University of Texas McDonald Observatory and Department of Astronomy

Austin, Texas 78712

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This report covers the period 1 September 2001–31 August 2002.

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 9.2-m Hobby•Eberly Telescope (HET) is doing astronomical observations 75% of the time while the remainder is being spent on a series of engineering upgrades and instrument commissioning. The partners in the HET include the University of Texas at Austin, Pennsylvania State, Stanford, Ludwig-Maximilians University in Münich and the Georg-August University in Göttingen.

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 Greg **Shields** as Assistant Chair. Frank N. **Bash** is the Director of McDonald Observatory and the Center for Advanced Studies in Astronomy. He has announced that he intends to retire from the directorship on August 31, 2003 and a search for his successor is underway. Philip W. **Kelton**, Edwin S. **Barker** and Mark **Adams** are Assistant Directors. Thomas G. **Barnes** III retired as Associate Director and returned to full-time research.

1.3 Teaching and Research Personnel

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

Academic

Named Chairs: John **Kormendy** (Curtis T. Vaughan, Jr. Centennial Chair in Astronomy); 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 Emeritus in Astronomy); Chris **Sneden** (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: James N. **Douglas** (Emeritus), Paul M. **Harvey**, Dan **Jaffe**, Pawan **Kumar**, John **Lacy**, Paul **Shapiro**, Derek **Wills**, and Don **Winget**.

Associate Professors: Harriet **Dinerstein** and R. Robert **Robbins**, Jr. *Assistant Professor*: Karl **Gebhardt**

Non-Academic

Senior Research Scientists: Thomas G. **Barnes** III, G. Fritz **Benedict**, Anita L. **Cochran**, William D. **Cochran**, Gary **Hill**, Peter J. **Shelus**, Laurence M. **Trafton**, and Robert G. **Tull**.

Research Scientists: Edwin S. **Barker**, Robert **Duncan**, Peter **Höflich**, Daniel F. **Lester**, Hugo **Martel**, and Beverley J. **Wills**.

Resident Scientists, Research Associates, Postdoctoral Research Associates and Other Research Staff: Carlos **Allende Prieto**, Brad **Behr**, John **Booth**, Mark **Cornell**, Niv **Drory**, Michael **Endl**, Oleg **Ershov** (deceased), Tony **Farnham**, Mary Kay **Hemenway**, Eric **Hooper**, Zach **Ioannou**, Sheila **Kannappan**, Phillip **MacQueen**, Jeff **Mader***, Barbara **McArthur**, Alvin L. **Mitchell**, Gajendra **Pandey**, Povilas **Palunas**, Brigitte **Ragot**, Bacham **Reddy**, Matthew **Richter**, Randy **Ricklefs**, Nils **Ryde**, Judit **Györgyey Ries**, Brian **Roman***, Brad **Schaefer**, Martha **Schaefer**, Yaron **Sheffer**, Matthew D. **Shetrone***, William **Spiesman**, Ted **von Hippel**, and Russel **White**.

1.4 Senior Research Support and Administration

Development Officer: Joel **Barna**.

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

McDonald supervisors: Phillip W. **Kelton** (mechanical engineering, *ad interim*), Edward **Dutchover**, Jr.* (administrative support), Earl **Green*** (observing support), Tom **Brown*** (physical plant), Mark **Cornell** (computing systems), Phillip **MacQueen** (CCD development), Alvin L.

Mitchell (electrical engineering), and Jerry R. **Wiant*** (MLRS).

Hobby•Eberly Telescope supervisors: John **Booth** (Project Manager and Chief Engineer), Mark **Adams*** (Facility Manager *ad interim*), James **Fowler*** (Computing), John **Vause*** (Mechanical Engineering), Matthew **Shetrone*** (Night Operations), Edmundo **Balderrama*** (Electrical), Tony **Distasio*** (Optics).

Financial Officer: Dotty **Frasch**

1.5 Board of Visitors

Lillian **Murray** was Chair of the McDonald Observatory and Department of Astronomy Board of Visitors, with Rob **Arnold** Vice Chair and David **King** III, Secretary.

1.6 Visitors and Affiliations

The following people visited the department for extended periods:

T. **Beers** (Michigan State U.)

A. **Bragaglia** (Osservatorio Astronomico di Bologna, Italy)

M. **Breger** (Institut für Astronomie der Universität Wien)

J. **Cowan** (U. Oklahoma)

E. **Gawiser** (U. California - San Diego)

J. **Gerssen** (Space Telescope Science Institute)

A. **Hatzes** (Tautenburg Observatory)

A. **Kanaan-Neto** (U. Federal de Santa Catarina)

S. O. **Kepler** (Porto Alegre U. Federal)

K. **Kinemuchi** (Michigan State U.)

G. **Preston** (Carnegie Inst.)

N. K. **Rao** (Indian Institute of Astrophysics)

D. J. **Sullivan** (National Observatory of New Zealand)

D. **Thomas** (Universitäts-Sternwarte München)

G. **Wallerstein** (U. of Washington)

McDonald Observatory is a partner in the Southern African Large Telescope, a copy of HET under construction at Sutherland South Africa. McDonald entered into agreements during the last year to host automated observing programs with three robotically operated small telescopes. These projects should begin their observing operations during the 2002-2003 timeframe. An agreement with the Yale Astrophysics Group headed by Professor Charles Baltay is resulting in the automation of the McDonald 0.91-meter telescope system and the addition of a 2400x2400 mosaic CCD camera for long time scale quasar survey work. Another agreement with Professor Carl Akerlof of the University of Michigan will place a 0.45-meter ROTSE3 automated telescope at McDonald for gamma ray burst studies and other synoptic astronomy projects. Lastly, McDonald will host one of the two 1.2-meter telescopes which will constitute the MONET (MOnitoring NEtwork of Telescopes) project headquartered at Universitäts-Sternwarte in Göttingen, Germany. The second telescope in the initial MONET network will be hosted by SAAO at Sutherland, South Africa. The robotically controlled MONET telescopes will be dedicated to CCD imaging and will perform both professional research programs and support for public education projects.

1.7 Awards, Honors, and Special Activities

The Board of Visitors Teaching Excellence Award in Astronomy went to D. **Winget**, who also received the College of Natural Sciences Teaching Excellence Award. J. Craig **Wheeler** has been elected as a permanent member of the University of Texas Academy of Distinguished Teachers.

Staff Excellence Awards went to Tom **Brown*** and Bob **Worley**.

J. Craig **Wheeler** was a Vice President of the American Astronomical Society. P. **Shelus** served his 24th year as Treasurer of the American Astronomical Society's Division on Dynamical Astronomy. W. **Cochran** was elected to the position of Vice-Chair of the Division for Planetary Sciences of the American Astronomical Society. Mary Kay **Hemenway** was Secretary to the Board of the Astronomical Society of the Pacific. P. **Shelus** was elected 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.

F. **Bash** was Chairman of the Hobby•Eberly Telescope Board of Directors and a member of the Southern African Large Telescope Board of Directors. He also is a member of the AURA Coordinating Council of Observatory Research Directors, which consists of the directors of the large, ground-based optical, infrared observatories, and is the immediate Past-President of the Astronomical Society of the Pacific.

John **Kormendy** continued to serve on the Space Telescope Users Committee. W. **Cochran** served as a member of the NASA Keck/IRTF Management Operations Working Group, and also as a member of the IRTF Time Allocation Committee. A. **Cochran** was an advisor to the Small Bodies Node of the Planetary data System and served on the NASA Origins of Planetary Systems Management Operations Working Group. P. **Shelus** serves on the Directing Board of the International Earth Rotation Service to represent the Lunar Laser Ranging community. T. **Barnes** served as the institutional representative to AURA, Inc., for The University of Texas at Austin. Mary Kay **Hemenway** was a member of the SOFIA Education and Public Outreach Working Group. D. **Lester** served on the Structure and Evolution of the Universe Subcommittee of the NASA Space Science Advisory Committee. He was an associate editor for the 2003 SEU Roadmap, and was an invited participant at the OSS Strategic Plan Convergence Meeting. D. **Lester** is on the SAFIR (Single Aperture Far Infrared Telescope) science and operations working group, recently constituted by NASA. This group is charged with laying the scientific and technical groundwork for a 10-m class space telescope for development around the end of the decade. D. **Lester** continued to serve on the steering committee of the Space Science Working Group of the American Association of Universities. This group is dedicated to congressional advocacy on behalf of space science. Mary Kay **Hemenway** was a Panel Moderator at NASA Office of Space Science Education and Public Outreach Conference. G. **Hill** was an external reviewer at Preliminary Design Reviews for the IMPALAS spectrograph on the Southern African Large Telescope, the MODS spectrographs on the Large Binocular Telescope, and a new double spectrograph for the Instituto de Astronomia (UNAM, Mexico). P. **McQueen** was an external reviewer at the preliminary design review for the SALTICAM imager on the Southern African Large Telescope.

Mary Kay **Hemenway** served on a Site Visit Team for a proposed NSF Science and Technology Center and was Chair of the review panel for NASA IDEAS Retrospective at Space Telescope Science Institute. A. **Cochran** was a member of a special NASA panel to review the Planetary Data System and served on the Committee of Visitors for the National Science Foundation Astronomy Program. E. **Barker** served on the NASA Near Earth Object Observations Review Panel. T. **Barnes** served on the National Science Foundation 'Stellar Populations' Peer Review Panel.

J. **Kormendy** is on the scientific organizing committee of IAU Symposium 220, ''Dark Matter in Galaxies'' (Sydney, 2003). K. **Gebhardt** was a meeting organizer for ''Black Holes: Theory Confronts Reality'' (Santa Barbara).

A. **Cochran** is an associate editor for ''Meteoritics and Planetary Science.'' Mary Kay **Hemenway** served on the Editorial Board of Astronomy Education Review and was a reviewer for ''CHOICE,'' a publication of the Association of College and Research Libraries.

Mary Kay **Hemenway** and Anita **Cochran** were American Astronomical Society Harlow Shapley Lecturers during this period. They visited Texas Tech University and Oklahoma Christian University, respectively.

A. **Cochran** was a Shell Lecturer at the National Science Teachers Association annual meeting.

2. ACADEMIC AND EDUCATIONAL PROGRAM

2.1 Graduate Program

The Graduate Studies Committee Chairman was Paul **Shapiro** with Graduate Advisor Craig **Wheeler**. The Fred T. Goetting, Jr. Memorial Endowed Presidential Scholarship was awarded to Pamela **Gay**. The Board of Visitors Second Year Defense Award was awarded to Jeong-Eun **Lee**.

Graduate students in 2000–2001 were Kyungjin **Ahn**, Shizuka **Akiyama**, Katelyn **Allers**, Marcelo **Alvarez**, Elisabeth **Ambrose**, Andrey **Andreeshchev**, Nairn **Baliber**, Marcel **Bergmann**, Anirban **Biswas**, Gregory **Doppmann**, Amy **Forestell**, Rica **French**, Pamela **Gay**, Tommy **Greathouse**, Inese **Ivans**, Mukremin **Kilic**, Claudia **Knez**, Jeong-Eun **Lee**, George **Marion**, Jasmina **Marsh**, Kaisa **Mueller**, Anjum **Mukadam**, Fergal **Mullally**, Eva **Noyola**, Diane **Paulson**, Zhaohui **Shang**, Yancy **Shirley**, Julia **Silge**, Jennifer **Simmerer**, Nicholas **Sterling**, Joseph **Tufts**, David **Wilson**, Marsha **Wolf**, Jingwen **Wu**, David **Yong**, Chad **Young**, Juntao **Yuan**, and Quingeng **Zhu**.

Doctoral Dissertations – Three Ph.D. degrees in astronomy were awarded in 2001–2002:

Gregory **Doppmann** – *Near Infrared Probe of Embedded Stellar Populations in Clusters* (Daniel Jaffe, chair)

Inese **Ivans** – *Chemical Abundances and Kinematics of Low-Metallicity Stars as Tracers of Early Galactic Evolution* (Christopher Sneden, chair)

Yancy **Shirley** – *Dense Gas and Star Formation: CS $J=5 -> 4$ Mapping of Cloud Cores Associated with Water Masers* (Neal Evans and Daniel Jaffe, co-chairs)

I. **Ivans** received a Hubble Postdoctoral Fellowship and Y. **Shirley** a Jansky Postdoctoral Fellowship.

2.2 Undergraduate Program

Harriet **Dinerstein** was the chair of the Undergraduate Studies Committee; John **Lacy** served as undergraduate advisor. There were 58 astronomy majors this year and 12 students received BAs.

Erin **Smith** was awarded the Outstanding Graduating Senior Award. Heather **Jacobson** received the Board of Visitors Undergraduate Scholarship. Rodolfo **Montez**, Jr. was granted the Karl G. Henize Memorial Scholarship in Astronomy.

E. **Hooper** began tenure in the UT Astronomy department as a member of the first group of NSF Astronomy and Astrophysics Postdoctoral Fellows, a new national fellowship program to fund independent research but which also includes an education and/or public outreach component. His main education efforts involved the UTeach program at UT Austin, which trains secondardy school science teachers (with M. Marder, director, & G. Carmack). He is also a staff member for teen & adult Astronomy Camps in Arizona (with D. McCarthy, director, U. Arizona). P. **Kumar** is also associated with the UTeach program.

2.3 Educational Services

The nine-inch refractor (directed by Michael **Yuan** and Yancey **Shirley**) was visited by over 650 people during public tours. School groups totaling over 1025 elementary/secondary students and teachers participated in Solar Telescope field trips presented by Lara **Eakins**. Regular star parties attracted 600 people.

Mary Kay **Hemenway** and Lara **Eakins** represented the Department at many other events, such as Amistad National Recreation Area star party, Freshman Orientation, Honors Colloquium, and UT Parents' Weekend. Over 300 people were served through these events.

2.4 Public Information and Education Office

Senior staff includes Sandra **Preston**, Director of Public Information and Education; Damond **Benningfield**, StarDate/Universo, Writer-Producer and StarDate Magazine, Executive Editor; Rebecca **Johnson**, StarDate Magazine Editor; and Frank **Cianciolo**, Sr. Program Coordinator, McDonald Observatory Visitors Center. The new McDonald Observatory Visitors Center opened February 2002. Decoding Starlight, an interactive bilingual (English/Spanish) exhibit on spectroscopy opened simultaneously. The new Visitors Center includes a 90-seat auditorium, a classroom, exhibit hall, gift shop, and StarDate Café. Outside amenities include a sundial court, terrace area for outdoor dining, telescope park, and 325-seat amphitheater. After several years of preparing curriculum, a K-12 education program was launched in 2002, which offers year-round teacher professional development workshops and K-12 student field experiences. The McDonald Observatory Visitors Center also conducts Elderhostel programs. Catering and meeting facilities are available for rent by groups. The McDonald Observatory visitors program currently serves over 130,000 visitors annually. For more information browse www.mcdonaldobservatory.org.

The Star Date radio program is heard on over 300 radio stations in the U.S. Universo, the Spanish-language version of StarDate, broadcasts on over 170 radio stations. Sternzeit, StarDate's German counterpart, continues to broadcast on Deutschland Radio in Germany. More than 1,000 teachers used StarDate and Universo in the classroom. StarDate and Universo are available online at stardate.org and radiouniverso.org. The StarDate magazine has 10,000 subscribers.

3. RESEARCH PROGRAM

3.1 The 9.2-Meter Hobby•Eberly Telescope

The Hobby•Eberly Telescope (HET) is nearing completion of its third year of early operations. During this last year, two-thirds of the HET night-time operations hours were scheduled for science observations, all in the queue mode. The remainder of the available night-time operations hours were assigned to science instrument commissioning, and telescope and facility improvement engineering. The facility instruments available to HET science users throughout this period were the Low Resolution Spectrograph (LRS: G. Hill, U. Texas, PI) and the High Resolution Spectrograph. (HRS: P. MacQueen, U. Texas, PI). The average CCD shutter-open, on-sky efficiency of the HET during science operations has improved over the past year from 30% to 45%. Science spectra were delivered to Principal Investigators at all five collaborating institutions and to the United States national community through the National Optical Astronomy Observatory. University of Texas at Austin proposals accounted for 52% of the HET science operations time.

Throughout this year, the HET benefited from a major McDonald Observatory engineering effort. Its scope included completing critical aspects of the telescope that were not supported in the original constrained construction budget and rectifying deficiencies identified during commissioning and early operations. Phase I consisted of four major elements: (1) a Segment Alignment Maintenance System (SAMS); (2) a Dome Ventilation System (DVS); (3) a Mirror Alignment Recovery System (MARS); and (4) two Differential Image Motion Monitors (DIMMs).

SAMS uses 480 inductive edge sensors to continually correct small misalignments of the HET's 91 primary mirror segments when the segments are perturbed from their reference positions. SAMS has improved telescope performance. The mean time between primary mirror alignment operations has increased from once per hour, prior to SAMS installation, to once every three hours. Delivered telescope image quality has improved by $0\farcs3$. Since the as-built SAMS system delivered by the contractor does not yet meet its specifications, a McDonald Observatory effort was initiated to improve system performance. The goals for this effort include further image quality improvements and a further reduction in primary mirror alignment operations to no more than once per night.

The initial phase of the DVS project included designing, fabricating, and installing large ring wall louvers in the HET cylinder wall. It resulted in significant improvements to the delivered HET image quality. Phase II of the DVS project will minimize dome supercooling by covering the dome with low emissivity aluminum foil and insulating its interior surface. A comprehensive Facility Thermal Management project was also initiated to address remaining heat sources within the enclosure and other thermal issues.

MARS is a prototype Shack-Hartmann-based segment alignment system for the primary mirror array. It replaced the original failed Center of Curvature Alignment System (CCAS). Performance is assessed by measuring the image quality at the primary mirror array's center of curvature. MARS has consistently delivered $0\farcs9$ (EE50) or better. An upgraded, more operationally robust MARS II instrument entered the design phase during summer 2002 for delivery to west Texas in March 2003.

Two DIMM telescopes were assembled, tested and placed in regular operation atop Mount Fowlkes, where HET is located. These instruments have now provided a quantitative site seeing dataset over an entire annual cycle. The mean zenithal site seeing during the months March - October was $0\farcs9$ (FWHM). The mean zenithal site seeing during months November - February was $1\farcs2$ (FWHM). Averaged over the entire year, the mean site seeing was $1\farcs0$ (FWHM). The seeing was $\leqslant 0\farcs7$ (FWHM) in 6% of the DIMM samples. DIMM operation has materially aided HET operations by providing real-time feedback on seeing, an important input to science operations decision-making and to decisions regarding when to realign the primary mirror array. Construction of a permanent DIMM tower has begun. Plans are in place to design and implement fully remote DIMM operation from the HET control room.

HET instrument developments during the last year include improvements to LRS and HRS (see Section 3.3.1), development work at UT Austin on LRS-J (the J band extension of LRS), and installation and first light for the Medium Resolution Spectrograph (MRS, Larry Ramsey, Pennsylvania State U., PI). MRS is the third HET facility instrument.

MRS is to be a versatile, fiber-fed echelle spectrograph. Designed for a wide range of scientific work, it includes single-fiber inputs for point sources, synthetic slits of fibers for long slit spectroscopy, nine independently-positionable probes for multi-object spectroscopy, and a circular fiber integral field unit (IFU). The MRS consists of two beams. The visible beam has wavelength coverage from 450 - 900 nm in a single exposure with resolving power between 5,300 and 20,000 depending on the fibers configuration selected. This beam also has capability from 380 - 950 nm by altering the angles of the cross-disperser gratings. A second, near-infrared beam covers 900 - 1300 nm with resolving power between 5,300 and 10,000. The visible and near-infrared MRS beams can be used simultaneously. The MRS Fiber Instrument Feed (FIF) is mounted at the telescope's prime focus. It positions the fibers feeding MRS. Both the visible beam and the NIR beam began initial testing on the HET this last year. Basic modes for the visible beam will be available in early 2003, with the near-infrared beam coming online in the second quarter of 2003.

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 below. Scheduled hours are measured from civil twilight to civil twilight, plus any especially scheduled daytime hours. (The daytime hours for all four telescopes together account for only 276 hours.) Category ‘‘Other’’ is comprised primarily of time when the telescope was not scheduled.

The 2.7-m telescope logs are 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 problems, etc., the usable time is estimated as 60% for the last fiscal year. This value may be compared with 59% from the previous year and 64% which is the mean for 3, 10 year periods since 1939. Until 1992 the 0.9-m telescope was heavily used for photometric programs. From 0.9-m telescope statistics during the period 1981 - 1992, we can estimate the photometric weather to be 39.8% of the available hours. The 0.9-m has not been used for regular photometric programs in recent years.

3.3 Scientific Results

3.3.1 Instrumentation:

A team led by A. Cochran and consisting of A. Mitchell, P. Odoms, F. Harvey, and M. Cornell completed the upgrade of the Automated Telescope Offset Guider (ATOG) for the 2.7-m telescope. Modern, flexible, electronics and drivers were installed, tested and calibrated. A new GUI controller was developed which incorporates user-definable parameters, history, and other features. An ICE interface was also developed so that the ATOG functions can be accessed by the data acquistions software for the first time. The new system has been working flawlessly since installation in April and is a pleasure to use. In addition, during August, D. Lester, A. Cochran, P. S. Odoms and M. Cornell installed a new CCD acquisition camera into the ATOG, to replace the old, unstable camera. New guider software was installed at the time.

The Texas Echelon Cross Echelle Spectrograph (TEXES; J. Lacy, PI, M. Richter, T. Greathouse, D. Jaffe, and Q. Zhu), a high resolution mid-infrared spectrograph, continues to be a productive instrument, providing spectral resolving power as high as 100,000 at 5-25 microns. It is open to the astronomical community for collaborative observations on the NASA IRTF.

D. Lester continues efforts on the hydroDIMM concept, which allows a conventional DIMM telescope to economically and conveniently measure precipitable water vapor. Such an instrument is of value for site surveys for new generation ground-based infrared telescopes. Proof-of-concept for this instrument is complete, and system characterization is now being done.

D. Lester works with the Ten Meter Telescope (TMT) group, which is a consortium of universities that seeks to build a 10-20m class telescope at a quality site, and represents the Texas interest in the project. Lester is working on a study to consider operations planning and cost-impacts of 5000+m sites, which would offer major advantages to infrared science.

G. Hill continued to support operation of the Marcario Low Resolution Spectrograph (LRS) on the HET. P. MacQueen continued support of the CCD system for the LRS. As the image quality of the telescope has improved, the LRS has succeeded in observing fainter targets, including QSOs at the highest redshifts, faint sources from the CHANDRA satellite, and high redshift galaxies and clusters. Notable are the observations of M. Bergmann and K. Gebhardt of the kinematic structure of elliptical galaxies at up to 4 effective radii, the deepest such observations ever made. By virtue of its relatively large slit width at a given resolution, the LRS beats comparable instruments on other large telescopes for observations of the low surface brightness extremities of galaxies.

G. Hill and M. Wolf continued development of volume phase holographic grisms for the LRS. Grism 3 covering 630-900 nm at R=2000 (1 arcsec wide slit), has been commissioned and will enter limited science use in the upcoming trimester. It offers high throughput and higher resolving power that the current grisms.

J. Tufts and G. Hill, with help from E. Hooper delivered multi-object spectroscopy (MOS) setup capability for the LRS, including the ability to generate MOS setups directly from astrometry. This makes it possible to observe objects that are invisible in setup images. The LRS MOS unit allows 13 fixed format slits to be positioned remotely over a 3x4 arcmin field of view.

G. Hill, P. MacQueen, J. Tufts and D. Boyd continued work on the J-band extension of the HET LRS (LRS-J). The project involves construction of a cryogenic f/1 camera that will replace the optical camera of the LRS to extend coverage to 1.3 microns. The opto-mechanical design is complete and will enter fabrication shortly. The optics were designed by F. Cobos and C. Tejada (IAUNAM) and G. Hill, and put 80% of the light into a single 18.5 micron pixel of the HAWAII-1 array. P. MacQueen and J. Tufts have completed design modifications to a Version 2 McDonald CCD Controller to allow it to run this array. Following some software development we will read out the engineering array by the end of the year

G. Hill delivered new capabilities and an updated manual for the Imaging Grism Instrument (IGI) with help from E. Hooper and M. Wolf. IGI is used primarily on the 2.7 m but can also be used on the 2.1 m for imaging and spectroscopy. A new volume phase holographic grism with 930 fringes/mm covering 400-800 nm with the 50 mm camera lens has more than doubled throughput and allows objects as faint as R=21 to be observed in several hour exposures. A multi-object mask capability (allowing masks to be generated from astrometric data in a few day turn-around) has been developed and tested successfully. Several programs are now using this capability.

G. Hill and MacQueen developed a concept for a 1000+ object multi-IFU spectrograph consisting of 64 individual spectrographlets, the Visible Replicable Ultra-cheap Spectrograph (VIRUS).

The new McDonald Observatory Visitors Center incorporates a Solar Spectrum Projector which displays a live real time spectrum of the sun. The system (optical design by M. Jones, Lockheed-Martin Corporation and implemented by P. Kelton, M. Jones, J. Good, and D. Lester) features a roof-mounted heliostat feeding a 9-inch f/104 refractor whose beam is folded into and across the upper part of the building interior, forming an 8-inch image of the sun near the entrance to the spectroscopy exhibit hall. An imaging mirror behind the long slit assembly feeds a slice of the solar image to a Littrow configuration spectrometer which incorporates a high quality 1200 line/mm grating from the retired coude spectrograph of the McDonald 2.1-meter telescope. This produces an 8-inch tall solar spectrum that is spatially resolved in the vertical direction and over 6 feet wide, with a maximum resolution of order 20,000. Visitors can vary the spectrometer's slit width with a handpaddle so the relation between slit width, resolution, and brightness can be demonstrated.

3.3.2 Extrasolar Planetary Systems:

G. Fritz Benedict and B. McArthur (in collaboration with T. Forveille, CFHT, X. Delfosse, Grenoble, E. Nelan, STScI, R. P. Butler, Carnegie, W. Spiesman, U. Texas, G. Marcy, UC Berkeley, B. Goldman, New Mexico State U., C. Perrier, Grenoble, W. H. Jefferys, U. Texas, and M. Mayor, Geneva) determined the semi-major axis of a perturbation of Gl 876 due to a planetary companion previously detected by Doppler spectroscopy. Radial velocities first provided an ephemeris with which to schedule a significant fraction of the HST/FGS observations phased to occur near peri- and apastron. Astrometry residuals exhibit a systematic deviation consistent with a perturbation due to a planetary mass companion. The complete analysis involves modeling both astrometry and radial velocities simultaneously. This is the first extrasolar planet mass determined astrometrically and only the second extrasolar planetary mass known (after HD 209458). Benedict and McArthur continue similar studies with HST/FGS astrometry of the longer period systems ϵ Eri and υ And.

W. Cochran, M. Endl, and A. Hatzes (TLS-Tautenburg) started a large radial velocity survey for planetary mass companions using the High Resolution Spectrograph of the HET. The major goal of the survey is to quantify any dependence of planet formation on stellar metallicity. The survey will eventually include 800-1000 target stars spanning a wide range in metallicity. Preliminary results with the HET telescope and the HRS instrument are extremely encouraging. The spectrograph is specifically designed to have excellent mechanical and thermal stability. We have achieved a routine precision of $\sim 3\,\mathrm{m\,s^{-1}}$. There are several steps we plan to take to improve this precision level toward our goal of $1\,\mathrm{m\,s^{-1}}$.

D. Paulson (W. Cochran, supervisor) continued a high precision radial velocity survey of dwarf stars in the Hyades star cluster using the Keck 1 telescope and its HIRES spectrograph. This survey of the Hyades is designed to study the dependence of planetary system formation on stellar mass, in a well controlled sample of stars. With the Hyades they have demonstrated $3-6\,\mathrm{m\,s^{-1}}$ radial velocity precision for main sequence stars between F8 and M2. Because of the youth and consequent high level of stellar activity of these stars, they have conducted a detailed investigation of whether magnetic activity of these Hyades target stars will interfere with precise radial velocity ($v_{\rm rad}$) searches for substellar companions. They measure chromospheric activity by computing the equivalent of the $R'_{\rm HK}$ activity index from the Ca II K line, and find that there is a significant correlation between $R'_{\rm HK}$ and the radial velocity in only 5 of the 82 stars in our Hyades sample.

M. Endl joined the McDonald Observatory planet search group and began work on the 2.7m-telescope radial velocity survey. Together with W. Cochran he started a large survey using the HET/HRS to search for giant and low-mass planets around nearby M-dwarf stars. The structure and frequency of planetary systems in the low-mass regime of the Hertzsprung-Russell diagram is virtually unknown due to the current incompleteness of Doppler searches. The HET/HRS M-dwarf planet search will survey up to 200 M-stars in the next years and was specifically designed to address this topic. M. Endl is also involved in planet search programs in the southern hemisphere using the ESO VLT & ESO 3.6m-telescope (together with M. Kürster, TLS-Tautenburg), as well as the Italian GALILEO-telescope on La Palma (with S. Desidera, Padova Observatory), and in near-IR adaptive optics searches for circumstellar debris disks and faint companions (with S. Els, Isaac Newton Group of Telescopes).

N. Baliber (W. Cochran, supervisor) has led the Texas McDonald Photometric Extrasolar Search for Transits (TeMPEST), a photometric survey for transits of extrasolar giant planets in short-period orbits around their parent stars. This survey is conducted with the McDonald Observatory 0.76 m Prime Focus Corrector, which provides a 46.′2 x 46.′2 field of view. From August through December, 2001, they obtained a first full season of data on two fields in the Galactic plane, one in the constellation Cassiopeia and the other in Camelopardus. In these two fields, V-band time-series photometry with a cadence of $\sim$9 minutes has been performed on over 5000 stars with sufficient precision, better than 0.01 mag, to detect transits of close-orbiting Jovian planets.

D. Winget (with A. Mukadam, F. Mullally, E. Nather, and T. von Hipple) began a search for planetary systems around pulsating white dwarf stars. This search may yield planetary systems dynamically similar to our own solar system.

3.3.3 Astrobiology:

J. Scalo and J. Craig Wheeler continued their study of the rates and relevance of sources of astronomical radiation for various problems related to the origin and evolution of life. They and students presented poster papers at the National Astrobiology Institutes Symposium at Ames and the Space Telescope Science Institute Symposium on ''Astrophysics and Life.''

Scalo, Wheeler, and graduate student D. Smith continued to study the Compton scattering of gamma-rays in model planetary atmospheres to determine the intensity and spectrum of the energy that reaches the ground. For thick atmospheres about 1% of incident hard radiation can reach the ground in biologically active form as UV auroral line radiation.

3.3.4 Solar System:

A. Cochran and W. Cochran completed their atlas of high resolution spectra of comet 122P/de Vico. They identified 12,219 lines in the optical spectrum and observed another 4,051 unidentified lines. Complete identifications and plots have been archived in the Planetary Data System's Small Bodies Node (psssbn.astro.umd.edu). This atlas will facilitate future high spectral resolution observations of comets.

T. Farnham and A. Cochran completed their study of comet 19P/Borrelly. These observations were obtained to place the Deep Space 1 mission flyby results into a greater historical context. Using McDonald Observatory images and spectra, they were able to constrain the postion of the rotation pole to be $\alpha = 214°$, $\delta = -5°$. They obtained evidence that the pole may have shifted by 5–10° since discovery. Using their pole position and the published nongravitational acceleration terms, they computed a mass of the nucleus of 3.3×10^{16} g and a bulk density of 0.49 $\mathrm{g\,cm^{-3}}$ (with a range of $0.29 < \rho < 0.83$ $\mathrm{g\,cm^{-3}}$). This result is the least model-dependent comet density known to date.

A. Cochran published the results of a search for N_2^+ in comet C/2002 C1 (Ikeya-Zhang). No N_2^+ was observed and sensitive upper limits were placed on the ratio N_2^+/CO^+ of 5.4×10^{-4}. Nitrogen is believed to preferentially be in the form of N_2 in the early solar nebula so observing N_2^+ is important for constraints on models. The importance of the upper limit she derived depends on whether H_2O was deposited in the crystalline or amorphous forms in comets. If deposited in the crystalline form, other molecules would be incorporated via clathration. The derived ratio has strong implications for H_2O/H_2 in the early solar nebula.

T. Greathouse, along with collaborators from Observatoire de Paris, Lowell Observatory, and Univ. of Arizona, has been observing the atmospheres of Jupiter, Saturn, and several of their satellites with TEXES, a high resolution mid-infrared spectrograph. Molecules as complex as C_3H_8 have been mapped.

B. Schaefer along with D. Rabinowitz and S. Tourtellotte (Yale) have been observing outer Solar System bodies with unprecedented time coverage for synoptic light curves with the Yale 1-m telescope on Cerro Tololo. The brightest Kuiper Belt Object (2000 EB_{173}) was observed on 78 nights, and this produced the first ever measure of the opposition surge for a trans-Neptunian object. The Neptunian moon Nereid was observed on 54 nights, with the startling result that its extraordinarily high opposition surge *changed* its shape from one year to the next.

J. Ries, E. Barker, P. Shelus and R. Ricklefs continue astrometric observations of small, inner solar system bodies, supported by NASA. CCD observations are made using the f/3 Prime Focus Corrector (PFC) on the McDonald 0.76-m reflector, reaching about R=22, with more than 3-sigma significance on stellar objects. The objective is to obtain accurate positions of newly discovered and under observed Near Earth Approaching Objects (NEO's). Search programs are discovering 20-50 moving objects per month and placing them on an IAU sponsored NEO Confirmation list. Once discovered, follow-up observations must be made quickly to confirm, establish, and then maintain, orbits. The more time that passes between discovery and follow-up, the more likely that the object will be lost. Their program concentrates on fainter moving targets and those objects which have orbital and physical characteristics which result in a PHA (Potentially Hazardous Asteroid) designation.

Observations are made with three successive exposures, using frame blinking to maximize the certainty of target identification. While one exposure is being taken, previous exposures are measured and reduced. On average 3 positions for 15-20 targets are obtained per night, then electronically transmitted to the Minor Planet Center. For those targets with photometric standards present on the CCD frame, we produce B-R and V-R colors of the NEOs. These colors provide an initial taxonomic classification for an NEO before it becomes too faint to observe. Further work is underway toward a totally automated observing and measuring sequence, eventually to locate and measure all moving objects appearing on any series of frames.

NEO's provide an opportunity to do laboratory celestial mechanics. These objects are in chaotic, planet-crossing orbits, derived from fragments produced by collisions in the main asteroid belt. Collisional physics and the observed distribution of orbital elements of minor planet families suggest that changes in velocity imparted to km-size fragments during collisions generally do not exceed a few hundred $\mathrm{m\,s^{-1}}$. These changes are too small to directly inject main-belt minor planet fragments into Earth-approaching orbits. But, the small changes in velocity imparted to collisional fragments can be sufficient to shift them into dynamical resonances. Resonant amplification of the eccentricity of the orbit of a fragment can lead to a planet-crossing orbit. Synergistic interplay between resonant perturbations and perturbations due to encounters with Mars can then produce NEO's. Investigations are underway to characterize the magnitude of non-gravitational forces.

L. Trafton completed his modeling of Visible - NUV spectra of Io in Jupiter's shadow obtained in August 1999 with HST/STIS. This is part of a Galileo-HST campaign to study Io. It was found that Io's continuum contributes negligibly to Io's NUV eclipse spectrum, which is therefore entirely emission produced by electron impact of SO_2. The emission spectrum was fitted to laboratory data provided by J. Ajello (JPL) and the effective electron energy exciting Io's SO_2 atmosphere was derived.

With S. J. Kim (U. Kyunghee), L. Trafton tentatively detected the H_2 dimer features in spectra of Uranus. Coadded from several observing runs in order to build up the signal to noise ratio, these spectral features are in the near-IR, around 2.1 μm, and arise from the fundamental band of H_2. They had already detected these H_2 dimer features in the spectra of Jupiter, Saturn, and Neptune; but strong absorption from the pressure-induced H_2 absorption in the clear Uranian atmosphere prevented previous detection. They are useful indicators of the ortho-H_2/para-H_2 ratio in the atmospheres of the giant planets because their line ratios are insensitive to the temperature, unlike the H_2 quadrupole lines. The ortho-/

para-H_2 ratio is diagnostic of dynamical processes in these atmospheres.

Also with S. Kim, L. Trafton analyzed the meridional 2 μm spectra of Jupiter and Saturn, which were observed in July, 1999 at the UKIRT telescope in collaboration with T. R. Geballe (Gemini). The equivalent widths vs latitude of two prominent dimer absorption features near 2.122 μm were measured. They compared them with an ab-initio model of the $(H_2)_2$ dimer, constructed by modifying a quantum mechanical model. The extracted ortho/para ratio of H_2 and its latitudinal variation, are diagnostic of dynamical processes. This work is being extended with more accurate quantum mechanical calculations in collaboration with L. Frommhold (U. Texas).

L. Trafton analyzed selected ground-based observations of Jupiter's auroral H_2 emission taken at the McDonald Observatory using the CoolSpec Cassegrain IR spectrometer at the 2.7m telescope. Jupiter's auroral cascade causes H_2 emission in the near-IR quadrupole lines, in addition to the FUV emission. Unlike the FUV aurora, the near-IR aurora can be observed from ground-based observatories; and has in fact been observed as emission in the H_2 (1-0) band in the spectra of Jupiter and Uranus. Unlike the near-IR H_3^+ aurora, which is formed by the reaction of H_2 ionized by the cascade reacting with neutral H_2, the H_2 aurora can emit from atmospheric levels below the homopause, where H_3^+ would be destroyed by chemical reaction with hydrocarbons. H_2 thus probes the auroral energy input at deeper levels. Using the (1-0) H_2 Q-branch, he measured preliminary rotational temperatures and excited H_2 columns in Jupiter<s northern auroral arc for various extracted System III longitudes. Significant non-equilibrium overpopulation of the v=1 vibrational level was generally found, due to the intensity of the auroral cascade. Comparison to similar data from the now-retired IRGS instrument revealed an unusually hot auroral event on January 1, 1989.

L. Trafton examined spectra of Jupiter taken with TEXES at the IRTF in Feb 2001 searching for the pure rotational emission lines of H_3^+. These would be useful in establishing the thermal response of Jupiter's ionosphere to auroral precipitation and Joule currents. No emission was found; but this appears to be because the exploratory 3-5 min exposures used were too short. Further observations are planned with much longer exposures.

B. Schaefer has resolved the issue as to the true cause of the infamous 'Black Drop' effect seen during transits of Venus, an effect that killed transit utility in measuring the Astronomical Unit in the 1700's and 1800's. In the scholarly, popular, and internet literature, four explanations are all presented as true. Schaefer presents theoretical and observational proofs that three of these explanations are certainly false, yet these false ideas account for 69% of the claims equally in all types of literature. The true explanation (first presented by de la Lande in 1770) is that the ideal view (of a dark circle silhouetted against a bright circle) suffers smearing (from atmospheric seeing, diffraction in the telescope, telescope aberations) and this produces isophots that have 'black drop' shapes. It is predicted that the next Venus transit (on 8 June 2004) will generally have the Black Drop go unnoticed due in part to the prevalence of large-aperture and high-quality telescopes. It is also predicted that a significant fraction of the scholarly and popular articles will still quote a wrong explanation for the Black Drop.

3.3.5 Stars and Stellar Systems, Stellar Ejecta:

B. Behr continued his studies of abundances and rotation velocities of evolved stars. He also developed an automated spectral synthesis package for the analysis of stellar spectra, and collaborated with R. Robinson and M. Bitner on a project to model the rotational line-broadening modulation of tidally-distorted secondary stars in tight binary systems.

The HST Astrometry Science Team was based at the University of Texas. Local members included G. Fritz Benedict (Deputy P.I.), B. E. McArthur, R. Duncombe (Aerospace Engineering), W. H. Jefferys (P.I.), and P. J. Shelus. This year the team finished reducing and analyzing HST/FGS astrometry for two critical distance indicators, RR Lyrae and δ Cephei. For RR Lyr we find $\pi_{abs}=3.82\pm0.2$ mas, hence, $M_V^{RR}=0.61^{-0.11}_{+0.10}$. This provides a distance modulus for the LMC, m-M=18.38 – $18.53^{-0.11}_{+0.10}$ with the average extinction-corrected magnitude of RR Lyr variables in the LMC remaining a significant uncertainty. Constraining δ Cep and the nearby astrometric reference star HD 213307 to belong to the same association (Cep OB6), we find $\pi_{abs}=3.66\pm0.15$ mas, and an absolute magnitude $M_V=-3.47\pm0.10$. Adopting an average V magnitude, $\langle V\rangle = 15.03 \pm 0.03$, for Cepheids with log P = 0.73 in the LMC, we find a V-band distance modulus for the LMC, m-M $=18.50\pm0.13$ or, 18.58 ±0.15, where the latter value results from a highly uncertain metallicity correction. We note with some satisfaction agreement with our RR Lyr *HST* parallax-based determination of the distance modulus of the LMC.

G. Fritz Benedict and B. McArthur continue Guest Observer parallax studies with HST of AM CVn stars; the magnetic Cataclysmic Variables EX Hya and V1223 Sgr; and the Cataclysmic Variables WZ Sge, RU Peg, and YZ Cnc.

Diverse avenues of research, ranging from the physics of matter at high temperatures and densities to galactic structure and cosmochronology, intersect in the study of white dwarf stars. D. Winget exploits 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 envelope, core composition, and more. Winget uses this information to study the behavior of matter under extreme conditions and to explore the history and population of our galaxy.

B. Schaefer continued with a program started in 1987 to time eclipses from recurrent novae (U Sco and CI Aql). The old data provides an accurate measure of the orbital period *before* their eruptions (in 1999 and 2000 respectively). Now, further *post-eruption* timings will give an accurate dynamical measure of the mass ejected by the eruption. Are white dwarf in recurrent novae on-average gaining mass and hence must become a Type Ia supernova? Within one (or at most two) years, enough eclipse timings will be accumulated so that the mass ejected will be confidently measured. Thus the decades-old Type Ia supernovae progenitor mystery will be solved.

T. von Hippel, along with A. Sarajedini (U. Florida) has been using near-IR imaging to study gravitational lensing source stars in the LMC to test whether line-of-sight low mass main sequence stars are the lenses.

R. French, along with T. von Hippel and collaborators in the WIYN Open Cluster Study (WOCS), has begun a precision study of the instrinsic width of the main sequence in open clusters. The goal of the project is to measure the dispersion of stellar metallicities and rotations in open clusters to high precision. Along with WOCS collaborators, von Hippel continues to study ages and abundances of open clusters and constrain stellar evolution theory for low mass stars.

C. Allende Prieto, D. Lambert, and M. Asplund (Australia National University) analyzed the [C I] line at 8727 Å in the solar flux spectrum using a hydrodynamical simulation of surface convection to derive the abundance $\log\epsilon(\mathrm{C}) = 8.39 \pm 0.04$. Combining this result with their parallel analysis of [O I] 6300 Å they found C/O $= 0.50 \pm 0.07$, in agreement with the ratios measured in the solar corona from gamma-ray spectroscopy and solar energetic particles. The updated carbon and oxygen solar photospheric abundances – a reference for chemical analyses of astronomical objects– are about 50% lower than previous determinations.

P. Barklem and his colleagues at Uppsala's Astronomical Observatory, together with Allende Prieto, have carried out an analysis of Balmer line profiles in a sample of 30 cool dwarf and subgiant stars based on the most recent calculations of the line opacities. The program stars span temperatures from 4800 to 7100 K and include a small number of population II stars. Effective temperatures have been derived using a quantitative fitting method with a detailed error analysis, finding good agreement with those from the Infrared Flux Method (IRFM) at near solar metallicity. They find differences at low metallicity where the two available IRFM determinations themselves are in disagreement.

D. Lambert and Allende Prieto have revisited a previous claim by P. Magain (U. de Liège) that a pure r-process mix of the barium isotopes was inconsistent with the mix of odd to even barium isotopes derived from analysis of the BaII line at 4554 Å in the spectrum of the metal-poor subgiant HD 140283. The new study shows that Magain's error bars were likely underestimated, and that a solar-like r-process isotopic mixture provides a fair fit to ultra-high dispersion observations of the 4554 Å profile from McDonald Observatory.

A group of astronomers led by M. Zapatero Osorio (Caltech), including Allende Prieto, acquired intermediate- to low-resolution optical spectra of low mass stars and brown dwarfs in the cluster σ Orionis using telescopes in Calar Alto, the Roque de los Muchachos Observatory, Mauna Kea, and McDonald. Comparison of the observations to model atmosphere calculations of the Li line at 6708 Å allowed the group to infer that no lithium depletion has yet taken place in the cluster, and that the observed lines are consistent with a cluster initial lithium abundance close to the cosmic value. Hence, the upper limit to the σ Orionis cluster age could be set at 8Myr, with a most likely value around 2-4Myr.

Allende Prieto, Lambert, R. Tull and P. MacQueen obtained ultrahigh-resolution spectra with the HRS and the HET for a set of nearby F-G-K stars. The wavelength shifts of stellar lines relative to their laboratory positions were measured for more than a thousand Fe I lines per star, finding a clear correlation with line depth. The observed patterns were interpreted as convective blueshifts that become more prominent for weaker lines, which are formed in deeper atmospheric layers. A morphological sequence with spectral type or effective temperature was apparent in the data. Two K giant stars were also studied for the first time. The velocity span between weak and strong lines for these stars is larger than for the dwarfs and subgiants of similar spectral types.

Allende Prieto, Lambert, K. Cunha (Observatório Nacional, Rio de Janeiro), and P. Barklem (Uppsala) have completed all the observations in a high-resolution survey of nearby stars. The sample represents all the stars brighter than $M_V = 6.5$ within 47 light years of the Sun. Observations were collected with the McDonald 2.7m telescope and the ESO 1.52m telescope at La Silla (Chile). A catalogue of radial velocities, stellar parameters and chemical abundances for some 30 species is being produced and will be released soon. This dataset will provide the first spectroscopically-determined metallicity distribution for a complete sample of stars in the solar neighborhood. More information about the project is available online at http://hebe.as.utexas.edu/s4n/. The group will monitor the stars on a regular basis, looking for signs of extraterrestrial (carbon-based or not) life in orbiting planets.

G. Pandey, D. Lambert, and N. Kameswara Rao (Indian Institute of Astrophysics, Bangalore) have studied R Coronae Borealis (R CrB) stars, hydrogen-deficient supergiants. The dominant source of continuum opacity in the visible region is due to the photoionization of neutral carbon. As expected, a C I line retains its equivalent width even as ''metal'' lines may vary considerably from star to star. But, the expectation is not met in one crucial way. The predicted equivalent width of a C I line exceeds the observed equivalent width by a considerable factor. This discrepancy is termed ''the carbon problem.'' To search for a solution to the problem they have investigated [C I] 9850 Å, a line which is expected to be unsaturated in the R CrB spectra. The [C I] 9850 Å line also shows the carbon problem.

Working with E. Sandquist (San Diego State U.), M. Shetrone concluded a survey of blue stragglers in nearby open clusters to determine how many were formed by collision and how many by mass transfer. This is the first complete spectroscopic survey of blue stragglers. This project includes observations with the Mount Laguna 1m, McDonald 2.1m, McDonald 2.7m, and HET.

M. Slovak (Louisiana State U.) and T. Barnes used 2.1m telescope radial velocities to improve the orbit of the single-lined spectroscopic binary θ Draconis.

T. Barnes and W. Jefferys, in collaboration with J. Berger and P. Müller of Duke and K. Orr and R Rodriquez (UT Austin), completed a determination of distances and radii for thirteen Galactic Cepheids, using Bayesian statistical methods. They made use of the surface brightness method newly calibrated by Cepheid interferometric angular diameters of T.

Nordgren (USNO) and collaborators. Their approach fully accounts for errors in the data, provides unbiased distance estimates, provides objective model selection for the photometric and velocity curves, and includes a Lutz-Kelker correction. The analysis uses Markov Chain Monte Carlo simulations to sample the posterior probabilities of the individual models and then to properly weight the models.

N. Ryde and K. Eriksson modelled the 2.6–3.7 μm spectrum of the red semiregular variable R Doradus observed with the Short-Wavelength Spectrometer on board the Infrared Space Observatory. They calculated a synthetic spectrum using a hydrostatic model photosphere in spherical geometry, showing an encouraging agreement. This suggests that a hydrostatic model photosphere is adequate for the calculation of synthetic spectra in the near infrared for this moderately varying red giant star. However, an additional absorption component is needed at 2.6–2.8 μm. The spectral signatures are dominated by water vapor in the stellar photosphere.

N. Ryde, Lambert, Richter, and Lacy report detections of pure rotation lines of OH and H_2O in Arcturus, using high-resolution, infrared spectra recorded with the TEXES spectrometer used on the IRTF. Arcturus is the hottest star yet to show water-vapor features in its disk-averaged spectrum. They argue that the water vapor lines originate from the photosphere, albeit in the outer layers. They can predict the observed strengths of OH and H_2O lines satisfactorily after lowering the temperature structure of the very outer parts of the photosphere compared to a flux-constant, hydrostatic, standard model photosphere.

G. Marion (supervised by P. Höflich and J. Craig Wheeler) has an observing program with the SPEX instrument on the IRTF to obtain routinely near infrared spectra of supernovae. The focus of the program is on Type Ia. Marion uses hydrodynamic simulations of the explosion and a radiation transport code for the nucleosynthesis to learn more about their explosion dynamics and the systematic variations that might affect the use of Type Ia as distance indicators. The spectral evolution suggests that the intermediate mass elements are layered in a way that there is little mixing, and that they result from a detonation. The peculiar Type Ic SN 2002ap was shown to have no helium, but to form carbon monoxide at later epochs.

P. Höflich, J. Craig Wheeler, and G. Marion continued a program of routine spectropolarimetry of all accessible supernovae. They now concentrate on data from the ESO VLT in a target of opportunity program of which D. Baade (European Southern Observatory) is PI and L. Wang (Lawrence Berkeley Natioanal Laboratory) takes the lead on reducing and analyzing the data. Data on the peculiar Type Ic SN 2002ap showed that it was significantly polarized with material moving as fast as 20,000 km s^{-1}, but not higher, as claimed in some preliminary work. The Type Ia SN 2001el showed a very distinct, highly polarized shell of Ca II that might be some clue to the binary nature of the progenitor. The polarization of Type Ia suggests that their luminosity is not emitted isotropically. This has implications for their use as cosmological distance indicators.

The polarization studies suggest that core collapse supernovae are routinely strongly asymmetric, even commonly bipolar. One means to do this is to produce a jet as the neutron star forms. J. Wheeler, graduate student S. Akiyama, I. Lichtenstadt (Hebrew University) and D. Meier (Jet Propulsion Laboratory) have begun a study of how jets may be produced by MHD processes in the collapse of stellar cores to form neutron stars. Akiyama *et al.* show that the magnetorotational instability may be a robust mechanism to grow large magnetic fields ($\sim 10^{15}$ Gauss) in only several hundred milliseconds.

J. Craig Wheeler continued as a member of the HST SuperNovae INtensive Study (SINS) team (R. Kirshner, PI, Harvard). Much of the work has focused on the interaction of the shock from SN 1987A with the circumstellar rings and the shape of the debris. In the latter case, the asymmetry in the debris was shown to be consistent with the expectations of jet models of the explosion and the coalignment of the ejecta image with the polarization axis.

3.3.6 Interstellar Medium, Compact Regions, Protostellar Disks, Star-Forming Regions:

J. Lacy and collaborators have used TEXES to concentrate on observations of star-forming regions and planetary atmospheres. M. Richter (now at U.C. Davis) *et al.* showed that molecular hydrogen emission observed with the ISO satellite could not have come from protoplanetary disks in the T-Tauri stars also observed with TEXES. Most likely the emission is from a larger region. C. Knez, J. Lacy, N. Evans *et al.* have been studying infrared absorption by interstellar molecules along lines of sight to high-mass embedded protostars. Several unexpected molecules, including hot CH_3 and CH_4, have been seen.

H. Dinerstein, with T. Geballe (Gemini Observatories), identified the 3.625 μm emission line, seen in the bright planetary nebulae NGC 7027 and IC 5117, as the ground-state fine-structure line of [Zn IV]. This will provide a direct method for measuring zinc abundances in planetary nebulae, once an accurate collision strength becomes available. The importance of this is illustrated by the fact that zinc is often used in place of iron as a metallicity indicator for high-redshift quasar absorbers, because iron itself is depleted out of the gas phase into dust grains.

Continuing a multi-wavelength campaign to measure the enhancement of s-process nuclei in planetary nebulae, N. Sterling, H. Dinerstein, and C. Bowers at (NASA/GSFC) discovered an absorption line of Ge III in the spectra of several planetary nebulae observed with the *Far Ultraviolet Spectroscopic Explorer*. Taken relative to other elements, such as S or Fe, the abundance of Ge is found to be enhanced by factors of $\geqslant$ 3–10. This self-enrichment of the nebular gas can be understood as the result of slow neutron-capture nucleosynthesis deep within the star followed by “dredge-up” (to the envelope and surface) of these nuclear products, during the AGB phase of evolution.

H. Dinerstein and C. Bowers (NASA/GSFC) continued a survey of planetary nebulae with bright central stars using the *Far Ultraviolet Spectroscopic Explorer, FUSE*. The objective is to search for the resonance ($v = 0$) Lyman and Werner H_2 lines in absorption against the stellar continuum, a highly sensitive method for detecting small amounts of molecular material in planetary nebula envelopes. Surprisingly, only a few planetary nebulae are seen to have nebular H_2 in absorption; even the Ring Nebula, NGC 6720, which exhibits near-infrared H_2 emission, is not detected with *FUSE*. This implies that the molecular material is highly clumped or asymmetrically distributed. One of the few planetary nebulae which does show nebular H_2 in its *FUSE* spectrum is BD+30°3639. In a related study, Dinerstein, with C. Sneden, B. Draine and E. Jenkins (Princeton), and C. Bowers and S. Heap (NASA/GSFC), are examining the STIS UV-MAMA spectrum of this object, which shows a rich assortment of H_2 absorptions from excited vibrational levels. The column densities of levels up to $v = 5$, $J = 11$, etc., are as high as a few times 10^{13} cm^2, providing a superb testing board for models of the UV excitation of H_2.

H. Martel and N. Evans have started a collaborative effort to study the formation of stars and star clusters by fragmentation of giant molecular clouds. This study will be based on numerical simulations, performed with the Adaptive Smoothed Particle Hydrodynamics (ASPH) algorithm that was developed by H. Martel and P. Shapiro for their research on galaxy formation. The first objective of this project is to determine the stellar initial mass function (IMF), and how its form is affected by the various physical processes occurring in the cloud before and after the formation of the first stars. This work will improve upon previous studies on two different fronts. First, current simulations are unable to resolve the lower end of the stellar mass range, making comparisons with the observed IMF difficult. An Adaptive Particle Density Refinement algorithm (also called Particle Splitting) will be implemented into the ASPH algorithm. This will dramatically extend the dynamical range of the algorithm toward lower masses. Second, they will include feedback processes, such as heating, stellar winds, and outflows, which can greatly affect the late-stage evolution of the cloud.

3.3.7 Galactic and Extragalactic:

H. Dinerstein was part of the *Infrared Space Observatory* Key Project team on ''The ISM of Normal Galaxies,'' led by G. Helou (IPAC, Caltech). This project involved a survey of approximately 60 galaxies of diverse morphological types, luminosities, and blue-to-infrared brightness ratios. Mid-infrared spectra for 45 disk galaxies have been analyzed, and will be described and compared in a paper written by N. Lu (IPAC) with several members of the Key Project team. The 2.5–12 μm integrated spectra of galaxies are dominated by a set of relatively narrow emission features attributed to aromatic carbon material (large molecules or small grains). As is also seen in diverse environments with the Milky Way galaxy, the appearance of these emission features is relatively invariant, and independent of key physical parameters such as the mean intensity of the UV radiation field. Only in the strongest UV fields do the features decrease in strength relative to the underlying continuum, and do their shapes (profiles) change significantly. This helps constrain the nature of the carriers of the mid-IR bands.

S. Kannappan continued research on the physical drivers that cause offsets from the Tully-Fisher (TF) relation, the fundamental scaling relation between luminosity and rotation velocity for disk galaxies. After demonstrating that spiral galaxies follow correlations between TF offsets and star formation indicators (with D. Fabricant, CfA, and M. Franx, Leiden), Kannappan worked with E. Barton Gillespie (Arizona State U.) to show that interacting galaxies follow the same correlations, provided their velocity profiles are not strongly disturbed in specific quantifiable ways. Kannappan also reanalyzed the intermediate-redshift TF sample of N. Vogt (New Mexico State U.) in conjunction with her own low-redshift TF sample, taking into account the correlations between TF offsets and star formation indicators. She found evidence that stellar mass fractions were lower at intermediate redshifts (indirect evidence that less of the initial gas reservoir had turned into stars).

With E. Barton Gillespie and R. Jansen (ASU), Kannappan analyzed the statistics of galaxies whose centers are bluer than their outer parts, suggesting current bulge growth, and established that the star formation is driven by interactions and mergers rather than internal mechanisms such as bar instabilities. Kannappan also joined J. Kormendy and E. Ambrose in an observational program to identify and characterize pseudobulges (bulges formed by inflowing disk gas as opposed to primordial collapse or early mergers) by their structural properties. This project is in the data collection stage.

M. Shetrone continued his work on abundances in dwarf spheroidal galaxies with collaborators K. Venn (Macalester College) and E. Tolstoy (ESO) with observations with UVES on UT2. This is the largest data set of extra galactic high resolution abundances obtained to date.

Using the HET M. Shetrone, P. Côté (Rutgers) and P. Stetson (DAO) surveyed the Draco and Ursa Minor dwarf spherical galaxies to identify the nature of a very red population of RGB stars found in recent proper motion surveys. They identified each red spectroscopic member as a previously unidentified CH star missed by previous carbon star surveys.

Z. Shang, B. Wills and E. Robinson have completed a spectral Principal Component Analysis of a sample of low-redshift PG quasars, using HST and ground-based (McDonald Observatory) spectra covering wavelengths from Ly α to Hα. Three significant principal components are identified, and they account for 78% of the total intrinsic variance of the sample. The first principal component is dominated by emission line cores and is anti-correlated with the luminosity, suggesting that mostly low-velocity gas is involved in the Baldwin effects. The second principal component represents the UV-optical continuum slope in QSO spectra, which is probably the result of dust reddening in the QSO environment. The third principal component includes Boroson and Green's ''Eigenvector 1'' and many spectral properties in the UV region, such as the line widths of MgII, Lyα and CIII], and an anticorrelation between UV and optical FeII emissions. This component may be driven by the Eddington accretion ratio.

K. Gebhardt has been studying local and distant galaxy properties. There are three main areas in his research. He is helping to characterize the mass function of supermassive black holes and their relation to their host galaxy properties;

this includes examining the smallest central black holes by looking for them in globular clusters. Gebhardt has been working with various groups to measure the large radial dynamics using globular cluster systems and the faint stellar light in galaxies to probe the dark halo and orbital structure. This data involves a substantial amount of time on the HET, providing some of the deepest spectra ever obatined for diffuse stellar light. Finally, Gebhardt continues his work on distant galaxies (at redshifts near 1) to compare with nearby galaxies to study evolutionary effects.

B. Schaefer has turned classical Gamma-Ray Bursts into calibratable standard candles, with a total of four different luminosity indicators that can be measured from the gamma-ray light curves alone. Two of the luminosity indicators (spectral lag and variability) had been previously discovered, but Schaefer has proved their validity by testing the relation with further bursts and by finding the predicted lag-variability relation in 112 independent bursts. Schaefer has theoretically predicted two new luminosity indicators (the minimum rise time and the number of peaks) and then confirmed their validity with two independent sets of bursts. In addition, Schaefer has presented simple and general theoretical models to explain all four luminosity indicators, along with an off-axis correction based on the observed E_{peak} value of the spectrum. The accuracy of bursts as standard candles is now with a one-sigma uncertainty of 0.13 in the log of the derived distances. Schaefer has been extending the measurement of all four indicators to lower energies, as required for use with the SWIFT satellite soon to be launched.

B. Schaefer has been exploiting Gamma-Ray Bursts as standard candles by creating the first GRB Hubble Diagram, involving nine bursts out to a red shift of 4.5. The shape of this Hubble Diagram is consistent with the flat $\Omega = 0.3$ Universe. The number of bursts are currently too small to be useful, but this demonstrates the validity of the method. This new method has the great advantages that it extends to very high red shifts and is impervious to extinction. With the launch of the SWIFT spacecraft in September 2003, Schaefer will get 40 bursts per year that can be placed on the Hubble Diagram, some of which are likely to be in the redshift range of 5-10. Thus, by the end of 2005, the SWIFT Hubble Diagram Key Project is expected to get 100 bursts in a Hubble Diagram from $0.1 < z < 10$. The results will test the inflationary and quintessence models of the expansion of the Universe.

J. Craig Wheeler participated in a consortium to study gamma-ray bursts with the Hubble Space Telescope and the Chandra X-ray Observatory (PI Shri Kulkarni, Caltech). Observations of GRB 011121 showed evidence for a supernova-like brightening several weeks after the gamma-ray event.

J. Craig Wheeler, B. Schaefer, P. Höflich, and P. Kumar are the Texas representatives of an HET consortium with target of opportunity time to observe gamma-ray burst afterglows. Observations in 2001/2002 were hampered by weather the low rate of discovery of optical transients.

Arrangements have been made to install one of the four new RObotic Transient Source Experiment (ROTSE) telescopes to monitor gamma-ray bursts in their first 100 seconds at McDonald Observatory. J. Craig Wheeler, B. Schaefer, and P. Kumar are the Texas members of the ROTSE team.

E. Hooper utilized the IGI multislit mode at the McDonald 2.7-m to get redshifts and source classifications for two research projects: the Chandra Multiwavelength Project (ChaMP), a large serendipitous X-ray survey (with B. Wills and B. Wilkes, CfA), and a ground-based and HST study of quasar environments (with R. Finn and C. Impey, U. Arizona). Hooper and Wilkes worked on an Infrared Space Observatory project to characterize the spectral energy distributions of AGN.

T. Barnes, A. Forestell, C. Sneden and T. Moffett (Purdue Univ.) used the HET to acquire low S/N spectra of Cepheid variables in Local Group Galaxies M31 and M33. This effort has led to the first ever radial velocity curves for Cepheids in M31 and M33. At this writing a velocity curve for V2203_D31F in M31 is nearly complete and one for V22665_D33B in M33 is underway. Using statistical techniques on these spectra, they have begun to extract [Fe/H] values.

G. Shields carried out a study of black hole masses and host galaxies in QSOs. This work was done in collaboration with K. Gebhardt, S. Salviander, B. Wills, and J. Yuan (U. Texas), B. Xie (Rutgers), M. Brotherton (U. Arizona), and M. Dietrich (U. Florida). Recent studies of supermassive black holes in nearby galaxies show a tight correlation between black hole mass ($M_{\rm BH}$) and the velocity dispersion of the bulge stars (σ) of the host galaxy. Shields and collaborators investigated the evolution of this relationship since the early universe using the emission lines of low and high redshift QSOs. Black hole masses were derived from the width of the Hβ emission line, and bulge velocity dispersions from the width of the [O III] $\lambda 5007$ Å line from the narrow line region. The results indicate that the $M_{\rm BH}$–σ relationship at redshifts $z \approx 2$ to 3 was similar to that at recent times. Shields is also carrying out a program of high resolution observations of supernovae to look for high velocity clouds in the host galaxies in collaboration with L. Blitz, A. Filippenko, and J. Simon (U.C. Berkeley).

J. Kormendy continued work on supermassive black holes in galactic nuclei as part of the "Nuker" collaboration that also includes K. Gebhardt. A current high priority is a black hole mass measurement in NGC 4258 using STIS spectroscopy obtained with HST. Kormendy carried out the surface photometry required for the measurement. This was based on *K*-band images kindly provided by the 2MASS project and on *K*-band images obtained with graduate student E. Ambrose (Kitt Peak National Observatory). NGC 4258 is the best BH candidate after our Galaxy – it is the object with the spectacular water maser dynamical BH detection by Miyoshi et al. (1995). Because the BH mass is so accurately measured using the maser sources, NGC 4258 is the ideal galaxy with which to demonstrate the accuracy of the Nuker dynamical modeling technique. The BH mass derived from stellar dynamics agrees very well with the mass found using masers.

Kormendy and graduate student Ambrose began an observing program to characterize pseudobulges of disk galaxies. These are believed to form by a different process than do the classical, elliptical-galaxy-like bulges that have been recognized since the time of Hubble. Bulges, like ellipticals, are thought to form by a series of mergers that trigger dissipative collapse of gas in the progenitor galaxies followed by starbursts. That is, bulges and ellipticals form rapidly, via dynamically violent events in a galaxy that is far from equilibrium. In contrast, ''pseudobulges'' are thought to form by secular evolution of disks that are always close to equilibrium. Nonaxisymmetries drive gas toward the center and feed star formation that builds up the central stellar density. Instabilities in dense disks then heat them until they look similar to classical bulges. This is why pseudobulges were not already recognized long ago. However, the more extreme examples can easily be recognized, because they retain some memory of their disky origin. They rotate more rapidly, in relation to their random mothions, than do classical bulges. A paper on prototypical examples is in preparation. Also, Ambrose and Kormendy used the KPNO 2.1 m telescope to obtain *K*-band photometry and internal kinematic measurements of pseudobulge candidates.

Kormendy and K. Freeman (Australian National U.) continued work on the observed correlations between the core radii, central densities, and central velocity dispersions of dark matter halos of galaxies.

G. Hill and S. Rawlings (Oxford) continued their TexOx radio source survey collaboration. The TexOx-1000 (TOOT) radio source survey (with 151 MHz flux density limit of 0.1 Jy) is now about half complete, and initial results are being prepared or are already in press. The survey is already the largest of its kind. The remaining half of the survey involves faint red galaxies at $z>0.5$ that constitute the (possibly unevolving) FRI radio source population at lower radio powers. These will be observed with HET, once its throughput improves. The additional TexOx NVSS Survey (TONS) is aimed at obtaining detail on the large-scale distribution of radio sources, using the fainter NRA VLA Sky Survey. TONS has so far obtained data in three fields: the TOOT08 region, where we have uncovered two huge (100 Mpc scale) structures in the radio source distribution; the 2dFGRS region, where we are comparing the bias of radio galaxies with that of field galaxies; and the Subaru XMM Deep Field (SXDF) region. The combined dataset on these regions already exceeds 300 redshifts. Graduate students Tufts (UT) and K. Brand and E. Mitchell (Oxford) are working on TOOT and TONS.

G. Hill continued his involvement in the MUNICS Project with R. Bender, N. Drory, and U. Hopp (Universitäts-Sternwarte München). The project currently has the largest sample of K-band selected galaxies at $z<1$ with 5000 photometric redshifts and over 500 spectroscopic redshifts. Drory has taken up a Feulner Fellowship from the Humboldt Foundation, at Texas, and the collaboration is continuing with further HET and HST observations planned to map the specific star formation rate (per unit mass) in a mass-selected sample of field galaxies as a function of redshift. Graduate students Wolf and A. Bauer are studying galaxy evolution using the MUNICS dataset.

3.3.8 Theory:

B. Ragot suggested that accretion of interstellar dust material onto stellar atmospheres could be responsible for the lack of low-metallicity G dwarfs observed in the disk of our Galaxy, known as the G-dwarf problem. This interpretation of the G-dwarf problem would be consistent with a peaked distribution of G-dwarf metallicities and reconcile the observations of both a well-mixed interstellar gas and a large scatter in the stellar age-metallicity relation. This interpretation has important consequences for our understanding of the early history of the Galaxy. It would imply a change in the age-metallicity relation and relax the constraint on the early enrichment of the interstellar medium. To investigate this possibility of a pollution of the G-dwarf atmospheres by interstellar iron in the disk of our Galaxy, Ragot estimated the accretion rate of interstellar dust iron by the Sun. Ragot considered as iron sources the submicron- and micron-sized interstellar dust grains detected by *Ulysses* and *Galileo* as well as the interstellar micrometoroids (very large grains of size $>40\ \mu$m) detected by the Advanced Meteor Orbit Radar. The micrometoroids, much more massive, give (with a lesser flux) an iron accretion rate orders of magnitude higher than the micron-sized dust. If the accreted matter can accumulate for a sufficiently long period of time in the stellar atmosphere of a low-metallicity star, it will modify the observed metallicity of the star. Grains of interstellar origin only were considered because their Sunward speeds at the time they are destroyed by solar radiation are much higher than those of the other grains orbiting the Sun. As a result, most of the matter released from these interstellar grains and micrometoroids in the solar corona will not be picked up by the solar wind and may reach the solar atmosphere. B. Ragot also suggested that, while the initial metal content of the Sun might be too high to have its observed, atmospheric metallicity affected by the interstellar pollution, the downflow of matter resulting from the micrometeoroids' destruction in the solar corona ($>10^9$ g per second) could have important consequences for our understanding of the various abundance anomalies observed in the solar corona and solar energetic particles.

B. Ragot explored the coupling of dust grains to interstellar gas through plasma wave emission from the spinning dust particles. Indeed, not only do dust particles spinning in the interstellar medium radiate electromagnetic waves, they also emit longitudinal plasma waves. Ragot showed that this coupling via plasma wave emission is much more efficient than that due to binary collisions with the surrounding gas. Ragot estimated analytically the deceleration time resulting from the plasma wave emission and found that, in most interstellar environments, it is orders of magnitude shorter than the usual slowing-down time due to collisional friction.

B. Ragot considered the effect of plasma wave emission on the grain spin. While for grain speeds V higher than the electron thermal speed a spin-up of the grains is predicted, for ''subthermal'' speeds the rotation is damped and the damping time is derived there in the limit of small V. In this limit, the damping timescale is again shorter than the damping time due to binary collisions. This result is critical to the interpretation of the new Galactic component of microwave emission correlated to the infrared emission that was detected at $14-90$ GHz while searching for anisotropies in the Cosmic Microwave Background. In general, the strongest plasma effects on the spinning dust grains are expected to occur in the cold neutral matter and reflection nebulae. There, a low temperature combined with a still relatively large electron density favors long-range interactions and associated collective effects. The importance of plasma-wave emission is, however, not restricted to these environments. To determine the dynamics of the smallest cosmic grains up to, possibly, the largest submicron ones (especially if the charging processes are efficient) emission of plasma waves under most interstellar conditions has to be taken into account.

B. Ragot and S. Kahler (Air Force Research Lab.) considered the effects of interactions between dust grains in the solar F corona and particles and fields of coronal mass ejections (CMEs). They computed dust grain orbits to compare the drift rates between periods of minimum and maximum solar activity, assuming a simple CME model to distinguish between the two periods. They found that the ion drag force of CMEs results in significantly shorter drift times of the large (>3 microns) dust grains, hence faster depletion rates and lower dust grain densities, at solar maxima. This could explain a relatively strong ($>15\%$) solar cycle variation of the near-infrared brightness close to the dust plane of symmetry. While trapping the smallest of the grains, the CMEs also help scatter the grains of intermediate size (0.1 to 3 microns) in latitude, producing a solar cycle variation of the optical brightness not exceeding 10% at high latitudes.

J. Scalo and A. Biswas explored how the star formation rate in galaxies should be related to the fraction of gas that can attain densities large enough for gravitational collapse. In galaxies with a turbulent interstellar medium, this fraction is controlled by the effective barotropic index, γ, which measures the turbulent compressibility. When the cooling time-scale is smaller than the dynamical time-scale, γ can be evaluated from the derivatives of cooling and heating functions, using the condition of thermal equilibrium. They derived calculations of γ for protogalaxies in which the metal abundance is so small that H_2 and HD cooling dominates. For a heating rate independent of temperature and proportional to the first power of density, the turbulent gas is relatively 'hard', with $\gamma > \sim 1$, at large densities, but moderately 'soft', $\gamma < \sim 0.8$, at densities below around 10^4 cm^{-3}. At low temperatures the density probability distribution should fall rapidly for densities larger than this value, which corresponds physically to the critical density at which collisional and radiative de-excitation rates of HD are equal. The densities attained in turbulent protogalaxies thus depend on the relatively large deuterium abundance in our Universe. They expect the same physical effect to occur in higher metallicity gas with different coolants. The case in which adiabatic (compressional) heating resulting from cloud collapse dominates was also investigated, suggesting a criterion for the maximum mass of Population III stars.

H. Martel, P. Premadi (Bandung Institute), R. Matzner (Dept. of Physics, U. Texas) and T. Futamase (Tohoku U.) 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 (CDM) 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. The main conclusions of this work are that (a) the properties of gravitational lensing, both weak and strong, depend much more strongly upon λ_0 than any other cosmological parameter, and (b) magnification and shear are examples of weak lensing caused primarily by the distribution of background matter, with negligible contribution form galaxies, while multiple images and rings are examples of strong lensing, caused by direct interaction with galaxies, with negligible contribution from the background matter. Observations of weak lensing can be used to determine the cosmological constant and the density structure of the universe, while observations of strong lensing can be used to determine the cosmological constant and the internal structure of galaxies and clusters. Gravitational lensing depends much more weakly upon Ω_0 and H_0 than σ_8 and λ_0, making a determination of these parameters from observations more difficult.

In parallel with this work, H. Martel, P. Premadi (Bandung Institute), and R. Matzner (Dept. of Physics, U. Texas) have studied the distribution of image separations for various cosmological models, using an analytical model. These results support the conclusions drawn from the numerical parameter survey. They show that while the actual number of multiple images is sensitive to the values of the cosmological parameters, the distribution of their angular separations is not.

P. Shapiro and H. Martel further developed and tested Adaptive Smoothed Particle Hydrodynamics (''ASPH''), the new and improved version of SPH. The ASPH method replaces the isotropic smoothing algorithm of standard SPH, in which interpolation is performed with spherical kernels of radius given by a scalar smoothing length, with anisotropic smoothing involving ellipsoidal kernels and tensor smoothing lengths. It also utilizes a shock-tracking algorithm for locally adapting artificial viscosity so as to restrict viscous heating to particles encountering shocks. ASPH has significantly better resolving power at fixed particle number than standard SPH for a wide range of problems, including that of cosmological structure formation. A major new problem for SPH codes was also identified — false cooling — which occurs when strong shocks occur in the presence of radiative cooling. Preliminary attempts to solve the problem by using the shock-tracking algorithm of ASPH yield promising results.

Shapiro and Martel (and collaborators) applied ASPH to a number of cosmological problems. These included simulations of cosmological gas dynamics in 3D, specifically explosions during galaxy formation. When density fluctuations collapse gravitationally out of the expanding cosmological background universe to form galaxies, the secondary energy release which results can affect their subsequent evolution profoundly. H. Martel and P. Shapiro focused on the effects of one form of such energy release – explosions, such as might result from the supernovae which end the lives of the first generation of massive stars to form inside protogalaxies. Their simulations reveal that such explosions are anisotropic. Infall quickly replenishes ejected gas and gradually restores the gas fraction as the halo mass continues to grow. Estimates of the collapse epoch and SN energy-release for galaxies of different mass in the CDM model relate these results to scale-dependent questions of blow-out and blow-away and their implication for early IGM heating and metal enrichment and the creation of dark-matter-dominated dwarf galaxies.

P. Shapiro, A. Raga (UNAM), and I. Iliev (Arcetri) carried out the first gas dynamical simulations of the photoevaporation of a cosmological minihalo overtaken by the ionization front which sweeps through the intergalactic medium during the reionization epoch in the currently-favored ΛCDM universe, when either a stellar or a quasar-like radiation source turns on. Shapiro, Martel, and Iliev used N-body simulations of halo formation in the ΛCDM model to show that these sub-kpc minihalos with virial temperatures below $10^4 K$, which are photoevaporated by the I-fronts which reionized the universe, were so common during reionization as to dominate the absorption of ionizing photons. Previously, the number of ionizing photons required per H atom in the universe to complete reionization was seriously underestimated by approaches which neglected this highly clumped, small-scale structure.

Adaptive SPH and N-body simulations were carried out by M. Alvarez, P. Shapiro, and H. Martel to study the collapse and evolution of dark matter halos that result from the gravitational instability and fragmentation of cosmological pancakes. Such halos resemble those formed by hierarchical clustering in a CDM universe and serve as a convenient test-bed model for studying halo dynamics. These pancake halos are in approximate virial equilibrium and roughly isothermal, as in CDM simulations. Their density profiles agree quite well with the fit to N-body results for CDM halos by Navarro, Frenk, and White. This test-bed model enabled Alvarez, Shapiro, and Martel to study the evolution of individual halos. They conclude that the fundamental properties of halo formation and evolution are generic to the formation of cosmological halos by gravitational instability and are not limited to hierarchical collapse scenarios or even to Gaussian-random-noise initial conditions.

A new 3D version of an Eulerian AMR radiation-hydro code is under development by Raga in collaboration with Iliev, Shapiro, and Alvarez. In addition, an interdisciplinary collaboration by Shapiro, Martel, and Alvarez is underway with Chandrajit Bajaj (U. Texas Center for Computer Visualization) to incorporate radiative transfer in cosmological ASPH simulations, by adding a ray-tracing algorithm and algorithmic advances developed for the computer science fields of computational visualization and computational geometry.

The postcollapse structure of objects whichformed by gravitational condensation out of the expanding cosmological background universe is a key element in the theory of galaxy formation. P. Shapiro, I. Iliev, and A. Raga developed a model for the postcollapse equilibrium of cosmological structure, generating truncated isothermal spheres from top-hat density perturbations. These results have a significant effect on a wide range of applications of the Press-Schechter and other semi-analytical models to cosmology. The truncated isothermal sphere (TIS) solution reproduces many of the average properties of the halos in CDM N-body simulations. It also 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. Following their initial derivation of the TIS model for an Einstein-de Sitter universe, Iliev and Shapiro generalized this TIS model to the case of a low-density background universe $(\Omega_0 < 1)$, with and without a cosmological constant.

P. Shapiro, I. Iliev, and A. Raga then considered the origin of the rotation curves of dark-matter-dominated galaxies. Their analytical model for the postcollapse equilibrium of cosmological halos reproduces many of the average properties of halos in CDM simulations to good accuracy, including the density profiles outside the central region, while avoiding the problem of the steeply singular cores. The halo model is a unique, truncated, isothermal sphere (TIS), with a core density proportional to the critical density at the epoch of collapse. Iliev and Shapiro further showed that the TIS rotation curve is in excellent agreement with the observed ones and yields the mass and collapse epoch of an observed galactic halo from the parameters of its rotation curve. They then used this model to predict correlations amongst rotation curve parameters, such as the maximum velocity and the radius at which it occurs, for different mass halos collapsing at different epochs in the CDM model. This enable them to derive the observed $v_{\rm max} - r_{\rm max}$ relation analytically for the first time, with preference for the flat ΛCDM model. This model may also be of interest as a description of halos in nonstandard CDM models like "self-interacting dark matter," proposed to eliminate the discrepancy between the cuspy halos of standard CDM simulations and observed halos with uniform-density cores.

Current data suggest that the central mass densities and phase-space densities of cosmological halos in the present universe are correlated with their velocity dispersions σ_V over a very wide range of σ_V from less than 10 to more than $1000\ \mathrm{km\,s^{-1}}$. P. Shapiro and I. Iliev showed that a simple analytical theory of halo formation and virialization based upon the nonsingular, truncated isothermal sphere (TIS) model and the Press-Schechter (PS) approximation predicted such correlations for a CDM universe. Their predictions are generally consistent with the data, with preference for the currently-favored, flat ΛCDM model. Such a comparison serves to test the basic CDM paradigm while constraining the background cosmology and the power-spectrum of primordial density fluctuations, including larger wavenumbers than have previously been constrained.

H. Martel and P. Shapiro derived the basic lensing properties of TIS halos, including the image separation, magnification, shear, and time-delay. They also provided analytical expressions for the critical curves and caustics. They showed how the scale-free results they derived yield scale-dependent lensing properties which depend upon the cosmological background universe and the mass and collapse redshift of the lensing halos, according to the truncated isothermal sphere (TIS) model of CDM halos. They described the application of these results to the currently-favored ΛCDM universe. The nonsingular TIS model differs from the N-body results for CDM halos only in the very center, where CDM N-body halos show density profiles which vary as $\rho \sim r^{-\alpha}$, $\alpha \gtrsim 1$, instead of a small flat core.

Observations of a flat density profile in the cores of dark-matter-dominated halos on the two extremes of mass for virialized objects in the universe, dwarf galaxies and galaxy clusters, present a serious challenge to the current standard theory of structure formation involving CDM. A flat-density core on the cluster scale is indicated by gravitational lensing observations, most significantly by the strong-lensing measurements of CL 0024+1654 by HST. One recent re-analysis of this cluster suggested that a uniform-density core is not demanded by the data, thereby eliminating a significant piece of the conflict between the observations and the CDM theoretical predictions. P. Shapiro and I. Iliev investigated the mass profile of this galaxy cluster, which they inferred from strong lensing. They showed that the singular mass profile which that analysis reports as consistent with the lensing measurements of CL 0024+1654 implies a velocity dispersion which is much higher than the measured value for this cluster.

K. Ahn and P. Shapiro studied the formation and evolution of self-interacting dark matter (SIDM) halos in an Einstein-de Sitter universe. Observations of dark matter dominated dwarf and low surface brightness disk galaxies favor density profiles with a flat-density core, while cold dark matter (CDM) N-body simulations instead form halos with central cusps. This apparent discrepancy has motivated a re-examination of the microscopic nature of the dark matter in order to explain the observed halo profiles, including the suggestion that CDM has a non-gravitational self-interaction. They used a fluid approximation to describe the dynamics, modified to take account of the collisional interaction of SIDM particles. They assumed that SIDM halos will evolve self-similarly, with a cold, supersonic infall which is terminated by a strong accretion shock. These similarity solutions are relevant to galactic and cluster halo formation in the CDM model and are in good agreement with previous results of N-body simulation of SIDM halos. They also show that, for some combinations of parameters, the central density acquires a singular profile, thereby explaining some of the N-body results for the first time.

P. Shapiro, H. Martel, I. Iliev, and A. Ferrara calculated the emission from individual minihalos and the radiation background contributed by their combined effect to explore 21-cm emission from minihalos and predict the direct detectability of the cosmic ‘‘dark ages’’ ($z>6$). In the standard CDM theory of structure formation, virialized minihalos (with $T_{\rm vir} \lesssim 10^4$ K) form in abundance at high redshift, $z>6$. The hydrogen in these minihalos, the first nonlinear baryonic structures to form in the universe, is mostly neutral and sufficiently hot and dense to emit strongly at the 21-cm line. They predicted that the angular fluctuations in this 21-cm background should be detectable with the planned LOFAR and SKA radio arrays, thus providing a direct probe of structure formation during the ‘‘dark ages.’’ Such a detection will serve to confirm the basic CDM paradigm while constraining the background cosmology parameters, the shape of the power-spectrum of primordial density fluctuations, the onset and duration of the reionization epoch, and the conditions which led to the first stars and quasars.

I. Iliev, E. Scannapieco (Arcetri), H. Martel, and P. Shapiro considered the effects of the nonlinear clustering of minihalos on their emitted 21-cm background and improved the treatment of the ‘‘bias’’ on the predicted angular fluctuations, thereby confirming the accuracy of their previous calculations. They also used N-body simulations of structure formation in a ΛCDM universe at high redshift to test this new bias calculation and to produce illustrative radio maps of the fluctuating 21-cm background radiation.

3.3.9 Laser Ranging:

Personnel are Project Director P. Shelus, senior staff members R. Ricklefs, J. Ries, and J. Wiant, observers A. Garcia, K. Harned, M. Villarreal, and W. Williams, and technician R. Green. This project is in the 2nd year of a 5-year contract from NASA/Goddard Space Flight Center. Additional grants from NASA Headquarters and the National Science Foundation supplement the lunar laser ranging (LLR) portion of the experiment. This continues almost 35 years of continuous observation and research for laser ranging at McDonald Observatory. The McDonald Laser Ranging Station (MLRS) is a fundamental station in a global network. It consists of a 0.76-m telescope and a short pulse, frequency-doubled, 532-nm, neodymium-YAG laser, with computer, electronic, and timing hardware. It shares Mt. Fowlkes with the HET. The MLRS operates with single member observing crews, 24 hours a day, 365 days/year, weather and equipment permitting. Observations are made to 15-20 artificial satellites, according to priorities set by the International Laser Ranging Service (ILRS), as well as to the Moon. The MLRS is the only LLR station in the US and is only one of two routinely lunar capable stations in the world.

Measuring the time for a laser pulse to leave a ground station, bounce off of a target reflector, and return to the ground station, effectively gives a very precise distance estimate between the station and the target. Comparing a series of measurements (almost 35 years of lunar data and more than 25 years of satellite data exist), scientific research is performed in four broad areas: solar system ephemeris development, general relativity and gravitational physics, lunar science, and geodynamics. Research activity suported by these data includes monitoring the exchange of angular momentum between the solid earth and its atmosphere, the principal geopotential terms of the Earth’s gravity field, plate tectonic activity, tidal dissipation in the lunar orbit, the lunar free libration, and the equivalence principle of general relativity. The MLRS site also hosts a GPS TurboRogue receiver and serves as a fundamental node within the International GPS Service. In addition, the continuous meteorological data accumulated by the MLRS is part of an international meteorological data-base. The project serves as an Observing Center and an Analysis Center in the International Earth Rotation Service (IERS) and the International Laser Ranging

Service. In a supporting role to other observing techniques, it obtains millisecond accuracy estimates of the constant of precession, coefficients of nutation, polar motion, and Earth rotation. Finally, personnel within the project cooperate with NASA/GSFC in the development, construction, and eventual deployment of a network of 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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In addition, University of Texas scientists contributed to 16 IAU Circulars, 4 Gamma Ray Bursters Network Circulars, and 121 Minor Planet Circulars during the year.