University of Texas
McDonald Observatory
Department of Astronomy

Austin, Texas 78712

This report covers the period 1 September 1995–31 August 1996.

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.

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 Ethan **Vishniac** 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** is Assistant Director. Mark **Adams** is the resident Superintendent.

1.3 Teaching and Research Personnel

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

Named Professors: Frank N. **Bash** (Frank N. Edmonds Regents Professor in Astronomy); Gérard H. **de Vaucouleurs** (Jane and Roland Blumberg Professor Emeritus in Astronomy, deceased September 1995); 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); David L. **Lambert** (Isabel McCutcheon Harte Centennial Chair 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); Steven **Weinberg** (Regents Professor and Jack S. Josey–Welch Foundation Chair in Science); and J. Craig **Wheeler** (Samuel T. and Fern Yanagisawa Regents Professorship in Astronomy). *Professors*: Michel **Breger** (adjunct), James N. **Douglas**, Paul **Shapiro**, Roman **Smoluchowski** (emeritus, deceased January 1996), Chris **Sneden**, Paul A. **Vanden Bout** (adjunct), Ethan **Vishniac**, Derek **Wills**, and Don **Winget**.

Associate Professors: Harriet **Dinerstein**, Paul M. **Harvey**, Dan **Jaffe**, John **Lacy**, and R. Robert **Robbins**, Jr. **Non-Academic**

Senior Research Scientists: Thomas G. **Barnes** III, Laurence M. **Trafton**, and Robert G. **Tull**.

Research Scientists: Edwin S. **Barker**, George F. **Benedict**, Anita L. **Cochran**, William D. **Cochran**, Robert **Duncan**, Artie P. **Hatzes**, Paul D. **Hemenway**, Gary **Hill**, Alexei **Khokhlov**, Daniel F. **Lester**, Frank **Ray**, Peter J. **Shelus**, Verne **Smith**, Jocelyn **Tomkin**, Arthur L. **Whipple**, and Beverley J. **Wills**. *Research Associates*: Mark **Cornell**, Willam **Gressler**, Mary Kay **Hemenway**, Victor **Krabbendam**, Larry **Long**, Phillip **MacQueen**, Hugo **Martel**, Alvin L. **Mitchell**, Ed **Nelan**, and Darrell **Story**.

Postdoctoral Research Associates and Other Visiting Staff: Janna **Anossova**, Eric **Bakker**, Don **Barry**, Guillermo **González**, William **Hix**, Christopher **Johns-Krull**, Inger **Jørgensen**, Soon-Wook **Kim**, Jeremy **King**, Chris **Koresko**, Masaaki **Kusunose**, Kepler **Oliveira**, Matt **Richter**, Judit **Györgyey Ries**, Yaron **Sheffer**, Josef **Stein**, Keith L. **Thompson**, Lifan **Wang**, and Chunyan **Wei**.

1.4 Senior Research Support and Administration

HET Project Manager: Tom **Sebring**.

Special Assistant to the Director (Development): Joyce C. **Sampson** (departed January 1996) and Joel **Barna**.

Associated member of another department: Raynor L. **Duncombe**, Professor of Aerospace Engineering and Engineering Mechanics.

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

McDonald supervisors: Gordon **Wesley** (mechanical engineering, departed September 1995), Edward **Dutchover**, Jr.* (administrative support), Earl **Green*** (observing support), George E. **Grubb*** (physical plant), Mark **Cornell** (computing systems), Phillip **MacQueen** (CCD development), Alvin L. **Mitchell** (engineering support), and Jerry R. **Wiant*** (MLRS).

Administrative Services Officer: Cecilio **Martinez**

1.5 Board of Visitors

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

Members of the Board of Visitors: Lucy **Alexander**, Grant **Billingsley**, Mark **Bivins**, William **Block**, Wm. Terry **Bray**, J.P. **Bryan**, George **Christian**, Joseph **Cialone**, Anne

Dickson, Marshall **Doke**, George **Finley**, William **Guest**, Henry **Hamman**, Paul **Hobby**, Katherine **Johnson**, Herbert **Kelleher**, Garland **Lasater**, Thomas **Link**, James **McCartney**, Arthur **Miller**, Bradford **Moody**, Lillian **Murray**, Judy **Newton**, Pike **Powers**, William **Ratz**, Jon **Ruff**, Carl **Ryan**, Karen **Skelton**, F. Ford **Smith**, Marshall **Steves**, Curtis **Vaughan**, David **Weeks**, Gene **Wiggins**, and Francis **Wright**.

1.6 Visitors and Affiliations

Dr. James E. Peebles received the Antoinette de Vaucouleurs Medal. He presented the Antoinette de Vaucouleurs Lecture on October 31, 1995 entitled ''Is the Universe Open or Closed? Comments on the Ideas and the Evidence.'' In addition, on November 1 he presented a popular lecture entitled ''Images of the Physical Universe.''

The following people were visitors to the department: verse C. **Colomé**, Universidad Nacional Autonoma de México A. **Davidsen**, Johns Hopkins University D. **Deyoung**, National Optical Astronomy Observatories G. **Ferland**, University of Kentucky C. **Heiles**, University of California, Berkeley P. **Höflich**, Harvard University M. **Kaufman**, Ohio State University A. **Klypin**, New Mexico State University B. **Milvang-Jensen**, Copenhagen University Observatory J. **Moran**, Smithsonian Astrophysical Observatory F. **Shu**, University of California, Berkeley S. **Starrfield**, Arizona State University J. **Stein**, Hebrew University of Jerusalem D. **Turnshek**, University of Pittsburgh C. **Wei**, China verse

G. Shields spent 7/15–8/7/96 at the Center for Astrophysics and Space Science (CASS) at the University of California at San Diego, formulating plans to study QSO chemical abundances with F. Hamman, V. Junkkarinen, and others.

P. Shapiro was an invited member of the Institute for Theoretical Physics Workshop on Galaxy Formation and Radiation Backgrounds at the University of California at Santa Barbara, 5/15– 6/15/96.

On August 31, 1996, E. Barker completed a three-year Intergovernment Personnel Act (IPA) assignment to the Office of Space Science at NASA Headquarters where he was the Discipline Scientist for Planetary Astronomy. He now returns full-time to his position as Research Scientist at the University of Texas.

C. Sneden was on research leave from the Astronomy Department, spending the academic year at NOAO/KPNO (Tucson).

1.7 Awards, Honors, and Special Activities

Robert Tull won the Astronomical Society of the Pacific's 1996 Maria and Eric Muhlmann Award. This award is given for ''recent significant observational results made possible by innovative advances in astronomical instrumentation, software, or observational infrastructure.'' In Tull's case, he is being recognized for his designs of spectrographs, in particular the coudé spectrographs of the 2.7-m telescope at McDonald Observatory, and for pioneering work in solid-state image detectors and computer automation in astronomical observations.

Lifan Wang received a Hubble Postdoctoral Fellowship, which he will use to remain in Texas and work on supernova spectra and polarimetry.

Mike Brotherton was awarded an AAS International Travel Grant to attend IAU Colloquium No. 159, held in Shanghai, China, June 17–20, 1996.

Anita Cochran was Chair of the Division for Planetary Sciences of the American Astronomical Society. Mary Kay Hemenway served as the Education Officer for the American Astronomical Society. Frank Bash was elected to the Council of the American Astronomical Society, and he is a member of the Board of Directors of the Astronomical Society of the Pacific. Anita Cochran was elected to the U.S. National Committee, IAU. Craig Wheeler was a member of the Tinsley Prize Committee and the Committee on the Status of Women in Astronomy for the American Astronomical Society.

Judit Ries served on the Committee of the AAS Division on Dynamical Astronomy; Peter Shelus served as its treasurer. Art Whipple was secretary of the Division on Dynamical Astronomy. In this capacity, he was a member of the organizing committee for the 27th meeting of the DDA, at the U.S. Naval Observatory in Washington, DC.

Frank Bash is the Member Representative from the University of Texas to AURA, the AURA Coordinating Council of Observatory Research Directors, and the Council of Directors of Independent Astronomical Observatories.

Peter Shelus was elected as LLR Vice-Chairman of the SLR Subcommittee within the international fundamental reference system working group, CSTG. Mary Kay Hemenway served on the American Institute of Physics Committee on Physics Education (term 1992–8). She also was the Director for the Steering Committee of the Coalition for Earth Science Education (1995–6).

Craig Wheeler was Chair, Panel on Stars and Stellar Evolution, National Academy of Science Task Group on Space Astronomy and Astrophysics.

Bev Wills finished a term on the Hubble Space Telescope's User Committee. She was also on the AGN Panel for the HST Cycle 6 Proposal review. Harriet Dinerstein served on the Interstellar Medium Panel for the HST Cycle 6 proposal review.

William Cochran served on the NASA Origins Subcommittee and the NASA Keck TAC.

Paul Shapiro served on the NASA Review Panels for the HPCC Grand Challenge Program and the Long-Term Space Astrophysics Program.

Mary Kay Hemenway served on the following organizing committees at the University of Texas: 1996 Conference for the Advancement of Science Teaching of the State Science Teachers Association of Texas; College of Natural Sciences' meeting on Discovery Learning; 1996 Summer Advanced Placement Institute.

Phillip MacQueen won the University President's Excellence Award, and Cleota Gambino won the College of Natural Sciences Staff Excellence Award.

Peter Shelus, Randall Ricklefs, and Jerry Wiant each received a Productivity Group Award from the Goddard Space

Flight Center as members of the NASA Satellite Laser Ranging Network Engineering Team.

Tom Barnes served on the Organizing Committee of Commission 27 (Variable Stars) of the IAU this year and wrote the triennial summary of research on field RR Lyrae stars for the commission.

Larry Trafton, Tom Barnes, and Anita Cochran served on the Local Organizing Committee for the January 1996 meeting of the American Astronomical Society in San Antonio.

Craig Wheeler served as a General Member, Board of Trustees, Aspen Center for Physics. He was a Co-Chair of the Organizing Committee for the Aspen Winter Workshop on Black Hole X-Ray Transients and on the Organizing Committee for the Texas Symposium on Relativistic Astrophysics. Craig Wheeler is on the organizing committee for the International Astronomical Union Commission 42–Close Binary Systems.

Chris Sneden is an associate editor of *The Astrophysical Journal*. Larry Trafton is an Associate Editor of *Icarus*. Ethan Vishniac served as a Divisional Associate Editor of *The Physical Review Letters*. Tom Barnes was a technical editor for StarDate Radio and *StarDate* magazine. Derek Wills was a technical editor for the popular science program ''Earth and Sky'' on National Public Radio.

2. ACADEMIC AND EDUCATIONAL PROGRAM

2.1 Graduate Program

The Graduate Studies Committee Chairman was Ethan Vishniac, with Graduate Advisor Neal Evans. The Fred T. Goetting, Jr. Memorial Endowed Presidential Scholarship was awarded to Byron **Mattingly**. The David Alan Benfield Memorial Fellowship was awarded to James **Di Francesco**. The Frank N. Edmonds, Jr. Memorial Fellowship was awarded to Wenbin **Li**. The Board of Visitors second-year project award was given to Vincent **Woolf**. Graduate students in 1995–1996 were Jay **Boisseau**, Michael **Brotherton**, David **Chappell**, Jungyeon **Cho**, Cecilia **Colomé**, James **Di Francesco**, Gregory **Doppmann**, Cynthia **Froning**, Niall **Gaffney**, Youxin **Gao**, Erik **Gregersen**, Rodney **Heyd**, Daniel **Hiltgen**, D. Andrew **Howell**, Renée **James**, Antônio **Kanaan-Neto**, Luke **Keller**, Scot **Kleinmann**, Eric **Klumpe**, Paul **Kornreich**, Anand **Kudari**, Wenbin **Li**, Zhiqing **Li**, Feng **Ma**, Byron **Mattingly**, Rebecca **McQuitty**, Michael **Montgomery**, Micahel **Moscoso**, Atsuko **Nitta**, Soojong **Pak**, Christine **Pulliam**, Divas **Sanwal**, Joe **Wang**, Qiangguo **Wang**, Vincent **Woolf**, Bingrong **Xie**, and Eric **Zink**.

Doctoral Dissertations: Eight Ph.D. degrees in astronomy were awarded in 1995–1996:

Cecilia **Colomé** (Supervisor P. Harvey): ''Far-Infrared Photometry and Near-Infrared Polarimetry of High-Mass Star-Forming Regions: Diagnosing Their Density Structure''

Paul **Kornreich** (Supervisor J. Scalo): ''Vorticity Generation by Shocks in the Interstellar Medium''

Scot **Kleinmann** (Supervisor R.E. Nather): ''G29-38 and the Advent of Cool DAV Asteroseismology''

John **Boisseau** (Supervisor J.C. Wheeler): ''The Multidimensional Structure of Detonations in Type IA Supernovae''

Niall **Gaffney** (Supervisor C. Sneden): ''Near-Infrared Measurements of Kinematics in Infrared Bright Galaxies''

Michael **Brotherton** (Supervisor B. Wills): ''The Nature of QSO Emission-Line Regions''

Daniel **Hiltgen** (Supervisor C. Sneden): ''Lithium in Evolved Stars''

Antônio **Kanaan-Neto** (Supervisor D. Winget): ''Magnetism and Pulsating Stars''

Master's Theses: Five Master's degrees in astronomy were earned in 1995–1996:

Erik **Gregersen** (Supervisor N. Evans): ''New Protostellar Collapse Candidates: An HCO^+ Survey of the Class O Sources''

Anand **Kudari** (Supervisor E. Vishniac): ''Thermodynamics and Radiative Transfer in Highly Magnetized Pair Plasmas: A Model of Soft Gamma Repeaters''

Cynthia **Froning** (Supervisor E. Robinson): ''The Infrared Properties of a Compact Binary Accretion Disk in Quiescence''

Eric **Klumpe** (Supervisor D. Winget): ''Carbon/Oxygen Phase Separation and Its Non-Influence on White Dwarf Cosmochronology''

Eric **Zink** (Supervisor P. Harvey): ''High Resolution 100 Micron Observations of Far-Infrared Luminous Galaxies''

2.2 Undergraduate Program

Derek Wills is the chair of the Undergraduate Studies Committee; Dan Jaffe served as undergraduate advisor. There were 31 astronomy majors this year, and seven students received BAs.

Sonali Kolhatkar was awarded the Outstanding Graduating Senior Award. She will be entering graduate school in astronomy at the University of Hawaii in the fall of 1996. Benjamin Shaw was the winner of the Karl G. Henize Memorial Scholarship in Astronomy. Bianca Basso is the recipient of this award for 1996–97. Audress Johnson is the winner of the Board of Visitors Undergraduate Scholarship in Astronomy.

2.3 Educational Services

The Painter Hall observatory, a 9-inch refractor telescope, was operated by Antônio Kanaan-Neto, Anand Kudari, and Feng Ma. From September 1995 through the end of August 1996, the observatory hosted 29 public nights with 670 visitors and 29 ''UT'' nights with 170 visitors. Thirteen group tours were arranged for 260 visitors.

The Educational Office of the Department hosted star parties every Wednesday, weather permitting, on the 14th floor observing deck of the Astronomy Department building. A large number of those were cancelled due to bad weather, but a total of 200 visitors participated. In March, we had 130 visitors at two special star parties to view Comet Hyakutake and a total lunar eclipse. 300 elementary school students visited the department during the twelve specially arranged solar tours.

In the course of the *Texas Energy Symposium for High School Students and Teachers*, Judit Ries hosted two special astronomy laboratory sessions for the participants.

Ethan Vishniac and Judit Ries participated in the Annual Honors Colloquium, giving a lecture and an informal discussion session. A special viewing session was also arranged by Judit Ries and Lara Eakins, with the help of the astronomy graduate students, for 70 high school students.

Lara Eakins and Judit Ries created a Web site for Education Office Services as a part of the departmental Web site. Information about tours, star parties, educational resources, and equipment is now available on line.

2.4 Public Information Office

The StarDate radio program continues to broadcast to an audience of 2.5 million daily on over 200 radio stations in the U.S. Universo, the Spanish-language version of StarDate, broadcasts on over 150 radio stations. It is heard in 40 of the top 50 markets in the U.S. Universo also broadcasts in Mexico, Venezuela, and South Africa. Sternzeit, StarDate's German counterpart, continues to broadcast on Deutschland Radio throughout Germany. *StarDate* magazine continues to be very popular among radio listeners and others in the U.S.

Universo was also made available to 60 school teachers for use in the classroom. A survey of these teachers indicated the need for a teacher guide to accompany the program and showed that each teacher exposed the program to an average of 77 students. The National Science Foundation has provided supplemental funds for the guide. Estrada Communications Group joined the Universo team to syndicate the series, search for corporate sponsorship, and provide public relations in the Hispanic community.

The W.L. Moody, Jr. Visitors' Information Center served over 130,000 visitors. Improvements were made that enable live video of the sun and the planets to be shown on the television screen inside the Visitors' Center. A volunteer program was successfully implemented by the Visitors' Center team. Staff uniforms were also added to the improvements made at the Center this year.

The project for a major expansion of the visitors' programs and facilities at McDonald Observatory was named the Texas Astronomy Education Center. The Texas Astronomy Education Center is a six-phase, $7.7-million-dollar project (including a $2 million endowment). It has been declared one of the top priority fundraising projects for the University of Texas by the Vice President for Development. A grant from the National Science Foundation totalling $943,000 was awarded for an interactive science exhibit entitled Fingerprinting the Universe. The Texas Department of Transportation awarded $420,000 for transportation enhancements in association with the expansion. Together with the private funds raised, the $2 million fundraising milestone for the Texas Astronomy Education Center was achieved in fiscal 1995–1996.

3. RESEARCH PROGRAM

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

In August, 1995, Phase II of construction of the het facility commenced. This included build-out of the interior, and followed installation of the telescope structure and the dome enclosure. In September 1995, problems with the structure's air bearing azimuth rotation system were debugged. An order was placed for the Segment Positioning System which consists of 273 linear actuators under computer control.

In October, final acceptance testing of the structure and azimuth rotation system was completed. Fabrication of the ULE blanks for the four spherical aberration corrector mirrors was procured from Corning Glass. Production of primary mirror segments (96 total, 1-m hexagons 50 mm thick, made of Zerodur) by Eastman Kodak went well, with four segments completed in October.

All 96 Primary Mirror segment blanks were received by Kodak from Schott Glass in November. Following a change in management, construction activities reached their best pace with regard to schedule. Development of electronics and software subsystems proceeded on schedule. Detailed design of the Prime Focus Instrument Platform commenced.

In December, two crates of completed primary mirror segments were delivered to Denton Vacuum for coating with protected silver. Work on the tracker system by Orbital Sciences Corporation continued, albeit at a slow pace. By January 1996, construction activities were virtually complete, including interior finishes, the large glycol/water air conditioning system, and landscaping. Additional development work was performed on the Hindle type primary mirror segment mounting system, resulting in fully acceptable performance.

In March, HET personnel began increasing their on-site participation. Previously, most work had been performed by contractors, but integration of mirrors, software, electronics, tracker, and instruments is to be performed by HET personnel.

In April, weather station installation was completed, and installation of software controls for dome rotation and structure interface were completed.

In May 1996, a contract was let to Space Optics Research Lab to fabricate three of the four radical aspheres of the Spherical Aberration Corrector. The fourth mirror was contracted to Tinsley Optical. The first two primary mirror segments were successfully coated at Denton, and a total of 34 man–days of HET personnel time was spent at the site.

Eleven completed primary mirror segments were received on site, and components were received to assemble quantities of the primary segment mounts. A surrogate, single-point diamond turned aluminum spherical aberration corrector assembly was received from II–IV Optical. This surrogate allows first light and telescope debug prior to completion of the Prime Focus Instrument Package.

In June, the first three primary mirror segments were installed, and the Center of Curvature Alignment Sensor (CCAS) was installed atop the 90-foot-tall tower provided for it. The CCAS is a polarization shearing interferometer used to sense segment tip, tilt, and piston positions for alignment.

In July, demonstration of the CCAS was accomplished, ensuring that interferometry could be performed over the long, exposed optical path. Initial final acceptance testing of the Tracker system was performed, and development of a thermal control algorithm for coarse segment position correction was in work.

As of August, the HET awaits installation of the Tracker, delivery of which is expected in September. The facility (including HVAC and downdraft ventilation system), the structure (including azimuth rotation system), the dome, and the CCAS instrument are all operational under full computer control. It is expected that first light will be achieved in November 1996, three months behind the schedule date established in August of 1992 at the inception of the project. It is expected that the HET will be fully operational by August 1997 and will be completed for the originally budgeted cost of $13.5 million.

3.2 Observing Conditions at McDonald Observatory

A summary of the hours scheduled, hours lost to poor weather, hours lost to telescope/instrument problems, and hours assigned to maintenance is given below. Available hours are measured from civil twilight to civil twilight, plus any especially scheduled daytime hours. (The daytime hours for all four telescopes together total only 21 hours.) Category ''Other'' is comprised primarily of time when the telescope was not scheduled or no program object was available.

The 2.7-m telescope records may be used to infer an estimate of the fraction of time the sky was suitable for spectrometry or imaging. After correcting for downtime due to maintenance, equipment, etc., the usable time is estimated as 67% for the last fiscal year. This value may be compared with 65% for the previous year and 62.4% for a fifteen-year mean. Until recently, the 0.9-m telescope was used predominately for photometry, so its usage can be used to infer the photometric weather statistic. From the 0.9-m telescope statistics for 1981–1992, the photometric weather at McDonald Observatory has averaged 39.8% of the available hours. (Since then, the 0.9-m telescope has been used only for special programs without sufficient statistics to infer the weather.)

3.3 Scientific Results

3.3.1 Instrumentation:

D. Lester has been active on the SOFIA Science Working Group and in activities to develop this important new observatory. He has been a leader in efforts to privatize SOFIA in order to achieve lower costs to the government by competitive procurement of the entire facility for development and operations. The University of Texas has played a major role in developing partnerships that are necessary for this effort.

TABLE 1. Utilization Statistics for McDonald Observatory Optical Telescopes (1995–1996) (hours)

			2.1-m		0.9-m		0.8-m	
a)	4034		4025		4020		4020	
b)	2406	(60%)	2402	(60%)	666	(16%)	1650	(41%)
c)	1203	(30%)	1410	(35%)	751	(19%)	851	(21%)
d)	35	(1%)	54	(1%)	104	(3%)	15	(1%)
e)	217	(5%)	1	(0%)	158	(4%)	49	(1%)
f)	173	(4%)	158	(4%)	2341	(58%)	1455	(36%)

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

R. Tull and colleagues are continuing the planning and design of a high-resolution fiber-fed broad-band optical spectrometer for the HET. The spectrograph will work in the range of resolving powers $30{,}000 \leqslant R \leqslant 120{,}000$, using an R-4 echelle mosaic with cross-dispersing gratings. The local team includes P. MacQueen, C. Sneden, W. Cochran, D. Lambert, A. Hatzes, D. Barry, and J. Good. The international team includes members at the HET member organizations at Penn State University and the University of Munich. Full funding has been obtained through an NSF grant together with private gifts, a State of Texas appropriation, and a NASA enhancement of an existing grant, plus University of Texas matching funds. Many of the major optical components have been ordered, and the all-refracting camera is currently under design by H. Epps (Lick Observatory). Completion is planned for the autumn of 1998.

D. Lester, G. Hill, and P. Harvey, with graduate students G. Doppmann and C. Froning, are finishing construction of the CoolSpec near-infrared spectrometer for use on the McDonald Observatory 2.7-m telescope. This spectrometer uses the ROKCAM HgCdTe camera as a detector which is mated to a spectrometer that can be cooled to 150 K to reduce background emission out to three microns. This instrument should see first light on the telescope in 1997.

The University of Texas Fabry–Perot Spectrometer has been upgraded. S. Pak and D. Jaffe have built a Fabry–Perot cooling box for the instrument. The low and stable temperature of the Fabry–Perot Etalon can reduce the background signal by a factor of two to four and stabilize the alignment of the Fabry–Perot mirrors. E. Klumpe and Jaffe have designed and built a 6-inch ''mini-telescope'' that will be integrated with the University of Texas Near-IR Fabry–Perot spectrometer. They will use this system to survey molecular clouds both near the solar circle and in the inner Galaxy. Currently, they are in the process of evaluating the pointing performance of the telescope.

L. Keller, T. Benedict, and D. Jaffe have improved their processing technique for fabrication of chemically etched (micromachined) diffraction gratings in silicon. They have done extensive testing on a prototype immersion echelle and found that the diffraction efficiency suffers from scattered light due to defects produced in the fabrication process. Keller has begun a design for installing an etched immersion echelle and a 256×256 near-IR (InSb) detector array into an existing spectrograph (IRSHELL, built by J. Lacy). The new spectrograph will have a resolving power of $R=100{,}000$ in the 1–5 μm spectral region. Keller is also working with Lacy, Jaffe, and M. Richter on a mid-IR spectrograph design for SOFIA.

W. Wren and J.C. Wheeler have put into operation a novel new telescope at McDonald Observatory to be used for a visual search for nearby supernovae. This telescope sits on an optical bench with a fixed 18-inch primary mounted with its optical axis horizontal. The only moving part is a flat at the opposite end of the optical bench. Comparison images are stored and accessed by a hyperlink connected to the software that selects the next closest galaxy to the last observed and slews the telescope accordingly. The rapid slewing of the Supernova Search Telescope caused some initial pointing problems. These were solved by Wayne Rosing of the Robotic Telescope Company by remachining both bearings (altitude and azimuth) and writing custom software to meet the unique optical and mechanical needs of this instrument. The Supernova Search Telescope became operational in March 1996. In April, the telescope set a program record of 2,549 observations for a single month. A lighting strike disabled the telescope for two weeks in July, and summer weather hindered observations. Totals for the Supernova Search Telescope as of September 29, 1996 are 8,704 observations of 2095 galaxies, one near miss, no discoveries (yet).

F. Bash, T. Sebring (HET Project Manager), L. Ramsey (Penn State and HET Project Scientist), and F. Ray (HET Lead Engineer) have examined the design of a telescope patterned on the Hobby●Eberly Telescope but with a diameter of 25 meters. The preliminary design allows cost estimates which suggest that the telescope with initial instruments could be built for less than $200 million.

3.3.2 Solar System:

The McDonald Observatory Planetary Search (MOPS) program (W. Cochran and A. Hatzes) continued survey observations designed to detect planetary systems in orbit around nearby solar type stars. Extremely high-precision measurements are obtained of radial velocity variations of a sample of 36 dwarfs and subgiants of spectral types F, G, and K. A time series of such observations will reveal the orbital motion of the star around the star–planet barycenter. An I_2 gas absorption cell placed in front of the 2.7-m telescope coudé spectrograph allows velocity precision of about 5–10 m s^{-1} to be achieved. A companion southern hemisphere survey is being conducted at the European Southern Observatory in collaboration with M. Kürster, K. Dennerl, and S. Döbereiner (MPI Garching). The eso survey uses an I_2 absorption cell at the 1.4m CAT. Four years of data from eso have demonstrated a long-term precision of better than 10 m s^{-1}.

The Hubble Space Telescope Astrometry Science Team continued to monitor the nearby stars Proxima Centauri and Barnard's Star for low-mass companions (investigation led by G.F. Benedict), and this year it added L726-8AB (P.J. Shelus, lead). Ten new data sets for Proxima Centauri were acquired this year with which to either confirm or refute the weak perturbation detected at P $\sim$80 days. They continue to analyze the astrometric residuals for the signature of a companion. With 35 observation sets acquired over three years, there are no obvious brown dwarf companions to Barnard's Star. Present companion mass detection limits for both Proxima Cen and Barnard's Star vary from 0.3 to one Jupiter mass for periods ranging from 100 to 600 days. The ten epochs for L726-8AB already yield a companion lower mass limit of two Jupiter masses for periods less than one-half year. Eight more epochs will be secured this year.

A. Cochran, along with H. Levison, S.A. Stern (both of SwRI), and M. Duncan (Queens University) continued their investigations of the structure of the Kuiper belt by studying the comet-sized bodies. They analyzed images of an additional field obtained with the HST WFPC2, but increased noise in the images (over the first field in August 1994) did not allow faint enough limiting magnitudes to detect the small objects. The lack of detected objects is consistent with the limiting magnitudes if the population was identical to that observed in the first hst field.

Comets deVico and Hyakutake (1996B2) were observed with the $R=60{,}000$ and $R=200{,}000$ modes of the 2DCoudé spectrograph and the $R=60{,}000$ Cassegrain Echelle spectrograph by J. Tomkin, W. Cochran, D. Lambert, C. Johns-Krull, and A. Hatzes. These spectra are being processed and analyzed by A. Cochran. With the highest resolution data, they are studying the line widths of the O (^{1}D), O (^{1}S) and H α lines along with single lines from NH_2, C_2, and CN. All lines are spectrally resolved. The NH_2 line is the narrowest, while all of the other lines except Hα are about the same width. The Hα line width is consistent with excess ejection velocity from photodissociation of H_2O. The modeling of these line widths is being performed by M. Combi (Michigan) using his Monte Carlo Particle Trajectory Model.

W. Cochran, A. Cochran, and K. Baines (JPL) obtained spectra of Jupiter to investigate a weak absorption band at 920–940 nm which Karkoschka (*Icarus* **111**, 174, 1994) suggested might be due to H_2O. High-resolution ($R=200{,}000$) spectra with the 2.7-m telescope 2DCoudé spectrograph revealed several absorption features from this band. These absorptions, however, do not coincide with the wavelengths of expected H_2O absorptions. The identification of the band remains uncertain, but the band morphology and the tendency of the features to weaken near the limb of the planet all suggest NH_3 as the most likely candidate.

L. Trafton and S.A. Stern (SwRI) completed their analysis of Pluto's UV light curve down to 2500 Å obtained with the Hubble Space Telescope. The absolute amplitude was found to vary little with wavelength from the visual to 2500 Å, but the relative light curve amplitude was found to increase by 40% over this range. Below 3100 Å, the light curve profiles and albedos are nearly independent of wavelength. No strong gaseous absorbers were found. They established an upper limit on the haze optical depth at 2600 Å of 0.54, or 0.26 extrapolated to the visual, which is still too high to rule out atmospheric haze as the cause of the sudden drop-off in the stellar occultation light curve.

With S.A. Stern (SwRI) and M.W. Buie (Lowell), L. Trafton analyzed high-resolution images of Pluto taken with hst to obtain albedo maps of Pluto's surface. These maps reveal that Pluto has a highly variegated surface, with extensive bright but asymmetric polar regions, large mid-latitude and equatorial spots, and possible linear features hundreds of kilometers in extent. Regions of fresh ice deposits were located. These maps will be useful for constraining models of Pluto's volatile transport, and for comparative studies of Pluto and Triton.

L. Trafton reduced spectra of Uranus' H_2 and H_3^+ emissions obtained with the UKIRT CGS4 and IRTF CSHELL. A variation with Uranus' rotational phase was noted for both species. This was attributed to the localization of auroral emission from the planet's tilted magnetic pole, and to a global ionospheric emission component which is relatively strong. This is different than Jupiter's case, where the non-auroral emission is quite weak. Comparative auroral studies are expected to elucidate the reasons for the different excitations on the two planets.

L. Trafton extended his FUV analysis of HST spectra of the G impact zone from comet SL9 by attempting to model and remove the Lyman H_2 band emissions to search for CO and other emissions. No such emissions were found. Strong saturation in the 4th positive CO bands limited their visibility relative to the large CO abundance derived from mm-wave observations; hence the weak FUV emissions appear not to be inconsistent with the large mm-wave CO column abundance.

3.3.3 Stars and Stellar Systems, Stellar Ejecta:

Using HST FGS astrometry data, it was determined that Barnard's Star is a periodic photometric variable, with a period clearly different than that found by HST for Proxima Centauri. G.F. Benedict (assisted by P. Shelus, A. Whipple, and D. Cornell) has instigated a ground-based photometric monitoring program to confirm or refute the period indicated by HST for Barnard's star. They used the McDonald Observatory Prime Focus Camera. The wide field allows for differential photometry with a large number of reference stars. They achieved 0.008 magnitude (one-sigma) precision, but only during photometric conditions. The data in hand are consistent with the variation found with HST but span an insufficient time interval to confirm the period.

J. Fernley (ESA-Vilspa) and T. Barnes completed their program on the metal abundances and radial velocities of field RR Lyrae stars. High resolution metal abundances of nine stars have permitted a recalibration of the relation: $[Fe/H]=-0.16-0.195\Delta S$. The velocities will be combined with HIPPARCOS proper motions for a new determination of the mean absolute magnitudes of RR Lyraes.

In collaboration with E. Luck (Case Western Reserve University) and T. Moffett (Purdue University), T. Barnes is investigating the metallicities of Magellanic Cloud Cepheids. A successful observing run by Moffett at the CTIO 4-m telescope led to collection of spectra of 16 Cepheids for this program. The spectra are in reduction by Luck. These will not only clarify the abundance anomalies noted by Luck and D. Lambert in Magellanic Cloud Cepheids, they are also needed for the application of the surface brightness method to determination of these Cepheids' distances. The latter work is in collaboration with W. Gieren (Catholic University of Chile).

G. González has been studying the photospheric abundances of field RV Tau variables since 1993 in collaboration with D.L. Lambert and S. Giridhar (Indian Institute of Astrophysics). The field RV Tau's have been found to exhibit abundance patterns similar to that seen in the ISM, where the abundances of the elements correlate with their condensation temperatures.

G. González has also been studying the spectra of the recently discovered extra-solar planetary systems. The results of the analyses show that the stars in these systems are metal-rich. This finding might have far-reaching impact not only in planet formation studies, but also on stellar and galactic chemical evolution.

A. Hatzes, W. Cochran, and C. Johns-Krull searched for variability in the spectral line profiles of 51 Pegasi to determine whether the radial velocity variability discovered by Mayor and Queloz (*Nature* **378**, 355, 1995) is really due to a planetary companion or might, instead, be a result of stellar pulsations. They found no evidence for line variability and thus excluded the presence of nonradial sectoral modes with $l \geqslant 4$. They did not find any variation in the equivalent width of spectral lines, thus placing a limit of $\Delta T = 4$ K for any disk-integrated temperature variations of the stellar surface. The projected rotational velocity was also measured using nine spectral lines, yielding a mean value of $v \sin i = 2.35 \pm 0.1$ km sec^{-1}. This along with the published rotation period of 37 d yields a minimum stellar radius of 1.7 $R_\odot$. The planetary companion hypothesis is still the most likely explanation for the radial velocity variations.

A. Hatzes and W. Cochran conducted further high-precision radial velocity measurements of the K-giant β Oph. These data show radial velocity variations with a period of 13.05 days. Rotational modulation, low-mass companions, and radial velocity variations can be excluded as an explanation for these variations. Most likely this period results from a nonradial g-mode. A period analysis of the residual radial velocities after subtracting the contribution of the dominant period yields a long-term period of 142.3 days and a short-term period of 0.2589 ± 0.005 days. The latter is consistent with previous work by Hatzes and Cochran. The long-term period, if real, most likely arises from rotational modulation of surface features, although the presence of a planetary companion cannot be excluded at the present time.

C. Sneden, J. Cowan (University of Oklahoma), and J. Truran (University of Chicago) have strengthened the use of thorium (Th, $z=90$) as a cosmochronometer in ultra-metal-poor stars by combining ground based data and HST ghrs spectra of the bright metal-poor stars HD 126238 and HD 122563 to demonstrate that a solar-system r-process abundance distribution persists in metal-poor stars out to elements (Os, Pt, and Pb) of the ''3rd neutron-capture peak.''

C. Sneden, G. Preston and A. McWilliam (Carnegie Observatories), J. Cowan and D.L. Burris (University of Oklahoma), and B. Armosky have continued their detailed exploration of the spectrum of the ultra-metal-poor, but neutron-capture-rich, halo giant star CS 22892-052. Abundances for 20 neutron-capture elements from over 200 spectral features have been deduced. Element abundances in the range $56 \leqslant Z \leqslant 76$ match the scaled solar system r-process abundance distribution very well and bear little relation to the scaled solar s-process distribution. This r-process abundance pattern could only have been generated in the explosive nucleosynthesis of a prior supernova (surely one of the very earliest element donors of our Galaxy). The depressed abundance of the radioactive element Th in CS 22892-052 signals a large age for the progenitor to this star; a lower limit for the ''age'' of its supernova precursor ($\simeq$ the Galactic halo age) is 15.2 ± 3.7 Gyr from the Th abundance. In related work, this group has considered the Th-based age in more detail. Investigation of effects of nucleosynthesis and galactic chemical evolution mainly push the implied age of CS 22892-052 material to higher values, with a likely maximum age of about 18 Gyr.

For more ordinary metal-poor stars ([Fe/H] ~ -2), C. Sneden, J. Wright, and B. Carney (University of North Carolina) have recently completed a study of five stars from the Carney-Latham metal-poor star sample that might have Galactic disk kinematics. One candidate star (BD+80 245) has a nearly unique abundance signature among metal-poor ([Fe/H] $\simeq -1.9$) stars. It is α-capture-poor: [Mg, Si, or Ca/Fe] $\simeq -0.2$. This is a vivid exception to the standard assumption of α-rich metal-poor star material. They are currently gathering further spectra of this star to provide a complete abundance distribution.

C. Sneden, R. Kraft (UCSC), E. Langer (Colorado College), and C. Pilachowski (NOAO/ KPNO) have been deriving light element abundances from echelle spectra of large stellar samples (typically $\geqslant 10$) on the upper red giant branches (*RGB*s) of globular clusters spanning the metallicity range $-0.8 \geqslant$ [Fe/H] $\geqslant -2.3$. They find that the very large star-to-star variations of the light elements C, N, O, Na, Mg, and Al are linked via the common culprit of high temperature proton-capture fusion. At some time(s), in some place(s) in cluster evolution, advanced proton captures have reshuffled substantial numbers of light element abundances via C,O$\rightarrow$N, Ne$\rightarrow$Na, and Mg$\rightarrow$Al synthesis chains. Research this past year has concentrated on M13. First, Na abundances for 130 giants with luminosities extending down to the level of the *HB* ($M_v = +0.3$) were derived; the data were moderate-resolution spectra from the kpno/wiyn Hydra multi-object spectrograph. The Na abundances are always high in stars near the *RGB* tip ($M_v < -1.7$ or $\log g < 1.0$), and many lower luminosity *RGB* stars have Na abundances similar to those of field metal-poor stars. However, high Na-abundance stars occur at all M13 *RGB* positions, indicating either a) that there were indeed primordial star-to-star Na abundance variations, or b) that high-temperature proton-capture nucleosynthesis and convective envelope mixing of processed material happened quite early in the stars' evolution after leaving the main sequence. Second, they observed 11 lower luminosity M13 *RGB* stars at high resolution with the Keck I HIRES spectrograph, and combined these stars with 23 others previously and newly observed with the Lick Hamilton Echelle spectrograph. This 34-star sample demonstrates that the O–Na, O–Al anticorrelations and O–Mg, Na–Al correlations do not depend on *RGB* positions.

Detailed studies have been made of the photosphere and the circumstellar environment of several candidate post-AGB stars by E. Bakker. A survey has been initiated (with D.L. Lambert) which aims at detecting at ultra-high-resolution ($R = 200{,}000$) molecular absorption lines in optical spectra obtained using the 2.7-m telescope at McDonald Observatory. They find complex line profiles and line widths significantly broader than expected from thermal broadening.

H. Dinerstein and C. Sneden have been studying the neutral envelopes of planetary nebulae by observing resonance absorption lines from species such as Na I, which arise in these layers and can be seen against the optical continuum of the central star; such lines offer a new probe of these photodissociation regions, which appear to be a major mass constituent of most planetary nebulae. Their earlier survey of 21 planetary nebulae in the Na I D lines (5889.95 Å) at a spectral resolving power of 30,000 (Dinerstein, Sneden, and Uglum 1995, *ApJ* **447**, 262) revealed that over 50% of the sample showed evidence for Na I, and hence for neutral material in the circumnebular environment. They are currently extending this work by observing a larger number of nebulae at higher spectral resolution with the 2DCoudé spectrograph on the McDonald Observatory 2.7-m. In addition to improving the statistics on the prevalence of the neutral envelopes, the new work aims at measuring additional, weaker lines which provide diagnostics of the chemical and thermal structure of these regions. An initial result from the new observations, undertaken in collaboration with K. Volk (University of Calgary), is that the weakness of the Ca II emission lines near 7300 Å implies very severe depletion of calcium into dust grains and sets strong limits on the extent of dust destruction in these regions of planetary nebulae.

H. Dinerstein, with graduate student C. Pulliam and D. Garnett (University of Minnesota), has begun a new observational study of faint optical emission lines from recombining oxygen atoms in planetary nebulae. Since the emissivities of these lines have similar, weak dependences on the gas temperature as those of recombination lines of hydrogen and helium, the ratios among these lines should yield reliable O/H abundances for the ionized gas, avoiding the uncertainties due to the strong dependences of the collisionally-excited forbidden [O III] lines on electron temperature. However, recent results from other groups have yielded surprisingly large O/H values, some greater than solar, and large discrepancies between O/H as determined from the two kinds of lines in the same nebulae. Observations of about 10 planetary nebulae at a spectral resolving power of 2000 were obtained at McDonald Observatory on the 2.7-m in the summer of 1996 and are being analyzed and combined with the higher-resolution coudé data of Dinerstein, Sneden, and Volk. This study should yield accurate new fluxes for the O recombination lines in several nebulae, and enable us to test the claims of high O/H values.

M. Adams, W. Wren, M. Ward, L. Wang, and J.C. Wheeler have begun a search program for supernovae in clusters with redshift in the range $Z = 0.03$–0.15. This search will take advantage of the wide field of view of the Prime Focus Camera on the 0.76-m telescope to survey entire Abell clusters in a single image. Search software provided by B. Schmidt (Mt. Stromlo) has been configured for the McDonald instrumentation, and a large collection of comparison images have been obtained. Graduate student A. Howell has joined the project and was instrumental in customizing the search software. The search will resume in the fall.

L. Wang and J.C. Wheeler have continued their program of supernova polarimetry. They showed that a classic Type II supernovae is polarized before maximum at about the one-percent level, similar to all other well-observed Type II at later times. These early observations constrain models in which the polarization is due to asymmetric distributions of radioactive elements, because it is less likely that they can effect the results before the envelope becomes thin. This may imply that some asymmetry in the outer envelope is present. Wang, Wheeler, and P. Höflich established that the Type Ia supernova SN 1996X is polarized at about the level of 0.1 percent, roughly consistent with the upper limits placed on other Type Ia. The polarization spectrum is much more wavelength-dependent than the total flux spectrum due to the dominance of scattering lines as confirmed by atmosphere models. More thorough study of the cause of this polarization is underway. A principle candidate is composition inhomogeneity at the iron/silicon interface.

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

J. Scalo and M. Miesch (University of Colorado) continued their investigation of the statistics of the Bell Labs ^{13}CO survey of local star-forming regions. Previous results demonstrated near-exponential tails in the probability distribution of centroid velocities of many of the regions. A new result is that the probability distributions of linewidths appear uniformly exponential or possibly log normal, an unexpected and unexplained result. One possible complication, at least for the velocity centroids, is that the statistics may be affected by the fact that filtering is unable to convert the observations into a statistically homogeneous field: large-scale structure remains. Coupled with an observational sampling that is biased to large signal strengths, the net effect is for much of the tail distribution to arise from spatial outliers that are sampling regions where the large-scale velocity differs from that in the densely sampled regions. The importance of this effect is being investigated. Interpretations in terms of physical processes are also underway.

J. Scalo and A. Lazarian (Princeton University) investigated the effects of cloud occlusion (blocking of one cloud by a larger foreground cloud) on observational estimates of the cloud size and mass spectra in order to understand the discrepancy between size and mass spectra derived from extinction and from spectral line surveys. The effect is of the right magnitude, but only if the surveys span a sufficient range in size or mass. The range of most observed surveys is insufficient for a clear resolution of the discrepancy.

A group comprised of N. Evans, D. Jaffe, J. Di Francisco, W. Li, S. Pak, E. Gregersen, L. Keller, and E. Klumpe continues to study star formation on scales ranging from giant molecular cloud complexes to molecular cores forming clusters and to cores forming individual or binary low-mass stars. Their primary tools are the Caltech Submillimeter Observatory, including a re-imaging device, and the University of Texas Near-IR Fabry–Perot Spectrometer. They also use data from many other telescopes, including ISO. These data are then modeled with 1-D and 2-D Monte Carlo radiative transfer codes.

N. Evans, collaborating with E. Lada (University of Florida) and E. Falgarone (Ecole Normal Superieure) has completed a multitransition CS study of the cores in L1630 for the physical conditions in the star-forming cores. E. Gregersen, Evans, and S. Zhou and M. Choi (Institute for Astronomy and Astrophysics, Taiwan) have surveyed 23 Class 0 sources in HCO^+ to study the density, temperature, and velocity structure. They found that nine sources have line asymmetries (skewed to the blue) characteristic of collapse. W. Li, Evans, and Lada have surveyed a large region of the L1630 cloud in the near-IR. They found very few objects with a color excess outside the known cluster, suggesting that there is very little recent star formation distributed through the cloud.

S. Pak and D. Jaffe have finished observations of near-IR H_2 emission lines in the Magellanic Clouds using the UT Fabry–Perot Spectrometer. The H_2 molecule is excited by far-UV radiation, and the emission will trace the photodissociation regions (PDRs) in the clouds. Pak and Jaffe, collaborating with G. Stacey (Cornell), have also observed the H_2 lines from the central regions of nearby gas-rich galaxies (M82 and IC 342).

J. Di Francesco, N. Evans, and P. Harvey have analyzed new high-resolution, far-infrared continuum kao maps of the intermediate-mass, pre-main-sequence Herbig Ae/Be stars and found further evidence for extended envelope structure around these sources. These results suggest that the relevance of disk structures at far-infrared wavelengths is reduced. In addition, similar observations have been analyzed of ten highly-embedded IRAS sources that may be precursors to the Herbig Ae/Be stars, revealing that this sample mostly exhibits extended emission indicative of envelope structure. Comparison of these samples will probe how envelope structures evolve with their young central objects towards the main-sequence.

J. Di Francesco, N. Evans, and C. Chandler (Mullard Radio Astronomy Observatory) observed two Herbig Ae/Be stars at the VLA in the 7-mm, 1.3-cm, and 3.6-cm continuum to constrain the contribution of free-free emission from thermal dust emission to the detected emission at 2.7 mm. One source (Elias 3-1) was detected at all three wavelengths, allowing better-constrained models of its small-scale circumstellar structure. J. Di Francesco and collaborators have continued their large-scale mapping of regions surrounding Herbig Ae/Be stars in the $J = 3–2$ line of both ^{12}CO and ^{13}CO, allowing them to compare the gas and dust envelopes of these pre-main-sequence objects.

3.3.5 Extragalactic:

G. Shields continued a study of chemical abundances in extragalactic H II regions using the HST. With D. Garnett and E. Skillman (University of Minnesota) and R. Dufour (Rice University), he found log C/O $= -0.6 \pm 0.1$ in I Zw 18, the most metal-poor galaxy known. This value is lower than in the sun, but it departs from a trend of decreasing C/O with decreasing O/H shown by other metal poor galaxies. This suggests that I Zw 18 experienced an earlier burst of star formation and is not a ‘‘primeval galaxy,’’ despite its low abundance of heavy elements.

H. Dinerstein has begun a program of optical spectroscopy of H II regions in the sample of galaxies observed by the ISO Key Project on ‘‘The Interstellar Medium of Normal Galaxies.’’ This project, which involves 11 co-investigators (G. Helou of Caltech/IPAC is the Principal Investigator), includes a survey of about 60 galaxies of a wide range of morphological types and infrared emission characteristics. The iso observations include measurements of the infrared dust continuum and far-infrared emission lines from diffuse ionized and neutral gas. Ground-based observations of these galaxies at McDonald Observatory and elsewhere (by other members of the Key Project team) will provide measurements of the metallicity (e.g., O/H) in the ISM of these galaxies and will enable us to examine relationships between metallicity and other properties of the galaxies, particularly those determined from the iso observations.

D. Lester, with graduate student E. Zink, has been completing a high-spatial resolution study of the distribution of far-infrared continuum emission around luminous galaxies. This study has been completed using the Kuiper Airborne Observatory, with diffraction-limited detector arrays. This work shows that in many of the $L > 10^{11} L_\odot$ galaxies that were observed, the far-infrared emission is significantly extended on kiloparsec scales. This work helps in the understanding of the distribution of luminosity in interacting pairs, which constitute a large fraction of these luminous sources. Their sample size of fifteen galaxies appears to offer a representative picture of the far infrared structure of distant, luminous galaxies.

D. Lester, N. Gaffney, and G. Doppmann have been analyzing the kinematics of starburst galaxies using infrared recombination lines and the 2.3-micron CO bandhead from the cool stellar component in these galaxies. This work has been done using the IRTF CSHELL infrared spectrometer. The work has identified differences in the kinematics of ionized gas and red starlight. It is presumably the latter that best represents the dynamical properties of these galaxies. The study of M82 is complete, while the data on NGC4736 and NGC3256 is still being analyzed.

I. Jørgensen and M. Franx (Kapteyn Institute, Groningen, Holland) have continued the study of elliptical and lenticular galaxies in nearby clusters. Analysis of absorption line strengths shows that a large fraction of the galaxies have abundance ratios of magnesium relative to iron above the solar value. Further, the abundances of magnesium and iron as well as the abundance ratio of magnesium relative to iron depend on the density of the cluster environment. To further understand the stellar populations of nearby cluster elliptical and lenticular galaxies Jørgensen, B. Milvang-Jensen (Copenhagen University), and Franx have obtained data for large magnitude-limited samples of galaxies in four nearby clusters.

I. Jørgensen, M. Franx, and J. Hjorth (NORDITA, Denmark) have established the fundamental plane (FP) for two galaxy clusters at $z = 0.2$. The FP is a tight relation between effective radius, surface brightness, and velocity dispersion for the galaxies. It is possible to use the FP to quantify the luminosity evolution of elliptical and lenticular galaxies. The evolution implied from the FP for the two clusters at $z = 0.2$ is consistent with a passive luminosity evolution and a formation redshift for the galaxies of four or larger. S. Luo, H. Martel, and E.T. Vishniac have continued to study the use of statistical measures to categorize galaxy clustering. They have applied these statistics to a set of numerical simulations and found that they are a robust means of distinguishing between models with similar correlation functions. Applied to real galaxy catalogs, they find significant differences between the CfA and Perseus–Pisces catalogs, implying that neither is a fair sample of the universe.

G.F. Benedict obtained two orbits of HST WFPC2 data (V- and I-band) on NGC 7479 on 16 October 1995 and is in the process of analyzing the frames. He obtained five orbits (U, B, V, I, H-alpha bandpasses) of WFPC2 data of NGC 4314 on 29 December 1995. All data have been reduced, but the team (I. Jørgensen, D. Cornell, A. Whipple, D. Chappell, B. Smith (IPAC), J. Kenney (Yale University), and S. Laine (University of Florida)) has only partially analyzed the NGC 7479 images. NGC 7479 has asymmetric spiral arms and strong star formation along its bar, yet has no observed companions (confirmed with digitally stacked PFC data obtained this year), suggesting that it has recently undergone a merger with a low-mass galaxy. Our HST V and I images of this system show a galactic core with high extinction. In the central 1″ of this galaxy, three distinct sources are observed, similar to those of the super star clusters found in merging and starburst galaxies. Once fully analyzed, these observations will aid in understanding the feeding of nuclear engines by bars, the evolution of bar-driven nuclear structure, and the genesis of pathological grand-design spiral galaxies.

G. Shields proposed an explanation of the observed high abundances of heavy elements in the broad absorption line (BAL) gas of QSOs. Several workers have found abundances of C, N, O, and Si one to two orders of magnitude higher than solar, and Junkkarinen *et al.* (1995) reported P/C $\approx 65(\mathrm{P/C})_\odot$. Shields showed that these abundances resemble those of classical novae. He suggested that the BAL gas is in fact nova material accelerated to high outflow velocities by the QSO radiation pressure or a wind. Accretion of gas onto single white dwarfs passing through an accretion disk around a supermassive black hole can result in a large rate of nova explosions in QSOs.

M. Brotherton undertook statistical investigations of the broad emission lines in several samples of intermediate-redshift QSOs and discovered strong relationships among line ratios, widths, asymmetries, and redshifts of Ly α, the λ1400 feature, C IV λ1549, C III] λ1909, and other weaker UV lines characterizing a range of excitation conditions. These relationships, together with photoionization modeling, led to the derivation of rather different physical and chemical properties for gas with lower ($\sim$2000 km s^{-1}) and higher velocity dispersion ($\sim$7000 km s^{-1}) (Brotherton, Wills, Francis, and Steidel, *ApJ* **430**, 495, 1994). This was the first investigation to show highly significant differences in the emission-line spectra of radio-loud and radio-quiet QSOs (C IV λ1549 and C III] λ1909 are narrower in radio-loud QSOs) (Brotherton, Wills, Steidel, and Sargent, *ApJ* **423**, 131, 1994). The H β profile shows clear dependences on the dominance of a compact radio core, an indicator of orientation of the central engine's rotation axis. Several relations suggested a strong link between the $\sim$2000 km s^{-1} gas on scales of $\sim$1 pc, and that of the narrow line region at distances of $>$ several pc from the nucleus. This was confirmed by obtaining and measuring IR spectra in the H β – [O III] λ region in the same QSOs for which C IV λ1549, C III] λ1909, or Mg II λ2798 data were available. The main collaborators on some aspects of the above investigations were P.J. Francis (University of Melbourne), B. Wills, D. Wills, and F. Ma.

The HST team (B. Wills, D. Wills, K. Thompson, M. Brotherton, J. Baldwin (CTIO), H. Netzer (Tel Aviv University), G. Ferland (University of Kentucky), R. Caswell (Institute of Astronomy, Cambridge University), and I. Browne (Jodrell Bank Observatory)) continued investigations of relationships among line, continuum, and radio-structure measurements on the complete dataset of spectra from below Ly α to beyond H β for almost 60 radio-loud QSOs. Spectral Principal Component Analyses show that ratios of broad-line strengths, and their profiles, are quite similar from one QSO to another. However there are relationships between continuum shape and narrow line emission that we are still investigating. With C. Wei, a comparison is being made with the HST archival Faint Object Spectrograph data for both radio-loud and radio-quiet QSOs, and we are making spectral principal component analyses for both the HST radio-loud QSO sample and archival spectral data.

B. Wills and F. Ma are investigating the meaning of the new core-dominance factor (the ratio of relativistically beamed radio-core flux to optical or near-infrared non-synchrotron flux). This core-dominance factor is likely to be useful as an indicator of orientation of the spin-axis of the central engine in radio-loud QSOs (Wills and Brotherton, *ApJ* **448**, L81, 1995).

In collaboration with A. Laor (Technion, Israel), B.J. Wilkes (Harvard–Smithsonian Center for Astrophysics), G. Ferland (Kentucky), D. Wills, and M. Brotherton (now at LLNL), B. Wills is investigating relations of UV and optical broad emission lines, absorption lines, and continua with the ROSAT X-ray spectra. This is for a complete subset of 23 of the Palomar–Green (B–V selected) sample having redshift <0.4 and Galactic hydrogen columns $<1.9\times10^{21}\ \mathrm{cm}^{-2}$ (Laor, Fiore, Elvis, Wilkes, and McDowell, *ApJ* **435**, 611, 1995). With respect to data, the project is half complete. When completed, it will provide a valuable comparison with samples of different luminosity, radio and X-ray and infrared selection criteria.

B. Wills, B. Xie, and M. Brotherton are investigating the dependence of narrow [O III] λ5007 profile parameters on ROSAT X-ray spectra using the above subset of the PG sample. This investigation was suggested by Brotherton's (1996) finding that [O III] profiles are broader when the optical-to-X-ray spectra are steeper.

D.C. Hines (University of Arizona) and B. Wills, along with G. Schmidt, P. Smith, R. Allen (Steward Observatory), and M. Sitko (University of Cincinnatti), have made spectropolarimetric measurements of the UV emission from two IRAS-selected QSOs. The rapid rise in polarization observed in the optical becomes independent of wavelength ($p\approx$ 1012%) for $\lambda\lesssim3000$ Å (rest). The spectrum of polarized light peaks near $\lambda\sim3000$ Å (rest) and decreases rapidly for shorter wavelengths. This behavior is similar to that seen in high redshift radio galaxies and some BALQSOs, and has been interpreted as evidence for dust scattering.

D.C. Hines (University of Arizona) and B. Wills, along with G. Schmidt, P. Smith, (Steward Observatory), R. Goodrich (Keck), and M. Sitko (University of Cincinnatti) have used the WFPC2 on HST to obtain images in polarized light of the hyperluminous infrared galaxy IRAS P09104+4109. A highly polarized biconical structure centered on the nucleus is revealed. This strongly reinforces the spectropolarimetry results of Hines and Wills (1993) which suggested that P09104+4109 is a misdirected QSO that would appear as a typical luminous QSO if viewed from the direction of the scattering (polarizing) material.

F. Bash participated in a research project which discovered and analyzed a radio-frequency jet or arc found near the center of M81. The arc extends 0.9 kpc in the plane of the sky and has no apparent optical counterpart. The arc is highly polarized and, most likely, is highly inclined to the plane of the galaxy.

The Texas Survey of discrete radio sources is based on 365 MHz observations made at the University of Texas Radio Astronomy Observatory (UTRAO) during the period 1974–1983. After an extended period of data reduction and calibration, the final version of the Texas Survey, listing arcsecond positions, flux densities, and structure models for 66841 discrete radio sources between −35 and +71 degrees declination, was published in the *Astronomical Journal* in May 1996 by J.N. Douglas, F.N. Bash, and former department members F.A. Bozyan, G.W. Torrence, and C. Wolfe. Douglas continues to reduce post-survey observations to extend the time-base and precision of flux density variability data on the approximately 1000 variable sources discovered by the Survey. The Survey may be accessed on the World-Wide Web: http://utrao.as.utexas.edu/txs.html.

3.3.6 Theory:

R. Duncan, in collaboration with C. Thompson (University of North Carolina at Chapel Hill), studied the evolution of neutron stars with very strong magnetic fields, $B_{\mathrm{dipole}}\sim10^{14}$–$10^{15}$ G and $B_{\mathrm{internal}}\sim10^{15}$–$10^{16}$ G. The magnetic field, rather than the rotation, is the main source of free energy in such ''magnetars.'' These stars might be observed as soft gamma repeaters (SGRs), anomalous X-ray pulsars (AXPs) like 1E 2259+586, and/or gamma-ray burst sources. Their fields evolve primarily via ambipolar diffusion in the liquid interior and Hall drift in the crust. Magnetic dissipation heats the nuclear fluid, powering steady, thermal X-ray emissions, as observed in SGRs and AXPs. Magnetically-induced crust fractures also occur, and could power SGR bursts. Such fractures drive pulses of Alfvén waves into the magnetosphere which undergo nonlinear damping, creating a magnetically-confined thermal pair plasma with a trace contamination of baryons. The pair plasma cools via hyper-Eddington thermal X-ray emissions with little spectral evolution, as observed in SGR bursts and in the soft-spectrum tail of the exceptional 1979 March 5th gamma-ray burst. A. Kudari and Duncan studied radiative transfer in the outer layers of these confined pair bubbles. Absorption and emission processes are suppressed because of the large Landau-level energy, but magnetic photon–electron scattering maintains energy equipartion. Photon number-changing occurs primarily via the exotic QED processes of photon merging and splitting in the strong magnetic field. In his Master's thesis, Kudari calculated the Bose–Einstein photon spectrum at the E-mode scattering photosphere. Further photon splitting occurs outside this photosphere and must be included in realistic calcuations of SGR burst spectra.

R. Duncan and H. Li (Los Alamos National Laboratory) made Monte Carlo models of the distribution of high-velocity neutron stars in the halo of our Galaxy, in order to test halo gamma-ray burst models. In particular, they considered a ''halo beaming model'' (HBM) in which emergent gamma rays are beamed along a magnetic axis which is directionally correlated with the peculiar velocity of a burster escaping from the galaxy. Such conditions occur in the magnetar theory of GRBs. The HBM gives an adequate fit to GRB observations for a range of beam widths of about 10° to 30°. In this scenario, GRBs are magnetic reconnection events, like stellar flares.

J. Scalo and P. Kornreich examined the vorticity produced by shocks propagating through the interstellar medium. General analytic results were derived for three cases: 1. Curved shock propagating through a uniform medium; 2. Planar shock encountering a general density inhomogeneity; 3. Planar shock encountering a general velocity inhomogeneity. In each case the vorticity generation has two components: 1) a kinematic vorticity production just behind the shock, which arises purely because of the nature of the shock jump conditions and does not involve any dynamical or thermal effects, such as baroclinic vorticity production; 2) a dynamical vorticity production downstream from the shock, which represents the amplification or destruction of vorticity due to the velocity, density, and pressure gradients in the post-shock flow. Explicit analytical results are found for the kinematic component and numerical solutions are presented for the dynamical component.

J. Scalo and P. Kornreich applied their analytic derivations of vorticity production behind shocks to the case of a planar shock encountering a spherically symmetric, density-stratified cloud. The results show that, at large Mach numbers, the kinematic vorticity generation dominates over the dynamical production, the induced vortical velocities (and by symmetry, the induced compressional velocities) are a significant fraction of the shock speed, and the induced velocities depend on the inverse square root of the cloud internal density. The results were supported by lattice gas simulations of a shock-cloud encounter at mildly supersonic shock speeds. The induced vortical motions should rapidly be converted into comperessible or MHD modes with accompanying density fluctuations. The results suggest that the source of the supersonic linewidths and internal density structure seen in interstellar clouds is shock waves, which provide a means of generating internal density and velocity structure without any source of instabilities.

D. Chappell and J. Scalo investigated the question of whether the behavior of ''one-zone'' models for star formation activity in galaxies, including self-regulating stability, limit cycles, or chaos, would survive when spatial degrees of freedom were included in the models. A two-dimensional lattice simulation of local and nonlocal heating or stirring by star formation, which inhibits further star formation, along with dissipation due to gas interactions at a subgrid scale, was studied. Star formation is assumed to occur at the Toomre condition threshold and at a rate corresponding to the fastest growing mode. A linear stability analysis of the system with and without spatial couplings was also performed. The results show that at least five distinct modes of behavior can be found in the (coupling parameter–gas column density) phase diagram. These phases include steady behavior, small isolated patches of star formation, coherent propagating waves of star formation, and synchronized behavior of the entire lattice, with star formation occuring in huge ''cloudy'' structures. The synchronized behavior appears to be an emergent property of the model and would not be expected given the long timescales for communication across the lattice. This work demonstrates the possibility that coherent self-organized behavior of star formation can occur over large scales without the presence of organizing forces such as self-gravity, spiral waves, etc., and that the behavior of galactic disk gas may proceed through phases as the average column density changes. Whether or not this result persists in the presence of hydrodynamical spatial couplings remains to be seen.

D. Chappell and J. Scalo studied simulations of the spatial structure and temporal behavior of a model interstellar medium. The simulations are intermediate-level representations in which stellar/cluster winds and hydrodynamical advection are the dominant processes, but thermal pressure is ignored, as if the effective ratio of specific heats were zero. The models can also be thought of as simulations of a driven quasi-Burgers equation that includes the mass conservation constraint. The simulations are two-dimensional, and incorporate a finite difference representation of advection, a momentum-conserving model for the action of cluster winds, and a threshold gravitational instability criterion for star formation in the shells generated by the winds. The simulations generally evolve by a bottom-up hierarchical agglomeration of interacting wind-driven shells, generating a highly filamentary spatial structure over a range of scales. The power spectrum of the velocity field, the mass spectrum of coherent ''clouds,'' the probability distribution of velocity, and the temporal behavior of the star formation rate are examined. One interesting result is that the velocity distribution of gas in dense shells is non-Gaussian and often nearly exponential. A cloud mass spectrum with a power law index of around -1.5 is found, similar to predictions of coalescence models but with no assumptions about cross section or velocity distribution, which arise from the simulated hydrodynamics. However, the index appears to vary with the star formation activity. A simple ''one-zone'' model is found to account satisfactorily for the scaling of the velocity dispersion with other parameters for the simulations.

J. Scalo continued an investigation of models for the stellar and ''cloud'' initial mass spectrum (IMF), emphasizing models that couple the IMF to the statistics of the velocity field, such as velocity fields dominated by stellar or cluster winds, by externally-driven shock waves, or by some sort of more traditional ''turbulence'' or motions driven by MHD waves. The main goal is to understand how different assumptions about the dominant physics affects the predicted degree of universality and variations in the IMF, and to examine whether meaningful choices between theories can presently be made, given the range of possible physical scenarios and the weakness of observational constraints. A number of simplified models for the gas velocity distribution function have been examined: an ensemble of stellar or cluster winds, a Fokker–Planck approach to the energy-input/cloud collision model, and the statistical mechanics of systems in which momentum, but not energy, is conserved. With D. Chappell, quasi-hydrodynamical simulations are being examined in which the velocity field is calculated explicitly and the mass spectrum is allowed to feed back on itself.

A. Khokhlov, E. Oran (Naval Research Laboratory), and J.C. Wheeler developed a theory of deflagration to detonation transition in unconfined flames based on the Zel'dovich gradient mechanism. They proposed that the necessary gradient in conditions of compostion and temperature is produced by turbulence and local quenching of any laminar and turbulent flame. They derived a criterion for the minimum length scale of the premixed turbulent region which should apply both to chemical terrestrial and nuclear astrophysical flames. This theory can be applied to thermonuclear explosions in white dwarfs to predict the needed strength of turbulent premixing and the critical density for the transition, which should be a little in excess of 10^7 gm cm^{-3}. This theory will be incorporated in future three-dimensional models of the dynamics of Type Ia supernovae.

A. Khokhlov, I. Lichtenstadt (Hebrew University of Jerusalem), and J.C. Wheeler continued to work on the development of the multi-energy multi-dimensional neutrino transport and fluid dynamics model for Type II supernova explosions. Preliminary calculations in the core of a star of 15 solar masses revealed convection in the proto-neutron star, but no explosion. Other masses are being explored.

A. Clocchiatti (CTIO) and J.C. Wheeler analyzed the asymptotic behavior of supernova light curves to show that there can be a convergence of slopes for ejecta masses in the range 1–2 solar masses that do not require precisely identical conditions. The time when the asymptotic regime is reached depends on the mass of the ejecta and the gamma ray opacity, but the slope subsequent to that does not depend on those quantities. This may help to explain the category of supernovae with common late time light curve behavior, but different spectral classification.

Y. Stein, Z. Barkat (Hebrew University of Jerusalem), and J.C. Wheeler continued to study the vexing problem of the convective Urca neutrino process in carbon/oxygen white dwarfs. The previous study by Barkat and Wheeler concluded that when gradients in mean molecular weight and the associated currents in composition are properly taken into account, the convective Urca process will lead to cooling, the control of the carbon burning, and associated instabilities displayed by computer simulations. New work suggests that account must also be taken of the kinetic energy associated with the convective flow. Although nominally small, the effect of the kinetic energy is to ensure that while the convective Urca process will result in less thermonuclear heating than would be the case without it, there can be no decrease in entropy. This will mean that the convective Urca process is less effective in postponing the dynamical runaway of carbon burning in models for Type Ia supernovae than previous models suggested.

Y. Stein and J.C. Wheeler explored, for the first time with multi-dimensional calculations, the process of quasi-static carbon burning in carbon/oxygen white dwarfs near the the Chandrasekhar limit. This is a particularly difficult calculation because the stars are very close to the limits of dynamic and thermal instability. Preliminary models show that plumes of burning carbon form which penetrate beyond the region that is nominally convectively stable. Such behavior, not seen in previous one-dimensional computations, could substantially affect the nature of the ultimate dynamical runaway in Type Ia supernovae, whether they develop subsonic deflagrations or supersonic detonations, and how sensitive the results of the explosion are to initial conditions.

W.R. Hix has constructed a reduced reaction rate network consisting of only six or seven effective nuclei that captures the basic energetics and composition shift due to burning on the alpha chain and the silicon quasi-equilibrium bottle neck. This routine will be very valuable for use in three-dimensional computations of the reactive flow of models of Type Ia supernova where both speed and memory are at a premium.

J. Wang has developed a model for convection in one-dimensional core-collapse calculations, a ''two-stream'' formalism to simulate the effects of convection and overshoot. Such a code will allow a study of a broader range of parameter space than full multi-dimensional models. Wang is also developing a semi-analytic model of core collapse shock waves to establish the criteria under which such shocks are successful. The post-shock entropy seems to be more important than the neutrino flux.

S.-W. Kim and J.C. Wheeler have continued to study time-dependent irradiated disk models for black hole X-ray transients. Of particular interest are the limits for exposure to irradiation that will cause the disks to remain in a hot steady state when non-irradiated disks could not, and whether that limit is different for steady state and for time-dependent disks which are subject to shadowing of the outer disk by the inner disk. Another key issue is the role of nearly radial two-temperature advection flow which may be able to account for the observed X-ray flux, but which is not easily compatible with the outer Keplerian disk, especially the cold disks with low flow rate predicted by the disk instability models for the outbursts.

M. Moscoso has continued work to develop a code that can compute the radiation-induced pair wind expected to be driven from a pair-dominated corona around a black hole.

I. Yi (Institute for Advanced Study), E. Vishniac, and J.C. Wheeler have developed a theory for the newly discovered symmetry in spin up and spin down of accreting X-ray pulsars. This observation is a challenge to standard theories of magnetic accretion which would predict a strong asymmetry in spin up and spin-down torque. The new theory invokes the changes in the disk state that accompany the onset of radial, advective, high temperature flow at a critical accretion rate. This transition shifts the inner edge of the Keplerian disk and hence alters the torque.

E.T. Vishniac and C. Zhang have studied the parametric tidal instability in accretion disks. They have derived general formulae for calculating growth rates in disks with arbitrary vertical structure, including the effects of tidally induced pressure perturbations. They have shown that this mechanism is extremely effective in producing torque and generating internal waves from the radius of the vertical resonance (between the 4:1 and 5:1 orbital resonances) on out. A significant, but smaller, growth rate appears at smaller radii. In a related piece of work, D. Ryu (Chungnam University), J. Goodman (Princeton), and Vishniac have shown that this tidal instability is completely insensitive to boundary conditions and can produce waves with a range of azimuthal wavenumbers.

E.T. Vishniac and J.C. Wheeler have produced a new theory of the propagation of cooling waves in accretion disks. This work reproduces the computational results of Cannizzo *et al.* and shows that the exponential decline of the luminosity of soft X-ray transients is a direct measure of the functional form of the viscosity in the hot part of the disk. The results are consistent with the wave-driven dynamo model for accretion disk viscosity.

G. Shields and D. Husfeld (Munich University Observatory) continued work on the energy distribution and polarization of thermal continuum from accretion disks around supermassive black holes in AGN. Models of the disk atmosphere were improved to include a hydrostatic density law and an exact calculation of the polarization due to electron scattering. Results confirm the recent discovery by Blaes and Agol (*ApJL*, submitted, 1996) of an abrupt rise in the polarization in the Lyman continuum region of the spectrum for certain disk parameters. Shields and Husfeld also found that similar polarization features can occur in the Lyman continua of He I and He II for hotter accretion disks. A qualitatively similar polarization rise has been observed in the Lyman continuum of a few QSOs (Koratkar *et al.*, *ApJ* **450**, 501, 1995) and may provide an important clue to the nature of AGN.

E.T. Vishniac has continued to work on the formation of flux tubes in turbulent magnetized plasmas. S.J. Park (Korea Astronomy Observatory) and he have shown that as a consequence of this process, accretion disks tend to push poloidal magnetic field lines outward. In radiation pressure dominated accretion disks this process overwhelms the inward motion of field lines due to the accretion process.

E.T. Vishniac and A. Brandenburg (University of Newcastle) have discovered a new kind of magnetic dynamo which can occur in a differentially rotating system and does not require any loss of symmetry in the underlying turbulence. Applied to accretion disks it predicts a dimensionless viscosity which will scale as $(h/r)^2$, which is a steeper dependence than is seen in most systems. This suggests that this is not usually the dominant dynamo mechanism in hot accretion disks in binary systems. However, it may play a role in systems which seem to show an anomalously low viscosity.

P. Shapiro and H. Martel continued their development of a new and improved version of the numerical gas dynamics method known as Smoothed Particles Hydrodynamics (SPH), with application to cosmology. As a Lagrangian method, SPH is well-suited to the simulation of galaxy formation by the growth of cosmological density fluctuations since it uses particles which move with the flow as centers of interpolation and which replace the fixed grid points of finite-difference codes, thereby increasing its resolving power in high density regions as density contrasts arise. The standard version of SPH, however, suffers from two deficiencies which are particularly acute in cosmology simulations: (1) the smoothing, or interpolation, of particle data, which is at the heart of the method, uses an isotropic interpolation kernel which is parametrized by a scalar smoothing length, even though the gravitational collapse and shock waves which dominate the flows involve highly anisotropic volume changes; and (2) shocks are handled by artificial viscosity which causes widespread, spurious viscous heating of compressing regions far from any shocks. The new method, Adaptive SPH (ASPH), solves these problems by introducing an anisotropic interpolation kernel and a tensor smoothing length which automatically adjust the resolving power in time, in space, and in *direction* by tracking the mean particle spacing along different directions around each particle in the flow. In addition, shock-tracking is accomplished using the tensor smoothing lengths to predict the occurrence of density caustics and thereby to restrict viscous heating to gas encountering a shock. As a result, the new ASPH method has at least an order of magnitude better resolving power than standard SPH. Collaborators include J. Owen (Ohio State University) and J. Villumsen (Max Planck Institute for Theoretical Astrophysics).

P. Shapiro, H. Martel, and A. Valinia applied their new ASPH numerical gas dynamics method to simulate the formation of the large-scale structure and evolution of the intergalactic medium (IGM) in cosmology models including Cold Dark Matter (CDM) and to address the problem of mass determinations of X-ray clusters. Observed X-ray surface brightness profiles of galaxy clusters have been used recently to measure the cluster total mass and the baryonic gas fraction, by assuming the cluster is an isothermal sphere in hydrostatic equilibrium. This has led to claims of a so-called ''baryon catastrophe,'' since the results indicate that the cluster baryon mass fraction is significantly higher than the mean value allowed by Big Bang nucleosynthesis abundance constraints if the total universal mean density is enough to make the Universe flat. They have used their simulations of flat models of cosmology to test the assumptions underlying the analysis which leads to the baryon catastrophe. They find that clusters are not relaxed, virialized, and in hydrostatic equilibrium but are, instead, comprised of merging subclusters. Mergers and projection effects are found to cause the standard mass determinations to underestimate the total mass and overestimate the gas fraction. Their results help resolve the baryon catastrophe.

P. Shapiro has continued his study of the re-ionization of the intergalactic medium (IGM) and of quasar absorption line clouds (QALCs). Recent observations of QALCs have detected heavy elements for the first time in high-redshift clouds with neutral hydrogen column densities at the low end of the column density distribution known as the Lyman alpha forest (LF). In addition, new measurements of He II Lyman alpha absorption in quasar spectra have led to an interpretation in terms of unresolved absorption lines by the LF QALCs. In collaboration with Y. Gao and A. Davidsen (Johns Hopkins University), photoionized cloud models of LF QALCs were used to make a detailed set of predictions of detectable absorption lines by heavy elements, consistent with other known constraints on the LF, including the He II opacity.

P. Shapiro and H. Martel considered the feedback on the IGM and on the rate of formation of new objects due to the ionizing energy released by the first generation of bound objects to form by condensing out of the IGM. If energy is released at a rate high enough to re-ionize the IGM, this reheats and raises the Jeans mass of the uncollapsed IGM, which suppresses and delays the growth of the collapsed fraction. In order to investigate the importance of the feedback effect of this reionization and reheating of the IGM on the rate of formation of galaxies and QALCs out of the IGM, Shapiro and Martel have applied their ASPH method to simulate the gas dynamical response of the IGM to such reheating, and to determine the consequences for the rate of formation of galaxy-sized and subgalactic gas clouds. Their results indicate that the observed amount of baryonic mass already formed into QALCs by redshift 3 is too high to be consistent with predictions of the Cold+Hot Dark Matter (CHDM) model, while the CDM model is consistent if either photo-heating *alone* reheats the IGM, or if explosive heating occurs as well and this heating is accompanied by very efficient radiative cooling.

R. Benjamin (University of Texas and University of Minnesota) and P. Shapiro continued their modeling of hot gas which cools radiatively in the Galactic halo as in the Galactic fountain model. Their calculations of a steady-state, 1D flow of gas cooling from close to 10^6 K to below 10^4 K, including nonequilibrium ionization, radiative cooling, and radiative transfer, make detailed predictions for comparison with Galactic halo ISM observations. They show that UV emission and absorption lines from highly ionized species in our Galactic halo, observed with iue, HST, and various other spaceborne detectors, can be self-consistently explained by such a Galactic fountain flow when the self-illumination of the cooling gas by the radiation emitted by the hotter part of the flow is properly taken into account. These calculations have been generalized to describe steady-state, radiative MHD shocks. They have also been applied successfully to predict and explain the metal lines observed in quasar Lyman-limit absorption-line systems, believed to originate in galactic halos over a range of earlier redshifts.

A. Valinia, P. Shapiro, H. Martel, and E. Vishniac have studied the gravitational instability of cosmological pancakes. They have modeled these pancakes as 1D, plane-wave density fluctuations in a collisionless gas, which collapse into sheets along the planes of each density maximum and have subjected the pancakes to transverse perturbations which are either symmetric (density) or antisymmetric (bending) modes. They have shown by high-resolution 2D, gravitational N-body simulations by the Particle-Mesh (PM) method that pancakes are unstable to the formation of clumps for perturbations of any wavelength roughly less than or equal to the pancake mode wavelength. Numerical gas dynamical simulations using the new ASPH method developed here have also been performed, revealing similar instabilities when a collisional gaseous component is included. In addition, this gaseous component develops significant vorticity, which may be important in explaining the origin of galactic rotation.

H. Martel, P. Shapiro, and P.J.E. Peebles (Princeton) used high-resolution, 2D Particle-Mesh (PM) simulations of the growth of cosmological density fluctations to answer the question, ''How generic is pancake formation when density fluctuations arise from Gaussian random noise with a power-law power spectrum?'' They find that pancakes are generic to a wide range of initial conditions.

S. Weinberg, P. Shapiro, and H. Martel have applied the anthropic principle to explain why the cosmological constant in our observed universe has a value as small as it does and why it is likely that this small value is, nevertheless, nonzero. They show, using the CDM model, that a value of the cosmological constant that is currently favored by several observational constraints (i.e., a vacuum energy density about three times as large as the matter density, in a flat universe) is close to the median value expected to be observed in an ensemble of universes in which the constant is equally likely to have any (positive) value.

3.3.7 Laser Ranging:

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 ancilliary computer, electronic, and timing hardware. The station is located at McDonald Observatory on Mt. Fowlkes, to the northeast of Mt. Locke in West Texas, and shares the mountaintop with the new Hobby ●Eberly Telescope. With a two-crew observing operation, laser ranging is carried on to a host of artificial satellites (Fizeau, ERS-1, ERS-2, Tips, Starlette, Stella, Meteor-3, Ajisai, TOPEX/Poseidon, LAGEOS-1, LAGEOS-2, Etalon-1, Etalon-2, GPS-35, GPS-36, and GLONASS) as well as the moon. The MLRS is the only lunar-capable laser ranging station in the United States and only one of two lunar-capable stations in the entire world. By measuring the time it takes for a laser pulse to leave a ground station, bounce off a targeted reflector array, and return to the ground station, one can measure 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 than 10 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.

Lunar and artificial satellite laser ranging, with Project Director P.J. Shelus and staff members R.L. Ricklefs, J.G. Ries, A.L. Whipple, and J.R. Wiant, continued under the support of NASA. A new five-year laser ranging operations contract from the Goddard Space Flight Center was awarded continuing nearly three decades of effort along this avenue of observation and research. Support for lunar laser ranging efforts comes from the Ultraviolet, Visible, and Gravitational Astrophysics Research and Analysis Program at NASA Headquarters.

Lunar and artificial satellite laser ranging observations were obtained with the MLRS at record setting levels for the seventh straight year, as personnel cooperated with colleagues around the world, making maximum use of the data type in earth, moon, and solar system related dynamics. In 1995, for the first time ever, the MLRS attained lunar data densities that surpassed that obtained during the very best years of 2.7-m telescope system operation, but at levels of accuracy and precision more than five times better. Principal research activity included 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 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.

The MLRS Auto-Guiding and Imaging System (AGIS) has approached full integration in virtually all facets of the lunar laser ranging operation. The AGIS is an integrated hardware and software system that accepts real-time video signals as input, i.e., highly magnified images of a small portion of the lunar surface, or stellar or artificial satellite point-source images. It performs real-time image processing and allows a user to select among various levels and types of image enhancement. The AGIS also produces raw and filtered tracking error signals, that under user selection, are communicated to a control computer for guiding control. At this time, most use of the AGIS is applied to the lunar effort, producing a marked increase in the volume of LLR data. The project is beginning to investigate ways of using the AGIS in the artificial satellite ranging portion of the operation.

An improved Avalanche Photo-Diode (APD) was received from the Wettzell, Germany laser ranging site to replace the MLRS Varian high quantum efficiency photomultiplier tube in lunar laser ranging operations. An APD detector now in use at the LLR station in the south of France has exhibited a significant increase in sensitivity and improved accuracy and precision. Similar devices are used for artificial satellite laser ranging operations around the world. The first test results on the moon have been very encouraging.

The replacement of the MLRS's 15-year-old Data General NOVA control computer system with a LynxOS-based, X-Windows, real-time Unix system running on PC hardware is now completed. This has been coordinated with similar upgrades at other NASA-based laser ranging systems. It has created a system having highly compatible, transportable, and transferable hardware and software architecture in an open-systems (POSIX) environment. The approach has allowed a maximum amount of software portability and sharing. All MLRS data, both lunar and artificial satellite, are now being obtained with this system.

3.3.8 Astrometry:

The Hubble Space Telescope Astrometry Science Team is based at the University of Texas. Local members include G.F. Benedict (Deputy P.I.), R. Duncombe (Aerospace Engineering), W. Jefferys (P.I.), B. McArthur, P. Hemenway, E. Nelan (STScI), P. Shelus, D. Story (Goddard Spaceflight Center), and A. Whipple. The team continued 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, planetary nebulae central stars, the Hyades, and low-mass M-dwarfs). All data are obtained with Fine Guidance Sensor 3 aboard HST. Precision of 1–2 milliarcsecond per measurement is obtained. This year the science pipeline was modified to deal with nearly simultaneous transfer scan and position mode astrometry with FGS3. This capability will be used to obtain precise orbits, parallaxes, and masses for close binary stars difficult or impossible to study from the ground.

P. Shelus and A. Whipple continue their astrometric observations of faint solar system objects. This effort has completely moved from the photographic process to a CCD using 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. The PFC is capable of reaching $R=22$, with more than three sigma significance on stellar objects, in co-added integrations. Software has been developed within IRAF 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 determine the centers and intensities for all identified objects within the fields, and then process the measures to obtain astrometric positions and magnitudes. The total astrometric system is fully functional 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.

A. Whipple and P. Shelus also obtained observations of the satellites of Jupiter, Saturn, Neptune, and Uranus with the PFC. Many of these objects that they observe have, in the past, been grossly underobserved. Orbit refinements require that a continuous set of precise and accurate positional observations be maintained. Positions of all target objects are determined in a standard reference frame. Many of these observations are crucial for spacecraft trajectories.

3.3.9 History of Astronomy:

D.S. Evans has continued his interest in astronomical history. In addition to contributions to the forthcoming Garland Encyclopedia of the History of Astronomy, the new (British) Dictionary of National Biography, and the new Handbook of Texas, he is revising his personal memoir of the late Sir Arthur Eddington and preparing a contribution on J.-C.

Houzeau, the celebrated Belgian astronomical bibliographer who spent several of his earlier adventurous years in Texas.

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