

**University of Texas McDonald
Observatory and Department of Astronomy**
Austin, Texas 78712

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This report covers the period 1 September 1998–31 August 1999.

1. ORGANIZATION, STAFF, AND ACTIVITIES

1.1 Description of Facilities

The astronomical components of the University of Texas at Austin are the Department of Astronomy, the Center for Advanced Studies in Astronomy, and McDonald Observatory at Mount Locke. Faculty, research, and administrative staff offices of all components are located on the campus in Austin. The Department of Astronomy operates a 23-cm refractor and a 41-cm reflector on the Austin campus for instructional, test, and research purposes.

McDonald Observatory is in West Texas, near Fort Davis, on Mount Locke and Mount Fowlkes. The primary instruments are 2.7-m, 2.1-m, 91-cm, and 76-cm reflecting telescopes and a 76-cm telescope dedicated to laser ranging to the moon and artificial satellites. The new 9.2-m Hobby•Eberly telescope is substantially completed.

McDonald Observatory is also a partner in the Caltech Submillimeter Observatory on Mauna Kea, Hawaii.

1.2 Administration

Chris **Sneden** is Chair of the Department of Astronomy, with Dan **Jaffe** as Assistant Chair. Frank N. **Bash** is the Director of McDonald Observatory and the Center for Advanced Studies in Astronomy, Thomas G. **Barnes III** is Associate Director, and Phillip W. **Kelton** and Edwin S. **Barker** are Assistant Directors. Mark **Adams** is the resident Superintendent.

1.3 Teaching and Research Personnel

(In the lists that follow, asterisks denote Mount Locke residents.)

Academic

Named Chairs: David L. **Lambert** (Isabel McCutcheon Harte Centennial Chair in Astronomy); Steven **Weinberg** (Regents Professor and Jack S. Josey–Welch Foundation Chair in Science).

Named Professors: Frank N. **Bash** (Frank N. Edmonds Regents Professor in Astronomy); David S. **Evans** (Jack S. Josey Centennial Professor Emeritus in Astronomy); Neal J. **Evans II** (Edward Randall, Jr. Centennial Professor), William H. **Jefferys** (Harlan J. Smith Centennial Professor in Astronomy); R. Edward **Nather** (Rex G. Baker, Jr. and McDonald Observatory Centennial Research Professor in Astronomy); Edward L. **Robinson** (William B. Blakemore II Regents Professor in Astronomy); John M. **Scalo** (Jack S. Josey Centennial Professor in Astronomy); Gregory A. **Shields** (Jane and Roland Blumberg Centennial Professor in

Astronomy); and J. Craig **Wheeler** (Samuel T. and Fern Yanagisawa Regents Professorship in Astronomy).

Professors: Michel **Breger** (adjunct), James N. **Douglas**, Paul M. **Harvey**, Dan **Jaffe**, John **Lacy**, Paul **Shapiro**, Chris **Sneden**, Derek **Wills**, and Don **Winget**.

Associate Professors: Harriet **Dinerstein** and R. Robert **Robbins, Jr.**

Non-Academic

Senior Research Scientists: Thomas G. **Barnes III**, George F. **Benedict**, William D. **Cochran**, Laurence M. **Trafton**, and Robert G. **Tull**.

Research Scientists: Edwin S. **Barker**, Anita L. **Cochran**, Robert **Duncan**, Artie P. **Hatzes**, Gary **Hill**, Peter **Höfflich**, Daniel F. **Lester**, Hugo **Martel**, Frank **Ray**, Peter J. **Shelus**, Verne **Smith**, Jocelyn **Tomkin**, and Beverley J. **Wills**.

Research Associates: Mark **Cornell**, James **Fowler***, Niall **Gaffney**, Mary Kay **Hemenway**, Grant **Hill***, Phillip **MacQueen**, Alvin L. **Mitchell**, Ed **Nelan**, Francois **Piché***, Matthew **Richter**, Matthew **Shetrone***, William **Spiesman**, Darrell **Story**, and Ron **Wilhelm**.

Postdoctoral Research Associates and Other Visiting Staff: Cecilia **Colomé**, Peter **Diener**, Oleg **Ershov**, John **Jurcevic**, Ruth **Knill-Dgani**, Marc **Kutner**, Judit **Györgyey Ries**, Yaron **Sheffer**, Jihad **Touma**, Daniel **Vanden Berk**, Lifan **Wang**, William **Welsh** and Vincent **Woolf**.

1.4 Senior Research Support and Administration

HET Commissioning Manager: Thomas **Barnes**.

HET Facilities Manager: Mark **Adams*** (*ad interim* to May 1999); Craig **Nance*** (from May 1999).

Development Officer: Joel **Barna**.

Director of the McDonald Public Information Office: Sandra L. **Preston**.

McDonald supervisors: John **Booth** (mechanical engineering), Edward **Dutchover, Jr.*** (administrative support), Earl **Green*** (observing support), Tom **Brown*** (physical plant), Mark **Cornell** (computing systems), Phillip **MacQueen** (CCD development), Alvin L. **Mitchell** (engineering support), and Jerry R. **Wiant*** (MLRS).

Administrative Services Officer: Cecilio **Martinez**

1.5 Board of Visitors

Mark **Bivins** was Chair of the McDonald Observatory and Department of Astronomy Board of Visitors, with Lillian **Murray** Vice Chair and Francis **Wright, M.D.**, Secretary.

1.6 Visitors and Affiliations

The *Antoinette de Vaucouleurs Centennial Lectureship in Astronomy* was presented this year by Dr. Peter **Goldreich**. Dr. Goldreich was presented with the medal at a departmental colloquium. In addition, he presented a public talk on campus.

Jim **Truran** was the Beatrice Tinsley Visiting Professor. He presented many informative lectures in the department and worked extensively with several members of the faculty and research staff.

The following people visited the department for extended periods:

- Tim **Beers** – Michigan State University
- Robert **Benjamin** – University of Wisconsin
- Chen Hanliang** – Nanjing Astronomical Instruments Research Center, Chinese Academy of Sciences
- John **Cowan** – University of Oklahoma
- Simona **di Tomasa** – Oss. Astr. Bologna
- Imaculata **Dominguez** – University of Granada
- Rafael **Gratton** – Padova Observatory
- Jennifer **Johnson** – UC Santa Cruz
- Robert **Kraft** – UC Santa Cruz
- Ed **Langer** – Colorado College
- Kathleen **Matyn** – Belgium (Exchange Student)
- Michael **Montgomery** – Institute for Astronomy, University of Vienna, Austria
- John **Norris** – ANU Mt. Stromlo Observatory
- S. Kepler **Olivera** – Instituto de Fisica, Universidade Federal do Rio Grande do Sul, Brazil
- Premana **Premadi** – Astronomical Institute, Tohoku University, Japan
- George **Preston** – Carnegie Observatory
- Francesca **Primas** – ESO
- Friedrich **Theilemann** – University of Basel
- Ted **von Hippel** – Gemini Observatory
- Jenny **Westin** – University of Uppsala, Sweden (Exchange Student)
- Insu **Yi** – Korean Institute for Advanced Studies
- Zhu Yongtian** – Nanjing Astronomical Instruments Research Center, Chinese Academy of Sciences
- William **Jefferys** was on leave at Duke University, where he worked with Jim Berger and Peter Müller of Duke's Institute for Statistics and Decision Sciences, on applications of Bayesian model selection and model averaging, using Markov Chain Monte Carlo (MCMC) techniques, to the Cepheid distance scale and to CCD image centroiding.
- Greg **Shields** spent February – June, 1999 at the Workshop on Black Hole Astrophysics at the Institute for Theoretical Physics, University of California, Santa Barbara.
- Cecelia **Colomé** was associated with the astronomy programs at both The University of Texas and UNAM, Mexico. She is currently working to publish her lecture notes from a graduate course on "Polarimetry With Applications in Astronomy," which was given at UNAM in August 1998.

1.7 Special Activity: 193rd American Astronomical Society Meeting

The 193rd meeting of the American Astronomical Society was held 5–9 January 1999 at the Austin Convention Center. It was hosted by McDonald Observatory and the Department of Astronomy of the University of Texas at Austin. The chair

of the Local Organizing Committee was Anita **Cochran**. Approximately 100 volunteers helped with the meeting.

The meeting was attended by approximately 1800 people, with over 1000 abstracts submitted. One of the highlights of the meeting was an invited talk and an oral session on the new Hobby•Eberly Telescope.

1.8 Awards, Honors, and Special Activities

Robert **Duncan** received the University Co-Op Research Paper Award for the best research paper at the University of Texas in 1998. The honored paper is "Global Seismic Oscillations in Soft Gamma Repeaters" which appeared in *Astrophysical Journal Letters* (May 1998). Craig **Wheeler** won the Dad's Association of the University of Texas at Austin Teaching Fellowship and also received the President's Association Teaching Excellence Award. Robert **Robbins** was awarded the College of Natural Sciences Teaching Excellence Award. The Board of Visitor's Teaching Excellence award went to Jimmy **Welborn**. The staff excellence award for Astronomy was given to Natasha **Papousek** and for McDonald Observatory was given to Tim **Jones**.

Craig **Wheeler** was a Vice President of the American Astronomical Society. Frank **Bash** was President of the Astronomical Society of the Pacific and finished a term as councillor of the American Astronomical Society. Mary Kay **Hemenway** was selected Secretary to the Board of the Astronomical Society of the Pacific in February 1999. Peter **Shelus** served his 21st year as Treasurer of the American Astronomical Society's Division on Dynamical Astronomy. Edwin **Barker** served as Past-Chair for the Division for Planetary Sciences of the American Astronomical Society. William **Jefferys** was elected to a term on the committee of the Division on Dynamical Astronomy of the American Astronomical Society.

Anita **Cochran** served on the Dannie Heineman Prize committee of the American Astronomical Society and was its chair in 1999. She is also a member of the US National Committee of the International Astronomical Union.

Mary Kay **Hemenway** was on the American Astronomical Society Shapley Lectureship Program Advisory Committee and a member of the American Geological Institute Advisory Board for "Earth Science in the Community."

Frank **Bash** chaired the Hobby•Eberly Telescope Board of Directors and is their representative on the Southern African Large Telescope Board of Directors. Frank **Bash** was the Member Representative from the University of Texas at Austin to the Associated Universities for Research in Astronomy and was a member of ACCORD, the AURA-sponsored group of the directors of the large ground-based, optical-infrared observatories. He also was a member of the NOAO MAXAT Steering Committee.

Peter **Shelus** was reappointed to the Directing Board of the International Earth Rotation Service to represent worldwide Lunar Laser Ranging efforts. He was also appointed to the Governing Board of the International Laser Ranging Service as Lunar Laser Ranging representative and deputy coordinator within the ILRS's Analysis Working Group. Craig **Wheeler** was a General Member of the Board of Trustees of the Aspen Center for Physics.

Harriet **Dinerstein** served as a member of the External Science Review panel for NASA's Next Generation Space Telescope (NGST).

Rica **French** served on the Organizing Committee, as the Volunteer Coordinator, of Austin Expanding Your Horizons (EYH) in Science and Mathematics conferences. EYH, the flagship program of the national Math/Science Network, is designed to "nurture girls' interest in science and math courses and encourage them to consider science and math based career options." (For more information, see www.scicomp.com/eyh)

Matt **Richter** served as a member of the preliminary design review committee for the Airborne Infrared Echelle Spectrometer (AIRES) being built at Ames as a facility instrument for SOFIA. Robert **Tull** participated as the invited outside reviewer in a two-day design review for a spectrograph planned for the Spanish 10-meter telescope to be built on La Palma, in the Canary Islands. The review was held at La Laguna on Tenerife, Canary Islands.

Peter **Shelus** was honored by the International Astronomical Union Minor Planet Center with their naming Asteroid (7925) Shelus, for his contributing work to Astronomy in general and his work in astrometry and dynamics in particular. Edwin **Barker** was honored by the International Astronomical Union's Minor Planet Center with their naming Asteroid (7868) Barker, for his work on physical observations of both major and minor planets and his contributions to the operation of McDonald Observatory.

Frank **Bash** chaired an AASC "Cross Panel" for the Decade Study on the NSF-funded National Observatories, and he is a member of the Education and Policy Panel of the Astronomy and Astrophysics Survey Committee.

William **Cochran** served as a member of the NASA Origins SubCommittee. Edwin **Barker** served on NASA's Planetary Astronomy Management Operations Working Group. Anita **Cochran** served on NASA's Origins of Planetary Systems management operations working group. Mary Kay **Hemenway** was a member of the SOFIA education and Public Outreach Working Group.

Craig **Wheeler** was a member of the International Organizing Committee of the Texas Symposium on Relativistic Astrophysics. He was also on the Scientific Organizing Committee for the meeting "Twenty Five Years of The Disk Instability Model," Kyoto Japan.

Anita **Cochran** wrote the section on cometary comae for the IAU Commission 15 Triennial Report. Craig **Wheeler** was on the Organizing Committee for IAU Commission 41, Close Binary Systems.

Chris **Snedden** served on the NOAO Telescope Allocation Committee. Anita **Cochran** served on the solar system panel of the NOAO Telescope Allocation Committee.

Chris **Snedden** was a Scientific Editor for the *Astrophysical Journal*. William **Cochran** was a receiving editor for *New Astronomy*. William **Jefferys** serves as an Associate Editor of *Celestial Mechanics*. Cecilia **Colomé** collaborated with the StarDate radio program as translator and editor for the Spanish-language version, *Universo*. Craig **Wheeler** was a co-editor, along with S. Mineshige, of the book *Disk Instabilities in Close Binary Systems* (Universal Academy Press,

Tokyo). Mary Kay **Hemenway** was a consultant to *Choice*, the journal of college libraries. Larry **Trafton** served as an Associate Editor of *Icarus*. Anita **Cochran** was an advisor to the Planetary Data System's Small Bodies Node.

Robert **Robbins** led a group of college professors to investigate archaeoastronomical sites in Belize and Guatemala under the sponsorship of the NSF-Chautauqua program.

2. ACADEMIC AND EDUCATIONAL PROGRAM

2.1 Graduate Program

The Graduate Studies Committee Chairman was Neal **Evans** with Graduate Advisor Craig **Wheeler**. The Fred T. Goetting, Jr. Memorial Endowed Presidential Scholarship was awarded to Marcel **Bergmann**. The David Alan Benfield Memorial Fellowship was awarded to Cynthia **Froning**. The Frank N. Edmonds, Jr. Memorial Fellowship was awarded to Juntao (Michael) **Yuan**. Inese **Ivans** was the recipient of the Board of Visitor's Second Year Project Award.

Graduate students in 1998–1999 were Nairn **Baliber**, Marcel **Bergmann**, Anirban **Biswas**, Jungyeon **Cho**, Lara **Cross**, Greg **Doppmann**, Erik **Fierce**, Rica **French**, Cynthia **Froning**, Pamela **Gay**, Thomas **Greathouse**, D. Andrew **Howell**, Inese **Ivans**, Renee **James**, Luke **Keller**, Eric **Klumpe**, Feng **Ma**, Travis **Metcalfe**, Michael **Moscoso**, Anjum **Mukadam**, Atsuko **Nitta**, Divas **Sanwal**, Zhaohui **Shang**, Yancy **Shirley**, G. Roger **Stanley**, Joseph **Tufts**, Marsha **Wolf**, Juntao **Yuan**.

Doctoral Dissertations: Seven Ph.D. degrees in astronomy were awarded in 1998–1999:

Cynthia **Froning** – "Infrared Properties of Interacting Binary Systems" (Edward Robinson, Chair). Dr. Froning is currently a Post-Doc at Space Telescope Science Institute.

Luke **Keller** – "New Devices and Techniques for High Resolution IR Spectroscopy and A New Study of Old Stars" (Dan Jaffe, Chair). Dr. Keller is currently a Post-Doc at Cornell University

Eric **Klumpe** – "Mini-Telescope Survey of Molecular Hydrogen Fluorescence in the ISM" (Dan Jaffe, Chair). Dr. Klumpe is currently at Middle Tennessee State University.

Michael **Montgomery** – "The Evolution and Pulsation of Crystallizing White Dwarf Stars" (Don Winget, Chair). Dr. Montgomery is currently a Post-Doc at The University of Vienna Austria.

Michael **Moscoso** – "Electron-Positron Pair Winds" (Craig Wheeler, Chair).

Divas **Sanwal** – "Optical Study of Pulsars" (Edward Robinson, Chair). Dr. Sanwal is currently a Post-Doc at Penn State University.

Joseph **Wang** – "A One Dimensional Model of Convection in Type II Supernovae" (Craig Wheeler, Chair). Dr. Wang is a consulting software engineer for a geological company in Austin.

Master's Theses: Six Master's degrees in astronomy were earned in 1998–1999:

Marcel **Bergmann** "Morphology and Evolution of E and SO Galaxies: HST Observations of a Cluster at $z=0.4$ " (Greg Shields, Inger Jørgensen Chairs).

Lara **Cross** “The Polarization of 3C 273” (Bev Wills, Derek Wills, Chairs).

Erik **Fierce** “Searching for Accretion Disk Signatures in AGN” (Greg Shields, Chair).

Pamela **Gay** “Variable Stars in the Ursa Minor Dwarf Spheroidal Galaxy: A Story of Stellar Formation as Told by the Horizontal Branch” (Edward Robinson, Chair).

Inese **Ivans** “Chemical Composition of Globular Cluster M4” (Chris Sneden, Chair).

G. Roger **Stanley** “Exploration of the Lithium-Star-Planet Connection in Solar Systems” (Chris Sneden, Chair).

2.2 Undergraduate Program

Derek Wills was the chair of the Undergraduate Studies Committee; Bob Robbins served as undergraduate advisor. There were 42 astronomy majors this year and 1 student received a BA.

Patrick **Young** was awarded the Outstanding Graduating Senior Award. Shizuka **Akiyama** was the winner of the Karl G. Henize Memorial Scholarship in Astronomy. Erik **Brugmyer** was the winner of the Board of Visitors Undergraduate Scholarship in Astronomy.

2.3 Educational Services

The nine-inch refractor (directed by Feng **Ma** and Divas **Sanwal**) was visited by 1100 people during public tours. Forty-six school groups totaling over 1300 elementary/secondary students and teachers participated in Solar Telescope field trips presented by Lara **Eakins**. Regular star parties attracted 1100 people. Special lectures in astronomy had an attendance of 130. The SkyWatcher’s Report logged almost 3200 calls throughout the year.

Mary Kay **Hemenway** and Lara **Eakins** represented the Department at ten other events, such as Austin Science Fun Day, UT Interactive, and Amistad National Recreational Area. About two thousand people were served through these events

3. RESEARCH PROGRAM

3.1 The 9.2-Meter Hobby•Eberly Telescope (HET)

In the past year, the Hobby•Eberly Telescope has reached the end of its Commissioning phase and is expected to enter “Early Operations” in October 1999. The Early Operations phase emphasizes research operation of the HET approximately 50% of each lunation, with instrument commissioning and facility improvements occupying the remainder of the time.

In September 1999, the HET is operating at specification in pointing, tracking, autoguiding, and all other essential electro-mechanical functions. The primary mirror is in operation with a full array of 91 segments. The array is routinely aligned using the Center of Curvature Alignment System (CCAS, a shearing interferometer) in about 10 minutes to a median mirror quality of better than 1.1 arcseconds (50% encircled energy). An intensive program to improve primary mirror quality to specification, $EE(50) = 0.6$ arcsecond, is continuing.

The Prime Focus Instrument Platform (PFIP) was brought nearly to completion this year. PFIP rides on the prime focus tracker and incorporates subsystems for acquisition and guiding, fiber handling, the Spherical Aberration Corrector, and support for the prime focus Low Resolution Spectrometer. Except for improvements to the instrument calibration system, light baffling, and the atmospheric dispersion corrector, the PFIP is now complete.

The Low Resolution Spectrometer (LRS, PI Gary Hill, McDonald Observatory) entered instrument commissioning in April 1999. With the exception of the yet-to-be completed multi-object capability, the LRS is now in research operation. The first published result from the HET used the LRS to confirm supernova 1999bv in MCG +10-25-14 (IAU Circular 7186, 1999). Additional papers from commissioning science in April – June 1999 are in preparation.

Progress continued on the High Resolution Spectrometer (HRS, PI Robert Tull, McDonald Observatory). With the exception of coating and mounting the camera optics, the optomechanical portion of HRS is complete and installed. The detector system is well into construction with delivery expected early in 2000.

The Medium Resolution Spectrometer (MRS, PI Larry Ramsey, Pennsylvania State University) continued to make progress toward a delivery in 2000.

Observing time on the HET will be offered to the US national community starting in June 2000. NOAO will handle all interactions with national researchers. Approved projects from the national community will be entered into the HET queue and observed on the same basis as projects from the five partner institutions. In the first competition for time, LRS and HRS will be available.

A contract was let in October 1999 to Marshall Space Flight Center/Blue Line Engineering to design, fabricate, and install a Segment Alignment and Maintenance System (SAMS) on the primary mirror array. SAMS will provide closed loop control of the 91 segments and their global radius of curvature. We expect SAMS to reduce the need to align the segments using the CCAS from hourly to twice monthly. Completion of SAMS is expected early in 2001.

New staff who joined the HET operations team in 1999 were Ben Rhoads (Telescope Operator) and Tom Worthington (Mechanical Engineer). Francois Piché departed the HET staff on 31 August 1999. Craig Nance was promoted to HET Facility Manager on 1 May 1999. The HET is a joint project of five universities: The University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universität München, and Georg-August-Universität Göttingen.

3.2 Observing Conditions at McDonald Observatory

A summary of the hours scheduled, hours lost to poor weather, hours lost to telescope/instrument problems and hours assigned to maintenance is given in Table 1. Scheduled hours are measured from civil twilight to civil twilight, plus any especially scheduled daytime hours. (The daytime hours for all four telescopes together only total 51 hours.)

TABLE 1. Utilization Statistics for McDonald Observatory Optical Telescopes (1997–1998) (hours)

	2.7-m		2.1-m		0.9-m		0.8-m	
a)	4039		4015		4008		4019	
b)	2303	(57%)	2020	(50%)	233	(6%)	1200	(30%)
c)	1248	(31%)	1373	(34%)	127	(3%)	856	(21%)
d)	113	(3%)	48	(1%)	0	(0%)	15	(0%)
e)	216	(5%)	133	(3%)	0	(0%)	0	(0%)
f)	159	(4%)	442	(11%)	3648	(91%)	1938	(48%)

a) Available; b) Observed; c) Lost to weather;
d) Lost to telescope/instrument problems;
e) Scheduled maintenance; f) Other

Category “Other” is comprised primarily of time when the telescope was not scheduled or no program object was available.

The 2.7-m telescope records may be used to infer an estimate of the fraction of time the sky was suitable for spectrometry or imaging. After correcting for downtime due to maintenance, equipment, etc., the usable time is estimated as 65% for the last fiscal year. This value may be compared with 66% for the previous year, and 62.7% for an eighteen year mean. From 0.9-m telescope statistics for photometric observing in 1981–1992, the photometric weather at McDonald Observatory has averaged 39.8% of the available hours. The 0.9-m telescope is now closed to regularly scheduled programs and is only used for special projects.

3.3 Scientific Results

3.3.1 Instrumentation:

A new Telescope Control System (TCS) for the 2.7-meter Harlan J. Smith (HJS) Telescope was put into service in April 1999. The HJS Telescope was built in the 1960s and the main components of its old control system were over 30 years old. In the upgraded TCS, the underlying mechanical system was retained, and modern encoders, electronics, servo subsystem, computer control, autoguiders, software, command language for access by instruments, and graphical user interfaces were implemented. Delta Tau’s PMAC embedded servo controller was used. The new TCS system is highly integrated and adds a great deal of new functionality for observers. Many obsolete components (for example wiring, handpaddles, encoders, consoles, computers and software) were replaced to improve maintainability, including most of the original 1960s-era electronics. Integration, validation, and commissioning presented special challenges, since the telescope is very much general purpose with a wide variety of instruments, foci, and observing modes, and was taken out of service only for periodic engineering runs but not for any extended period of downtime. The new TCS system has been in regular use since April 1999. Primary participants in the

TCS project were P. Kelton, M. Cornell, W. Spiesman, R. Ricklefs, P. S. Odums, E. Green, M. Ward, M. Blackley, A. Mitchell, and J. F. Harvey.

J. Lacy, M. Richter, T. Greathouse, D. Jaffe, and M. K. Hemenway continued development of the Texas echelon-cross-echelle spectrograph (TEXES) and the SOFIA echelon-cross-echelle spectrograph (EXES), two high resolution, mid-infrared spectrographs. TEXES is designed for ground-based operation, while EXES is being designed for the Stratospheric Observatory for Infrared Astronomy. 36 inch (TEXES) and 40 inch (EXES) echelon gratings have been delivered by Hyperfine, Inc. Lab tests show that both gratings achieve the design resolving power of $R = 10^5$. TEXES was tested on the Harlan J. Smith telescope at McDonald Observatory, and detected C_2H_2 emission lines from Jupiter’s stratosphere. It is currently being improved with a larger detector, new electronics, and new software.

R. Tull and associates brought the HRS, the high resolution spectrograph of the HET, near completion this year. The Newport optical bench and the thermal isolation chamber were assembled at the HET in December 1998. In March–April 1999, the camera lenses, the second collimator mirror, and the last of three diffraction gratings were completed and delivered. Tests of the control electronics and pneumatics were carried out in August 1999, followed by assembly of the optical system (less camera) at the HET. The camera lenses await anti-reflection coatings and assembly. Two CCDs have been ordered from EEV and are due for delivery in December 1999. The CCD dewar and operating system are nearing completion. First-light commissioning and operation of the completed HRS are anticipated in early 2000.

G. J. Hill and P. MacQueen delivered the HET Low Resolution Spectrograph. This instrument is a very efficient imaging grism spectrograph with multi-object capability that covers 360–1000 nm, with a future extension to 1350 nm. Resolving powers between $R=500$ and 1500 are currently available, and the instrument images the 4 arcminute field of view of the HET. First light was obtained in April 1999, followed by 2 months of commissioning observations in May and June. Objects observed included quasar and L dwarf candidates from the Sloan Digital Sky Survey, high redshift cluster candidates, AGN, and supernovae.

C. Colomé designed and constructed a new polarimeter mode for CoolSpec, the near-infrared spectrograph at McDonald Observatory. The polarimeter is now available to the general astronomical community.

While visiting the department for six months, Zhu Y. worked with R. Tull while developing spectrograph designs for the Chinese LAMOST telescope project. He also participated in the assembly of the high resolution spectrograph of the Hobby•Eberly Telescope.

Chen H. worked with McDonald engineer F. Ray on a mirror support design for LAMOST.

3.3.2 Extrasolar Planetary Systems:

The McDonald Observatory Planetary Search program, operated by W. Cochran and A. Hatzes, has continued on the McDonald Observatory 2.7-m telescope. This program surveys about 140 nearby F, G, K, and M dwarfs for Jovian

mass companions. A companion southern-hemisphere survey, operated in collaboration with M. Kürster, M. Endl, S. Els (ESO), K. Dennerl, and S. Döbereiner (MPI Garching) has discovered a planetary companion to the young G0V star ι Horologii. The planet has an orbital period of 320 days, and a minimum mass of 2.26 Jupiter masses. With an eccentricity of 0.16 and a semi-major axis of 0.92 AU, this object moves in the most Earth-like orbit found so far among extrasolar planets. Moreover, with an estimated age between 30 My and 2 Gy, ι Hor is the youngest star with a known planet. The ESO planetary search program has also placed very tight constraints on possible planetary companions to the nearest star to our sun – Proxima Centauri. Differential radial velocity measurements of Prox Cen collected over 4 years with the ESO CES with a mean precision of 54 m s^{-1} show no evidence of a periodic signal that could corroborate any claims of the existence of a sub-stellar companion. We put upper limits (97% confidence) to the companion mass ranging from 1.1 to 22 Jupiter masses at orbital periods of 0.75 to 3000 days, i.e. separations of 0.008 – 2.0 AU from Prox Cen. These mass limits concur with limits found by precise astrometry which strongly constrain the period range of 50–600 days and the mass range to 1.1–0.22 Jupiter masses. Combining both results we exclude a brown dwarf or super-massive planet at separations 0.008–0.69 AU from Prox Cen. We also find that, at the level of our precision, the RV data are not affected by stellar activity.

The Hubble Space Telescope Astrometry Science Team has completed its search for sub-stellar companions to Proxima Centauri and Barnard’s Star (AJ, **118**, 1086). Once low-amplitude instrumental systematic errors are identified and removed, our companion detection sensitivity is less than or equal to one Jupiter mass for periods longer than 60 days for Proxima Cen. Between the astrometry and the Kürster *et al.* (1999, A&A, **344**, L5) radial velocity results we exclude all companions with $M > 0.8M_{Jup}$ for the range of periods $1 < P < 1000$ days. For Barnard’s Star our companion detection sensitivity is less than or equal to one Jupiter mass for periods longer than 150 days. Our null results for Barnard’s Star are consistent with those of Gatewood (1995 Ap&SS, **223**, 91).

3.3.3 Solar System:

Working with University of Texas Aerospace engineers, D. Goldstein and S. Nerem, E. Barker proposed to NASA and then coordinated observations of the controlled crash of NASA’s Lunar Prospector spacecraft into a permanently shadowed crater near the south pole of the Moon on July 31, 1999. Over 10 observing teams at major ground- and space-based observatories around the world participated in the campaign to detect direct evidence of water ice on the floor of the crater. The impact produced no observable evidence of a dust plume, H₂O plume or its photo-dissociation byproduct OH. The lack of positive evidence from this ambitious, but low success probability, attempt to confirm the indirect evidence for water ice, leaves open the question of the source of the enhanced hydrogen abundances seen by Lunar Prospector in the polar regions of the Moon.

A. Cochran, with F. Vilas (NASA/JSC) and K. Jarvis

(Lockheed-Martin), has explored the relationship between Vesta and the small asteroids suggested by Binzel and Xu (1993, *Science* **260**, 186) to be chips off Vesta. Using the 506.5-nm pyroxene feature as a tracer, they have shown that only some of the chips (or Vestoids) truly resemble Vesta. The most similar objects are exterior to Vesta’s orbit, between Vesta and the 3:1 mean motion resonance with Jupiter. They investigated the dynamical possibilities for forming these Vestoids from Vesta and the applicable lifetimes of these objects. The Vestoids represent important tracers of the collisional evolution of the asteroid belt.

E. Howell (Arecibo), F. Vilas (NASA/JSC) and A. Cochran have been exploring the use of mineral absorption bands in the optical region of the spectrum as a tracer of hydrated minerals in the asteroid belt. Hydration features have typically been discovered at $3 \mu\text{m}$ in asteroid spectra. However, it is more difficult to obtain IR observations of asteroids and fainter asteroids cannot be observed in the IR. Thus, they are seeking an optical proxy for determining the hydration history of the main asteroid belt. If an optical counterpart to the $3 \mu\text{m}$ band can be found that is well correlated with the $3 \mu\text{m}$ band, many more asteroids can be observed. This will allow the determination of where in the solar nebula conditions existed which were wet enough to hydrate minerals.

A. Cochran and E. Barker completed a study of comet 19P/Borrelly. This comet is a potential target of the DS1 spacecraft in 2001. The observations compiled cover three apparitions of Borrelly, with Image Dissector Scanner spectra of Borrelly in 1981 and 1987 and Large Cassegrain Spectrograph (long slit CCD) observations of Borrelly in 1994. They showed that Borrelly is a member of the class of comets depleted in C₂ and C₃ relative to OH and CN.

A. Cochran, E. Barker and W. Cochran have analyzed high spectral resolution observations of Hale-Bopp and DeVico to determine if there is any N₂⁺ in the spectra. N₂⁺ is an important molecule to study because it traces the nitrogen compounds in comets and because N₂ is deposited in ices in an analogous manner to argon at the deposition temperatures of comets (50K). If we understand N₂⁺ in comets, we can understand argon. This is important because it is believed that differences in noble gas abundances in the terrestrial planets is caused by delivery of volatiles and noble gases from cometary impacts.

A. Cochran and M. Festou (SwRI-Boulder) have begun investigating the cometary ratio of ¹²CN/¹³CN using high spectral resolving power observations of Hale-Bopp, DeVico and Hyakutake obtained at McDonald Observatory. A resonance fluorescence model with collisional effects is being used to analyze these data.

L. Trafton proposed an explanation of why Triton’s CH₄ spectrum shows lines with a shift characteristic of a dilute solid solution of CH₄ in N₂, while Pluto’s spectrum shows that these lines are shifted at intermediate positions between the solid solution and pure CH₄ gas. The explanation is that CH₄ ice is more abundant on Pluto’s surface, so that it is saturated in the N₂ ice. The excess leads to a component of the ice mixture that is a dilute solid solution of N₂ in CH₄ ice. This leads to a disk-averaged spectrum where the CH₄

wavelength shifts are intermediate to the two cases. On Triton, the CH_4 abundance is inadequate to saturate the N_2 ice, so only the $\text{CH}_4:\text{N}_2$ solid phase results.

With S. Miller (UCL), L. Trafton obtained further NSF-Cam near-IR images of Uranus' H_2 and H_3^+ emissions at the IRTF in July using the telescope's new tip-tilt capability to reveal a more detailed distribution of the excited species over the planetary disk than in 1998. Evidence of morning-evening asymmetry was found, which should be diagnostic of the solar EUV excitation process and deviations from thermal equilibrium in the atmosphere.

With T. Geballe (Gemini), L. Trafton observed Uranus, Neptune, Titan, and Saturn at the UKIRT in the dimer lines of $\text{H}_2\text{-H}_2$ and $\text{H}_2\text{-N}_2$ in order to attempt the detection of these features in Uranus' and Titan's near-IR spectra. They had previously detected them in the spectra of the other major planets. These lines potentially constrain both the temperature and ortho/para ratio of the molecular species separately, avoiding ambiguities when one attempts to derive these quantities from the few quadrupole lines available at quite different wavelengths.

L. Trafton and D. Lester observed Jupiter's K-band spectrum using the new CoolSpec IR spectrograph at McDonald Observatory. The objective is to compare the relative distribution of Jupiter's auroral H_2 and H_3^+ emission, which is known to vary. Further observations are needed to map out the H_2 emission.

Using the high spectral and spatial resolution of the 2dcoude spectrograph on the 2.7-m telescope, E. Barker continued his long term monitoring of the martian atmospheric H_2O vapor. During the 1998–2000 apparition, the northern hemisphere summer and fall seasons were covered. Abundances up to $60\mu\text{m}$ of ppt water vapor were seen at the edge of the retreating north polar cap, with only small amounts ($3\text{-}5\mu\text{m}$) seen at southern latitudes during these seasons. The strong diurnal variations noted in the 1996–1998 apparition were confirmed. Nearly simultaneous spectra of the 8689\AA CO_2 band provided an independent measurement of the effective pathlength in the lower martian atmosphere. In collaboration with A. Sprague and D. Hunten (U. Arizona), Barker found CO_2 abundances indicated a reduction in the pathlength due to the dust content of the lower atmosphere. The measurement of the CO_2 abundance also provides a method to correct for martian topographic effects.

3.3.4 Stars and Stellar Systems, Stellar Ejecta:

The first detection of the polarization in the CO band in an astronomical object, a young star, was made at McDonald Observatory by C. Colomé and collaborators, using the new polarimetry mode of CoolSpec. In addition, large differences between the polarization in the CO band and the polarization of the stellar radiation were found, and through this result they were able to conclude that the CO emitting gas is not distributed uniformly around the central star, but instead is most likely located in the inner parts of very flat disks around young stars. This new infrared instrument provides a new technique in the search for protoplanetary disks in our Galaxy, and a powerful tool to study their physical characteristics.

In work on galactic halo field stars, J. Cowan (U. Oklahoma), B. Pfeirrer, K.-L. Kratz (U. Mainz), F.-K. Thielemann (U. Basel), C. Sneden, S. Burles (U. Chicago) and D. Tytler (UCSD) have performed theoretical computations of rapid neutron-capture nucleosynthesis (the r-process), yielding excellent agreement with the observed solar-system r-process abundances, including those of the heaviest observable elements Pb, Th, and U. Their predicted abundances match well the total elemental abundances of the neutron-capture elements with atomic numbers 56 and greater, confirming r-process dominance in the synthesis of these elements in the early galaxy.

J. Westin, C. Sneden, B. Gustafsson (Uppsala U.), and J. Cowan (U. Oklahoma) performed a detailed differential abundance analysis between the bright very metal-poor field giants HD 122563 and HD 115444, confirming the large overabundances of the heaviest neutron-capture elements and their r-process signature in detail. This is the second very metal-poor star to undergo such close scrutiny of its neutron-capture elemental abundances, and the analysis also yielded an abundance of the radioactive element Th. This in turn suggests an age of about 15 Gyrs for the material of HD 115444, in reasonable agreement with other recent age estimates for the galactic halo.

C. Allende Prieto, D. L. Lambert, R. García López (IAC), B. Ruiz Cobo (IAC), and B. Gustafsson (Uppsala Astronomical Observatory) have derived semi-empirical model atmospheres for the metal-poor star Gmb1830 and the active solar-metallicity K2 dwarf ϵ Eridani, by applying an inversion code to extremely high resolution optical spectra ($\lambda/\Delta\lambda \approx 200,000$) acquired with the 2dcoude spectrograph at the McDonald 2.7-m telescope. The same group of people, with M. Asplund (Nordita) and Å. Nordlund (TAC), have compared the line asymmetries observed in the very metal-poor star HD140283 with three-dimensional hydrodynamical simulations of surface convection for that star. The agreement, as was found previously for the solar case, is astoundingly good. Allende Prieto and Lambert have investigated the errors in the stellar masses, radii, and effective temperatures (T_{eff} s) obtained from the comparison of absolute magnitudes, derived from HIPPARCOS parallaxes, and broad-band colors, with calculations of stellar evolution. The study made use of published masses and radii for nearby eclipsing binary systems, and InfraRed Flux Method T_{eff} s, concluding that the typical accuracy with which those parameters can be estimated is 8% for the mass, 5% for the radius, and 2% for the T_{eff} . These results have been applied to 17,219 stars observed by HIPPARCOS within 100 pc from the Sun. Allende Prieto and Lambert have also exploited the HIPPARCOS parallaxes available for relatively-nearby metal-poor stars, to translate low-resolution IUE fluxes observed at Earth to fluxes at the stellar surface, and compare them to the predictions of classical model atmospheres. They find a good agreement for stars in the range $4,000 < T_{\text{eff}} < 6,000$ K.

D. Burris (U. Oklahoma), C. Pilachowski, T. Armandroff (NOAO), C. Sneden, and J. Cowan (U. Oklahoma) completed an abundance analysis of selected neutron-capture elements in about 50 field halo giant stars. These abundances show clear evidence for a large star-to-star dispersion in the

neutron-capture element to iron ratios. This condition must have arisen from individual nucleosynthetic events in rapidly evolving halo progenitors that injected newly manufactured neutron-capture elements into an inhomogeneous early Galactic halo interstellar medium. The abundances also confirm that at metallicities $[\text{Fe}/\text{H}] \leq -2.4$, the abundance pattern of the heavy ($Z \geq 56$) neutron-capture elements in most giants is well matched to a dominant r-process nucleosynthesis pattern. Contributions from the s-process (that is, slow neutron-capture nucleosynthesis) can first be seen in some stars with metallicities as low as $[\text{Fe}/\text{H}] \sim -2.75$, and are present in most stars with metallicities $[\text{Fe}/\text{H}] > -2.3$. The appearance of s-process contributions as metallicity increases presumably reflects the longer stellar evolutionary timescale of the (low-mass) s-process nucleosynthesis sites.

R. Gratton (Padova Obs.), C. Sneden, E. Carretta (Padova Obs.), and A. Bragaglia (Bologna Obs.) have determined Li, C, N, O, Na, and Fe abundances, and $^{12}\text{C}/^{13}\text{C}$ isotopic ratios for a sample of 62 field metal-poor stars in the metallicity range $-2 \leq [\text{Fe}/\text{H}] \leq -1$. Stars were selected which had accurate luminosity estimates from the literature, so that evolutionary phases could be clearly determined for each star. These abundances showed that lower-RGB stars (i.e. stars brighter than the first dredge-up luminosity and fainter than that of the RGB bump mid-way up the RGB) have light element abundances in agreement with predictions from classical evolutionary models: tiny changes in the CNO elements, and decreases of Li by a factor of about 20 (due simply to dilution within the convective envelope). A second mixing episode occurs in metal-poor stars just after the RGB bump, when the molecular weight barrier left by the maximum inward penetration of the convective shell is canceled by the outward expansion of the H-burning. This second mixing episode only reaches regions of incomplete CNO burning, causing a depletion of the surface ^{12}C abundance by about a factor of 2.5, and an increase in the N abundance by about a factor of 4. The $^{12}\text{C}/^{13}\text{C}$ drops to about 6 to 10 (close to but distinctly higher than the equilibrium value of 3.5), while the remaining Li disappears.

C. Sneden, R. Kraft (UCSC), and collaborators continued their program of using high resolution echelle spectroscopy to determine the chemical compositions of large stellar samples (typically ≥ 10) on the upper red giant branches (RGBs) of globular clusters in the metallicity range $-0.8 \geq [\text{Fe}/\text{H}] \geq -2.3$. Very large star-to-star variations of the light elements C, N, O, Na, Mg, and Al occur in many globulars; positive correlations exist among N, Na, and Al abundances, and these are anticorrelated with C, O, and Mg abundances. This suggests strongly that at some time(s), in some place(s) in cluster evolution, advanced proton captures have reshuffled these light element abundances via $\text{C}, \text{O} \rightarrow \text{N}$, $\text{Ne} \rightarrow \text{Na}$, and $\text{Mg} \rightarrow \text{Al}$ synthesis chains.

This past year, I. Ivans, C. Sneden, R. Kraft (UCSC), N. Suntzeff (CTIO), E. Langer (Colorado Coll., deceased), and J. Fulbright (UCSC) analyzed 37 stars in the ‘‘CN-bimodal’’ globular cluster M4, the closest cluster to the Sun. Using high resolution spectra, they not only confirmed the evidence for the light element abundance correlations and anticorrelations suggestive of proton-capture nucleosynthesis,

but also uncovered uniform enhancements of aluminum, magnesium, silicon, barium and lanthanum. The enhancements of these elements, combined with the slight excess of europium in the cluster stars, is evidence that the period of star formation and mass-loss that preceded the formation of the observed stars in M4 was long enough for stars of 3–10 solar masses to evolve into AGB stars and contribute their ejecta into the ISM of the cluster. The investigation also successfully employed the use of spectroscopic line ratios as temperature indicators. The line ratio calibrations of the very large high resolution data set are currently being employed in the analysis of other clusters.

R. Kraft, R. Peterson, P. Guhathakurta (UCSC), C. Sneden, J. Fulbright (UCSC), and E. Langer (Colorado Coll., deceased) have serendipitously discovered an extremely lithium-rich RGB star in globular cluster M3 (star IV-101). Their analysis yielded one of the largest Li abundances of any metal-poor giant star: $\log \epsilon(\text{Li}) \approx +3.0$. They suggested that Li synthesis has occurred recently in the hydrogen-burning shell of this star, just below the convective envelope. While such enrichment could conceivably only happen rarely, it may in fact regularly occur during RGB evolution but be rarely detected because of rapid subsequent Li depletion.

I. Ivans, C. Sneden, B. Carney (UNC), L. de Almeida (UNC), and R. James have begun a chemical analysis of a group of high-velocity metal-poor field stars, seeking to determine whether, as a group, they show any distinctive abundance ratios. A number of stars on very large galactic orbits have been discovered that have unusual ratios of elements such as sodium, calcium, and magnesium to iron. The unusual abundance ratios may suggest a chemical ‘‘signature’’ of previous merger or accretion events. That is, these stars may have originated within a satellite galaxy or galaxies that experienced a different nucleosynthetic chemical evolution history than the Milky Way and which were later accreted by it. By combining the kinematics with the chemical abundances, they hope to trace what may have occurred during the formation of the halo and subsequent evolution of the Galaxy. Already, a few of the stars have been found to exhibit unusual abundance ratios of the iron-elements, perhaps indicating some differences in the SN progenitors of these stars from those that contributed to the mix of the general halo population.

D. A. Howell, L. Wang and J. C. Wheeler completed a study of the radial distribution of Type Ia supernovae in host galaxies. They showed that the calibration sample used in cosmological studies discovered photographically has a different distribution than those in the deep sample discovered with CCDs. This may be significant for determining systematic effects in the use of Type Ia supernovae as probes of cosmology.

L. Wang and J. C. Wheeler have continued their program of routine spectropolarimetry of all accessible supernovae. They have now nearly tripled the sample of supernovae with polarimetry data compared to that available at the beginning of this effort. They still find that core collapse supernovae (SN II, SN Ib/c) are polarized at the 1% level and SN Ia much less so in general. They found that the narrow line

Type II supernova 1998S was significantly polarized. They also obtained the first polarization data ever on a subluminous Type Ia and found that it was modestly polarized. The polarization of Type Ia supernovae is an important probe of the combustion physics. The polarization of the core collapse events suggests that the core collapse process itself is very strongly asymmetric and may require something like a jet to induce the explosion.

T. Barnes, I. Ivans, J. Martin, C. Froning and T. Moffett (Purdue Univ.) completed a photometric study of Cepheids in the Magellanic Clouds. They have published light curves in VRI_C for 21 Cepheids with a typical uncertainty of 0.03 mag.

W. Jefferys and T. Barnes continued their application of Bayesian statistics to the surface brightness method for determining distances and radii of Cepheids. They have applied both approximately Bayesian methods and fully Bayesian methods to the analysis of eight Cepheids. Both methods successfully account for errors in the data, provide unbiased distance estimates, and provide objective model selection for the radial velocity curve. In addition, the fully Bayesian analysis objectively selects a model for the magnitude curve, averages over models using different Fourier orders properly weighted by the posterior probabilities of the individual models, and includes a Lutz-Kelker correction. The results are consistent with each other, although there is a tendency for the fully Bayesian results to give slightly larger Cepheid radii.

G. F. Benedict, A. Hatzes, O. Franz (Lowell Observatory), and T. Henry (Harvard-SAO) have continued a program of radial velocity measurements of low-mass binary stars. These data, once combined with HST astrometry, will permit a full, three-dimensional characterization of the orbits, and very precise determination of masses and mass-ratios for these objects. The primary goal is to firm-up the lower main sequence mass-luminosity relationship. The secondary goal is to sift for additional low-mass companions. A tertiary goal is to obtain dynamical parallaxes with which to resolve possible discrepancies between HIPPARCOS and HST parallaxes. Analyses for two objects are nearly complete, Gl 748 (= Wolf 1062) and Gl 831 (= Wolf 922). Comparisons with HST astrometry indicate radial velocity precision of order 200 m s^{-1} .

G. F. Benedict and B. McArthur (in collaboration with O. Franz, Lowell Observatory and T. Henry, Harvard-SAO) continued an HST Guest Observer program of simultaneous transfer scan and position mode astrometry with FGS 3. They will obtain precise orbits, parallaxes, and masses for close binary stars difficult or impossible to study from the ground. Some of these data were used to define an empirical mass-luminosity relation for stars with masses $0.08 - 0.20M_{\odot}$ (Henry *et al.* 1999, ApJ, **512**, 864). The targets are nearby, red dwarf multiple systems in which the magnitude differences are typically measured to ± 0.1 mag or better. The M_V values are generated using the best available parallaxes and are also accurate to ± 0.1 mag, because the errors in the magnitude differences are the dominant error source. In several cases, this is the first time the observed sub-arcsecond multiples have been resolved at optical wave-

lengths. The mass-luminosity relation defined by these data reaches to $M_V = 18.5$ and provides a powerful empirical test for discriminating the lowest mass stars from high-mass brown dwarfs at wavelengths shorter than $1 \mu\text{m}$.

R. French is working with J. A. Smith (U. Michigan), T. Oswalt (NSF and Florida Institute of Technology), and S. Leggett (Joint Astronomy Centre, Hawaii) on BVRI photometry of white dwarfs in common proper motion binaries.

Diverse avenues of research, ranging from the physics of matter at high densities and temperatures to galactic structure and cosmochronology, intersect in the study of white dwarf stars. D. Winget and collaborators exploited the intrinsic simplicity of these high gravity objects by applying the powerful theoretical machinery of asteroseismology to determine many of the fundamental structural and evolutionary parameters of white dwarf stars: rotation rates, magnetic field strengths, total mass, compositional stratification of the envelopes, core composition, and more. Winget used this information to study the behavior of matter under extreme conditions and to explore the history and population of our galaxy. Much of his and his collaborators efforts in the past year have been aimed at using HST and ground-based observations, along with extensive theoretical calculations, to study massive pulsating white dwarf stars. The idea is to carry out the first empirical tests of the process of crystallization as it is thought to occur in the deep interior of white dwarf stars or neutron star crusts.

H. Dinerstein, L. Likkell (U.Wisc.-Eau Claire) and D. Lester continued their study of the near-infrared H_2 emission lines in planetary nebulae, utilizing Lester's new near-infrared spectrometer, CoolSpec, on the McDonald 2.7-m telescope. These emission lines are generally interpreted as originating from shocked gas, although earlier work at McDonald Observatory (in the 1980's) demonstrated that the lines can be excited by fluorescence processes. New K-band observations with CoolSpec of three compact, relatively unstudied planetary nebulae (Vy 2-2, IC 5117, and J 900) seem to indicate a more complex picture: either both mechanisms are contributing, or the line emission is due to very dense gas illuminated by ultraviolet photons, in which collisions modify the emergent spectrum.

H. Dinerstein, C. Sneden, and R. French have been analyzing a set of broad-wavelength coverage, high-resolution spectra of 44 planetary nebulae obtained with the coude spectrometer at the McDonald 2.7-m telescope. The primary purpose for obtaining these spectra was to detect circumstellar neutral material associated with the nebulae, via resonance absorption lines of species such as Na I, Ca II, and K I. Earlier work by Dinerstein and Sneden had revealed the presence of at least neutral atomic gas in about 40% of observed planetary nebulae with no other evidence for neutral or molecular gas. If present, these features imply that the nebular is ionization-bounded, rather than matter-bounded. The new spectra are yielding new detections of neutral envelopes in some objects, and providing more detailed information on the expansion velocities of the neutral layers.

W. F. Welsh and collaborators at Keele University (UK) continued their study of the properties of post-common envelope binaries (PCEB, pre-cataclysmic variables). Emphasis

was placed on determining the stellar rotation velocity in these tidally-locked interacting binaries, because this can be used to determine the system mass ratio and inclination. The same technique is used in the X-ray binaries, but in the clean PCEB systems, one can investigate the large systematic effects that bias the results.

E. Robinson spearheaded team efforts to explore black hole and neutron star X-ray binaries. Robinson, with W. Welsh and P. Young, obtained photometry of Aql X-1, J0422+32 and GS2000+25 for the purpose of measuring the ellipsoidal variations in their light curves, which then yields the system inclination. Combined with the mass function, this gives accurate masses for the compact object. In Aql X-1, a revised orbital period and system inclination was determined. Techniques for measuring the rotation velocity in X-ray binaries were investigated. With I. Ivans, long-term high resolution spectroscopy of the X-ray transient CI Cam was obtained, and a study of this peculiar system is underway. C. Froning observed the unique X-ray binary SS 433 in September 1998, concluding a six-month program to examine variations in the near-infrared spectra of SS 433 over a full binary precession cycle.

D. Sanwal and E. Robinson obtained multicolor optical photometry of the Crab pulsar with $1 \mu\text{sec}$ time resolution, a factor of 20 better than previous investigations. They found the peak of the main pulse in the B band arrives $140 \mu\text{sec}$ before the peak of the radio pulse. The color of the emission changes across the phase by 20%. The bluest color occurs in the bridge region between the main pulse and the interpulse. The autocorrelation function (ACF) of the light curve shows extra correlations at very short time scales, near 20 and 100 microseconds. The extra correlations are attributed to microstructures; this is the first time microstructures have been seen outside radio wavelengths.

C. Froning, E. Robinson and W. Welsh continued their study of cataclysmic variables (CVs). Welsh, with collaborators from Keele University (UK), continued his investigation of the rapid oscillations in WZ Sge. Froning continued modeling the H- and K-band light curves of IP Peg, RW Tri and SW Sex, producing the first infrared eclipse maps of CVs. The accretion disk in IP Peg appears to be primarily optically thin in the NIR, while the accretion disks in RW Tri and SW Sex are hot and opaque; the secondary stars in the latter CVs show broadband emission from the irradiated faces of the secondary stars.

R. French is collaborating with K. A. Lewis (Colorado School of Mines) and E. Friel (NSF) on BVRI CCD photometry of two relatively unstudied, young (1–2 Gyr) open clusters, IC 361 and NGC 6802. They have constructed color-magnitude diagrams of both clusters, and are fitting the data with isochrones to estimate properties such as reddening, distance, metallicity, and refined age estimates. These data are ideal for testing models of stellar evolution.

3.3.5 *Interstellar Medium, Compact Regions, Protostellar Disks, Star-Forming Regions:*

H. Dinerstein, former graduate student C. Pulliam Lafon (now at Brookhaven Nat. Lab.), and D. Garnett (U. Arizona) continued to investigate the anomalous O II recombination

lines in planetary nebulae, which indicate implausibly high O/H abundances in some objects. Analysis of our McDonald observations of about a dozen planetary nebulae has revealed intriguing patterns in the line strength enhancements. The data suggest that an unknown physical mechanism is contributing to the line emission to different degrees in different objects; this mechanism may be dielectronic recombination in hot gas. If we can account for its contribution, the recombination lines offer an extremely valuable method for measuring O/H abundances in ionized nebulae because it is insensitive to the temperature-sensitivity that plagues the collisionally-excited “forbidden” lines which are usually used for abundance determinations. New observations at higher spatial and spectral resolution, obtained by Garnett and Dinerstein at Steward Observatory in June 1999, should help identify this mechanism, which apparently enhances the strengths of recombination lines of carbon and nitrogen, as well as those of oxygen.

3.3.6 *Extragalactic:*

After conducting a three year ground-based optical survey of nearby galaxies, J. Jurcevic and M. Pierce (Indiana Univ.) have discovered red supergiant variables (RSVs) in the galaxies M81, NGC 2403, NGC 2366, and M101. By using the optical (*R* and *I*-band) period-luminosity relations for RSVs – recently identified and calibrated by Jurcevic – they were able to determine distances to those galaxies. These RSV distances were in agreement with, and were of similar accuracy to, Cepheid-based distances to the galaxies, including the HST Cepheid distance for M101. The results show that RSVs form an important new distance indicator that can verify Cepheid distances and address problems with current distance scales.

H. Dinerstein continued to participate in the analysis of data obtained by the ISO Key Project on the Interstellar Medium of Galaxies (G. Helou of Caltech/IPAC is the project PI). This project constituted a broad survey of the infrared emission from gas and dust from galaxies with different global properties and different levels of star formation activity. The strongest infrared emission lines in the integrated spectra of most galaxies are the [C II] $158 \mu\text{m}$ and [O I] $63 \mu\text{m}$ lines. In general, these lines appear to arise mostly from photodissociated gas associated with recent star formation, although three of the four earliest-type galaxies (E and S0) in the sample may be exceptions to this rule. With the assistance of two Texas undergraduate students, S. Akiyama and M. Huerta, Dinerstein has compiled a data base of information from the literature and optical spectra obtained at McDonald Observatory. The optical data on the Key Project galaxies will provide information on the extinction, excitation, and elemental abundances, and assist in the interpretation of the ISO data.

G. J. Hill, with S. Rawlings (Oxford University), continued the TEXOX survey of radio galaxies from the NVSS and FIRST surveys. The aim of this survey is to discover clusters of galaxies to high redshift, using radio selection, for comparison with other selection techniques. The space distribution of the radio sources will also be used to study evolution of large scale structure since $z=1$. The technique has proven

very successful, with candidate clusters at probable redshifts as high as $z=1$ already discovered. Several intermediate redshift clusters already have confirmed redshifts between 0.38 and 0.6 from HET LRS spectroscopy. Graduate students P. Gay (UT), and S. Croft (Oxford) have been working on aspects of the the TEXOX survey.

W. Welsh and E. Robinson continued their investigation of variability in AGN. Welsh has shown that AGN time lag measurements derived from the cross-correlation function are both biased and contain very large variances, throwing into question whether the observed year-to-year changes in lag seen in some AGN are real. Welsh completed his study of NGC 7469, in which HST high-speed spectrophotometry was used to search for ultra-rapid variability in this Seyfert 1 galaxy.

W. Welsh, E. Robinson, G. Hill, G. Shields, and B. Wills and collaborators from Penn State (M. Eracleous and N. Brandt) and Göttingen (W. Kollatschny) have initiated the ‘‘HET Echo Mapping Project,’’ a long-term spectroscopic program to map the gas flows inside AGN. By using time-delay information in the emission lines, structure at the microarcsecond scale can be resolved. With the HET, full 2-D velocity-resolved echo mapping can be achieved, and high-redshift QSOs can be mapped. A photometric study is underway, and spectroscopic observations await final HET+LRS commissioning.

W. Welsh and E. Robinson are part of the ‘‘Kronos’’ project, a proposed MIDEX-class satellite to probe black holes and accretion processes in AGN, X-ray binaries and cataclysmic variables (B.M. Peterson, Ohio State Univ., is the P.I.).

G. Shields completed a review of the history of research on active galactic nuclei. The article traces observational and theoretical developments from the beginning of the twentieth century through the 1980s.

3.3.7 Theory:

R. Duncan studied X-ray observations of soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs) in collaboration with scientists at NASA’s Marshall Spaceflight Center (E. Gogus, C. Kouveliotou, J. van Paradijs, P. Woods and others). These observations give corroborating evidence for the magnetar model, which was proposed in 1992 by Duncan and C. Thompson (U. N. Carolina at Chapel Hill). In particular, SGR 1900+14 was found to have undergone a ‘‘spindown glitch’’ during the giant flare of August 27, 1998. This can be understood as a sudden transference of angular momentum between a magnetar’s crust and the more slowly-rotating superfluid component. In a magnetar, crustal deformation induced by the stresses of an evolving magnetic field generally induce the crustal superfluid to rotate more slowly than the rest of the star. This is the opposite of what happens in ordinary rotation-powered radio pulsars, and leads to glitches of opposite sign.

R. Duncan and collaborators studied the steady spindown histories of SGRs and AXPs. Angular momentum loss from SGRs is enhanced by relativistic wind channeled by the star’s ultrastrong field. Quasi-steady magnetic vibrations (Alfvén waves) can drive such a wind, due to frequent,

small-scale fractures in the deep crust. The AXPs seem to be magnetars that are observed during episodes of inactivity; they have less rapid spindown rates due to their milder outflows. Free precession is potentially observable in magnetars because of the distortion of stellar equilibrium shapes by the strong magnetic field. Duncan and his collaborators predicted that this will soon give the first direct measures of magnetic field strengths deep inside neutron stars.

J. C. Wheeler, I. Yi (Korean Institute for Advanced Study), P. Höflich, and L. Wang completed a study of the possibility of matter and radiation-dominated jets from newly formed neutron stars and how they might induce asymmetric supernovae and gamma-ray bursts of various strengths. Core collapse that gives rise to very strongly magnetized neutron stars, magnetars, identified with soft gamma ray repeaters, could produce very strong Poynting flux that could provide jets with collimated energy of $\sim 10^{52}$ ergs, sufficient to account for cosmic gamma-ray bursts.

A. Khokhlov (Naval Research Laboratory), P. Höflich, E. Oran (Naval Research Laboratory), J. C. Wheeler, L. Wang, and A. Chtchelkanova (Naval Research Laboratory) simulated three dimensional jets emerging from a newly born neutron star and propagating through the mantle of a hydrogen-deficient Type Ib supernovae. The jets emerged from the mantle in about 10 seconds and generated lateral shocks that converged on the equator. The subsequent expansion yielded the sort of oblate asymmetries required to account for the polarization of core-collapse supernovae. This work gave more substance to the notion that ordinary core collapse supernovae are induced by jets rather than traditional processes of neutrino transport. The jets might be related to gamma-ray bursts.

P. Höflich, J. C. Wheeler, and L. Wang explored light curves of asymmetric configurations for supernovae and showed that the high optical luminosity of SN 1998bw might be accounted for by asymmetries, without the need for the very high energies associated with spherically symmetric ‘‘hypernova’’ models

P. Höflich, K. Nomoto (Tokyo), H. Umeda (Tokyo) and J. C. Wheeler showed that Type Ia progenitors of low metallicity would have smaller carbon/oxygen ratios than solar metallicity progenitors. This would tend to make the peak light a little dimmer for distant, high redshift, low metallicity events. This is the effect seen which is then interpreted as the effect of cosmology. This could be a source of systematic differences in brightness that needs to be resolved from the effects of cosmology.

G. Shields began a theoretical study of the quasar PG1222+228. This is one of several QSOs observed to have a strong, abrupt rise in polarization in the Lyman continuum spectral region (Koratkar and Blaes 1999 *PASP* **111**, 1). In this object, the polarization rise coincides in wavelength with a Lyman limit absorption feature. Shields is exploring the possibility that the feature is caused by high velocity outflow. Such an interpretation would contrast with attempts to relate such polarization rise features to the presumed accretion disk in QSOs. Shields and O. Blaes (UCSB) studied the viability of a new accretion disk model for Lyman continuum polarization rises in QSOs. This model (Beloborodov

and Poutanen 1999, *ApJ*, **517**, L77) involves Compton scattering in an accretion disk corona or wind. Blaes and Shields found that the model does not give a sufficiently rapid rise in polarized flux as a function of wavelength. Shields and E. Agol (Johns Hopkins U.) began an effort to explain Lyman continuum polarization rises of QSOs in terms of general relativistic “returning radiation.” The angular distribution of this radiation as it strikes the disk can give strong polarization because of electron scattering.

H. Martel, P. Premadi (Tohoku University), and R. Matzner (Dept. of Physics and Center for Relativity, University of Texas) have pursued their study of light propagation in inhomogeneous universes. Using the multiple-lens plane algorithm, they studied the effect of gravitational lensing on light propagation for 43 different COBE-normalized Cold Dark Matter models, with various values of the density parameter Ω_0 , cosmological constant λ_0 , Hubble constant H_0 , and rms density fluctuation σ_8 . This constitutes the largest cosmological parameter survey ever done in this field. These experiments provide statistics of the magnification, shear, and multiple imaging of distant sources. They intend to compare these statistics with available observations of lensed sources in order to determine or impose limits on the values of the cosmological parameters.

H. Martel, T. Hamana (Tohoku University), and T. Futamase (Tohoku University) computed statistical properties of weak gravitational lensing by large-scale structures in 3 different Cold Dark Matter models. They performed 1.1×10^7 ray-tracing experiments for each model, by computing the Jacobian matrix along random lines of sight, using the multiple lens-plane algorithm. From the results of these experiments, they calculated the probability distribution functions of the convergences, shears, and magnifications, and their rms values. They found that the probability distribution functions of the magnifications, μ , have a peak at values slightly smaller than $\mu = 1$, and are strongly skewed toward large magnifications. In particular, for the high-density models, a power-law tail appears in the distribution function at large magnifications for sources at redshifts $z_s > 2$. They also studied the effect of magnification bias on the luminosity functions of high-redshift quasars, using the calculated probability distribution functions of the magnifications. They showed that the magnification bias is moderate in the absence of the power-law tail in the magnification distribution, but depends strongly on the value of the density parameter, Ω_0 . In the presence of the power-law tail, the bias becomes considerable, especially at the bright end of the luminosity function where its logarithmic slope steepens.

P. Shapiro, H. Martel, and J. Owen (Lawrence Berkeley Livermore Labs) continued the development and application of their new anisotropic version of Smoothed Particle Hydrodynamics (SPH), called Adaptive SPH (ASPH), for cosmological gas dynamics. The ASPH method improves the spatial resolving power of the SPH method at fixed numbers of simulation particles, by replacing the spherical interpolation kernels of SPH by triaxial ellipsoidal kernels whose size, orientation, and axis ratios are dynamically adjusted continuously throughout a simulation, so as to respond to the variation of the interparticle separation distances in time, position,

and direction around each particle. A new 3D version has been developed by Shapiro and Martel, with a Particle-Particle/Particle-Mesh (P3M) gravity solver, and tested against a variety of problems with well-known solutions, including that of cosmological pancake collapse, the Sedov problem of a point explosion in a uniform gas, and the cosmological self-similar spherical infall problem. The new 3D version includes a refined algorithm for suppression of artificial viscous heating away from shocks, which automatically adjusts the threshold criteria used to suppress viscous heating, in a time- and space-varying manner, according to local conditions and particle resolution. A new numerical instability for the standard SPH method has been identified in which artificial viscosity couples to radiative cooling so as to produce a spurious isothermal shock jump whenever the time for particles to transit the shock transition zone is longer than the cooling time inside the zone. This may have significant implications for the large body of research already in the literature on galaxy formation, in which the kinetic energy of gravitationally-driven infall is dissipated by radiative cooling following shock-heating, most of which is based upon simulations using the standard SPH method. Work to eliminate this problem is underway.

H. Martel and P. Shapiro studied the effect of explosions inside protogalaxies on their formation. When density fluctuations collapse gravitationally out of the expanding cosmological background universe to form galaxies, the secondary energy release which results from supernovae following the formation of the first generation of massive stars inside the protogalaxy can affect the subsequent evolution profoundly. Their study focused on the consequences of the nonspherical geometry and continuous infall, which are characteristic of galaxy formation from realistic initial and boundary conditions. As an idealized model, they studied the effect of explosions on the quasi-spherical objects which form at the intersections of filaments in the plane of a cosmological pancake, as a result of gravitational instability and fragmentation of the pancake. Numerical gas dynamical simulations of the formation and evolution of these “galaxies,” subject to the explosive injection of energy at their centers, were performed of the self-similar behavior which results when the gas is unable to cool by radiating away its internal energy. The results indicate that such explosions channel the gas mass ejected from the protogalaxy away from the pancake central plane along an axis perpendicular to that plane, but infall within the pancake plane, especially along the filaments, continues and eventually replenishes the original lost gas. Computer visualization and animation of these simulation results was developed with the help of undergraduate physics major M. Alvarez.

H. Martel and P. Shapiro calculated the maximum fraction of matter which is able to condense out of the expanding background universe, for any universe which will expand forever. They used a simple, pressure-free, nonlinear, spherical model for the growth of density fluctuations in the universe. This model includes the cases of an open matter-dominated universe and universes in which there is a uniform background component (e.g. the cosmological constant or “quintessence”), of great current interest because

luminosity distances measured for Type Ia supernovae now indicate that cosmic expansion today is accelerating, as it would be in such a universe. In these background universes, the growth of density fluctuations freezes out, gravitational instability is suppressed, and with it so is the growth of the collapsed fraction. The asymptotic collapsed fraction is a quantity of interest in anthropic probability calculations, to explain why it is natural for us to observe a small, but positive cosmological constant comparable in energy density to the matter density today, in cosmologies in which there are an infinite number of subuniverses in each of which the cosmological constant can take on any value. In addition, this asymptotic collapsed fraction serves to identify a limitation of the well-known Press-Schechter approximation for the time-dependent mass function of cosmological structure formation. In the latter approximation, the mass function determined from the extrapolation of linear density fluctuation growth for Gaussian random noise fluctuations to nonlinear amplitudes is conventionally multiplied by a factor of two to correct for the fact that linear growth predicts that only initially positive fluctuations are able to condense out, which neglects the accretion of matter from initially underdense regions. These calculations of the asymptotic collapsed fraction indicate that, contrary to this expectation, when freeze-out occurs, the correction factor reduces to unity and the simple PS formula must overestimate the collapsed fraction.

P. Shapiro, I. Iliev, and A. Raga (UNAM) developed a new model for the postcollapse equilibrium structure of objects which form by gravitational condensation out of the expanding cosmological background universe, a key element in the theory of galaxy formation. The outcome of the nonlinear growth of a uniform, spherical density perturbation in an unperturbed background universe – the cosmological “top-hat” problem – was reconsidered. The usual assumption was adopted, that the collapse to infinite density at a finite time predicted by the top-hat solution is interrupted by a rapid virialization caused by the growth of small-scale inhomogeneities in the initial perturbation. The standard description of the postcollapse object as a uniform sphere in virial equilibrium was replaced by a more self-consistent one as a truncated, nonsingular, isothermal sphere in virial and hydrostatic equilibrium, including for the first time a proper treatment of the finite-pressure boundary condition on the sphere. The results differ significantly from both the uniform sphere and the singular isothermal sphere approximations for the postcollapse objects. These results will have a significant effect on a wide range of applications of the Press-Schechter and other semi-analytical models to cosmology. The unique truncated isothermal sphere solution derived by Shapiro, Iliev, and Raga predicts the virial temperature and integrated mass distribution of the X-ray clusters formed in the CDM model as found by detailed, 3D, numerical gas and N-body dynamical simulations remarkably well. With this solution, they derived analytically for the first time the numerically-calibrated mass-temperature and radius-temperature scaling laws for X-ray clusters which were previously found empirically from simulation results for the CDM model and are consistent with the observations of X-ray clusters.

P. Shapiro, A. Raga (UNAM), and G. Mellema (Stock-

holm Obs., Sweden) performed the first gas dynamical simulations of the photoevaporation of an intergalactic gas cloud overtaken by the R-type ionization front which results when a quasar or stellar source turns on in the neutral intergalactic medium (IGM) during the reionization of the universe at an epoch earlier than redshift 5. Located 1 Mpc from a quasar of modest luminosity, a cloud of gas mass a few million solar masses can trap the ionization front and gradually evaporate by expelling a supersonic wind in the direction of the quasar, while accelerating away from the quasar by a “rocket effect.” Observationally, such a cloud would initially appear as a Lyman limit quasar absorption line cloud in the spectrum of that quasar and evolve into Lyman alpha forest absorption line gas, as the photoevaporation reduces its neutral column density over the course of more than 100 Myr. Shapiro and Raga have followed this work by considering a more realistic, centrally-concentrated, gravitationally-bound structure as the initial condition for a minihalo or protogalaxy at high redshift at the time of passage of the global ionization front responsible for reionizing the intergalactic medium.

P. Shapiro and R. Benjamin (U. of Wisconsin) updated and revised their earlier work on the nonequilibrium ionization, radiative cooling, and emergent emission and absorption spectra of hot gas cooling radiatively in the galactic halo, such as in the galactic fountain model.

3.3.8 Astrometry:

The Hubble Space Telescope Astrometry Science Team is based at the University of Texas. Local members include G. Fritz Benedict (Deputy P.I.), B. McArthur, R. Duncombe (Aerospace Engineering), W. Jefferys (P.I.), and P. Shelus. The team continued obtaining, reducing and analyzing data bearing on planet searches (see Planet Detection, above), parallaxes of astrophysically interesting objects (δ Cephei, RR Lyrae, Feige 24, the central star of the planetary nebula NGC 6853, RW Tri, and TV Col), and astrometry of low-mass M-dwarfs. All data are obtained with Fine Guidance Sensor 3 aboard HST. They continue to obtain 1–2 milliarc-second precision per measurement and sub-milliarcsecond precision parallaxes. The team obtained absolute parallax values for Proxima Cen $\pi_{abs} = 0''.7687 \pm 0''.0003$ and for Barnard’s Star $\pi_{abs} = 0''.5454 \pm 0''.0003$.

Led by Otto Franz (Lowell Observatory), the M dwarf binary, Wolf 1062 (Gliese 748), was observed with Fine Guidance Sensor 3 in the fringe scanning mode to determine the apparent orbit. This is the first orbit defined fully and exclusively with HST, and is the most accurate definitive orbit for any resolved, noneclipsing system. The orbital period is 2.4490 ± 0.0119 yr and the semimajor axis is $0''.1470 \pm 0''.0007$ – both quantities are now known to better than 1%. Using the weighted mean of seven parallax measurements and these HST data, they found the system mass to be $0.543 \pm 0.031 M_{\odot}$, where the error of 6% is due almost entirely to the parallax error. The mass uncertainties should decline to about 3%, once their ongoing HST parallax analysis is completed.

B. McArthur lead an astrometric investigation of RW Triangulum (RW Tri), carried out with HST. RW Tri is a 13th

magnitude nova-like cataclysmic variable star with an orbital period of 0.2319 days (5.56 hr). Infrared observations of RW Tri indicate that its secondary is most likely a late-K dwarf. Past analyses predicted a distance of 270 pc, derived from a blackbody fit to the spectrum of the central part of the disk. The Hubble Space Telescope Fine Guidance Sensor interferometric observations allow the determination of the first trigonometric parallax to RW Tri. This determination puts the distance of RW Tri at 341_{-31}^{+38} pc, one of the most distant objects with a direct parallax measurement.

With FGS 3, G. F. Benedict and B. McArthur have determined a parallax for the white dwarf–M dwarf interacting binary, Feige 24. The white dwarf (DA) component has an effective temperature, $T_{eff} \sim 60,000K$. A weighted average with past parallax determinations ($\pi_{abs} = 14.6 \pm 0.5$ mas) narrows the range of possible radius values, compared to past estimates. They obtained $R_{DA} = 0.0199 \pm 0.0022R_{\odot}$, with the temperature uncertainty the dominant contributor to the radius error. A recently refined model Mass-Luminosity Relation (Baraffe *et al.* 1998 A&A, **337**, 403) for low mass stars provides a mass estimate for the M dwarf companion, $M_{dM} = 0.37 \pm 0.20M_{\odot}$, where the mass range is due to metallicity and age uncertainties. Radial velocities from Vennes and Thorstensen (1994, AJ, **108**, 1881) provide a mass ratio from which we obtain $M_{DA} = 0.49_{-0.05}^{+0.19}M_{\odot}$. Independently, the radius and recent $\log g$ determinations yield $0.44 < M_{DA} < 0.55M_{\odot}$. In each case the minimum DA mass is that derived by Vennes & Thorstenson from their radial velocities and Keplerian circular orbits with $i \leq 90^{\circ}$. Locating Feige 24 on an $M - R$ plane suggests a carbon core.

B. McArthur and G. F. Benedict assisted in determining astrometric parallaxes for three well-known dwarf novae. This work resulted in a parallax for SS Aurigae of $\pi = 5.00 \pm 0.64$ mas, for SS Cygni $\pi = 6.02 \pm 0.46$ mas, and for U Geminorum $\pi = 10.37 \pm 0.50$ mas. These represent the first true trigonometric parallaxes of any dwarf novae. This program and our RW Tri results demonstrated, again, that with a very modest amount of HST observing time, the Fine Guidance Sensors can deliver parallaxes with sub-milliarcsecond precision.

P. Shelus, J. G. Ries, and E. Barker continued their astrometric observations of small, faint solar system bodies. This effort employs a CCD using the Prime Focus Corrector (PFC) on the McDonald 0.76-m reflector. This instrument is capable of reaching $R=22$, with more than 3-sigma significance on stellar objects. Primarily, they are working to observe minor planets. There is a substantial non-observational part to this project. They continued their software development efforts within IRAF and ICE to perform real time processing of CCD frames, identify star fields and solar system objects, digitally determine center and intensity for all identified objects, and process measures to obtain astrometric positions and magnitudes. They continued to automate extensive portions of the astrometric measuring and reduction script for increased efficiency during data processing. They are also removing the effects of ‘‘personal equation’’ during the measuring process by applying robust estimation theory to the reduction. They will soon be making measures directly

in the International Celestial Reference Frame (ICRF) by replacing the GSC with USNOA-2.0 and its derivatives. Replacing the fundamental reference catalog will also remove significant systematic effects on the measures.

The total PFC astrometric system continues to be fully functional during the continuing upgrade, and excellent results are being obtained. They have just begun a major new thrust this year with the timely observation of objects that appear on the nightly MPC NEO Confirmation Page. As a consequence, and as a sign of success in this endeavor, the number of Minor Planet Electronic Circulars containing their observations has increased. Also, a very recent software upgrade gives the ability to query a generalized JPL minor planet data base in real time to identify all known targets within the field that was just observed. The software has been modified to physically identify all such targets on the exposure, assuring that all known field objects are measured, in addition to the target. It remains routine to have a night’s worth of minor planet and cometary positional observations electronically sent to the Minor Planet Center the morning after the observations were taken.

P. Shelus and co-workers are investigating a cooperative effort with the 3-m aperture liquid mirror telescope (LMT) that is located near Cloudcroft, NM. This facility is located approximately 250 km north-west of McDonald Observatory. The major thrust of the effort is to discover and confirm new NEO’s. While the LMT can discover and identify objects, it cannot perform follow up, since it is zenith staring. McDonald Observatory is joining an effort to make regular follow-up observations of objects that are found by the LMT. This project will depend strongly upon real time, at-the-telescope communications between the two observatories. Initial observations should begin in the fall.

3.3.9 Laser Ranging:

The lunar and artificial satellite laser ranging staff consists of Project Director P. Shelus and staff members R. Ricklefs, J. G. Ries, and J. Wiant. This year continued nearly 3 decades of observation and research efforts. The McDonald Laser Ranging Station (MLRS) is a fundamental station in the world-wide laser ranging network. It consists of a 0.76-m reflecting telescope and a very short pulse, frequency-doubled, 532-nm wavelength, neodymium-YAG laser, with ancillary computer, electronic, and timing hardware. The station is located at McDonald Observatory on Mt. Fowlkes, to the north-east of Mt. Locke in west Texas and shares the mountain top with the new Hobby•Eberly Telescope.

During the spring of this year, a slaved, pencil-beam radar was installed at the MLRS, which eliminated the need for a human airplane spotter. This allows the station to operate with single member observing crews. During installation and shake-down operations, extensive coordination was maintained with National Radio Astronomy Observatory personnel to assure non-interference of the MLRS radar with the NRAO Fort Davis facility. The MLRS is now in continuous operation, 24 hours a day, 365 days/year, weather and equipment permitting. Laser ranging observations are carried out to 15–20 artificial satellites, according to the priorities and specifications of the International Laser Ranging Service, as

well as to the Moon. The MLRS continues to be the only lunar capable laser ranging station in the United States, and only one of two routinely lunar capable stations in the entire world. By measuring the time it takes for a laser pulse to leave a ground station, bounce off a targeted reflector array, and return to the ground station, one measures very precisely the distance between the station and the reflector array. Comparing a series of measurements (almost 30 years of lunar laser ranging observations have now been accumulated, together with almost 20 years of artificial satellite data), scientific results are obtained in four broad areas: solar system ephemeris development, general relativity and gravitational physics, lunar science, and geodynamics. Finally, the laser site at McDonald Observatory hosts a permanent GPS receiver and satisfies all other requirements for being a fundamental site in a world-wide geophysical network. The continuous, real time meteorological data that is monitored routinely by the MLRS automatically becomes a part of an international meteorological database. The MLRS site also serves as a fundamental node in the International GPS System.

Lunar and artificial satellite laser ranging observations were obtained with the MLRS at record setting levels for the 10th straight year, as personnel cooperated with colleagues around the world, making maximum use of the data type for earth, moon, and solar system related dynamics. Principal research activity using LLR data includes monitoring the exchange of angular momentum between the solid earth and its atmosphere, the principal geopotential terms, plate tectonic activity, tidal dissipation in the lunar orbit, the lunar free libration, and the equivalence principle of general relativity. In a service capacity, the project also serves as Observing Center and Analysis Center in the International Earth Rotation Service (IERS) and the International Laser Ranging Service, obtaining millisecond accuracy estimates of the constant of precession, coefficients of nutation, polar motion, and Earth rotation. This constitutes the only near-real time source of this information that includes the lunar laser ranging data type.

Finally, the laser ranging team is cooperating with NASA/GSFC in the development, construction, and eventual deployment of a network of what are to be known as SLR2000 receivers. These are small, unmanned, eye-safe laser ranging systems that will provide inexpensive coverage for most laser ranging targets on a continuous, 24 hour/day, 365 day/year schedule.

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