

**University of Illinois**  
**Department of Astronomy**  
*Urbana, Illinois 61801*

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This report covers activities of the department for the period 1 September 2001 - 31 August 2002.

## 1. PERSONNEL

During this report year the scientific staff consisted of the faculty: You-Hua Chu, Richard M. Crutcher (Chair), H  l  ne R. Dickel (emerita), John R. Dickel (emeritus), Brian Fields, Charles Gammie, Icko Iben, Jr. (Distinguished Professor Emeritus), James B. Kaler, Fred K. Lamb, Susan A. Lamb, Peter McCullough, Margaret Meixner, Joseph Mohr, Telemachos Ch. Mouschovias, Michael L. Norman, Edward C. Olson (emeritus), Sidney Rosen (emeritus), Ed Seidel, Stuart L. Shapiro, Lewis E. Snyder, Edmund C. Sutton, George W. Swenson (emeritus), Laird A. Thompson, Benjamin D. Wandelt, William D. Watson (retired August 2002 as Professor Emeritus), Ronald F. Webbink, Kenneth M. Yoss (emeritus); postdoctoral research associates: Subha Majumdar, David Meyer, Anuj Sarma, Ronak Shah, Angela Speck and Toshiya Ueta; and research support staff: Rami Dass, Daniel Goscha, Robert Gruendl, Martin Guerrero, David Mehringer, Grant Miller, Raymond Plante, Kevin Pointer, and Harold Ravlin.

Research in theoretical astrophysics and general relativity and related areas was also carried out by other faculty in the physics department, including Thomas Baumgarte, G. Baym, V. R. Pandharipande, D. G. Ravenhall (emeritus), Masara Shibata, and H. W. Wyld (emeritus). The department hosted visits during the reporting year from Yael Naz   (Universit   de Liege, Belgium), Wallace Sargent (California Institute of Technology), Chris Smith (Cerro Tololo Inter-American Observatory), Andrei Ostrovskii (Ural State University in Russia), Andrej Sobolev (Ural State University in Russia), and Yao-Heng Xiong (Yunnan Observatory, PR China).

Twenty-two graduate students were enrolled during the 2001-2002 academic year. Sean Points and Shih-Ping Lai received their PhDs in October 2001; Richard Frazin and T. Ueta received their PhDs in May 2002. Office support staff included Willa Hollis, Karen Miiller, Sandie Osterbur, and Deana Pettigrew under the guidance of the Administrative Assistant, Carol Stickrod.

Ed Sutton was on sabbatical during Spring 2002.

## 2. FACILITIES

### 2.1 Campus Computation

The Astronomy Department has access to the facilities of the National Center for Supercomputing Applications (NCSA) at the University of Illinois, both through a national peer review allocation mechanism and a time allocation to the University of Illinois community. Astronomy Professor R. Crutcher serves as NCSA Senior Associate Director for Computational Science and Chief Application Scientist. Current production facilities include a 1536-processor SGI Origin 2000 that provides about 0.8 teraflop of computer power and two Linux clusters, a Pentium3 (IA-32) cluster and an

Itanium (IA-64) cluster, each with 1 teraflop compute power. NCSA is in the process of adding a 2 teraflop IBM Power4 system and an 8 teraflop Itanium2 Linux cluster, and plans to replace the Pentium3 cluster with a Pentium4 cluster with 5 teraflop compute power. Disk capacity is also being substantially upgraded, with about 490 terabytes of rotating disk available by Spring 2003. Also available are advanced visualization systems such as a CAVE 3D virtual environment and a 32-megapixel projector display wall.

### 2.2 Laboratory for Astronomical Imaging

The Laboratory for Astronomical Imaging (LAI) is a unit within the Astronomy Department through which the University of Illinois participates in the Berkeley-Illinois-Maryland Association (BIMA) Array consortium. Faculty personnel associated with the LAI during this time were L. E. Snyder (director), R. M. Crutcher, H. Dickel, M. Meixner, J. Mohr, and E. C. Sutton. Graduate students were P. Cortes, D. Fong, D. Friedel, S.-P. Lai, A. Remijan, and J. Shaw. The senior research programmer was H. Ravlin, and the LAI administrative secretary was D. Pettigrew. The BIMA Array scheduler was R. Gruendl. Arrivals: K.-T. Kim joined us as a postdoctoral research associate from Seoul in August; L. Looney will join us as an assistant professor from MPIfEP in Garching in October; and J. Nakashima will join us as a postdoctoral research associate from NRO in December. Departures: S.-P. Lai assumed a postdoctoral position at JPL in September; R. Shah accepted a postdoctoral position at Boston U. in May; and M. Meixner became a Scientist at STScI in July.

BIMA Array observing time is awarded on a competitive basis. Electronic observing proposal submission has been initiated. Information can be found on the WWW at <http://www.astro.uiuc.edu/~bima/callforproposals.html>, <http://www.astro.uiuc.edu/~bima/proposal/WhatsNew.html>, and <http://www.astro.uiuc.edu/~bima/proposal/instructions.html>.

#### 2.2.1 *The Combined Array for Research in Millimeter Astronomy, or CARMA*

Planning continued for combining the BIMA Array with the Caltech Owens Valley Array on a new high site near the Owens Valley with operations starting in 2004. The new array will be called the Combined Array for Research in Millimeter Astronomy, or CARMA. CARMA will be a heterogeneous array, initially with six 10.4 m OVRO telescopes and nine 6.1 m BIMA telescopes. Ultimately, the CARMA Array will be joined by eight 3.5 m telescopes from the University of Chicago, which will make CARMA a superb array for cosmological imaging observations. CARMA will be at least ten times more powerful than either of the original arrays. More CARMA information can be found at <http://www.mmarray.org/>.

### 2.2.2 AIPS++

The Laboratory for Astronomical Imaging continues to contribute to the development of the AIPS++ package for processing radio astronomy data. As part of the development team R. Plante, D. Mehringer, D. Goscha, and A. Sarma have specialized in supporting the calibration and imaging of BIMA data in AIPS++. AIPS++ is being used to deploy the BIMA Image Pipeline to process data from the BIMA telescopes automatically. Plante, Mehringer, and graduate student P. Cortes have specialized in supporting AIPS++ on the parallel processing platforms at NCSA. The AIPS++ team continues to conduct training and outreach in the use of AIPS++ through local training workshops and on-line documentation.

### 2.3 Mt. Laguna Observatory

Through a cooperative agreement with San Diego State University, the UI Astronomy Department uses 25% of the observing time on the 1-m telescope at Mt. Laguna Observatory. Continuing in successful operation are (1) a 2048x2048 Loral CCD camera and (2) a 256x256 NICMOS-3 array camera, both of which provide excellent wide-field imaging capabilities especially with the  $f/7.6$  telescope secondary.

### 2.4 Large Telescope Participation

Throughout the past year, active discussions were held with optical and IR observational astronomers at the University of Chicago and Northwestern University with the aim of building an Extremely Large Telescope. The science justification includes (1) high dispersion  $R = 6000$  near-IR spectroscopic survey of faint galaxies to redshifts as high as  $z = 6$ , and (2) a complimentary survey at 300 microns wavelength. The proposed telescope would have a collecting area  $\sim 1000 \text{ m}^2$ , implying that the aperture will be approximately 36-m. To maintain a reasonable project cost, the primary mirror structure would be a segmented adaptive surface mounted on a frame that resembles a radio telescope. These discussions continue.

### 2.5 Optical Instrumentation

Excellent progress was made toward the commissioning of the NSF-funded UnISIS project (University of Illinois Seeing Improvement System), a laser guided adaptive optics system being installed at the Mt. Wilson 100-inch telescope. Personnel currently involved in the project include L. Thompson (PI) and S. Teare (Co-PI) who is a professor of electrical engineering at New Mexico Tech. Also joining the project (part time) in the last year is R. Gruendl.

The projection of the 351 nm Rayleigh laser guide star is routine at 167 Hz (with the final aim of running the laser at 333 Hz). The laser guide star optical projection system transfers the laser light from the basement of the 100-inch telescope and up the Coudé optics train for a final focus at 18 km altitude. Closed-loop performance of the adaptive optics system was demonstrated on natural stars, and the next step is to collect science images using the laser guide star signal. Pa-

pers were written during the past year on the UnISIS laser guide star system and on the high speed shuttering system used to hold back the burst of low altitude Rayleigh light emitted by the UnISIS 30 Watt laser every time it fires.

### 2.6 Infrared Instrumentation

The Near-Infrared Imager (NIRIM) has been used at both the Mt. Laguna Observatory 1 m telescope and the Wisconsin-Indiana-Yale-NOAO (WIYN) 3.5 m telescope.

## 3. RESEARCH

### 3.1 Stars

#### 3.1.1 Binary Stars

Olson continued to collaborate with P. Etzel of San Diego State University. A time of minimum of the long-period Algol RX Gem, obtained from observations between December 2001 to March 2002, further supports the presence of an unseen third star in this binary.

As part of a campaign organized by D. Mkrtichian on pulsations in hot components of Algol binaries, Olson obtained photometry of RZ Cas, SW Cyg, and X Tri at the Mount Laguna Observatory.

With assistance from A. Linnell, Olson incorporated accurate projected stellar boundaries from Linnell's Binary Synthesis program into his non-LTE Algol disk model. Hydrogen-line emission profiles during disk eclipses by cool lobe-filling components can now be calculated, revealing disk structure more clearly.

Under the direction of G. Henry (Tennessee State University), APT observations continued, in a search for mass-transfer bursts in this active binary.

Webbink continues to participate in regular updating of the Catalog and Atlas of Cataclysmic Variables (CVs) maintained by R.A. Downes (STScI) at <http://icarus.stsci.edu/~downes/cvcat>. Since the last annual report, 95 new objects have been added to that catalog, bringing the total number to 1371.

H. E. Bond (STScI), D. L. Pollacco (Queens University, Belfast), and Webbink announced the discovery of a barium star nucleus in the planetary nebula WeBo 1. This planetary, discovered quite accidentally by Webbink on the Digital Sky Survey, is a nearly perfect ellipse, a morphology which suggested that it might harbor a binary nucleus. In follow-up photometry, Bond found that the apparent central star is cool and variable, showing an approximately sinusoidal light curve of small amplitude (0.007 mag in  $V$ ), with a period of 4.7 days. This modulation is almost certainly rotational in origin, with the binary period much longer, but indeterminate. A spectrum of the central star obtained by Pollacco at La Palma revealed prominent molecular bands of  $C_2$ , CH, and CN, and extremely strong lines of Sr II at 4077 Å and Ba II at 4554 Å, marking it as a strong barium star. Follow-up observations, including detection of the white dwarf companion, determination of the orbital period, and abundance analyses of the nebula and central star, including a search for technetium in the atmosphere of the barium star, could provide important new insights into the origins of barium stars.

Current consensus holds that they are the product of accretion from the wind of a thermally-pulsing asymptotic giant branch star companion, revealed when that companion expires as a white dwarf. In the case of WeBo I, that event must have been of very recent vintage.

Webbink and P.P. Eggleton (Lawrence Livermore) have embarked on an effort to model the structure and evolution of contact binary stars. These are binary systems in which the two stars are in physical contact, as revealed by the strong tidal distortions manifest in their continuously varying light curves. In their most commonly observed form, as W UMa-type variables, they reside within the stellar main sequence, but the individual component stars (especially the less massive component) depart significantly from a main sequence mass-luminosity relation. Energy generated in the core of the primary star is transferred to, and radiated by, the lower-mass secondary. The secondary is bloated with respect to the main sequence, filling a common equipotential surface with its contact companion, and radiating at virtually identically the same effective temperature as that companion. The fact that W UMa binaries comprise roughly 1 percent of solar-type stars implies that they are a long-lived, stable configuration. Numerous attempts to build structural and evolutionary models of these systems in the late 1960's to late 1970's failed to produce satisfactory models of these systems. Those attempts used ad hoc models of energy exchange, typically removing from the primary star and injecting it into the secondary at the innermost common equipotential surface. Webbink and Eggleton have developed a simplified fluid dynamical model of mass and energy exchange, driven by lateral pressure gradients within the common envelope. This model is being implemented in fully implicit side-by-side models of binary stars coupled throughout their common envelope.

### 3.1.2 Variable Stars

Some 72 years after her first discovery paper, D. Hoffleit (Yale), provided vital notes and input to M. Hazen (Harvard) and Webbink enabling them to identify and publish accurate coordinates for some 671 variables she discovered and published in a series of five papers in the Harvard Bulletins. Without adequate means of identification, all but a handful had languished unstudied since their discovery.

### 3.1.3 Evolved Stars

Meixner, Ueta, D. Moser (UIUC), and L. Pyzowski (UIUC) have finished the near-infrared photometry of  $\sim 77$  proto-planetary nebulae which used NIRIM at the SDSU/UIUC MLO 1 m telescope. A paper has been submitted. These imaging data provide a substantial improvement over the large aperture photometry data previously published on these sources.

A. K. Speck (U of Missouri), M. Meixner, D. Fong, P. R. McCullough, D. Moser, and T. Ueta have observed the Helix nebula (NGC 7293) in  $H_2$  2.122  $\mu\text{m}$  with NIRIM at MLO, cool dust with ISO, and constructed  $H\alpha$  images from the Southern H-Alpha Sky Survey Atlas. They have modeled the emission from various species in the Helix using a simple, spherically symmetric radiative transfer model.

Meixner, Speck, P. Knezek (WIYN), and G. Jacoby (WIYN) have imaged the Ring Nebula in molecular hydrogen ( $H_2$ ) using NIRIM on the WIYN telescope. The image captured sufficient detail to compare with the HST Hubble heritage image of the Ring, and they found that the  $H_2$  was concentrated in the knots.

Fong, K. Justtanont (Stockholm Obs.), Meixner, and M. Campbell have imaged the circumstellar envelope of the extreme OH/IR star OH26.5 with BIMA. After modeling the gas kinetic temperature and density distribution of the envelope, the CO emission was solved through a full radiative transfer code. Model maps of the CO emission were then generated and compared directly to the BIMA data.

Meixner, Fong, Sutton, W. J. Welch (UC Berkeley), and Justtanont have finished the data processing of their BIMA and NRAO 12 m CO J=1-0 imaging survey of 12 evolved stars. They are now preparing two papers for publication: one on the survey data and a second on detailed modeling of the molecular envelopes. Two additional papers have already been submitted on this survey: 1) on the detection, size and model of the molecular envelope of OH 26.5 and 2) a full mosaic of IRC+10216 in which Fong and Meixner discovered enhancements of mass loss indicating a thermal pulse in this famous carbon star occurred  $> 7000$  years ago. The scientific goal of the survey is to determine how the predominantly molecular envelope of an asymptotic giant branch (AGB) star is transformed into the ionized plasma of a planetary nebula. This BIMA molecular gas survey provides the picture of the molecular gas.

Ueta and Meixner have submitted a paper on 2-Dust, their axially symmetric radiative transfer dust code that they have been using to model proto-planetary nebulae.

### 3.1.4 White Dwarfs

I. O'Dwyer, Chu, Gruendl, Guerrero, and Webbink have correlated a white dwarf catalog and a ROSAT point X-ray source catalog, and found 76 white dwarfs associated with X-ray sources at a high level of confidence. While most of them are dominated by soft, photospheric emission at  $< 0.5$  keV, 17 of them show significant hard X-ray emission near 1 keV. Twelve of the white dwarfs with hard X-ray emission are in binary systems, and the hard X-ray emission originates from either the coronal activity of the late-type companions or the accretion of the companion's material onto the white dwarf. However, five of these white dwarfs with hard X-rays appear single. The lack of near-IR excess for the nearest objects indicates that perhaps new X-ray emission mechanisms are needed.

## 3.2 Diffuse Matter

### 3.2.1 Magnetic Fields

R. Crutcher continues his work on the measurement of magnetic fields in molecular clouds in order to improve our understanding of the role magnetic fields play in cloud evolution and in star formation.

D. Balsara, D. Ward-Thompson, and Crutcher carried out a sequence of simulations of gravitational collapse in a turbulent magnetized region. The parameters were chosen to be

representative of molecular cloud material. They found that several protostellar cores and filamentary structures of higher than average density form. The filaments interconnect the high-density cores. Furthermore, the magnetic field strengths are found to correlate positively with the density, in agreement with recent observations. They made synthetic channel maps of the simulations, and showed that material accreting on to the cores is channeled along the magnetized filamentary structures. This was compared with recent BIMA and JCMT observations of S106, and shown to be consistent with these data. They postulated that this mechanism of accretion along filaments might provide a means for molecular cloud cores to grow to the point where they become gravitationally unstable and collapse to form stars.

S.-P. Lai, Crutcher, J. Girart, and R. Rao obtained the first interferometric polarization map of the W51 e1/e2 molecular cores; observations were with the Berkeley-Illinois-Maryland Association (BIMA) array at 1.3 mm wavelength, with approximately  $3''$  resolution. The polarization angle varies smoothly across the double cores with an average position angle of  $23^\circ \pm 5^\circ$  for W51 e1 and  $15^\circ \pm 7^\circ$  for W51 e2. The inferred magnetic field direction is parallel to the minor axis of the double cores, consistent with the theoretical picture that clouds collapse along the field lines. However, the magnetic field may not determine the axis of angular momentum of these two cores, since the field directions of the two cores significantly differ from the previously measured directions of rotational axes. The polarization percentage decreases toward regions with high intensity, suggesting that the dust alignment efficiency decreases toward high-density regions. The field directions are highly ordered, and the small dispersion of the polarization angles implies that magnetic fields are strong ( $>1$  mG) and perhaps dominate turbulence in W51 e1/e2.

Lai, Crutcher, Girart, and Rao also obtained the first interferometric polarization maps of the NGC 2024 FIR 5 molecular core; observations were with the BIMA array at approximately  $2''$  resolution. They measured an average position angle of  $-60^\circ \pm 6^\circ$  in the main core of FIR 5 and  $54^\circ \pm 9^\circ$  in the eastern wing of FIR 5. The morphology of the polarization angles in the main core of FIR 5 suggests that the field lines are parabolic, with a symmetry axis approximately parallel to the major axis of the putative disk in FIR 5, which is consistent with the theoretical scenario that the gravitational collapse pulled the field lines into an hour-glass shape. The polarization percentage decreases toward regions with high intensity and close to the center of the core, suggesting that the dust alignment efficiency may decrease at high density. The plane-of-sky field strength can be estimated with the modified Chandrasekhar-Fermi formula, and the small dispersion of the polarization angles in FIR 5 suggests that the magnetic field is strong ( $>2$  mG) and perhaps dominates the turbulent motions in the core.

### 3.2.2 Interstellar Medium

Using VLA, BIMA, and published data, H. Dickel is investigating the spatial relationship and velocity fields of the ionized, atomic, and molecular hydrogen, and other molecules in the DR21 outflow-star forming complex.

D. S. Meier, along with collaborators J. L. Turner (UCLA) and S. C. Beck (Tel Aviv) are studying the interplay between the youngest star forming regions and their associated physical and chemical properties, in nearby starburst galaxies. Meier and Turner have made the first interferometric astrochemical survey of a starburst galaxy, IC 342. Along with CO and its isotopomers, HCN,  $\text{HCO}^+$ , and  $\text{NH}_3$ , they have imaged  $\text{C}_2\text{H}$ , HNC, HNC,  $\text{HC}_3\text{N}$ ,  $\text{N}_2\text{H}^+$ ,  $\text{C}^{34}\text{S}$ , and  $\text{CH}_3\text{OH}$ , along with tentative detections of  $\text{NH}_2\text{CHO}$ ,  $\text{CH}_3\text{CHO}$ , and  $\text{HCOOCH}_3$ . They find that strong chemical differentiation survives even to galactic scales. Dense molecular clouds exhibiting young star formation (surveyed in 3 and 1 mm continuum) have different chemical compositions when compared to dense molecular clouds without associated starbursts, indicating that star formation and gas chemistry are intimately linked. Observations of  $\text{C}_2\text{H}$ ,  $\text{N}_2\text{H}^+$ , and HNC argue that there are large quantities of molecular gas that exist in both quiescent and active phases in the same starburst nucleus. Evidently, young starbursts strongly affect gas conditions only locally, and do not cause widespread ‘damage’ to the nuclear ISM. Observations of  $\text{CH}_3\text{OH}$  and HNC argue for the widespread importance of grain chemistry, especially in locations of large-scale dynamical shocks. As a follow up, Meier, Turner and L. E. Snyder are using the BIMA array to undertake similar chemical surveys in the nearby starburst galaxies, NGC 253, M 82 and Maffei 2, to investigate the impact of star formation strength, evolutionary state, and gas dynamics on the chemistry of nuclear ISMs.

Meier, Turner, and Beck have also been studying the molecular ISM in dwarf starburst galaxies, which show evidence for the formation of massive, young, super-star clusters (likely proto-globular cluster analogs). In a series of interferometric studies of  $^{12}\text{CO}(2-1)$  in the dwarf galaxies, NGC 5253, NGC 3077, and He 2-10, they consistently find molecular clouds in the halo of each galaxy with anomalous rotational velocities, indicating accretion triggered star formation. Long time lags between the current young starburst and past galaxy interactions suggest that starburst events can be triggered long after closest approach, as gas disrupted in the interaction settles back onto the dwarf galaxy.

### 3.2.3 Giant HII Regions

Gruendl, Chu, and M. Corcoran (GSFC/NASA) obtained long-slit echelle spectra of the Carina Nebula with the CTIO 4m telescope. High-velocity shocked gas is detected over a large portion of the nebula, with good correspondence to regions of diffuse X-ray emission detected in ROSAT PSPC observations. The kinematic characteristics of the Carina Nebula are very similar to those of the giant HII region 30 Dor, indicating that the heating is provided by supernova remnants, rather than fast stellar winds.

C.-H. R. Chen, Chu, and K. Johnson (U Wisc) have analyzed the stellar content in three luminous giant HII regions in M101: NGC 5461, NGC 5462, and NGC 5471. Among the large number of clusters identified, the most massive ones are at the core of NGC 5461. It is surprising that such ‘‘superstar clusters’’ usually seen in interacting galaxies are

found in NGC 5461 along a relatively quiescent spiral arm of M101.

### 3.2.4 Planetary Nebulae

M. Guerrero, Gruendl, and Chu analyzed the XMM-Newton X-ray observations of the planetary nebula NGC 7009 (the Saturn Nebula). Diffuse X-ray emission is detected. Spectral analyses indicate a low plasma temperature of  $\sim 2 \times 10^6$  K in the PN interior.

E. Jaxon, Guerrero, and Chu analyzed the ionization and density structure of the planetary nebula NGC 7662 using archival HST images and ground-based echelle spectra. The results are qualitatively consistent with theoretical models of planetary nebula formation and evolution.

Gruendl, Chu, and Guerrero have obtained FUSE observations of a number of central stars of PNe, covering a wide range of stellar effective temperatures. Optical spectra of these PNe have also been obtained to provide reference nebular velocities. The FUSE observations are being compared with the optical observations to differentiate between nebular and interstellar O VI absorption against the stellar spectra, in order to search for hot ( $10^5$  K) gas and study its physical condition. Tentative detections of nebular O VI absorption for a few objects have been obtained.

### 3.2.5 Supernova Remnants

J. Dickel continues to investigate the relation between the x-ray and radio emission of a variety of pulsar wind SNRs. In several cases there appears to be an excess of x-ray emission relative to the radio, suggesting two separate populations of relativistic electrons. Evidence for time variability in the particle injection is also present. The best examples of remnants with these effects are N157B in the LMC, G21.5-0.9, and MSH 15-56.

### 3.2.6 Circumstellar Nebulae

Chu, Guerrero, and Gruendl have obtained XMM-Newton observations of the circumstellar bubble S 308 around the WR star HD 50896. Diffuse X-ray emission is unambiguously detected. Analysis of the X-ray spectrum shows a very low plasma temperature, only  $\sim 1 \times 10^6$  K. The presence of a conduction layer is implied by the spatial gap between the optical shell and the outer edge of the diffuse X-ray emission region.

### 3.2.7 Astrochemistry

Snyder and his colleagues have been studying the astrochemistry of large, highly saturated molecules of biological importance (e.g., formic acid, acetic acid, acetone, methyl formate, urea, methanol, ethyl cyanide, vinyl cyanide) in both the ISM and comets by utilizing three properties of radio interferometric arrays: high angular resolution over a large field of view to determine the size of individual dust emission regions in hot molecular cores; interferometric spatial filtering which promotes the study of dust chemistry in hot compact cores by filtering out most of the extended spectral line emission from cold cloud gas-phase ion-molecule reactions; and flexible correlators which allow the simulta-

neous observation of multiple spectral lines in the same object and the kinematic resolution of individual cores.

### 3.2.8 Molecular Clouds

A. Sobolev (Ural State U.), S. Salii (Ural State U.), S. Ellingsen (U. Tasmania), I. Zinchenko (IAP, Novgorod), L. Johansson (Onsala), and Sutton are studying methanol, CS, HCN,  $\text{HCO}^+$ , and  $\text{N}_2\text{H}^+$  emission in G34.26+0.15/34.24+0.13. They conclude that despite the great amount of activity in the region, the material around the G34.24+0.13MM protostar is rather quiescent. Furthermore, the star is forming at the edge of a dense clump and near a cavity, which may profoundly affect the development of this young star.

Sutton and Sobolev have been studying the characteristics of formaldehyde ( $\text{H}_2\text{CO}$ ), methanol ( $\text{CH}_3\text{OH}$ ), ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ), dimethyl ether [3]( $\text{CH}_3\text{OCH}_3$ ), and methyl formate ( $\text{HCOOCH}_3$ ), in a number of astrophysical sources. They also investigated some of the uncertainties in calculating fractional abundances and found an independent method, which generally confirms the standard method of calibration. And they have made interferometric measurements of fractional abundances in W3(OH).

Sobolev, Sutton, A. Ostrovskii (Ural State U.), and A. Malyshev (Ural State U.) are extending their work on methanol excitation around W3(OH) with a detailed study of 38 methanol lines. The excitation pattern of methanol near class II methanol masers is strongly determined by infrared radiation, which pumps the methanol through a series of levels spanning the ground torsional state and the first two torsionally excited states ( $v_t=1,2$ ). The pumping mechanism strongly affects the intensities of the majority of observable methanol lines, not just the maser transitions. In W3(OH) they see anomalously strong emission in the  $1_0 - 2_1$  E  $v_t=1$  and  $6_1 - 7_2$  A<sup>-</sup>  $v_t=1$  transitions and anomalously weak emission in the  $6_1 - 5_0$  E  $v_t=1$  transition, in accordance with a model for the excitation mechanism and confirming the critical role of the torsionally excited levels. They are able to reproduce the intensities and complex line profiles of the methanol lines in this region using a two component model of the emitting/absorbing/masing gas in front of W3(OH).

Sutton, Sobolev, Ostrovskii, Malyshev, Salii, and Zinchenko are studying other aspects of methanol emission in a variety of regions distinct from, but near, W3(OH). To the southwest of W3(OH) there is a region of diffuse emission visible in a number of molecular tracers. They model the methanol emission from this general region plus that from two distinct compact clumps strongly evident in the  $5_{-1} - 4_0$  E and  $8_0 - 7_1$  A<sup>+</sup> lines. The excitation in these regions is similar to that of class I methanol masers, indicating a region of moderate density lacking substantial infrared radiation. The region around the water maser source W3(H<sub>2</sub>O) is optically thick in many methanol lines, but shows an excitation temperature of order 150-200 K.

Sobolev, Sutton, and Zinchenko have also been studying the kinematics and spatial distribution of CS, SiO,  $\text{CH}_3\text{CN}$ , HDO, SO, and other chemical species throughout the W3(OH)/W3(H<sub>2</sub>O) region. The methyl cyanide data show

substructure in the W3(H<sub>2</sub>O) source, indicating that more than one young stellar object is present. SiO emission, which is thought to trace shock excitation, is located primarily to the south of both W3(OH) and W3(H<sub>2</sub>O), and is not well correlated with other molecular tracers. It is spatially extended and clumpy and may be outlining a region of interaction between a protostellar outflow and the ambient molecular cloud.

### 3.3 Extragalactic Astronomy

#### 3.3.1 Normal Galaxies

I. Barton (Ph.D. student) continued to make progress during the year analyzing a multi-wavelength set of visual images for population synthesis analysis in two moderately nearby spiral galaxies: NGC 4258 and NGC 5055. High signal-to-noise images are available for these two galaxies from the Mt. Laguna 1-m telescope in B, V, R, and ubv colors. The analysis of the stellar population in both NGC 4258 and NGC 5005 is nearly completed, as is the dynamical analysis to determine the galaxy mass distribution. The aim is to detect spatial variations in the stellar population and in the galaxy mass-to-light ratios.

L. Thompson and M. Griffin (Ph.D. student) continued to analyze “blank” field observations taken with the NICMOS-3 camera at the Mt. Laguna 1-m telescope in their search for distant clusters of galaxies at near-IR wavelengths. The method is an extension of earlier work at visual wavelengths by Dalcanton. All observations for this project have been completed, including the JHK near-IR imaging in many “blank” fields as well as visual wavelength CCD observations of a nearby galaxy cluster ( $z = 0.1$ ) to assist in a Monte Carlo simulation of the near-IR detection process.

#### 3.3.2 Large Magellanic Cloud

J. Dickel, V. McIntyre (ATNF), D. Milne (ATNF), and colleagues are undertaking a continuum radio survey at 5 and 8.6 GHz using the Australia Telescope Compact Array. Full coverage with short spacings of the individual antennas in the array gives a nominal resolution at 5 GHz of about 30 arcsec, but limited additional data at long spacings allows separation of small diameter sources down to about 2 arcsec. The program should provide complete catalogs of the SNRs and H II regions in the LMC and their properties.

Y. Nazé (Liege), Chu, Guerrero, M.S. Oey (Lowell Obs), Gruendl, and R.C. Smith (CTIO) have analyzed HST and ground-based images and long-slit echelle spectra of three ring-like HII regions in the HII complex N44 in the Large Magellanic Cloud (LMC). They find that the physical properties of these nebulae are marginally consistent with theoretical models of interstellar bubbles.

S. Points (Northwestern), Chu, S. L. Snowden (NASA/GSFC), and L. Staveley-Smith (ATNF, Australia) are examining the physical structure of the supergiant shells LMC 1 and LMC 4. They have used the ROSAT PSPC mosaics of LMC 1 and LMC 4 to examine the distribution of hot ( $10^6$  K) gas, and CTIO 4m echelle spectra, to examine the kinematics of the warm ( $10^4$  K) gas. The physical structure of these two

supergiant shells are very different from each other and from the supergiant shell LMC 2.

B. Dunne, Chu, and Staveley-Smith have been studying HI gas associated with superbubbles in the LMC. A co-expanding HI shell may host more kinetic energy than the visible, ionized gas shell. This work, together with the previous study of the hot gas in superbubble interiors, allows a comprehensive analysis of stellar energy feedback into the interstellar medium.

C.-H. R. Chen, Dunne, and Chu have obtained CCD images in the UBV bands for 15 OB associations in the LMC. These images will be used to study the stellar content in order to determine the star formation history and expected stellar energy injected into the ambient interstellar medium.

Chu, Gruendl, Dunne, and C. Howk (JHU) have obtained FUSE observations for 10 stars in the young HII region N11B in the LMC. Many of these stars are surrounded by expanding shells which are likely the bubbles blown by their stellar winds. The FUSE observations are used to search for OVI absorption from the interface between the shocked stellar winds and the surrounding nebular shells. Being located at the northwestern outskirts of the LMC, the sightlines toward N11B are not overwhelmed by the hot gas halo of the LMC, thus tentative detections of OVI absorption at interfaces have been obtained.

#### 3.3.3 Gamma-Rays

The high-energy ( $> 100$  MeV)  $\gamma$ -ray sky includes an isotropic and thus cosmic component, which receives contributions from—and thus constrains—a host of sources, from active galaxies to decaying dark matter. Pavlidou and Fields considered the contributions to the background from guaranteed sources: those already detected observationally, namely, active and normal galaxies. The background is well-fit by a combination of existing models for active galaxies and a new model for normal galaxies whose star formation history is given by the cosmic star formation rate. Future  $\gamma$ -ray observatories (GLAST) can disentangle these two components, and then probe any additional, more exotic sources.

#### 3.3.4 Nucleosynthesis

Many of the heaviest elements—and all heavier than lead—are synthesized by the “ $r$ -process” mechanism. The physics of this process is well-known: free neutrons are captured onto “seed” nuclei such as iron, building up elements in timescales of seconds. This recipe clearly calls for an extreme, explosive environment, yet the astrophysical site for this process has not been conclusively identified. B. Fields, J. Truran (Chicago), and J. Cowan (Oklahoma), show how the abundance pattern of very heavy elements in primitive (Pop II) stars sheds light both on the  $r$ -process and on the history of Galactic element synthesis.

P. McCullough, Fields, and V. Pavlidou have identified the nearest known remains of a supernova explosion. The supernova remnant was identified via its H $\alpha$  and X-ray signature. In addition, it shows a possible signature in  $\gamma$ -rays, which would indicate the presence of the radioactive nucleus  $^{26}\text{Al}$ , which would be the first identification of freshly synthesized  $^{26}\text{Al}$  in a supernova remnant. Finally, the

motion of a nearby, high-velocity (proper motion) pulsar is consistent with an origin in the supernova explosion, which occurred several million years ago, and would have been about as bright as the full Moon.

### 3.3.5 Big Bang Nucleosynthesis

Fields and S. Sarkar (Oxford) reviewed the basic physics of primordial nucleosynthesis, in which the lightest elements were formed in the first seconds and minutes of the big bang. By comparing the predicted light element abundances with their observed levels, one probes the early universe and measures the normal matter (baryon) content of the universe. Measurements of the cosmic microwave background radiation can now also derive independent measures of the cosmic baryon content; the comparison of these two marks a fundamental test of the hot big bang cosmology. Furthermore, if the two agree, R. Cyburt, Fields, and K. Olive (Minnesota) showed that they can be used together to gain new and sharper probes of astrophysics and of particle physics in the early universe.

A key observational probe of big bang nucleosynthesis is the cosmic deuterium abundance. Fields, Olive, J. Silk (Oxford), M. Cassé, and E. Vangioni-Flam (Institut d'Astrophysique, Paris) examined the consequences of the observed scatter in high-redshift deuterium abundances. A possible decline in deuterium versus heavy element abundances may signal the action of the first generation of stars. Additional deuterium observations can constrain this scenario and enhance the power of deuterium for cosmology.

### 3.4 Cosmology

B. Wandelt's recent projects included studying the bispectrum of the CMB anisotropy as measured by the space mission COBE/DMR. Together with collaborators at Princeton University, and with M. Schneider, an undergraduate student at UIUC, Wandelt has developed statistical techniques for measuring the size of non-linear corrections to the perturbations created during inflation. This is one of very few probes of physics at ultrahigh energies.

I. O'Dwyer has been working on CMB power spectrum estimation techniques. Wandelt and O'Dwyer are collaborating with a group from UCSB who have a ground based cosmic microwave background (CMB) experiment (BEAST). A modified version of a pseudo- $C_\ell$  algorithm proposed by Hivon et. al., the MASTER method, is being implemented and used to generate a power spectrum for the experiment. Cosmological parameter estimation will also be performed with this data.

For future CMB missions with large, high-resolution datasets these methods are inadequate. Wandelt has worked on creating Bayesian methods to estimate the power spectrum of anisotropies in the cosmic microwave background. These new techniques have now been implemented on scalar processors by two first year physics graduate students A. Lakshminarayanan and D. Larson. They allow computing the exact statistics of the CMB in a fraction of the time required by traditional and approximate techniques and therefore en-

able the detailed analysis of the large, arc-minute-resolution datasets of the future.

Also using a Bayesian approach, Wandelt and G. Huey have extended this work to translate the exact statistics of power spectrum estimates into quantitative determinations of confidence regions for cosmological parameters. The goal is to provide an easy to use WWW-interface where the community could view how the latest observations increase our knowledge of the global properties of the Universe.

In the universe today we are faced with puzzles related to observations of the clustering properties of matter on galaxy scales. Cold dark matter theories predict more cosmic structure on these "small" scales than observed. Together with R. Cyburt, B. Fields and V. Pavlidou, Wandelt has studied what would be expected for these and other observations if the dark matter were self-interacting or interacting strongly with baryons. They discovered that baryon-dark matter interactions have the potential to solve these problems, and do not interfere with the primordial production of light elements but are tightly constrained by observations of the diffuse  $\gamma$ -ray background.

On even smaller scales, a difficult problem in numerical simulations of the early universe is the computation of radiative transfer around luminous point sources (e.g. quasars), leading for example, to photo-ionization of the primordial atomic hydrogen. T. Abel and Wandelt used techniques that Wandelt and collaborators had originally developed for Cosmic Microwave Background analysis to develop an efficient algorithm for evolving a photo-ionization front around each ionizing object in the highly irregular density field of adaptive hydro-simulations.

### 3.5 Theoretical Astrophysics and General Relativity

S. L. Shapiro tackled a number of problems in theoretical astrophysics and general relativity theory. This work ranged over a wide variety of topics, with much of the effort focused on gravitation physics, both Newtonian and relativistic. Some of the main themes included the inspiral and coalescence of binary neutron stars and black holes and the associated generation of gravitational waves, the effect of general relativity on the stability of rapidly rotating neutron stars against radial collapse and the formation of bars, and the gravothermal catastrophe in self-interacting dark matter halos (SIDMs) formed in the early universe. Shapiro and his team developed a new, relativistic hydrodynamics code, which can integrate the Einstein field equations coupled to the equations of hydrodynamics in full 3+1 general relativity. This code has been used successfully to study rotating, collapsing and binary neutron stars. It has also been tested in vacuum spacetimes by tracking the long-term evolution of static and rotating black holes. This exercise is in preparation for applying the code to tackle the binary black hole inspiral and coalescence problem that is so important for gravity wave detection by LIGO, LISA and the world-wide network of gravitational wave laser interferometers. Shapiro has also studied the origin of supermassive black holes (SMBHs) believed to power quasars and AGNs and to reside in most, if not all, galaxies (including the Milky Way). Shapiro and his group have simulated several plausible SMBH formation

scenarios, including the collapse of supermassive stars and the collapse of the inner cores of dynamically evolved SIDM halos. Some of the problems Shapiro has pursued have been tackled analytically, others by means of large-scale computations on supercomputers.

Shapiro supervises a large team of graduate students and postdoctoral research associates. In addition, Shapiro trains and supervises, together with F. K. Lamb, a talented undergraduate research team that works on forefront problems in theoretical astrophysics and general relativity. Students in the group are top-ranked undergraduates in physics, astronomy and engineering physics.

#### 4. ASTRONOMICAL NOMENCLATURE

H. Dickel continues as President of the Working Group on Designations (IAU Commission 5) whose main activity during the past year has been reviewing submissions to the “IAU Registry for new Acronyms” at <http://cdsweb.u-strasbg.fr/cgi-bin/DicForm> and answering questions regarding nomenclature.

#### 5. PUBLIC SERVICE AND EDUCATION

H. Dickel continues to serve as Tour Speaker for the American Chemical Society, Shapley Lecturer for the American Astronomical Society, and Lecturer for the Society of Physics Students. J. Dickel is a Shapley Lecturer for the AAS.

J. Kaler continues his work in public education. The “Greatest Hundred Stars” was published by Copernicus Books (Springer NY) last fall, and the paperback version of “The Ever-Changing Sky” was published this past summer (Cambridge University Press, 2002). He published a set of encyclopedia articles on spectroscopy, and is now developing an encyclopedia of stellar astronomy. Kaler also helped develop an educational planetarium show (“The Stargazer”) produced by the Great Lakes Planetarium Society in conjunction with the Minneapolis Planetarium. He continues weekly sky news on “Skylights” (both emailed and on the web at <http://www.astro.uiuc.edu/~kaler/skylights.html>), and continues to expand the “Star of the Week” website (<http://www.astro.uiuc.edu/~kaler/sow/sow.html>). He also lectured extensively to both the public and to professional societies.

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Edmund Sutton  
Deana Pettigrew