**Northern Arizona University**
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This report describes the activities of both the Department of Physics and Astronomy at Northern Arizona University (NAU) and the National Undergraduate Research Observatory (NURO) from July 1995 to July 1996.

## 1. PERSONNEL

### 1.1 Northern Arizona University

Astronomers on the faculty of the Department of Physics and Astronomy were K. DeGioia-Eastwood, C. Griffith, R. Hall, B. Lutz, A. Odell, S. Tegler, and R. Wildey. Lutz continued serving as chairman of the Department. DeGioia-Eastwood spent the year on sabbatical at Lowell Observatory. K. Tryka joined the Department in January as a postdoctoral research associate after finishing her Ph.D. at Cal. Tech. Visitors during the summer months included P. Massey from Kitt Peak National Observatory, H. Nations from the College of Charleston, W. Romanishin from the University of Oklahoma, D. Weistrop from the University of Nevada Las Vegas, and M. Womack from the Pennsylvania State University at Erie. The American Astronomical Society Teacher Resource Agents summer program involved J. Lockwood, S. Forthman, and D. Hoff.

During the summer of 1996 the Department hosted its sixth Research Experiences for Undergraduates program, funded by the National Science Foundation and directed by DeGioia-Eastwood. Students worked with astronomers at NAU and the Lowell Observatory, as well as summer visitors to the Department. The students in 1996 were S. Anderson (Guilford Coll.), V. Burkholder (Mt. Holyoke), N. Butler (U. Arizona), J. Levine (U. Mass.), A. Sickafoose (Denison U.), R. Simcoe (Princeton U.), M. Turnbull (U. Wisconsin), and D. Vakil (U. Arizona).

### 1.2 The National Undergraduate Research Observatory

During this period the members of the NURO Consortium were Alma College, Ball State University, Benedictine College, Central Michigan University, College of Charleston, Denison University, Dickinson College, Franklin and Marshall College, Gettysburg College, the Maria Mitchell Observatory, the University of Nevada Las Vegas, the University of Oklahoma, Northern Arizona University, Western Connecticut University, and Widener University. B. Taylor continued as the astronomical instrumentation specialist for NURO. Lutz served as Director of NURO while DeGioia-Eastwood was on sabbatical.

Visiting observers to the NURO facility included H. Augensen (Widener), S. Baird (Benedictine), D. Backman and M. Seeds (Franklin and Marshall), R. Boyle and A. Morgan (Dickinson) E. Friel (Maria Mitchell), P. Lu (Western Connecticut State), L. Marschall (Gettysburg), H. Nations (College of Charleston), W. Osborn (Central Michigan), T. Robertson (Ball State), W. Romanishin (Oklahoma), D. Weistrop (UNLV), and S. Yorka (Denison).

## 2. FACILITIES

### 2.1 Northern Arizona University

In addition to their involvement with NURO and Lowell's 0.8-m telescope, NAU maintains a 0.6-m telescope on campus as well as six 10-inch Meade telescopes for instructional use. The students can use a ST-6 CCD camera on the 0.6-m and 35-mm cameras on the small telescopes.

Within the Department is a well-maintained network consisting of eleven SUN workstations with a total of over 50 GB of storage space as well as many PCs and Macintoshes. Undergraduate majors have access to both workstations and high-speed PC's. The undergraduate laboratories for non-majors are equipped with Macintoshes.

Wildey maintains the Robot Lunar Observer telescope for the project described below. This robotic 8-inch telescope is located on McMillan Mesa in Flagstaff, and uses a thermo-electrically cooled Photometrics CCD.

### 2.2 The National Undergraduate Research Observatory

NURO continued to have 60% of the observing time on the 0.8-m telescope owned by Lowell Observatory on Anderson Mesa outside of Flagstaff. The telescope is computer controlled from a warm room in an adjacent construction trailer. NURO maintains an imaging CCD made by Photometrics which uses a Tektronix back-illuminated 512 X 512 chip. The chip has a Metachrome coating for improved sensitivity in the UV, and the instrument is cooled with liquid nitrogen. Workstations are available at the telescope and also on campus for data reduction.

## 3. RESEARCH

### 3.1 Northern Arizona University

An interdisciplinary collaboration has been formed at NAU to study the chemical evolution of ice mixtures as a result of bombardment by X-rays and particles. The collaboration involves Tegler, Lutz, Tryka, two physicists (D. Cornelison and R. Dillingham) and a chemist (M. Robinson). The group is using X-Ray Photoelectron Spectroscopy and Mass Spectroscopy to perform laboratory simulations relevant to ices in astrophysical environments. These laboratory data will be compared to astronomical observations.

While on sabbatical DeGioia-Eastwood finished work on the stellar content of the open clusters Tr14 and Tr16. The photometry was deep enough to fit the observations of pre-main sequence stars to the stellar birthline, which put constraints on the star formation history of these young regions. In addition she made the observations for two new projects.

At the KPNO 2.1-m and 0.9-m telescopes she made spectroscopic and photometric observations of Wolf-Rayet nebulae. These data will be used to empirically determine the Lyman continuum fluxes of the Wolf-Rayet stars and compare them to new models. With the Perkins telescope at Lowell she used the OSIRIS to take infrared spectra of luminous stars in active star-forming regions.

Griffith is presently beginning to work on the structure of brown dwarfs. Excited by the discovery last year of the first brown dwarf, Gl229B, she began a program of research which involves observations of Gl229B at the KECK and UKIRT telescopes on Mauna Kea and at the CTIO 4-m telescope. These observations are scheduled for December of 1996 and January of 1997. Griffith also continues to pursue interests in the planetary bodies within our solar system. She is working on data from the Hubble Space Telescope in an investigation of the atmosphere of Titan, Saturn's largest moon. Kitt Peak 4-m observations of Jupiter's outer moons (observed in June of 1996) are also presently being analyzed to study the origin of these strange objects.

Tegler and Romanishin are carrying out a B, V, and R band photometric survey of Kuiper Belt comets and Centaur objects using the Steward Observatory 2.3-m telescope. Their measurements of $B-V$ and $V-R$ colors for the Kuiper Belt comets 1994 TB and 1993 SC and the Centaur object 1993 HA2 show that these objects are among the reddest objects in the solar system. Such an extreme red color is consistent with surfaces rich in complex organic molecules. In addition, Tegler and Romanishin are carrying out V and R band photometry of Kuiper Belt comets to constrain the shapes and periods of rotation of these newly discovered objects.

Tegler is also working with D. Weintraub (Vanderbilt U.) and G. Rieke (U. Arizona) on a near-infrared spectroscopic investigation of the protostar W33A and comet Hale-Bopp. The objective of the program is to detect a broad absorption band near 2.3 $\mu$m associated with the solid material known as X(C≡N). The group's previous work on the X(C≡N) band at 4.6 $\mu$m (the fundamental) in the spectra of young stellar objects strongly suggests that X(C≡N) molecules are synthesized by stellar ultraviolet or ion bombardment of precometary icy grains in circumstellar environments of young stellar objects. A detection of the 2.3 $\mu$m (overtone) band in the spectrum of W33A would make W33A the first astronomical source to show both the fundamental and overtone bands, thereby providing stringent constraints on the identity of the X(C≡N) molecule. In addition, the detection of this band in W33A and comets would establish a chemical link between solid solar system material and circumstellar material around young stellar objects.

Tryka is working on two projects: modeling the distribution of volatiles on the surfaces of the Uranian satellites, and collecting and analyzing data from Comet Hyakutake. The volatile transport modeling has been done in collaboration with R. Brown (U. Arizona) and R. Johnson (U. Virginia). The model traces the movements of volatiles as they sublime from the surface of the satellites. They find that the net migration of volatiles is toward the equatorial regions of the satellites, which receive the least amount of solar radiation due to Uranus's high obliquity. They have also considered the effects of charged particle bombardment on the overall volatile inventory of the satellites, and find that it is a less important mechanism for the loss of volatiles than sublimation when average seasonal temperatures are greater than about 60 K.

Tryka made observations of Comet Hyakutake during March and April at Lowell's 31-inch telescope using the NURO CCD. Images of the comet were taken using narrowband filters optimized for cometary emissions. Initial analysis shows that there are significant differences in the comet's structure from filter to filter, and that there are differences as a function of time within each filter. Also, the images show evidence for a periodic outburst on the sunward side of the comet.

Wildey and H. Keiffer of the U. S. Geological Survey in Flagstaff are directing the Robot Lunar Observer in support of the radiometric calibration of the space platforms of the Earth Observing System and ancillary scientific investigations of the light-scattering properties of the lunar surface. The telescope is near the end of the first year of routine data collection for wavelengths between 350 and 1000 nm. A 256 x 256 NICMOS array and 10 filter cryogenic camera, for use on a bore-sighted parallel telescope to be placed on the same mount, is nearing completion at the University of Arizona under the direction of G. Rieke. The spectral response will overlap that of the current telescope and extend out to 2500 nm.

### 3.2 The National Undergraduate Research Observatory

NURO continued to support two collaborative research programs as well as individual research projects. The first was monitoring of supernova light curves. As part of this effort, observers from five NURO institutions obtained observations on twelve different nights of SN 1995D, a type Ia supernova in NGC 2962. Observations were obtained over three nights at maximum light. So far, only one other group has published photometry of this object, and that group did not observe in the B filter, as the NURO group did. Romanishin is analyzing the data and submitting it for publication.

The other collaboration involved primarily Backman and Seeds from Franklin and Marshall, Boyle from Dickinson, and Marschall from Gettysburg. Students involved included K. Beisser, D. Dahari, J. Dalton, A. Drucker, M. Renda, and P. Turcotte from Franklin and Marshall, and R. Anand, A. Mude, A. Rizvi, J. Smith, P. Tcherneva, and A. Wexler from Gettysburg. The group measured the rotational light curves of solar-type stars in young clusters. They also began a project looking for rapid rotators among field M dwarfs, in collaboration with J. Stauffer of Harvard/SAO. The data were reduced and are being analyzed by collaborators at Harvard and Ohio State. Some of the observers also participated in a world-wide all-wavelength 'watch' of the quasar 3C279 which was undergoing an outburst.

Baird (Benedictine) and two students, B. Speck and W. Chambers, continued collecting and analyzing Caby photometric data of RR Lyrae stars with the goal of establishing a metallicity grid in the hk/b-y color-color diagram for this class of variable star. The NURO work is being combined

with southern hemisphere data obtained by Baird to provide a set of RR Lyr standards with a range of metallicity that cover the entire sky.

Osborn (Central Michigan) and student R. Miller have completed a project to obtain BVRI photometry of spectroscopic binaries with orbits published by R. Griffin and colleagues (Cambridge). Eighty-two objects were observed, many of which previously lacked photoelectric magnitudes. A paper giving the results has been submitted and accepted by The Observatory. As part of an observing program with the Hubble Space Telescope, Osborn and Miller also obtained BVR photometry of stars the fields of two high-proper motion stars, G166-37 and G16-25. The photometry will be used to correct the parallaxes and proper motions derived relative to the reference stars to the absolute values needed for space velocity computations.

Undergraduate J. Hill (Central Michigan) has obtained images of the globular cluster M13 for the purpose of studying its variable stars. This project is intended to determine new light curves in BVRI for the variables of short-period.

Robertson at Ball State has been working on the development of an intermediate-band photometric system which can be used with CCD cameras to permit luminosity classification of red stars. Synthetic photometry was used to design filters in the red and near infrared. Filters have been purchased with grants from the Fund for Astrophysical Research and the Small Grant Program of the AAS. Robertson and N. Furiak have been collecting data at the NURO facility to evaluate the effectiveness of the system. Robertson and students C. O'Hara and A. Ulman have also been investigating surface density variations for low-mass stars detected on objective-prism plates. Surface densities have been computed using models of the galaxy to estimate the expected variations due to differences in galactic longitude and galactic latitude. The observed variations appear to be greater than those predicted by the model. The Simbad database was used to identify stars with prior observations in an attempt to confirm the luminosity classes based on objective prism spectra. There is no evidence that giant contamination is a major contributor to the problem.

Augensen from Widener, with students A. Abu-Hasan, J. Healy-McKinney, N. L'Arman, S. Thanki, and D. Weisel, used the NURO facility to monitor selected RV Tauri and semiregular variable stars. Targets included TX Persei, CT Orionis, DY Orionis, GT Orionis, TW Camelopardalis, HQ Monocerotis, UY Canis Majoris, UZ Canis Majoris, SV Ursa Majoris, CE Virginis, BT Librae, UZ Ophiuchi, R Sagittae, and CU Delphini. CCD images have been taken through B, V, R, and I filters. In addition, they obtained CCD images of supernova SN1995D near maximum light during February 1995 as part of the NURO collaborative effort.

Lu from Western Connecticut, along with students J. Bombaci and H. Condosta, continued their studies of galactic structure using photometric observations of F and G dwarfs. They continue to present their work at the National Conference of Undergraduate Research.

Weistrop from UNLV has initiated a program to study the magnitudes, colors, and morphology of galaxies in voids. Understanding such regions will lead to a better knowledge of the formation and evolution of galaxies, and also can constrain models of the large-scale structure of the universe. Several undergraduate students have participated in obtaining observations and reducing data for this program. She and UNLV Adjunct Professor D. Shaffer are also continuing their program to study the variability of radio-loud quasars. Some models of quasars suggest that the source of energy at the center of the galaxy is a black hole surrounded by an accretion disk. In these models, jets of plasma may be ejected along the rotation axis of the accretion disk. If these models are true, optical variability of the quasars may constrain models of the accretion disk. Such variability has been studied in other active galactic nuclei, but this is the first investigation in a complete sample of radio luminous quasars. Undergraduate students participating in this program have included V. Harvey, C. Hoopes, and J. Smith.

Kathy DeGioia Eastwood