

University of Minnesota
Department of Astronomy
Minneapolis, MN 55455

I. PERSONNEL

The teaching and research staff in the Department of Astronomy during the academic year 1999-2000 consisted of Professors Kris Davidson, John M. Dickey, Robert D. Gehrz (Director, U of M Observatories), Roberta M. Humphreys, Terry J. Jones (Director of Undergraduate Studies), Thomas W. Jones, Leonard Kuhi (Chair), Lawrence Rudnick, Evan Skillman (Director of Graduate Studies), and Paul R. Woodward [Director, Laboratory for Computational Science and Engineering (LCSE)]; Adjunct Assistant Professor Kim Venn (Macalester College); Professor Emeritus Karlis Kaufmanis; Sr. Research Associate David K. Porter; and Research Associates W. Wenlong Dai, Dennis Dinger, B.K. Edgar, Udo Gieseler, and Hyesung Kang. Other academic positions include: Assistant Director (LCSE) Thomas Ruwart and Research Fellow (LCSE) Alexander Elder. Liliya Williams and Charles Woodward were appointed as Assistant and Associate Professors, respectively, for 2000-2001. Additional members of the Astronomy and Astrophysics Graduate Faculty included Physics Assistant Professors Shaul Hanany and John Wygant, Associate Professor Cynthia Cattell, Professors Robert Lysak, Keith Olive, Robert O. Pepin and Professor Emeriti Paul J. Kellogg and C.J. Waddington.

Graduate students were John Cannon, Tracey Delaney, Gianluca Gregori, Eric Hallman, April Homich, Kazunori Ishibashi, Michael Jacobs, Barron Koralesky, Geoffrey Lawrence, Jennifer Lockman, James Lyke, Chris Mason, Naomi McClure-Griffiths, Francesco Miniati, Justin Morgan, Joshua Nollenberg, Jennifer Parker, Edward Rhoads, Konstantin Sapogin, Michael Schuster, Nathan Smith, Igor Sytine, Ian Tregillis, and Andrew Young.

The Assistant to the Chair is Virginia Olson; the Astronomy Executive Assistant is Terry L.T. Foley; the Student Office Assistant was Joni Kilzer and the LCSE Assistant to the Director is Julia Sytina. The Principal Electronics Technician is Allen Knutson, the Systems Administrator is Ben Jarvis, and the Information Technology Professionals (LCSE) are Benjamin Allen and Sarah Anderson.

Gehrz served as President of the American Astronomical Society until June 2000, and will serve the AAS as its Past President from June 2000 through June 2001.

Humphreys was vice-chair of the University/faculty Senate and Chair of the AAS Nominating Committee, 1999-2000.

Kuhi serves as Treasurer of the American Astronomical Society and as Chairman of the Board of Directors of the Associated Universities for Research in Astronomy (AURA) which operates the U.S. National Optical Astronomy Observatories (NOAO) under contract to the National Science Foundation (NSF), the Space Telescope Science Institute under contract to NASA and manages the International Gemini Project for the Gemini Board and NSF.

II. GRADUATE DEGREES AWARDED

Masters:

Justin Morgan, September 2000, Advisor - Roberta M. Humphreys, Plan B

Ph.D.:

Kazunori Ishibashi, November 1999, Advisor - Kris Davidson, "Multi-wavelength Investigation of the Supermassive Star Eta Carinae"

III. OUTREACH ACTIVITIES

The LCSE has initiated a novel Secondary Education of Computational Science (SpECS) project designed to teach secondary students why science is being done on computers and to give them an idea of what kinds of problems lend themselves to computational solutions

Rudnick is Co-PI for an NSF funded five-year project for the Minneapolis School District to carry out the systemic reform of science teaching in K-12 in line with the national science standards developed by the AAAS and NRC. University science faculty and graduate students (including many from Astronomy) participate in kit-training workshops and serve as resources for school teachers. The major goal is the District wide use of kit-based instruction for all science classes. A secondary goal is the establishment of a permanent cooperative relationship between the University and the Minneapolis School District to ensure the long-term success of the systemic reform effort.

Skillman initiated a successful summer public outreach program called "Universe in the Park" which featured slide presentations followed by telescopic viewing of celestial objects at four local state parks.

Kuhi and Jetty St. John of the Science CentrUM received funding from NASA for a program to interest children of color in science by establishing science clubs on Indian reservations.

Departmental faculty and graduate students continue to visit local schools to present talks on astronomy as part of the Department's own outreach program.

IV. FACILITIES

a. Observatories

The University of Minnesota Observatories (R.D. Gehrz, Director) is comprised of two major facilities. The first is the Mt. Lemmon Observatory (MLOF) at 2776m elevation near Tucson, Arizona. The MLOF houses a 1.5m telescope equipped for visual and infrared observations. The new software system continues to be upgraded under contract with FORTH, Inc. of Manhattan Beach, CA. Pointing with the telescope is now better than 9" rms and tracking for solar system objects is fully implemented. Instruments used on the

telescope include the U of Rochester InSb camera, mid-infrared instrumentation from Aerospace Corporation, the University of Denver mid-IR camera TNTCAM, an optical CCD camera, the University of Nagoya IR spectropolarimeter PASP2, as well as the usual complement of optical and infrared photometers and polarimeters maintained by the University of Minnesota.

The second facility is O'Brien Observatory, with a 0.75-m telescope, located at Marine-on-St. Croix, Minnesota. It continues to be used for instrument development, student training, and studies of ephemeral objects such as comets and novae. It has been involved for several years in a survey of infrared sources with emphasis on monitoring infrared variable stars. The telescope is operated using the same FORTH control system as the Mt. Lemmon 1.5m telescope. Pointing is now excellent and tracking for solar system objects is routine. In addition to the IR photometers, an optical CCD camera is used by undergraduate juniors and seniors in the Astrophysics program for a course on astronomical techniques.

The Department continues to pursue its effort to obtain a share of a large telescope project. Rapidly changing developments have made the exact course of action less certain at this time two options are under consideration: 1) buying out Washington State University's share of the ARC 3.5 meter telescope at Apache Point, New Mexico, or 2) a capital investment in the Large Binocular Telescope project with Steward Observatory and the University of Arizona. Funding is being sought from private donors.

b. Instrumentation

Gehrz, T.J. Jones, Mason, Lyke and Schuster recently completed a 1-5 micron camera (MINNECAM) in collaboration with J.L. Pipher and W. Forrest of the University of Rochester, and C. Woodward and C. McMurtry at the University of Wyoming. MINNECAM which uses a Santa Barbara Research Center 256x256 InSb detector array, saw first light at MLOF in Fall of 1998. It has subsequently been in regular operation at both MLOF and O'Brien Observatory (OBO). The MINNECAM is being used in collaboration with S. Willner (Smithsonian Astrophysical Observatory) to image external galaxies in support of Gehrz's SIRTf GTO Science Program.

c. Computational and Image Processing Facilities

A general purpose computing and image and data processing center functioned around a departmental cluster of Sun and SGI workstations. A wide variety of standard and local special purpose software exists for both optical-infrared and radio imaging and general purpose computing and visualization.

The University of Minnesota operates several supercomputing systems for large scale scientific computation and its development. The Minnesota Supercomputing Institute (MSI) currently operates an IBM SP2 computer with 256 processors and 192 Gbyte of shared memory, as well as a Silicon Graphics Origin 2000 computer with 128 processors and 64 Gbyte of shared memory. Each of these systems has more than 1 Tbyte of disk available. These facilities are

maintained for computational research by faculty and students at the University, as well as their collaborators. Excellent user support is also provided. Information on the extensive programs provided by the MSI can be found on the World Wide Web at <http://www.msi.umn.edu/>.

The Laboratory for Computational Science and Engineering (LCSE) develops parallel application software targeted to SMP cluster and other parallel platforms, performs large-scale parallel calculations primarily in fluid dynamics, and then post-processes, visualizes and animates the large datasets generated by these simulations. Innovations are made at the systems level, using parallelism in storage, graphics, computing and networking hardware and software to achieve high performance and scalability at reasonable cost. The LCSE is under the directorship of Woodward and works with many collaborators throughout the University.

Building on the experience and achievements in nearly 10 years of high-end storage and visualization work by Woodward and his team, the LCSE was founded in 1995 with generous equipment donations and loans from the founding corporate sponsors, including Silicon Graphics, Seagate Technology, Ciprico, and National Peripherals (now part of MTI). Shortly after the founding of LCSE, they were awarded an NSF Metacenter Regional Alliance grant and, combined with direct grants to Woodward from the NSF, DoE, and NASA, were able to accelerate their joint research and development activities.

The LCSE role in the NSF CISE (Computer and Information Science and Engineering) Research Infrastructure Project was to build and operate a "PowerWall" (a very high resolution display and digital animation system) and to oversee the development of the high performance disk systems and special network connections which support its operation. "Collaborative Research Activities over vBNS" is a supplement to this NSF CISE Project. The LCSE uses the vBNS to move very large quantities of data generated at the NCSA (National Center for Supercomputing Applications) back to the LCSE. They also will investigate use of the vBNS to drive the "PowerWall" from remote locations.

The key projects at the LCSE include:

- a) the "PowerWall" scalable parallel high-resolution display system,
- b) new techniques for interactive visualization of large scientific datasets,
- c) innovative numerical techniques for the SMP Cluster architecture,
- d) Grand Challenge computations in:
 - 1) thermal convection in the Sun and the development of associated magnetic field structures
 - 2) laser fusion
 - 3) convection in the Earth's mantle
 - 4) large-eddy simulation of compressible, turbulent flows,
- e) introduction of computational science into the high school curriculum, and
- f) outreach to industrial users of LCSE computing technologies

With over \$3 million in computer hardware, including several state-of-the-art SGI Graphics and Computer Servers,

$\frac{1}{2}$ Terabyte of disk and Terabytes of tape storage, the LCSE staff continues its tradition of being at the leading edge in high-end storage and graphics systems for visualizing large datasets. Their success in developing parallel, scalable applications and their collaborations with national supercomputing efforts, including DoE's ASCI program, NASA's Grand Challenge Program (subcontracted through the University of Chicago), and NSF Supercomputing Center at Illinois (NCSA) and Pittsburgh (PSC), mean that they must continue this tradition to manage and control the enormous simulation datasets soon to be generated on next-generation parallel platforms.

d. The Automated Plate Scanner

Humphreys and collaborators have used the Automated Plate Scanner at the University of Minnesota to digitize glass copies of the blue (O) and red (E) plates of the original POSS with galactic latitudes $|b| > 20^\circ$ (664 fields). The scans are done in threshold densitometry mode, recording all pixels above the scanning threshold set at 65% of the mean local background. This detects almost all the real images on the POSS plates. Positional repeatability is about one micron, with a scanning resolution of 5×12 microns. This threshold corresponds to $\mu_B \sim 24.5 \text{ mag/arcsec}^2$ on a typical plate.

The APS Catalog of the POSS I provides individual information for several hundred million stars in our galaxy and tens of millions of galaxies down to 21st magnitude (in the blue). The database entries include coordinates, magnitudes (O and E), colors (O-E), and other computed image parameters for all of the matched images on the blue and red plates. The stellar and non-stellar images are separated using a neural network image classifier with a success rate better than 90% to about 19.5 magnitude. The neural network uses various image parameters with a back-propagation algorithm and two hidden layers to generate an output layer with two nodes, star or non-star. This "node-gal" value, which ranges from 0 to 1 also provides a confidence level of the classification. These values are cataloged along with the classification, "star" or "galaxy."

The photometric calibration for stars uses a magnitude-diameter relation for each plate that is calibrated with standard stars and normalized. The rms for stellar magnitudes is 0.15-0.20 between magnitudes 12 and 20. Galaxy photometry uses a derived density-to-intensity relation from the stellar PSF for each plate giving an rms of 0.08-0.15 magnitude scatter in surface brightness. Accurate astrometry is achieved from plate solutions using the Lick Northern Proper Motion catalog and the Astrographic Catalog of Reference Stars. Once all mapped distortions are removed the rms per plate is commonly 0.30 arcseconds.

The catalog of objects is available as an on-line database over the Internet URL is (<http://aps.umn.edu>). Querying is achieved with a custom-designed database management system (DBMS) called StarBase. This DBMS was developed in collaboration with faculty and students of the University of Minnesota Computer Science Department. StarBase uses specialized hashing on each image parameter derived for every catalog entry, including a 2D hierarchical algorithm for positional search and retrieval. This level of optimization

provides us with a DBMS that is faster and smaller than commercial equivalents and is capable of handling many millions of entries.

Several improvements have been made to the database pipeline that creates the individual plate databases queried by StarBase. The changes include improved positions, especially for galaxies, using a new median centroider and integrated magnitudes for galaxies with an improved density-to-intensity calibration with a "sky" background subtraction. In the original version of StarBase the object classification fainter than 19.5-20.0 mag was an extrapolation of the networks trained on brighter objects. Now the Infante and Pritchett (1992) catalog of galaxies at the NGP has been used to train a neural network on objects fainter than 20th mag. This improved classification is used in the new version of StarBase. The results of a more accurate classifier at faint magnitudes can be seen in the luminosity function for galaxies displayed at the APS web site. The Catalog is being re-issued with these improvements and is now available at the APS website.

The galaxy classification code calculates over 500 photometric and shape parameters for each galaxy image in the training sample of over 1500 visually classified galaxies. Using this vast data set, Kriessler has built on Odewahn's (1995) initial results on morphological classification. Working with members of the computer science department, Kriessler has applied a number of data mining and pattern recognition codes to this large data set. They have been able to identify the most useful image parameters for the different classes. Using a simple 3 class system, early (E-S0), intermediate (Sa-Sc) and late (Sd-Im), they get an accuracy of 82-92% depending on the definition of borderline galaxies. Kriessler is currently working on separating the spirals (Sa/Sb/Sc) and the E and S0 classes and is experimenting with more sophisticated image analysis procedures including multiscale wavelet analysis and image indexing.

The APS Image Database is a complementary database of all digitized blue and red images above the photographic noise threshold. It includes all of the matched images in the object catalog as well as those unmatched images above the noise threshold. The matched image data in the object catalog have the advantage of confirming the reality of the images. This is especially important for small images near the plate limit. But these are not all of the detected real images; very blue or very red faint objects may be excluded by this matching requirement. The image database allows information on them to be retrieved. (The new pipeline now saves the unmatched data. Although it is not publicly available, these data are archived and include object classification.) The custom DBMS (a version of StarBase) maps each query into the corresponding POSS plate(s). The pixels are assembled into a GIF image file for browser display, and a FITS format image file for retrieval. The FITS images have a pixel size of 0.33 arcseconds. The FITS header contains astrometric and photometric information. The software development and creation of the image database was supported by a separate NASA ADP grant.

The digitization of the "Luyten red" plates, a set of "second epoch" Palomar sky survey plates taken in the late

1960's with the same plate centers as POSS I, has been completed. The intention was to create a proper motion database but NSF did not agree. Consequently the Luyten red plates have been loaned to Dave Monet at the Naval Observatory for digitization.

The APS Catalog of the POSS I and its associated image database are available to the community through the APS WWW (<http://aps.umn.edu/StarBase2/>) pages and NASA Skyview (<http://skyview.gsfc.nasa.gov/>). A variety of WWW forms have been developed to meet the needs of users for access to the catalog. These forms not only manage database queries, but also have self-contained tutorials and links to an extensive collection of on-line documentation covering all aspects of the object catalog. A meta-database called (APS-Platelist) provides users with specific information on each of the POSS fields, including plate centers, magnitude limits, and information on the photometric and astrometric calibrations of each blue and red plate. The finder chart server plots objects from the APS Catalog of the POSS I within a given sky region with a choice of map projections and image parameter limits, including object class and magnitude. This leverages the power of StarBase for rapid searches, producing a finder chart and a concurrent list of catalog entries.

A new Federated Database (FDBS) has been installed that allows a single query to access both the Catalog of objects and the image database. The APS project also provides a service to the astronomical community by responding to users' questions and requests. This includes requests for POSS fields not yet on-line and for fields not included in the official catalog release, e.g. low galactic latitude fields. The average response time for placing requested data on-line has been approximately 3 days. At the request of users, a batch job service has been created to enable large-scale cross-identification of source objects with the on-line databases. The user can e-mail a file containing a list of positions, which is then automatically processed. The user is then notified when the batch job is complete and their data are available. Batch job querying has been used to cross-identify over 100,000 objects, including the optical counterparts to the FIRST survey.

During the past two years the APS web site has averaged 42 real queries per day (total number >29,000). Over 15.4 Mb of data per day were transferred, or more than 11 Gb of data. No user identification of any kind is required to use the APS database so a record of who specifically is accessing APS data or for what purpose unless they identify themselves with special requests or questions is not available. The most frequent requests are for positions for fiber spectroscopy with very large telescopes.

The APS Catalog of the POSS I, an object catalog of over 100 million stars and galaxies, is being archived on DVD-ROMs for distribution to various database centers and to interested astronomers. The MAPS/NGP, a catalog of over 200,000 galaxies and their parameters at the North Galactic cap (Cabanela 1999) is available at the APS website and has already been made available to NED.

The APS Project is supported by NASA and the University of Minnesota.

V. RESEARCH

a. Solar System

Gehrz and Mason obtained a sequence of IR photometric observations of Comet Hyakutake showing that a strong $10\mu\text{m}$ silicate feature appeared abruptly when the comet neared perihelion. These data have now been published.

Mason and Gehrz, et al., made extensive observations of Comet Hale-Bopp. Initial evaluation of the data has shown that the dust grains composing the comet's coma are significantly smaller than in any other comet observed to date. The size of the grains is important in the study of the formation of comets and in turn, the formation of the solar system.

Mason concluded the analysis of the extensive observations of Comet Hale-Bopp he made with Gehrz, Williams, Lyke, and Schuster in the spring and summer of 1997. They were able to sample many regions in the coma and tail and are working to determine the types of dust grains resident in the different regions. These data have been analyzed along with similar data from several recent bright comets in order to obtain a more global understanding of comet dust grain properties. The dust grain characteristics found in comets Hale-Bopp and Hyakutake have been compared with those found in the novae V705 Cassiopeiae and V1425 Aquilae in order to track the evolution of these particles as they travel from regions with conditions similar to their birthplace to their most recent state in comet ejecta.

b. Galactic

Humphreys, Smith, Davidson and Gehrz have completed their analysis of their HST/WFPC2 images and infrared images of the very luminous OH/IR star VY Cma. Our WFPC2 data show a complex distribution of knots and filamentary in the asymmetric reflection nebula around the obscured central star. The prominent reflection arcs are evidence for multiple, asymmetric ejection episode possibly due to localized events on VY CMA's surface. Such events probably involve magnetic fields and convection by analogy with solar activity. Surface photometry of the WFPC2 images indicates that the star may have experienced enhanced mass loss over the past 1000 years. The apparent asymmetry of the nebula is due to a combination of high extinction and back-scattering by dust grains. The mid-infrared images reveal a more symmetric distribution, elongated along a nearly east-west direction. They conclude that VY CMA has a flattened disk-like distribution of dust with a NE/SW polar axis, and most importantly that it may be experiencing activity analogous to solar prominences; magnetic fields and surface activity may play an important role in VY CMA's mass loss history. The presence of an axis of asymmetry raises interesting questions for a star the size of Saturn's orbit.

Humphreys, Smith and undergraduates Mark Halvorson and Lynn Gravatt have begun the analysis of additional HST/WFPC2 and infrared images of several other evolved cooler hypergiants including VX Sgr, NML Cyg, S Per, ρ Cas and HR 8752. The WFPC2 of VX Sgr show an extended asymmetric nebulosity associated with this OH/IR red supergiant, and its 4.5 micron image shows evidence for what may be a bipolar structure. The WFPC2 image of the highly obscured

OH/IR supergiant NML Cyg shows a peculiar beam-like shape. The image of S Per is non-stellar but the other objects appear to be stellar with no evidence for any obvious circumstellar nebulosity.

Smith and Humphreys obtained current UBVRI and JHK photometry of the η Carinae-like variable V12 in NGC 2403 also known as SN1954j. Their observations confirm that V12 survived its eruption and its current energy distribution clearly shows that it is now very red and has an infrared excess most likely due to circumstellar dust. V12 is a member of a relatively rare group of stars once considered supernovae but which are now recognized to be examples of η Carinae/P Cygni-type eruptions.

Davidson's HST/STIS observations of Eta Carinae have continued to produce unexpected, and in some cases strange, results. New data were obtained in March 2000, continuing the survey of Eta's 5.5-year spectroscopic cycle. One such discovery occurred mid-1999: at all wavelengths from UV to near-IR, Eta had doubled in brightness during the preceding year! Since colors and spectra show that this was not a normal LBV eruption, it is a phenomenon without clear precedent among very massive stars. The March 2000 observations showed that the brightening had continued, at a slower rate, through 1999. Meanwhile the emission line profiles varied in ways that appear systematic but which defy simple explanation. This is especially true of the helium lines, which changed significantly in 1999; standard binary models predict much less change. A co-investigator in the STIS/Eta Carinae project, Torgil Zethson (Lund), discovered forbidden lines of strontium in the ejecta near Eta Carinae; Davidson's preliminary assessment of the necessary excitation rates suggests that an abnormally high strontium abundance may be indicated. This seriously violates theoretical expectations for Eta and its ejecta, and no satisfactory explanation has appeared yet. Davidson and Smith have also used the STIS data to produce the first accurate three-dimensional cross-section of the "Homunculus" ejecta nebula of Eta Car.

For her Ph.D. thesis research, Parker is extending the Larsen & Humphreys (1996) investigation of the asymmetry in the distribution of halo/thick disk stars. They compared nine pairs of fields on either side of the Sun-Center line and found an excess in faint blue star counts averaging 30% to 40% between fields at $l = 20^\circ$ to 50° and their complementary fields at $l = 340^\circ$ to 310° at $b = +30^\circ$. The excess in star counts appears to increase with fainter magnitudes. The stars responsible for the excess are apparently 1-2 kpc above the stellar "bar" in the disk. Parker has extended the survey to 40 pairs of fields ranging from $l = \pm 17^\circ$ to $\pm 80^\circ$ and $b = +20^\circ$ to $+60^\circ$. In April 1999, observations with the CTIO 4 meter + HYDRA multi-object spectrometer were conducted to obtain stellar spectra in seven of the fields studied by Larsen. In May and June 2000, additional stellar spectra were obtained at the CTIO 4 meter and the KPNO WIYN 3.5 meter using HYDRA. She is currently measuring the radial velocities and determining the spectroscopic classification of 1080 stars. It is the goal of this project to identify the extent of, and the stellar population responsible for, the asymmetry and determine its kinematics. It is possible that the excess in star counts could be due to a bar-induced "wake" or that the

asymmetry may indicate that the thick disk/inner halo is tri-axial. Research has begun to study 40 additional fields below the galactic plane to determine if the excess in star counts is present beneath the galactic disk.

Using the Australia Telescope Compact Array in mosaicing mode, and the Parkes multibeam system, Dickey and McClure-Griffiths are doing a survey of the Southern Galactic Plane at 21-cm (SGPS). This is a collaboration with Anne Green at Sydney University, Bryan Gaensler at M.I.T., and Raymond Haynes and Mark Wieringa at the ATNF. This Southern Galactic Plane Survey (SGPS) has made very rapid progress this year. All the observations are finished with both the Parkes and Narrabri telescopes. The Parkes telescope was used to extend the survey area up to plus/minus 10 degrees of latitude over the longitude range of 253 to 357 degrees. The compact array portion of the survey, which is limited to plus/minus one degree latitude, is still being processed. In the test region, which has been fully analyzed, many dramatic interstellar structures have been found. Progress and results from the Southern Galactic Plane Survey can be found at <http://www.astro.umn.edu/~naomi/sgps.html>.

The atomic hydrogen, traced in the SGPS by its 21-cm line emission, shows many dramatic shells and super-shells. Some of these break through the disk and appear to open into the lower halo as chimneys. One which was found near longitude 280 is extremely large, nearly a kpc in diameter, which suggests a very high energy input, as high as 10^{53} ergs, and an age of roughly 15 million years.

The radio continuum emission from the inner galaxy also shows complex structure in the SGPS data. The most interesting feature of this Galactic synchrotron emission is its linear polarization properties. Dickey, working with Gaensler and McClure-Griffiths has found that the linearly polarized emission at low latitudes shows completely different structure from that of the Stokes I (unpolarized) emission. This can be understood in terms of the Faraday Rotation of the ionized, magnetized component of the interstellar medium.

A new survey of the 21-cm emission from the inner galaxy has been started by an international team headed by Dickey and A.R. Taylor (Univ. of Calgary). This effort uses the VLA to map the first quadrant of the Milky Way, which cannot be covered by either the SGPS or the Canadian Galactic Plane Survey. The VLA data to fill in this equatorial gap were obtained in a VLA Large Project (roughly 260 hours of VLA observing) during July, August and September, 2000. When these data are calibrated and mapped they will surely reveal even more exciting structure in the HI line and continuum emission from the inner Galaxy.

J. Kim (Illinois), Ryu, S. Hong (Seoul) and T. W. Jones completed the initial stages of a 3D study of the nonlinear Parker instability and its possible role in formation of molecular clouds. They carried out two sets of high resolution isothermal 3D MHD numerical simulations following the development of the instability from initial random fluctuations through nonlinear development and then relaxation. Both sets of calculations involved a simple, uniform gravity model. One included the effects of uniform rotation, while the other assumed no rotation. In both cases magnetic recon-

nection allowed the efficient vertical exchange of plasma and lead to the formation of clouds with sheet-like topology. The density contrasts, however, are only a few, so much too small to lead to formation of giant molecular cloud complexes. Therefore, the Parker instability alone does not appear capable of triggering the formation of such clouds.

Gregori and Miniati, along with T. W. Jones and Ryu, completed a numerical study of the influence of magnetic fields on the evolution of supersonic plasma clouds through the ISM or in supernova remnants. This extended a long series of calculations carried out over the past decade investigating the deceleration and destruction of shocked and fast moving clumps. The influence of the magnetic field on the stability of such clumps was the main study objective. Previously in 2D studies we demonstrated that fields may form a kind of “magnetic bumper” shielding the clump against Kelvin-Helmholtz and Rayleigh-Taylor instabilities. We found in 3D flows that the bumper forms, but that in the plane containing the field and the velocity vector of the clump motion instabilities are actually enhanced, while growing magnetic pressure can squeeze plasma along the normal to this plane, almost like a tube of toothpaste.

Kang and Ryu, along with G. Lake (University of Washington) studied the formation of old globular clusters in the Galactic halo. They simulated how an overdense region inside a protogalactic halo condenses by thermal instability and collapses to form a dense parent cloud which later becomes a globular cluster. They found that the cloud is compressed out of pressure equilibrium due to supersonic infall and becomes much denser than expected in an isobaric compression.

Graduate student DeLaney, working with Koralesky, Rudnick, and J. Dickel (U. Illinois), worked on new epoch VLA maps of the Kepler SNR. Comparisons with a previous epoch’s map were used by Koralesky to derive the proper motions of features throughout the remnant. Large deviations from radial expansion are seen, with a typical angle of 40 degrees between the proper motion and radial vectors. These deviations must occur through interactions with an inhomogeneous circumstellar medium. In addition, the local motion and magnetic field directions are well-correlated, demonstrating that the magnetic field is amplified through shears in the flow.

DeLaney studied the spectral index variations in the Kepler SNR between 6cm and 20cm. Most of the flat spectrum radio emission in the northern and southern rings is at larger radii than the steep spectrum emission. Some spectral index features also have distinct rotation measure and depolarization properties. There are also correlations between X-ray, optical, and infrared emission and flat and steep radio emission. The spectral index and multi-wavelength studies, along with proper motions, will be used to better understand the three dimensional structure, the dynamics, and the physical relationships between the various non-thermal and thermal plasmas.

DeLaney and Rudnick, along with other collaborators, are analysing their simultaneous multifrequency VLA data on the Cassiopeia A SNR, to separate spectral index variations between different locations from temporal flux variations,

which are also a function of position. Five wavelengths between 4m and 3.7cm are under study.

Koralesky, along with Rudnick, T.W. Jones and collaborators S. Holt, R. Petre, and U. Hwang (NASA/GSFC) and E. Gotthelf (Columbia) have performed a variety of detailed comparisons between the radio emission in Cas A and new X-ray data (both performance verification and 50 ks GTO time) from Chandra. They have identified the long-sought-after outer and reverse shocks. The outer shock and material somewhat downstream is much stronger in the 4-6 keV continuum, compared to the reverse shock, which shows strong line emission. There is a sharp rise in the radio emissivity at the outer shock, but no thin rim of emission as seen in the x-rays. This is important for understanding where magnetic fields and particle populations are amplified in blast waves. A comparison of radio and x-ray emissivities throughout the remnant shows an approximately constant ratio within specific regions, viz. exterior to, and at/inside the reverse shock. However, this correlation breaks down completely at scales less than approximately 5 arcsec. At that finer scale, the substructure of the clumpy emission is being resolved, which will enable us to disentangle the relationship between the thermal and relativistic plasmas. Along with DeLaney, they are obtaining a second epoch of Chandra measurements, along with a new epoch of VLA data, to enable them to study the relationship between the kinematics of the two plasmas.

c. Extragalactic

Dickey and Cabanela (St. Cloud State U.) are continuing their research into the gas content of very blue galaxies. These galaxies “on the blue edge” are in the extreme ten-percentile in color index of the galaxy population at their magnitude. They find from observations at Arecibo that selection by color in this way leads to a very high detection rate in the 21-cm line. The gas mass to optical luminosity ratio for these systems is much higher than for samples of galaxies chosen in other ways. Miniati, along with T. W. Jones, Ryu, Kang, J. Ostriker (Princeton) and R. Cen (Princeton) carried out a detailed study of the properties and influences of shocks produced during cosmic structure formation. They found that large scale shocks are much more common and more complex than usually assumed. This comes from the fact that galaxy clusters, rather than being isolated structures, form at vertices in cosmic filaments. Therefore, intergalactic infall onto clusters is highly non-spherical and unsteady. Accretion shocks often penetrate well into the inner reaches of clusters. In addition, flows along filaments and associated shocks can pass through cluster media, disturbing the intracluster media (ICMs) similarly to cluster mergers. The energy dissipated in these shocks is enormous. If the shocks are capable of cosmic-ray (CR) acceleration similar to what happens in other astrophysical environments, then those CRs may contribute a nonthermal pressure to the ICM that is sufficient to influence the cluster evolution and also observational efforts to determine cluster masses from the thermal pressure of the ICM. Those latter issues are the focus of Miniati’s Ph.D. thesis research.

Tregillis and T. W. Jones continued a major effort using numerical MHD simulations to study radio galaxy dynamics. They carried out the first 3D simulations of radio galaxies including explicit treatments of the relativistic electrons responsible for observed radio and X-ray emissions. Thus, they computed “synthetic” observations of the simulated objects so that they can be compared directly with observed sources. From the dynamics they discovered that the terminal shocks in these flows are very much more complex than the standard cartoon for radio galaxy flows. The jet terminus is highly unstable, so that it “flaps” dramatically. That makes a simple terminal shock a rare event, but creates an intricate “shock web” associated with the end of the jet. This, in turn, makes the energy spectra of the relativistic electrons highly nonuniform. When radiative aging of the electrons is included, the highly intermittent character of the magnetic field in the flows adds to the complexity of the electron energy distributions. Simple models relating spectra to dynamical age are almost certainly too simplistic to provide practical tools for studying source dynamics. On the other hand, carefully combined radio and X-ray observations do seem a practical tool for calculating the strengths of magnetic fields. Emphasis should be placed on the words “carefully combined”, however, since the radio synchrotron and X-ray Compton emissions are weighted to different source regions. Especially if the electron spectra are curved, due to energy losses, it becomes crucial to observed at a pair of frequencies that represent the same energy electrons.

Young and Rudnick are continuing their spectral tomography and color-color diagram work on radio galaxies. In collaboration with D. Katz-Stone (Naval Academy) and A. A. O’Donoghue (St. Lawrence U.), Young and Rudnick have extensively analyzed Wide-Angle Tailed radio sources (WATs). Through spectral tomography, two spectral components have been identified: the jet and sheath. Using color-color diagrams, they have shown that the jet and sheath spectra are both consistent with a single electron distribution, with a low-frequency (injection) spectral index of -0.55. It is therefore likely that they have a common origin, and separated as the jet interacted with its surrounding medium. In collaboration with

Katz-Stone and G. Giovannini (CNR), Young and Rudnick have analyzed several other FRI (non-classical double) sources, and found evidence for sheath structures in them. It appears likely that many/most jets in low-luminosity sources will show a non-uniform cross sections. Spectral analysis of other samples of sources are being carried out with K. Blundell (Oxford), U. Klein (Max Planck), K.-H. Macke (CNR, Bologna) and J.P. Leahy (Jodrell Bank). Young and Rudnick, in collaboration with K. Makishima, M. Tashiro, N. Iyomoto (U. Tokyo), N. Kassim (Naval Research Lab), and D. Worrall (U. Bristol), have begun investigating the internal dynamics of radio galaxies with large diffuse lobes. The population of relativistic electrons that is responsible for synchrotron emission also produces x-ray emissions through self-Compton interactions and inverse Compton interactions with the cosmic microwave background photons. Analysis of data from the VLA and future x-ray observations from XMM and Chandra will allow us to measure the magnetic field

strengths and pressures in these sources, which cannot be done directly from either radio or x-ray measurements alone.

Young and Rudnick, in conjunction with N. Kassim (Naval Research Lab), Bruce Slee (ATNF), C. Sarazin (U. Virginia), H. Andernach (U. Gaunajuato), and A. Roy (MPIfR), are examining relic radio sources in clusters of galaxies through spectral and polarization mapping using the VLA. X-ray emitting hot gas within clusters contain shocks that move ~ 1000 km/sec. These shocks may be indicators of current galactic mergers or may be the remnants of large shocks generated early during the cluster formation process. In examining the radio and x-ray observations of the cluster relics, issues of relic energetics, shock models, dynamical evolution of clusters will be explored.

Venn has worked with Rolf Kudritzki (U. Munich, now director of U. Hawaii’s Institute of Astronomy), Danny Lennon (La Palma), Andreas Kaufer (VLT), and other colleagues on the first high resolution spectra of individual stars in the dwarf irregular galaxy, NGC 6822. The spectra of two A-type supergiants were obtained at the VLT+UVES and Keck+HIRES. A detailed model atmospheres analysis was used to determine the atmospheric parameters and elemental abundances, in particular the first iron-group abundance determinations in NGC 6822. They confirmed that NGC 6822 has a metallicity that is slightly higher than that of the SMC. The mean stellar oxygen abundances are in good agreement with the nebular oxygen results, and the O/Fe ratio is very similar to that seen in the Magellanic Clouds, which supports the picture that chemical evolution occurs more slowly in these lower mass galaxies. Combining all of the available abundance observations for NGC 6822 showed that there is no trend in abundance with galactocentric distance. However, a subset of the highest quality data do suggest a radial abundance gradient, which, if confirmed, could have severe consequences on the current understanding of galaxy evolution. Venn also worked with Kudritzki, Lennon, Jim McCarthy (Caltech), and other colleagues on the first stellar abundances in M31. Observations for four stars were based on Keck+HIRES spectroscopy, and a full model atmospheres analysis was completed for 3 A-F supergiants, with a preliminary analysis of a fourth star. We found that the stellar oxygen abundances are in good agreement with those determined from nebular studies, even though the stars do not show a clear radial gradient in oxygen. The same stars were also used for a preliminary study of the distribution of heavier elements in M31.

Skillman has been working with Olive on improving the analysis of extragalactic HII region spectra for the purpose of determining the primordial helium abundance. In order to provide a useful constraint on standard big bang nucleosynthesis predictions, the primordial helium abundance must be determined with an accuracy of a few percent. They have investigated the estimation of errors in deriving and reporting nebular helium abundances from optical emission line spectra of HII regions. They have shown that while an estimation of reddening and underlying stellar absorption in H Balmer emission lines can be made by solving for these quantities simultaneously, a minimization routine may underestimate the true errors in the solution due to the degen-

eracy of the sensitivities of the individual lines. They also show that Monte Carlo modeling allows for a better estimate of the errors in underlying absorption and reddening which need to be propagated to all of the data. It is emphasized that a comparison of the corrected Balmer line strengths relative to their theoretical values provides a robust test of the magnitude of their associated errors. A detailed examination was conducted of “self-consistent” methods for determining not only the He⁴ abundance from H I and He I emission line ratios, but also other physical parameters. Strong degeneracies in the sensitivity of the He⁴ abundance to various physical parameters were discovered. Because of this, Monte Carlo simulations of the data are required to derive accurate estimates of both the He⁴ abundance and the appropriate errors. For the first time, it was demonstrated how to quantify the effects of stellar absorption underlying the HeI emission lines (as opposed to assuming that the effects are negligible). It was further shown that HeI λ 4026 is a sensitive diagnostic of underlying HeI absorption, and adding it to minimization methods is recommended. Finally, it demonstrated that solving for physical parameters via a minimization routine opens up the possibility of incorrect solutions if there are any systematic problems with even one observed HeI emission line.

Working with A. Saha, A. Dolphin (NOAO), E. Tolstoy (Gemini), A. Cole (Massachusetts), R. Dohm-Palmer, M. Mateo (Michigan), J. Gallagher, J. Hoessel (Wisconsin), Skillman has been leading an effort to use the Hubble Space Telescope to study the stellar populations in nearby dwarf irregular galaxies. IC 1613 and Sextans A each were observed for 25 orbits of HST time, and the analysis is in progress. The observations were conducted in a manner to both study the variable star populations and to produce very deep color-magnitude diagrams. For IC 1613, a study of the variable stars results in the discovery of 13 RR Lyraes and 11 Cepheids. Distance to IC 1613 were derived from the tip of the red giant branch, the luminosity of the red clump, the RR Lyraes, and the Cepheids. Taking into account the metallicity dependencies of the various distance estimators, self-consistent distance ratios were found between IC 1613 and both the Small Magellanic Cloud (with a similar metallicity) and the Large Magellanic Cloud (with a significantly higher metallicity). A best distance modulus to IC 1613 of $\mu_0 = 24.29 \pm 0.07$ is found, corresponding to a distance of 720 ± 20 kpc. This distance produces an RR Lyrae absolute magnitude of 0.63 ± 0.08 at $[Fe/H] = -1.4$.

A preliminary look at the star formation history for the deep HST field in the halo of IC 1613 reveals that IC 1613 has experienced relatively constant star formation over the period 0.8-3 Gyr ago. However, presently (in this field) the star formation rate is quite a bit lower than this past level. There is also tentative evidence at the faint end that beyond 3 Gyr ago there was an enhancement in the star formation rate. However, this is critically dependent on the incompleteness calculations. They are currently constructing models which take into account the information from the entire CMD.

They have constructed a new spatially resolved SFH for Sextans A, combining older data (an adjacent field) with the

new. They find the same patterns evidenced in the new construction. Star formation episodes tend to last a few 100 million years, and return to the same locations (near the present day HI column density peaks). They do not find evidence for a radial pattern of star formation, as suggested by the observations of van Dyk et al. However, their observations only cover the center of the galaxy. The central stars are probably, on average, much younger than the stars in the periphery of the galaxy, and thus, there is a radial gradient in stellar ages. However, with the high spatial and time resolution afforded by the HST data, a detailed picture emerges which is consistent with star formation episodes wandering around the inner parts of Sextans A, not propagating radially.

d. Computational Astrophysics

T.W. Jones, students and collaborators continued a successful pioneering program to develop efficient computational methods to simulate relativistic particle, or cosmic-ray transport in important astrophysical environments. Cosmic-rays (CRs) and their emissions are often crucial diagnostics of high energy phenomena, such as supernova remnants, gamma ray bursts, active galaxies and even galaxy clusters. The nonequilibrium character of the CRs makes it necessary to simulate the microphysics of their transport, and that typically involves length and time scales orders of magnitude smaller than conventional gasdynamical techniques are designed to handle. The most important process for CR acceleration is first order Fermi acceleration at shocks. Jones, Kang, R. LeVeque (U. Washington) and K.M. Shyue (National Taiwan University) successfully implemented an “adaptive mesh refinement” (AMR) scheme to treat this process, thus creating the first code capable of studying the evolution of CR acceleration at shocks with realistic transport coefficients while including backreaction on the plasma flow. In collaboration with M. Malkov and P. Diamond (UCSD) this will be used for the first self-consistent study of nonlinear shock evolution with CRs. The code will also be applied to study of supernova remnant shocks. Gieseler, Jones and Kang successfully implemented the first numerical treatment of a plasma physics based nonlinear model for CR injection from thermal plasma at shocks. This was based on Malkov’s theory of MHD wave regulation of collisionless shocks.

Miniati, as part of his Ph.D. thesis study of CR acceleration during cosmic structure formation, implemented and extended one of the group’s earlier schemes for CR transport into a hydrodynamic/N-body cosmology code. This work was done in collaboration with Jones, Kang and Ryu.

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