

University of Illinois
Department of Astronomy
Urbana, Illinois 61801

[S0002-7537(90)02501-X]

This report covers activities of the department for the period 1 September 1998 - 31 August 1999.

1. PERSONNEL

During this report year the scientific staff consisted of the faculty: Thomas Baumgarte, You-Hua Chu, Joanne Cohn, Richard M. Crutcher (Chair), Helène R. Dickel, John R. Dickel, Brian Fields, Charles Gammie (started in January 1999 in a joint appointment with the physics department), Icko Iben, Jr., James B. Kaler, Fred K. Lamb, Susan A. Lamb, Kwok-Yung Lo, Peter McCullough, Margaret Meixner, Dimitri Mihalas, Telemachos Ch. Mouschovias, Michael L. Norman, Edward C. Olson (emeritus), Sidney Rosen (emeritus), Stuart Shapiro, Larry L. Smarr, Lewis E. Snyder, Edmund C. Sutton, George W. Swenson (emeritus), Doug Swesty, Laird A. Thompson, William D. Watson, Ronald F. Webbink, Martin White, John A. Williams (visiting), Kenneth M. Yoss (emeritus); postdoctoral research associates: Jerry Acord, Alan Calder, Jose Miguel Girart, Robert Gruendl, Martin Guerrero, Damien Guillaume, Sungeun Kim, Raymond Plante, Ramprasad Rao, Doug Roberts, Angela Speck, Scott Teare (resident at Mt. Wilson Observatory with UnISIS project), Rosa Williams; and technical support staff: Richard Castle, Grant Miller, Rami Dass, and Harold Ravlin.

Research in theoretical astrophysics and related areas was also carried out by members of the physics department: G. Baym, E. A. Jackson, D. Pines, and D. G. Ravenhall (emeritus), and staff of NCSA: Ed Sidell. The department hosted visits during the reporting year from Adeline Caulet (France), Alexei Kritsuk (St. Petersburg State University-Russia), and Chun-Chuan Pei (Purple Mountain Observatory). Twenty graduate students were enrolled during the 1998-99 academic year. Office support staff included Willa Hollis, Sandie Osterbur, and Deana Pettigrew under the guidance of the Administrative Assistant, Carol Stickrod.

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 through a national peer review allocation mechanism. The facilities include a 512 processor Thinking Machines CM-5 massively parallel computer, a 190 processor Silicon Graphics Power Challenge Array, and a 64 processor Convex Exemplar 1600.

2.2 Laboratory for Astronomical Imaging

The Laboratory for Astronomical Imaging (LAI) is a unit within the Astronomy Department through which the Uni-

versity of Illinois participates in the Berkeley-Illinois-Maryland Association (BIMA) Array consortium. Faculty personnel associated with the LAI are L. E. Snyder (director), R. M. Crutcher, H. Dickel, K.-Y. Lo (on leave as Director, ASIAA, Taipei), M. Meixner, and E. C. Sutton. Visiting Professor C. C. Pei returned to Purple Mountain Observatory. D. M. Mehringer has joined the LAI to develop new array software for the MMA Development Consortium (MDC). The LAI postdoctoral research associates during this period were J. Acord, J. M. Girart, and R. Rao. Graduate students during this period were D. Fong, D. Friedel, S.-P. Lai, S.-Y. Liu, M. Lenigan, A. Meyertholen, R. Rao, and A. Remijan. The LAI administrative secretary is D. Pettigrew. The current BIMA Array scheduler is E. C. Sutton. 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/call_for_proposals.html, <http://www.astro.uiuc.edu/~bima/proposal/WhatsNew.html>, and <http://www.astro.uiuc.edu/~bima/proposal/instructions.html>.

2.3 Mt. Laguna Observatory

The UI Astronomy Department operates a 1-m telescope at Mt. Laguna Observatory jointly with San Diego State University. Operations during the past year were routine with little change in the instrumentation. Continuing in successful operation are (1) a 2048x2048 Loral CCD camera and (2) a 256x256 NICMOS-3 array camera, both of which continue to provide excellent wide-field imaging capabilities especially with the $f/7.6$ telescope secondary.

2.4 Optical Instrumentation

Progress continued 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, research associate (resident at Mt. Wilson Observatory).

The projection of the 351 nm Rayleigh laser guide star has now become 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 subsystem 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. All steps of the full calibration procedure were demonstrated on the optics table in which laser guide star wave front data are captured while the system operated in closed-loop on a natural guide star. Two

artificial stars (one for the laser guide star and the second for the natural calibration star) are incorporated into UnISIS. Co-alignment of UnISIS with the 100-inch telescope Coude optics train was successfully completed, as was the installation of a field acquisition camera. Full operation of UnISIS is anticipated soon.

2.5 Infrared Instrumentation

M. Meixner is the PI for the Near-InfraRed Imager (NIRIM) camera (0.76-2.5 μm) on the Mt. Laguna 1 m telescope has been operating since July 1995. NIRIM features a 256×256 NICMOS3 array made by Rockwell, three plate scales (0.5, 1 and 2" per pixel) and 13 filters including broadband (I,J,H,K, and K') and narrow-band filters (H_2 , HeI, Cl, FeII, Br γ and CO). Probably the most unique aspect of the camera is its wide field of view, which at maximum is 8' .5 (2" per pixel). NIRIM has been used for a number of projects: photometry of proto-planetary nebulae, emission line imaging of photodissociation regions and Wolf-Rayet bubbles, broad band imaging of starburst galaxies.

3. RESEARCH

3.1 Stars

3.1.1 Binary Stars

E. Olson and P. Etzel (San Diego State) continued their investigation of accretion disks in long-period Algols, including multi-color photometric and radial velocity solutions. Binary properties are needed to study disk $\text{H}\alpha$ emission, and $\text{H}\beta$ and O I $\lambda 7774$ line absorption. A new velocity curve of the RX Geminorum cool loser was obtained with the re-furbished Cassegrain spectrograph on the 1-m Mount Laguna Observatory reflector. This binary is one of several that have shown significant light-curve changes in the 20th century. Examination of $\text{H}\alpha$ emission wavelengths in RX Gem as a function of orbital phase showed velocity perturbations likely due to stream impact on the accretion disk. Several years ago, large nearly chaotic variations were found $\text{H}\alpha$ emission. On re-examining roughly 300 spectra in nine long-period Algols, Olson found that of 22 sudden emission increases, 20 occurred in the stream impact region of disks. That is, $\text{H}\alpha$ brightenings are likely produced by mass-transfer bursts. Thus, both long- and some short-period Algols share that property.

Z. Han (Yunnan Observatory and University of Cambridge) and Webbink have re-examined energy constraints on the extent of systemic mass loss in interacting double white dwarfs. They show that super-Eddington mass loss tends to stabilize mass transfer, but that the binding energy which must be supplied from the radiation field severely limits the fraction of the mass transfer stream which can be ejected in this fashion. In particular, strongly super-Eddington accretion flows cannot be stemmed by radiation outflows, as assumed in models of the accreting white dwarf which purport to show that white dwarf mergers invariably lead to core collapse, rather than to type Ia supernovae.

In collaboration with D. T. Wickramasinghe (Astrophysical Theory Centre, Australian National University), Webbink

continues to explore transient and secular effects in the evolution of cataclysmic variables. Braking rates have been calculated for aligned double dipole (white dwarf plus donor star) models of magnetic cataclysmic variables, and will be applied to secular evolutionary models to determine how the suppression of braking by closure of the coupled field influences the width of the famous period gap seen in cataclysmic variables. This is a promising mechanism for explaining the surfeit of AM Her-type magnetic CVs within this gap. Work also continues on building realistic models of illumination effects on the donor stars of CVs by their hot white dwarf companions and their accretion disks. This model has been elaborated to account for shielding of the inner Lagrangian point by the accretion disk, and energy losses by the heated atmosphere of the donor as it flows toward that point.

3.1.2 Stellar Mass Loss

M. Meixner, graduate student, T. Ueta, and M. Bobrowsky (Orbital Sciences Corp.) have compiled the largest optical imaging survey of 27 proto-planetary nebulae using the HST WFPC2 camera and the paper on these results has been accepted for publication in the ApJ. Optical reflection nebulosities, which trace the scattered light from the star, were found in 21 objects. All of the nebulosities had an axial symmetry and they concluded that proto-planetary nebulae were inherently axially symmetric. In addition, they found two distinct types of reflection nebulosity which they called Star-Obvious Low-level-Elongated (SOLE) and DUSt-Prominent Longitudinally-EXTended (DUPLEX) proto-planetary nebulae. Comparison of spectral energy distributions, infrared colors, and mid-IR images shows that SOLE and DUPLEX nebulae differ in more than just their optical images. They suggest that SOLE and DUPLEX proto-planetary nebulae are physically different types and may be pre-cursors to the elliptical and bipolar planetary nebula morphologies. This work builds on the large mid-IR imaging survey published by Meixner *et al.* (1999) in ApJ Suppl.

Meixner and graduate student, D. Fong, E. Sutton, W. Welch (Berkeley) are pursuing a large BIMA CO imaging project of 9 evolved stars in order to study the mass loss history and evolution of the molecular circumstellar envelopes. Preliminary analysis of four objects shows that the three proto-planetary nebulae have an axisymmetric structure in CO similar to what is observed in optical reflection nebulosity. The fourth, a planetary nebula, shows an absence of CO at the center caused by the photodissociation of the molecular gas. Future work on this BIMA project will involve detailed modelling in collaboration with K. Justtanont (Stockholm Observatory).

Fong, Meixner, Sutton, V. Bujarrabal (Observatorio Astronomico Nacional), A. Castro-Carrizo (Observatorio Astronomico Nacional), M. Barlow (Univ. College London), A. Tielens (Kapetyn Astronomical Inst.) are using ISO to study the atomic line emission ([CII] 158 μm , [OI] 63 and 146 μm , [SiII] 35 μm , [FeII] 26 μm) from these 9 evolved stars. They find that atomic gas does not appear until the planetary nebulae stage suggesting that photodissociation as opposed to shocks is a more important modifying force in the evolution of the circumstellar envelope. Combining the atomic and

molecular emission studies, Fong *et al.* will be able to trace the evolution of atomic to molecular mass ratios in these nebulae. It is expected that this ratio will increase as the star evolves from the asymptotic giant branch to planetary nebulae phases because the hardening of the stellar radiation field will photo-dissociate the molecular envelope.

3.2 Diffuse Matter

3.2.1 Cosmic Rays

B. Fields and K. Olive (Minnesota) have developed a model for the nucleosynthesis and evolution of lithium, beryllium and boron in the Galaxy, obtaining results which shed new light on the origin of Galactic cosmic rays, primordial nucleosynthesis, as well as stellar evolution. In the past decade, Be and B abundance trends in halo stars have been interpreted as inconsistent with the standard picture of Li, Be, and B nucleosynthesis by Galactic cosmic rays. However, Fields and Olive (1999a) challenged the view that standard cosmic ray nucleosynthesis fails. They performed a consistent compilation of the Be and B observations, and compared this to expected trends in chemical evolution models. They showed that the data may be explained by nucleosynthesis due to standard cosmic rays and supernova neutrinos only, with no need for additional or unconventional cosmic ray components. An important test of this model is the boron isotope ratio in halo stars. L. Rebull, D. Duncan (Chicago), S. Johansson (Lund, Sweden), J. Thorburn (Yerkes) and Fields (1998) used the HST GHRS to make the first search for boron isotope splitting in HD 76932. The results were inconclusive due to possible blending effects, but future observations can address this issue and yield the first stellar boron isotope data.

Fields and Olive (1999b) applied their nucleosynthesis model to showed that their scenario provides them a natural explanation of ${}^6\text{Li}$ data in halo stars. This model implies that there has been minimal *in situ* stellar depletion of this fragile element, a result that has an impact on stellar evolution. This further provides evidence that the ${}^7\text{Li}$ abundance in these stars has been essentially undepleted from its original, mostly primordial level.

3.2.2 Photodissociation Regions (PDR)

R. Young Owl, Meixner, M. Haas (NASA Ames), Tielens (Kapetyn Astronomical Inst.) and A. Rudolph (Harvey Mudd College) have used spectra of the [OI] $63\mu\text{m}$ and [CII] $158\mu\text{m}$ lines taken aboard the KAO to study the energetics in nine low excitation photodissociation regions found in reflection nebulae. They have derived estimates of the physical conditions in each source. They found that the CII/OI line ratio decreased with increasing far ultra-violet intensity and that the color temperature of the star showed no noticeable trend in the heating efficiencies, consistent with theoretical expectations. A detailed look at NGC 1977, the best-studied source, showed that it is not purely edge-on. Results are published in Young Owl's thesis and a paper is in preparation for the ApJ.

3.2.3 Planetary Nebulae

Y.-H. Chu, M. Guerrero, and R. Gruendl continue to study X-ray emission from planetary nebulae, using both archival and proprietary ROSAT X-ray observations. They have been awarded AXAF time to study the Helix Nebula and NGC 6543.

3.2.4 Supernova Remnants

J. Dickel with D. Milne (ATNF), B. Gaensler (MIT), A. Green (U. yd), R. Strom (NFRA), D. Bock (UCB), M. Wright (UCB), and B. Stappers (U.Amsterdam) are investigating several extended SNRs with Crab-like components to characterize their magnetic fields and any relation to pulsar stimulation. J. Dickel and J. Lazendic (U. yd) have also made the first detection of radio polarization in N157B, a Crab-like remnant in the Large Magellanic Cloud.

Graduate student R. Klinger is modeling thermal conduction in hot plasmas to apply to the heating of mixed-morphology SNRs with centrally filled thermal x-ray emission but radio synchrotron shells. He and J. Dickel are also analyzing radio data from N206, an example of this class of object in the Large Magellanic Cloud.

B. Dunne, R. Gruendl, and Y.-H. Chu have studied the ultraluminous supernova remnant MF16 in NGC 6946, using archival HST WFPC2 images and proprietary KPNO 4-m echelle spectra. They find that the kinetic energy of this remnant requires only a normal supernova explosion. They also find that the [N II] lines are particularly strong, indicating that the pre-shocked material may be nitrogen-rich and that the progenitor of the supernova might be a WR star or a luminous blue variable. The high luminosity of this supernova remnant is caused by its expansion into a dense circumstellar bubble. The results have been reported in a paper submitted to the AJ.

Y.-H. Chu, S.-P. Lai, and C.-H. Chen have obtained HST WFPC2 images and KPNO 4-m echelle spectra of the two hypernova remnants, MF83 and NGC 5471B in M101. These data have been analyzed to determine the size, luminosity, kinetic energy, and explosion energy of each remnant. The HST continuum images of MF83 reveal a group of stars at its center, suggesting that MF83 is a superbubble with interior supernova remnants. Only NGC 5471B might be produced by a single powerful supernova explosion. These results have been reported in meeting proceedings.

S. Y. Kim, M.-M. Mac Low (American Museum of Natural History) and Y.-H. Chu have modeled the structure and evolution of a hypernova remnant in a stratified interstellar medium, in order to determine the conditions for blow-out to occur. The models have been presented in an AAS meeting, and will be reported in a journal paper.

Y.-H. Chu, A. Caulet, M.J. Montes (NRL), and collaborators analyzed a high-dispersion spectrum of SN1978K. The spectrum resolved the $H\alpha$ and [N II] lines into a broad component and a narrow component, corresponding to the supernova ejecta and ambient medium, respectively. The narrow component has a high [N II]/ $H\alpha$ ratio, suggesting a high nitrogen abundance in the surrounding medium. The high nitrogen abundance implies that it is stellar material ejected by the progenitor, possibly a luminous blue variable. The

analysis and results have been published in a Letter of the *Astrophysical Journal*.

Y.-H. Chu, S. Van Dyk (IPAC), and R. A. Gruendl have obtained high-dispersion spectra for a number of young supernovae at distances up to 30 Mpc to study their ambient interstellar environments and to search for circumstellar nebulae. No new circumstellar nebula similar to the one around SN1978K is found. The narrow velocity components are used to determine whether the supernovae were in HII regions or superbubbles. Preliminary results have been reported in an AAS meeting.

3.2.5 Interstellar Medium

J. Lazendic (U. yd) and J. Dickel are investigating the radio spectrum of the giant H II region 30 Doradus. They find no convincing deviations from a thermal spectrum throughout the object but faint SNRS could well be masked by the strong thermal emission.

Gammie has developed a quasi-analytic model for magnetized inflow from an accretion disk onto rotating black hole. The model is fully relativistic, and demonstrates that under realistic astrophysical circumstances the efficiency of thin disks can be significantly different from the classical value. The model also shows that, in the presence of a sufficiently strong magnetic field, energy can be extracted from a rapidly rotating hole.

Gammie, with J. Goodman (Princeton), and G. Ogilvie (MPA-Garching), studied the stability of warping modes in unmagnetized Keplerian disks. Warps are now of particular theoretical interest given the direct detection of a warped disk in NGC4258 and the discovery of an instability that plausibly causes warps in disks. Warps were found to be subject to a parametric instability. Three dimensional numerical models showed that this instability leads to decay of in-plane motions associated with warps in Keplerian disks.

Gammie, with E. Ostriker (UMCP) and J. Stone (UMCP), continued their efforts to investigate the structure of the cold interstellar medium using direct numerical simulations in two and three dimensions. The purpose of this work is to probe the dynamics and energetics of turbulence in molecular clouds and to understand the initial conditions for star formation. Gammie has been focusing on the statistical properties of clumps, including the distribution of clump shapes, masses, and magnetic field strengths. In related work, Gammie, with P. Myers (CfA), investigated a simple analytic model for generation of size-linewidth relations in the cores of molecular clouds.

Gammie, with undergraduate K. Obenschain and physics graduate student J. McKinney, is also assembling a small cluster of computers ('beowulf'). This cluster will serve as a workbench for developing parallel algorithms and provide computing cycles for Gammie's work in computational astrophysics.

Peter R. McCullough and his colleagues Gaustad, Van Buren, and Rosing have completed their first set of southern-sky H α images from Cerro Tololo Inter-American Observatory. A second set of images, each offset from the original images by approximately 7 degrees, is nearly complete also. Substantial additional funding has been secured for data

analysis, 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.

3.2.6 Circumstellar Nebulae

W. Brandner (IfA, Hawaii), E. Grebel (Washington), Y.-H. Chu, and S. D. Points have obtained HST WFPC2 images of the Galactic giant HII region NGC 3603. These images detected proplyds that are more than 100 times larger than those present in the Orion Nebula. The physical structure and morphology of the proplyds in NGC 3603 have been modeled and reported in a paper that has been accepted by the AJ. The circumstellar rings around the blue supergiant Sher 25 were resolved. The physical structure of the rings are being analyzed.

3.2.7 Astrochemistry

S.-Y. Liu and L. E. Snyder studied the Sgr B2 region with the BIMA Array at sub-arcsecond resolution (Liu & Snyder 1999, ApJ, in press for Oct. 1). The 3 mm continuum, vinyl cyanide (C₂H₃CN), and ethyl cyanide (C₂H₅CN) line emission were detected. These observations have the highest angular resolution ever reported for C₂H₃CN and C₂H₅CN. With 0.8'' resolution, it is possible to probe physical scales only Oort cloud.

C. C. Pei, Liu, and Snyder conducted the first astronomical measurements of the $J_k = 18_2 - 18_1, 19_2 - 19_1,$ and $20_2 - 20_1$ E transitions of methanol (CH₃OH) toward the Sgr B2(N) region (Pei, Liu, & Snyder 1999, ApJ, in press) A rotational temperature $T_{rot} = 170(13)$ K was determined for the Sgr B2(N-LMH) core. The total column density of CH₃OH is $N_T(\text{CH}_3\text{OH}) = 4.2(6) \times 10^{17} \text{ cm}^{-2}$, and the fractional abundance of CH₃OH is $X(\text{CH}_3\text{OH}) \approx 4 \times 10^{-8}$. The H59 α recombination line and a new unidentified line were detected.

Liu, Snyder, and D. M. Mehringer completed the BIMA Array observations for a survey of HCOOH in the molecular cores W3(OH), Orion IRC2, Sgr A-A, Sgr B2, G34.3+0.2, W51 M, DR21(OH), NGC 7538 IRS9, and IRS1. The best sources were Sgr B2(N-LMH), W51, and Orion. As a follow-up to the formic acid survey, A. Remijan, Liu, and Snyder started a survey of interstellar acetic acid sources that are coincident with formic acid sources.

Snyder has been collaborating with Y.-J. Kuan (Nat'l Taiwan Normal U. & ASIAA), S. B. Charnley (NASA/Ames & UC-Berkeley), T. L. Wilson (SMTU/U. Arizona), M. Ohishi (NAO Japan), and H.-C. Huang (Nat'l Taiwan Normal U.) to test models of gas-grain alcohol chemistry (Kuan, *et al.* 1999, BAAS 31, 942). This was done by searching for diethyl ether ((C₂H₅)₂O) and methyl ethyl ether (CH₃OC₂H₅) in the cloud cores Sgr B2(N), W51 e1/e2 and Orion-KL, where alcohols have been evaporated from ice mantles. Both the NRAO 12-m and the BIMA Array were used for these searches. The 12-m detected various line transitions which closely match the two molecular species in the 1-mm, 2-mm and 3-mm regimes in all 3 molecular cloud cores. Furthermore the BIMA maps show a clear concentration of CH₃OH

and what may be $\text{CH}_3\text{OC}_2\text{H}_5$ and $(\text{C}_2\text{H}_5)_2\text{O}$ toward Sgr B2(N), as predicted by the model. The unambiguous identification of the two ether molecules hinges on further work in matching the observed astronomical rest frequencies to predictions from theoretical molecular Hamiltonian models.

The symmetric top molecule methyl cyanide (CH_3CN) has long been recognized as an important interstellar molecule for determining temperatures in molecular clouds. Y. Miao (Illinois & Lucent Tech.), Q. Zeng (PMO), and Snyder used BIMA Array observations of vibrationally excited CH_3CN emission from Sgr B2(N-LMH) to determine an excitation temperature of about 300K. Remijan, Liu, Snyder, & Pei used BIMA Array data to study CH_3CN emission from two W51 compact hot core regions, W51 e1/e2 and W51 IRS 2 (Remijan *et al.* 1999, BAAS 31, 943). They found that the cores of each region have a temperature greater than 100K and a density greater than 100 cm^{-3} , in agreement with the observations of Zhang *et al.* (1998, ApJ, 494, 636).

3.2.8 Star Formation: Observations

J. A. Williams (Albion College) and H. Dickel have completed their radiative transfer modeling of observations of the CS $J=2-1$ line with the BIMA array and higher CS observations from the literature for the W 49 A north star-forming complex. Colliding clumps do not reproduce the observed CS absorption towards the central region unless a lower density envelope is added. The global collapse model reproduces the lower transitions towards the center but the higher transitions are too weak; a second cloud around HII region A partially overcomes this deficiency. This modified global collapse model reproduces the position-velocity diagrams better than the other two models, but localized collapsing fragments give the best overall fit to the data. These results (paper 2) are being written up for publication; the observational paper (1) is in press for ApJ Suppl December 1 1999, Volume 125 #2 with preprints available at URL- <http://www.astro.uiuc.edu/departments/preprints/hdickel/>.

H. Dickel is resuming analysis of high resolution observations of H_2CO towards the star-forming region ON3 obtained with the WSRT and VLA and of high resolution recombination line data for DR21 obtained with the BIMA array.

3.2.9 Molecular Clouds

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.

Crutcher and collaborators carried out VLA Zeeman observations of H I absorption lines toward the H II region in the M17 giant molecular cloud complex. The maps showed an H I component at the same velocity ($\sim 20 \text{ km s}^{-1}$) as the southwestern molecular cloud. This component seems to originate from the edge-on interface between the H II region and M17 SW in unshocked photodissociation region gas. A steep enhancement in the 20 km s^{-1} H I column density and line-of-sight magnetic field strengths (B_{los}) were detected toward this boundary. The peak $B_{los} \sim -450 \mu\text{G}$. Crutcher and collaborators also made VLA Zeeman observa-

tions of absorption lines of H I and OH toward the molecular cloud associated with the NGC 2024 H II region. The maps of the magnetic field showed that the magnetic field comes from a line subcomponent at $v_{LSR} \approx 10.2 \text{ km s}^{-1}$ which corresponds in velocity and in spatial morphology with the northern dense molecular ridge in NGC 2024, with B_{los} varying from 0 to the northeast of the northern molecular ridge to almost $100 \mu\text{G}$ to the southwest, possibly due to the field being mainly in the plane of the sky to the northeast but having a significant line-of-sight component to the southwest.

Crutcher and collaborators also achieved the first detections of the Zeeman effect in mm-wave lines of CN, toward the Orion Molecular Cloud 1 (OMC1) and toward two cores in the DR21OH molecular cloud, and probably toward the M17SW molecular cloud. The line-of-sight magnetic field strengths inferred were $B_{los}(\text{OMC1}) = -0.36 \pm 0.08 \text{ mG}$, $B_{los}(\text{DR21OH}_1) = -0.36 \pm 0.10 \text{ mG}$, $B_{los}(\text{DR21OH}_2) = -0.71 \pm 0.12 \text{ mG}$, and $B_{los}(\text{M17SW}) = -0.33 \pm 0.14 \text{ mG}$.

Crutcher used all 27 available sensitive Zeeman measurements of magnetic field strengths in molecular clouds together with other relevant physical parameters in order to calculate input parameters to magnetic star formation theory and compare predictions of theory with observations. Results for this cloud sample were: (1) Internal motions are supersonic but approximately equal to the Alfvén speed, which suggests that supersonic motions are likely MHD waves; (2) The ratio of thermal to magnetic pressures $\beta_p \approx 0.04$, implying that magnetic fields are important in the physics of molecular clouds; (3) The mass-to-magnetic flux ratio is about twice critical, suggesting but not requiring that static magnetic fields alone are insufficient to support clouds against gravity; (4) Kinetic and magnetic energies are approximately equal, suggesting that static magnetic fields and MHD waves are roughly equally important in cloud energetics; and (5) Magnetic field strengths scale with gas densities as $|\mathbf{B}| \propto \rho^\kappa$ with $\kappa \approx 0.47$, in agreement with the prediction of ambipolar diffusion driven star formation. This study has made it clear that magnetic fields are a crucial component of the physics governing cloud evolution and star formation.

Girart, Rao, Crutcher, from 1 mm BIMA observations, detected and mapped the linearly polarized emission of the CO $J=2 \rightarrow 1$ due to the Goldreich-Kylafis effect. The polarization maps towards the NGC 1333 IRAS 4A make it possible to define the direction of the magnetic field in the outflow. We also detect and map the linearly polarized dust continuum emission. The two techniques for mapping magnetic field morphologies agree. They in general sample different column densities and together allow study of magnetic field morphology over wider areas that either alone would permit.

Using BIMA, Girart, Rao, Crutcher carried out spectropolarimetric observations of IRC +10216, to search for linear polarization emission of molecular lines that theoretical models predict to be polarized: CS, SiS or SiS. Preliminary maps show no polarized emission in any of the lines higher than a $\sim 1\%$ level.

Girart, Estalella and Beltran (Univ.Barcelona, Spain), Ho

(CfA), Anglada (IAA, Spain) continue to study the L723 region, which encompasses a quadrupolar molecular outflow. Submm dust continuum maps show a strong emission peaks around L723 VLA 2, the powering source of the east-west lobes of the quadrupolar outflow. However, the maps does not allow to identify the powering source of the other pair of lobes.

Girart, Ho, Estalella and Rudolph (Harvey Mudd College) continues to study the HCO^+ emission in star forming regions with strong molecular outflow activity. We have carried out LVG analysis of the multi-transition HCO^+ observations towards NGC 2264G. The ‘‘anomalous’’ $J=1 \rightarrow 0$ emission found seems to be due to absorption by cold, low density foreground gas in the same region.

Girart and Acord carried out BIMA observations of the SiO $J=2 \rightarrow 1$ towards L1448. The goal is to try to measure proper motions of the extremely high velocity ‘‘bullets’’ from comparing with 1990 PdB maps of the same transition at a similar angular resolution. The data has been reduced and comparison of the maps are underway.

E. Sutton, A. Sobolev (Ural State U., Ekaterinburg), S. Ellingsen (U. Tasmania), D. Mehringer, and D. Cragg (Monash U.) have been studying class II methanol masers in the molecular cloud W3(OH) using the BIMA array. They have observed three new weak maser transitions: $7(2)-6(3)\text{A}^-$, $7(2)-6(3)\text{A}^+$, and $3(1)-4(0)\text{A}^+$. In all three lines the masing region is about $0.6''$ north of the center of the W3(OH) ultra-compact HII region at $V_{LSR} = -43.1$ km/s, suggesting the lines are emitted from the same physical region. Maser emission is absent from the transitions $7(2)-8(1)\text{A}^-$ and $7(2)-8(1)\text{A}^+$, which have the same upper levels as two of the maser lines, and from the maser candidate lines $5(-1)-4(0)\text{E}$, $13(-3)-14(-2)\text{E}$, and $0(0)-1(-1)\text{E}$. The strengths of the observed maser lines, previously reported maser lines, and the various upper limits put strong constraints on the physical characteristics of the emitting region. Among other things, it appears that this region is of rather low physical density. Model calculations are capable of roughly reproducing the observed fluxes, although more detailed model calculations are needed.

Sobolev, Sutton, and I. Zinchenko (IAP, Novgorod) are also studying the spatial distribution of CS, SO, methanol, and SiO emission in the vicinity of W3(OH) and W3(H₂O). The goal of this work is to determine the morphology of the region and the impact of outflows and shocks on the overall cloud structure. The methanol emission provides strong evidence for a rotating disk around W3(H₂O). C^{34}S emission, indicative of high density, is also strong in this region, consistent with the disk hypothesis. On larger scales, the lowest energy methanol lines show the presence of large amounts of very low excitation material, particularly extending to the southwest from W3(OH). But C^{34}S is present in absorption in front of W3(OH), and C^{34}S emission is also seen extending to the southwest from W3(OH). This indicates a more complex intermingling of low- and high-excitation material throughout this region. SO, another high density tracer, is more clearly confined to W3(H₂O). SiO emission, which is thought to trace shock excitation, is weak, spatially extended, and displaced to the south of both W3(OH) and W3(H₂O).

This may be an interaction region between an outflow (presumably originating from W3(H₂O)) and ambient material to the south of W3(H₂O). Continuum emission shows the partially resolved ultra-compact HII region around W3(OH), dust emission elongated east-west in the vicinity of W3(H₂O), and some evidence for emission in a region north-east of W3(OH) near a postulated champagne flow from W3(OH).

W. McCutcheon (U. of British Columbia), G. Sandell (NRAO), H. Matthews (JAC Hilo, HI), T. Kuiper (JPL), E. Sutton, W. Danchi (UC Berkeley), and T. Sato (Kwantlen U., British Columbia) have been studying molecular line and millimeter continuum emission from the northern parts of the molecular cloud complex NGC 6334. The dominant star forming regions are NGC 6334 I and I(N). Each has associated outflow, the outflow from I being of particularly high velocity and mechanical luminosity. The source I has a chemistry which is rich in methyl-group molecules such as methanol, methyl formate, and dimethyl ether. A high degree of excitation is also present in I, with some lines originating from molecular levels 900 K above the ground state. The gas associated with I(N) appears to be denser and cooler than that associated with I. Both star forming regions are young, with I(N) being the younger of the two.

3.3 Solar System

Comet Hale-Bopp was observed successfully during its 1997 apparition in both line and continuum emission at 3 mm wavelength with the BIMA Array. L. E. Snyder and collaborators continued analyzing the data. Comet collaborators include: P. Palmer (Chicago); M. F. A'Hearn and L. M. Woodney (Maryland); M. C. H. Wright, I. de Pater, and J. R. Forster (Berkeley); Y.-J. Kuan (Taiwan) and graduate students A. Meyertholen and J. M. Veal. The cometary molecules specifically targeted for observation included HCN, HCO^+ , CS, CH_3OH and CO, but many other species had transitions which could be observed simultaneously with the target molecules. During this period, mosaiced images and spectra of HCN and HCO^+ were produced which show that the HCO^+ is extended and the HCN roughly follows a Haser model in which about 80% comes from the nucleus (Wright *et al.* 1998, AJ, 116, 3018). In addition, single-field images of CS and HCN emission were used to determine molecular photodissociation lifetimes (Snyder *et al.* 1999, BAAS 31, 848). Haser modeling of the HCN images yielded scale length values in excellent agreement with both the theoretical prediction (Huebner, Keady, & Lyon 1992, A&SS, 195, 1) and the previous mosaicked image value (Wright *et al.* 1998). On the other hand, this same method applied to CS gives a scale length which is ~ 10 times smaller than the commonly accepted value. Consequently, the CS fraction in comets is increased with respect to some earlier determinations.

3.4 Extragalactic Astronomy

3.4.1 Normal Galaxies

C.-H. Chen and Y.-H. Chu have been analyzing M101 giant HII regions NGC 5471 and NGC 5461, using HST

WFPC2 images and KPNO 4-m echelle spectra. The HST continuum images are used to study the distribution and colors of OB associations and cluster within the giant HII regions. The colors of the clusters will be modeled to determine their ages. The goals for this project are to study the star formation history in very luminous giant H II regions and to determine whether globular clusters are formed in giant H II regions.

I. Barton (Ph.D. student) made excellent progress during the year analyzing a multi-wavelength set of visual wavelength images for population synthesis in two moderately nearby spiral galaxies: NGC 4258 and NGC 5055. Very high signal-to-noise images are available for these two galaxies at the Mt. Laguna 1-m telescope in B,V, R, and ubvy colors. The aim is to analyze the stellar population changes as a function of radial distance from the galaxy nucleus in order to detect spatial variations in the galaxy mass-to-light ratios. These results are important in determining the nature of dark matter in spiral galaxies.

L. Thompson and M. Griffin (Ph.D. student) used the NICMOS-3 camera at the Mt. Laguna 1-m telescope to search for distant clusters of galaxies at near-IR wavelengths. The method seems to be a very promising extension of earlier work at visual wavelengths by Dalcanton (ApJ, 466, 92, 1996).

D. Goscha (M.S. student) built a website which contains several Mbytes of galaxy catalog data. The data itself was produced in its original form by L. Thompson and S. Gregory (University of New Mexico). While galaxy luminosity functions were derived by Thompson and Gregory from these data when they were first collected, the catalog data itself was never been published. The website provides finder charts as well as lists of galaxy position, morphology, ellipticity, magnitude, etc. Clusters in the catalog include A1656 (Coma), A2147 and A2151 (Hercules), A2197 and A2199 and several others. The website is built around the language PERL to provide a convenient means for on-line catalog search.

Fields and K. Olive (Minnesota) studied the chemical evolution of helium and metals in dwarf irregular galaxies, via data analysis and theoretical models. While supernova-driven outflow models can qualitative reproduce the observed trends, the models cannot reproduce the helium evolution quantitatively.

Fields (1999) compared the emerging cosmic star formation rate with the star formation history in the solar neighborhood. Using the local stellar luminosity function, he showed that at least one of the three simple and apparently reasonable assumptions must be false: (1) the initial mass function is time-independent, (2) the initial mass function has a smooth shape, and (3) the local star formation rate is representative of the cosmic mean.

3.4.2 Large Magellanic Clouds

Chu and Wakker (U. Wisconsin) continue their Long Term Space Astrophysics program to investigate the physical structure and evolution of the interstellar medium (ISM), using the Large Magellanic Cloud (LMC) as an astrophysical laboratory. Specifically, they study the different phases of

the ISM and their relationship with the underlying population of massive stars. They have been using X-ray data taken with the ROSAT and ASCA satellites to map and analyze the 10^6 K ionized gas, UV data taken by the HST STIS and to be taken by the FUSE satellite to analyze the 10^5 K ionized gas, and optical data taken with the CTIO telescopes to study the 10^4 K ionized gas structures and their stellar content. The interstellar structures they study include interstellar bubbles around single massive stars, supernova remnants (SNRs), superbubbles around OB associations, HII complexes, the giant HII region 30 Doradus, supergiant shells, and large-scale structures.

Y.-H. Chu, C.-H. Chen, *et al.* are using the HST WFPC2 images of LMC HII regions to search for small wind-blown bubbles in young HII regions, and SNR shocks in X-ray bright superbubbles. Six HII regions are included in this program: N11B, N30, N44, N51D, N63, and N180. No wind-blown bubbles are found in young HII regions. This can be explained if the interstellar medium is cloudy, and the evaporation of the cloudlets in a bubble interior quickly fills up the central cavity.

R. Williams, Y.-H. Chu, J. Dickel, D. Milne (ATNF), Sungeun Kim and other colleagues continue their multi-wavelength studies of the SNRs in the Magellanic Clouds. They have completed an X-ray atlas of LMC SNRs, using archival ROSAT HRI and PSPC data. They are also using archival ROSAT PSPC data to determine the plasma temperature and thermal energy of all LMC SNRs.

S. Kim is analyzing the distribution and physical structure of H I in the LMC, using the ATCA mosaic survey. She is cataloging the shell structures and determining their formation mechanisms. She is also examining the H I structure around OB associations in order to study how massive stars interact with the interstellar medium.

S. D. Points, Y.-H. Chu, and S. L. Snowden (NASA/GSFC) are examining the physical condition of the 10^6 K gas interior to the supergiant shell LMC 2. They have obtained ROSAT PSPC and HRI mosaics of LMC 2 to examine the distribution of hot gas and ROSAT PSPC and ASCA SIS spectra to study the physical conditions of the hot gas. The analysis has been completed and is being written up in a paper to be submitted soon.

S. D. Points, Y.-H. Chu, and S. L. Snowden (NASA/GSFC) are identifying and cataloging diffuse X-ray sources in the LMC, using the mosaic of ROSAT PSPC pointed observations. Preliminary results have been presented in an AAS meeting.

Y.-H. Chu, S. L. Snowden (GSFC/NASA), *et al.* have carried out a ROSAT HRI survey of the LMC and the SMC. The observations have been mosaicked together to illustrate the large-scale diffuse X-ray emission. These observations are also suitable for a survey of discrete and point X-ray sources. These data are being analyzed.

R. C. Smith (CTIO), Y.-H. Chu, *et al.* are continuing an emission line survey of the Magellanic Clouds using the Curtis Schmidt Telescope and a CCD camera at CTIO. These images show the warm ionized gas, which can be compared with the hot ionized gas shown in X-ray images. This com-

parison allows us to examine the multi-phase structure of the ISM.

3.5 Astronomical Nomenclature

H. Dickel continues as Chair of the Task Group on Designations of the IAU Commission 5. The TG has organized an electronic FORUM on Designations of Stellar Companions (including extrasolar planets) <http://aries.usno.navy.mil/ad/wds/iaujd.html>. Currently there are 25 members involved from 10 different commissions and 10 different countries. The goal is to find possible solutions to the problem of designating stellar companions which will then be presented at a multi-commission meeting which is being organized for the IAU General Assembly in Manchester in August 2000. To participate in the Forum contact H. Dickel at hdickel@nfra.nl.

3.6 New Instruments

J. Dickel has participated in several meetings on the Square Kilometer Array and was a contributor to the Science Case, edited by R. Braun (NFRA) and A. R Taylor (U. Calgary), for this vital new radio telescope.

4. PUBLIC SERVICE AND EDUCATION

H. Dickel and J. Dickel continued to serve as Harlow Shapley lecturers for the AAS and as regional lecturers for Sigma Xi. They also are "Faculty Friends" to students of Snyder Residence Hall on campus. H. Dickel continues to be a Tour Speaker for the American Chemical Society.

J. B. Kaler continues his work in public education. He is in the process of writing four books on different aspects of stellar astronomy, and wrote articles for encyclopedias, magazines, and books. 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>). Both sites have won several awards. With B. Balick, Kaler produced a captioned slide set on planetary nebulae for the Astronomical Society of the Pacific. He continues to lecture extensively to both the public and to professional societies.

George Swenson and colleagues A. Richard Thompson (NRAO) and James M. Moran (CfA) have completed the manuscript for the second edition of INTERFEROMETRY AND SYNTHESIS IN RADIO ASTRONOMY (John Wiley & Sons).

PUBLICATIONS

Bobrowsky, M., Meixner, M., Axon, D., Hines, D. C., and Skinner, C. J. 1998, "Imaging and Polarimetry of the Nebula around IRC+10216," AAS Meeting 193, abstract #69.15

Brogan, C. L., Troland, T. H., Roberts, D. A., and Crutcher, R. M. 1999, "Detection of Magnetic Fields toward M17 through the H I Zeeman Effect," *ApJ*, 515, 304

Cassisi, S., Iben, I. Jr., and Tornambé, A. 1998, "Hydrogen Accreting Carbon-Oxygen White Dwarfs," *ApJ*, 496, 376

Chu, Y.-H. 1999, "Hot Gas in the Large Magellanic Cloud," in *The Magellanic Clouds and Other Dwarf Galaxies*, eds. T. Richtler and J.M. Braun, 11-24

Chu, Y.-H., Caulet, A., Montes, M. J., Panagia, N., Van Dyk, S. D., and Weiler, K. W. 1999, "Detection of Pre-Shock Dense Circumstellar Material of SN 1978K," *ApJ*, 512, L51-54

Chu, Y.-H., Weis, K., and Garnett, D. R. 1999, "Physical Structure of Small Wolf-Rayet Ring Nebulae," *AJ*, 117, 1433-1440

Crutcher, R. M. 1999, "Magnetic Fields in Molecular Clouds: Observations Confront Theory," *ApJ*, 520, 706

Crutcher, R. M., Roberts, D. A., Troland, T. H. and Goss, W. M. 1999, "The Magnetic Field of the NGC 2024 Molecular Cloud," *ApJ*, 515, 275

Crutcher, R. M., Troland, T. H., Lazareff, B., Paubert, G. and Kazès, I. 1999, "Detection of the CN Zeeman Effect in Molecular Clouds," *ApJ*, 514, L121

Dickel, J. and Carter, L. 1999, "The Possible Relation Between the SNR RCW103 and the PSR AXS J161730-505505," *The Relation Between Neutron Stars and Supernova Remnants*, ed. by R. Bandiera *et al.*, *Memorie della Societa Astronomica Italiana*, 69, 845

Fields, B. D. 1999, "Testing the Relation Between the Local and Cosmic Star Formation Histories," *ApJ*, 515, 603

Fields, B. D., and Olive, K. A. 1998, "On the Evolution of Helium in Blue Compact Galaxies," *ApJ*, 506, 177

Fields, B. D., and Olive, K. A. 1999a, "The Revival of Galactic Cosmic-Ray Nucleosynthesis?," *ApJ*, 516, 797

Fields, B. D., and Olive, K. A. 1999b, "The Evolution of ${}^6\text{Li}$ in Standard Cosmic-ray Nucleosynthesis," *New Astronomy*, 4, 255

Fong, D., Meixner, M., Sutton, E., Bujarrabal, V., Kelly, D., Haas, M., Barlow, M., Glassgold, A., Nguyen-Rieu, Q., Skinner, C. J., and Tielens, X. 1998, "Observations of Atomic Gas in Post-AGB Envelopes," in *Asymptotic Giant Branch Stars*, IAU Symposium 191 Poster Session held in Montpellier, France, 505

Fujimoto, M. Y., Aikawa, M., and Iben, I. Jr. 1999, "The Evolution of Metal-Deficient Stars And the Search for Population III Stars," in *The Third Stromlo Symposium: The Galactic Halo*, eds. B. K. Gibson, T. S. Axelrod, and M. E. Putman (San Francisco: ASP Series), 466

Gammie, C. F. 1999, "Instabilities in Circumstellar Discs," in *Astrophysical Discs*, ed. J. Sellwood and J. Goodman, (San Francisco: ASP), 122

Gammie, C. F. 1999, "Accretion Disk Turbulence," in *Interstellar Turbulence*, ed. J. Franco and A. Carraminana, (Cambridge: Cambridge), 277

Gammie, C. F. 1999, "Efficiency of Magnetized Thin Accretion Disks in the Kerr Metric," *ApJL*, 522, L57-60

Gammie, C. F., Narayan, R., and Blandford, R. 1999, "What is the Accretion Rate in NGC 4258?" *ApJ*, 516, 177-186

Garnett, D. R., Walsh, J. R., Chu, Y.-H., and Lasker, B. M. 1999, "Bok Globules in the LMC," *AJ*, 117, 1285-1291

Girart, J. M., Ho, P. T. P., Rudolph, A., Estalella, R., Wilner, D., and Chernin, L. M. 1999, "The HCO⁺ Molecular Outflow in NGC 2071," *ApJ*, 522, 921

Iben, I. Jr. 1998, "On the Evolution of AGB Stars which

- Develop Electron-Degenerate ONe Cores,” in *Modern Problems of Stellar Evolution*, ed. D. S. Wiebe (Moscow: Geos), 52
- Iben, I. Jr. 1999, “Asymptotic Giant Branch Stars: A Theoretical Retrospective,” in *IAU Symposium 191: Asymptotic Giant Branch Stars*, eds. T. Le Bertre, A. Lèbre, and C. Waelkens (San Francisco: ASP), 591
- Iben, I. Jr. 1999, “The Effects of Possible Binary and Tertiary Companions on the Behavior of Eta Carinae,” in *Eta Carinae at the Millennium*, eds. J. Morse, R. Humphreys, and A. Damineli (San Francisco: ASP), 367
- Iben, I. Jr. and Tutukov, A. V. 1998, “Comment on ‘Intrinsic Kicks at Birth are Required to Explain the Observed Properties of Single and Binary Neutron Stars’,” *ApJ*, 501, 263
- Iben, I. Jr. and Tutukov, A. V. 1999, “On the Evolution of Close Triple Stars which Produce Type Ia Supernovae,” *ApJ*, 511, 324
- Iben, I. Jr. and Tututkov, A. V. 1999, “On the Production by Triple Stars of Binary Blue Stragglers and Cataclysmic Variables,” in *11th European Workshop on White Dwarfs*, 169, ed. J.-E. Solheim and E. G. Meiřtas (San Francisco: ASP), 169, 432
- Iben, I. Jr., Tutukov, A. V., and Fedorova, A. V. 1998, “On the Luminosity of Degenerate Dwarfs in Close Binaries, Merging Under the Influence of Gravitational Wave Radiation,” *ApJ*, 503, 344
- Kaler, J. B. “Ask Astro,” “Astronomy,” continuing contributions: Sept. 1998 (Sun from Alpha Centauri); Oct. 1998 (transuranic elements); Nov. 1998 (green stars); Feb. 1999 (future of the Sun); March 1999 (biggest star); April 1999 (rotation); June 1999 (Greek letters)
- Kaler, J.B. 1998, “Double and Variable Stars,” in *The Universe Revealed*, Mitchell Beazley, Reed Consumer Books Ltd., London, 104-109
- Kaler, J. B. 1999, “Astronomy Update 1998,” in *Proc. of the 34th Annual GLPA Conference*, 19
- Kaler, J. B. 1999, “Eyewitness to Stellar Evolution,” in *Sky and Telescope*, (March), 97, 40
- Kaler, J. B. “Skylights,” on the web at <http://www.astro.uiuc.edu/kaler/skylights.html>
- Kaler, J. B. “Stars,” on the web at <http://www.astro.uiuc.edu/kaler/sow/sow.html>
- Kaler, J. B. and Balick, B. 1999, “Planetary Nebulae,” captioned slide set for the Astronomical Society of the Pacific
- Kuan, Y.-J., Charnley, S. B., Wilson, T. L., Ohishi, M., Huang, H.-C., and Snyder, L. E. 1999, “Alcohol Chemistry: Tentative Detections of Two New Interstellar Big Molecules CH₃OC₂H₅ and (C₂H₅)₂O,” *BAAS*, 31, #3, 942
- Lazendic, J. and Dickel, J. 1999, “The Crab-like Supernova Remnant N157B,” in *The Relation Between Neutron Stars and Supernova Remnants*, ed. by R. Bandiera *et al.*, *Memorie della Societa Astronomica Italiana*, 69, 843
- Linnell, A. P., Etzel, P. E., Hubeny, I., and Olson, E. C. 1998, “A Photometric and Spectroscopic Study of MR Cygni,” *ApJ*, 494, 773
- Liu, S.-Y., Mehringer, D. M., and Snyder, L. E. 1999, “Observations of Formic Acid Toward Galactic Hot Molecular Cores,” *54th OSU Internat. Symp. on Molec. Spectr.*, FA05, 244
- Liu, S.-Y., Mehringer, D. M., and Snyder, L. E. 1999, “Observations of Formic Acid Toward Galactic Hot Molecular Cores,” *BAAS*, 31, #3, 995
- Mehringner, D. M., and Snyder, L. E. 1999, “Locating Complex, Saturated Organic Molecules in the Interstellar Medium,” *54th OSU Internat. Symp. on Molec. Spectr.*, RA04, 196
- Meixner, M., Campbell, M. T., Welch, W. J., and Likkell, L. 1998, “Mass Loss Histories of Three Carbon Rich Evolved Stars as Revealed by the ¹²CO Emission,” *ApJ*, 509, 392
- Meixner, M., Ueta, T., and Bobrowsky, M. 1998, “Two Types of Proto-Planetary Nebulae?” *AAS Meeting 193*, abstract #62.04
- Meixner, M, Ueta, T., Dayal, A., Bobrowsky, M., Hrivnak, B.J., Skinner, C.J., Hora, J., Deutsch, L. K., Hoffmann, W. F., and Fazio, G. 1998, “The Morphology of Proto Planetary Nebulae Dustshells,” in *Asymptotic Giant Branch Stars*, *IAU Symposium 191 Poster Session* held in Montpellier, France, 5-15
- Meixner, M., Young-Owl, R. C., and Leach, R. W., 1999, “NIRIM: a Dual Purpose Near Infrared (0.76 – 2.5 μm) Imaging Camera for Wide Field and High Resolution Imaging,” *PASP*, 111, 997
- Miao, Y., Zeng, Q., and Snyder, L. E. 1998, “Vibrationally Excited CH₃CN in Sgr B2,” *Chin. A&A*, 22, 315
- Moore, T. J. T., Emerson, J. P., Skinner, C. J., Meixner, M. M., Arens, J. F., and Jernigan, J. G. 1998, “Mid-infrared Imaging of WL16: The Spatial Distribution of the Hydrocarbon Emission Features,” *MNRAS*, 299, 1209
- Myers, P. C. and Gammie, C. F. 1999, “On the Turbulent Velocity Dispersion in Molecular Clouds,” *ApJL*, 522, L141-144
- Ostriker, E. C., Gammie, C. F., and Stone, J. M. 1999, “Kinetic and Structural Evolution of Self-gravitating, Magnetized Clouds: 2.5-Dimensional Simulations of Decaying Turbulence,” *ApJ*, 513, 259-274
- Points, S. D., Chu, Y.-H., Kim, S., Smith, R. C., Snowden, S. L., Brandner, W., and Gruendl, R. A. 1999, “The Supergiant Shell LMC2: I. Kinematics and Physical Conditions,” *ApJ*, 518, 298-323
- Rebull, L., Duncan, D. Johansson, S., Thorburn, J., and Fields, B. 1998, “Limits on the Boron Isotopic Ratio in HD 76932,” *ApJ*, 507, 387
- Remijan, A. J., Liu, S.-Y., Snyder, L. E., and Pei, C. C. 1999, “Methyl Cyanide (CH₃CN) Observations of W51,” *BAAS*, 31, #3, 943
- Ritossa, C., Garcí a-Berro, E., and Iben, I. Jr. 1999, “On the Evolution of Stars which Form Electron-Degenerate Cores Processed by Carbon Burning V. Isotope Abundances, Core Collapse, and Thermal Pulses in a 11M_⊙ Model with an ONe Core,” *ApJ*, 515, 381
- Roberts, D. A., Crutcher, R. M., Young, W., and Kemball, A. J. 1999, “Status and Future Plans for Parallelization of AIPS++,” in *Astronomical Data Analysis Software and Systems VIII*, *ASP Conference Series*, Vol. 172, eds.

- David M. Mehringer, Raymond L. Plante, and Douglas A. Roberts, 15
- Shuping, R. Y., Snow, T. P., Crutcher, R. M., and Lutz, B. L. 1999, "CO and C₂ Absorption Toward W 40 IRS 1a," *ApJ*, 520, 149
- Skinner, C. J., Meixner, M., and Bobrowsky, M. 1998, "The Birth of a Planetary Nebula Around the Carbon Star IRC +10216," *MNRAS*, 300, L29
- Snyder, L. E. 1999, "Large Interstellar Molecules: Are They Formed by Gas Phase Chemistry, Gryain Surface Chemistry, or Both?," 54th OSU Internat. Symp. on Molec. Spectr., RA07, 199
- Snyder, L. E., Meyertholen, A., Veal, J. M., Kuan, Y.-J., de Pater, I., Forster, J. R., Wright, M. C. H., Woodney, L. M., A'Hearn, M. F., and Palmer, P. 1999, "BIMA Array Molecular Searches in Comet Hale-Bopp(c/1995 O1)," 54th OSU Internat. Symp. on Molec. Spectr., RF14, 218
- Snyder, L. E., Veal, J. M., Woodney, L. M., A'Hearn, M. F., Kuan, Y.-J., Forster, J. R., Wright, M. C. H., Plambeck, R. L., de Pater, I., Pound, M. W., Engargiola, G., and Palmer, P. 1999, "BIMA Array Spectral Line Observations of Comet Hale-Bopp (C/1995 O1)," *BAAS*, 31, #3, 848
- Tornabé, A., Cassisi, S., Piersanti, L., and Iben, I. Jr. 1998 "Hydrogen Accreting Carbon-Oxygen White Dwarfs: An Evolutionary Scenario," in Proceedings of the 9th Workshop on "Nuclear Astrophysics," eds. W. Hillebrandt and E. Müller (Max-Planck-Institut für Astrophysik: Garching b. München), 61
- Ueta, T., Meixner, M., and Bobrowsky, M. 1998, "The HST Snapshot Survey of Reflection Nebulosity Around Proto-Planetary Nebulae," AAS Meeting 193, abstract #14.02
- Webbink, R. F. and Han, Z. 1998, "Gravitational Radiation from Close Double White Dwarfs," in *Laser Interferometer Space Antenna*, ed. W. F. Folkner (American Institute of Physics, CP-456), 61-67
- Weis, K., Duschl, W. J., and Chu, Y.-H. 1999, "The Nature of Strings in the Nebula around Eta Carinae," *A&A*, 349, 467-474
- Williams, R. M., Chu, Y.-H., Dickel, J. R., Petre, R., Smith, R. C., and Tavarez, M. 1999, "Supernova Remnants in the Magellanic Clouds III: An X-ray Atlas of LMC Supernova Remnants," *ApJS*, 123, 467-485
- Williams, R. M., Chu, Y.-H., Dickel, J. R., Smith, R. C., Milne, D., and Winkler, P. F. 1999, "Supernova Remnants in the Magellanic Clouds II: Breakouts from N11L and N86," *ApJ*, 514, 798-817
- Wrigge, M., Chu, Y.-H., Magnier, E. A., and Kayama, Y. 1998, "ASCA SIS X-ray Observations of the Wind Blown Bubble NGC 6888," in *The Local Bubble and Beyond*, IAU Colloquium No. 166, 425-428
- Wright, M. C. H., de Pater, I., Forster, J. R., Palmer, P., Snyder, L. E., Veal, J. M., A'Hearn, M. F., Woodney, L., Jackson, W. F., Kuan, Y.-J., and Lovell, A. J. 1998, "Mosaicked Images and Spectra of J=1-0 HCN and HCO⁺ Emission from Comet Hale-Bopp (1995 O1)," *AJ*, 116, 3018
- Wright, M., Dickel, J., Koralesky, B., and Rudnick, L. 1999, "The Supernova Remnant Cas A at Millimeter Wavelengths," *ApJ*, 518, 248

D. Pettigrew

