teach these courses in person. Last year UA astronomers taught 2,339 Tier One and Tier Two General Education students (the largest number of students taught by any UA College of Science department). Faculty members in the department have been innovative in the use of preceptors, classroom response devices, and instructional technology. Since 1922, our continuing public and education outreach programs have included the Steward Observatory Public Evening Lectures. The department also houses the Center for Astronomy Education (CAE), the largest college-level astronomy education research group in the nation, and the internationally renowned Astronomy Camp. (See the Astronomy Camp and CAE sections of this document.)
The Center for Astronomy Education (CAE), lead by Ed Prather & Gina Brissenden, is devoted to improving teaching and learning in Astro 101 by conducting fundamental research on student beliefs and reasoning difficulties related to astronomy, and instructor implementation difficulties related to teaching astronomy. The center uses the research results to inform the development of research-validated curriculum and assessment materials for use in the Astro 101 classroom. These research-validated curricula & assessment materials frame the CAE Teaching Excellence Workshops for Astro 101 instructors. The goal of these professional development workshops is to increase the pedagogical content knowledge of Astro 101 instructors and improve implementation of these curricula and assessment materials.

To create sustainability and broaden the national impact and scope of the work, CAE, in collaboration with other leaders in astronomy education and research (Chris Impey, SO; Kevin Lee, U. of Nebraska; and Doug Duncan U. of Colorado), developed the NSF funded Collaboration of Astronomy Teaching Scholars (CATS) Program. The primary goals of CATS are to:

1) Increase the number of Astro 101 instructors conducting fundamental research in astronomy education
2) Increase the amount of research-validated curriculum & assessment instruments available for use in Astro 101
3) Increase the number of instructors prepared to develop & conduct their own CAE Teaching Excellence Workshops

Astronomy Camp is an internationally known science education program held since 1988 at the Catalina Observatories on Mt. Lemmon. Created by astronomer Don McCarthy and sponsored by the UA Alumni Association, the Camp engages an international audience of teenagers, adults, educators, and school groups in research-based science education using telescopes as large as 1.5 meters. Begun as a service to the public, the Camp has grown steadily and benefits the UA by providing major external funding (research and education), undergraduate and graduate recruitment (National Merit, Intel Science Search, minority), student funding (salaries, fellowships), postdoctoral education grants, etc. Astronomy Camp is the primary focus of NASA's James Webb Space Telescope NIRCam outreach to all 317 Councils of the Girl Scouts of the USA (GSUSA) and has led to a major improvement of the GSUSA's national astronomy curriculum.

The Camp is financially self-sufficient and supports an internal scholarship program. The donations of a former adult Camper now provide major support for the site and are funding the development of the Mt. Lemmon SkyCenter to expand the present activities in a multi-disciplinary approach.
Theoretical Astrophysics Program (TAP) in the Department of Astronomy
http://www.astrophysics.arizona.edu/

The Department of Astronomy at the UA has an active theoretical astrophysics group comprised of 5 faculty members and numerous postdoctoral researchers, graduate students, and undergraduates, with leading experts in the theory of supernovae, cosmology, planetary physics, stars, nucleosynthesis, stellar atmospheres, galaxy formation, and active galactic nuclei. Theorists in the department have performed pioneering work in the physics of the cosmic microwave background, weak gravitational lensing, the mechanism of supernova explosions, the structure of the intergalactic medium at high redshifts, multi-dimensional stellar evolution, and the atmospheres and spectra of giant planets and brown dwarfs. Astrophysics is becoming increasingly computational, and UA faculty members are at the forefront of associated numerical developments. These developments include numerical hydrodynamics and fluid flow, radiative transfer, N-body simulations, and astrophysical visualization. In the last ten years, the theorists in the department have published on average about 25 papers per year in refereed journals, and collectively garnered on average $1,000,000 per year in federal grant money to support their research enterprises.

The Theoretical Astrophysics Program, whose current chair Professor D. Eisenstein resides in the Astronomy Department, aims to encourage interactions among the astrophysics theory groups in the departments of Astronomy, Physics, and Planetary Sciences. About 15 theory faculty, spread among these departments, make Arizona’s one of the largest astrophysics theory groups in the country. The Program runs colloquia, a visitors program for distinguished scholars, short topical meetings, a graduate student research prize, and a small grants program, and sponsors a prize post-doctoral research fellowship. The program has two faculty who are members of the National Academy of Sciences, one of whom is situated in the Department of Astronomy.

Figure 4. This image is from a multi-dimensional simulation of the collapse of a rapidly rotating white dwarf star, and it depicts the disk formed and the bipolar jets that arise. Such calculations require many hundreds of thousands of CPU hours on supercomputers and represent the state-of-the-art in astrophysical simulation. Image by D. Fisher.

Figure 5. This snapshot is of the velocity field from a 3D hydrodynamic simulation of hydrogen burning core convection in a massive star. A hydrodynamic simulation such as this shows a phenomenon not predicted by standard stellar theory: motion in convectively stable regions. Image by graduate student C. Meakin.

Figure 6. This graphic depicts the early universe some 750 million years after the Big Bang. The filaments that form are proto-galactic clusters and proto-galaxies that coalesce due to gravity. The bright yellow colors depict regions of high temperature. Image by graduate student B. Oppenheimer.
Astrobiology is an interdisciplinary science spanning the sciences of astronomy, biology, chemistry, geology, and physics, and related interdisciplinary areas. Its goal is to answer fundamental questions about the origins of life. How did terrestrial life arise and evolve? Is there life elsewhere in the Universe? What is the future of life on Earth and beyond?

LAPLACE began in 2003 when NASA’s Astrobiology Institute (NAI) granted a five year cooperative agreement with the UA - National Optical Astronomy Observatory (NOAO) team. The UA share (80%) involves work in our laboratories and observatories in the astronomy, planetary sciences, and chemistry departments. The UA-NOAO team collaboration is one of 16 teams in NAI, a virtual institute with national and international participants.

We have strong and growing interactions with other NAI team members through regular conferences and meetings and through our Astrobiology Winter School and student exchanges with other NAI members. Graduate students in LAPLACE organized the first ever Astrobiology Graduate Student Conference. LAPLACE and another NAI team, the University of Washington (UW), conducted a highly successful exchange, the type critical to the success of astrobiology research; biologists came to UA to learn about astronomy, and astronomers and planetary scientists went to UW to learn about biology. This exchange serves as a model of hands-on, cross-disciplinary interaction for our other educational and cooperative efforts.

In 2005, under the leadership of Professor Nick Woolf, LAPLACE became a Center at the UA. One of the Center’s primary goals is to increase the interdisciplinary reach at the UA to include life sciences (e.g. biology, biochemistry, and cellular and molecular biology) so as to grow vibrant interactions among the many sciences of astrobiology. LAPLACE is working toward establishing interdisciplinary astrobiology minors for undergraduate and graduate students. Our researchers use state-of-the-art facilities such as the Arizona Radio Observatory, the Spitzer Space Telescope, and the various optical and infrared telescopes available through Steward Observatory.

We are implementing innovative approaches to science education under the unifying theme of astrobiology. Students work with scientists searching for molecules in space, investigating disks and planet formation around other stars, and searching for habitable planets in nearby planetary systems. This research is linked to the evolution of life on Earth. LAPLACE is building a community of astrobiologists that will explore some of the most profound questions of the Universe.

http://www.as.arizona.edu/
Because of their high altitude and the personal interest of Gerard Kuiper (founder of the UA Lunar and Planetary Laboratory), the Mt. Lemmon telescopes were central in the early development of infrared astronomy under Kuiper, Harold Johnson, and Frank Low. The outstanding optical quality of the Mt. Bigelow reflector, built under Kuiper’s leadership, has provided some of the most exquisite images of Saturn and of the Moon ever taken by ground-based telescopes. Today, the availability of large amounts of time on this telescope allows programs to monitor variable sources, covering a range of possibilities from very low luminosity white dwarfs to supernovae. The telescope is ideal for tracking fast-moving near-Earth asteroids. The Catalina facilities provide learning opportunities for undergraduate and graduate student research and are the keystones of an emerging public and teacher outreach network. These programs, as part of the Mt. Lemmon Science Center, will be dedicated to advancing the role of the UA in science education activities in and beyond the Tucson area. (See the Astronomy Camp section of this document.)

Catalina Facilities
http://www.as.arizona.edu/telescopes/telescopes.html

The UA observing facilities in the Catalina mountains include 1.5-m and smaller telescopes on Mt. Bigelow (elevation 8,230 ft.) and Mt. Lemmon (9,160 ft.), plus additional facilities operated under site maintenance contracts for universities and laboratories outside Arizona. The pre-eminence of astronomy-related research and development in and around Tucson owes its history in large part to the role the UA played in enabling the establishment of the first national observing facility for optical/infrared astronomy on Kitt Peak (6,875 ft.) in the 1960’s and 70’s. Since that time, the UA’s presence on Kitt Peak has been highlighted by an extremely productive 2.3-m (90”) telescope, as well as smaller facilities whose scientific accomplishments include the identification of the optical pulsar at the center of the Crab Nebula supernova remnant. The 2.3-m Bok telescope, named after famous Milky Way astronomer and former department head Professor Bart Bok, is still the largest optical telescope wholly owned by the state of Arizona. As such, it can be equipped with any of a wide array of state-of-the-art instrumentation and time is awarded on a competitive basis to fulfill the varied requirements of faculty and graduate student research programs at Arizona’s three state universities. Like those in the Catalinas, the Kitt Peak telescopes of more modest aperture are dedicated to targeted research programs under long-term grants, such as the Spacewatch survey to search for near-earth asteroids and comets, and Trans-Neptunian objects, operated by the UA’s Department of Planetary Sciences. There are two Spacewatch telescopes: 0.9-m and 1.8-m reflectors.

Kitt Peak Facilities
http://www.as.arizona.edu/telescopes/telescopes.html

The outstanding optical quality of the Mt. Bigelow reflector, built under Kuiper’s leadership, has provided some of the most exquisite images of Saturn and of the Moon ever taken by ground-based telescopes. Today, the availability of large amounts of time on this telescope allows programs to monitor variable sources, covering a range of possibilities from very low luminosity white dwarfs to supernovae. The telescope is ideal for tracking fast-moving near-Earth asteroids. The Catalina facilities provide learning opportunities for undergraduate and graduate student research and are the keystones of an emerging public and teacher outreach network. These programs, as part of the Mt. Lemmon Science Center, will be dedicated to advancing the role of the UA in science education activities in and beyond the Tucson area. (See the Astronomy Camp section of this document.)
The telescope called the MMT (formerly the Multiple Mirror Telescope) on Mt. Hopkins (8,550 ft.) was constructed in the late 1970's as a cooperative project between the University of Arizona and the Smithsonian Institution. This telescope pioneered several features of modern large-telescope design, including multiple objective mirrors, a short overall length, an alt-azimuth mount, and a co-rotating enclosure. In addition to producing high-quality optical spectroscopy and infrared (IR) images, the six 1.8-m primary mirrors enabled important interferometric tests that led to the observatory’s forefront adaptive optics research, nulling interferometry, and development effort aimed at virtually eliminating the optical effects of our turbulent atmosphere in the near-IR.

Conversion of the multiple mirror telescope to a single 6.5-m mirror served as an essential stepping stone toward the development of the even larger 8.4-m diameter spin-cast borosilicate mirrors now installed in the Large Binocular Telescope (LBT) and those planned for the Giant Magellan Telescope (GMT). At the MMT, techniques were developed to control mirror temperature, figure measurement and correction, secondary handling, and in situ primary mirror aluminization; many of these solutions have been incorporated into the twin 6.5-m Magellan telescopes and the LBT. The present aperture of the MMT offers twice the collecting area of the original telescope and provides a much cleaner IR pupil to make best use of the high, dry site. Several powerful instruments constructed by both parent institutions exploit the large collecting area, a one degree field of view, and technological developments of semiconductor detector arrays to yield a research tool that is competitive with the largest telescopes in the world. Adaptive optics continues to be emphasized at the MMT for reducing sky background and obtaining near diffraction-limited images that are essential for studies of the formation and content of galaxies at high redshift, the extragalactic distance scale, star formation in dense molecular clouds, and in searches for extra-solar planetary systems.

The Magellan Telescopes
http://www.ociw.edu/magellan/

The Magellan Telescopes at Las Campanas (8,000 ft.) in Chile (~360 miles north of Santiago) are two separate 6.5-m state-of-the-art optical telescopes on alt-azimuth mountings. In collaboration with the Observatories of the Carnegie Institution, Harvard University, MIT, and the University of Michigan, the University of Arizona utilizes these telescopes to explore the southern sky. UA’s 10% share of the facility provides valuable access to the southern hemisphere and such unique targets as the Galactic Center and the Large Magellenic Clouds. The site is known for its excellent weather and “seeing” (image quality). The instrumentation includes a wide-field optical spectrograph used to probe the most distant reaches of the universe, a high-spectral-resolution spectrograph used in planet searches, and a rapid-deployment imaging camera intended to monitor...
The LBT, located on Mt. Graham (10,500’) in southeastern Arizona, is the major telescope development for the University of Arizona (with ASU and NAU) and its partners from Italy (13 observatories under the National Astrophysics Institute, INAF), Germany (LBTB: a consortium of 5 research institutions), and within the USA (Ohio State University and the Research Corporation). With its two 8.4-m primary mirrors on a common mount, the LBT has the light collecting power of an 11.8-m telescope and the spatial resolution capability of a 22.8-m aperture. Indeed, with its adaptive secondary mirrors and beam-combining optics, the LBT may be viewed as the first of the next generation of extremely large telescopes. It is the forerunner of the Giant Magellan Telescope.

The suite of instruments makes Magellan competitive with even larger telescopes. One of the key instruments available at Magellan is the Inamori Magellan Areal Camera and Spectrograph (IMACS), which enables simultaneous observations of hundreds of objects in the standard mode and thousands of objects in a special mode conceived and designed by UA and MIT astronomers. In this latter mode it is the most efficient instrument in the world for measuring spectroscopic redshifts of faint objects. The Low Dispersion Survey Spectrograph (LDSS-3) has been updated to work in the red portion of the optical spectrum and is now more efficient than the Echelette Spectrograph and Imager at the Keck telescopes for measuring the internal kinematics of faint galaxies.

The LBT has five focal stations where instruments may be mounted permanently. In accordance with weather conditions, observers may switch rapidly (~15 minutes) among them. The initial instruments are twin wide-field prime-focus cameras, optical spectrometers, and near-infrared imager/spectrometers; these will be followed by two interferometers optimized for the mid- and near-infrared regions respectively.

The LBT’s unique spatial resolution capabilities on faint objects make it an ideal instrument for studying problems as diverse as extra-solar planets, zodiacal disks around nearby stars, and newly forming galaxies in the early universe. LBT began regular observations in late 2006 with two prime focus cameras.
The Giant Magellan Telescope (GMT)
http://www.gmto.org/

The GMT would consist of seven 8.4-m mirrors (six off-axis plus one central element) configured to be part of a 25-m f/0.7 single primary. It would provide collecting area equivalent to a single 21.5-m telescope and resolution corresponding to a 25 m. Like the Large Binocular Telescope, the GMT would be equipped with adaptive secondaries, but in this case, seven mirrors segmented like the primary aperture.

The GMT project is a collaboration among the Magellan partners (Carnegie, Harvard, Michigan, MIT, and Arizona), the Smithsonian Astrophysical Observatory (MMT partner), Texas A&M, U. Texas at Austin, and the Australian National University.

The GMT project represents the outgrowth of the very successful Magellan telescopes and a recommendation by the National Academy of Sciences to build a significantly larger ground-based optical/infrared telescope.

In February 2006, GMT conducted a conceptual design review, which resulted in a very positive evaluation from the international review team. Much of the GMT design was produced at the UA (Steward Observatory and Optical Sciences). Participation in the project is a key to the future of both the Steward Observatory Mirror Laboratory and Arizona Astronomy.

Large Synoptic Survey Telescope (LSST)
http://www.lsst.org

In 1997, Professor Roger Angel at Steward Observatory embarked upon the design of a system that could survey the entire night sky rapidly, repeatedly, and to great depth. This design was clearly an enabling step for a wide variety of science, and the concept rapidly gained community support. Over the next several years, plans developed into a design for the LSST, a project endorsed by three National Academy of Sciences panels.

With its three-mirror optical system, the LSST will have an 8.4-m aperture with a field of view 400 times the area of the full moon. This image will be recorded by a 3.2 gigapixel camera, the largest ever built, to be supplied by a Department of Energy (DOE) team lead by the Stanford Linear Accelerator Center.

The LSST data will be processed in real time, tracking change in more than five billion sources and discovering thousands more each night. The LSST will be an “open-data” project; all data will be on-line, freely accessible to the public.

The contract for the unique primary/tertiary mirror combination has been awarded to Steward Observatory’s Mirror Lab.
The Arizona Radio Observatory (ARO) has embarked on a program in millimeter and submillimeter radio astronomy with a goal of understanding the processes of star formation, the evolution of the chemical composition of galaxies, and the influence of cosmic events leading to the origins of life. The ARO group offers observational support and state-of-the-art instrumentation for researchers at its two world-class radio telescopes. Group members are performing groundbreaking research in astrochemistry and astrobiology. In support of this work, the group is developing and applying advanced instrumentation, such as the first detector systems from the ALMA (Atacama Large Millimeter Array) Project, which is the future international flagship radio telescope.

ARO facilities include the 10-meter Heinrich Hertz Submillimeter Telescope (SMT) on Mt. Graham. Originally developed in partnership with the Max-Planck Institut fur Radiostromomie in Bonn, Germany, it is now operated by the University of Arizona (UA). The high surface accuracy of the 10-m antenna, complemented by its elevation (3175 m), is arguably the best sub-mm telescope in the world observing at wavelengths shorter than 1 mm. Since 2001, Steward Observatory has operated the Kitt Peak 12-m telescope (formerly run by the National Radio Astronomy Observatory). This facility provides observational capabilities primarily at wavelengths of 2 - 3 mm and is the only facility worldwide that provides access to the longer wavelengths in the 3-mm atmospheric window.

The focus of both research and instrumentation development involves heterodyne astronomy and spectroscopy. Collaborations outside ARO include other organizations, as well as departments within the UA and the Steward Observatory Radio Astronomy Lab (SORAL). UA departments involved in research at the ARO include Chemistry, Electrical and Computer Engineering, Optical Sciences, Planetary Sciences, and Biology.

Astrochemistry is the study of the molecular composition of the interstellar medium. In interstellar space, molecules are identified by measuring their rotational spectra using millimeter and submillimeter telescopes, such as those of the Arizona Radio Observatory (ARO). Key to this endeavor are laboratory measurements of rest frequencies that serve as a finding list, enabling observers to identify such molecules. Led by Professor Lucy Ziurys, the laboratory has
developed a series of spectrometers that enable the measurement of the pure rotational spectra of potential interstellar molecules over 7 octaves in frequency (4 – 800 GHz). Of particular interest are free radicals and molecular ions that must be produced in situ using non-standard chemical methods involving electrical discharges, supersonic expansions, Broida-type ovens, and exotic precursors (Figure 18).

Four spectrometers, designed and built in the lab, are currently in operation there: two millimeter/submillimeter direct-absorption systems, a velocity-modulation spectrometer for selective detection of molecular ions, and a pulsed Fourier Transform Microwave (FTMW) spectrometer. Thus far, rotational spectra of 83 molecules have been acquired, including many unstable species, such as MgCN, FeCO⁺, and AIS. On the basis of laboratory measurements, several of these species have been detected in interstellar space.

Steward Observatory Radio Astronomy Laboratory (SORAL)
http://soral.as.arizona.edu/

SORAL, founded and managed by Professor Christopher Walker, has become a world leader in developing leading-edge submillimeter-wave receiver systems. SORAL constructed the world’s first 810 and 345 GHz heterodyne array receivers. These instruments are multi-institutional efforts, with key components coming from NASA, other universities, and a number of industrial partners. Equipment developed at SORAL have served as primary facility instruments at the Heinrich Hertz Submillimeter Telescope on Mt. Graham and the Antarctic Submillimeter Telescope and Remote Observatory at the South Pole for over the past decade (the latter for which Dr. Walker received the Antarctic Service Medal of the USA). Funded by the NSF, SORAL is leading the effort to design and build the world’s largest submillimeter-wave heterodyne array receiver. The team is also employing laser micromachining techniques to fabricate the first integrated THz array receivers. The lab offers research opportunities to graduate and undergraduate students.

Steward Observatory Mirror Laboratory (SOML)
http://mirrorlab.as.arizona.edu/

The Steward Observatory Mirror Laboratory (SOML), located under the east side of the UA football stadium, is a unique facility for fabricating large mirrors (up to 8.4 m) for ground-based telescopes. The brainchild of Professor Roger Angel, SOML alone can fabricate mirror blanks using spin-cast borosilicate honeycomb technology, finish them optically to exquisite tolerances with the unique, stressed lap polishing systems, and integrate the completed mirrors into telescope support systems before they are shipped to the observatory site.
The SOML mirrors, which combine low thermal inertia, short focal length, and high mechanical rigidity, have demonstrated their superb performance and relatively low cost in numerous telescopes, including three 3.5-m telescopes (ARC, WIYN, and SOR), the 6.5-m Multiple Mirror Telescope conversion, the two 6.5-m Magellan telescopes, and most recently, the two 8.4-m mirrors for the Large Binocular Telescope (LBT). The SOML is completing work on a 6.5-m collimator for the Lockheed Martin Company and has recently cast the first 8.4-m experimental off-axis primary segment for the Giant Magellan Telescope (GMT).

The SOML is planning to cast the combined primary/tertiary mirror (8.4m/5.2m) for the Large Synoptic Survey Telescope as well as a 6.5-m mirror for an international observatory headed by Mexico to be located on San Pedro Martir in Baja California. If the first GMT off-axis mirror is successful and the GMT project proceeds to construction, the SOML will likely fabricate all seven primary mirrors (see page 14).

The SOML has also pioneered the concept of adaptive secondaries (in collaboration with the Italian partners in the LBT), novel optical test methods (such as holographic test plates for convex surfaces) and concepts for light-weight space optics. SOML faculty and staff collaborate closely with members of the College of Optical Sciences who work on large optics. The SOML operates without any state funding.

Imaging Technology Laboratory (ITL)
http://www.itl.arizona.edu/

The UA’s Imaging Technology Laboratory is dedicated to developing scientific imaging detectors for the worldwide scientific community. Originally known as the Steward Observatory (SO) CCD Laboratory, ITL has been a research group within SO under Director Dr. Michael Lesser since 1990. ITL is entirely dedicated to imaging technology research. The core focus, to enhance detector quantum efficiency, has led to several technology transfers to industry. ITL is internationally recognized as the leader in blue and UV optimized Charge-Coupled Devices (CCDs). With undergraduate and graduate students, ITL staff have developed new techniques for scientific CCD processing, including antireflection coatings, mosaic and large format imager packaging methods, silicon thinning methods, and backside charging thin film technologies. The UA receives scientific and industrial grants and contracts to provide optimized imaging detectors and technologies that are incorporated into camera systems all over the world. Several thousand devices have been processed over the past 15 years. The map (Figure 21) shows the locations of some of these detectors and the home countries of the UA sponsors. Due to limited laboratory space, ITL is located off-campus.
Adaptive optics (AO) has the goal of compensating for atmospheric distortion in real time so that large ground-based telescopes can acquire diffraction-limited images that are even sharper than those from the Hubble telescope. The Center was established in 1994 with the goal of developing advanced adaptive optics techniques for the Multiple Mirror Telescope (MMT) and Large Binocular Telescope. A major thrust has been to integrate adaptive wavefront correction directly into the secondary mirrors of these telescopes, which are made deformable. This strategy gives unique, high sensitivity in the infrared, and the MMT system is now being used in a campaign to obtain the first image of an extra-solar planet. Special optics required for space telescopes to make very high contrast optical images of extrasolar planets are also being developed. The Center is now testing the first tomographic adaptive optics system with multiple laser guide stars, which are key to increasing the size of the corrected field of view for current ground telescopes, and to making AO correction of faint objects with the Giant Magellan Telescope or any future very large telescope.

Infrared Detector Laboratory

In recent years, astronomers have seen a phenomenal increase in infrared observing capabilities. Much of this gain has come from advances in detector technology, where sensor arrays have grown in size and increased in sensitivity. Unlike the situation at optical and near-infrared wavelengths, astronomers working at far infrared wavelengths (longer than 30 microns) have not had the benefit of extensive commercial or military detector development. To make advances, they have had to be both astronomers and detector physicists.

The Infrared Detector Laboratory at Steward Observatory, a leading center in this field, has played an important role in virtually all of the space-based infrared astronomy missions to date. Starting with the Infrared Astronomical Satellite (IRAS) launched in 1983, the laboratory has contributed key technologies to various missions. The focal plane arrays for the Spacelab II Infrared Telescope that flew on the Space Shuttle, as well as detector elements for the Short Wavelength Spectrometer on the European Infrared Space Observatory, were developed at Steward Observatory. The readout technology used in IRAS was initially developed in the Infrared Detector Lab and then adapted to IRAS by Infrared Laboratories, Inc. The Infrared Detector Lab also tested the NICMOS (Near Infrared Camera and Multi-Object Spectrometer) flight arrays prior to their being integrated into the Hubble Space Telescope. The largest far infrared detector array ever produced was built in the Infrared Detector Laboratory as part of MIPS, the Multiband Imaging Photometer on the Spitzer Space Telescope. Consisting of an array of 1024 pixels operating at a wavelength of 70 microns, this array enabled true imaging for the first time at such long wavelengths. An even more exotic array, also built for MIPS, consists of detectors for which the individual detector crystals are mechanically stressed to give an efficient response at 160 microns. Both far infrared arrays, currently in orbit around the Sun, are producing a wealth of data. The current principal project of the Infrared Detector Laboratory is the packaging of the detector arrays for the NIRCam instrument on the 6.5-meter James Webb Space Telescope. These detector arrays will be the largest ever flown on a space mission. (See the NICMOS, MIPS, and NIRCam sections of this document.)
Near Infrared Camera and Multi-Object Spectrometer (NICMOS)
http://nicmos.as.arizona.edu/

Steward Observatory (SO) provided the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) for the Hubble Space Telescope (HST). This instrument, which is still operational on HST, images at three different spatial resolutions in the 0.8 to 2.5 micron wavelength range. Also, it takes low resolution slitless spectra in the same range. In addition to these primary functions, it has the capability for polarization imaging and coronagraphic observations. It is currently the only HST instrument capable of observations at wavelengths longer than 1 micron. Professor Rodger Thompson was the Principal Investigator for NICMOS and led the Instrument Definition Team, with many SO personnel as members.

NICMOS has acquired infrared images and spectra of the most distant galaxies ever imaged, the dust obscured nuclei of galaxies, star formation regions in our own galaxy, and candidates for extra-solar planets. The detector arrays developed for NICMOS revolutionized near-infrared astronomy and placed the UA at the forefront of this discipline. NICMOS was also one of the first large research contracts within the UA and led the way for how the UA handles large projects.

NICMOS was installed on HST by space shuttle Discovery astronauts in February 1997. A mechanical cooler was added by astronauts on Columbia in March 2003.

The Spitzer Telescope is NASA’s primary infrared astronomy mission, along with the Chandra Observatory for the X-ray, and the Hubble Space Telescope for the ultraviolet and optical. The overall design of Spitzer is based on a concept developed by University of Arizona Professor Emeritus Frank Low. Professor George Rieke led the development of the far-infrared photometer (MIPS), one of three Spitzer instruments, and two of the initial six large science projects originated from the UA (under Professors Michael Meyer and Robert Kennicutt).

The MIPS required development of specialized technologies for far-infrared detector arrays, which were then constructed at Steward Observatory. The flight array for the 70 micron band was the first large format detector array ever constructed for the far-infrared. An example of its power is shown in figure 24 which compares the systems of planetary debris (dust produced in collisions of asteroids in other planetary systems) for the two nearby stars, Vega and Fomalhaut. The Fomalhaut system is nearly edge-on and is dominated by a ring of material similar to the Kuiper Belt in the Solar System, but at a radius about 2.5 times larger. The Vega system is face-on, and extends to a radius five times larger. Modeling to account for the difference between the systems shows that there has probably been a huge collision in the Vega "Kuiper Belt" and that fine dust particles

Multiband Imaging Photometer for the Spitzer Space Telescope (MIPS)
http://mips.as.arizona.edu/mipspage/
are being ejected by photon pressure. Both stars are about 300 million years old. Thus, the dramatic behavior of the Vega system is similar in timing to the Late Heavy Bombardment ~4 billion years ago that concluded planet building in the Solar System. Similar observations of other stars are letting us witness the evolution of hundreds of planetary systems.

Figure 24. Image showing the power of MIPS (taken by NASA’s Spitzer Space Telescope.) Two systems of planetary debris, reproduced to the same physical scale.

NIRCam: Near-Infrared Camera and Wavefront Sensor for the James Webb Space Telescope (JWST)
http://ircamera.as.arizona.edu/nircam/

Under the leadership of Professor Marcia Rieke, Steward Observatory (SO) is developing a 40-Mpixel camera for use on JWST. NIRCam is the only JWST project element being developed by a university team. SO has partnered with Lockheed Martin’s Advanced Technology Center in Palo Alto, CA, which is responsible for instrument fabrication, and with Teledyne Imaging Sensors in Camarillo, CA, which is providing the detector arrays. UA provides oversight and is packaging the Teledyne arrays into mosaics for flight use. The residual arrays will be available for use on ground-based telescopes such as the MMT and the Large Binocular Telescope. The team will receive an allocation of observing time that will be used to investigate the earliest light emitting aggregates in the Universe, to probe the physical processes underlying star and planet formation, and to characterize Jupiter-class planets around nearby stars.

Figure 25 (above). Artist’s conceptual drawing of JWST and a solar system in formation. NIRCam will be mounted in the structure attached to the back of the telescope. JWST illustration courtesy Northrop Grumman. Artist’s representation © David A. Hardy www.astroart.org / PPARC

Figure 26 (left). CAD drawing of one NIRCam module with baffles removed to reveal the optical path. The real instrument will be approximately 1 meter in the vertical direction.

http://www.as.arizona.edu/
Steward Observatory is the research arm of the Astronomy Department at the University of Arizona (UA). With Andrew Ellicott Douglass as the director, it was founded in 1916 as a result of a gift from Mrs. Lavinia Steward.

Steward Observatory telescopes are operated on several mountains in southern Arizona and available on a competitive peer-reviewed basis to scientists at the UA, Arizona State University, and Northern Arizona University. The astronomical facilities focus on research that benefits from Arizona’s dry, clear weather over wavelengths from ~3 mm to 0.3 microns.

Profiting from instrument development associated with ground-based work, Steward Observatory conducts space astronomy research mainly in the mid- and far-infrared region. Steward personnel use external research facilities in other wavelength ranges as well, from x-ray to cm-wavelength radio astronomy.

The Steward Observatory Mirror Lab, located under the east side of the UA football stadium, is developing the world’s largest spun-cast mirrors for the next generation of large telescopes including the 8.4-m LSST and the 25-m Giant Magellan Telescope. The Mirror Lab has provided large, high quality optics for three 6.5-m mirrors (MMT and Magellan Telescope Project) and two 8.4-m mirrors (Large Binocular Telescope).

FRONT COVER: Spiral galaxy M101, taken with the Steward Observatory 90” prime-focus camera. The excellent sensitivity of this camera in the ultraviolet (shown in blue) captures very young stars far out on the edges of the galaxy.