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 Radioteleskop 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 effort 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 AlSH. 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.

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.

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.)