This report covers the period 1 September 1997–31 August 1998.

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 (see below) is substantially completed and is in the process of being commissioned.

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

1.2 Administration

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

1.3 Teaching and Research Personnel

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

Academic

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

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

Professors: Michel Breger (adjunct), James N. Douglas, Paul M. Harvey, Dan Jaffe, John Lacy, Paul Shapiro, Chris Sneden, Paul A. Vanden Bout (adjunct), Ethan Vishniac (on leave 1997-1998), 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
_HET Facilities Manager:_ John Glaspey
_Development Officer:_ Joel Barna

_Director of the McDonald Public Information Office:_ Sandra L. Preston.

_McDonald supervisors:_ Phil 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 (engineering support), and Jerry R. Wiart* (MLRS).

_Administrative Services Officer:_ Cecilio Martinez

1.5 Board of Visitors

George Christian was Chair of the McDonald Observatory and Department of Astronomy Board of Visitors, with Mark Bivins Vice Chair and Francis Wright Secretary.

1.6 Visitors and Affiliations

The _Antoinette de Vaucouleurs Centennial Lectureship in Astronomy_ was presented this year by Bohdan Paczynski. Dr. Paczynski was presented with the medal at a departmental colloquium. In addition, he presented a public talk on campus.

The following people visited the department for extended periods:

- Niel Brandt (Penn State Univ.)
- John Cowan (Univ. of Oklahoma)
- Arlin Crotts (Columbia Univ.)
- Andrea Ghez (Univ. of California at Los Angeles)
- Gerard Gilmore (Cambridge Univ.)
- James Graham (Univ. of California at Berkeley)
- Carole Haswell (Univ. Sussex)
- Robert Hynes (Univ. Sussex)
- Wolfram Kollatschny (Göttingen)
- John Kormendy (Univ. of Hawaii)
- Robert Kraft (Univ. of California at Santa Cruz)
- Kenneth Lanzetta (SUNY-Stony Brook)
- Alex Lazarian (Princeton)
- Chris McKee (Univ. of California at Berkeley)
- David Miktichian (Odessa State Univer-
sity, Ukraine)
- Bohdan Paczynski (Princeton)
- Alejandro Raga, (Univ. Nacional Autonoma
de Mexico)
- Francois Roddier (Univ. of Hawaii)
- Sergei Shandarin (Univ. of Kansas)
- Charles Steidel (Caltech)
- Josef Stein (Hebrew University of Jerusalem)
- Michael Strauss (Princeton)
- Nicholas Sunzef (Cerro Tololo Inter-American Observatory)
- David Tytler (Univ. of California at San Diego)
- Rogier Windhorst (Arizona State Univ.)


J. Craig Wheeler was a Visiting Scientist at the Institute for Theoretical Physics, University of California, Santa Barbara.

1.7 Awards, Honors, and Special Activities

The Department of Astronomy Staff Excellence Award went to Elizabeth Korves. The College of Natural Science Staff Excellence Award and the McDonald Observatory Staff Excellence Award went to George Barczak. The College of Natural Sciences Teaching Excellence Award went to Harriet Dinerstein.

Ed Barker served as Chair of the Division for Planetary Sciences of the AAS. Frank Bash is a councilor of the American Astronomical Society and is President-Elect of the Astronomical Society of the Pacific. G. Fritz Benedict served as the Vice-Chair of the AAS Division on Dynamical Astronomy. Judit Ries served her 3rd year on the Committee of the AAS Division on Dynamical Astronomy. Peter Shelus served his 20th year as treasurer of the AAS Division on Dynamical Astronomy. Anita Cochranc is a member of the US National Committee of the International Astronomical Union. She also completed her term as the AAS Division for Planetary Sciences Past-Chair.

Frank Bash is the member representative from the University of Texas at Austin to the Associated University for Research in Astronomy and he is a member of the AURA Coordinating Council of Observatory Research Directors which is composed of the directors of the larger optical/infrared observatories. He also serves on the AURA committee which is considering a 30–50 meter diameter
ground-based optical and infrared telescope.

Peter Shelus was elected as Lunar Laser Ranging Representative on the Directing Board of the International Laser Ranging Service.

J. Craig Wheeler was a member of the Board of Trustees for the Aspen Center for Physics.

Frank Bash chairs the Hobby-Eberly Telescope Board of Directors and is its representative on the Board of Directors of the Southern African Large Telescope.


Chris Sneden served as an External Program Reviewer for the University of Oklahoma, Physics & Astronomy Dept.


Chris Sneden is a Scientific Editor of the Astrophysical Journal. Larry Trafton is an Associate Editor of Icarus. Anita Cochran chaired the editor search committee for Icarus.


tems.” Beverley Wills served on the Scientific Organizing Committee for the meeting “Structure and Kinematics of Quasar Broad Line Regions”, held in Lincoln, NE, March 1998.

Mary Kay Hemenway served as an AAS Harlow Shapley Visiting Lecturer to Jackson State University and Tougaloo College in Jackson, MS and Holmes Community College in Goodman, MS, with additional talks given for the MS Science Partnership at area schools and planetarium in April 1998. G. Fritz Benedict served as a Shapley Visiting Lecturer to the University of Dallas, Dallas, TX.

R. Robert Robbins led an interdisciplinary group of college teachers on field trips into Mesoamerica on the study of archaeoastronomy.

Mary Kay Hemenway directed a three-week summer institute for teachers; the institute included a four-night observing run at McDonald Observatory in July. She also directed a three-week course for undergraduates in the College of Natural Sciences who are preparing to become secondary school teachers. A six-night observing run at McDonald Observatory was held for both these teachers and a similar group of students from UT-El Paso led by Verne Smith.

2 Academic and Educational Program

2.1 Graduate Program

The Graduate Studies Committee Chairman was Neal Evans with Graduate Advisor Edward Robinson. The Fred T. Goetting, Jr. Memorial Endowed Presidential Scholarship was awarded to Cynthia Froning. The David Alan Benfield Memorial Fellowship was awarded to Eric Klumpe. The Frank N. Edmonds, Jr. Memorial Fellowship was awarded to D. Andrew Howell.


Doctoral Dissertations: Three Ph.D. degrees in astronomy were awarded in 1997–1998:

Erik Gregersen “Collapse and Beyond: An Investigation of the Star Formation Process” (Neal
Evans, Chair). Dr. Gregersen is currently a post-Doc with C. Wilson at Caltech and McMaster University.

Wenbin Li “Star Formation and Astrochemistry in Peripheral Regions of Molecular Clouds” (Neal Evans, Chair). Dr. Li is currently working for Sun of Canada.

Vincent Woolf “Mercury Elemental and Isopic Abundances in Mercury-Manganese Stars” (David Lambert, Chair). Dr. Woolf is currently a post-Doc with D. Lambert at U. Texas at Austin.

*Master’s Theses*: Six Master’s degrees in astronomy were earned in 1997–1998:

Greg Dopmann “Coolspec: The Development of an IR Spectrograph for the McDonald Observatory 2.7M Telescope” (Chris Sneden/Dan Lester, Chairs).

D. Andrew Howell “An Abell Cluster Supernova Search” (Craig Wheeler, Chair).

Travis Metcalfe “Breeding the Best Fit Binary Star: Genetic-Algorithm-Based Optimization Applied to the W Uma Star BA Cas” (Ed Nather, Chair).

Christine Pulliam “Oxygen Abundances and Temperature Fluctuations in Planetary Nebulae” (Harriet Dinerstein, Chair).

Zhaohui Shang “Ring Structure and Warp of NCG 5907: Interaction with Dwarf Galaxies” (Bev Wills/Neal Evans, Chairs).

Wanglong Yu “Morphology of the Galactic Center” (John Lacy, Chair)

### 2.2 Undergraduate Program

Derek Wills was the chair of the Undergraduate Studies Committee; Bob Robbins served as undergraduate advisor. There were 32 astronomy majors this year and 2 students received BAs.

James Crawford was awarded the Outstanding Graduating Senior Award. Chris Laws was the winner of the Karl G. Henize Memorial Scholarship in Astronomy and was a Dean’s Honored Graduate in the College of Natural Sciences. Patrick Young was the winner of the Board of Visitors Undergraduate Scholarship in Astronomy.

### 2.3 Educational Services

The nine-inch refractor (directed by Feng Ma and Divas Sanwal) was visited by 1620 people during public tours, including thirteen special groups. Thirty-five school groups totaling over 835 elementary/secondary students and teachers participated in Solar Telescope field trips presented by Lara Eakins. Regular star parties attracted 425 people. Special lectures in astronomy had an attendance of 260. The SkyWatcher’s Report logged almost 3400 calls throughout the year. Eakins represented the Department at Austin Science Fun Day.

With the assistance of an NSF Instrument and Laboratory Improvement grant and a donation from a member of the McDonald Observatory and Department of Astronomy Board of Visitors, the mount and drive system for the 16-inch Undergraduate Telescope was replaced with one from Optomechanics Research.

As part of the EXES project (see instrumentation section), a group of 15 middle school and high school science teachers meet monthly to follow the development of the instrument and to learn about the scientific goals of the project.

### 2.4 Public Information Office

The daily StarDate radio program continues to broadcast to an audience of 5 million people on over 268 radio stations in the U.S. Universo, the Spanish-language version of StarDate, is the largest Spanish-language syndicated radio program in the U.S. It is heard by over 3 million people and broadcasts on 194 radio stations. Universo also broadcasts in Mexico, Venezuela, and Guatemala. Sternzeit, StarDate’s German counterpart, continues to broadcast on Deutschland Radio throughout Germany. The StarDate magazine continues to be very popular among radio listeners and others in the U.S. Over 15,000 readers subscribe to the magazine.

StarDate and Universo were also used by 1,054 teachers in the U.S. last year. On average each teacher shares the CDs and other materials with 100 students.

Hispanic Heritage Month programs were added to the programs produced by StarDate and Universo staff. Hispanic Heritage Month is a national celebration that takes place each year from September 15 to October 15. Pilot StarDate and Universo Hispanic Heritage Month programs were underwritten in 1997 by the American Honda Foundation. 1998 programs for Hispanic Heritage Month were made possible by Puerto Rico Space Grant, Texas Space Grant, the Texas statewide Systemic Initiative, and the McDonald Observatory and Department of Astronomy Board of Visitors. The programs were heard by over 9 million people.

The W. L. Moody, Jr. Visitors’ Information Center continued to serve more than 130,000 visitors. Fundraising is underway to build the Texas
Astronomy Education Center, which is an 11,000 square-foot expansion of the existing visitors’ center. Construction drawings are complete for the Texas Astronomy Education Center. Exhibits on spectroscopy are currently being designed for the new exhibit hall.

3 Research Program

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

There was significant progress on commissioning the 9.2 meter Hobby•Eberly Telescope (HET) during the past year. Work to complete construction of several HET subsystems proceeded in parallel with commissioning. HET infrastructure completed included the Mount Fowlkes utilities, five new houses for on-site HET employees, and the George T. Abell Gallery (GTAG) for visitors. The HET was dedicated on October 8, 1997, and the GTAG was dedicated on December 20, 1997. We anticipate that HET commissioning will continue until April 1999 and that research with HET using 50% of the available time will begin in spring 1999.

First spectrum with HET was achieved on September 5, 1997. This was the first end-to-end test of the HET, using the Upgraded Fiber Optic Echelle (UFOE) commissioning instrument provided by Penn. State and a two-element aluminum surrogate spherical aberration corrector (SAC). Construction of the production SAC optics had been long delayed, and they were finally completed in April 1998. The HET also first achieved its pointing specification in September 1997, i.e. to better than 30 arcseconds peak to peak.

A major effort went into testing, characterizing, and optimizing the performance of the 91-segment HET primary mirror and its associated mechanical support system, electronic controls, and software. The primary mirror segment construction and coating contracts were completed and the major parts for the primary mirror cover were also completed. Development of techniques for aligning segments in tip, tilt, and piston and for maintaining alignment under changing thermal conditions was a major focus of the primary mirror effort. Development of segment alignment maintenance techniques has proven to be a significant challenge. As of September 1998, we are routinely aligning 66 mirrors in 8 minutes to a median EE(50) of 1.1 arcsec, which gives a 7–8 meter aperture. We expect to routinely align all 91 segments by spring 1999, giving the full 9.2-m aperture for early science operations, and with improved image quality as the commissioning effort continues to improve the alignment accuracy as we move toward reaching full specification.

The production SAC optics were successfully tested on the HET in August 1998 in the Prime Focus Instrument Platform (PFIP) instrumentation. Construction of PFIP was another major task during the year. PFIP incorporates the top end subsystems for acquisition and guiding, fiber handling, support for the Low Resolution Spectrometer now nearing completion, and other auxiliary subsystems such as the cooling system. The SAC performance was judged to be acceptable to the level tested thus far, hence one of the HET’s major risk areas has now been overcome.

Major progress was also made on the HET software, including PFIP, mirror control, tracking, autoguiding, user interfaces, subsystem integration, and science operations for planning and scheduling observations. Many improvements to reliability and efficiency were also achieved.

Steady progress was also made on the three initial HET facility instruments: the Low Resolution Spectrometer (LRS, Gary Hill, U. T. McDonald Observatory, P.I.); the High Resolution Spectrometer (HRS, Bob Tull, U.T. McDonald Observatory, P.I.); and the Medium Resolution Spectrometer (MRS, Larry Ramsey, Penn State, P.I.). Installation and commissioning of these instruments at the HET will begin in late 1998. Progress reports on these instruments can be found in the proceedings of the March 1998 SPIE meetings in Kona. Details on a number of other key HET subsystems can also be found in the Kona SPIE proceedings, including the primary mirror development, the tracker development, and science planning software. Consult the publication list for specific references.

We anticipate that HET will be available to the national community about one year after early science operations begin in spring 1999, after commissioning of the HRS and MRS instruments (both partially funded by the National Science Foundation under the Facility Instrument Program).

New staff who joined the HET Operations team during the year were François Piché (optical engineer) and Matthew Shetrone (Resident Astronomer). John Glaspey (Facility Manager) left his position as HET Facility Manager on August 31 and McDonald Superintendent Mark Adams took on the role of Facility Manager ad interim until a new HET Facility Manager has been recruited. Mechanical Engineer
3.3 Scientific Results

3.3.1 Instrumentation:

A. Hatzes in collaboration with C. Johns-Krull (UC Berkeley) and J. Valenti (NOAO) have installed a Zeeman analyzer for use at the 2douche spectrometer at McDonald Observatory’s 2.7-m telescope. This instrument is capable of measuring the circular polarization (left and right) in spectral lines at a resolving power of 60,000 or 200,000.

A. Hatzes and G. Wesley completed installation of the new slit assembly for the Sandiford Cassegrain Echelle Spectrometer. This new assembly consists of highly reflective slit apertures mounted on a rotating wheel. The new slits now enable Sandiford users to guide on objects as faint as 15th magnitude.

Work continued by R. Tull and colleagues toward completion of HRS, the fiber-coupled high resolution spectrometer for the HET, with funding provided by NSF and by private gifts, a State of Texas appropriation, a NASA grant, and University of Texas matching funds. Milestones include manufacture of the cells for the R4 mosaic echelle and for the collimator mirrors. Installation is now projected for spring, 1999, following delays due to slow delivery of CaF$_2$ for the Epps-designed camera lenses.

Gary Hill continued development of the HET Low Resolution Spectrograph. This instrument is an imaging grism spectrograph with multi-object capability that will cover 360–1000 nm with a future extension to 1350 nm. Resolutions between R=500 and 3000 will be available; the instrument images the 4 arcmin field of view of the HET. P. MacQueen is developing the CCD system for the LRS, which is expected to see first light at the end of 1998.

J. Lacy, M. Richter, W. Yu, and B. Basso are continuing their work on a very high resolution mid-infrared spectrograph using an echelon as the primary disperser and an echelle as a cross disperser (TEXES). They have given up attempting to hand-assemble the 1-m long echelon from 100 diamond-machined aluminum facets, but have identified a vendor, Hyperfine, Inc., capable of manufacturing it from a single bar of aluminum. The echelon is being made, and first telescope tests of the instrument are expected early in 1999. The instrument will have various spectroscopic modes, with resolving power ranging over 4000–100,000 at wavelengths of 5-25 μm.

J. Lacy, M. Richter D. Jaffe and M. K. Hemen-
way began working on the Echelon-cross-echelle spectrograph (EXES). EXES, a 5-25 $\mu$m spectrograph with resolving power up to $10^5$, is a PI-class first-light instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA). EXES had a successful preliminary design review in August 1998. The instrument is expected to be done before the end of 2001.

F. Piché joined the HET operations team, in November 1997, as opto-mechanical engineer. He proceeded in making a thorough evaluation of the mirror array alignment procedure. This work includes evaluation of the center of curvature alignment system performance, characterization of the mirror support system mechanical behavior, and development of a coarse alignment procedure with Grant Hill.

3.3.2 Extrasolar Planetary Systems:

A. Hatzes and W. Cochran resolved the controversy surrounding the purported spectral variability of 51 Peg. They obtained a series of high signal-to-noise ratio, high resolution spectral data ($R=200,000$) using the 2dcoudé spectrometer of the 2.7-m telescope at McDonald Observatory. These data spanned a complete rotation period of the planetary companion first reported by Mayor and Queloz and their analysis showed no spectral variability to a level of 1 m/s in the line bisector velocity span and 3 m/s in the velocity bisector curvature. These lack of variations contradicted the findings reported by David Gray and firmly established that the radial velocity variability in this star is due to a planetary companion.

The McDonald Observatory Planetary Search program, operated by W. Cochran and A. Hatzes, has continued on the McDonald 2.7-m telescope. The program has now been shifted to the 2dcoudé spectrometer, and has expanded to over 100 target stars. In collaboration with M. Kürster (ESO), K. Dennerl, and S. Döbereiner (MPI Garching), a companion southern-hemisphere survey has continued operation. The ESO survey uses an $I_2$ absorption cell at the 1.4m CAT. In addition, W. Cochran and A. Hatzes have continued observations using the Keck I telescope on a high precision radial velocity survey to search for planetary-mass companions to Hyades dwarfs.

A. Schultz (STScI) and collaborators, including G. F. Benedict, reported on HST observations that provide possible evidence for a companion to Proxima Centauri (Gl 551). Data acquired with the FOS, used as a coronagraphic camera, showed excess light that can be interpreted as being from a substellar object within 0.5" of Proxima Cen. Two observations of Proxima Cen separated by 103 days indicate a point source (or a feature) superposed on the wing of the point-spread function in the FOS images. This feature moves relative to the aperture, and on the plane of the sky. Comparisons with other FOS images of stars acquired using the coronagraphic mode reveal no comparable features or evidence that this feature can be explained by any instrumental anomaly, although Proxima Cen is by far the brightest target observed in this mode. If this feature denotes a companion to Proxima Cen, it has an apparent separation corresponding to $\sim 0.5$ AU at Proxima Cen and is $\sim 7$ mag fainter than Proxima Cen in the bandpass of the FOS red detector. The small apparent separation could result from a highly eccentric orbit, which could project a close companion. Alternately, the small separation could imply a short ($\sim 1$ yr) period. Further coronagraphic observations, using the HST NICMOS, are being obtained to verify this tentative result. The inferred companion is inconsistent with the FGS astrometry, unless the object has an extraordinarily low mass-to-light ratio or an orbit with orientation pointed right down our line of sight, or really is an unmodeled internal reflection within HST.

The HST Astrometry Science Team continued to monitor the nearby stars Proxima Centauri and binary L726-8AB for low-mass companions. They now have a valid Lateral Color calibration for FGS 3. After removing that effect and proper motion and parallax signatures, they derive detection limits for a companion to Proxima Cen of from one down to 0.18 Jupiter mass for periods ranging 50 to 600 days.

3.3.3 Solar System:

W. Cochran and A. Cochran analyzed high resolution spectra of the 9300Å region in the atmosphere of Jupiter. This spectral region is in the middle of the strong $\rho$ band of H$_2$O; it has been suggested that a possible very weak absorption in Jupiter might be due to Jovian H$_2$O. The new spectra do, indeed, reveal the presence of a Jovian absorption band. However, this band is not due to H$_2$O, but rather is most likely due to NH$_3$.

and H₂ upper atmospheric and auroral emissions. These observations show a weak rotational phase variation indicating that the auroral component is weaker than the atmospheric/ionspheric component of the emission. This is unlike Jupiter. They also show a longer term variation which is not yet understood. The H₂ emissions arise from the high temperature of Uranus’ upper atmosphere, which transitions into a hot H corona. The H₃⁺ emissions are enhanced by a low homopause relative to the other major planets, which prevents the chemical destruction of H₃⁺ by hydrocarbons. Variations in the rotational temperature of H₂ and the rotational-vibrational temperature of H₃⁺ were measured; variations along the central meridian for both species were modeled. They found that the H₂ emissions can be explained by a hot, elevated, emitting shell around the planet but the H₃⁺ emissions are far more concentrated towards the center of the disk, suggesting primarily solar excitation.

Working with E. Barker and Y. Sheffer, L. Trafton observed eclipses of the Galilean satellites by Io during the 1997 series of mutual events. These occur every six years when the Sun and Earth pass through Jupiter’s equatorial plane. The eclipses were observed in the light of the Na D lines with the objective of determining the distribution of Na in Io’s corona at a distance from Io which cannot be observed by direct observation due to Io’s brightness and twinkling. Measurement of the Na scale height in the collisional regime of the extended atmosphere is expected to reveal the source regions on Io for the Na, and perhaps the presence of any other major atmospheric gas besides SO₂.

With S. Miller (UCL), L. Trafton obtained near-IR images of Uranus’ H₂ and H₃⁺ emissions with NSFCam at the IRTF in July. These supplement the earlier spectral observations by revealing the detailed distribution of the excited species over and beyond the planetary disk. This will be diagnostic of the excitation processes — solar EUV vs atmospheric heating vs auroral precipitation.

A. Cochran and F. Vilas (NASA JSC) observed Vesta during a complete rotational cycle in order to study the 5060Å pyroxene feature on its surface. They found that the equivalent width of this feature varied by 20% as a function of rotational phase, but the band position did not shift. This led to the conclusion that there is a single type of pyroxene on the surface, but that some other material may be mixed with it. The equivalent width of the pyroxene feature correlates well with the HST maps of the surface topography, with the weakest features being at a region of maximum topographical relief.

D. Boice (SwRI), C. Laffont (Obs. de Besançon), along with A. Cochran and E. Barker, analyzed high resolution spectra of comet Hale-Bopp to determine the connection between CH production and dust. Based on Halley ion mass spectrometer observations, it was thought likely that a significant parent of CH would be dust. Thus, one would expect a correlation of the dust in the coma and the CH line strengths. The Hale-Bopp observations show no such correlation exists. In fact, there may be an anti-correlation. Thus, dust is unlikely to be a significant source for CH.

M. Combi (U. Michigan), along with A. Cochran, W. Cochran, D. Lambert and C. Johns-Krull (UC Berkeley) completed their study of line widths in comet Hyakutake. High spectral resolving power (R=180,000) observations of Hyakutake were modeled with a hybrid kinetic/hydrodynamic and Monte Carlo model to determine the velocity structure of the inner coma. The data are consistent with the expansion of a water-dominated coma, with a significant exothermic component to the O (1D) line width. The H α line width is consistent with production by dissociation by H₂O and OH and partial thermalization.

E. Barker, A. Cochran and W. Cochran analyzed very-high spectral resolution observations of the neutral Na emission within the inner coma of Comet Hale-Bopp. Asymmetric Na D line profiles implied both an in situ, or core, Na source, as well as a secondary Na source at locations within the inner coma. The FWHM of the core velocity distribution of the Na emission was ±2km s⁻¹. The extended source velocity dispersion increased with distance from the nucleus (up to ~6 km s⁻¹), but appeared smaller in the more dusty regions (~2.5-3.0 km s⁻¹) of the inner coma. The D₂/D₁ line strength ratio was consistent with an optically thin inner coma. The core emission profile comes from Na atoms being locally released in the region sampled by the spectrograph slit, either from the nucleus or from an extended source within the inner coma. The velocity dispersion of the secondary emission increases with radial distance, as it would if additional Na atoms were being produced and entrained in the antisolar flow of Na atoms being accelerated by solar radiation pressure. The extended source within the coma is probably linked to the dust since the core line profiles tend to be stronger and narrower in the dustier regions.
A. Cochran, along with H. Levison, P. Tamblyn, S. A. Stern (SwRI) and M. Duncan (Queens U. Canada) recalibrated the HST cycle 4 Kuiper belt search data and demonstrated that it was indeed possible to detect objects of \( V = 28.4 \) with these data. They showed that their reduction process varied significantly from that of Brown et al. (1997, ApJ490, L119) who contended that false detections would overwhelm the signal from faint objects.

E. Barker, in collaboration with A. Sprague and D. Hunten (LPL) developed uniform data reduction and analysis procedures to put their respective high-dispersion CCD observations on a common basis. The two groups are in the process of reanalyzing their observational data sets obtained during the 1993–4, 1995, and 1996–7 Martian apparitions to provide more complete and uniform measurements of the seasonal, diurnal and temporal behavior of the Martian water vapor cycle. To improve the compatability of the ground-based datasets, they used: (1) HITRAN 96 lines strengths for the (211) \( \text{H}_2\text{O} \) band. These are 20–40\% stronger than those used previously; (2) the Mars GCM to predict the effective atmospheric temperature for each \( \lambda_s \) and sampled Martian latitude and longitude; (3) and common definitions seeing disk size and airmass for each sampled region of the Martian disk. Using these new procedures, the McDonald Observatory dataset for the 1996–7 apparition shows spatial variations of 4–5\times or more in the the water vapor abundance to be present on the disk at all seasons. Nominal amounts up to 25\( \mu \)m of ppt. \( \text{H}_2\text{O} \) were seen at higher northern latitudes (50° to 70°N) with barely detectable amounts (\( \sim 2 \mu m \)) present at southern latitudes (0° to -30°S). Small amounts (2-5\( \mu \)m) were seen above the morning and evening terminators, with the diurnal maximum at a sampled latitude occurring 1 to 2 hours after local noon. Ground-based measurements showed 11.6±1.0\( \mu \)m above the Pathfinder site on July 5, 1997. Evidence is seen for spatial variations in the abundance that are not controlled by normal seasonal and diurnal insolation.

3.3.4 Stars and Stellar Systems, Stellar Ejecta:

A collaboration of E. Luck (Case Western Reserve Univ.), T. Moffett (Purdue Univ.), T. Barnes and W. Gieren (Univ. of Concepcion, Chile) determined abundances for 12 Magellanic Cloud Cepheids using spectra from the 4-m Blanco Telescope at CTIO. This work nearly doubled the number of Cepheids with spectroscopic abundances in the SMC and tripled the number in the LMC. By comparing with abundances determined for 11 Galactic supergiants, they showed that the SMC has a small intrinsic range in \([\text{Fe/H}]\) about the mean value of \(-0.68\) and that the LMC has a negligible cosmic dispersion about the mean of \(-0.34\).

E. Robinson, I. Evans and W. Welsh are analyzing high-resolution spectroscopy of CI Cam. After their discovery of the optical counterpart of this very unusual X-ray transient using the PFC at McDonald, their ongoing spectroscopic study has revealed substantial changes in the line profiles of the immensely strong Balmer, \( \text{He} \) and \( \text{Fe} \) II emission lines. Several kinematically and thermally distinct shells have been found.

D. Sanwal, E. Robinson and R. Stiening (Univ. Mass, Amherst) have obtained multicolor optical photometry of the Crab pulsar with 1 microsecond time resolution. The color variation during the pulse light curve is small and the pulsar has faded by about 4\% since the observations in 1992.

C. Sneden, R. Kraft (UCSC), and collaborators are deriving light element abundances from echelle spectra of large stellar samples (typically \( \geq 10 \)) on the upper red giant branches (\( \text{RGB} \)s) of globular clusters spanning the metallicity range \(-0.8 \geq [\text{Fe/H}] \geq -2.3 \). They find that very large star-to-star variations of the light elements \( \text{C, N, O, Na, Mg, and Al} \) occur in many globular clusters, and there are positive correlations among \( \text{N, Na, and Al} \) abundances, all of which are anticorrelated in some way with the \( \text{C, O, and Mg} \) abundances. This suggests strongly that at some time(s), in some place(s) in cluster evolution, advanced proton captures have reshuffled substantial numbers of light element abundances via \( \text{C,O→N, Ne→Na, and Mg→Al} \) synthesis chains.

R. Kraft (UCSC), C. Sneden, G. Smith, M. Shetrone and J. Fulbright (UCSC) have determined the chemical compositions of six giant stars of the outer halo globular cluster NGC 7006 ([\text{Fe/H}] \sim -1.5); this cluster exhibits only very mild star-to-star abundances differences in the light elements. I. Evans, Sneden, Kraft, V. Smith (UTEP), N. Suntzeff (CTIO), and E. Langer (Colorado College) have analysed the “CN-bimodal” globular cluster M4, the closest cluster to the Sun, using high resolution echelle spectra obtained for 20 giant stars. The same abundance positive and negative correlations among the light elements are found in M4 as in other clusters. All of the M4 stars also show extremely low carbon isotope ratios, indicating that
the onset of the mixing of CNO-cycled material occurs at a luminosity lower than that of the observed stars. Some elemental abundances, such as aluminum and barium, show uniform enhancements indicative of primordial enrichment of the gas out of which the present stars formed. The analysis also confirmed previously reported anomalous absorption properties of the dust along the line of sight to M4 that deviate from the normal law of interstellar extinction. Langer, D. Fischer (UCSC), Sneden, and M. Bolte (UCSC) have demonstrated that one M92 red giant has a significantly higher metallicity ($\delta[\text{Fe/H}] = +0.17$) than other stars of similar color and luminosity; this is one of the clearest demonstrations of star-to-star metallicity variations in ordinary globular clusters.

J. Crawford, C. Sneden, J. King (STScI), C. Deliyannis (Indiana), and A. Boesgaard (Hawaii) have detected the resonance lines of the element silver in four metal-poor stars, using Keck HIRES spectra obtained for other purposes. This is the first-ever detection of silver in metal-poor stars. The derived relative abundances are slightly greater than solar ([Ag/Fe] $\simeq +0.2$), and are consistent with the overabundances of heavier neutron-capture elements in these stars.

C. Sneden, J. Johnson, M. Bolte and G. Smith (UCSC) have obtained blue spectral region high resolution data for four M15 giant stars. Inspection of these spectra reveals the same star-to-star neutron-capture abundance variation that was suspected from previous data that we obtained in the red spectral region. Additionally, the 4019Å transition of ionized thorium is detectable. This will enable the derivation of an age estimate for these stars that is independent of color-magnitude diagram arguments.

C. Sneden, R. Gratton and E. Carretta (Padua Obs.), and G. Clementini (Bologna Obs.) have determined accurate stellar parameters and metallicities of nearly 100 dwarf stars with HIPPARCOS parallaxes. Careful screening for double stars was undertaken, and the overall metallicity scale was linked to literature abundance scales. A significant result is that departures from LTE in the ionization equilibria must be extremely small.

H. Rocha-Pinto (IAG, Brazil), W. Maciel (IAG, Brazil), J. Scalo, and C. Flynn (Tuorla Obs., Finland) 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 metalicities from $\text{uvby}$ data and parallaxes and proper motions from HIPPARCOS. These stars, while currently nearby, have birthsites 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 corrections, stellar evolutionary corrections, and volume corrections. They found 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 showed 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 compared with estimated epochs of close encounters with the Magellanic Clouds.

A. Hatzes and A. Kanaan, in collaboration with D. Mkrtichian (Odessa State University, Ukraine) began a program to use precise stellar radial velocity measurements to study the pulsations in rapidly oscillating Ap stars ($\text{roAp}$). These objects pulsate in low-degree nonradial modes with periods of a 4-15 minutes. So far they have detected radial velocity variations in 5 roAp stars. This work has established that the radial velocity pulsational amplitude depends on both the atomic species as well as the line strength, with weaker lines exhibiting a pulsational amplitude that is 10-100 times smaller than for strong lines. They are currently investigating whether the inhomogeneous surface distribution of elements that occur on these stars can be used as spatial filters to detect high degree ($\ell > 4$) pulsation modes that are inaccessible from photometric measurements.

E. Robinson continues to lead a research team investigating interacting binaries and compact objects. A long-term study of the soft X-ray transients is underway. Robinson and Young discovered giant, repeating optical flares in Aql X-1. Robinson, Welsh and Young are now investigating the ellipsoidal variations in Aql X-1, GS2000+25 and J0422+32.

W. Welsh continued his research on cataclysmic variables. Using high-speed spectrophotometry, Welsh, K. Horne (St. Andrews Univ.) and R. Gomer (Rice Univ.) studied the Hα flaring in AE Aquarii, and proposed a variant of the propeller model to explain AQ Aqr's peculiar behavior. Welsh, W. Skidmore and J. Wood (Keele Univ.) continued their investigation of the rapid oscilla-
tions in WZ Sge. Along with E. Sion and F.-H. Cheng (Villanova), they discovered the UV counterpart of the 28s optical oscillations, and showed that the oscillations must originate on the surface of the white dwarf.

C. Froning is continuing near-infrared observations of compact binary objects. Results of the first near-infrared map of an accretion disk in the dwarf nova IP Peg were presented at the 2nd Magnetic Cataclysmic Variables Workshop in Annapolis, MD. Froning has also completed a six-month series of observations of the unusual X-ray binary SS 433 using the near-infrared spectrometer, Coolspec, at McDonald Observatory. The J-, H-, and K-band spectra cover a full precession cycle in SS 433 and measure the variations in the NIR spectral lines as the viewing aspect of the accretion disk changes.

The Zeeman analyzer (described in section 3.3.1) was used by A. Hatzes, C. Johns-Krull (UC Berkeley) and J. Valenti (NOAO) to detect circular polarization in the emission lines of the T Tauri star BP Tau. This polarization was not seen in the stellar photospheric lines, indicating that it arises near the accretion disk of the star.

T. Moffett (Purdue Univ.), W. Gieren (Univ. of Concepcion, Chile), T. Barnes and M. Gomez (Univ. Catolica, Chile) completed their photometric study of Cepheids in the Magellanic Clouds. They have published light curves in BVRI for 22 Cepheids with a median of 46 measures per star in each bandpass. The typical uncertainty is 0.01 mag.

W. Gieren (Univ. of Concepcion, Chile), T. Moffett (Purdue Univ.) and T. Barnes have completed a study of the Cepheid period-radius relation using the aforementioned photometric data for Magellanic Cloud variables. The surface-brightness (B-W) method was used to establish radii for 16 long-period Cepheids. When these results are used to extend the previously established period-radius relation for Galactic Cepheids to longer period, they show that the PR relation remains linear with small dispersion up to the long pulsation periods.

G. F. Benedict and co-workers, while carrying out astrometric monitoring of Proxima Centauri (a known flare star, V 645 Cen) for planetary mass companions with HST FGS 3, obtained photometry and astrometry for several significant and several minor flare events. For one major flare that produced a Delta V ~ -0.6, time-resolved astrometry (effective 1 Hz rate) indicates a detonation at a distance 5.2 ± 2.4 stellar radii from the center of Proxima Cen.

G. F. Benedict and co-workers have completed analysis of photometry of Proxima Centauri and Barnard's Star (obtained with HST FGS3) to search for periodic variations. Proxima Cen exhibits small-amplitude, periodic photometric variations. Once several sources of systematic photometric error are corrected, they obtain 2 millimag internal photometric precision. They identify two distinct behavior modes over the past 4 years: higher amplitude, longer period and smaller amplitude, shorter period. Within the errors, one period (P ~ 83 days) is twice the other. Barnard’s star shows very weak evidence for periodicity on a timescale of approximately 130 days. If they interpret these periodic phenomena as rotational modulation of starspots, they identify three discrete spots on Proxima Cen and possibly one spot on Barnard’s star. They find that the disturbances change significantly on timescales as short as one rotation period.

G. F. Benedict, along with A. Hatzes, O. Franz (Lowell Observatory), and T. Henry (Harvard-SAO) has continued a program of radial velocity measurements of low-mass binary stars. These data, once combined with HST astrometry, will permit a full, three-dimensional characterization of the orbits, and very precise determination of masses and mass-ratios for these objects. The primary goal is to firm-up the lower main sequence mass-luminosity relationship. The secondary goal is to sift for additional low-mass companions. A tertiary goal is to obtain dynamical parallaxes with which to resolve possible discrepancies between HIPPARCOS and HST parallaxes.

L. Wang and J. C. Wheeler continued their program of routine spectropolarimetry of all accessible supernovae. They have now nearly tripled the sample of supernovae with polarimetry data compared to that available at the beginning of this effort. They still find that core collapse supernovae (SN II, SN Ib/c) are polarized at the 1% level and SN Ia much less so in general. They have found an exception, however: SN Ia 1997bp is polarized at about the 1% level. SN Ic 1997C had an especially high polarization, several percent. This suggests that the asymmetry may be directly related to an asymmetric mechanism of core collapse. They have also compiled a large data set on new supernovae that resemble SN 1983J and on SN 1988S, which was a Type IIb with prominent narrow emission lines.

The McDonald Observatory Supernova Search
team continued the search for supernovae in Abell clusters with the prime focus camera on the 0.76-

m telescope at McDonald Observatory. The goals are to study the systematic effects of supernova
with redshift and to directly check the results of Lauer and Postman for the orientation of the velocity
dipole of distant matter by using SN Ia in the Lauer and Postman Abell clusters to determine dis-
tances to the clusters and deviations from the Hubble flow. Their first supernova, SN 1997cq, proved
to be a peculiar narrow-emission line SN II. The second supernova, SN 1997ea, was a normal SN Ia.

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

With collaborators D. Garnett (Un. Minnesota, now at U. Arizona) and graduate student C. Pulliam, H. Dinerstein continued an investigation of weak optical O II recombination lines in planetary
nebulae. By using these recombination lines to determine oxygen abundances, one avoids serious un-
certainties that arise from our incomplete knowledge of the temperature structure in ionized nebulae
when using collisionally-excited forbidden lines of [O III]. Thus, in principle the recombination line
method offers a more accurate way of measuring O/H. They find that for some of our sample of
10 nebulae the recombination line abundances are in good agreement with the forbidden-line values,
while for others the recombination line strengths appear to be enhanced by up to factors of 3–5. Fur-
thermore, this enhancement is selective, occurring more strongly for certain transitions than for oth-
ers, with a pattern similar to that seen in the Orion

H II region by Esteban et al. (1998, MNRAS 295, 401). By examining the larger sample of nebulae, however, they may find clues to the nature of the process responsible for enhancing the line strengths.

H. Dinerstein, with collaborators L. Likkel and A. Kindt (U. Wisc.-Eau Claire) and D. Lester, has
begun a new study of the near-infrared H2 emission from planetary nebulae. When excited by the
UV fluorescence process, as for the planetary nebula

Hubble 12 (Dinerstein et al. 1988, ApJ, 335, L23), these lines trace the photodissociation zone
of warm, atomic material adjacent to the ionized gas. In other planetary nebulae, the H2 line ra-
tios suggest thermal excitation, as in shocked gas. Our current knowledge of how prevalent H2 emis-
sion is among planetary nebulae in general, and to what extent each of the excitation mechanisms
is contributing, is very incomplete. Other lines of
evidence, ranging from the ubiquity of circumstel-
lar Na I absorption features (Dinerstein, Sneden,
& Uglum 1995, ApJ, 447, 262) to the presence of strong emission in far-infrared lines of [O I] and [C II], imply that massive neutral envelopes are com-
mon in planetary nebulae. The study of H2 emis-

ion using CoolSpec, McDonald Observatory’s new
long-slit near-infrared spectrometer, will help estab-
lish the properties of these envelopes and their role
in the final major mass-loss event in the lives of
moderate-mass stars.

M. Miesch (NASA Goddard), J. Scalo, and J.
Bally (JILA) have studied the probability density
functions (pdfs) of molecular line centroid velocity
fluctuations, and of line centroid velocity fluctua-
tion differences at different spatial lags, for several
nearby molecular clouds with active internal star
formation. The data consist of over 75,000 12CO
line profiles divided between twelve spatially and/or
kinematically distinct regions, and the pdfs are con-
structed using three different types of statistical esti-
mators. Although three regions (all in Mon R2)
exclude nearly Gaussian centroid pdfs, the other re-
gions 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 neu-

tral HI component of the ISM was also presented,

based on older published data for optical absorption
lines and HI emission and absorption lines. Spatial
images of the centroid velocity differences showed
that the regions of largest velocity difference are
“spotty,” with no indication of the filamentary ap-
pearance predicted by turbulence decay simulations
dominated by vortical interactions. They conclude
that turbulence in both molecular and diffuse HI

regions involves physical processes which are not
adequately captured by incompressible turbulence
or by mildly supersonic decay simulations, contrary
to some previous claims.

J. Lacy, J. Scalo, and M. Richter are exploring
alternative models to explain blue line asymmetries
seen in molecular clouds which do not require gravi-
tational collapse. Double-peaked optically thick
molecular line profiles with a blue asymmetry, com-
bined with single-peaked optically thin lines along
the same lines of sight have previously been inter-
pred in terms of gravitational collapse. It was
shown that it is possible to obtain such profiles us-

ing a general velocity field with correlated fluctu-
ations. The major assumption is that line excita-
tion increases in regions of convergent flows. A sim-
ple model with a fractional Brownian noise velocity field was used as an illustration. The dependence of the frequency distribution of line profile skewness on the exponent of the fractional Brownian noise was investigated. Comparison with line profiles taken through two-dimensional simulations of driven self-gravitating MHD turbulence will be used to understand the contribution of various physical effects to the predicted shapes of the profiles.

3.3.6 Extragalactic:

As a member of the ISO Key Project Team on the ISM of Normal Galaxies, H. Dinerstein has been active in the team’s program of observing far-infrared emission lines in a sample of about 70 galaxies with diverse morphological types, dust content, and luminosities. The observed lines include the major cooling lines of the warm atomic gas that is a major component of the global interstellar medium in galaxies. The team’s survey of integrated line fluxes from a large number of galaxies confirms, and extends to lower levels of star-formation activity, a trend seen in very IR-luminous galaxies: the strength of the [C II] 158 μm line relative to the far-infrared dust continuum decreases as the UV radiation field intensifies (Malhotra et al. 1997, ApJ, 491, L27). The most likely cause for this trend is the decreased efficiency of grain photoelectric heating at high UV-field strengths due to the build-up of charge on the grains. Additionally, the line strength ratios of [O I] 63 μm/[C II] suggests that the gas density in the star-forming regions within these galaxies also increases with increasing UV field strength. Far-infrared lines arising from the ionized phases, such as [N II] 122 μm and [O III] 88 μm, were also measured in some of the galaxies. The team will make use of optical spectra of the brightest H II regions in each galaxy, obtained at McDonald Observatory by Dinerstein and C. Pulliam, and at Lowell Observatory by D. Hunter (Lowell Obs.), to help interpret the lines observed with ISO.

J. D. P. Kenney (Yale), Benedict, and D. Friedli (Obs. de Geneva) collaborated on modeling the HST UBVI and H-alpha images of the circumnuclear region of the barred spiral galaxy NGC 4314 (http://oposite.stsci.edu/pubinfo/pr/1998/21/) obtained by Benedict and the Astrometry Science Team. These images show a narrow star-forming ring filled with young star clusters, an embedded nuclear bar, and surrounding spiral arms, all embedded deep within a large-scale bar, and located near its inner Lindblad resonance. Outside the star-forming ring are 2 major dust lanes and 2 stellar spiral arms. The dust lanes penetrate the ring, and trace the gas which is flowing into the ring from the large-scale bar. The 2 stellar arms located outside the ring are oriented approximately 90 degrees away from the major dust lanes, and probably not directly related to them. These stellar arms contain very little dust or gas, and may be formed by the action of the nuclear stellar bar which is embedded within the ring. The optical colors outside the ring, including those in the spiral arms, are very blue, indicating that many stars here are relatively young (<100 Myr). This suggests that either the star-forming ring has been shrinking over time, or that the nuclear bar has driven some young stars radially outwards. Kenney et al. produced simulations of galaxies with nuclear bars which are able to reproduce many of the observed features.

G. Shields completed a study of the interstellar carbon abundance in the spiral galaxies M101 and NGC 2403 with D. Garnett and E. Skillman (U. Minn.), M. Peimbert and S. Torres-Peimbert (UNAM), R. Dufour (Rice U.), and E. Terlevich and R. Terlevich (RGO). The measurements involved HST spectroscopy of six H II regions in each galaxy. The C/O ratios increase systematically with O/H in both galaxies, implying that radial gradients in C/H across spiral galaxies are steeper than the gradients in O/H. The variation in C/O likely results from the effects of stellar winds on the evolution of massive stars.

D. Vanden Berk, I. Jørgensen, M. Bergmann, and G. Hill have been creating a multi-color imaging map of a 70 × 1.5 sq. deg. strip of sky at McDonald Observatory, which traces the optimal tracking declination of the HET. The survey will reach faint magnitudes in five photometric bands, in order to generate targets which can be observed for the maximal tracking time per night with the HET. On average, objects in this survey strip can be observed with the HET more than twice as long per night as objects at other declinations, thus increasing the observing efficiency of the telescope.

P. Gay studied the variable star population of the Ursa Minor Dwarf spheroidal galaxy (dSph UMi) using new data from the McDonald 0.76-m telescope’s Prime Focus Camera. Using improved periods for 71 RR Lyrae stars and Anomalous Cepheids, she found that dSph UMi has a Oosterhoff type II Globular Cluster-like stellar population. This indicates that it is possible to form Dwarf
Galaxies with coeval stellar populations.

I. Jørgensen and G. Hill used their new redshift data for 340 faint galaxies in the central part of the Coma cluster together with other available redshift data and new photometry to establish the luminosity functions for galaxies in this cluster, in four different passbands. All four passbands show significant deviations from the Schechter luminosity function.

I. Jørgensen, in collaboration with J. Hjorth (Copenhagen University, Denmark), M. Franx and P. van Dokkum (both Leiden University, The Netherlands), has studied the evolution of elliptical galaxies based on data for five intermediate redshift clusters (redshifts up to 0.6) and two nearby rich clusters. The data show a very slow luminosity evolution during the last half of the age of the Universe. It is also found that the low luminosity galaxies evolve faster than the high luminosity galaxies, an indication that the stellar populations in the low luminosity galaxies are younger than those in the high luminosity galaxies.

M. Bergmann and I. Jørgensen, using archival HST WFPC2 data, have derived two dimensional surface photometry in two colors, for a sample of 88 early-type galaxies in the galaxy cluster CL0024+16 at z=0.39. The surface photometry has been used to determine the distribution of disk-to-bulge ratios for these galaxies. The distribution is very broad. Comparison of this distribution with the distribution for Coma cluster galaxies points to a lower fraction of disk-like early-type galaxies at the earlier epoch.

I. Jørgensen has studied the mean ages and abundances of magnesium and iron for a large sample of elliptical and lenticular galaxies in the Coma cluster. The distribution of the ages and abundances are very broad, e.g., the mean ages vary between 3 Gyr and 15 Gyr for the 115 galaxies in the sample. Further, Jørgensen finds that it is possible to derive an estimate of the variation of the fraction of dark matter in the galaxies. In a related study, Jørgensen and B. Møllvang-Jensen (Copenhagen University, Denmark) find that the stellar populations of the elliptical and lenticular galaxies in the Coma cluster are very similar to those of the galaxies in the Hydra cluster.

I. Jørgensen has started a project aimed at obtaining very deep spectroscopic data of the outskirts of nearby elliptical galaxies. The data will eventually provide information about the dynamics of the halo of these galaxies and therefore address the question about their dark matter content. Further, radial gradients in the ages and metal content of the stellar populations will be derived.

I. Jørgensen and H. Jonch-Sørensen (Copenhagen U., Denmark) have obtained Strömgren photometry of stars in the direction of the Perseus cluster of galaxies. The photometry will be used to accurately map the galactic extinction in the direction of the cluster of galaxies.

Gary Hill and S. Rawlings (Oxford University) started the TEXOX survey of radio galaxies from the NVSS, FIRST and WENS surveys. The aim of this survey is to discover clusters of galaxies to high redshift using radio selection for comparison with other selection techniques. The space distribution of the radio sources will also be used to study evolution of large scale structure since $z = 1$. A preliminary study of the 5C7 radio survey field has revealed the presence of a supercluster delineated by 7 radio galaxies and 3 QSOs at $z \sim 0.25$ of about 100 Mpc size in all three dimensions. If confirmed, this would be the largest structure known. Graduate students M. Bergmann, P. Gay, and S. Croft (Oxford) have been working on aspects of the the TEXOX survey.

W. Welsh, with B. Peterson (Ohio State), A. Koratkar (STScI) and K. Korista (Univ. Mich.) have completed their study of rapid variability in the Seyfert galaxy NGC 7469 using HST. The very small amplitude fluctuations – $4\%$ over 10 hours – roughly agrees with a power law extrapolation of the much longer timescale IUE observations. No high frequency cutoff or periodicities were found. Welsh and E. Robinson have begun a time series analysis of the rapid UV/optical variations in AGN using the IUE Archive. Welsh, Robinson, Gary Hill, G. Shields, and B. Wills, along with N. Brandt and M. Eracleous (Penn State) and W. Kollatschny (Göttingen) have initiated the “HET Echo Mapping Project” (HEMP), a long-term project to resolve the structure and flow of gas inside AGN BLRs using the echo mapping technique.

D. Vanden Berk and J. Quashnock (U. Chicago) have examined the large-scale clustering properties of heavy-element QSO absorption line systems from redshifts beyond $z = 4$ to the present, and on scales from 1 to several hundred comoving Mpc. The form of the absorption system correlation function is found to be remarkably similar to that for luminous galaxies, and the amplitude is shown to grow rapidly over a very long cosmic baseline, demonstrating strong evidence for the growth of large-scale structure via gravitational instability.
other researchers have completed a large HST project to examine the clustering properties of low-redshift QSO absorption line systems in relatively narrow regions towards the Galactic Poles, where luminous galaxy clustering is well-mapped. While most of the very low redshift ($z < 0.18$) Ly$\alpha$ systems are associated with large galaxy structures, there is no evidence for a large-scale “periodicity” in the distribution of the systems at slightly higher redshifts, as has been found for the galaxies. The clustering of the low-$z$ Ly$\alpha$ systems is also much weaker than that for luminous galaxies.

D. Vanden Berk, G. Richards (U. Chicago), and other researchers have studied the distribution of heavy-element QSO absorption line systems with respect to the properties of the backlighting QSOs. Contrary to the hypothesis that the majority of absorption systems arise in intervening material well-removed from, and uninfluenced by the QSOs, the distribution of systems up to very high velocity separations appears to be correlated with QSO luminosity and radio properties. This lends evidence either to the idea that the intervening systems often gravitationally lens the background QSOs, or that much more absorbing material is physically associated with the QSOs than has previously been thought.

Gary Hill continued studying the rest frame optical and UV spectra of very high redshift QSOs with R. Elston (Florida) and K. Thompson (RGO). They have demonstrated that the UV Fe II/Mg II emission line ratio of QSOs is remarkably similar for objects at redshifts up to $z \sim 4.5$, implying little evolution in the Fe/Mg abundance ratio. The enrichment of Fe is expected to take at least 1 Gyr as it is due to supernovae type Ia explosions, implying that the age for the universe at $z \sim 4.5$ is greater than 1 Gyr. This result implies a low value of $\Omega$.

B. Wills and D. Wills, with A. Laor (Technion, Israel), B. J. Wilkes (Harvard-Smithsonian Center for Astrophysics), G. Ferland (Univ. Kentucky), and M. Brotherton (LLNL), have investigated relationships among X-ray spectra, optical emission lines and UV emission lines and continua in a unique complete sample of QSOs with high quality constraints on the soft X-ray ionizing continua. The discovered an important new set of relationships linked to the Boroson & Green’s “Eigenvector 1”. These relationships probably relate high-density, Fe II emitting gas to the fueling of the accretion-powered central engine.

N. Visvanathan (Mt. Stromlo & Siding Springs Observatories) and B. Wills reported broad-band polarization for 52 radio-loud QSOs and B1 Lac objects, including the discovery of perhaps the highest redshift, high polarization QSO, and a new candidate for the rare class of radio-loud scattering-polarized QSOs.

F. Ma and B. Wills predicted that free-free heating due to the beamed infrared continuum can greatly enhance C IV$\lambda$1549 and other collisionally excited emission lines in radio-loud QSOs, whether or not the beamed continuum is pointed toward (core-dominated blazars) or away (radio-lobe dominated quasars) from us. An observational program is in progress to search for the emission, expected to be variable like blazar's relativistically beamed continua.

Z. Shang and collaborators showed that the prototype “non-interacting” warped galaxy NGC 5907 is not as non-interacting as believed: NGC 5907 is very close to the focus of a faint elliptical ring, suggesting that ring material is in orbit around the galaxy and the result of a past interaction. Also they noticed a faint companion galaxy at the tip of the H I warp of NGC 5907. These results suggest that tidal interaction with a mere 1% of the mass may be sufficient to excite warps in the parent galaxy.

D. Hines, G. Schmidt and P. Smith (Steward Observatory), with B. Wills reported WFPC2 and ground-based imaging polarimetry and new spectropolarimetry of IRAS P09104+4109, a type 2 QSO. The new data revealed a highly polarized ($\sim$20%), giant ($\sim$5 kpc) bipolar reflection nebular, expanding upon their previous interpretation of this radio-loud AGN as a buried QSO having undergone a past violent change in the axis direction of the central engine.

3.3.7 Theory:

The study of Soft Gamma Repeaters (SGRs) was revolutionized in 1998 by several observational breakthroughs, including the first measurements of SGR rotation periods and spindown rates, and the first detection of a giant burst from an SGR in our galaxy. This new evidence strongly supports the idea that SGRs are ultra-magnetized neutron stars, or “magnetars.” The magnetar theory was proposed in 1992 by R.C. Duncan and C. Thompson (UNC Chapel Hill). The theory accounts for the formation of magnetars via neutron star dynamos, their subsequent evolution during the magnetically-
heated SGR phase, the origin of ordinary SGR bursts as magnetically-induced starquakes, and giant SGR bursts (observed on March 5, 1979 and August 27, 1998) as magnetic flares. A team of scientists from NASA’s Marshall Spaceflight Center, led by C. Kouveliotou, worked with Duncan in acquiring and interpreting X-ray data on the spin-down of SGR 1900+14.

R. Duncan also studied the distributions of SGR burst energies and compared it with the predictions for starquakes in a crust that is stressed to a state of “self-organized criticality” by an evolving, ultrastrong magnetic field. The empirical power-law distribution of burst energies exhibits a turnover consistent with a global limit on (lateral slip) crust fractures. This suggests that the significant excitation of global seismic oscillations (GSOs) is possible. Duncan estimated the eigenfrequencies of low-order toroidal modes as a function of stellar mass and radius, and their magnetic and rotational shiftings/splittings, and how the modes may be excited and damped. There is marginal evidence for such modes in the initial hard pulse of the 1979 March 5th event. Evidence for GSOs in recent data from SGR 1806-20 is now under study.

SN 1998bw was associated with GRB 980125 and a relativistically-expanding radio source. L. Wang and J. C. Wheeler presented evidence that at least some fraction of observed gamma-ray bursts may be associated with SN Ia/c. They speculated that all SN Ia/c may produce gamma-ray bursts and that all gamma-ray bursts may be associated with SN Ia/c explosions, abetted by strong collimation and beaming. P. Höflich, Wheeler, and Wang explored light curves of asymmetric configurations and showed that the high optical luminosity of SN 1998bw might be accounted for by asymmetries without the need for the very high energies associated with spherically symmetric “hypernova” models.

A study of gamma-ray and X-ray line and continuum emission from SN Ia was was completed by P. Höflich, J. C. Wheeler and A. Khokhlov (NRL) who also explored the capability of new satellites, such as INTEGRAL, to detect distant SN Ia events in this manner and to discriminate various models of SN Ia. Wheeler and co-workers showed, with theoretical models, that IR spectroscopy is a powerful tool to explore the structure of exploding white dwarfs. In the IR, both outer layers, where the opacity is high, and inner layers, where the opacity is low, can be probed with a single spectrum. Preliminary results gave strong support for the paradigm of a deflagration/detonation explosion in a Chandrasekhar-mass model and showed how IR spectra can constrain details of the burning process including the deflagration to detonation transition. Höflich, Wheeler and F-K. Thielemann (Univ. Basel) presented the first exploration of the possible systematic effects involved in detecting and evaluating very distant SN Ia and their application to determine the fundamental cosmological parameters. Changes in the average mass of progenitor stars at higher redshift could, in principle, introduce systematic shifts in peak luminosity of about 0.1 to 0.3 magnitudes, of the same order as cosmological effects.

I. Lichtenstadt (Hebrew U.), A. Khokhlov (NRL) and J. C. Wheeler have completed work on a code for two-dimensional dynamics of core collapse with two-dimensional multi-energy group flux limited diffusion. They find that despite the strong asymmetry in entropy and composition due to post-collapse convection, the neutrino flux distribution is very symmetric. They do not find an explosion in these models. Future models will add the effects of $\mu$ and $\tau$ neutrinos. J. Wang and Wheeler have also done one-dimensional, multi-energy group calculations with an algorithm that reproduces some of the effects of convection with the goal of being able to explore a greater range of parameter space than can practically be done with a multi-dimensional code.

J. C. Wheeler, J. Cowan (U. Oklahoma), and W. Hillebrandt (MPI Astrophysik) explored the issue of whether core collapse in stars of 8 to 10 solar masses that make degenerate cores of oxygen, neon, and magnesium could be a fertile site for the r-process either in the collapse or a subsequent neutrino-driven wind. R. Gearhart, Wheeler and D. Swartz (NASA Huntsville) re-examined the production of CO in SN 1987A with models that include a full radial structure and radiative transfer. They find less CO than recent studies and discuss the possible reasons for the discrepancy.

In collaboration with E. Oran and A. Khokhlov (Naval Research Laboratory), J. C. Wheeler pursued fundamental combustion issues to better understand the mechanism for the transition from deflagration to detonation. A new compact scheme for calculating nuclear statistical equilibrium and quasi-equilibrium was developed by W. Hix et al. Detailed multidimensional studies of detonation instabilities in the context of SN Ia were published by
V. Gamezo et al. The detonation instability may weaken the propagation of the burning front in deflagration/detonation models of supernovae and alter the final composition. J. Stein (Hebrew U.) and Wheeler continued multi-dimensional computation of the convective phase of degenerate carbon burning. The nature of the “convective Urca” process in white dwarfs has been reevaluated. They conclude that this process can reduce the rate of increase of entropy, but cannot reduce the entropy as previous studies (including our own) have argued.

J. Scalo and D. Chappell showed how the observed power law two-point correlation function of young stars in nearby star-forming regions and of Cepheids in the LMC can be accounted for by a model in which stellar winds drive expanding shells that are subjected to nonlinear fluid advection and interactions with other shells, and in which star formation occurs when a threshold shell column density is exceeded. Numerical simulations of this model predict how the power law slope should depend on the maximum age of the stellar sample and the average star formation rate, and how stellar migration flattens the power law slope at small scales, an effect which may explain the secondary breaks in the observed correlation functions of some regions. Problems with using the correlation function as a descriptor of clustering structure for statistically inhomogeneous data sets were explored.

J. Scalo, E. Vazquez-Semadeni (UNAM, Mexico), D. Chappell, and T. Passot (Obs. de la Cote d’Azur, France) investigated the probability density function (pdf, or frequency distribution) for the density field of the interstellar medium using two-dimensional numerical simulations that successively reduce the number of physical processes included. This function must play a crucial role in any galactic model in which the star formation rate is controlled by a threshold density criterion. The simulations range from self-gravitating supersonic MHD turbulence including rotation and heating and cooling, to decaying Burgers turbulence that only includes advection but no other processes. In all cases filamentary density structures with evidence for a power-law density pdf at large densities with logarithmic slope around -2 are found, suggesting that these results are the signature of the nonlinear advection operator. These results do not agree with previous claims that the density pdf is lognormal. The discrepancy was shown to be due to the fact that the density pdf is controlled by the effective polytropic exponent. A detailed discussion of heating and cooling rates and resulting polytropic exponents for a range of densities in molecular gas was given. Several applications were also discussed.

J. Ballesteros-Paredes (UNAM), E. Vazquez-Semadeni (UNAM), and J. Scalo examined the viability, in a turbulent medium, of thermal and turbulent pressure-confined clouds, a common model for clouds in the interstellar and intergalactic medium. Two-dimensional self-gravitating MHD simulations were used to follow the topology of the velocity, density, and magnetic fields within and at the boundaries of the clouds emerging in the simulations at scales of 1kpc down to a few pc. The “clouds,” defined by imposing a density threshold criterion, are not static entities, but are continually forming, deforming, and dissolving. The velocity field is continuous across cloud boundaries for a hierarchy of clouds of progressively smaller sizes, and the apparent cloud boundaries have no correspondence to any actual physical boundary, such as a density discontinuity. The velocity field exhibits abrupt jumps at density maxima, indicating that the clouds are formed by colliding gas streams. Evaluating the volume and surface terms in the Eulerian Virial Theorem for a cloud ensemble shows that both terms are comparable. These results were used to argue that thermal pressure equilibrium is irrelevant for cloud confinement in a turbulent medium, since inertial motions can still distort or disrupt a cloud, unless it is strongly gravitationally bound. Turbulent pressure confinement appears self-defeating, because turbulence contains large-scale motions which necessarily distort and/or disrupt the cloud.

J. Scalo reviewed several classes of theoretical models for the stellar initial mass function (IMF), and showed that many of them depend on the same common underlying physical functions, including the density and velocity probability density functions, the effective polytropic exponent of the gas as a function of density, and the star formation rate itself. Viewed in terms of these functions, many of these theories can be formulated in terms of the same generic integro-partial differential equation, the discrete-continuous Chapman-Kolmogorov equation. Examples were given showing how several of the models can give a flattening or turnover of the IMF at small masses which have nothing to do with the Jeans mass. The dependence on the effective polytropic exponent, which involves the heating and cooling rates, indicates how the redshift-dependence of the IMF might be estimated for different models.
J. Scalo developed a new model for the mass spectrum of clouds and stars, based on the interaction of shocks, from a variety of sources, with clouds. Most shock-cloud interactions will be at small Mach numbers, and, instead of disrupting a cloud, will generate internal motions which can prevent its collapse or fragmentation, a result derived in an earlier paper by P. Kornreich and Scalo. In the simplified model examined, fragmentation can only occur if the internal kinetic energy has time, before the next shock encounter, to fall below some critical value, so only “lucky clouds,” which can avoid a shock pumping during the time required for dissipation to the critical value and during the subsequent fragmentation timescale, can form stars. The process favors star formation in low-mass clouds, since the internal dynamical readjustment timescale decreases with decreasing cloud size, while the mean time between shock arrivals is independent of cloud size. The resulting mass spectrum is derived, exhibiting how it depends on the pdf of shock energies, the time-dependence of turbulent dissipation, and the dependence of fragmentation timescale on mass. Since the solution depends on the mean time between shock arrivals, it depends on the IMF itself. Generalizations to include triggered star formation and cloud disruption were discussed.

J. Scalo and D. Chappell examined the question of star formation feedback efficiency: For a given local star formation rate, how much energy is ultimately distributed over larger scales? This question is known to play a crucial role in models of galaxy formation and evolution. A series of numerical simulations were carried out for a model in which stellar winds drive expanding shells that are subjected to nonlinear fluid advection and interactions with other shells, and in which star formation occurs when a threshold shell column density is exceeded. The key to the efficiency question appears to involve the balance between energy injection and the “turbulent” dissipation due to the interaction of the multiple shells. Using a simple “cloud fluid” model for these processes, they derived a simple scaling relation between the star formation luminosity and the kinetic energy increase in the surrounding gas, and the dependence on other parameters. The simulations agree remarkably well with this scaling relation, suggesting that it can be used as an input function for larger-scale simulations of galaxy formation and evolution.

G. Shields and E. Fierce continued work on models of QSO accretion disks. Fierce constructed a grid of models of disks around nonrotating black holes with the aid of the TLUSDISK code kindly made available by Dr. I. Hubeny of the Goddard Space Flight Center. The models are being used to fit individual and composite QSO energy distributions. Shields searched for physical mechanisms that might give rise to a Lyman emission edge in the polarized flux from disk atmospheres. Previous work showed that such a jump in polarization at the Lyman edge in the rest frame of the orbiting gas would look like Lyman polarization rises observed in some QSOs, after relativistic effects are included.

H. Martel, P. Premadi (Astronomical Institute, Tohoku University, Japan), and R. Matzner (Center for Relativity, University of Texas) pursued their research on weak gravitational lensing in cosmology. The goal of this project is to determine the cosmological parameters by matching results of numerical experiments to observations. This project involves the largest parameter survey ever done in this field: 43 Cold Dark Matter cosmological models, parametrized by the values of the density parameter \( \Omega_0 \), the cosmological constant \( \lambda_0 \), the Hubble constant \( H_0 \), and the rms density fluctuation \( \sigma_8 \). About 1000 ray-tracing experiments (between 20 and 40 per model) have been performed so far, and several thousand additional experiments will follow. In each experiment, a beam composed of \( 341 \times 341 = 116,281 \) light rays is traced backward in time to redshifts of order 3 or more. These experiments produce statistics such as (1) the fraction of quasars that are magnified, (2) the distribution of magnification and shear, (3) the fraction of magnified quasars that have multiple images, (4) the image multiplicities (i.e., the frequency of occurrence of double images, triple images, quadruple images, ...), (5) the distribution of image separations and image ratios, and (6) the occurrence of Einstein rings. These statistics can be directly compared with observations, and will eventually narrow the range of possible cosmological models.

P. Shapiro, A. Raga (UNAM), and G. Mellema (Stockholm Obs., Sweden) performed the first gas dynamical simulations of the photoevaporation of an intergalactic gas cloud overtaken by the R-type ionization front which results when a quasar or stellar source turns on in the neutral intergalactic medium (IGM) during the reionization of the universe at an epoch earlier than redshift 5. These simulations were based upon a 2D axisymmetric, Eulerian hydro code, with Adaptive Mesh Refinement and a Riemann solver involving Van-Leer-
Flux-Splitting, including nonequilibrium ionization rate equations for the elements H, He, C, N, O, and S and radiative transfer equations which take explicit account of H and He bound-free opacity. Located 1 Mpc from a quasar of modest luminosity, a cloud of gas mass of a few million solar masses can trap the ionization front and gradually evaporate by expelling a supersonic wind in the direction of the quasar while accelerating away from the quasar by a “rocket effect.” Observationally, such a cloud would initially appear as a Lyman limit quasar absorption line cloud in the spectrum of that quasar and evolve into Lyman alpha forest absorption line gas, as the photoevaporation reduces its neutral column density over the course of more than 100 Myr.

J. Canto (UNAM), A. Raga (UNAM), W. Steffen (U. of Manchester UK), and P. Shapiro studied the regions within photoionized nebulae in which the ionizing radiation from the central source is blocked by an intervening neutral, opaque clump—the shadow zones. The shadow gas can be partially ionized by diffuse ionizing radiation from the unshadowed H II region which surrounds it and is dynamically affected by the pressure of that surrounding gas. An analytical model for the final, steady configuration of the shadows was derived involving a neutral core surrounded by a layer which is ionized by the diffuse radiation of the surrounding H II region. Time-dependent, numerical gas dynamics simulations which include radiative transfer and the hydrogen ionization rate equation were performed to demonstrate in detail how the shadow gas relaxes to this final state, in which the ionized shadow gas is denser and cooler than the surrounding H II region in pressure balance with it, with the shadow’s mass substantially increased by the accretion of gas from the surrounding H II region. These results will have broad astrophysical application, from circumstellar to interstellar to intergalactic H II regions. They already serve to explain, for example, the long-tailed clumps observed in Planetary Nebulae (e.g. Helix nebula) as an effect of the enhanced emission rate of the shadow zones relative to the surrounding H II region gas.

P. Shapiro, H. Martel, and J. Owen (Lawrence Berkeley Livermore Labs) continued the development and application of their new anisotropic version of Smoothed Particle Hydrodynamics (SPH), called Adaptive SPH (ASPH), for cosmological gas dynamics. The method was tested in 2D and 3D against a variety of problems, including the Sedov blast wave, the interaction of two blast waves, the cosmological pancake collapse, and problems involving collapsing and shearing disks. These tests demonstrated that the method consistently outperforms the standard isotropic SPH, by exhibiting higher spatial resolving power at fixed initial particle number per dimension, while maintaining an adequate level of global conservation of energy and linear and angular momentum. Owen applied a version of this method in 3D to simulate the formation of an X-ray cluster, the ASPH entry in the Santa Barbara Cluster comparison paper by C. Frenk et al. on cosmological numerical gas dynamics methods, which demonstrated that ASPH gives reasonable results in comparison with other methods currently in use, even when using only a relatively smaller number of particles. A new 3D version of ASPH, with a Particle-Particle/Particle-Mesh (P3M) gravity solver, was tested by Shapiro and Martel against the cosmological self-similar spherical infall problem and found to give results comparable to those of standard SPH with the same number of particles, but with a somewhat reduced amount of spurious preshock viscous heating. This new version included a refined algorithm for suppression of artificial viscous heating away from shocks, which automatically adjusts the threshold criteria used to suppress viscous heating, in a time- and space-varying manner, according to local conditions and particle resolution. Owen has succeeded in parallelizing ASPH for massively parallel computers which accept the new standard Open-MP parallel programming directives, and tests of the speed-up which results as a function of the number of processors used are underway.

A. Valinia (Goddard Space Flight Center), P. Shapiro, and H. Martel continued their investigation of the gravitational instability of cosmological pancakes by gas dynamical simulation in 2D with SPH and a PM gravity solver, to reveal that the filamentation of a planar pancake which results from this instability leads to strong vorticity generation inside the filament which forms when a pancake is perturbed by a density fluctuation whose wavevector is parallel to the pancake plane. This vorticity generation results primarily from the creation of a nonzero baroclinic term in the postshock pancake gas in the region of the filament and leads to coherent vortices which may be relevant to the origin of galactic rotation. The proportionality between the strength of this vorticity and that of a cosmic magnetic field which would be generated at the same time by the Biermann battery effect, for
gas which is initially field- and vorticity-free prior to its gravitational collapse and shock-heating, makes these results relevant as well to the origin of galactic magnetic fields by large-scale structure formation in cosmology.

H. Martel and P. Shapiro generalized the comoving variables which Shandarin had first introduced for matter-dominated cosmological models in 1980, to the cases of cosmological models in which there is a nonclumping background of energy density (e.g. cosmological constant), in addition to baryonic and dark matter. Such models are of great current interest because they help reconcile the Cold Dark Matter (CDM) model of structure formation with data on galaxy clustering and large-scale structure, the COBE CMB temperature anisotropy measurement, the average estimates of the age of globular clusters, the Hubble constant, and dynamical estimates of the mean cosmic matter density. In terms of these variables, which Martel and Shapiro refer to as supercomoving variables, fluid properties for an ideal gas with ratio of specific heats equal to 5/3 are stationary in the absence of perturbations, and fluid equations are identical to the fluid equations for noncosmological gas in a non-expanding background. This property makes the variables extremely useful for solving problems in cosmological structure formation, by allowing the known solutions and techniques of noncosmological gas dynamics to be applied immediately in a straightforward way.

I. Iliev and P. Shapiro solved the problem of the nonlinear collapse of cylindrical, planar, and spheroidal top-hat density fluctuations in cosmology, for comparison with the well-known solutions for spherical top-hats, including the post-collapsed virialized object which forms as a result. These results showed that cylindrical top-hats collapse somewhat earlier than spherical ones, but result in a lower post-collapse virial temperature and density. These results suggest that the Press-Schechter approximation for the rate of collapse of bound objects when a general distribution of density fluctuations grows to produce nonlinear structure might be modified so as to account for the different collapse times predicted for different geometry of collapse. In addition, these results allow a more accurate assessment of simulations of cosmological structure formation in 2D, for comparison with 3D calculations. Finally, the postcollapse virialization of non-spherical top-hats is relevant to the description of filamentary structures that form in cosmology.

H. Martel and P. Shapiro solved the problem of the collapse of spherical top-hat density perturbations, well-known for matter-dominated cosmological models, in the more general models in which a nonclumping component of energy density is present (e.g. cosmological constant), in addition to the standard baryonic and dark matter. Together with I. Iliev, this work was further generalized to the case of nonspherical top-hat perturbations—i.e. uniform density cylinders, sheets, and spheroids embedded in an unperturbed background universe.

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

S. Weinberg, P. Shapiro, and H. Martel offered a probability calculation to help resolve the longstanding cosmological constant problem. This
problem results from the fact that particle physics predicts a natural value for the vacuum energy density which results from quantum fluctuations in the early universe which is as much as 120 orders of magnitude larger than the rest mass energy density of matter in the universe today. To be compatible with our known universe, such a vacuum energy density must be perfectly canceled by some unknown physical mechanism, to this extraordinary level of accuracy, so as to leave a net cosmological constant which is only comparable to or less than the matter density. No fundamental physics explanation has yet been found which would achieve such precise cancellation. In models of cosmology in which the universe is comprised of an infinite number of subuniverses in which the cosmological constant may take on different values, it was shown that the probability of observing any given value of the cosmological constant depends upon the fraction of matter which is able to collapse out into galaxies in such a subuniverse, which is sensitive to the value of the constant because if it is too high, galaxy formation is suppressed altogether. The probability calculation used the Cold Dark Matter (CDM) model and the primordial density fluctuations detected by the COBE satellite to show that a small, but nonzero, value of the cosmological constant is the most likely for us to be able to observe, even if there is no a priori reason that any particular value is favored over any other.

M. Moscoso, a graduate student supervised by J. C. Wheeler, has continued work on pair winds that might be expected from pair-dominated coronae around a black hole.

3.3.8 Laser Ranging:

Lunar and artificial satellite laser ranging, with Project Director P. J. Shelus and staff members R. L. Rickles, J. G. Ries, and J. R. Wiant, continues under the support of the National Aeronautics and Space Administration.

The McDonald Laser Ranging Station (MLRS) is a fundamental station in the world-wide laser ranging network. It consists of a 0.76-m reflecting telescope and a very short pulse, frequency-doubled, 532-nm wavelength, neodymium-YAG laser, with ancillary computer, electronic, and timing hardware. The station is located at McDonald Observatory on Mt. Fowlkes, to the north-east of Mt. Locke in west Texas and shares the mountain top with the new Hobby-Eberly Telescope.

With a two-crew observing operation, laser ranging is carried on to a large number of artificial satellites (Fizeau, ERS-1, ERS-2, Tips, ADEOS, Starlette, Stella, Diadem-C, Diadem-D, Meteor-3, Ajisai, TOPEX/Poseidon, WESTPAC, LAGEOS-1, LAGEOS-2, Etalon-1, Etalon-2, GPS-35, GPS-36, and several GLONASS targets) as well as the Moon. The MLRS continues to be the only lunar capable laser ranging station in the United States and only one of two routinely lunar capable stations in the world. By measuring the time it takes for a laser pulse to leave a ground station, bounce off a targeted reflector array, and return to the ground station, one measures very precisely the distance between the station and the reflector array. Comparing a series of measurements (almost 30 years of lunar laser ranging observations have now been accumulated, together with more almost 15 years of artificial satellite data), scientific results are obtained in four broad areas: solar system ephemeris development, general relativity and gravitational physics, lunar science, and geodynamics. Finally, the laser site at McDonald Observatory hosts a permanent Turbo-Rogue GPS receiver and satisfies all requirements to be a fundamental site in the world-wide GPS network. The continuous, real-time meteorological data that is taken by the MLRS also becomes a part of the international GPS database.

Lunar and artificial satellite laser ranging observations were obtained with the MLRS at record setting levels for the 9th straight year, as personnel cooperate with colleagues around the world, making maximum use of the data type for earth, moon, and solar system related dynamics. The quality and quantity of the MLRS data coverage continues through the present time. Principal research activity includes monitoring the exchange of angular momentum between the solid earth and its atmosphere, the principal geopotential terms, plate tectonic activity, tidal dissipation in the lunar orbit, the lunar free libration, and the equivalence principle of general relativity. In a service capacity the project also serves as Observing Center and Analysis Center in the International Earth Rotation Service (IERS), obtaining millisecond accuracy estimates of the constant of precession, coefficients of nutation, polar motion, and Earth rotation. This constitutes the only near-real-time source of this information that includes the lunar laser ranging data type.

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

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.), R. Duncombe (Aerospace Engineering), W. Jefferys (P.I.), B. McArthur, and P. Shels. The team continued obtaining, reducing and analyzing data bearing on planet searches (see Solar System, above), HIPPARCOS-quasar reference frame tie-in, and parallaxes of astrophysically interesting objects (Delta Cephei, RR Lyrae, Feige 24, the central star of the planetary nebula NGC 6853, RW Tri, TV Col, the Hyades, and low-mass M-dwarfs). All data are obtained with Fine Guidance Sensor 3 aboard HST. They continue to obtain 1-2 milliarcsecond precision per measurement.

G. F. Benedict and B. McArthur participated in a study of HD 98800, a unique stellar system of post-T Tauri stars. HD 98800 is a system of four stars, and it has a large infrared excess that is thought to be due to a dust disk within the system. They obtained new astrometric observations made with HIPPARCOS, as well as photometry from HST WFPC2 images. They used the FGSs on Hubble Space Telescope during cycles 5 and 6 to measure the parallaxes and proper motions of the $Aa + Ab$ and $Ba + Bb$ components separately. The parallax series, obtained with FGS 3, occurred at three epochs, with two orbits of observations at each epoch and with each epoch separated from the next by 6 months. This strategy has been used successfully on other targets to achieve parallaxes with precision of 1-2 mas. However, in this case the complexity and multiplicity of the targets and the angular sensitivity of FGS 3 render the data set insufficient. Both the POS and TRANS mode observations appear to be perturbed by the duplicity of both HD 98800A and HD 98800B. The expected orbital period of each system is near 1 yr, which is nearly ideal for contaminating parallax measurements that are taken 1 yr apart. As a result, the FGS parallaxes for HD 98800 A and B are in agreement with the Hipparcos value and show that both stars are at the same distance, but the Hipparcos parallax is used here for determining the luminosities. Combining these observations and reanalyzing previous work allow an estimate of the age and masses of the stars in the system. Uncertainty in these ages and masses results from uncertainty in the temperatures of the stars and any reddening they may have. It was found that HD 98800 is most probably about 10 Myr old, although it may be as young as 5 Myr or as old as 20 Myr. The stars in HD 98800 appear to have metallicities that are about solar. An age of 10 Myr means that HD 98800 is a member of the post-T Tauri class of objects, and they argue that the stars in HD 98800 can help us understand why post-T Tauri stars have been so elusive. HD 98800 may have formed in the Centaurus star-forming region, but it is extraordinary in being so young and yet so far from where it was born.

G. F. Benedict and B. McArthur (in collaboration with O. Franz, Lowell Observatory and T. Henry, Harvard-SA0) continued an HST GO program of simultaneous transfer scan and position mode astrometry with FGS 3. They will obtain precise orbits, parallaxes, and masses for close binary stars difficult or impossible to study from the ground.

P. Shels, J. G. Ries, and E. Barker continue their astrometric observations of faint solar system objects. This effort employs a CCD and the Prime Focus Corrector (PFC) on the McDonald 0.76-m reflector. The f/3 PFC is ideal for astrometric observations of faint solar system objects. This instrument is capable of reaching $R=22$, with more than 3 sigma significance on stellar objects, in co-added integrations. Primarily, the observations are used to answer a set of the questions posed by the NAS Committee on Planetary and Lunar Exploration (COMPLEX) Space Studies Board in a report on Near-Earth Objects. As summarized by COMPLEX: “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”. The aims are: 1) obtain follow-up positional observations of recently discovered or under-observed NEO’s; 2) perform orbital analysis to investigate the circumstances of encounter; 3) obtain understanding of early orbital evolution to investigate the origin and dynamical history of NEO’s.

Besides observing, there is a substantial non-observational part to the Solar System Astrometry project. The software efforts continue to be developed within IRAF and ICE to perform routine, real-time processing of CCD frames taken with the PFC (or any other CCD), identify star fields and solar system objects within the fields, digitally de-
termine the centers and intensities for all identified objects within the fields, and then process the measures to obtain astrometric positions and magnitudes. Extensive portions of the astrometric measuring and reduction script are being automated for increased efficiency during data processing. Effects of "personal equation" during the measuring process are being removed, robust estimation theory is being applied to the reduction, and measures will soon be made directly in the International Celestial Reference Frame (ICRF) by replacing the GSC by USNOA-1.0 and its derivatives. The replacement of the fundamental reference catalog will also remove significant systematic effects on the measures.

The total McDonald astrometric system continues to be fully functional during the up-grade and excellent results are being obtained. It is routine to have a night’s worth of minor planet and cometary positional observations electronically sent to the Minor Planet Center the morning after the observations were taken. Additional observations are occasionally made of the natural satellites of Jupiter, Saturn, Neptune, and Uranus. Many of these objects have, in the past, been underobserved and orbit refinements require that a continuous set of precise and accurate positional observations be maintained. Positions of all interesting objects are determined in a standard reference frame.

3.3.10 History of Astronomy:

R. Robbins completed a study on the continuity of astronomical symbols from Mante Albán to the Aztec stone at Tenochtitlan. He concluded that Cassiopeia was an important star grouping to the early cultures in Mesoamerica and that evidence for this can be found at several sites. There is also some evidence suggesting that the 1572 supernova is represented on the Aztec stone.

R. Robbins discovered a Sun Dagger hierphony in central Texas that produces a show at the winter and summer solstices. The daggers occur at the Sun’s maximum altitude.

PUBLICATIONS


