University of Illinois
Department of Astronomy
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This report covers activities of the department for the period 1 September 2000 - 31 August 2001.

1. PERSONNEL

During this report year the scientific staff consisted of the faculty: You-Hua Chu, Richard M. Crutcher (Chair), Hélène R. Dickel (retired August 2001 as Professor Emerita), John R. Dickel, 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, William D. Watson, Ronald F. Webbink, Kenneth M. Yoss (emeritus); postdoctoral research associates: Jose Miguel Girart, Martin Guerrero, Damien Guillaume, Subha Majumdar, Anuj Sarma, Ronak Shah, Angela Speck; and research support staff: Robert Berry, Rami Dass, Robert Gruendl, David Mehringer, Grant Miller, Raymond Plante, 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 Francis Lovas (NIST), Andrej Sobolev (Ural State University in Russia), Dayal Wickramasinghe (Australian National University in Canberra), Lisa Young (New Mexico Tech), and Wes Young (NRAO).

Twenty-one graduate students were enrolled during the 2000-2001 academic year, and Sean Points successfully defended his thesis for the PhD in July 2001. Office support staff included Willa Hollis, Sandie Osterbur, Ginger Passalacqua, and Deana Pettigrew under the guidance of the Administrative Assistant, Carol Stickrod.

T. Ch. Mouschovias was on sabbatical during Spring 2001.

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. The major facility is a 1536-processor SGI Origin 2000 that provides up to about 0.8 teraflop of computer power. Other systems include an Intel 256-processor NT cluster and both IA-32 and IA-64 Linux clusters; the Linux clusters are currently being upgraded to provide 2 teraflops of computing power. Also available are advanced visualization systems such as a CAVE virtual environment and a multi-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. R. Shah continued on as a postdoctoral research associate. Graduate students were P. Cortes, D. Fong, D. Friedel, S.-P. Lai, and A. Remijan. The senior research programmer was H. Ravlin, and the LAI administrative secretary was D. Pettigrew. BIMA Array scheduler duties were transferred from E. C. Sutton to R. Gruendl. During this period, K.-Y. Lo left to become Director of the Institute of Astronomy and Astrophysics in Taipei, Taiwan. J. M. Girart moved back to his native Spain. H. Dickel announced her retirement effective in August 2001.

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 with operations starting in 2004. The BIMA Array consists of ten 6-meter wide antennas (nine of which will go to CARMA) and the Caltech array consists of six 10-meter wide antennas. CARMA, the array of combined telescopes, 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: Aips++ Users Group and Help (LAUGH) was formed during the academic year to develop an Aips++ Cookbook for BIMA users. Members of LAUGH were H. Dickel, D. Fong, D. Mehringer, R. Plante, and A. Sarma. H. Dickel was also the local BIMA member of the international Aips++ User Group which met at the University of Illinois in January 2001. In the course of preparing the first draft of the Cookbook, a series of 5-minute Tutorials were given in the spring 2001, followed by a ''Hands-on'' Aips++ Tutorial on April 13, 2001. A report appears as AIPS++ Note 245 =

AIPS++ Tutorials at UIUC – http://monet.astro.uiuc.edu/aips++/forBIMA/TUTORIAL/laitut.html. The first draft of the Cookbook was completed in June 2001 and is available at http://monet.astro.uiuc.edu/aips++/forBIMA/cookbook.ps. The full capability of aips++ to handle multiple spectral windows with differing numbers of channels was not available initially; thus, sections on the BIMA-specific tools for editing and calibrating BIMA uv data will be added in the near future.

2.3 Mt. Laguna Observatory

The UI Astronomy Department has operated a 1-m telescope at Mt. Laguna Observatory jointly with San Diego State University for 20 years. Approximately 50% of the telescope time has gone to each institution. During the past year an agreement was reached to reduce the University of Illinois participation to 25% and to phase out Illinois participation over a 10-year period. Otherwise, few changes have occurred. Continuing in successful operation are (1) a 2048 $\times$2048 Loral CCD camera and (2) a 256$\times$256 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 year, active discussions were held among the optical and IR observational astronomers regarding the possibility of joining a consortium to build a very large optical/IR 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 Scott Teare (Co-PI) who relocated during the past year and is now a Professor of Electrical Engineering at New Mexico Tech.

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 Coude optics train for a final focus at 18 km altitude. Closed-loop performance of the adaptive optics system was demonstrated on natural stars, although no science data has been collected with this sub-system as the aim is to use the natural guide star system primarily to achieve closed-loop calibration of the laser guide star wave front signal. The major achievement during the past year was direct detection at excellent signal-to-noise of the return signal from the 351 nm laser guide star through the full optical system and into the laser guide star wave front sensor.

2.6 Infrared Instrumentation

The Near-InfraRed IMager (NIRIM) has been tested at the Wisconsin-Indianna-Yale-NOAO (WIYN) 3.5 m telescope by M. Meixner and A. K. Speck. NIRIM achieved a high image quality on WIYN, with point spread functions with full width half maximums of less than $0\farcs3$ at best and $0\farcs5$–$0\farcs7$ typically. In the future, NIRIM will visit WIYN for 4 months out of the year in exchange for 3 clear nights of observing time at the WIYN telescope.

Teare is the PI for the development of a low resolution, near infrared, grism spectrometer for the Near-InfraRed IMaging (NIRIM) camera used at the Mount Laguna and Mount Wilson Observatories to be completed early in 2001.

3. RESEARCH

3.1 Stars

3.1.1 Binary Stars

E. Olson and P. Etzel (San Diego State) continued work on stellar and accretion-disk properties of long-period Algols. Olson applied his non-LTE accretion disk model to Hα and disk continuum emission in RX Geminorum and DN Orionis. Radial velocities of red and violet Hα emission lobes reveal the kinematical effects of stream-disk impact in RX Gem. These effects are less clear in DN Ori, where the cool loser is slightly detached from its Roche lobe. Ultraviolet disk continuum comes from inner disk regions, while the bulk of the Hα emission originates farther out. Modeling both yields the approximate radial temperature distribution through the disk. The total disk mass in RX Gem is of order 10^{-9} $M_\odot$.

R. A. Downes (STScI), Webbink, M. M. Shara (Am. Mus. Nat. Hist.), H. Ritter (MPIfAp), U. Kolb (Open Univ.), and H. W. Duerbeck (Free Univ. Brussels) updated the Catalog and Atlas of Cataclysmic Variables (CVs), published originally by Downes and Shara and last updated in 1997. In its new form, it has been expanded to include orbital periods, where known, and has been made available on the World-Wide Web at tt http://icarus.stsci.edu/~downes/cvcat. At this writing, it contains 1276 objects, of which 207 have been reclassified as non-CVs. Finding charts and precise coordinates are provided for all CVs, along with references to published charts, variability type, coordinates, spectra, and orbital period determinations. This site will be continuously updated.

Webbink and D. T. Wickramasinghe (Australian Nat. Univ.) completed a study of the evolution of synchronous magnetic cataclysmic variables (AM Her binaries). In these systems, the accreting white dwarf has a magnetic dipole moment large enough to lock it in synchronous rotation with its mass-losing nondegenerate donor companion star. Among other CVs, the magnetically-entrained stellar wind from that companion star has long been believed to be the agent driving mass transfer. That magnetic stellar wind draws angular momentum directly from rotation of the donor star, but those losses are continuously restored from the orbit of the binary by tidal torques. In this picture, these angular momentum losses are large enough to drive the donor stars out of thermal equilibrium as their orbits decay toward a period of 3 hours. At roughly that period, the donor star becomes fully convective, its dipole field is no longer anchored in a radiative core, buoyancy of the field leads to its expulsion by the star, and magnetic braking suddenly subsides, allowing the thermally-distended donor star to contract within its Roche lobe, and cutting off mass transfer until the binary orbit decays (by gravitational radiation) to a period of about 2 hours. This is the explanation offered for the dearth of CVs observed with orbital periods between 2 and 3 hours. This ''period gap'' is however much less pronounced among the AM Her subclass of CVs.

In AM Her systems, the magnetic braking torques which drive evolution in other CVs can be suppressed by suitably large white dwarf magnetic dipoles. The open field lines, which otherwise allow the donor star stellar wind to escape, now become closed onto the magnetic poles of the white dwarf. For white dwarf dipole moments above $\sim 4\times10^{34}$ G cm^3, magnetic braking can be completely suppressed. The evolutionary consequence is that mass transfer is driven at a much lower rate, the donor stars are not driven nearly as far from thermal equilibrium, and the period gap begins to fill from its short-period end. Webbink and Wickramasinghe argue that this is precisely the behavior observed among AM Her stars, and furthermore that its effects are evident in just the range of magnetic field strengths expected for white dwarfs of typical mass (for CVs). AM Her systems are thus the exceptions indicating that magnetic stellar winds do indeed drive CV evolution above the period gap.

3.1.2 Evolved Stars

M. Meixner, D. Fong, E. Sutton, W. J. Welch (UC Berkeley), and K. Justtanont (Stockholm Obs.) have finished collecting data for their BIMA and NRAO 12 m CO J=1-0 imaging survey of 12 evolved stars. Methods for combining the single dish and interferometry data were tested. The finalizing of the data's image processing has begun. Fong, Campbell, Meixner, and Justtanont worked on model calculations of the evolved star, OH 26.5. M. T. Campbell and D. Fong have successfully transferred the output of these one dimensional model results into a 3 dimensional data cube that could be compared directly to the BIMA data. 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, which has been almost absent in the literature.

A. K. Speck, M. Meixner, P. McCullough, D. Fong, T. Ueta, and D. Moser have been investigating the nature of dust, molecules and ions in the Helix nebula, the closest planetary nebula. The infrared Space Observatory data and the Southern H-Alpha Sky Survey Atlas image reveal an enormous extent for the Helix of 18′. The dust emission suggests that there may be dust destruction in the central, highly ionized region of the Helix. The vibrationally excited molecular hydrogen images of the Helix, taken with NIRIM at the MLO 1 m telescope, show that this molecular gas emission is enclosed by the ionized gas and that it probably survives the ionization front in dense globules of gas.

A. K. Speck and A. M. Hofmeister (Washington University) have been investigating the optical properties of silicon carbide and find evidence for a 21 μm emission feature that may explain the one found in carbon rich proto-planetary nebulae.

M. Meixner, D. Moser and L. Pyzowski have been analyzing the near-infrared photometry of $\sim$40 proto-planetary nebulae. This photometry survey was taken with NIRIM at the MLO 1 m telescope. M. Meixner, L. Pyzowski and C. Busbey have pursued follow-up studies of the molecular gas emission content of these proto-planetary nebulae with NIRIM.

T. Ueta and M. Meixner have basically rewritten the axially symmetric dust radiative transfer code in Fortran 90, so that it could be easily parallelized. The code now handles anisotropic scattering expected from the dust grains, especially large dust grains. Most radiative transfer codes treat the scattering isotropically. The mid-infrared and optical images of proto-planetary nebulae have been modeled with this code and results of these model calculations have been published.

Yoss, H. Detweiler (Illinois Wesleyan), G. Miller (Southwestern College, San Diego State University) obtained DDO observations of a number of ''Upgren'' late-type stars near the North Galactic Pole, using the University of Illinois 1-meter telescope at the Mt. Laguna Observatory. This is an extension of their previous observations of all HD late-type stars within 15° of the NGP (J. Astrophys. Astr. (1997) 18, 161). They also have obtained Mg indices for late-type abundance standards to strengthen their Figures 1 and 3 (AJ (2001) 121, 458).

3.1.3 White Dwarfs

I. O'Dwyer, Gruendl, Guerrero, and Chu have used the *ROSAT* archive to search for X-ray emission from hot white dwarfs. They find a large number of hot white dwarfs that appear to be sources of hard (>0.5 keV) X-ray emission. Follow-up high-dispersion spectroscopic observations of the white dwarf at the center of the Helix Nebula show variable Hα line profiles. The variable Hα profile and the variability of the hard X-ray emission detected in *Chandra* observations suggest that this white dwarf has a dMe companion. They are also using near-IR photometric observations at Mount Laguna Observatory to search for late-type companions of these hot white dwarfs.

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.

A. Sarma, T. Troland, D. Roberts and R. Crutcher carried out OH and H I Zeeman observations of the NGC 6334 complex with the Very Large Array. Magnetic fields of the order of 200 μG have been detected toward three discrete continuum sources in the complex. Virial estimates suggest that the detected magnetic fields in these sources are of the same order as the critical magnetic fields required to support the molecular clouds associated with the sources against gravitational collapse.

D. Ward-Thompson, J. Kirk, R. Crutcher, J. Greaves, W. Holland, and P. Andre made the first maps of magnetic fields in prestellar cores to test theoretical ideas about the way in which the magnetic field geometry affects the star formation process. The observations are JCMT-SCUBA maps of $\lambda 850$ μm thermal emission from dust. Linear polarizations at typically 10 or more independent positions in each of three objects, L1544, L183, and L43, were measured, and the geometries of the magnetic fields in the plane of the sky were mapped from the polarization directions. The observed polarizations in all three objects appear smooth and fairly uniform. In L1544 and L183 the mean magnetic fields are at an angle of about 30° to the minor axes of the cores. The L43 B-field appears to have been influenced in its southern half such that it is parallel to the wall of a cavity produced by a CO outflow from a nearby T Tauri star, while in the northern half the field appears less disturbed and has an angle 44° to the core minor axis. No current model can explain these observations simultaneously with previous ISOCAM data.

R. Crutcher and T. Troland used the Arecibo telescope to observe the Zeeman effect in the 1665 and 1667 MHz lines of OH toward eight dark cloud cores. For L1544, the inferred line-of-sight magnetic field is $B_{LOS}=+11\pm2$ μG. The L1544 starless core has been observed to have infall motions; it may be very close to forming a star. $B_{LOS}=11$ μG is consistent with the prediction of an ambipolar diffusion model computed specifically for this core before the Zeeman measurements were made; however, in order to obtain agreement with the data this model has B inclined by only 16° to the plane of the sky. Virial arguments show that unless the magnetic field is mainly in the plane of the sky, it is not important for support of the L1544 core.

S. Levin, W. Langer, T. Velusamy, T. Kuiper, and R. Crutcher have measured the Zeeman splitting of the CCS $J_N=3_2-2_1$ line at 33 GHz toward L1498, a dense preprotostellar core, in an effort to measure the line-of-sight component of its magnetic field. The data suggest a line-of-sight component of the magnetic field in L1498 of 48 ± 31 μG, yielding an upper limit of $B_{LOS}<100$ μG at the 95% confidence level. This upper limit provides some constraints on models. The results show that the technique they have adopted to measure CCS Zeeman splitting holds great promise for determining magnetic field strengths in cloud cores using lower-frequency transitions of CCS.

D. Balsara, R. Crutcher, and A. Pouquet numerically explored self-gravitating magnetized flows in slab geometry. The overall characteristic scale of the turbulence, its Mach number, and the initial ratio of longitudinal to transverse turbulent velocities, as well as the extent of the initial density bulges within the fluid, are the main parameters of the study. Simulations have been performed with and without ambipolar drift. Velocity, density, and magnetic perturbations develop self-consistently to comparable levels in all cases. This includes those cases where the medium is initially static. However, a fully random flow produces substantially more density contrast with nested substructures. Collapse eventually occurs after typically three free-fall times. The magnetic field slows down the collapse as expected. For higher Mach numbers, the collapse is faster, and yet the peak densities reached in the final collapsed objects are lower. They also modeled the effects of ambipolar drift in the presence of cosmic ray ionization and far-ultraviolet ionization, finding that ambipolar drift does not play a significant role in gravitational collapse in a turbulent medium of the type modeled in these simulations.

W. Watson, D. Wiebe, and R. Crutcher developed statistical relationships between the rms values of the irregular component of the magnetic field and spatial variations in the circular polarization of the spectral line radiation. The irregularities are characterized in analogy with descriptions of turbulence – by a sum of Fourier waves having a power spectrum with a slope similar to that of Kolmogorov turbulence. For comparison, they also performed computations in which turbulent magnetic and velocity fields from representative MHD simulations by others are utilized. Although the effects of the variations about the mean value of the magnetic field along the path of a ray tend to cancel, a significant residual effect in the polarization of the emergent radiation remains for typical values of the relevant parameters. A map of observed spectra of the 21 cm line toward Orion A was analyzed and the results were compared with their calculations in order to infer the strength of the irregular component of the magnetic field. The rms of the irregular component was found to be comparable in magnitude to the mean magnetic field within the cloud. Hence, the turbulent and Alfven velocities should also be comparable.

3.2.2 Cosmic Rays

The history of cosmic rays in the Galaxy is encoded in the ''fossils'' of beryllium and boron, which are produced in collisions between cosmic rays and the interstellar medium (ISM). B. Fields, with K. Olive (Minnesota) and E. Vangioni-Flam and Michel Cassé (Institut d'Astrophysique, Paris) studied the energetics of Be and B evolution in the Galaxy. They showed that the energetic constraints on cosmic-ray nucleosynthesis models are equivalent to the observed abundance constraints on these models. Furthermore, a study of energetics provides a means to directly link global galactic observables and local cosmic ray properties.

3.2.3 Interstellar Medium

P. R. McCullough and his colleagues J. Gaustad, D. Van Buren and W. Rosing have completed their robotic Hα survey of the southern-sky from Cerro Tololo Inter-American Observatory. The resulting data constitutes the ''Southern H-Alpha Sky Survey Atlas,'' which is an online digital library of 542 pairs of astronomical images, each 10^6 pixels, with an interactive search facility (http://amundsen.swarthmore.edu/SHASSA/). SHASSA data are being analyzed to determine the structure of the warm ionized medium of the ISM and to provide a template for the free-free Galactic foreground emission that must be subtracted from the observations of the cosmic microwave background radiation such as will be made by the MAP and Planck satellites. Extended ionized structures around the planetary nebulae Abell 36 and the Helix nebula have been revealed by SHASSA data, and additional planetary nebulae are being studied.

McCullough and R. Benjamin have been studying an unusually thin, straight filament of ionized gas stretching 2.5 degrees across the sky in the constellation Ursa Major. The filament is roughly Y-shaped. The vertical segment of the Y is about 1.2 degrees long and about 20 arcseconds wide. The full width of the two diagonal segments is about 5 arcminutes. They hypothesize that the filament may be a ''Fossil Stromgren Trail'' left by a low luminosity ionizing source such as a white dwarf, but to date they have been unable to positively identify whatever is leaving the trail, if indeed the object is a trail and not simply a generic filament that by chance is unusually straight.

3.2.4 Planetary Nebulae

Y.-H. Chu, M. Guerrero, and R. Gruendl continue to study X-ray emission from planetary nebulae. They have obtained *Chandra* ACIS-S observations of NGC 6543 (the Cat's Eye Nebula) and NGC 7293 (the Helix Nebula), and *XMM-Newton* observations of NGC 7009 (the Saturn Nebula). The diffuse X-ray emission from NGC 6543 and NGC 7009 is clearly resolved, showing the distribution of hot (10^6 K) gas. Both NGC 6543 and NGC 7293 have a hard, point X-ray source at the central star.

Gruendl, Chu, and Guerrero have obtained *FUSE* observations of a number of central stars of PNe, covering a wide range of stellar effective temperatures. The observations will be used to examine the nebular O VI absorption against the stellar spectra, in order to search for hot (10^5 K) gas and study its physical condition.

Guerrero, Miranda (IAA, Spain), Chu, Rodrí guez (INAOE, Mexico), and Williams (NASA/GSFC) have investigated the kinematics of the straight jet-like feature emanating from the core of He 2-90. The jet-like feature is confirmed to be a highly collimated outflow expanding at a constant velocity. The central core of the nebula shows a high density and a profusion of emission lines that are typically observed in symbiotic stars and PNe associated with binary progenitors.

3.2.5 Supernova Remnants

The relation of neutron stars to supernova remnants and the evolution of each continues to be a topic of great interest. The extended Crab type SNR N157B with a 16 msec pulsar has been investigated at radio and x-ray wavelengths by J. Dickel with J. Lazendic (U. Sydney), D. Wang (U. Mass.), E. Gotthelf (Columbia), and Y.-H. Chu. The prototype composite SNR 0540-693 is being polarimetrically mapped in the radio by J. Dickel, undergraduate student M. Mulligan, R. Manchester (ATNF), D. Milne (ATNF), B. Gaensler (MIT), S. Staveley-Smith (ATNF), and M. Kesteven (ATNF). A possible plerionic SNR in the LMC, N206, has been found by R. Klinger, J. Dickel and B. Fields to have a peculiar jet-like feature which might be a bow-shock from the motion of a star within the remnant. A Chandra observation of the x-ray plerion component of the composite SNR MSH 15−56 that is not coincident with the radio plerion is being obtained by P. Pluncinsky (SAO), P. Slane (SAO), T. Gaetz (SAO), J. Dickel, and Klinger. The radio and x-ray sizes of G21.5-0.9 are being compared by D. Bock Berkeley), M. Wright (Berkeley), and J. Dickel. Most of these SNRs indicate only weak radio emission right at the position of the pulsar but then relatively bright radio outside an x-ray peak around the pulsar. This is the result of a combination of variable injection and decay of the relativistic electron energy.

Spectral index variations in the young remnant of Kepler's SN, which does not have a pulsar, are being investigated by T. Delaney (U. Mn.), L. Rudnick (U. MN), B. Koralesky (U. MN), and J. Dickel. L. Sjouwerman (JIVE) and J. Dickel have a tentative radio detection of SN 1885 in M31 and have observed three other SNRs in the center of that galaxy as well.

Gruendl, Chu and S. Van Dyk (IPAC) have analyzed high-dispersion spectra of 16 young supernovae at distances up to 30 Mpc. Only 6 SNe were detected. The interstellar medium is detected in 12 cases, but a circumstellar nebula is detected only around one supernova, SN 1978K.

3.2.6 Circumstellar Nebulae

C. Danforth (JHU) and Chu studied the circumstellar bubble around the luminous blue variable (LBV) S119 in the Large Magellanic Cloud. Using high-dispersion echelle spectra of the nebulae, they found a large velocity offset between the nebula and its host galaxy. Analyzing *FUSE* observations of interstellar absorption against the stellar spectrum and *HST* WFPC2 images of the nebula, they conclude that S119 is a runaway LBV and its circumstellar nebula is interacting strongly with the ambient interstellar medium.

R. C. Chen and Chu have searched for LBVs in giant HII regions in M101, using *HST* WFPC2 images in the R-band and Hα line. A large number of luminous stars with Hα emission were found. Only a small fraction of these LBV candidates have high-dispersion spectra available. One object in NGC 5471C shows Hα line widths over 2000 km s^{-1} similar to the ejecta of the Galactic LBV η Car.

3.2.7 Astrochemistry

S.-Y. Liu (Caltech), J. Girart (Barcelona), graduate student Remijan, and Snyder observed formic acid (HCOOH) with the BIMA Array at 1 mm toward the Orion KL region. Near the compact ridge, HCOOH emission is spatially resolved; its partial shell morphology is different from emission from other complex O-bearing molecules such as methyl formate and dimethyl ether. This unique distribution suggests that HCOOH is located in a layer which delineates the interaction region between the outflow and the ambient quiescent gas. HCOOH was also detected in the hot core.

Graduate student Remijan, Snyder, S.-Y. Liu (Caltech), D. Mehringer (Illinois), and Y.-J. Kuan (Nat. Taiwan N. U.) are working on detecting acetic acid (CH_3COOH) in regions outside of Sgr B2(N-LMH). They are concentrating on the hot cores of W51 and several other hot core regions including Orion KL, G34.3+0.2, W3(H_2O) and W49 A. Their results suggest that CH_3COOH emission is prevalent in the environment surrounding a newly forming star.

Graduate student Friedel, Snyder, and B. E. Turner (NRAO) started a survey where spectra taken with a millimeter array (BIMA Array) are compared with those from a single element telescope (12 meter radio telescope) toward the molecular cloud Sagittarius B2(N). The frequencies covered by this line survey are six 600 MHz wide bands centered at 86.2,86.8, 90.025, 106.058, 108.5 and 110.2 GHz. This survey is not only to discover what molecules are in the cloud but also a study of their kinematics and possible formation mechanisms. Since the array ‘‘sees’’ a smaller region than the single element telescope, it is more sensitive to compact sources (whose molecules have largely formed on grain surfaces) whereas the single element telescope is more sensitive to extended emission (where most molecular species have formed in the gas phase).

3.2.8 Star Formation: Observations

As a follow up to their observational paper on BIMA CS J=2-1 observations of the W 49 A north star-forming complex, J. A. Williams (Albion College), H. R. Dickel, and L. H. Auer (LANL) have done radiative transfer modeling of 3 proposed scenarios to explain the observations of multiple transitions of CS and isotopes, namely $C^{34}S$, seen towards W 49 A north. The 3 scenarios are colliding clumps, global collapse, and local collapse (around individual compact HII regions). Although varients of the initial models could reproduce the lower transitions, the predicted intensities for the J=7-6 transition were too low. In an effort to overcome this deficiency, the calculations were expanded to investigate the effects of gradients in the kinetic temperature and a core/envelope structure to the cloud components. It is the latter feature, which is key to matching the intensities of all the transitions in the directions of the embedded HII regions.

3.2.9 Molecular Clouds

J. M. Girart (now at Univ. Barcelona) in collaboration with S. Viti and D. A. Williams (Univ. College London), P. T. P. Ho (CfA), R. Estalella (Univ. Barcelona) and J. Hatchell (MPIfR) are carrying out a comprehensive theoretical and observational study to elucidate the nature of the quiescent clumps ahead of Herbig-Haro objects. Their study toward HH2 shows that the chemical composition of the quiescent clump is significantly affected by the radiation of the Herbig-Haro object. On the other hand, the clump ahead of HH80N shows clear signposts of star formation, and it is possible that the HH 80/81/80N flow has triggered or at least speed up the star formation in this region. New observations with the IRAM 30m were carried out towards several other Herbig-Haro objects to study how the chemical composition varies from one clump to another.

Girart, Crutcher, Lai and J. Greaves (Royal Observatory Edinburgh) are studying the polarized emission of the CO J=2-1 towards the Orion KL/IRc2 region. They have combined BIMA and single-dish JCMT spectro-polarimetric data towards the Orion KL/IRc2 region.

Girart, J. Acord (Syncretic Software) and S. Curiel (Instituto de Astronomia, UNAM, Mexico) continue the study of the proper motions of the extremely high velocity SiO emission towards L1448. Initial results showing for the first time proper motions in a molecular outflow were published in the Astrophysical Journal Letters.

Girart, Curiel and L. F. Rodriguez (Instituto de Astronomia, UNAM, Mexico) are studying the radio continuum properties of the strong X-ray emitting YSO YLW 15. This is a remarkable object since it exhibits phenomena, such as strong millimeter emission and association with a bipolar outflow, that characterize extremely young stars, while at the same time presenting strong, time-variable X-ray emission. The first results of this study were published in the Astrophysical Journal Letters. New VLA observations confirm that one of the two radio sources is a thermal radio jet.

R. Gruendl has continued collaboration with K.-Y. Lo and Dinh-V-Trung (ASIAA/Taiwan), W.-H. Wang (Hawaii), and Y. Gao (Caltech/IPAC), to study the molecular and neutral hydrogen gas content of luminous IR galaxies. The ultimate goal of this research is to better understand the evolution of the interstellar medium in merging galactic systems. To do so BIMA observations of the CO(1-0) emission from 15 galaxy pairs and in a few cases VLA observations of the HI 21 cm line have been obtained.

The most recent work has concentrated on the most widely separated galaxy systems in our sample. Our BIMA observations detect CO emission from five of six of the most widely separated luminous IR galaxies known (typical separation >20 kpc). In each case, only one of the galaxies has detectable CO emission, the molecular gas content is $>10^{10}$ $M_{\odot}$, and radio continuum observations suggest that this galaxy produces most of the IR emission from the galaxy pair. While the wide separation between the galaxies suggests that the merging pair is in an early stage of interaction, the molecular gas properties of the IR emitting galaxies suggest that they are in a late stage of merging (similar to ultraluminous IR galaxies).

More detailed analysis of BIMA CO(1-0) and VLA 21 cm and radio continuum observations of the NGC 6670 system have been completed. NGC 6670 consists of two edge-on galaxies with a projected separation of 16 kpc. The optical disks of these galaxies show little sign of interaction and appear to just touch, and the molecular gas disks do not appear to be distorted much. But the H I distributions shows two long tidal tails extending up to 90 kpc, suggesting these galaxies have already experienced one close encounter. While the radio continuum observations rule out active galactic nuclei as the source of IR luminosity from NGC 6670, the high-resolution CO(1-0) observations obtained with BIMA show that large molecular gas reservoirs have already formed in the centers of both galaxies and that both galaxies show an elevated star formation efficiency compared to the Milky Way. Other indications of starburst activity such as CO brightness temperature and IR surface brightness are also observed.

R. Y. Shah is working with several collaborators to analyze the spatial distribution of deuterated molecules, namely NH_2D, DCO^+, and DCN. Shah and A. Wootten (NRAO) are concentrating on observations of NGC1333 with J. McMullin (NRAO) and Serpens with McMullin, J. Williams (U. Florida), T. Bourke, and P. Myers (CfA). They are utilizing NRAO-12m, Caltech Submillimeter Observatory, BIMA, Very Large Array, FCRAO 14m, and GBT data. Towards Serpens, Shah and Bourke have successfully combined single-aperture and interferometer HCO^+ data and find inverse P-Cygni profiles towards dense cores. They are currently investigating theoretical studies for comparison to this result.

Shah and Wootten continue work with C. Carilli (NRAO) and K. Menten (MPIfR) on high redshift molecular absorption lines towards lensed quasar systems using the VLA and GBT. They are attempting to measure the physical conditions of gas at redshifts near 1 and to understand how this affects the star formation rate at a look-back time of 2/3 the current age of the Universe.

S.-P. Lai and R. Crutcher conducted a survey of the CCS $J_N=3_2-2_1$ line toward 11 dark clouds and star-forming regions with the BIMA array. CCS was detected only in quiescent clouds, not in active star-forming regions. The CCS distribution showed remarkable clumpy structure, and 25 clumps were identified in seven clouds. Seven clumps with extremely narrow nonthermal line widths (<0.1 km s^{-1}) are among the most quiescent clumps ever found. The CCS clumps tend to exist around the higher density regions traced by NH_3 emission or submillimeter continuum sources, and the distribution is not spherically symmetric. Variation of the CCS abundance was suggested as an indicator of the evolutionary status of star formation. However, they found only find a weak correlation between N(CCS) and n(H_2). The velocity distributions of CCS clouds reveal that a systematic velocity pattern generally exists. The most striking feature in the data is a ring structure in the position-velocity diagram of L1544 with an well-resolved inner hole of 0.04 pc by 0.13 km s^{-1} and an outer boundary of 0.16 pc by 0.55 km s^{-1}. This position-velocity structure clearly indicates an edge-on disk or ring geometry, and it can be interpreted as a collapsing disk with an infall velocity $\geqslant 0.1$ km s^{-1} and a rotational velocity less than the velocity resolution. The nonthermal line width distribution is generally coherent in CCS clouds, which could be evidence for the termination of Larson's Law at small scales, ~ 0.1 pc.

E. Sutton, A. Sobolev (Ural State U.), S. Ellingsen (U. Tasmania), D. Cragg (Monash U.) D. Mehringer, A. Ostrovskii (Ural State U.), and P. Godfrey (Monash U.) used the BIMA array to study nine methanol transitions in the molecular cloud W3(OH). All nine had been predicted as possible class II methanol masers. They saw maser emission in three lines: $7_2 - 6_3$ A$^-$, $7_2 - 6_3$ A$^+$, and $3_1 - 4_0$ A$^+$. The maser emission is confined to a particular region in the source near the northern edge of the ultra-compact HII region in W3(OH). The masers have a common v_{LSR} of -43.1 km/s. They placed upper limits on possible maser emission in the other six lines. The results support the mechanism of pumping of class II masers by far-infrared radiation from warm dust. The W3(OH) masers originate in high density (10^7 cm^{-3}), high temperature ($\geqslant 110$ K) material. The gas has a high methanol abundance, at least 10^{-6} N(H_2), indicating strong methanol enrichment by grain mantle evaporation. The dimensions of the maser region are of order 100 x 1000 AU. The kinematics of the gas are consistent with an expanding thin shell.

Sutton, Sobolev, Ostrovskii, A. Malyshev (Ural State U.), and S. Salii (Ural State U.) are studying other aspects of methanol excitation in the general vicinity of W3(OH) and W3(H2O) and in an extended region to the south and west of W3(OH), using data from a total of 41 methanol lines. The region around W3(H2O) shows strong emission in torsionally excited methanol lines and an excitation temperature of order 150-200 K. Towards W3(OH) there is some multiplicity in the lineshapes and some evidence of self absorption. The spatial distribution is also split, with some lines (at some velocities) concentrated near the northern edge of the ultracompact H II region and some lines (some velocities) near the southern edge. The emission to the south and west of W3(OH) is seen primarily in low-excitation lines and shows evidence of absorption by material near, but in front of, this region.

Sobolev, Sutton, and I. Zinchenko (IAP, Novgorod) are also studying the kinematics and spatial distribution of CS, SiO, CH_3CN, HDO, SO and other chemical species throughout the W3(OH)/W3(H2O) region. There is a large amount of low excitation material overlying the entire region, but especially extending to the southwest of W3(OH), as seen in methanol. SiO emission, which is thought to trace shock excitation, is located primarily to the south of both sources. It is spatially extended and clumpy and appears to be outlining a region of interaction between a protostellar outflow and the ambient molecular cloud. The vicinity of W3(H_2O) is particularly interesting as it relates to the nature of the TW object and the impact of outflows and shocks on the overall cloud structure. Evidence for a rotating disk around W3(H_2O) is seen in emission lines of $HCOOCH_3$, $C^{34}S$, $C^{33}S$, CH_3CN, OCS, HC_3N, and SO_2.

3.3 Extragalactic Astronomy

3.3.1 Normal Galaxies

I. Barton (Ph.D. student) made excellent progress during the year analyzing a multi-wavelength set of visual wavelength images for population synthesis analysis in two moderately nearby spiral galaxies: NGC 4258 and NGC 5055. Very high signal-to-noise images are available for these two galaxies from the Mt. Laguna 1-m telescope in B,V,R, and ubvy 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 use the NICMOS-3 camera at the Mt. Laguna 1-m telescope to search for distant clusters of galaxies at near-IR wavelengths. The method is a very promising extension of earlier work at visual wavelengths by Dalcanton (ApJ, 466, 92, 1996). All observations for this project are now complete, 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

E. Jaxon, Guerrero, Chu, J. C. Howk (JHU), N. R. Walborn (STScI), and B. P. Wakker (UWisc) have classified 42 OB stars in the Large Magellanic Cloud (LMC). These stars can be used as probes for the hot gaseous halo of the LMC.

Y. Nazé (Liege), Chu, Points, Danforth (JHU), M. Rosado (UNAM), and Chen have analyzed *HST* WFPC2 images and CTIO 4m echelle spectra of two young HII regions in the LMC - N11B and N180B. They find bubbles blown by main sequence O stars, but the expansion velocities are only 15-20 km s^{-1}, which are too low to provide strong compression to produce sharp, filamentary morphology.

Points, Chu, S. L. Snowden (NASA/GSFC), and 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.

Points, Chu, E. Grebel (MPIA), and W. Brandner (ESO) are examining the stellar content of the supergiant shell LMC 2 in order to study the production of hot (10^6 K) gas in the supergiant shell interior. They find that the stellar energy, including supernovae and stellar winds, injected by the massive stellar population is adequate to account for the thermal energy observed in the hot gas.

B. Dunne, Chu, and Staveley-Smith (ATNF) 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 allow a comprehensive analysis of stellar energy feedback into the interstellar medium.

3.3.3 Gamma-Rays

The most prominent feature in the gamma-ray sky above 100 MeV is the diffuse emission from the Galactic disk, created by high-energy cosmic-ray interactions with the interstellar medium. Yet the only other galaxy observed thus far in high-energy gamma-rays is the Large Magellanic Cloud (LMC). In anticipation of the upcoming gamma-ray telescope GLAST, V. Pavlidou and Fields (2001) made a systematic study of the diffuse gamma-rays from all local group galaxies. They found that in addition to the LMC, the Small Magellanic Cloud, Andromeda Galaxy, and possibly the M33 galaxy will be observable. A comparison of the gamma-ray emission from these galaxies will give unique insight into cosmic-ray energetics and propagation.

3.3.4 Big Bang Nucleosynthesis

R. Cyburt, Fields, & Olive (2000) completed a systematic study of theoretical uncertainties in big bang nucleosynthesis (BBN). Error studies such as this are now essential as the data on the cosmic microwave background drives cosmology to a new level of precision. Cyburt *et al.* quantified the theoretical *error budget* by (1) systematically calculating the uncertainties in the nuclear reaction data and (2) propagating these through the nucleosynthesis calculation of the primordial light element abundances. They found that the BBN uncertainties are significantly smaller than those using older reaction rate complications; the new results serve as a benchmark for future work.

3.4 Cosmology

3.4.1 Structure Formation

J. J. Mohr and R. Srinivasan have been using Chandra X-ray observations of the nearby galaxy cluster Abell 1644 and are awaiting Chandra observations of the clusters Abell 2319 and Abell 399 to study the effects of merging on the intracluster medium (ICM). Two specific issues are of particular interest. First, they are using the Chandra constraints on the ICM distribution in combination with weak lensing mass maps to study the extent to which the ICM is depleted from a subcluster during a major merger. In A1644 they have detected three mass clumps with weak lensing, but only two of them are X-ray bright. This is a direct indication of the collisionless nature of dark matter (and galaxies) versus the collisional nature of the ICM, and as such it is an important constraint on alternative models of gravity, which require no dark matter component. Second, they have detected a contact discontinuity between a cold, merging subcluster and the hot ICM of the primary cluster near the very core of the primary cluster. They are working to study the energy deposition of this merger in the core region of the main cluster; this source of energy may help explain the absence of cool ($<$ 0.5keV) gas in the cores of clusters, which should be experiencing a radiative cooling instability.

Mohr and D. Nagai are analyzing the structure of the intracluster medium (ICM) in the galaxy cluster Abell 1795. They have constructed single and multi-phase models of the ICM, where in multiphase models the ICM consists of a distribution of densities in pressure equilibrium at any given location in the cluster. This multiphase medium has dramatic effects on the X-ray emission and the Sunyaev-Zel'dovich effect signatures of the cluster. They show that in Abell 1795, a simple, single phase model along with the dark matter potential expected from recent numerical simulations provides an excellent description of the ICM. Strong multi-phase models are ruled out by present data.

3.4.2 Cosmology and Galaxy Cluster Surveys

Z. Haiman, Mohr and G. P. Holder continue to investigate the cosmological power of galaxy cluster surveys. They have demonstrated that large surveys, which yield thousands of clusters, provide constraints on cosmological parameters that are comparable to those available from cosmic microwave background anisotropies.

Mohr, B. O'Shea and A. E. Evrard are analyzing the importance of preheating through galaxy formation on the interpretation of the galaxy cluster surveys. Galaxy cluster surveys provide a method of making high precision measurements of the cosmological density parameter, the cosmological constant or dark energy, and the equation of state of this dark energy; however, successful interpretation of these surveys requires an understanding of the effects of non-gravitational effects such as preheating.

Mohr and Y. T. Lin are investigating the cosmological significance of the 1cm BIMA deep field observations carried out by the Carlstrom-Joy Sunyaev-Zel'dovich Effect (SZE) imaging team. SZE surveys are sensitive to galaxy clusters out to very high redshift, so the absence of detections in the BIMA survey allows us to rule out models with low cosmological density parameter or high-density fluctuations. This BIMA deep field analysis serves as a testbed for analyses of the higher sensitivity SZE surveys, which will be possible with the recently funded Sunyaev-Zel'dovich Effect Array (SZA).

Mohr is co-investigator on the recently funded Sunyaev-Zel'dovich effect Array (SZA: PI Carlstrom), which is an interferometer that is being built to carry out a high sensitivity survey for galaxy clusters through the effects those clusters have on the cosmic microwave background. Mohr is working to develop algorithms for source detection and characterization in the upcoming interferometric survey. This array will eventually be part of CARMA.

3.5 Theoretical Astrophysics and General Relativity

C. Gammie continued work on the theory of black hole accretion flows, star formation, and planet formation. With graduate student J. McKinney, Gammie developed two dimensional (axisymmetric) and three-dimensional nonrelativistic MHD models of black hole accretion in a pseudo-Newtonian potential. With McKinney and collaborator G. Toth (Eotvos U., Budapest), Gammie developed, tested, and parallelized a fully general relativistic MHD code. These computations were carried out on Gammie's Beowulf cluster and on the O2000 and linux cluster at NCSA. Gammie, with J. Goodman (Princeton) and physics graduate student E. Engelhard, continued work on the evolution of circumstellar disks. Engelhard and Gammie developed and are continuing to improve a numerical scheme for evolving phenomenological disk models. Gammie also continued his collaboration with E. Ostriker and J. Stone (UMCP), and graduate student Y.-T. Lin, on numerical models of star-forming molecular clouds.

S. L. Shapiro tackled a number of problems in theoretical astrophysics and general relativity theory. This work ranged over a wide variety of topics, but much of the effort was focused on gravitation physics, both Newtonian and relativistic. Some of the themes included the inspiral and coalescence of binary neutron stars and black holes and the associated generation of gravitational waves, the fallback of matter onto a black hole following a supernova explosion, and the effect of general relativity on the stability of a rapidly rotating neutron star against the formation of bars and r-modes. Shapiro has also studied the origin of supermassive black holes observed in dozens of nearby galaxies and believed to be the source of energy in quasars and AGNs. Some of the problems were treated analytically, others by means of large scale computations. Important advances were achieved this past year, including the advance (with Adjunct Professor T. Baumgarte) of a new code to solve Einstein's field equations of general relativity, which appears to be stable for many dynamical timescales; the demonstration that differential rotation can support ‘‘hypermassive’’ neutron stars with significantly more rest mass than nonrotating or uniformly rotating stars (with T. Baumgarte and Visiting Research Professor M. Shibata); and the calculation of the gravitational waveform from neutron star binary inspiral in the quasi-equilibrium approximation (with graduate student M. Duez and Baumgarte). Also, a recent calculation (with former research associates S. Balberg and L. Zampieri) of the accretion luminosity from a black hole in SN 1997D and 1999eu suggests that proof or disproof of the presence of a central black hole in such a supernova remnant might be decided by direct observations by HST.

Shapiro trains and supervises, together with Professor 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 Acronynms’’ 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 and as Shapley Lecturer for the American Astronomical Society. J. Dickel is a Shapley Lecturer for the AAS.

J. Kaler continues his work in public education. The ‘‘Little Book of Stars’’ was published by Copernicus Books (Springer NY) last fall, and ‘‘Extreme Stars: At the Edge of Creation’’ was published this past summer (Cambridge University Press, 2001). Two other books on stellar astronomy are in development, and various encyclopedia articles were either published or are awaiting publication. He has also written on astronomical topics for ‘‘Astronomy,’’ ‘‘Sky and Telescope,’’ and ‘‘Mercury.’’ Kaler 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’’). Both sites have won several awards. He also lectured extensively to both the public and to professional societies, the latter including the Great Lakes Planetarium Association, the Mid-Atlantic Planetarium Society, and the Southwest Planetarium Society.

On April 21, 2001, Snyder gave an invited talk to the 76th Annual Meeting of the West Virginia Academy of Science at West Liberty State College.

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