This report covers the period 1 September 1999–31 August 2000.

1 Organization, Staff, and Activities

1.1 Description of Facilities

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

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

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

1.2 Administration

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

1.3 Teaching and Research Personnel

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

Academic

Named Chairs: 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); Chris Sneden (Regents Professor, 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 Yanagawasaw Regent's Professorship in Astronomy).

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

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

Non-Academic


1.4 Senior Research Support and Administration

HET Commissioning Manager: Thomas Barnes.
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 George A. Finley III, Secretary.

1.6 Visitors and Affiliations

The Antoinette de Vaucouleurs Centennial Lectureship in Astronomy was presented this year by Dr. Reinhard Genzel of the Max Planck Institute. Dr. Genzel was presented with the medal at a departmental colloquium. In addition, he presented a public talk on campus.

Dr. K. Sellgren of Ohio State University visited as a Cox Visiting Professor during February-March 2000, to discuss scientific issues related to interstellar dust and to the properties of stars near the Galactic Center.

The following people visited the department for extended periods:

Amy Barger (U. Hawaii),
Timothy Beers (Michigan State U.),
Charles Cockell (British Antarctic Survey),
Patrick Côté (Caltech),
Stephane Courteau (Dominion Astrophysical Obs.),
John Cowan (U. Oklahoma),
Karl Gebhardt (U. C. Santa Cruz),
Andrew Karam (U. Rochester),
Wolfram Kollatschny (U. Göttingen),
Robert Kraft (UCSC),
Norm Murray (Canadian Inst. for Theoretical Astrophysics),
Richard Mushotzky (GSFC),
Jens Niemeyer (U. Chicago),
Brad Peterson (OSU),
George Preston (Carnegie Obs.),
Alejandro Raga (UNAM),
N. K. Rao (Indian Institute of Astrophysics),
Brigitte Ragot (NASA/GSFC),
Didier Saumon (Vanderbilt U.),
Kenneth Sembach (Johns Hopkins U.),
Krzysztof Stanek (Harvard-Smithsonian Center for Astrophysics),
J. Stein (Hebrew U. Jerusalem),
Bob Stobie (South Africa Astronomical Obs.),
Friedrich Thielemann (U. Basel),
Scott Trager (Carnegie Inst.), and
Frank vanden Bosch (U. Washington)

1.7 Special Activity: The Seventh Texas-Mexico Conference on Astrophysics

The Seventh Texas-Mexico Conference on Astrophysics, “Flows, Blows, and Glows”, was held on the UT Austin campus April 5-8, 2000 with 88 participants. G. Shields and C. Colomé respectively chaired the Scientific and Local Organizing Committees. The meeting had sessions on ionized nebulae, interstellar matter and star formation, AGN and black holes, cosmology and galaxy evolution, supernovae and gamma-ray bursts, and stars. Proceedings will be published in Revista Mexicana de Astronomía y Astrofísica, Serie de Conferencias.

1.8 Awards, Honors, and Special Activities

F. Bash was awarded an honorary D.Sc. degree by his undergraduate alma mater Willamette U. in Salem, Oregon. He received the Board of Visitors Teaching Excellence award. N. Evans received a Fulbright Scholar grant. R. Robbins won the University of Texas College of Natural Sciences Teaching Excellence award. University of Texas Staff Excellence award winners were Henry Cantu for the Department of Astronomy and David Doss* for McDonald Observatory.

F. Bash is President of the Astronomical Society of the Pacific J. Craig Wheeler served as Vice President of the American Astronomical Society. G. Fritz Benedict served as Past Chair of the AAS Division on Dynamical Astronomy.

F. Bash Chairs the Hobby-Eberly Telescope Board of Directors. He also serves on the Southern African Large Telescope Board of Directors. He concluded his term as Member Representative from the University of Texas at Austin to AURA. He is a member of ACCORD, the directors of large, ground-based optical-infrared observatories, which is a council of AURA. T. Barnes was appointed as the institutional representative to AURA, Inc.,
for The University of Texas at Austin. J. Craig Wheeler is a member of the Executive Committee, Aspen Center for Physics. M. K. Hemenway served as Secretary to the Board of the ASP. A. Cochran was a member of the US National Committee of the International Astronomical Union.

A. Cochran served on the NASA Origins of Planetary Systems Management Operations Working Group. She was a member of the 2000 Comparative Planetary Senior Review which analyzed extended planetary missions for NASA. W. Cochran served as a member of the NASA Origins sub-Committee. J. Kormendy served on the Space Telescope Users Committee (STUC). N. Evans served as first chairperson of the ALMA Scientific Advisory Committee (ASAC), an international committee that advises the ALMA partners (NSF, NRAO, ESO) until March, 2000, and continues to serve as first chairperson of the Program Advisory Committee, advisory to the director of NRAO. He served on the Radio and Submillimeter Panel of the Decadal Survey (NRC). He is now a member of the Committee on the Status of Women in Astronomy of the AAS.

M. K. Hemenway was on the Scientific Organizing Committee for the Astronomical Society of the Pacific July 2000 meeting “Cosmos in the Classroom”. Paul Shapiro served on the scientific organizing committees for the meetings “Astrophysical Plasmas: Codes, Models, and Observations,” Mexico City, October 1999, and “20th Texas Symposium on Relativistic Astrophysics and Cosmology,” Austin, TX, December 2000. J. Craig Wheeler is on the International Organizing Committee for the Texas Symposium on Relativistic Astrophysics. He is the Chair of the Local Organizing Committee for the “20th Texas Symposium on Relativistic Astrophysics and Cosmology”.

C. Sneden served on the NOAO Telescope Allocation Committee. A. Cochran served on the Planetary Astronomy and Survey Panels of the NOAO TAC.

M. K. Hemenway is a member of the SOFIA Education and Public Outreach Working Group. She was also a member of a Site Visit Team for an existing NSF Science and Technology Center in October 1999.


N. Evans took sabbatical leave last year. He spent the Fall 1999 at University College London with both a Fulbright Scholar grant and a grant from the Particle Physics and Astronomy Research Council of the U.K. He worked Spring 2000 at Leiden Obs. with support from grants from the Netherlands Organization for Scientific Research (NWO) and NOVA.

Chris Sneden was a Scientific Editor for the *Astrophysical Journal*. William Cochran was a receiving editor for *New Astronomy*. William Jefferys serves as an Associate Editor of *Celestial Mechanics*. Mary Kay Hemenway was a consultant to *Choice*, the journal of college libraries. Larry Trafton served as an Associate Editor of *Icarus*. Anita Cochran was an advisor to the Planetary Data System’s Small Bodies Node.

R. Robbins continued to lead groups of college teachers to Mexico and Mesoamerica to carry out workshops on archaeoastronomy with funding from the NSF. On the most recent trip, he discovered an equinox sun serpent at the Temple of the Giant Jaguar at Tikal – only the second ever found.

2 Academic and Educational Program
2.1 Graduate Program

The Graduate Studies Committee Chairman was Paul Shapiro with Graduate Advisor Craig Wheeler and John Scalo. The Fred T. Goetting, Jr. Memorial Endowed Presidential Scholarship was awarded to Pamela Gay. The Frank N. Edmonds, Jr. Memorial Fellowship was awarded to Inese Ivans.

Graduate students in 1999–2000 were Kyungjin Ahn, Nairn Baliber, Marcel Bergmann, Ryan Biggs, Aniran Biswas, Lara Cross, Gregory Doppmann, Rica French, Pamela Gay, Tommy Greathouse, Dale Andrew Howell, Inese Ivans, George Marion, Jasmina Marsh, Travis Metcalfe Anjum Mukadam, Atsuko Nitta, Diane Paulson, Zhaozhi Shang, Yancy Shirley, Joseph Tufts, Marsha Wolf, David Yong Juntao Yuan, and Qingfeng Zhu.

**Doctoral Dissertations:** One Ph.D. degree in astronomy was awarded in 1999–2000:

Feng Ma “Discovery of Hidden Blazars inside Quasars” (B. Wills and G. Shields, Chairs).

**Master’s Theses:** Two Master’s degrees in astronomy were earned in 1999–2000:


Juntao Yuan “Optical Polarization of Blazars
Over a 20-30 Years Time Span and its Relation to Core Radion Structure” (B. Wills, D. Wills, Chairs).

2.2 Undergraduate Program

Harriet Dinerstein was the chair of the Undergraduate Studies Committee; Bill Jefferys served as undergraduate advisor. There were 69 astronomy majors this year and 6 students received a BA.

Naveen Reddy was awarded the Outstanding Graduating Senior Award. Erik Brugamyer was the winner of the Karl G. Henize Memorial Scholarship in Astronomy. David Smith received the Board of Visitors Undergraduate Scholarship in Astronomy.

2.3 Educational Services

The nine-inch refractor (directed by Feng Ma and Michael Yuan) was visited by over 1400 people during public tours. Thirty-two school groups totaling over 1100 elementary/secondary students and teachers participated in Solar Telescope field trips presented by Eakins. Regular star parties attracted 1000 people.

Hemenway and Eakins represented the Department at nine other events, such as Austin Science Fun Day, Honors Colloquium, and Amistad National Recreational Area. About one thousand people were served through these events.

2.4 Public Information Office

Construction of the new Texas Astronomy Education Center (TAEC) began in Summer 2000. The TAEC is a major upgrade to the current Visitors’ Center at McDonald Observatory. Fund-raising for TAEC was completed early in 2000, the architectural plans were final in Spring 2000, and the UT Board of Regents approved the $5.75M TAEC project in May 2000. TAEC ground-breaking took place on July 29, and the building contractor received notice to proceed in late August.

In the first half of 2000, a new road and large parking lot for TAEC were constructed in a project funded separately by the Texas Department of Transportation.

The new TAEC building will be about 12,000 square feet, plus a large courtyard and entryway, two new 20-foot telescope domes, and an amphitheater in the back for public sky talks. The new TAEC building contains an exhibit hall, a classroom, an auditorium, a gift shop, and a small cafe, and it will include a heliostat on the roof feeding a solar spectrum projector inside the building. The current Visitors’ Center will be renovated after the TAEC goes into operation to provide additional space for operating TAEC and supporting its public outreach programs.

3 Research Program

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

On October 1, 1999, the Hobby - Eberly Telescope (HET) ended telescope commissioning and began the ‘early operations’ phase. Early Operations emphasizes research operation of the HET for 50% of the nights with instrument commissioning and facility improvements occupying the remainder of the time. In the period October 1 through July 31, the HET was scheduled for science operations 149 nights and 1552 spectra were obtained with the Low Resolution Spectrograph (LRS) and the Upgraded Fiber Optic Échelle, a medium resolution, fiber-fed spectrograph on loan from Penn State U.. The efficiency of operation was about that expected for this phase of HET operation: shutter open on science targets 34.2% of the clear time. Spectra were delivered to all five collaborating institutions: UT Austin, Penn State U., Stanford U., Georg August Universitaet, Göttingen, and Ludwig Maximilians Universitaet, München. The telescope was taken out of operation beginning August 1, 2000, for ‘summer shutdown’ engineering.

Observing time on the HET has been offered to the US national community starting late in the 2000B semester. NOAO handles all interactions with national researchers. Approved projects from the national community are entered into the HET queue and observed on the same basis as projects from the five collaborating institutions. In this first semester and in 2001A, LRS (single slit) and High Resolution Spectrograph (HRS) are available.

The greatest engineering effort this year was on improving HET image quality. Through a large number of test observations, led by J. Booth and assisted by the HET operations team and D. O’Donoghue of the South African Astronomical Observatory, considerable progress was made in understanding and improving image quality. Improvements in the prime-focus star-tracker mount-model, in the fore optics to the LRS, and in eliminating sources of dome seeing were made.

A contract was signed November 1, 1999, with Marshall Space Flight Center to design, build, in-
stall and verify an edge-sensor system on the 91 segments of the HET primary mirror array. Concept Design Review, Proof of Concept demonstration, and Preliminary Design Review have been completed successfully. Demonstration of the system on seven segments in the HET is in progress. Completion is anticipated mid-2001. The primary benefit of the edge-sensor system will be to markedly increase observing time by holding the primary mirror array in optical alignment.

Through the efforts of graduate student M. Wolf and computer analyst M. Ward, the Center of Curvature Alignment System (CCAS) was brought into interferometric operation. This shearing interferometer provides the ‘tip / tilt’ information for each segment in the primary mirror array necessary to create an interferometrically aligned array. The CCAS is necessary to the success of the edge-sensor system.

The LRS (PI Gary Hill, McDonald Obs.) was successfully commissioned this year by Hill and his team as a single slit instrument and substantial progress was made in testing its Multi-Object Slitlets configuration.

The High Resolution Spectrograph camera (PI Bob Tull, McDonald Obs.) was completed and installed in the HET spectrograph room by Tull and J. Good. First light has been observed. The fiber-feed for the HRS has been delivered and the detector system hardware is nearing completion by PI P. MacQueen. Software development and integration are in progress.


In March 2000 ten papers on the HET system were delivered at the Munich SPIE meeting on large telescopes.

### 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 only total 89 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 spectroscopy or imaging. After correcting for downtime due to maintenance, equipment, etc., the usable time is estimated as 71% for the last fiscal year. This value may be compared with 65% for the previous year, and 63.1% for a nineteen year mean. From 0.9-m telescope statistics for photometric observing in 1981-1992, the photometric weather at McDonald Observatory averaged 39.8% of the available hours. The 0.9-m telescope is now closed to research programs.

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<tr>
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<th>2.7-m</th>
<th>2.1-m</th>
<th>0.8-m</th>
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<tbody>
<tr>
<td>a) Available</td>
<td>4083</td>
<td>4044</td>
<td>4020</td>
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<tr>
<td>b) 2450(60%)</td>
<td>2195</td>
<td>823(21%)</td>
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<td>c) 974(24%)</td>
<td>1003</td>
<td>454(11%)</td>
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<td>d) 131 (3%)</td>
<td>101 (3%)</td>
<td>37 (1%)</td>
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<tr>
<td>e) 316 (8%)</td>
<td>101 (3%)</td>
<td>37 (1%)</td>
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<tr>
<td>f) 211 (5%)</td>
<td>703 (17%)</td>
<td>2700(67%)</td>
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- a) Available; b) Observed; c) Lost to weather;
- d) Lost to telescope/instrument problems;
- e) Scheduled maintenance; f) Other

### 3.3 Scientific Results

#### 3.3.1 Instrumentation:

Gary Hill and Phillip MacQueen delivered the HET Low Resolution Spectrograph into early science operations, where it is conducting science observations approximately half of the time. This instrument is an imaging grism spectrograph with multi-object capability covering 360-1000 nm. Resolutions between R=500 and 1500 are currently available, and the instrument images the 4 arcminute field of view of the HET. Hill and MacQueen received a grant from the National Science Foundation to build a camera to be used with the LRS covering 0.85 to 1.35 microns. The primary aim of the project (with M. Wolf and J. Tufts) is to provide multi-object spectroscopy of faint galaxies at redshifts greater than unity, where the familiar optical features are redshifted into the J band. Delivery of the instrument is expected in about 1 year.

Gary Hill continued as HET Prime Focus Instrument Platform Project Scientist. The PFP includes the 4 mirror corrector, and carries the Fiber
Instrument Feed and the LRS.

J. Lacy, M. Richter, T. Greathouse, and D. Jaffe successfully commissioned the mid-infrared Texas echelon-cross-echelle spectrograph (TEXES) on the 2.7 m telescope at McDonald Observatory. TEXES achieved resolving powers as high as $R = 65,000$. They observed late star photospheres, Jupiter, and evolved stars with significant mass loss. In all cases, TEXES proved to combine high sensitivity with higher spectral and spatial resolution better than previous mid-infrared instruments.

J. Lacy, M. Richter, T. Greathouse, D. Jaffe and M. K. Hemenway continued development of the echelon-cross-echelle spectrograph (EXES), a high resolution, mid-infrared spectrograph for the Stratospheric Observatory for Infrared Astronomy (SOFIA). Mechanical design work is nearly done while electronics and software are being used and improved during ground-based observations using the prototype instrument, TEXES.

3.3.2 Extrasolar Planetary Systems:

The McDonald Observatory Planetary Search program, operated by W. Cochran and A. Hatzenes, has continued on the McDonald 2.7m telescope. This program surveys about 160 nearby F, G, K, and M dwarfs for Jovian mass companions. Data from this program, in combination with data from other high precision radial velocity programs, show convincing long-period variations in the nearby (3.22 pc) K2V star ε Eridani. The reduction system used to combine totally independent radial velocity data sets was developed by B. McArther. A least squares orbital solution using robust estimation yields orbital parameters of period, $P = 6.9$ yrs, velocity $K$-amplitude of $19 \text{m s}^{-1}$ eccentricity $e = 0.6$, projected companion mass $M \sin i = 0.86 M_{\text{Jupiter}}$, and semi-major axis $a_2 = 3.3 \text{AU}$. Ca II H&K S-index measurements spanning the same time interval show significant variations with periods of 3 and 20 yrs, yet none at the RV period. If stellar activity is responsible for the RV variations then it produces a significantly different period than is seen in the Ca II data. Given the lack of Ca II variation with the same period as that found in the RV measurements, the long-lived and coherent nature of these variations, and the high eccentricity of the implied orbit, Keplerian motion due to a planetary companion seems to be the most likely explanation for the observed RV variations. The wide angular separation of the planet from the star (approximately 1 arc-second) and the long orbital period make this planet a prime candidate for both direct imaging and space-based astrometric measurements.

3.3.3 Astrobiology:

Scalo and Wheeler, in collaboration with P. Williams and C. Cockell (British Antarctic Survey), continued an investigation of the importance of intermittent Galactic events like supernovae, novae, and gamma ray bursts, for frequent and large perturbations to planetary atmosphere photochemistry and biological affect (primarily mutagenesis). Effort was centered on calculating the frequency distribution of events of given flux and fluence (time integrated flux) at the solar system for a realistic model of the distribution of sources and extinction in the Galaxy. Ultraviolet radiation supernovae are the most frequent contributors. It is estimated that the mean time between biologically significant fluences during the pre-ozone (Archaen) Earth was about 1 million years. Current work involves estimating the wavelength dependence of the radiation from the sources and the cross sections for different types of DNA damage. They are also investigating radiative transfer through atmospheres of different compositions and ozone erosion frequencies. They will generalize this effort to include cosmic rays and supernova remnant and superbubble shells.

Scalo, Wheeler, and Cockell have studied evolutionary implications of the remarkably radiation-resistant bacterium Deinococcus radiodurans. Current opinion is that the unique radiation resistance is an incidental byproduct to dessication resistance, since there has never been a fluence of ultraviolet or ionizing radiation comparable to its lethal dose, so there has never been a selection pressure for the evolution of the trait. They show that the dose (energy absorbed per gram) received by D. radiodurans during one generation time due to solar UV radiation field transmitted through the pre-ozone Earth atmosphere is comparable to its lethal dose, and that subsequent intermittent events due to Galactic sources could have reached similar levels.

Scalo has begun a study of various topics of relevance to astrobiology, in particular effects related to the planetary radiation environment. These include: stochastic models for DNA damage and repair for extrapolation to historical terrestrial and extraterrestrial mutagenesis rates; radiation-assisted biopolymerization which might be important in setting the sizes of RNA/PNA world nucleic acids; cell convection induced by heat deposited along radiation tracks and its possible role in the transition to
eukaryotic cell structure; and intermittent erosion of ice sheets by Galactic sources of UV and ionizing radiation and the consequent atmospheric and biospheric consequences.

3.3.4 Solar System:

A. Cochran, T. Farnham and E. Barker observed comet C/1999 S4 (LINEAR) in the weeks leading up to its total break-up. They obtained high dispersion spectra on 10 nights with accompanying imaging on 4 nights. The comet showed a marked depletion in C2 and C3, unusual for a long-period comet. As a result of this depletion, it was possible to observe the O (1S) emission line at 5577Å with no contamination from either the telluric emission or the cometary C2 emission. A. Cochran and W. Cochran are analyzing the ratio of the O (1S)/O (1D) in order to determine the relative contribution of H2O and CO to the O (1S).

A. Cochran, along with W. Cochran and E. Barker, completed their study of the N2+/CO+ ratio in comets 122P/1995 S1 (de Vico) and C/1995 O1 (Hale-Bopp). The stringent upper limits on this ratio have significant implications for the temperature and chemistry in the early solar nebula and act as a tracer of argon in comets. This has implications for the delivery of argon to terrestrial planets.

A. Cochran and D. Schleicher (Lowell Obs.) are continuing their study of the effects of solar activity on the photodissociation of H2O to OH. This is a follow-on study to their paper of 1993 (Icarus 105, 235). In the current study, they include many more observations of comets when the Sun was quiescent. They show that there are comet-to-comet variations of the OH and H2O scale lengths that cannot be easily understood in terms of either the outflow velocities or the level of solar activity. They are currently exploring cometary activity and rotation as an explanation for the observed gas distribution.

T. Farnham, in collaboration with D. Schleicher (Lowell Obs.) is continuing his analysis of over 65 nights worth of images of comet Hale-Bopp, obtained with the Lowell 42-inch telescope. The present stage of analysis focuses on the rotation properties of the nucleus, where Farnham used measurements of the arc motions in the near-nucleus region to determine the 11.31 hour rotation period. More recently, he has developed a Monte-Carlo computer code for analyzing the motions of the arcs to determine the orientation of the rotation axis, the locations of the primary active regions, and the relative strengths of each jet. Preliminary results from this analysis indicate at least three active regions exist and must be highly extended (60-80° across) in order to reproduce the morphology that is observed in the coma. Preliminarily, it appears that a simple rotation state will be sufficient for reproducing the features.

T. Farnham began a new project to measure light curves of distant comets, Centaurs, and the brighter Kuiper Belt Objects, in an attempt to determine some of the fundamental properties of these bodies. Analysis of the data is underway, with the present focus being the Centaur 5145 Pholus. Farnham has determined the orientation of the rotation axis (λ0 = 146°, β0 = +26°), the sidereal rotation period (0.4159256 day), and the dimensions of the body (250×140×140 km). In addition, he has found evidence that the northern hemisphere contains features that are of a different composition from those in the southern hemisphere.

T. Farnham, in collaboration with D. Schleicher (Lowell Obs.) and collaborator L. Woodney (U. Maryland) completed a study comparing the CN and HCN in comet Hale-Bopp. For the first time, extended HCN structure was detected at radio wavelengths when Hale-Bopp was near perihelion. At the same time CN observations were obtained at Lowell Obs. with the HB narrowband filters. These simultaneous observations provided the opportunity to compare the HCN and CN morphologies to determine whether or not HCN is the primary parent molecule of CN. It was determined that the respective morphologies are consistent with the HCN being a parent of the CN, but the correlation was not strong enough to rule out the possibility of a second parent, such as small dust or CHON particles.

Participating with members of the HST-Galileo Campaign team, headed by F. Bagenal at U. Colorado, L. Trafton reduced and analyzed NUV/FUV spectra of Io in Jupiter's shadow obtained in August 1999 with HST/STIS. The spectrum consisted mainly of dim, diffusely reflected sunlight diffracted by Jupiter's upper atmosphere into shadow and emission from SO2+SO bands. These are exited by electron impact from the magnetospherically trapped plasma torus distributed along Io's orbit. Also detected was emission from SI, a product of dissociative excitation of SO2 by electrons. Modeling the self-absorption of the SO2 emission may be necessary to fit the observed spectrum with laboratory data.
Reducing and analyzing HST/GHRS data obtained as part of a GTO program, and data in the STScI archives, L. Traffon resolved the diffusely reflected solar H Ly α line from the overlapping, Doppler-shifted, geocoronal line. A weak emission feature was also detected at the rest wavelength of H Lyα in Io’s frame, in the wing of the geocoronal line. This suggests the presence of iogenic hydrogen. Taken together, the observations indicate that H Lyα emission in recent HST/STIS low-resolution spectra of Io taken by Roesler et al. (Science, 1999, 283, 353) is mostly diffusely scattered sunlight, rather than originating from iogenic H.

With S. Miller (UCL), and T. Geballe (Gemini), Traffon obtained further spectra of Uranus’ H2 and H3+ emission at the UKIRT telescope in September using the CGS4 instrument. These should be diagnostic of the role that the solar cycle plays in the excitation of these species. Solar EUV ionization of H2 is thought to produce H3+, suggesting greater intensities approaching the 2001 solar maximum. These spectra will be compared with those similarly obtained in 1995, near solar minimum.

With D. Lester, Traffon continued to observe Jupiter’s and Uranus’ K-band spectrum using the new CoolSpec IR spectrograph at McDonald Observatory. These observations benefited from several improvements to the sensitivity of this instrument incorporated over the past year. The objective of this ongoing program is to investigate the cause of the temporal variation in the relative strengths of the H2 and H3+ emission. This is important for a quantitative understanding of the process that excites these species.

3.3.5 Stars and Stellar Systems, Stellar Ejecta:

C. Allende Prieto, M. Asplund (Uppsala Astronomical Obs.), Åke Nordlund (Copenhagen Astronomical Obs.), R. Trampedach and R. Stein (Michigan State U.) have completed a study of the spectral line formation in solar granulation. They make use of time-dependent three-dimensional hydrodynamical simulations of surface convection and 3D radiative transfer. The model was shown to reproduce, in detail, the line widths, asymmetries and shifts in the solar spectrum.

C. Allende Prieto, D. Lambert, M. Asplund (Uppsala Astronomical Obs.), and R. García López (Instituto de Astrofísica de Canarias) have carried out observations of the nearby F5 subgiant Procyon with the 2decondé spectrograph at the McDonald 2.7m telescope. The observations, which have extremely high resolution (λ/λ ≈ 2 × 10^5), large signal-to-noise ratio (> 500), and wide spectral coverage (4560–5780 Å), are unique and make it possible to extend Procyon studies of surface convective inhomogeneities previously performed for the Sun.

C. Allende Prieto extracted 3421 low-resolution spectra of 992 nearby stars (closer than 100 pc) from the archive of the International Ultraviolet Explorer (IUE). After estimating the angular diameters of the stars, by combining Hipparcos parallaxes and stellar evolutionary models, he derived gravities, effective temperatures (Teff) and metallicities ([Fe/H]). The distribution of stars in the Teff–[Fe/H] plane shows an apparent deficit of A-type stars of solar and higher metallicities. Such distribution might reflect large selection effects in the IUE sample, and further spectroscopic studies are needed.

C. Allende Prieto, D. Lambert, I. Hubeny and T. Lanz (NASA GSFC) have started a long-term project to produce a family of line-blanketed non-LTE model atmospheres for late-type stars. They have produced model atoms for neutral Na and S, singly-ionized Ne, and neutral and singly-ionized Li, Be, B, C, N, O, F, Mg, Al, Si and Ca, combining the most recent and accurate calculations of photoionization cross-sections with observed energy levels, and a series of approximate formulae for the atomic collisional processes.

C. Allende Prieto has derived a new method to estimate distances to stars and clusters from BVK photometry. The procedure takes advantage of the surface flux vs. (V–K)0 relationship, using nearby dwarfs with interferometric measurements of angular diameters and the well-determined radii of the components of detached eclipsing binary systems.

G. Benedict, in collaboration with B. McArthur, A. Hatzes, O. Franz (Lowell Obs.), and T. Henry (Georgia State U.) continued a program of radial velocity measurements of low-mass binary stars. The primary goal is to firm-up the lower main sequence mass-luminosity relationship with masses with 5% or better precision. The accuracy of these results are improved by the constraint that the HST astrometry and the radial velocities should describe the same physical system. The secondary goal is to sift for additional low-mass companions. A tertiary goal is to obtain orbital parallaxes with which to resolve possible discrepancies between HIPPARCOS and HST parallaxes. Analyses for one object is complete (Gl 748 = Wolf 1062). A second object
(Gl 831 = Wolf 922) awaits a few final Cycle 9 HST measurements.

H. Dinerstein and D. Garnett (U. Arizona) continued their investigation of the anomalous O II recombination lines in planetary nebulae (PN). Since the ratios of these to the H I recombination lines are insensitive to electron temperature, in principle this method should yield accurate O/H; however, recent observations of several PN indicate implausibly high abundance values. A systematic survey of 10 PN at McDonald Observatory in 1997-98 revealed patterns in the line strengths suggestive of a physical process which selectively enhances the O II line strengths in some regions. Spatially-resolved follow-up observations at Steward Observatory in summer 1999 offer further clues to the nature of this unidentified process. In the Ring Nebula, the O II line strengths peak in the low-surface brightness interior “cavity” rather than at the expected location - the edge of the O++ ionization zone. One possibility consistent with the data is that high-temperature recombination enhances these lines in a central hot bubble, a mechanism not accounted for in current photoionization models of planetary nebulae.

H. Dinerstein and D. Lester, with collaborator L. Likkel (U. Wisconsin, Eau Claire) and her students, continued a study of the vibrationally-excited near-infrared H$_2$ line emission in PN, using Lester’s recently completed modular “CoolSpec” spectrometer on the McDonald 2.7m telescope. We are finding that the emission from several young PN is consistent with UV photons still providing the initial pump, but collisions within the dense molecular zone causing the emergent line intensities to differ from the “pure fluorescence” case. Under these circumstances, the observed H$_2$ emission must arise from a relatively large amount of cool molecular gas. During the coming year, Dinerstein will collaborate with J. Lacy (UT) and K. Seigl (Ohio State U.) in a related study of the lower-energy rotational transitions of H$_2$ in PN, using Lacy’s TEXES instrument on the IRTF (Infrared Telescope Facility) at Mauna Kea.

P. Höflich investigated supernovae, generating model optical and IR light curves and spectra to compare with observations (with R. Fesen and C. Gerardy, Dartmouth and H. Marion, U. Texas). He explored supernovae thermonuclear explosions by modelling progenitor evolution of SNeIa with I. Domínguez (U. Granada) and O. Straniero (Colurania Obs.). He studied evolutionary effects in SNeIa and predicted observational consequences including a) the influence of the metallicity and masses of SNeIa on the explosion, light curves, and spectra, and b) the influence of metallicity on binary evolution (with N. Langer, U. Potsdam). He also carried out multidimensional calculations for runaway ignition of white dwarf cores (with J. Stein, Hebrew U.) and provided 3-D NLTE-spectra for analysis of the polarization spectra of SN1999y. Regarding core collapse supernovae, he modeled explosions, light curves and spectra for extreme plateau SNeIp, and explored their use as distance indicators for high redshifts ($z \geq 3$). This work included 3-D simulations for jet-driven explosions (with A. Khokhlov, NRL) that produced polarization predictions. Finally he produced models for molecule formation in SN1998s and provided these to collaborators Fesen and Gerardy (Dartmouth) for comparison with observations.

I. Ivans, with T. Beers (MSU), C. Masashi (National Astronomical Obs. of Japan) and collaborators from U. Leiden and Max-Plank, Garching, derived the chemical abundances of stars which show kinematic signatures of being the remnants of a merger between our Galaxy and a protogalactic system or dwarf galaxy $\sim10$ Gyr ago. The stellar residue of this ancient galactic merger has spread out all over the sky. But these stars show their common origins in high angular momentum values. The derived abundances are being compared against those found for halo stars that formed within the Milky Way in order to determine the nucleosynthetic sites, and to infer the mass function and star formation rate of the merged system prior to its capture by our Galaxy.

W. Jefferys and T. Barnes continue to explore Bayesian approaches of model averaging for the Cepheid distance scale. Their collaborators in this work are J. Berger and P. Müller (Duke U.). A fully Bayesian model has been developed using Markov Chain Monte Carlo simulation to produce samples from the posterior distribution.

A. Mukadam is measuring the evolution of the second most stable optical clock known: ZZ Ceti. Three decades of high speed time series photometry data now exist on this pulsating white dwarf, including recent observations by Mukadam in 1999 and 2000. The rate of change of two of its known pulsation periods with time ($\dot{P}$) is found to be of the order of a few times $10^{-15}$ s$^{-1}$. This makes ZZ Ceti the second most stable optical clock known and more stable than atomic clocks. Measuring a
\( \dot{P} \) is theoretically equivalent to measuring the rate of cooling. White Dwarf evolution is dominated by cooling, through a simple relation between age and temperature or luminosity of the white dwarf. Constraining the rate of cooling improves the precision in measuring the age of the white dwarf. The distribution of white dwarf ages in the galactic disk places a limit on the age of the Galaxy and the Universe itself. Hence, measuring \( \dot{P} \) reduces some of the uncertainties in measuring the age of the Galaxy and of the Universe.

H. Rocha-Pinto and W. Maciel (IA, Brazil), J. Scalo, and C. Flynn (Tuorla Obs.) re-determined the star formation history of the disk of our Galaxy using a metallicity-dependent chromospheric activity-age relation. The sample consists of 730 nearby late-type dwarfs with metallicities from \textit{uvby} data and parallaxes and proper motions from HIPPACOS. These stars have birth sites which sample a large volume of the Galactic disk, due to the effects of orbit diffusion over their lifetimes. The age distribution is transformed into a star formation history by the application of scale height, stellar evolutionary, and volume corrections. They find that the Galactic disk has experienced enhanced episodes of star formation at 0-1 Gyr, 2-5 Gyr, and 7-9 Gyr ago. Using simulations they show that the probability that these fluctuations are due to sampling statistical effects is extremely small. Models for disk galaxy evolution that assume a smooth monotonic star formation history require revision. They also compare with estimated epochs of close encounters with the Magellanic Clouds.

Working with E. Sandquist (San Diego State U.), M. Shetrone began a survey of blue stragglers in nearby open clusters to determine how many were formed by collision and how many by mass transfer. Shetrone continued his work on abundances in dwarf spheroidal galaxies with new collaborators P. Côté and W. Sargent (California Institute of Technology). These observations were taken on the Keck I telescope with the HIRES spectograph.

C. Sneden and collaborators from NOAO and Lick Observatory are continuing their program of using high resolution echelle spectroscopy to determine the chemical compositions of large stellar samples (typically \( \geq 10 \)) on the upper red giant branches (\textit{RGB}s) of globular clusters in the metallicity range \(-0.8 \geq [\text{Fe/H}] \geq -2.3 \). This past year I. Ivan's, C. Sneden, and R. Kraft (UCSC) have analysed new high resolution spectra of the globular cluster M5. This cluster has a similar metallicity to M4 ([Fe/H] \( \sim -1.2 \)), which was subjected to a detailed analysis by Ivans et al. (1999, AJ, 118, 1273). The new analysis of M5 brings into sharp contrast the detailed chemical compositions of these two clusters. Whereas M5 has the overall chemical mix expected of typical halo stars, M4 has substantial overabundances (in all stars studied to date) of Al, Si, Ba, and La. The differences for all these elements are in the range \([\text{X/Fe}] \sim 0.4\). Recently, J. Simmerer has studied the abundance of copper in these two clusters, using the same observational material, and has discovered that there is a difference in \([\text{Cu/Fe}]\) of the same sign and order of magnitude. This may indicate an overall difference in chemical composition between "disk" and "halo" globular clusters, but clearly more clusters need to be studied to test this suggestion.

Following on an earlier discovery of a very high lithium abundance in a red giant in globular cluster M3, C. A. Pilachowski (NOAO), R. P. Kraft (UCSC), and Sneden have gathered Li-region spectra with the multi-object spectrometer Hydra on the WIYN telescope of nearly 1000 giants in several clusters. No extremely large Li lines have been found, but the detection of any Li absorption is unexpected from standard theory, and analysis of these data is ongoing at present. These spectra will be used to investigate trends in H\alpha emission in cluster giants. Our group will next work on the reduction and analysis of high resolution spectra of the (suspected) multi-metallicity cluster M22, and on several giants of outer halo clusters.

With B. Carney (UNC) and L. de Almeida (UNC), I. Ivans and C. Sneden have continued their analyses of high velocity stars in the halo of the Milky Way, to search for chemical signatures of galactic mergers. In this kinematically selected sample, some chemically anomalous stars have been uncovered. They have derived chemical abundances in order to trace the contributions from SN Type Ia, SN Type II, as well as intermediate-mass AGB stars. Their results for sodium, magnesium, calcium, titanium, nickel, zinc, and barium confirm that not only does chemical substructure exist in the halo, but the chemical anomalies are not all the same within all elemental groups. Currently, they are investigating correlations between the abundances for these stars and the kinematic information in an attempt to identify their origins.

In collaboration with J. J. Cowan (Oklahoma), J. W. Truran (Chicago), I. Ivans, R. French, G. Fuller (UCSD), T. C. Beers (Michigan State), J.
E. Lawler (Wisconsin), and S. Burles (Chicago), Sneden is continuing his investigations of neutron-capture elements in very low metallicity stars. New laboratory transition probability data for several very heavy elements are being applied to the spectra of the Sun and of n-capture-rich stars to refine and increase the reliability of the overall abundance mix for elements with Z > 55. A search for more transitions of the radioactive chronometer element Th is underway, to provide more choices beyond the traditional Th II 4019Å line for work on this element More data are being gathered from STIS/HST Cycle 8 to determine abundances of n-capture elements not detectable with ground-based spectroscopy (such as Os, Pt, and Pb) in extremely metal-poor stars.

G. Marion is working with P. Höflich, and J. C. Wheeler, obtaining near infrared (NIR) spectra of Type Ia Supernovae (SNe Ia) to establish significant new constraints on the progenitor composition and explosion dynamics. The model uses hydrodynamic simulations of the explosion and a radiation transport code for nucleosynthesis from Höflich and Khokhlov (1996, ApJ, 457, 500). The constraints established for Type Ia Supernova (relative to progenitor composition and explosion dynamics) are critical for the cosmological use of supernova data. They have also identified features in the near infrared spectra of SNe Ia that discriminate between Population I and Population II progenitors. That knowledge will significantly restrict the evolutionary history of SNe Ia. In addition, the products of thermonuclear burning that radiate in the NIR will be examined to differentiate between several explosion models for SN Ia.

D. Howell and J. Wheeler studied the distribution of different types of Type Ia supernovae in galaxies of different morphological type. This study suggests that subluminous Type Ia are truly old.

J. Stein and J. C. Wheeler studied the flow of matter associated with the convective Urca process after the ignition of carbon burning in white dwarf progenitors. The numerical models confirm arguments that the convective Urca process can somewhat delay the rate of increase of nuclear burning after ignition, but cannot cause a decrease in the entropy or temperature.

D. Howell, L. Wang, P. Höflich and J. C. Wheeler have continued their program of routine spectropolarimetry of all accessible supernovae. They have now nearly tripled the sample compared to that available at the beginning of this effort. They still find that core collapse supernovae (SN II, SN Ib/c) are polarized at the 1% level and SN Ia much less so in general. They obtained the first polarization data ever on a subluminous Type Ia (SN 1999y) and found that it was modestly polarized. The polarization suggests that the supernovae has a well-defined axis of global asymmetry. The polarization of Type Ia is an important probe of the combustion physics. Excellent polarization data were obtained for the classic Type II plateau supernovae SN 1999em that showed the polarization increasing with time as greater depths were probed. This is consistent with the need to have a strongly asymmetric process driving core collapse explosions. The polarization of the core collapse process may require something like a jet from the new-born neutron star to induce the explosion.

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

M. Miesch (Cambridge), J. Scalo, and J. Bally (JILA) have studied the probability density functions (pdfs) of molecular line centroid velocity fluctuations, and of line centroid velocity fluctuation differences at different spatial lags, for several nearby molecular clouds with active internal star formation. The data consist of over 75,000 13CO line profiles divided between twelve spatially and/or kinematically distinct regions, and the pdfs are constructed using three different types of statistical estimators. Although three regions (all in Mon R2) exhibit nearly Gaussian centroid pdfs, the other regions show strong evidence for non-Gaussian pdfs, often nearly-exponential, with possible evidence for power law contributions in the far tails. Evidence for nearly exponential centroid pdfs in the neutral H1 component of the ISM is also presented, based on older published data for optical absorption lines and H1 emission and absorption lines. Spatial images of the centroid velocity differences show no indication of the filamentary appearance predicted by turbulence decay simulations dominated by vortical interactions. They conclude that turbulence in both molecular and diffuse H1 regions involves physical processes which are not adequately captured by incompressible turbulence or by mildly supersonic decay simulations, contrary to some previous claims.

N. Evans published a review article on physical conditions in star-forming regions in the Annual Reviews of Astronomy and Astrophysics, co-authored a review article on protostellar collapse in Protostars and Planets IV, and completed research arti-
icles on both low mass and massive star formation. During a sabbatical year, Evans developed models for the submillimeter continuum emission from starless cores in order to constrain the initial conditions for low mass star formation. The models, which incorporate dust temperature gradients, indicate that these cores are more centrally condensed than previously believed.

3.3.7 Extragalactic:

G. Benedict, in collaboration with D. Howell, I. Jorgensen (Gemini North), J. Kenney (Yale), and B. Smith (East Tennessee State U.) finished a study of star clusters in the nuclear star-forming ring of the barred spiral galaxy NGC 4314. These clusters are likely associated with an inner Lindblad Resonance, or IILR. Age estimates based on several reddening-free parameters and Hα emission indicate that the present epoch of star formation has lasted at least 30 My. By estimating the masses of stars in the clusters and comparing with the Hα luminosity, they conclude that ~20% of ongoing star formation in the nuclear ring of NGC 4314 occurs in clusters. Previous ground-based observations revealed two symmetric stellar spiral arms which may be associated with an outer Inner Lindblad Resonance, or OILR. The spiral arm colors from HST data are consistent with stellar ages between 40 and 200 My. Given the age difference between the inner ring of young stars (IILR) and the larger oval-like feature containing the blue arms (OILR), they speculate that as the gas distribution shrinks, it interacts with these two resonances. Each resonance triggers star formation, resulting in two distinct star formation epochs.

Benedict and collaborator J. Higdon (Kapteyn Inst.), obtained Hα velocity field observations with the OASIS/TIGER integral field spectrograph on the CFHT in February 2000. These are being analyzed to compare with a lower resolution CO velocity field obtained with OVRO (Benedict, Smith, and Kenney, AJ, 111, 1861).

H. Dinerstein continued to participate in the analysis of data obtained as part of the ISO Key Project on the Interstellar Medium of Galaxies (PI: G. Helou, IPAC/Caltech). The goal of this project was to survey the characteristics of infrared dust and gas emission from the global ISM of galaxies of different morphological types and luminosities. They found that the strength of the primary far-IR atomic cooling line, C II 158μm, decreases relative to the total far-IR dust emission in galaxies with higher mean densities of gas and UV-radiation field in their regions of star formation (e.g. in “starburst” galaxies). This fact must be borne in mind when considering the [C II] line as a measure of star formation activity in high-redshift galaxies. Dinerstein and several undergraduate students at University of Texas (S. Akiyama, M. Huerta) are analyzing optical observations of H II regions in some of the Key Project galaxies, obtained at McDonald Observatory and by collaborator D. Hunter (Lowell Obs.), in order to investigate the dependence of the infrared line emission on metallicity.

G. Hill and P. Gay with S. Rawlings and S. Croft (Oxford U.) continued the extensive TEXO surveys of radio galaxies. TEXO now has two parts: the TEXO Cluster (TOC) survey, and the TEXO-1000 (TOOT) survey. The aim of TOC is to discover clusters of galaxies to high redshift using radio selection for comparison with other selection techniques. Identifications with the 2.7-m and the Imaging Grism Instrument has revealed many clusters which have been followed up with multi-object spectroscopy with the HET LRS. The technique has proven very successful, with candidate clusters at probable redshifts as high as z=1 already discovered. More than 10 intermediate redshift clusters already have confirmed redshifts between 0.38 and 0.6 from HET LRS spectroscopy.

G. Hill, J. Tufts and M. Bergmann are carrying out an ambitious project (TOOT) to identify and measure the redshifts of 1000 radio sources selected to have 151 MHz flux densities greater than 100 mJy, about 100 times lower then the 3C survey. Among the aims of the survey are to determine the evolutions of the FRI and FRII radiosource populations to great accuracy, and to use them as probes of large scale structure out to high redshift. Radio sources are tracers of the densest environments, and are excellent tracers of the largest scale structures in the universe. The current status of the TOOT project has the imaging 80% complete and the redshifts 40% complete, with spectra from the WHT and HET telescopes.

J. Kormendy, in collaboration with the “Nuker” team (D. Richstone, Michigan, PI), reported on the systematics of supermassive black holes (BHs) in galactic nuclei at the Seventh TexMex Conference in Austin, at the Rochester AAS meeting and at the Rome conference on “Galaxy Disks and Disk Galaxies”. One of the major payoff periods for the Hubble Space Telescope is under way, as the Space Telescope Imaging Spectrograph (STIS) begins to
produce many high-quality spectra of galactic nuclei. At least 15 new detections were announced at the AAS meeting, about half of them by the Nuker group. This brings the total to at least 34 BHs. The demographics of these objects lead to the following conclusions: (1) BH mass correlates with the luminosity of the bulge component of the host galaxy, albeit with considerable scatter. The median BH mass fraction is 0.15% of the mass of the bulge. (2) K. Gebhardt and the Nuker team find that BH mass correlates with the mean velocity dispersion of the bulge component inside its effective radius, i.e., with how strongly the bulge stars are gravitationally bound to each other. (3) BH mass correlates with the luminosity of the high-density central component in disk galaxies independent of whether this is a real bulge (a mini-elliptical) or a “pseudobulge” (believed to form via inward transport of disk material). (4) BH mass does not correlate with the luminosity of galaxy disks. If pure disks contain BHs (and AGN observations argue that some do), then their BH mass fractions are much smaller than the canonical 0.15% for bulges.

Two main conclusions follow. First, the above results increasingly support the hypothesis that the major events that form a bulge or elliptical galaxy and the main growth phases of its BH — when it shines like a quasar — were the same events. Second, present observations show no dependence of BH mass on the details of whether BH feeding happens rapidly during a collapse or slowly via secular evolution of the disk. Further HST BH spectroscopy is in progress, including analysis of STIS observations of M31 and NGC 3115.

J. Scalco and J.C. Wheeler have estimated the local gamma-ray burst (GRB) rate per unit blue luminosity in galaxies for various assumptions about the cosmic star formation history as a function of redshift. These values are used to examine a number of phenomena with the following conclusions: 1) The ratio of supernova rate to GRB rate is so large that it is difficult to maintain that more than a small fraction of neutron star or black hole-forming events produced GRBs, even allowing for generous collimation; 2) The GRB rate is so small that it is impossible to use these events to account for the majority of large HI holes observed in our own and other galaxies; 3) The probability that the solar system was exposed to a fluence large enough to melt the chondrules during the first 10 million yr of solar system history is negligibly small; 4) They calculate the probability that the Earth’s surface has been subjected to irradiation from GRBs. They find that the Earth’s surface should have been exposed to biologically significant short-lived jolts of X-rays about 500 times.

G. Shields completed an analysis of the spectrum and polarization of the QSO PG 1222+228, one of several known QSOs with a strong rise in polarization in the Lyman continuum. He found that the coincident drop in flux at rest wavelength 750 Å results from an intervening Lyman limit absorber. The intrinsic continuum is consistent with a normal QSO power law, in contrast to the apparent pattern for Lyman continuum polarization rises to occur in objects with a flux drop in the Lyman continuum. This implies a strong rise in polarized flux, not just percent polarization in the Lyman continuum, placing especially stringent constraints on models.

In the course of an HST study of Broad Absorption Line (BAL) QSOs, G. Shields, with V. Junkkarinen, E. Burbidge, and R. Cohen (UCSD), and F. Hamann (U. Florida), discovered a binary QSO with a spacing of only 0.3 arcsec. This is a factor six smaller than any previously known true binary QSO. The binary nature of the object, LBQS 0103-2753 A/B, is shown by profound differences in the spectra of the two components, including strong BALs in component A only. At the redshift of z = 0.86, the physical separation is 2 kpc. The discovery of even one such pair may indicate a high probability of fueling of black holes during this stage of a galactic merger.

B. Wills, W. Brandt and S. Gallagher (Pennsylvania State U.), and A. Laor (Technion) and have investigated the dependence of UV and optical spectral properties on X-ray–optical spectral index for an essentially unbiased sample (Boroson and Green 1992, ApJS, 80, 109). About 11% of the sample are soft-X-ray–weak QSOs, defined by an optical–X-ray spectral index > 2. They find a remarkably strong correlation between the strength of intrinsic C IVλ1549 absorption lines and the weakness of soft X-ray emission. This suggests that absorption is the primary cause of soft X-ray weakness in QSOs. The correlation reveals a continuum of absorption properties connecting unabsorbed QSOs, X-ray warm absorber QSOs, soft-X-ray–weak QSOs, and broad absorption-line (BAL) QSOs.

B. Wills and Z. Shang, with Michael Yuan, have investigated the UV-optical (HST-McDonald Obs.) properties of the Laor et al. (1997, ApJ, 477, 93) complete sample of PG QSOs. A spectral Principal Component Analysis clearly demonstrates the
Boroson-Green Eigenvector 1, and shows an inverse correlation between strength of UV and optical Fe II emission line blends – as expected if strong optical Fe II emission arises from high optical depth in the UV resonance lines. The carefully flux-calibrated optical-UV-X-ray data set shows that flatter X-ray spectra in the ROSAT band (0.1-4keV), and weaker soft-X-ray emission corresponds to more reddened optical-UV spectra, and the presence of intrinsic UV line absorption.

I. Cross and B. Wills have investigated the 1988 February flare of 3C 273. The complex polarization wavelength-dependence and its night-to-night variation are well described by the combination of two simple synchrotron spectra, with power-law polarized flux-density and approximately orthogonal wavelength-independent polarization position angles. The steeper component shows polarization approximately transverse to the projected VILBI jet direction. The variations in polarized flux-density, spectral index and position angle, account for night-to-night variability, and track each other with no discernible time-lag. These results suggest an origin in two nearly co-axial components, the flatter spectrum one arising in the compressed magnetic field of a transverse shock, and the other arising from electrons accelerated just outside the shocked region, where the dominant magnetic field is parallel to the jet.

M. Yuan and B. Wills, with H. Tran (STScI) and D. Wills have investigated polarization properties of 53 well known blazars. Half the sample show preferred optical polarization position angles, with < 15% probability of being drawn from isotropic distributions. These blazars’ polarization is well aligned with the jet direction (half of these within 15°). Moreover, those with the best optical-radio alignment show the least jet bending on 1–20mas scales. This suggests that some optical synchrotron emission arises outside the unresolved VLBI radio core, in shocks that tend to be transverse to the jet direction. The standard deviation of polarization position angle increases with radio core dominance R, up to R ~ 100. They model this with magnetic field directions confined within the plane of a transverse shock, but changing randomly between observations (time-scales of days to months). They find that there is increasingly a preferred position angle parallel to the projected jet direction so the standard deviation of polarization angles decreases. For larger values of R, the bulk relativistic speed dominates R, so the dependence on viewing angle is less important.

F. Ma predicted theoretically that, in radio-loud quasars, it should be possible to detect interactions between the relativistic jet and the broad emission-line region (BLR). This is because the variable beamed infrared synchrotron emission should heat the BLR. This should result in large variations, over timescales of years, in collisionally excited lines such as C IVλ1549, but not in lines like Lyα or C IIIλ1909 that are excited mostly by UV photons that are sparse in the beamed continuum. Ma tested his prediction by comparing new spectra of ~58 quasars that he observed at McDonald Observatory, with historical spectra from a number of sources. Ma found two quasars that show variations consistent with his predictions. These results constrain the BLR to have gas at least partly in the beam. This motivated Ma’s investigation of photoionization of tidally disrupted stars that could contribute significantly to BLR emission.

3.3.8 Theory:

R.C. Duncan did interpretive and theoretical work on understanding the soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs). Much of this work was done in collaboration with scientists at NASA Marshall Space Flight Center in Huntsville, Alabama, and at a few other institutions. Collaborators include M. Feroci (CNR, Rome), E. Gögüs (NASA MSFC), A. Ibrhim (NASA GSFC), K. Hurley (Berkeley), C. Kouveliotou (MSFC), T. Strohmayer (GSFC), C. Thompson (N. Carolina, Chappell Hill) and P. Woods (MSFC).

The magnetar model, proposed in 1992 by Duncan and Thompson, holds that SGRs and AXPs are neutron stars with observable emissions powered via the dissipation of very strong magnetic fields. During 1999-2000, this model withstood several key tests and challenges. It is now the most widely accepted theory of SGRs and AXPs.

Duncan and his collaborators studied SGR and AXP spin-down histories, burst energy and duration distributions, quiescent X-ray emission light curves, spectra and variability, giant flare emissions, and post-burst afterglows. For all these phenomena, promising interpretations in the context of the magnetar scenario were proposed or developed. Analysis of the light curve of the 1998 August 27 giant flare gives evidence for strong high-order multipole components to the magnetic field of SGR 1900+14. Duncan proposed a new explanation for the “spin-down shift” in which the rotation period of SGR
1900+14 increased by 1 part in $10^4$ coincident with the 1998 August 27 event. This may be due to angular momentum loss in an Alfvén-wave wind that was driven out by toroidal oscillations in the crust of the magnetar which were excited by the giant flare.

P. Höflich developed algorithms and codes for massively parallel computers. The codes were specifically for 3-D radiation transport and for CO formation.

H. Martel, P. Premadi (Bandung Institute of Technology), R. Matzner (U. of 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 models, with various values of the density parameter $\Omega_0$, cosmological constant $\lambda_0$, Hubble constant $H_0$, and rms density fluctuation $\sigma_8$. This constitutes the largest cosmological parameter survey ever done in this field. These experiments provide statistics of the magnification, shear, and multiple imaging of distant sources. They intend to compare these statistics with available observations of lensed sources in order to determine or impose limits on the values of the cosmological parameters.

H. Martel started a collaboration with H. Eldad and T. Piran (Hebrew U.) and M. Lecar (Harvard). These authors have recently developed a void-finding algorithm for studying the properties of voids in the large-scale structure of the universe. They intend to apply this new tool through a combination of theoretical study and data analysis, testing the possibility of using voids as a robust cosmological indicator.

E. Vazquez-Semadeni and A. Gazol (UNAM), and J. Scalo investigated numerically the role of thermal instability (TI) as a generator of density structures in the interstellar medium (ISM), both by itself and in the context of a globally turbulent medium. With only TI operating, the condensation process is found to be highly dynamical and boundaries of clouds are accretion shocks, not static density discontinuities, and the clouds themselves are very fragile, suggesting that such configurations are highly unlikely. In the turbulent MHD case TI is found to be a second order effect in generating density fluctuations.

Scalo and P. Williams continued to develop a new model to explain the observed statistics and systematics of velocities, velocity dispersions (linewidths), and masses of interstellar “clouds.” The model is based on the intermittent arrival of impulsive energy inputs, due for example to shocks or nonlinear MHD waves, which generate cloud internal motions. During the time between these energy inputs, the internal motions decay by supersonic turbulent dissipation at some prescribed rate based on supersonic MHD simulations. They formulate a kinetic equation describing the probability distribution of cloud energies (i.e. linewidths) assuming a Markov process for the energy inputs, provide exact and approximate analytical solutions, and carry out a large number of Monte-Carlo simulations of the model. The predicted distribution of linewidths is compared with Bell Labs CO observations of a number of regions, and show how the form of this distribution can be used to infer the parameters of the model. Triggered star formation and cloud disruption will be included in future generalizations of the model.

Scalo and A. Biswas have studied the compressibility of a supersonic turbulent gas, using the result that in many situations this quantity can be estimated as the logarithmic derivative of the pressure with respect to the density in thermal equilibrium. The compressibility sets the probability of obtaining large densities, and hence star formation, during turbulent interactions. They evaluated the compressibility for a gas whose cooling is dominated by H2 and HD molecules, which is relevant to protogalactic objects at large redshift. The cooling rates are taken from recent quantum mechanical calculations and include collisions with all relevant species. The result is that protogalactic gas should be relatively "soft" for densities less than the critical value for which collisional de-excitation equals radiative de-excitation, but "hard" at larger densities, because of the changeover in the density dependence of the cooling rate at that density. They suggest that the critical density of the dominant coolant plays the same density-limiting role in all turbulent galaxies.

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. The ASPH method tested favorably by comparison with many other cosmological gas dynamics codes when applied in 3D to the simulation of X-ray cluster formation in the “Santa Barbara Cluster” comparison paper of Frenk et al. (1999, ApJ. 525, 554). Since then, they have revised and improved the ASPH algorithm in 3D, coupled it to a P2M gravity solver, and re-tested it against a battery of problems.

When density fluctuations collapse gravitationally out of the expanding cosmological background universe to form galaxies, the secondary energy release can affect their subsequent evolution. 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. As an idealized model of the effects of energy release by supernovae during galaxy formation, they considered an explosion at the center of a halo which forms at the intersection of filaments in the plane of a cosmological pancake. Such halos resemble the virialized objects found in N-body simulations in a CDM universe and, therefore, serve as a convenient, scale-free test-bed model for galaxy formation. Their simulations reveal that such explosions are anisotropic. The energy and metals are channeled into the low density regions, away from the pancake plane. The pancake remains essentially undisturbed. Infall quickly replenishes this ejected gas and gradually restores the gas fraction as the halo mass continues to grow.

Energy released by a small fraction of the baryons in the universe - which condensed out while the intergalactic medium (IGM) was cold, dark, and neutral - reheated and ionized the IGM before redshift 5. This exposed other baryons - already condensed into dwarf-galaxy minihalos - to the glare of ionizing radiation. The first gas dynamical simulations (including radiative transfer) of the photoevaporation of an intergalactic cloud overtaken by the ionization front which sweeps through the intergalactic medium when a quasar-like source turns on, were performed by P. Shapiro, A. Raga (UNAM), and G. Mellema (Stockholm Obs.). These results demonstrated the phenomena of ionization-front-trapping, the transition from R-type to D-type I-front with shock, a supersonic evaporative wind, and their observable consequences. Such hitherto neglected feedback effects were widespread during the reionization epoch.

These calculations were then generalized by Shapiro and Raga to the case of centrally concentrated minihalos in the Cold Dark Matter model, including stellar as well as quasar radiation sources. They were extended to the currently-favored ΛCDM universe by Shapiro, Raga, and I. Iliev. Shapiro, Martel, and Iliev used N-body simulations of halo formation in this ΛCDM model to show that these sub-kpc minihalos (with virial temperatures below 10^5K), which are photoevaporated by the I-fronts which reionized the universe, were so common during reionization as to dominate the absorption of ionizing photons. This means that previous estimates of the number of ionizing photons required per H atom in the universe to complete reionization which neglected this highly clumped, small-scale structure are serious underestimates.

The postcollapse structure of objects which form by gravitational condensation out of the expanding cosmological background universe is a key element in the theory of galaxy formation. Toward this end, P. Shapiro, I. Iliev, and A. Raga (UNAM) reconsidered the outcome of the nonlinear growth of a uniform, spherical density perturbation in an unperturbed background universe – the cosmological “top-hat” problem. They replaced the standard description of the postcollapse object as a uniform sphere in virial equilibrium by a more self-consistent one as a truncated, nonsingular, isothermal sphere (TIS) in virial and hydrostatic equilibrium, including for the first time a proper treatment of the finite-pressure boundary condition on the sphere. The results differed significantly from both the uniform sphere and the singular isothermal sphere approximations for the postcollapse objects. These results have a significant effect on a wide range of applications of the Press-Schechter and other semi-analytical models to cosmology. Following their initial derivation of the TIS model for an Einstein-de Sitter universe, Iliev and Shapiro generalized it to the case of a low-density background universe (Ω0 < 1), with and without a cosmological constant.

N-body simulations of the Cold Dark Matter (CDM) model yield singular halo density profiles in apparent conflict with halo profiles of dark-matter-dominated galaxies derived from observed rotation curves. The (TIS) model described above by P. Shapiro, I. Iliev, and A. Raga (UNAM) for the postcollapse equilibrium of cosmological halos reproduces many of the average properties of halos in CDM simulations. They can match the density
profile outside the central region while avoiding the problem of a steeply singular core. Iliev and Shapiro further showed that the TIS rotation curve is in excellent agreement with those observed. TIS 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 \( r_{\text{max}} = r_{\text{max}} \) relation analytically for the first time, with preference for the flat \( \Lambda \)CDM model.

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 Cold Dark Matter (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 the Hubble Space Telescope. A recent re-analysis of this cluster has 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 showed, however, 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.

Adaptive SPH and N-body simulations were carried out by M. Alvarez, P. Shapiro, and H. Martel to study the effect of gasdynamics on the structure of dark matter halos that result from the gravitational instability and fragmentation of cosmological pancakes. Such halos resemble those formed in a hierarchically clustering CDM universe and serve as a test-bed model for studying halo dynamics. With no gas, the density profile is close to the universal profile identified previously from N-body simulations of structure formation in CDM. When gas is included, the gas in the halo is approximately isothermal, and both the dark matter and the gas have singular central density profiles which are steeper than that of the dark matter with no gas. This result worsens the disagreement between observations of constant density cores in cosmological halos and the singular ones found in simulations. They also found that the dark matter velocity distribution is less isotropic than found by N-body simulations of CDM, because of the strongly filamentary substructure.

R. Benjamin (U. Wisconsin) and P. Shapiro calculated the time-dependent, nonequilibrium thermal and ionization history of gas cooling radiatively from \( T \approx 10^{8} \)K to \( T < 10^{4} \)K in a 1D, planar, steady flow model of the galactic fountain, including the effects of radiative transfer. They find that such a flow is capable of matching the UV absorption and emission lines observed from highly ionized species in our Galactic halo, provided that "self-ionization" - the photoionization feedback of radiation emitted by the flow on the flow itself - is included, and that gas stops cooling isobarically at some point in its evolution. A transverse magnetic field in the cooling flow would naturally produce this required non-isobaric cooling.

G. Shields, E. Agol (John Hopkins U.), and O. Blaes (UCSB) completed a study of physical processes that might contribute to the polarization rises seen in the Lyman continuum of some QSOs. Compton scattering of longer wavelength photons into the Lyman continuum by a hot disk wind or corona has difficulty giving a sufficiently sharp rise in polarization and especially in polarized flux. The same is true for polarization resulting from scattering of relativistic returning radiation by the disk atmosphere. The polarization rises continue to defy explanation.

J. C. Wheeler, I. Yi (Korean Institute for Advanced Study), P. Höflich, and L. Wang completed a study of the possibility of matter and radiation-dominating jets from newly formed neutrons stars and how they might induce asymmetric supernovae and gamma-ray bursts of various strength. Wheeler began a study of the induction of jets from neutron stars based on the winding up and axial expulsion of toroidal magnetic fields in analogy to processes thought to occur in accretion disks around black holes.

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

3.3.9 Astrometry:

The Hubble Space Telescope Astrometry Science Team is based at the University of Texas. Local members include G. Fritz Benedict (Deputy P.I.), B. McArthur, R. Duncombe (Aerospace Engineering), W. Jefferys (P.I.), and P. Shelus. Outside members are O. Franz (Lowell Obs.), W. van Altena (Yale), and L. Fredrick (U. Virginia). The team reduced and analyzed data bearing on parallaxes of astrophysically interesting objects (δ Cephei, RR Lyrae, Feige 24, the central star of the planetary nebula NGC 6853, and TV Col), and astrometry of low-mass M-dwarfs. All data are obtained with Fine Guidance Sensor 3 (FGS 3) on HST. FGS 3 produces parallaxes with better than 0.5 millisecond of arc precision.

The Team determined a parallax for the white dwarf - M dwarf interacting binary, Feige 24. The white dwarf (DA) component has an effective temperature, $T_{eff} \approx 60,000K$. The parallax precision ($\pi_{abs} = 14.6 \pm 0.4$ milliseconds of arc) narrows the range of possible radius values, compared to past estimates, yielding $R_{DA} = 0.0182 \pm 0.0014R_\odot$ with the temperature uncertainty the dominant contributor to the error. FGS photometry provides a light curve entirely consistent with reflection effects. A recently refined model Mass-Luminosity Relation for low mass stars provides a mass estimate for the M dwarf companion, $M_{DM} = 0.37 \pm 0.20 M_\odot$, where the mass range is due to metallicity and age uncertainties. Radial velocities from Vennes and Thorstensen provide a mass ratio from which $M_{DA} = 0.49^{+0.19}_{-0.05} M_\odot$ is obtained. Independently, this radius and recent log g determinations yield $0.44 < M_{DA} < 0.47 M_\odot$. Locating Feige 24 on an $M - R$ plane suggests a carbon core.

For the low-mass binary Wolf 1062 (=Gl 748) the Team (in collaboration with T. Henry, Georgia State U.) analyzed fringe scanning and fringe tracking astrometric data from FGS 3 and radial velocity data from two ground-based campaigns. The simultaneous solution resulted in parallax, proper motion and component masses for Wolf 1062 AB (component A, M3.5V). To derive the mass fraction, they related FGS 3 fringe scanning observations of the science target to a reference frame provided by fringe tracking observations of a surrounding star field. This approach resulted in an absolute parallax $\pi_{abs} = 98.1 \pm 0.4$ milliseconds of arc, yielding $M_A = 0.381 \pm 0.006 M_\odot$ and $M_B = 0.187 \pm 0.003 M_\odot$, component masses with a precision of 1.5%.

Benedict and McArthur (in collaboration with O. Franz, Lowell Observatory and T. Henry, Georgia State U.) continued an HST Guest Observer program of simultaneous transfer scan and position mode astrometry with FGS 3. They are obtaining precise orbits, parallaxes, and masses for close binary stars difficult or impossible to study from the ground. The first precise mass determinations from that program were for the low-mass binary system Gl 791.2A. Fourteen epochs of HST Guest Observer fringe tracking data spanning 1.7y provided a parallax ($\pi_{abs} = 113.1 \pm 0.3$ mas) and perturbation orbit. Contemporaneous fringe scanning observations yielded only three clear detections of the secondary on both interferometer axes. They provided a mean component magnitude difference, $\Delta V = 3.27 \pm 0.10$. The period ($P = 1.4731$ yr) from the perturbation orbit and the semi-major axis ($a = 0.963 \pm 0.007$ AU) from the measured component separations with the parallax provide a total system mass $M_A + M_B = 0.412 \pm 0.009 M_\odot$. Component masses are $M_A = 0.286 \pm 0.006 M_\odot$ and $M_B = 0.126 \pm 0.003 M_\odot$. Gl 791.2A and B are placed in a sparsely populated region of the lower main sequence mass-luminosity relation where they help define the relation because the masses have been determined to high accuracy, with errors of only 2%.

W. Jefferys is a member of the FAME (Full-sky Astrometric Mapping Explorer) science team and is investigating Bayesian approaches to the reduction of FAME data.

A COMPLEX Space Studies Board report on Near Earth Approaching Objects (NEO’s) stated, "The scientific goals of an NEO research program can be stated succinctly: to understand the orbital distribution, physical characteristics, composition, origin, and history of near-Earth objects". Further, the opportunity to do laboratory celestial mechanics is vast. NEO’s are in chaotic, planet-crossing
orbits, derived from fragments produced by collisions in the main asteroid belt. P. Shelus, J. Ries, E. Barker, and R. Ricklefes continue astrometric observations of these small 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 $S/N \sim 20$ for stellar objects. The objective is to obtain accurate positions of newly discovered and under-observed NEO's. 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. On average, they obtain 3 positions for 15-20 targets per night, at the end of which positions are electronically transmitted to the Minor Planet Center. To provide better and more positions, automatic frame registration and the USNO-A2.0 catalog are used to put the astrometric results on the ICRF. Further work is underway to produce a target magnitude determination and to totally automated the observing and measuring sequence.

3.3.10 Laser Ranging:

Personnel are Project Director P. Shelus, senior staff R. Ricklefes, J. Ries, and J. Wiant, observers K. Harned, M. Villarreal, and W. Williams, and part-time R. Green. A contract from GSFC continues more than 3 decades of observation and research for laser ranging in general and two grants from NASA Headquarters are specific to lunar laser ranging (LLR). They also have support from NSF for LLR. 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 the mountain top with the Hobby-Eberly Telescope. 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 from 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 a targeted reflector, and return to the ground station, effectively gives, very precisely, the distance between the station and the target. Comparing a series of measurements (more than 30 years of LLR data and more than 20 years of SLR data exist), science is performed in four broad areas: solar system ephemeris development, general relativity and gravitational physics, lunar science, and geodynamics. Research activity includes monitoring the exchange of angular momentum between the solid earth and atmosphere, the principal geopotential terms, plate tectonic activity, tidal dissipation in the lunar orbit, the lunar free libration, and the equivalence principle of general relativity. The MLRS site also hosts a GPS Turboguide receiver and serves as a fundamental site in a global geophysical network. It also serves as a fundamental node in the International GPS Service. The continuous meteorological data accumulated by the MLRS is part of an international meteorological data-base. In a service capacity they serve 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, they obtain millisecond accuracy estimates of the constant of precession, coefficients of nutation, polar motion, and Earth rotation. Finally, they are also cooperating 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.

3.3.11 Other:

The Hobby-Eberly Telescope Board became a partner in the Southern African Large Telescope (SALT) project. SALT is based on the design of the HET. HET is contributing the HET plans and the expertise of HET staff. In return, the HET Board receives a 10% SALT observing time share.

F. Bash of McDonald (Chairman, HET Board) and L. Ramsey (Penn State) represented the HET at SALT Board meetings. F. Bash also led the effort to reach agreement on legal issues between HET and SALT.

Transfer of HET design information to SALT continued throughout the year, and interaction between the HET and SALT staff members increased substantially during the year. The process of design transfer was led by P. Kelton, the designated liaison between HET and SALT. McDonald hosted visits to the HET site by SALT Project team members in October 1999 and March 2000, and a joint HET/SALT review meeting was held in Munich in
conjunction with the March 2000 SPIE meetings.

McDonald is also collaborating to help SAAO apply McDonald experience and expertise on public outreach to similar efforts associated with SALT and their collateral benefits plan. S. Preston of McDonald is leading this effort.

Senior McDonald administrative staff attended the SALT ground-breaking ceremony held at SAAO in Sutherland, South Africa on 1 September 2000. J. Booth and Kelton attended the SALT specification review meetings held after the ground-breaking, and Booth also consulted with the SALT team on various SALT engineering issues.

**PUBLICATIONS**


Bash, F. N. 1999, ”Origins of the Universe,” Discovery - Research and Scholarship at the University of Texas at Austin, 15, 6.


Clark, J. S., Miroshnichenko, A. S., Lariyov, V. M., Lyuty, V. M., Hynes, R. I., Pooley, G. G.,


Schneider, D. P., Hill, G. J., Fan, X., Ramsey, L. W., MacQueen, P. J., Weedman, D. W.,
Krzesinski, J., Pajdosz, G., Zola, S., Vauclair, G., Dolez, N. & Chevreton, M. 1999, Baltic Astronomy, 9, 211


