Florida Institute of Technology
Department of Physics and Space Sciences
Melbourne, Florida 32901

I. INTRODUCTION

This is the first report for the Department of Physics and Space Sciences at the Florida Institute of Technology, and summarizes the current personnel, facilities, and programs being performed by members of the department working in the area of Space Sciences during the period of 1 January 1991 to 1 November 1991. The Department offers B.S., M.S., and Ph.D. programs in Space Sciences and Physics, and has a strong emphasis on observational astronomy and condensed matter physics. The Department is currently developing a variety of observational facilities including the Southeastern Association for Research in Astronomy (SARA) 0.9-meter automated telescope at Kitt Peak National Observatory, and the 0.64-meter automated telescope at Bull Creek, Florida. The Department also works closely with the Center for Space Science Research within F.I.T.'s Space Research Institute, as well as with the Microgravity and Aeronomy groups of the Marshall Space Flight Center in Huntsville, Alabama.

II. PERSONNEL

The Department Head is J. D. Patterson, who reports to the Dean of the College of Science and Liberal Arts, G. Nelson. Faculty with instructional and research activities in Space Sciences include Professors J.H. Blatt, J. Burns, T.D. Oswalt (promoted to Professor this past year), J.D. Patterson, and J.B. Rafert; Associate Professor R.S. Jin; Assistant Professors J. Mantovani, H.K. Rassoul, G. L. Wallace, M. A. Wood, who joined the department this fall, and Adjunct Faculty J. Smith. Full-time research staff engaged on projects within the Department include E.T. Rusk, who joined our group last spring as a Research Scientist II, and J. Freel, who joined this fall as a Research Scientist I.

Current full-time Space Science graduate students include J. Barker, T. Beck, T. Bentley, R. Branly, F. Chiu, R. Duren, M. Ellis, J. Freel, S. Hathway, E. Holbert, H. Leckenby, M. Martinez, G. Sellar, J. Simpson, J. Smith, and E. Sotolongo.

III. FACILITIES AND EQUIPMENT

The Department is engaged in the construction of two observatory facilities: the Southeastern Association for Research in Astronomy (SARA) 0.9-m telescope at Kitt Peak National Observatory, and the 0.64-m F.I.T. telescope at Bull Creek Wildlife Refuge, Florida, and maintains a 0.35-meter telescope for undergraduate laboratories at the Dairy Road Observatory in Melbourne, Florida.

F.I.T. is the Administrative Institution of SARA, a consortium of the Florida Institute of Technology, East Tennessee State University, University of Georgia and Valdosta State College. SARA is recommissioning the former No.1 0.9-m telescope at Kitt Peak National Observatory as a fully-automated facility for CCD imaging and photometry at a new site on Kitt Peak. In its role as the primary astronomical research instrument for SARA universities and the first fully automated general purpose telescope at KPNO, the recommissioned 0.9-m telescope will support a long-term science program involving well over a dozen proposed research projects. Astronomers in the Southeast will be able to remotely access the telescope using conventional computer networks. In addition, it will remain accessible to the general astronomical community via time granted on a competitive at-cost basis to non-SARA users. The SARA telescope will be configured as an automatic telescope using the Autoscope system. This system will include the full telescope and observatory control package, clocks, precipitation and cloud sensors, four-port instrument selector, and will operate both CCD cameras and photometers under construction by SARA member universities.

Final assembly of the 0.64-m automated telescope at Bull Creek is underway. This instrument is equipped with an Autoscope control system, Lynxx CCD camera, and SSP-3a solid state photometer. Bull Creek is a state of Florida forestry preserve, located 25 miles west of Melbourne in an area of low sky background. The telescope will be used for photometric observations of; close binary stars, asteroids, white dwarf and cataclysmic variable light curves, and launches from the Kennedy Space Center.

The department operates two Sun 386i platforms, several PCs, and is linked via ethernet to the VAX and Harris HCX-9 at F.I.T.'s Academic Research Computing Services. Various of these machines are equipped with IRAF, the Wilson-Devinney Model, Lowtran, FLIP, SpeCal, FAIM, IRI, MSIS, Baily and other special purpose astronomical data reduction software.

IV. RESEARCH

a. Stellar Astronomy and Astrophysics

Oswalt, collaborators and 9 graduate and undergraduate students have been conducting an NSF-sponsored study of over 500 Common Proper Motion Binaries (CPMBs) with suspected white dwarf (WD) components. Primary objectives of this project include: (1) Extension of the low-luminosity ends of both the WD cooling track and main sequence; (2) correction of the corresponding luminosity functions for binary selection effects; (3) evaluation of competing models of WD spectral evolution; (4) determination of the age of the Galactic disk from the terminus of the WD cooling sequence; and (5) kinematics and gravitational redshifts of WDs. Spectroscopy of the sample is being primarily conducted with the 4.0-m telescopes at Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory.

Photometric parallaxes of the coolest members of the sample are being determined using BVRI/JHK data collected at the NASA/IRTF 3.0-m telescope at Mauna Kea Observatory and the 1.8-m Perkins telescope at Lowell Observatory. This material will likely serve as the focus of a Ph.D. dissertation by J.A. Smith. A multi-institution proposal for HST GO observing time on the GHRS and FOS will obtain UV spectra of several cool double degenerates identified by this project.

L. Roberts, received her B.S. in Space Sciences and presented a paper on her work on white drarfs in wide binaries at the January 1991 AAS meeting. This past year M. Adams, A. Hardacre, S. Shufelt, A. Simon, and L. Roberts (all undergraduates) and T. Beck (graduate) participated as research assistants in Oswalt's NSF-sponsored study of CPBMs.

Rafert continues his research in close binary star systems initiated via a series of NSF-sponsored projects, including the modelling of the light curves of U Cep, VV UMa, XZ CMi, RU UMi, CN And, and BV 267, and observations of the W Serpentis stars. The modelling effort has included a substantial computational effort aimed at determining the nature of solution hyperspace for the Wilson-Devinney Model for the binary U Cephei. This activity was conducted by Rafert and M. Sahi, who received her M.S. degree during the summer. Currently, Rafert and Branly are analyzing the light curves of CN And obtained by Branly as part of a long-term study of thermal discontinuities in contact binary systems.

Wood continues his research in theoretical and observational studies of the oldest stars in the Galaxy, the white dwarf stars. These stars, which are the remnants of some 99% of all stars formed, are stellar embers which slowly cool with age. Cooling slowly enough that even those formed from the first generation of stars in the Galaxy are still visible, the white dwarf stars are ideal tracers of the Galactic age and star-formation history. Wood has found that the local disk of the Galaxy is younger than the typical ages quoted for the central bulge and orbiting globular clusters, consistent with the idea that galaxies like our own form over a period of a few billion years, and not all at once as had previously been thought. In other work, Wood, in collaboration with P. Bergeron of the Universite de Montreal, has also found a significant trend in the observed log g vs. $T_{\rm eff}$ relation for hot white dwarfs, a result expected on the basis of stellar evolution, but previously undetected. With the results from additional planned observations, comparison to state-of-the-art white dwarf evolutionary sequences should provide a *direct measure* of the mean hydrogen-layer mass of the white dwarf stars. Wood and Simpson are developing a model to illustrate the time evolution of acretion disks in close binaries.

b. Solar System Astronomy

Rassoul's research interests are in planetary atmospheres and ionospheres. His current projects are (1) Photochemistry of the earth upper atmosphere, (2) Low latitude particle precipitation and ionospheric current system, (3) Geomagnetic tail and the low latitude Boundary Layer.

The first project entails analysis of the ATLAS-1 airglow observations, schedule for launch on March 11, 1992, by the Imaging Spectrometric Observatory (ISO). F.I.T.'s involvement in the collaborative ATLAS-ISO data interpretation with MSFC/SSL scientists

includes a comparisons between the conventional photochemical theory and neutral/plasma atmospheric models with the observations. The second project uses theoretical/empirical models of FAIM, Bailey, FLIP, and IRI to investigate the nighttime ionospheric current system, specifically the effect of Appleton anomaly in the F region contribution to the current system. The last project utilizes the geotail mission of ISEE-C data , the vector Helium Magnetometer and the Solar Wind Experiment observations, for a critical test of the two leading theories on solar wind- magnetosphere interaction: magnetic reconnection and viscous interaction. Five students are participating in these projects, three supported by a NASA grant and the other two by F.I.T.

Rusk is continuing his studies of zodiacal light and particle dynamics. Rusk has discovered several new dynamical mechanisms related to the rotation of the sun and solar magnetic field, which affect the orbits of the dust grains which compose the zodiacal light. New observations of the ZL are planned which will relate to these and other mechanisms to the distribution of zodiacal dust. Rusk, Rafert, and Rassoul plan a long-term sky-background monitoring program using the Bull Creek telescope.

Smith and Oswalt collaborate on a long-term photometric project to derive rotational light curves and taxonomic types for poorly observed minor planets that have been identified as potential stellar occultation targets.

c. Instruments

Blatt continues his work on Moire Profilometry on structures and has developed an optical non-contact method to measure the shape of a surface or to compare its shape to a finished shape with applications in robot assembly and space alignment, ranging, and docking. This technique also has applications in automated assembly. Blatt received an NSF grant for the Cray YM-P at the Pittsburgh Super Computer Center, which supports research on neural net processed machine vision systems. Blatt has also continued his development of a real time optical processor to produce spectra of an image with military, industrial, and pollution control applications., and studies of neural-net processed images of damage to structures.

Rafert and Freel have built a two channel high speed photometric system using two Thorn-EMI-Gencon Starlight-1 photometers, which is designed for looking a bright objects at speeds up to 3000Hz. This system has been installed on the F.I.T. 16-inch telescope, located at the Malabar Test Facility, and has been sponsored by Photon Research Associates.

Rafert and Rusk, in collaboration with P. Lucey from the Planetary Geosciences Institute at the University of Hawaii, are developing a spatially modulated imaging Fourier Transform spectrometer capable of IR operation, under the sponsorship of ONR and DARPA.

d. Space Sciences

Jin and Burns received an NSF grant in April to support the project entitled "Improvement of Senior Lab for Physics and Space Sciences Majors by Adding Computational Physics". The project entails the writing of experiments such as chaos, orbit simulation, and others. The students will use spreadsheets such as Excel and other software like Mathematica to do simulation problems in Physics and Space Sciences.

Jin is continuing his research in the relationship between the fluctuations of the rotation of the earth and the secular changes of the geomagnetic field using the method of maximum entropy power spectral density analysis. In addition, Jin is investigating the multi-year stochastic inversion of magnetic observatory annual means. The objective is to improve geomagnetic prediction modeling techniques.

Through the joint NASA/FIT JOVE Project, Mantovani continues his studies of the surface of microstructure of electo-optical materials and semiconducting crystals. These crystals are provided by NASA's Microgravity Science and Applications Division located at Marshall Space Flight Center. The crystals are studied at F.I.T. using a scanning tunneling microscope (STM) built by Mantovani. The STM, which is capable of imaging individual atoms on the surface of electrically conductive crystals, can directly image defects that occurred during crystal growth. The STM is capable of high resolution imaging, and does not damage the crystal surface. R. Friedfeld is currently working on this project, and is being supported by both NASA and F.I.T.

Patterson has an on-going program funded by NASA on predicting electron mobility in narrow gap semi-conductors. Assisting in this work is W.A. Gobba, a Post Doctoral Research Associate. Patterson and Gobba have done an extensive set of calculations on Mercury Cadmium Telluride (MCT). Their

calculations for Mercury Zinc Telluride (MZT) support the speculation that it might serve as a superior infrared detector to MCT. Where experimental data is available, it agrees well with the MZT calculations. The work is being extended into the area of superlatices. Patterson also serves as the administrative P.I. for the scientific work of Rassoul and Mantovani on the NASA/JOVE program, and continues his work on Spin Wave Resonance relevant to the Space Science community.

V. OTHER ACTIVITIES

Jin, Oswalt, and Patterson were judges of the 1991 International Sciences and Engineerings Fair.

Mantovani and Rassoul, and three of their students gave poster presentations on their research at the annual JOVE meeting at NASA's Marshall Space Flight Center in August 1991.

Oswalt serves as Director of the SARA Project to recommission the KPNO 0.9-m telescope and Chairman of the Board of Directors for SARA. He presented a summary of this project at the XXI IAU General Assembly on behalf of SARA. He also serves as Harlow Shapely lecturer for the AAS, and as Editor of the *IAPPP Communications.*

Rafert serves as Chief Scientist for the Harris Team Site R&D contract at the Malabar Test Facility. Rafert also serves as Director of the Center for Space Science Research, as a member of the SARA Board of Directors, and Director of the SARA Observatory.

VI. TEACHING PROGRAM

The space sciences curriculum has been reorganized during the past year, and now includes a new program at the Ph.D. level, in addition to our former Bachelor and Masters programs. Currently, the department enrollment in space sciences includes 79 undergraduates and 16 graduate students, of which 4 are pursuing the Ph.D. in Space Sciences.

VII. PUBLICATIONS

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This report covers the period 1 July 1989 through 30 June 1991.

PERSONNEL

Astronomy faculty in the Department of Physics and Astronomy were Ingemar Furenlid, Douglas R. Gies, Harold A. McAlister, H. Richard Miller, Paul J. Wiita, and David W. Wingert. Staff scientists were William G. Bagnuolo, Jr. and William I. Hartkopf; John W. Wilson was the Coordinator of Laboratories. Wiita was promoted to Associate Professor in September 1989.

Our continuing graduate students were Ali Al-Shukri, Donald J. Barry, Michael T. Carini, Edmund G. Dombrowski, Sethanne Howard, Brian D. Mason, Thomas Meylan, John Noble, Alexander Rosen, and Michael S. Wiggs. The following students received Ph.D.'s during this period: Howard is currently at Marshall Space Flight Center, after completing a post-doctoral fellowship at Los Alamos; both Carini and Meylan are on the International Ultraviolet Explorer staff; Dombrowski is working at the Naval Research Lab; Rosen has a post-doc at the University of Michigan; and Al-Shukri has returned to Saudi Arabia to take a teaching post at the King Fahd University of Petroleum and Minerals. Wiggs completed an M.S. and has joined the staff at the Space Telescope Science Institute. Students joining the program duirng this period were Navarun Gupta, Michael Hahula, Arun V. Mangalam, Laura R. Penny, and Nils H. Turner. Mollie Raby continues to serve as administrative assistant for astronomy.

Visitors and speakers included: S. Beckwith (Cornell U.), J. Davis (U. Sydney), F. Fekel (Vanderbilt U.), O.G. Franz (Lowell Obs.), J.S. Gallagher (AURA), Gopal-Krishna (Tata Inst. Fundamental Research), P. Heckert (Western Carolina U.), R. Hilliard (Opto Mechanics, Inc.), K. Kamper (David Dunlap Obs.), E. Kibblewhite (U. Chicago), G. Loos (Air Force Phillips Lab), E. Nather (U. Texas), G. Oertel (AURA), A. Sargent (Cal Tech), H. Smith (U. Texas), W. van Citters (NSF), and K. Weiler (NRL, USNO). The Distinguished Visiting Scientist to the University Center of Georgia in 1990 was D.E. Osterbrock (Lick Obs.).

HARD LABOR CREEK OBSERVATORY

Hard Labor Creek Observatory is operated by Georgia State University and houses the 30–inch Beck Telescope of Agnes Scott College, the 16–inch KPNO telescope which was awarded to Georgia State University by the National Science Foundation through a grant to CHARA; it will be the future home of the Multi–Telescope Telescope (discussed below). The observatory was dedicated April 4, 1990, with approximately 250 persons attending the event. The keynote speaker for the dedication was Dr. Harlan J. Smith, Randall Professor of Astronomy, The University of Texas. A picnic was held following the dedication and attendees were invited to stay for an open house that evening. The observatory has hosted fourteen public nights during 1990–91 as part of an agreement with the Georgia Department of Natural Resources which allowed GSU to locate the observatory on the grounds of Hard Labor Creek State Park. Approximately 2000 visitors attended these public nights. In addition, the observatory has hosted a number of amateur astronomy gatherings sponsored by CHARA and the Astronomical Society of the Atlantic.

The refurbishment and upgrading of the 30–inch Beck Telescope continues and is expected to be completed by late 1991. A mirror cell was installed in the summer of 1991 and the installation of new stepper motors is currently in progress. It is expected that this telescope, along with the 16–inch telescope, will soon be playing an important role in both the teaching and research efforts of the astronomy program.

CENTER FOR HIGH ANGULAR RESOLUTION ASTRONOMY

Participants in the activities of the Center for High Angular Resolution Astronomy during 1989–91 were faculty and staff members Bagnuolo, Furenlid, Gies, Hartkopf, and McAlister (Director), plus graduate students Al–Shukri, Barry, Dombrowski, Mason, and Turner. Dr. Otto Franz of the Lowell Observatory continued a long–standing collaboration in CHARA activities. Facilities operated for the GSU astronomy program by CHARA include a VAX 11/750 computer system equipped with an IIS 70F image processor, a network of DECStation 2100 and 3100 computers and PC's, and the 16–in telescope at the Hard Labor Creek Observatory. The VAX and IIS were officially "retired" by CHARA in the spring of 1990 and are now in operation at Valdosta State College. CHARA also operates speckle camera instrumentation used regularly at the 4–m telescopes on Kitt Peak and Cerro Tololo.

The ongoing program of binary star speckle interferometry conducted at Kitt Peak was expanded to the southern hemisphere during 1989 with the first of a series of observing runs at the CTIO 4–m telescope. The CTIO commitment represents an especially important step for the speckle program, as the southern skies have heretofore been almost completely neglected. (As evidence of this, the roughly 1,400 measures of systems south of -30° obtained in the first 2 1/2 years of this program represent a *40-fold* increase over the number previously published by all speckle teams worldwide.) As of June 1991, some 13,000 measurements are included in CHARA's catalog of all known interferometric binary star data; CHARA has contributed 85% of this total and

over three–fourths of the 300+ binaries first resolved interferometrically. About 40% of the CHARA measurements are of separations under 0".2; 14% are under 0".1. An additional 3,451 unresolved observations have been published as well; CHARA is responsible for 79% of them.

During eight 4–meter class runs between July 1989 and June 1991, CHARA astronomers obtained nearly 5,000 sets of speckle observations. The observing program includes close visual binaries for which an order of magnitude increase in accuracy of measurement over classic techniques can be obtained, long–period spectroscopic binaries that are potentially resolvable by speckle methods, occultation binaries, stars with secondary indications of duplicity such as suspected variable radial velocity, excess luminosity, *etc.*, and samples of stars to be surveyed for duplicity including, ultimately, a complete sample of all main sequence members of *The Bright Star Catalogue*, and samples of Cepheids, OB association stars, naked T Tauri stars, and Hyades and other cluster members. We also frequently inspect specific stars requested by other astronomers including stars of interest for the verification stage of HST.

The results of these observations are being published in three series of papers in *The Astronomical Journal* dealing with binary star astrometry, orbital analyses, and "speckle photometry", respectively. The last application involves the determination of differential magnitudes and colors of the individual components of binary stars having separations down to the diffraction limit of 4–m telescopes, *i.e.*, to separations as small as 0.03 arcsec. The results from these three concentrations are included in the list of publications in this report.

Dombrowski completed a Ph.D. dissertation involving the combined astrometric and speckle photometric analysis of a number of Hyades binary star systems in order to determine the physical and evolutionary properties of these binaries as well as to determine the cluster distance modulus. The systems considered were ADS 3135, 3210, 3248, 3475, 3483, as well as 51 Tauri and 70 Tauri. The latter two systems have only been observable by interferometric means. The derived distance modulus included the "anchoring" effect of the spectroscopic and eclipsing binary HD 27130 (following McClure's earlier procedures) as well as the additional information now available from the individual magnitudes of the components as obtained by the "fork" algorithm developed by Bagnuolo. The distance modulus was found to be m–M = 3.42±0.04 mag.

Combined speckle and spectroscopic analyses of a number of interesting systems continued in collaboration with Dr. Frank Fekel (Vanderbilt U.). One such system is ADS 784, an 83–year period visual binary, one of whose components is a 4–day spectroscopic system. Independent studies of perturbations in the long–period visual/speckle orbit and the short–period spectroscopic orbit led to discovery of a new 5–year component, the first example of a *speckle astrometric* binary. Examples of other systems undergoing combined analyses are the early A–type triple η Virginis, the close 1.9–year binary 31 Arietus, and the nearby binary HR 6697 (this last system also in collaboration with Roger Culver [Colorado State U.] and Philip Ianna [U. Virginia]).

Al-Shukri completed his Ph.D. dissertation involving an analysis of a very extensive series of binary star speckle data obtained at the 1.8–m Perkins telescope near Flagstaff in order to investigate the limiting astrometric accuracy of the data. The goal was to detect unseen low–mass companions that may be gravitationally bound in an orbit around one component of a binary system. In principle, speckle observations can detect sub–motions arising from brown dwarf objects or even Jovian–mass planets. The dissertation showed no definitive detections of new companions among the sample studied, but pointed to several systems for which submotions are suspected. These systems will continued to be observed in the CHARA speckle effort.

Work on *interspectroscopy*, an interferometric technique to obtain separated spectra of close binary stars, has continued by Bagnuolo and Dr. Karl Kamper (U. Toronto). The most recent set of data comparing Albireo Aa and Vega, obtained at the 1.9-m David Dunlap Observatory telescope with a pulse-counting fiber-fed spectrograph, is being analyzed.

Bagnuolo, Gies, and Wiggs have begun a program of re-constructing the individual spectra of the components of close binary systems using a tomography algorithm. This method is an iterative scheme that uses the velocity curves of both components and an assumed intensity ratio to determine the spectrum of each from an ensemble of Doppler-shifted, composite spectra. The method has been applied to *IUE* high dispersion spectra of the O-type binary systems AO Cas and Plaskett's Star (HD 47129). Despite the low *S/N* ratio inherent to these spectra, the secondary component was successfully extracted in both cases, and spectral classifications were made through comparisons with the UV spectra of MK standard stars. They have also used relative line strengths to estimate the intensity ratio of the stars, and have found regions with strong secondary features suitable for radial velocity determination by cross-correlation. The secondary of Plaskett's Star is a somewhat hotter object and a rapid rotator with broad lines. The N IV λ1718 feature in the secondary is a P Cygni profile but a pure absorption line in the primary, which indicates that the secondary has the stronger wind. Bagnuolo and Gies plan to apply the algorithm to optical spectra of close binaries in a program of high *S/N* spectroscopy with the Multi–Telescope Telescope (see below).

Bagnuolo, Barry, Furenlid, and Gies have designed an inexpensive (about $80K) 1-meter class spectroscopic telescope and a fiber-fed spectrograph that will be installed at HLCO later this year, thanks to partial funding by a grant by NSF. This novel instrument consists of nine 13-inch mirrors on a single mount, each of which feeds an optical fiber at prime focus. The spectrograph, designed by Furenlid and Barry, is a modified off-plane Ebert-Fastie type. The potential optical throughput advantages of this *Multi–Telescope Telescope* (MTT) and spectrograph combination make it attractive for a number of interesting projects. Three projects already planned are an examination of the Be-star phenomenon (Gies), determinations of radial velocities for close visual binaries on our speckle interferometry programs to obtain spectroscopic orbits to complement our astrometric results (Furenlid), and recovery of individual binary star

spectra by tomographic analysis of spectra obtained over the orbital phases (Bagnuolo).

The CHARA Array continued to be the flagship effort of CHARA. A proposal was submitted to the NSF in January 1990 for the detailed design and construction of this facility for sub-milliarcsecond imaging at optical wavelengths. Following a site visit to Atlanta in April 1991 by a committee appointed by the NSF, it is expected that further design work will commence in November 1991. The target date for fully embarking on the Array project is now late 1992 or early 1993. The CHARA Array represents a partnership between Georgia State University's Center for High Angular Resolution Astronomy and the Georgia Tech Research Institute (GTRI) of the Georgia Institute of Technology.

STELLAR ASTRONOMY

Furenlid took part in the design of the novel Multi-Telescope Telescope (MTT), adding optical-fiber technology to the system. In conjunction with the MTT, a spectrograph similar to the one described by Furenlid and Cardona has been constructed. The new instrument is modified to give negligible line rotation as well as symmetric aberrations. The MTT is designed to feed the new spectrograph via an optical cable, leaving the spectrograph resting in a temperature controlled room; the main purpose of the special features in the design is to provide unusually high precision in radial velocity measurements. These efforts are carried out as part of a NSF funded project of high-precision radial velocities; in the same program a new algorithm with applications to binary stars has been developed (a variation of the Cross Correlation Method).

In the field of quantitative spectroscopy the work on chemical abundances in Alpha Centauri A relative to the Sun was finished. The higher abundances found in the star could with a high degree of certainty be assigned to an additional – relative to the solar nebula – infusion of material from a supernova of type II into the material forming the star. This approach of very high signal-to-noise ratio spectrophotometry was employed by Meylan in his dissertation research, with Furenlid as the adviser, in a study of a number of solar-like stars in the solar neighborhood. Abundances relative to the Sun were determined in order to assess mean abundances in the vicinity of the Sun and to probe the extent to which solar abundances are representative of abundances at the Sun's distance from the galactic center. Results are forthcoming in several works, presently in preparation.

An atlas and atmospheric analysis of Sirius is nearing completion by Furenlid in collaboration with R. Kurucz (CFA) and T. Westin. Spectral coverage reaches from 3250Åto 11000Åand the data are of very high precision with a signal-to-noise in the visible of around 500.

Gies collaborated in several projects on the rapid profile variations found in O- and B-type stars. Many hot stars show systematic blue-to-red moving sub-features in their photospheric lines when studied at high S/N. The periodic component of variability is probably the result of photospheric nonradial pulsations (NRP) that can re-distribute the flux in a rotationally broadened profile through the creation of sectors of differing velocity and temperature in the visible hemisphere of the star. The velocity fields associated with NRP could provide seed instabilities in the stellar wind that become amplified at greater distances and may produce the narrow absorption components observed in UV P Cygni lines. Several campaigns of simultaneous optical and UV spectroscopy have been launched to search for correlated variability in the photosphere and wind. An extensive multiwavelength campaign on the targets λ Cep and ξ Per was conducted in October, 1989, using *IUE* (Henrichs, U. Amsterdam; Nichols-Bohlin, CSC) and optical spectroscopy from KPNO (Gies) and Calar Alto (Henrichs). Correlated changes were found between low velocity (He II λ4686) and high velocity (C IV λ1550) wind features in the spectrum of λ Cep, and this star also shows absorption line variability associated with an $l = -m = 5$ mode of NRP. A second campaign was staged in February, 1991, on the stars HD 34656, α Cam, 15 Mon, and HD 93521 that combined *IUE* and ground-based spectroscopy from Calar Alto (Henrichs), Haute Provence (Kaper, U. Amsterdam), KPNO (Gies; Fullerton, Bartol Research Inst.), and Okayama (Ando and Kambe, U. Tokyo). The first target HD 34656 is of special interest since Fullerton, Gies, and Bolton (U. Toronto) find that this star is a radial pulsator with a period of 8.2 hours.

Gies has also participated in similar multi-wavelength campaigns on the line profile variability in Be stars. In this group of rapidly rotators, it is possible that NRP promotes mass loss into a dense circumstellar envelope that produces Balmer emission lines. Two new campaigns have been undertaken. The first, on 28 Cygni, involved *IUE* (Peters, U. Southern California; Henrichs), optical photometry (Percy, Toronto), optical polarimetry (McDavid, U. Texas–San Antonio), and spectroscopy from KPNO (Gies). A 16 hour period associated with an $l = -m = 2$ mode of NRP is found in both the photometry and optical profile variations in this star. A second campaign took place in March, 1991, on η Cen which involved the same participants plus Balona (SAAO: photometry). The optical spectroscopy was obtained with the BME spectrograph and 1.5-m telescope at CTIO (Gies and Hahula). A long term program of Be star spectroscopic monitoring is planned for the new CHARA MTT spectroscopic facility.

Gies, McKibben (Oxford College–Emory U.), Kelton, Opal, and Sawyer (U. Texas–Austin) have completed a study of a lunar occultation of the Be star Pleione which was observed at Hα using a novel method of imaging the spectrum onto a CCD during read-out mode to obtain high time resolution. The occultation light curve shows evidence of a companion star discovered in the CHARA speckle interferometry program, and the Hα flux appeared to disappear some 5.5 msec before the continuum light of the star. The time lag could be due to an asymmetry in the emission cloud with respect to the star.

A study of the He, C, N, and O line strengths in a sample of 39 early B-type stars has been completed by Gies and Lambert (U. Texas–Austin). Abundances have been determined using both LTE and non-LTE models. The He, C, N, and O abundances of the non-supergiant stars are very close to the values found for the Orion Nebula with the notable exception of a few stars which show enhanced N, a signature of CN-cycled material.

Five supergiants all appear N rich and probably He rich. The N enriched non-supergiant stars may be the result of moderate surface enrichment of CN-cycled material through mixing by turbulent diffusion. The evidence for partial mixing of CN-cycled elements among the supergiants suggests that significant mixing can occur before the red supergiant phase.

Wiggs and Gies have investigated the orbital phase related variations in the Hα and He I λ6678 line profiles of the massive binary systems AO Cas, ι Ori, Plaskett's Star, and 29 UW CMa. These stars have strong stellar winds, and in some circumstances the winds will collide and form a bow shock between the stars. *IUE* archival data has been collected on the major UV resonance lines to document the phase variations in the high velocity wind. In all but Plaskett's Star, the winds of the primary stars (those that appear most prominent in the optical spectrum) are found to dominate the wind outflow from these binaries. In Plaskett's Star, the secondary's wind dominates, and the emission and wind line variations are best explained in a model where a wide bow shock surrounds the primary and experiences a Coriolis deflection of approximately 50°. The Hα emission wings show large night-to-night changes in the spectrum of this star which may result from shocks in the wind-wind interaction zone. In the remaining three systems, the companion acts as an occulting disk in the wind of the primary, and Hα emission is observed that originates between the stars (29 CMa, ι Ori) or where the wind strikes the surface of the companion (AO Cas). In every case the P Cygni velocities associated with the terminal velocity of the wind are constant and effectively uncoupled from the orbital velocities of the star of origin.

Wilson has been collaborating with James R. Sowell at GTRI. This research involved the Strömgren photometry of over 300 speckle binary stars using the No. 2 0.9-meter telescope at KPNO. This photometry will be used in conjunction with the differential photometry obtained from speckle observations to determine individual magnitudes for the A and B components of each binary observed. It is hoped that an improved Mass–Luminosity relation can be established from these observations. Wilson has also written an astronomy laboratory manual.

Wingert and Furenlid are developing a reduction package for high S/N CCD spectra, to facilitate the analysis of asymmetric line profiles in early-type stars. Wingert participated in the Conference on CCD Observing and Reduction Techniques held in Tucson in 1991.

EXTRAGALACTIC ASTRONOMY

Miller, Carini, and Noble have expanded the program of investigating the nature of optical microvariability, i.e., variations with timescales of minutes to hours, to various classes of active galactic nuclei. The observations have been carried out at Kitt Peak National Observatory, Lowell Observatory, Capilla Peak Observatory, and Cerro Tololo Interamerican Observatory. The sample of BL Lacertae objects included in this study has now been expanded to a total of twenty–one objects. In addition, five OVV quasars and six Seyfert 1 galaxies have also been investigated. Preliminary results for the sample of BL Lacertae objects suggests that the microvariations are common for this class of AGN and exhibit structures which are quite complex. The timescales for these variations are usually much shorter than a day which suggests that the radiation is generated in a small spatial volume. However, since the microvariations are of relatively small amplitude (typically less than 10%), one should be cautious in interpreting these changes as the result of global variations of the source.

Four of the five OVV quasars which have been investigated have exhibited microvariability. An analysis of these variations is currently in progress. To date, no definitive detection of microvariability has been found for any of the six Seyfert 1 galaxies studied.

Carini completed a Ph.D. dissertation in which he demonstrated for the reality of optical microvariability for a selected sample of blazars utilizing CCD detectors and 1.0–meter class telescopes. The typical rate-of-change observed for these variations was found to be on the order of 0.01 mag/hour. Power density spectrum (PDS) analyses of these variations did not support the hypothesis which has been suggested for some of the x–ray active AGNs that these variations exhibit a 1/f–character, nor were any peaks indicative of periodic behavior found.

Miller and co–workers are also investigating the presence of the existence of microvariability at ultraviolet wavelengths for a small sample of blazars. Observations of PKS 2155–304 have led to the first conclusive evidence for microvariability at ultraviolet wavelengths. Simultaneous optical and *IUE* observations of PKS 2155–304 indicated similar variations occurred at both wavelengths. Thus this blazar is the first for which one is able to demonstrate that significant variability is occurring with similar timescales and amplitudes at both UV and optical wavelengths. This suggests that the emission in both bands arise as a result of the same, or two closely related, physical processes. It would be extremely useful to continue the observations of PKS 2155-304 as well as many other members of our sample. At this time, similar optical/UV observations are scheduled for Markarian 421.

One model, proposed by Wiita, Miller, Carini, and Rosen, would explain the observed microvariability as the result of excess emission produced by *flares* or *hot spots* randomly appearing and disappearing on the accretion disks around supermassive black holes. A similar model, stressing the X-ray fluctuations in AGN, has also been independently proposed by Zhang and Bao and Abramowicz et al. The lack of observed periodicities is in accord with this class of models, which assume contributions from typically 10–100 flaring regions at any given time. Early results reported by Wiita, Miller, Gupta, and S.K. Chakrabarti (Tata Inst. Fundamental Res.–TIFR) yield good matches to the PDS observed for sources where the data has been taken with high sampling frequencies over several consecutive nights. Mangalam has joined Wiita and Gupta in further investigations of the statistical properties of these phenomenological models. Chakrabarti and Wiita are investigating the possibility that non-axisymmetric instabilities within accretion disks, perhaps triggered by the passage of a massive star, could grow to yield weak spiral shocks. Preliminary hydrodynamical simulations indicate that

such shocks do form, fragment, and reform on timescales adequate to explain much of the microvariability. Additional physical models for such *flares*, involving magnetic instabilities in the disk, will be undertaken by Wiita and Mangalam.

Rosen and Wiita continued their study of the development of radio galaxies, using both Monte Carlo simulations involving boundary following computer runs and sophisticated two-dimensional hydrodynamics in collaboration with M. Norman (U. Illinois), and, more recently, Mangalam. The Monte Carlo runs were capable of matching the distributions of linear size of radio galaxies as functions of redshift and radio power if a low density baryonic intergalactic medium is present, but can also give adequate fits if there is essentially no IGM. The hydrodynamical simulations have been extended to a wide range of jet and galactic halo parameters, and recent work has used finer zones to give higher resolution to the simulations. While we confirmed most of the conclusions from our earlier work, we have now also shown that jets whose supply of matter and momentum is cut off, either within the galactic halo or out in the ICM, continue to move outwards for substantial distances before a rarefaction wave completely disrupts them; such starved jets must be very weak synchrotron sources. We also showed that jets of wider opening angles and concomitantly higher powers will propagate somewhat faster than our simple analytical models would predict. Rosen finished his Ph.D. dissertation with a careful statistical comparison between the analytical models (discussed below), numerical simulations, and observations.

Wiita continued his analytical studies of radio galaxy propagation with Gopal-Krishna (TIFR), and demonstrated that if the efficiency with which beam power is converted into radio power is taken into account, then the analytical models give superb fits to the observed relations between radio power, redshift, and linear-size for powerful radio galaxies. These models also allow one to understand Compact Steep Spectrum radio galaxies as relatively weak jet sources whose emission is enhanced and whose growth is retarded because the jets are plowing through a denser ISM. The fact that CSS galaxies are more common at higher redshifts can be explained if such galaxies undergo more interactions, as expected.

Gopal-Krishna and Wiita have also been examining models for rapid variability in BL Lacertae objects in terms of bending relativistic beams. They found that very small deviations in viewing direction towards a shock propagating down such a beam would lead to correlated changes in the total observed flux, the fractional polarization, and the apparent transverse velocity. Proposals for frequent monitoring of selected blazars at high frequencies with the VLBA will be submitted to test these model predictions.

Along with D.J. Saikia and A.K. Singal (TIFR), Wiita has been examining statistical indicators that bear upon the "unified" models for radio sources, quasars, and blazars. They found that the relation between core flux and linear size, the degree of non-collinearity, and the magnitude of variability all support the basic unification schemes. Wiita and Saikia are continuing their analysis of an interesting wide-angle-tailed quasar, 1226+216, where there is evidence for the interaction of radio jets with companion galaxies, as well as the more usual ram-pressure bending of the jets.

V. Krishan (Indian Inst. Astrophys.) and Wiita have continued their investigations of plasma processes in the cores of AGN; most recently they have compiled a catalog of the timescales of expected variability that should be produced by different processes including Raman scattering, solar-like flares on accretion disks, and hydromagnetic waves.

Chakrabarti and Wiita have just completed a preliminary effort at fitting the IR–UV spectral energy distributions of various AGN using transonic accretion flow models developed by Chakrabarti. These lead to accretion disks which contain an essentially standing shock in the inner region, interior to which excess UV emission is emitted, while much of the IR excess could arise from an extended "normal" accretion disk at larger radii. These fits seem to be superior to the best models published based upon standard accretion disks; although they have not yet incorporated Fe II line emission and some relativistic features, it is expected that these corrections will only improve the fits obtained so far.

Howard completed her Ph.D. dissertation in which the galaxy M51 was modelled utilizing an N–body simulation code to investigate the hypothesis that NGC 5195 is tidally interacting with M51 and is responsible for producing th spiral structure in the latter galaxy. An extraordinarily good fit to the structure of M51 has been obtained as a result of this simulation. Further work on this problem is continuing in collaboration with G.G. Byrd (U. Alabama).

CONFERENCE ON VARIABILITY OF ACTIVE GALACTIC NUCLEI

Miller and Wiita co-hosted a meeting on 2–4 May 1990, held at GSU. Over 80 scientists attended, with more than 30 participants coming from overseas. The emphasis was on observations of variability at all wavelengths, and exciting new results on extremely rapid changes in the radio and optical bands were presented, although there were also many theoretical interpretations put forward. The first discussions of the coordinated campaigns on NCG 5548 were highlights of the meeting. Thirteen invited and 17 contributed oral papers were read, and 35 posters were presented. The proceedings, including poster papers and discussions, were published by Cambridge University Press in May 1991.

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