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This report covers the period 1 July 1997 through 30 June 1999.

1. PERSONNEL

Astronomy faculty in the Department of Physics and Astronomy were William G. Bagnuolo, Jr., Douglas R. Gies, William I. Hartkopf, Harold A. McAlister (CHARA Director), H. Richard Miller, Mark A. Shure, Paul J. Wiita (Director of Graduate Studies in Astronomy), and David W. Wingert. Donald H. Gudehus returned as a Visiting Lecturer in 1999. Stephen Ridgway continued a half-time appointment as a CHARA visiting scientist and Technical Manager of the CHARA Array project along with his primary appointment as Astronomer at NOAO. Staff scientists and post-doctoral fellows within CHARA were Theo ten Brummelaar, Christian Martin, Laszlo Sturmann and Nils Turner. Post-doctoral fellows in extragalactic astronomy were Gang Bao and Damo Nair. Robert Cadman continued with CHARA as Array Site Manager at Mt. Wilson, while John W. Wilson was the Coordinator of Laboratories, and Alexandra Land was the CHARA business manager.

Gies continued as Technical Editor for the paper and electronic versions of the Be Star Newsletter (now at URL http://www.limber.org/benews) for issues 32 (July 1997) and 33 (June 1998). Hartkopf is currently on leave at the US Naval Observatory. McAlister was appointed Regents Professor in 1999. Wiita spent two months in 1997 and 1999 as a Visiting Professor at the Indian Institute of Astrophysics (IIA) and the National Centre for Radio Astrophysics (NCRA) in India. Nair left to join Physical Optics Corp. in 1998. Martin returned to France in 1999 to teach at the University of Nice.

Our continuing graduate students during this period were Thomas Fallon, Elizabeth Ferrara, Kenneth Guyton, Michael E. Hahula, Jagbir S. Hooda, Amy E. Johnson, Anthony B. Kaye, Li Zhongjie, Reed Riddle, Lewis Roberts, Jon Sowers, Michelle L. Thaller, Nils H. Turner, and Xiong Ying. The following students joined the graduate program in this period: David Berger, Alyssa Daya, A. Benjamin Hocking, Huang Wenjin, John McFarland, Mary V. McSwain, Wang Zhongxiang and Amy Williams. Hooda received his Ph.D. in 1997 and joined the Institute of Paper Science and Technology (IPST) as a post-doctoral fellow; he is currently an Assistant Scientist there. Thaller finished her Ph.D. in 1998 and joined IPAC at Caltech as a post-doc; she currently has a staff position with SIRTF there. After completing his Ph.D. in 1998, Turner took up a post-doctoral position at Mt. Wilson, where he divides his efforts between the CHARA Array and adaptive optics work for the Mt. Wilson Institute. Upon completing his dissertation in 1998, Kaye accepted a post-doctoral position at Los Alamos National Laboratories where he is continuing his work on stellar pulsation in F-type stars. With the award of his Ph.D. in 1998, Roberts joined Rocketdyne Technical Services, where he works on the Air Force AEOS Telescope in Hawaii. Johnson completed her M.S. (as well as a M.Ed. at GSU) in 1998 and is teaching astronomy, physics, and mathematics at the Wesleyan School of Atlanta. After completing his M.S. in 1998, Sowers taught at Perimeter College. Xiong enrolled in the Computer and Information Sciences Department at GSU after receiving her M.S. in 1997, as did Li after receiving his M.S. in 1998. Wang was awarded an M.S. degree in 1999, and is now pursuing a Ph.D. at MIT.

Visitors included Gopal Krishna (NCRA, Pune), Andrzej Zdziarski (Copernicus Astr. Center, Warsaw), Jagbir Hooda (IPST), David Leckrone (NASA/GSFC), Donald Clayton (Clemson), Alexander Rosen (U. Alabama), Arne Henden (USNO, Flagstaff) Achim Feldmeier (U. Kentucky), and Geraldine Peters (U. Southern California). The University Center in Georgia Visiting Scholars in 1997 and 1998 were Stephen Maran (NASA/Goddard Space Flight Center) and Benjamin Zuckerman (UCLA), respectively.

2. HARD LABOR CREEK OBSERVATORY

Hard Labor Creek Observatory (HLCO) is operated by Georgia State University and houses the Multiple Telescope Telescope (MTT), which was designed by Bagnuolo, Don Barry and the late Ingemar Furenlid and built at Georgia State, and the $16''$ Boller & Chivens (B&C) Classical Cassegrain telescope, which was formerly at KPNO and was awarded to Georgia State University by the National Science Foundation through a grant to CHARA. In 1998 Miller obtained funds to purchase a $16''$ Meade telescope and CCD camera, which is currently being installed at HLCO and is to be used predominantly for instruction. The observatory hosted 17 public nights during 1998–99

The Multiple Telescope Telescope, a 1-m class instrument for high dispersion spectroscopy has proved to be an effective tool for spectroscopic studies of bright objects. With the addition of a more advanced user interface, automation and improved operational guidelines, the MTT has moved from being an experimental telescope to a robust research instrument. Riddle and Bagnuolo have continued efforts to improve the user interaction with the MTT, with the goal of making the telescope as efficient as possible. The mirror control software has undergone several revisions to allow automated mirror alignment, and the slewing and tracking systems have been upgraded to allow for more automatic operations. In further efforts to automate the MTT, a new dome will be erected (the current shelter cannot be operated automatically), and upgrades to a Linux based operating system are under study. It is hoped that the MTT will eventually be remotely operable.

The spectrograph CCD camera control system is being rewritten by Riddle (with the help of Barry) to operate under Linux. Other spectrograph improvements include new tem-

perature control, flat fielding, and grating alignment systems. Three gratings are available for science operations (600, 1200 and 2160 grooves mm^{-1}), and current performance is a SNR of 100 per pixel for a 6.0 magnitude star at 600 nm with the 600 g/mm grating in second order ($R \sim 14{,}800$) in five minutes; the spectrograph can work effectively at resolutions up to $R \sim 60{,}000$. A standard IRAF package for data reduction has been completed by Riddle and Bagnuolo; an entire night of data can be reduced in an hour or less using this software (and realtime reduction is possible).

The MTT has been used for various projects, from studying Comet Hale-Bopp (Ferrara and Boichat [Nottingham]) to giant stars (Riddle and E. Griffin [Oxford]), but the primary use of the MTT has been spectroscopic studies of massive binary stars. The MTT is also contributing to the education of graduate students in using instrumentation; the Astronomy Instrumentation course used the MTT extensively, and the Spectroscopy course for Fall, 1999 will use the MTT for a major portion of the course. Two versions of the MTT are also in development elsewhere: one is under Profs. E. Kambe and A. Yamasake at the Japanese National Defense Academy (NDA), and the other is the Sydney University Multiple MIrror Telescope (SUMMIT) under Drs. J. Davis and A. Moore. We anticipate new joint spectroscopic programs on short period variables and binary stars where the extended longitudinal coverage will greatly reduce diurnal gaps in observations.

Miller, Wilson, Ferrara, Daya and McFarland have initiated a program for monitoring the optical variability of variable AGN utilizing the Photometrics CCD camera at the B&C $16''$ telescope. The primary focus of the program is to provide temporally extended studies of the microvariability for bright blazars. During the summer of 1997, a highly concentrated effort was made to monitor the major optical outburst of BL Lac. Variations of more than 1.0 mag day^{-1} were observed on several occasions. Of particular interest were coordinated optical/EGRET observations of BL Lac which detected a simultaneous flare of BL Lac at both γ-ray and optical wavelengths. We anticipate expanding the program utilizing the new Meade telescope equipped with a CCD camera.

3. CENTER FOR HIGH ANGULAR RESOLUTION ASTRONOMY

3.1 Binary Star Speckle Interferometry

The time period encompassed by this report saw the gradual winding down of CHARA's long-running speckle observing program, as resources and efforts were concentrated on the CHARA Array. Some 2,400 observations were obtained during four observing runs on the Hooker 100-in telescope at Mt. Wilson Observatory, during the period August 1997 – July 1998. Reduction continues for some of these data, and we expect various collaborative projects to continue for some time to come, using both these new observations and our extensive archive of speckle data. Work on our ongoing series of speckle measurements of binary stars resulted in 8 measurement papers being published in this period. Work also continued on the determination of accurate orbital elements of close visual binaries; elements were published for a total of 75 binary or multiple systems during this period. The primary participants in this effort were Hartkopf, Mason (USNO), McAlister, and ten Brummelaar.

Data from the Hipparcos astrometry satellite, released in May 1997, provided considerable grist for the research mill during this period. Martin, with Hartkopf, McAlister, and Mignard (CERGA) determined masses for 28 astrometric systems, using Hipparcos data together with new and published CHARA speckle measures. Observations were made to confirm some of the binaries discovered by Hipparcos and to determine the true nature of many systems listed as ''questionable'' or ''problem'' binaries by the satellite reduction teams. Much of the Hipparcos work was a collaborative effort between the CHARA group (Martin, Hartkopf, McAlister, ten Brummelaar) and the speckle group at the U.S. Naval Observatory (Mason, Worley, Douglass, Germain, Wycoff). Franz (Lowell Obs.) and Barry (U. Texas) also participated in this effort.

McKibben (Oxford College of Emory U.), Bolton (U. Toronto), Fullerton (U. Victoria), Mason (USNO), Penny (College of Charleston), and Thaller (Cal Tech) collaborated with CHARA astronomers on analysis of a long-period spectroscopic binary in the O-star multiple system HD 193322. The spectrum of this SB1 is contaminated by that of a more distant companion discovered by speckle in 1987 (McAlister *et al.* 1987, AJ, 92, 183). This speckle component, CHR 96 Aa, orbits the spectroscopic system with a period of approximately 30 years.

Various studies in recent years have shown that stellar duplicity may evolve with time, from nearly 100% for some pre-main sequence stars to perhaps 50 - 60% for ''middle-aged'' solar-type stars. The evolutionary period during which binaries are presumably disrupted is very poorly defined, however. In an effort to narrow down this interval, Mason, Henry (CfA), Hartkopf, ten Brummelaar, and Soderblom (STScI) published a multiplicity survey of 245 solar-type stars. Speckle was combined with archival micrometry to look for companions in a search region of approximately 2 – 127 AU from each star, while chromospheric activity was used to segregate stars in age. A multiplicity fraction of about 18% was found for the younger ($\sim$ 1 Gyr) sample, decreasing to 8.5% for the older (4 Gyr) stars. We hope to refine these results through more speckle observations, plus astrographic and radial velocity surveys to increase the search region.

A major effort to survey the binary properties of the massive stars using the CHARA speckle camera at KPNO, CTIO, and CFHT is almost complete. Gies, Hartkopf, Mason (USNO), Bagnuolo, McAlister, and colleagues have published results on magnitude limited surveys of O-type and Wolf-Rayet stars and on selected Be-type stars (results on B-supergiants are in preparation). The CHARA group completed an all-sky speckle survey of all O stars brighter than $V=8$, and published a catalogue of all astrometric and spectroscopic duplicity data available for these 227 systems. This work has also been posted on the web as an ''organic'' catalogue for the hot-star community, to be maintained and up-

dated as additional data are obtained for these objects. The O-star survey demonstrated that most O-stars in clusters and associations are members of a binary or multiple star system, and when future interferometric searches are made for binaries with periods of years or decades, it may be found that almost all such O-stars have companions. The speckle survey uncovered some dozen new astrometric binaries; many of these systems are triples that may play an important role in cluster ejection processes. Gies has obtained new high dispersion spectra from Mt. Stromlo Obs. (MSO) of many of these speckle binaries to search for the spectral signature of the companions and to determine generally the limits of spectroscopic detection of long period binaries.

Bagnuolo, Riddle, and Gies are continuing a long term effort to measure precise radial velocities for speckle binaries (with periods of years to decades) using the GSU Multi-Telescope Telescope and fiber-fed spectrograph. The combination of spectroscopic and astrometric orbits should lead to fundamental determinations of masses and distances. Preliminary orbital results will soon be available for the O-star binaries, 15 Monocerotis, HD 193322, and HD 199579.

In collaboration with Moffat (U. Montreal), Shara (STScI), and Wallace (STScI), the CHARA group also published a survey of the 29 brightest Wolf-Rayet stars. Only one object, WR 48 = θ Mus, was resolved as a close astrometric binary. This system is probably a triple, containing as well a distant O supergiant companion. The duplicity fraction found for the WR stars was considerably smaller than that found in the O star survey, but this is probably due to the WR stars' greater distance and fainter average magnitude.

Hartkopf continues to maintain the *Double Star Library* on the WWW, containing IAU Commission 26 (Binary and Multiple Stars) circulars, as well as address lists, catalogues, bibliographic data, meeting information, and related web links of interest to the double star community.

3.2 Adaptive Optics Imaging of Binaries

The CHARA adaptive optics program has continued through NSF funding on the Mount Wilson 100 inch Hooker telescope using the Mount Wilson Adaptive optics system. ten Brummelaar and Turner are leading this effort. This has been an extension of the work done previously at Starfire Optical range and is focussed on two areas: differential photometry of binary stars systems and the search for faint companions of nearby stars. Several papers have either been published or are in preparation based on this work.

We have also done some experiments of combined aperture masking and adaptive optics. In standard aperture masking experiments the sample time must be short, decreasing observing efficiency and severely limiting the magnitude limit. With the use of an AO system one can phase up the entire aperture and achieve stable fringes using the mask. This allows long integration times and can, in theory, produce twice the resolution of the full aperture. Fringes have been achieved in this way and we are now pursuing this method in the hope of resolving close binaries and even imaging stellar surfaces.

3.3 Spectroscopy with the Multi-Telescope Telescope

There are several ongoing science projects associated with the MTT. Through the use of a tomography algorithm developed by Bagnuolo, it is possible to separate binary star spectra into spectra of each component. Using this algorithm, Bagnuolo, Barry, Riddle, Gies and collaborators have studied several systems (Plaskett's Star, ι Ori, 55 UMa, 29 CMa among others) and discovered interesting new results for each. There is a continuing survey of massive O-B binary stars, which will allow further insight into the physical processes (mass transfer and winds, orbital dynamics, collisions between binary systems) of these massive stars. The ''Struve-Sahade'' effect is being examined for several stars. The MTT is also being used by Riddle and Bagnuolo to develop an improved technique to study stellar oscillations as part of Riddle's dissertation.

Bagnuolo, Riddle, Barry and Gies have examined the binary star system Iota Ori, and determined that the stars are not coeval and possibly result from a binary-binary collision. Ongoing studies of Plaskett's Star and 15 Mon continue to contribute knowledge about these important binary systems. Riddle and E. Griffin (Oxford) have completed observations of 22 Vul, an eclipsing binary composed of a red giant and a blue dwarf star. This will (literally) elucidate knowledge of the giant's outer atmosphere. In a campaign by Gies and others on the Be-star Epsilon Persei, the MTT data filled a coverage gap of IUE data for measuring stellar oscillations.

Bagnuolo, Riddle, and Gies are continuing a long term effort to measure precise radial velocities for speckle binaries (with periods of years to decades) using the GSU MTT and fiber-fed spectrograph. The combination of spectroscopic and astrometric orbits should lead to fundamental determinations of masses and distances. Preliminary orbital results will soon be available for the O-star binaries, 15 Mon, HD 193322, and HD 199579.

3.4 The CHARA Array

We present here a very brief report on the status of the CHARA Array, as details are in our *Quarterly Reports* and *Technical Reports* which can be found on our website: www.chara.gsu.edu/chara.html.

Construction on the CHARA Array continued on Mount Wilson during this period. Specific construction tasks completed to date include the installation of access trails to the telescope sites, pouring of massive concrete piers and enclosure foundations for the telescopes, construction of electronics bunkers at each telescope site, laying of underground conduit to the telescope sites to carry power and communication lines, installation of vertical support structures for the vacuum tubes relaying light from the telescopes to the central Beam Synthesis Facility, completion of all interior work on the BSF which houses the optical delay lines and the beam combination laboratory, installation of all telescope enclosures and domes, and installation of the two telescopes comprising the southern arm of the Array. Construction of the Control/Office building began in the summer of 1999. The program plan calls for completion of all construction activities during the fall of 1999, a period during which we

also expect to achieve ''first fringe'' with the southern pair of telescopes.

In addition to the installation of telescopes at the ''S1'' and ''S2'' sites, the southern vacuum tubes were installed and aligned in the spring of 1999. The vacuum system has been tested and minor leak repairs are underway. Five delay line carts, delivered to CHARA by JPL in 1998, have been installed and shown to work well within specification under closed-loop control. An important step towards first fringe was reached during the summer of 1999 by obtaining internal white-light fringes over a path length of 160 meters including some 16 surface reflections.

The primary and secondary optics for the original five telescopes of the Array have been completed by Telescope Engineering Company and delivered to CHARA, and a large number of relay mirrors and beam splitters, as well as the optics for the Beam Reducing Telescopes and the Optical Path Length Equalizers have been delivered. Fabrication of vacuum turning boxes and vessels for the incremental fixed components of the vacuum delay lines (the ''Pipes of Pan'') is either complete or well underway.

In June 1998, Shure and Sturmann received funding from the National Science Foundation to construct a near-infrared camera for high-resolution studies of star formation. This camera will operate in the 1–2.5 micron range and will be used to measure the visibility of fringes from the CHARA Array. By imaging the recombined light from all six telescopes over one quadrant (128$\times$ 128 pixels) of a HgCdTe PICNIC array from Rockwell Science Center, observers will be able to reconstruct a rough image of the source structure. By working in the near-infrared portion of the spectrum, the camera will take advantage of the greater stability of the Earth's atmosphere. One of the primary goals of the camera observations will be the detection of proto-planetary disks around stars, which are believed to be an important stage in their evolution.

The camera will also be used on the HLCO $16''$ B&C telescope and the Mount Wilson Institute $100''$ telescope to observe lunar occultations of infrared sources. By recording the Fresnel diffraction pattern observed during the passage of the Moon over the disk of the source, it is possible to infer the light distribution along the occultation direction. Though restricted to sources which fall along the Moon's path, this is one of the only complementary techniques which can match the angular resolution of the CHARA array (down to 1 mas) and will be invaluable for comparison to the Array results.

Full funding for the CHARA array was achieved during this period. The W. M. Keck Foundation is providing $1.5 million for the addition of a sixth telescope, enabling significant expansion of (u,v)-plane coverage, as well as for full implementation of a fiber optic based imaging beam combination system for the Array. A $574,000 gift from the David and Lucille Packard Foundation enabled Georgia State to complete its obligation to the NSF to match the original $5.6 million NSF grant. In its final form, the CHARA Array budget is $\approx$ $13.5 million, and all of the required funds have been raised to complete the instrument. We anticipate that all subsystems will be installed and initially operational by early 2001.

The closing date for this report finds the CHARA Array poised for its initial science programs. A site visit by an NSF-appointed panel in April 1999 led to clear recommendations about the importance of early and continuous scientific results from the Array, and we anxiously look forward to fulfilling that recommendation.

4. STELLAR ASTRONOMY

Guyton and Gies are developing a code to calculate accurate spectroscopic line profiles for rapidly rotating stars (such as the Be stars). Hahula and Gies are continuing their studies of the rapid spectroscopic line variations observed in Be stars. The variations take the form of blue-to-red moving subfeatures which cross the profiles on timescales of hours. A working hypothesis is that the variations result from photospheric nonradial pulsations which effectively redistribute the flux in rotationally broadened lines to create the moving patterns. The presence of the variations in rapidly rotating Be stars may be related to the mass loss processes that lead to the formation of circumstellar disks. Gies and colleagues have found evidence that beating between nonradial pulsation modes appears to promote mass loss in the variable B-star, ϵ Per. Much of the optical spectroscopy of Be stars was obtained in conjunction with *IUE* UV spectroscopy by Peters (USC), and Gies, Peters, and Huang have begun to reanalyze the *IUE* spectra using cross-correlation techniques to study for the first time the variations in the UV photospheric lines. The goal is to combine these spectroscopic studies of the photospheric lines with data on the continuum flux variations to develop pulsational models for the Be stars, and then to compare the photospheric variations with those observed in the UV wind lines in order to search for a connection between pulsation and mass loss.

Gies, Bagnuolo, Riddle, Thaller (IPAC), and Penny (College of Charleston) are continuing a long term program of determining the physical properties of the components of massive close binaries using a Doppler tomography algorithm to reconstruct the individual spectra. The original application was a study of archival *IUE* spectra to determine spectral classifications and projected rotational velocities (most recently for the O-supergiant binary, HD 152248), and to model the light curves to determine limits on the orbital inclinations and masses. The work has now been extended to optical spectroscopy with the GSU Multi-Telescope Telescope (MTT), and Bagnuolo and collaborators have finished detailed studies of the massive binaries, Plaskett's star (HD 47129) and ι Orionis.

Gies has obtained high dispersion spectra from MSO of a number of very short period O-binaries that were discovered through their light variations by the Hipparcos satellite, and work is underway to establish spectroscopic orbits for these systems. Thaller (IPAC), Gies, Kaper (Amsterdam), and Fullerton (Victoria) are studying the orbital variations in the Hα emission of a number of massive binaries (most recently HD 149404) in order to search for colliding wind effects in the outflow.

An extensive survey of O-B binary systems by Bagnuolo and Riddle, using the MTT, is underway, with the goal of understanding mass transfer, orbital interactions, and deter-

mining physical parameters of the systems. Many, if not most, binary stars have poorly characterized orbital parameters, and it is usually the binary star information that is lacking when determining physical parameters (such as mass) from combining spectroscopic data with, for example, astrometry. With the advent of instruments such as the CHARA Array, it is necessary to improve the spectroscopic observations. Data from the MTT will be combined with Array measurements in an effort to improve this area of astronomy. Bagnuolo and Riddle are obtaining new MTT spectra of additional massive binaries to find other examples of systems like Plaskett's star in which the mass donor has been stripped to reveal nuclear processed material in the photosphere and the mass gainer has been spun up.

After performing research at the National Solar Observatory (Tucson) in the field of helioseismology, Riddle is completing his dissertation using the MTT to study oscillations on the surface of other stars, under the guidance of Bagnuolo. He is developing new techniques, using different types of spectral measurements and physical effects, to attempt to improve the methods used currently. Measurement of the oscillations of other stars is extremely difficult, but the scientific rewards are immense: the oscillations allow a direct probe of the interior structure of the star.

Gies and collaborators are using high S/N spectroscopy (from the KPNO Coudé Feed telescope, the MSO 74-inch telescope, and the McDonald Observatory 2.1-m telescope) to study the properties of a number of highly evolved massive binaries. These range from systems like RY Scuti and HD 163181 which are beginning active mass loss and mass transfer to compact systems like V Sagittae which is probably a post-common envelope binary with strong colliding winds. Gies and collaborators have obtained HST UV spectra of the Be star, ϕ Persei, which show clear evidence of a hot, stripped-down, subdwarf companion (the brightest such hot subdwarf in the sky but prior to this lost in the glare of the Be star). This result demonstrates that Be stars can be formed through mass transfer in a close binary, and work is underway with Peters (USC), McDavid (Limber Obs.), Rivinius (Heidelberg), Štefl (Czech Acad. of Sciences), and Hummel (Munich) to search for evidence of hot companions in the binary Be stars, HR 2142 and 59 Cygni. Gies, McSwain, Riddle, and Wang are studying the Hα variations in the Be binaries, HDE 245770, V615 Cas and V662 Cas, to search for variations related to the orbital motion of the neutron star companion. Gies, Josephs, McSwain, Riddle, Wang, and Wingert are working with Tarasov (Crimean Astrophysical Obs.), Brocksopp (Sussex), and Roche (Leicester) to obtain intensive orbital phase coverage of the Hα emission line variations in the black hole binary, Cygnus X-1, to determine the mass transfer gas flow.

This same GSU team has begun an extended program of optical spectroscopy to investigate the orbital and precessional changes in the spectrum of the unusual binary, SS 433. The goal is to use Doppler tomographic techniques to isolate the spectral components due to the relativistic jets, accretion disk, and mass donor star. All of these X-ray binary targets are currently included in the X-ray survey program of the RXTE All Sky Monitor instrument, and Gies and collaborators will study how modulation of the mass transfer rate (as observed in Hα) ultimately results in X-ray flux variations.

Near-infrared images obtained by Shure with the NSFCAM array camera at the NASA Infrared Telescope Facility of the planetary nebula Minkowski 1-11 display an intriguing light distribution. Superimposed on a light distribution dominated by an inverse-square radial dependence, there is a ring of enhanced emission which is progressively more evident at the longer wavelengths. Initial polarization images rule out the possibility that this emission is due to light scattered from the bright central B star. Jao and Shure are investigating possible emission mechanisms which can explain this structure. One phase of the work is the use of the photoionization code CLOUDY developed by Ferland (Univ. Kentucky) and collaborators to model the line and continuum emission from the ionized gas surrounding the star. Jao and Shure are also studying the possible contribution of dust grain emission.

During an investigation of regions of star formation at the edges of the CMa supershell, Shure obtained K-band (2 micron) images of the only pulsar known in that region (pulsar J0729-1836). This source may be the remnant of one of the supernova explosions thought to have initiated the several hundred parsec shell of star formation which makes up the supershell. Harvin and Shure are using these images obtained with NSFCAM, as well as later images obtained by collaborator James Cordes (Cornell) with the Palomar 200-inch near-infrared camera, to investigate the possible detection of the a photoionized cocoon (or ''bubble'') of gas caused by the passage of the pulsar through the interstellar medium. Images obtained to date show a faint elliptical source coincident with the pulsar coordinates. The major axis of the emission lies along the direction toward the center of the CMa supershell and its separation from that position is consistent with the age and velocity of previous pulsar photoionization shells seen by Cordes and others. If the association of this source with the pulsar can be confirmed, this will represent the first detection of a photoionized pulsar shell in the infrared and poses interesting questions about possible sources of emission.

Miller, Wilson, Ferrara, and McFarland have obtained high-time resolution photometry of the cataclysmic variable star, PG 2337+12 utilizing the Photometrics CCD camera on the B&C 16″ telescope. Although variations have been detected on timescales ranging from minutes to days, no periodic modulation of these variations has been found.

Gudehus has upgraded his communications interface for SAOimage (Enhanced SAOimage v. 1.2E) and ported it to the Linux operating system. He has made available the source code for this, as well as his binary star combined solution, and his MIIPS package, available on the CHARA web site.

5. EXTRAGALACTIC ASTRONOMY

Miller and co-workers continue their program investigating the very rapid low amplitude variations in the optical and ultraviolet portions of the electromagnetic emission from active galactic nuclei (AGN). This group was the first to show

that microvariability was both real and common, at least for the blazar class of active galactic nuclei (BL Lacertae objects and Optically Violently Variable Quasars). Miller, Carini (Western Kentucky U.) and Noble (Boston U./Lowell Obs.) continue their detailed program of studying the variability for individual blazars on timescales of minutes to decades. The most recent study published was for 3C 371, with similar studies of OJ 131 and 3C 66A currently in preparation.

Miller and Noble have investigated samples of X-ray selected versus radio selected blazars and have found that there are is a correlation between the Lorentz factor associated with the jet and the presence of microvariability. The results of these studies will be submitted for publication shortly.

Miller and co-workers have also embarked upon a program to study the character of the microvariability for a large sample of EGRET blazars. Preliminary results suggest that large amplitude variations are present, independent of whether the blazar is in a flaring state or in a quiescent state. The analysis of the observations obtained in a coordinated campaign utilizing CGRO, RXTE, and ASCA to study the variability of PKS 1622 − 297 is expected to be completed in the next few months. Miller's group has participated in a number of other multifrequency monitoring programs to study blazars from gamma-rays to radio wavelengths. The objects studied have included PKS 2155 − 304, 3C454.3, 3C 279, PKS 0528+ 13, ON 231, 2A 1219+ 305, Mkn 421, Mkn 501, and PKS 1510 − 089.

This group is also studying a set of high-luminosity blazars and contrasting the findings for these objects with a sample of low-luminosity blazars. In addition, a major effort is currently underway to intensively study the TeV blazars, and see if additional evidence can be found that would link these objects to the X-ray selected blazars rather than the radio-selected blazars. This work is currently in progress.

Wiita has continued a collaboration with Ram Sagar and others at the Uttar Pradesh State Obs., India, along with Gopal-Krishna (NCRA) on optical observations of rapid variability in radio quiet quasars. Eighteen such objects have now been observed over the course of 8 observing seasons. These measurements have found excellent evidence for microvariability in several sources and hints of rapid changes in several others. In general, however, radio quiet QSOs seem to be less frequently variable than radio-loud QSOs; furthermore, their variations appear to be confined to shorter time periods than those of blazars. Additional observations of these and other QSOs could provide a powerful means of discriminating among various theoretical mechanisms proposed for the energy source and, in particular, the origin of optical microvariability in active galactic nuclei.

Miller and Ferrara have begun an investigation of a sample of 7 narrow-line Seyfert 1 galaxies (NLS1). This class of objects is known to exhibit giant-amplitude X-ray variability. This program plans to determine the relationship between the X-ray variability and the optical variability for the NLS1 galaxies. Preliminary results have demonstrated that in at least one case, IRAS 1322 − 3809, extremely rapid optical variability is present. X-ray observations have been requested, using RXTE, in order to determine if the X-ray/optical variations are simultaneous. Carini, Miller and Noble have studied the microvariability of 5 Seyfert 1 galaxies and have detected microvariability in all but one object.

Bao and Wiita have produced improved general relativistic models for active galactic nuclei and X-ray binaries where ''cold'' rotating matter is illuminated by a non-thermal source above it. Making the reasonable assumptions that the innermost part of an accretion disk around a black hole is unstable and clumpy they computed the X-ray variability induced both by a clump of matter moving relativistically around the black hole and by the non-thermal source moving above the disk. One interesting new result is that even for a face-on geometry, rotation induced variability can still be observed as long as the non-thermal source is not exactly at the symmetry axis. Also, the reflected X-ray component, peaked around several tens of keV, can vary more than other spectral components. This is because the reflected component experiences a double path through the gravitational field of the central mass, i.e., from the source to the disk, and then from the disk to the observer.

Wiita has collaborated with Krishan (IIA) and Ramadurai (Tata Inst. Fund. Res., Bombay) to show that a certain class of flare models for variability from accretion disk coronae is subject to beam-plasma instabilities. These instabilities can prevent significant direct acceleration and greatly reduce the variable X-ray emission argued to arise via inverse Compton scattering involving relativistic electrons in localized beams and soft photons from the accretion disk.

Gopal-Krishna and Wiita have developed evidence for a striking new feature of powerful radio galaxies: gigantic disk-like structures of thermal gas and dust oriented roughly perpendicular to the radio jets and situated around the elliptical host galaxy. These *superdisks*, or fat pancakes, appear to have a typical diameter of at least 75 kpc and a width of $\sim$ 25 kpc. Observational manifestations of the superdisks include the sharp, quasi-linear, edges of the radio lobes on the side facing the central elliptical, detected in at least a dozen well mapped radio galaxies at low to moderate redshifts. For radio galaxies with $z > 1.8$, evidence for superdisks is based on the apparent asymmetry of diffuse Lyα emission associated with the radio lobes. Superdisks can provide more consistent explanations for some of the best established correlations among the radio source properties, namely, the Laing-Garrington effect and the correlated radio-optical asymmetry. They are also likely to be responsible for part of the low-frequency flux variability of compact radio sources. They may provide an improved explanation of Lyα absorption dips in the emission profiles of distant radio galaxies.

The importance of a group of peculiar HYbrid MOrphology Radio Sources has recently been noted by Gopal-Krishna and Wiita. These HYMORS appear to have an FR I type radio lobe on one side of the active nucleus but an FR II type lobe on the opposite side. The mere existence of these hybrid sources causes severe difficulties for models which attribute the differences between FR I and FR II radio sources to some intrinsic property of the compact central engine, or the composition of the jet plasma. HYMORS support models for the FR dichotomy based upon the interaction of the jet plasma with the ambient medium, in that asymme-

tries in the external environment could more naturally produce the observed hybrid morphologies.

Three-dimensional numerical simulations of light supersonic hydrodynamic jets have been performed by Wang, Hooda and Wiita, following up on earlier computations by Hooda and Wiita. Extragalactic jets emerge through power-law atmospheres (ISM) of their host galaxies and then cross into hotter, but less dense, intracluster media (ICM) after striking denser clouds within the ISM. Usually the jets will erode and destroy the clouds; however, the collisions induce non-axisymmetry instabilities in the jets. Very weak jets can be stalled and effectively destroyed by the clouds. Certain rare morphologies such as 'dog-leg' quasars can be explained in terms of a restricted parameter space where jets can be stably bent and survive for extended distances after interacting with a massive cloud.

Along with S. Jeyakumar and D.J. Saikia (NCRA), Wiita and Hooda have constructed analytical and numerical models of Compact Steep Spectrum (CSS) Radio Sources. We have shown that simple analytical models, once relativistic effects are incorporated, can explain the rather large asymmetries in arm-length and lobe-power of CSSs in terms of modestly different properties of the ISM on different sides of the galaxy; such differences could be easily produced during a merger event which triggered the nuclear activity producing the jets. Both 2-D and 3-D simulations have been carried out and are being compared with the analytical work.

Gudehus has studied the bulk velocity of a sparse sample of nearby clusters, with a weighted average depth of 2214 km s^{-1}, finding a magnitude of 788 $\pm$ 113 km s^{-1} directed to $l = 266 \pm 18$,$b = 17 \pm 15$ deg, not greatly different in direction and magnitude from the motion of the Local Group relative to the microwave background radiation. The distance indicators used were mostly luminosity functions and reduced radius parameters. Gudehus has also continued investigating N-body simulations of cluster peculiar velocities, finding that most of the motion of the Local Group and of Virgo is accounted for by mass within $40h^{-1}$ Mpc, but that richer clusters must be assigned more mass than is given by their virial mass. In the area of scientific and astronomical visualization, Gudehus has been investigating techniques for displaying images in 3-D by means of lenticular screens. One of his methods allows 3-D prints to be made with an ink jet printer.

6. SPACE BASED ASTROPHYSICS

Gies and collaborators are continuing a multi-year project with the Fine Guidance Sensors aboard HST to obtain astrometric measurements of the O-star binary 15 Monocerotis. This binary is now close to periastron in its 25 year orbit, and HST/FGS measurements of separation and position angle have documented the orbital motion during this close passage. The most recent observation benefited from the improved resolution of the new FGS1r instrument aboard HST. Continued astrometric and spectroscopic observations of the system will lead to a combined orbital solution and, hence, masses and a distance for this important massive binary.

Miller has served as P.I. on programs utilizing RXTE and CGRO for a multiwavelength monitoring program investigating the nature of the variability of the Seyfert galaxy AKN 120. Extremely rapid variations have been detected in the X-ray and optical bands, and the relationship between them is being analyzed.

Miller and collaborators are also planning to propose to NASA for an extended duration (3–5 year) mission which will provide the capability of obtaining simultaneous optical, UV, and X-ray monitoring for a number of variable AGN. The goal of this mission would be to obtain continuous observations of several objects for a period of up to 3 months with a time resolution of a few seconds at all three wavelengths.

Additional information on the astronomy research program can be found at URL http://www.chara.gsu.edu.

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