University of Texas
McDonald Observatory and Department of Astronomy

Austin, Texas 78712

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This report covers the period 1 September 1996–31 August 1997.

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. 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, Jr., Regents Professor in Astronomy); David S. **Evans** (Jack S. Josey Centennial Professor Emeritus in Astronomy); Neal J. **Evans** II (Edward Randall, Jr. Centennial Professor in Astronomy), 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** (Regental Professor and Jack S. Josey–Welch Foundation Chair in Science); and J. Craig **Wheeler** (Samuel T. and Fern Yanagisawa Regents Professor in Astronomy).

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

Associate Professors: Harriet **Dinerstein**, Paul M. **Harvey**, Dan **Jaffe**, 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**, Robert **Harkness**, Artie P. **Hatzes**, Paul **Hemenway**, Gary **Hill**, Peter **Höflich**, Daniel F. **Lester**, Frank **Ray**, Peter J. **Shelus**, Verne **Smith**, Jocelyn **Tomkin**, Arthur L. **Whipple**, and Beverley J. **Wills**.

Research Associates: John **Booth**, Mark **Cornell**, John **Glaspey**, 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: Eric **Bakker**, Don **Barry**, Vadim **Gamezo**, Guillermo **Gonzales**, Dirk **Grüpe**, William **Hix**, Inger **Jørgensen**, Soon-Wok **Kim**, Ruth **Knill-Dgarni**, Matt **Richter**, Judit **Györgyey Ries**, Jihad **Touma**, Lifan **Wang**, and William **Welsh**.

1.4 Senior Research Support and Administration

HET Project Manager: Tom **Sebring** (departed May 1997).

Special Assistant to the Director (Development): 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: Tom **Brown*** (physical plant, acting since June 1997), Edward **Dutchover**, Jr.* (administrative support), Earl **Green*** (observing support), George E. **Grubb*** (physical plant, departed May 1997), 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.

1.6 Visitors and Affiliations

Dr. Sandra M. **Faber** (Univ. of California at Santa Cruz) received the 1996–1997 Antoinette de Vaucouleurs Medal. She presented a departmental colloquium and a public lecture.

Dr. Ewine F. **van Dishoeck** (Leiden University) was the Beatrice M. Tinsley Centennial Lectureship in Astronomy for 1996-97.

Dr. E. **Agol** (UCSB) visited G. Shields for two weeks in April 1997.

Mr. P. **Diener** was a visiting graduate student from the Danish Institute for Theoretical Physics.

Dr. C. **Koen** (SAAO) visited for the entire year.

Dr. C. **Wei** (China Institute of Science and Technology) has been a visitor working with Dr. B. Wills.

Dr. Ronald **Wilhelm** is a parttime assistant professor at Southwestern University.

Dr. Verne **Smith** is also assistant professor at The University of Texas at El Paso.

Dr. G. **Hill** spent the year as a visitor at the Universitäts-Sternwarte of Ludwig-Maximilians University in Munich. While there, he completed the design of the Low Resolution Spectrograph for HET and started its fabrication (see below).

Dr. Paul **Shapiro** was a visitor at the Instituto de Astronomia, National Autonomous University of Mexico (UNAM), Mexico City from January through August 1997.

Dr. J. Craig **Wheeler** was a visiting scientist at the Institute for Theoretical Physics of the University of California, Santa Barbara.

1.7 Awards, Honors, and Special Activities

Ed **Nather** was awarded the Astronomical Society of the Pacific's 1997 Maria and Eric Muhlmann Award.

Ed **Barker** was elected as Vice-Chair of the Division for Planetary Sciences of the American Astronomical Society and became Chair during the 29th annual meeting. Anita **Cochran** served at past-Chair of the Division for Planetary Sciences of the American Astronomical Society during the report period and chaired its prize committee. She also is a member of the US National Committee of the IAU. Frank **Bash** was elected to the Council of the American Astronomical Society. Mary Kay **Hemenway** concluded her service as Education Officer for the American Astronomical Society in June, 1997 and continued her service on the American Institute of Physics Committee on Physics Education. Peter **Shelus** served as the treasure of the Division on Dynamical Astronomy of the American Astronomical Society while Art **Whipple** served as its secretary and Judit **Györgey-Ries** served on this division's committee.

Frank **Bash** is Vice-President of the Astronomical Society of the Pacific, a Member Representative to the Associated Universities for Research in Astronomy (AURA), and a member of the AURA Coordinating Committee of Observatory Research Directors (ACCORD).

Craig **Wheeler** served on the Committee on the Status of Women in Astronomy of the American Astronomical Society. David **Lambert** chairs the Danny Heinemann Prize Committee of the American Astronomical Society. Anita **Cochran** is a member of this committee.

Mary Kay **Hemenway** was named to the Advisory Committee for the American Geological Institute's ''Earth Science in the Community'' Project and the SOFIA Education and Public Outreach Working Group. Hemenway received a 1996 Outstanding Service Award from the Science Teachers Association of Texas. Hemenway directed a three week summer institute for teachers; the institute included a six-night observing run at McDonald Observatory in July.

Peter **Shelus** was elected to the Directing Board of the International Earth Rotation Service, serving as Lunar Laser Ranging Representative.

Ed **Nather** was the winner of the Board of Visitors Teaching Award for 1996–1997.

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

Harriet **Dinerstein** and graduate student Luke **Keller** represented the University of Texas at the American Astronomical Society workshop on ''Re-examining Graduate Education,'' in Minneapolis, in November, 1996.

Inger **Jørgensen** and Lifan **Wang** were Hubble Space Telescope Post-Doctoral Fellows at the University of Texas.

Chris **Sneden** and Paul **Shapiro** were both awarded Big XII Visiting Faculty Fellowships. Sneden's was used at the University of Oklahoma, while Shapiro's was used at the University of Kansas.

Paul **Shapiro** was the recipient of a UT Dean's Fellowship in Spring 1997. In addition, he was awarded the National Chair of Excellence, 1997, by CONaCYT (Mexican National Science Foundation) in connection with his sabbatical visit to the Instituto de Astronomia, UNAM, Mexico City.

Ed **Barker** served on NASA's Planetary Astronomy Management Operations Working Group and on NASA's Keck Interferometry Steering Group. He also chaired Planetary Astronomy's small bodies/facilities review panel and served on the Discovery review panel for NASA's Research Program Management Division. William **Cochran** served on the NASA Origins SubCommittee, the Origins of Planetary Systems Review Panel and on the NASA Keck TAC.

Inger **Jørgensen** served as a member of the NSF Review Panel on Extragalactic Astronomy. Tom **Barnes** served as a member of the NSF Review Panel on Galactic Astronomy.

Tom **Barnes** served as a member of the SOAR telescope External Review Board.

The following departmental members served on panels in the HST Cycle 7 review process: Anita **Cochran**, Greg **Shields**, Chris **Sneden**, and Bev **Wills**.

Chris **Sneden** is a Scientific Editor for the Astrophysical Journal.

Derek **Wills** is a techincal editor for the popular science program ''Earth and Sky.''

Anita **Cochran** chaired the search committee for a new editor for the journal *Icarus.*

Craig **Wheeler** was a General Member, Board of Trustees, Aspen Center for Physics.

Greg **Shields** served on the organizing committee for the Sixth Texas-Mexico Conference on Astrophysics, held at Rice University March 6-8, 1997.

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.

Ed **Barker** served on the Program Committee for the 1997 Division for Planetary Sciences Committee.

Craig **Wheeler** served on the International Organizing Committee for the Texas Symposium on Relativistic Astrophysics and the Organizing Committee for the International Astronomical Union Commission 42–Close Binary Systems.

Anita **Cochran** is serving on the Scientific Organizing Committee for IAU Colloquium 169, to be held in Nanjing in May 1998.

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 Luke **Keller**. The David Alan Benfield Memorial Fellowship was awarded to Wenbin **Li**. The Frank N. Edmonds, Jr. Memorial Fellowship was awarded to Cynthia **Froning** The Board of Visitors second-year project award was given to Eric **Klumpe**.

Graduate students in 1996–1997 were Marcel **Bergmann**, Thomas **Chang**, David **Chappell**, Jungyeon **Cho**, Lara **Cross**, James **Di Francesco**, Gregory **Doppmann**, Erik **Fierce**, Cynthia **Froning**, Pamela **Gay**, Youxin **Gao**, Erik **Gregersen**, D. Andrew **Howell**, Inese **Ivans**, Renée **James**, Luke **Keller**, Eric **Klumpe**, Wenbin **Li**, Zhiqing **Li**, Feng **Ma**, Travis **Metcalfe**, Michael **Montgomery**, Michael **Moscoso**, Atsuko **Nitta**, Soojong **Pak**, Christine **Pulliam**, Cynthia **Rosenbaum**, Divas **Sanwal**, Zhaohui **Shang**, G. Roger **Stanley** Jr, Joe **Wang**, Vincent **Woolf**, Wanglong **Yu**, Eric **Zink**.

Doctoral Dissertations: Two Ph.D. degrees in astronomy were awarded in 1996–1997:

David **Chappell** (Supervisor: J. Scalo): ''Simulations of Wind-Driven Star Formation and Gas Dynamics''

James **Di Francesco** (Supervisor: N. Evans): ''High-Resolution Studies of Circumstellar Material Around Intermediate-Mass Young Stellar Objects at Far-Infrared and Millimeter Wavelengths''

Master's Theses: Four Master's degrees in astronomy were earned in 1996–1997:

Youxin **Gao** (Supervisor P. Shapiro): ''The Effect of radiative Transfer and NonEquilibrium Chemitry on Cosmological Pancake Hydrdynamics''

Zhiqing **Li** (Supervisor D. Lambert): ''The Isotopic Abundances of Oxygen in Red SuperGiants''

Atsuko **Nitta** (Supervisor D. Winget): ''On the Origin of the DB White Dwarfs''

Feng **Ma** (Supervisor B. Wills): ''Radio Core Dominance as an Indicator of Quasar Orientation''

2.2 Undergraduate Program

Derek Wills is the chair of the Undergraduate Studies Committee; Dan Jaffe served as undergraduate advisor. There were 27 astronomy majors this year, and three students received BAs.

James Crawford was awarded the Outstanding Graduating Senior Award. Bianca Basso was the winner of the Karl G. Henize Memorial Scholarship in Astronomy. Audress Johnson was the winner of the Board of Visitors Undergraduate Scholarship in Astronomy.

2.3 Educational Services

The nine-inch refractor (directed by Feng Ma and Divas Sanwal) was visited by 1,470 people. 44 school groups, totaling over 1000 elementary and secondary students and teachers, participated in Solar Telescope field trips presented by Lara Eakins. Regular star parties attracted 250 people, plus over 300 each at the Lunar Eclipses (September 26, 1996 and March 23, 1997). Our new monthly lecture series, which began in June, 1997, had an attendance of 300. The SkyWatcher's Report logged almost 5000 calls throughout the year.

An outreach program to visit central Texas schools and organizations resulted in 65 talks being given to over 2,000 students and adults; in addition, 10 talks were given at schools and organizations outside the immediate Austin area to over 1000 people. 21 astronomers participated in this program. In addition, Lara Eakins represented the department at Austin Science Fun Day, while Mary Kay Hemenway participated in The University's ''Year of the Child,'' both on the steering committee and in their outreach programs.

2.4 Public Information Office

A Radio Research Corporation Spring 1996 survey indicates that the StarDate radio program reaches an audience of 5 million listeners each week. The Star Date radio program is heard on 257 radio stations in the U. S. Universo, the Spanish-language version of StarDate, broadcasts on over 170 radio stations. It is the most widely syndicated Spanish language radio program in the U. S. Universo also broadcasts in Mexico, Venezuela and South Africa. Sternzeit, StarDate's German counterpart, broadcasts on Deutschland Radio throughout Germany on 44 transmitters. A pilot version of Hispanic Heritage Month programs was produced and distributed for the broadcast period Sep. 15 – Oct. 15. The Hispanic Heritage Month pilot was funded by the American Honda Foundation.

The StarDate magazine has 15,000 subscribers. The editors of StarDate contribute a ''StarDate for kids'' column to the Highlights for Children Outer Space Supplement which will be offered beginning in the fall to two million subscribers. StarDate editors and designers also make StarDate and Universo available on line to thousands of computer users each week at http://stardate.utexas.edu and http://universo.utexas.edu.

Universo was also made available to 200 school teachers for use in the classroom. StarDate was made available to 150 school teachers. A teacher's guide for StarDate and Universo was prepared and printed. A survey of the teachers indicates that each teacher exposes an average of 100 students to these materials, i. e. a total of 35,000 students.

A poster produced in association with six other observatories entitled ''See the Stars'' was made available to 5,000 teachers at the annual National Sciences Teachers Association Meeting.

A galaxy poster was printed and inserted into the National Science Teachers Association journal for 5th through 8th grade teachers entitled ''Science for Children.'' The journal was distributed to 24,000 educators.

Estrada Communications Group completed their contract to syndicate the series and provide public relations in the Hispanic community. Martin Acevedo was hired in the summer to maintain and build the syndication list, provide public relations in the Hispanic community and help to build the corporate sponsorship and underwriting for Universo.

The W. L. Moody, Jr. Visitors' Information Center served over 130,000 visitors. An 8.25 inch Maksutov telescope was added to the public programs. A fee for tours was instituted June 1. Temporary office space was added in the form of a rental trailer. The George T. Abell Gallery is under construction and due to be completed in the fall of 1997. Schematic design for the Texas Astronomy Education Center was completed. Design is underway for the exhibits for the Texas Astronomy Education Center.

3. RESEARCH PROGRAM

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

Many milestones were achieved in the completion and commissioning of the 9.2 meter Hobby*Eberly Telescope (HET). HET is a joint project of five universities (UT Austin, Penn State, Stanford, Georg-August University in Goettingen, and Ludwig-Maximilians University in Munich), and is operated by McDonald Observatory for the consortium. Ongoing debug, integration, optimization, and performance enhancement, typical of any new large telescope during its commissioning phase, continued throughout the year. Dedication of the facility is planned for October 7-8, 1997.

HET tracker development, led by J. Booth, and segmented primary mirror development, led by V. Krabbendam, were mostly completed by year's end. HET's tracker, a 10-axis subsystem with a 12-degree field of view which tracks objects in the spherical focal surface at the top end of the HET, was installed in the fall of 1996. The tracker and primary mirror array were sufficiently functional that first light with 7 primary mirror segments installed occurred in December 1996. The HET Project Team, led by Project Manager Tom Sebring, deserves credit for achieving this major HET milestone. Members of Sebring's Project Team during this year were G. Barczak, J. Booth, W. Gressler, F. Harvey, V. Krabbendam, L. Long, R. Poenisch, F. Ray, J. Sage, A. Sergi, and M. Steiner. Pointing and tracking debug and system integration continued all year and better than 30 arcsecond accuracy pointing has been achieved as of this writing. J. Booth, J. Glaspey, F. Ray, R. Ricklefs, W. Spiesman and W. Wren were instrumental in achieving this intermediate pointing milestone.

A commissioning instrument package came on-line in June 1997. It consists of a surrogate metal-mirror spherical aberration corrector, acquisition and guide cameras, and a fiber feed to a medium resolution fiber optic echelle spectrograph. The echelle spectrograph was provided by Penn State for use at HET until the initial set of facility instruments (high, medium, and low resolution spectrographs) are commissioned during 1998-1999. Development on the Prime Focus Instrument Package (PFIP), including the four-element spherical aberration corrector, continued toward a planned installation date in spring 1998. PFIP will be installed on the telescope after integration with the low resolution spectrograph. R. Tull is PI for the high resolution spectrograph, L. Ramsey of Penn State for the medium resolution spectrograph, and G. Hill for the low resolution spectrograph.

The primary mirror array was almost fully populated with all 91 segments as of August 31 (full population was subsequently achieved 30 September 1997). Supporting Krabbendam in this effort were F. Ray (analysis), G. Barczak (mirror supports), W. Gressler (alignment tower and optics in general), M. Steiner and J. Fowler (mirror control software), and D. Doss, J. Martin, and D. Otoupal (mirror installation), in addition to Sebring's and Facility Manager J. Glaspey's overall coordination and supervision. Effort was shifting at year end from fully populating the array to characterization and optimization of primary mirror performance and development of additional software tools and techniques needed for mirror segment alignment (J. Fowler).

N. Gaffney worked on manual and semi-automated tools for planning, scheduling, and executing queued observations on the HET. Gaffney and M. Cornell created a Phase II macro language for PIs to describe the details of their observing programs. Gaffney then wrote tools to accept these plans via email, check them for errors, and to compile them into a relational database. This database is used by the resident astronomer at the telescope to schedule observations and to command the control computers to set up the instruments and take the data automatically.

Major progress on HET-related infrastructure also occurred during the year. The George T. Abell Gallery for visitors was mostly completed, progress building five new houses for HET staff was substantial, the utilities to the HET site were nearly completed, and connection of the HET site to the Internet via a T1 line became fully operational. T. Barnes, P. Kelton, S. Barnes, M. Adams, G. Grubb, T. Brown M. Cornell, and Bart Kleiman led the effort on these essential HET-related projects.

Staffing for the HET changed significantly in spring 1997 when many McDonald staff and the growing HET Operations group took over responsibility from the HET Project Team to finish bringing the HET into full operation. T. Barnes assumed the role of Commissioning Manager in cooperation with the team consisting of M. Adams, HET Facility Manager John Glaspey, P. Kelton, and HET Project Scientist L. Ramsey from Penn State. The science ramp-up for HET was just beginning in summer 1997.

New staff who joined the HET Operations team during the year were John Glaspey (Facility Manager); Jim Fowler (Systems Analyst); Craig Nance (Electrical Engineer); Vickie Fowler (Administrative Assistant); Grant Hill (Resident Astronomer); and Brian Roman (Telescope Operator).

3.2 Observing Conditions at McDonald Observatory

A summary of the hours scheduled, hours lost to poor weather, hours lost to telescope/instrument problems and hours assigned to maintenance is given in Table 1. Scheduled hours are measured from civil twilight to civil twilight, plus any especially scheduled daytime hours. (The daytime hours for all four telescopes together total only 12 hours.)

TABLE 1. Utilization Statistics for McDonald Observatory Optical Telescopes (1996–1997) (hours)

	2.7-m		2.1-m		0.9-m		0.8-m	
a)	4019		4008		4008		4009	
b)	2075	(52%)	1901	(47%)	299	(7%)	1380	(34%)
c)	1279	(32%)	1311	(33%)	475	(12%)	1062	(26%)
d)	61	(1%)	57	(1%)	5	(0%)	6	(1%)
e)	426	(11%)	98	(2%)	1	(0%)	84	(2%)
f)	179	(4%)	642	(16%)	3228	(81%)	1477	(37%)

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

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

The 2.7 m telescope records may be used to infer an estimate of the fraction of time the sky was suitable for spectrometry or imaging. After correcting for downtime due to maintenance, equipment, etc., the usable time is estimated as 62% for the last fiscal year. This value may be compared with 67% for the previous year, and 62.4% for a sixteen year mean. From 0.9 m telescope statistics for photometric observing in 1981 – 1992, the photometric weather at McDonald Observatory has averaged 39.8% of the available hours. (More recently 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:

G. Hill continued the development of the Hobby*Eberly Telescope Low Resolution Spectrograph (LRS), spending the year as a visitor at the Universität-Sternwarte of Ludwig-Maximilians University, Munich. The design of the instrument was completed there and construction continues, with delivery to the HET expected in April 1998. Hill continued to collaborate with F. Cobos and C. Tejada of the Instituto de Astronomia, UNAM, Mexico on the design and fabrication of the optics for the LRS. The integration of the optics into the instrument will start in December. The LRS is an imaging spectrograph that rides at the HET prime focus. It has a 4 arcminute field of view with imaging, long-slit and multi-object spectroscopic capabilities. It will be the first HET facility instrument to enter science use, in May 1998.

R. Tull and colleagues continued work toward completion of HRS, the high resolution spectrometer for the HET, operating in the range of resolving powers $30{,}000 \leqslant R \leqslant 120{,}000$. Funding has been provided by NSF and by private gifts, a State of Texas appropriation, a NASA enhancement of an existing grant, and University of Texas matching funds. This year the R4 mosaic echelle was acquired from Spectronic Instruments, an off-axis collimator mirror was finished by Don Loomis in Tucson, optical glass was ordered and an optical shop was contracted for manufacture of the refractive camera. In addition, the thermal and seismic environment of the spectrometer room was characterized. HRS remains on track for installation in the autumn of 1998.

3.3.2 Solar System:

The McDonald Observatory Planetary Search (MOPS) program (W. Cochran and A. Hatzes) has discovered a planetary-mass companion to the nearby solar-type star 16 Cygni B. The planet was independently discovered by G. Marcy and P. Butler (SFSU and UC Berkeley) in data from Lick Observatory, and the datasets were combined for analysis. The orbital fit to the combined McDonald and Lick data gives a period of 800.8 days, a velocity amplitude (K) of 43.9 m s^{-1}, and an eccentricity of 0.63. This is the largest eccentricity of any planetary system discovered so far. Assuming that 16 Cygni B has a mass of $1.0M_{\odot}$, the mass function then implies a mass for the companion of 1.5/sin*i* Jupiter masses. While the mass of this object is well within the range expected for planets, the large orbital eccentricity cannot be explained simply by the standard model of growth of planets in a protostellar disk. It is possible that this object was formed in the normal manner, with a low eccentricity orbit, and has undergone post-formational orbital evolution through gravitational interactions with the companion star 16 Cygni A.

E. Barker continued long term coverage of the behavior of water vapor in the atmosphere of Mars with an extensive series of high-dispersion CCD observations during the 1996–97 apparition. During the northern hemisphere spring/summer season, the atmospheric water vapor at any given northern latitude increased as the insolation increased. The maximum amount was always near the edge of the northern polar cap. Diurnal studies revealed negligible amounts of water vapor at the morning terminator or limb, with the diurnal maximum found near the sub-solar longitude. Ground-based observations of the Mars Pathfinder site on July 5-6, 1997 showed about 15 microns of precipitable H_2O, somewhat larger than the 8 microns measured in-situ by the lander.

L. Trafton and E. Barker carried out successful observations of eclipses of other Galilean satellites by Io. The technique probes Io's coronal distribution of Na and K atoms. Different events probed various altitudes, latitudes and longitudes over Io's surface. Analysis is in progress to determine the degree of mixing in the atmosphere and any sodium specific sources on the surface. Any detected maximum in the altitude variation of the sodium density might be the signature of a molecular source of sodium which dissociates at a characteristic altitude. Such a maximum would also mitigate against a sputtering source of sodium.

C. Na (U. Colorado), L. Trafton, E. Barker and S. A. Stern (SwRI) completed their analysis of high S/N spectra of Io. These spectra allowed improved upper limits for other potential neutrals in Io's extended atmosphere and torus. No new species were detected, but much stricter upper limits were placed on the presence of 11 other metals. Al, Si, Ca and Fe appear to be significantly depleted relative to Na in

Io's atmosphere. Ti, Ni and Cu are at least moderately depleted. The reason for other metals to be under-represented is not clear. However, these new upper limits suggest that sputtering to neutral atomic species may not be the dominant source mechanism in populating Io's atmosphere.

In collaboration with S. A. Stern and J. Parker (SwRI), E. Barker obtained spectra of 12 asteroids in the region of the Na D lines in order to search for Na exospheres around these asteroids. No emissions were detected in the relatively high S/N data. An analysis of the significance of these upper limits is underway.

With S. Kim (Kyunghee U.), T. Geballe (JACH), and S. Miller (UCL), L. Trafton detected the $(H_2)_2$ dimer in the atmospheres of Saturn and Neptune based on spectra of the fundamental $S_1(1)$ collision-induced band of H_2. The lines of this dimer are potentially useful for probing the $(H_2)_2$ ortho-para ratio and its implications for atmospheric dynamical processes. They also detected the (1–0) S(1) quadrupole absorption line of monomeric H_2 in these spectra.

With H. Lam (UCL), S. Miller (UCL), R. Joseph (IFA), T. Geballe (JACH), J. Tennyson (UCL), and G. Ballester (U. Mich), L. Trafton analyzed IR images of Uranus obtained in the light of H_3^+ emission. These images show 20% variability and comparison with magnetic field modeling of Uranus indicates that sources of this variation may include auroral activity and other features, but the images show that the spatial variation is more limited than in the case of Jupiter. Also unlike Jupiter, either auroral or ionospheric emissions emanate from essentially the whole planet.

With H. Lam (UCL), N. Achilleos (UCL), S. Miller (UCL), J. Tennyson (UCL), T. Geballe (JACH), and G. Ballester (U. Mich), L. Trafton completed a baseline spectroscopic study of Jupiter's infrared H_3^+ aurorae. They derived rotational temperatures varying between 700 and 1000 K, and column densities on the order of $10^{12}\ cm^{-2}$. The integrated infrared auroral emission in each hemisphere is of the order of a $few \times 10^{12}$ W, making it comparable to Jupiter's auroral output in the ultraviolet. A simple geometric model of the emission distribution does not describe the data adequately.

With S. Miller (UCL), N. Achilleos (UCL), G. Ballester (U. Mich), H. Lam (UCL), J. Tennyson (UCL), T. Geballe (JACH), L. Trafton conducted a mid-to-low latitude study of Jupiter's H_3^+ emission. These are ionospheric emissions, in contrast to the polar auroral emissions. Ionospheric temperatures of ~ 800 K and column densities of the order of $10^{11}\ cm^{-2}$ were derived. The emission levels vary strongly over the globe but are generally of the order of 0.10 erg $s^{-1}\ cm^{-2}$, indicating that the cooling effect of H_3^+ is a significant factor in the ionosphere. These emission levels strongly suggest either that aurorally produced H_3^+ is being transported to non-auroral latitudes or that sources in addition to solar EUV are required to produce the ionization and excitation energy needed to account for the observed H_3^+ emission. The spatial distribution of H_3^+ emission suggests that this ion may be a useful probe of Jupiter's magnetic field at sub-auroral latitudes.

With S. Edgington and S. Atreya (U. Mich), J. Caldwell (York U.), R. Beebe and A. Simon (NMSU), R. West (JPL), and C. Barnet (GSFC), L. Trafton analyzed the latitudinal variation of NH_3, C_2H_2, and PH_3 altitude profiles on Jupiter using HST spectra. They found that NH_3 condenses below the 150 mbar level, above which it departs from saturation due to photolysis. They employed photochemical models to derive the atmospheric eddy mixing coefficients at the observed latitudes, which were found to vary from 1.5×10^4 $cm^2\ s^{-1}$ at 450 mbar to $4.9 \times 10^2\ cm^2\ s^{-1}$ at 120 mbar. A C_2H_2 mixing ratio of $(10-30) \times 10^{-8}$ near 80 mbar was found, and an upper limit of 1.5×10^{-7} for the PH_3 mixing ratio, if PH_3 is mixed uniformly below the 140 mbar level.

With V. Dols and J.-C. Gerard (U. Leige), J. Waite, Jr. and G. Gladstone (SWRI), and G. Munhoven (U. Liege), L. Trafton analyzed HST spectra of Jupiter's FUV aurora to search for heavy ion precipitation. They found, for the aurorae searched, that electrons constitute the dominant population of charged particles precipitating from the magnetosphere. They modeled the S II 1256 and O 1304Å line profiles from precipitating ions and were the first to take into account the Doppler broadening ($\sim$10Å) and shifting due to the motion of the precipitating ions about Jupiter's magnetic field lines. Brightnesses in H_2 emission as high as 2 Mega-Rayleighs were observed on the morning limb. Emission from either ambient S II 1256Å or else from another ambient species was detected at the 4σ level. No other ambient heavy ion or neutral emission was detected above 35 Rayleighs. The morning aurora was found to emit more hydrocarbon absorption than the afternoon aurora for CML longitudes near 180 degrees. Similarly, the brighter aurora were found to be more absorbed than the weaker ones. Two hypotheses were advanced to explain this behavior. They also detected the resonance-fluoresence of H_2 possibly due to auroral H Ly β.

A. Cochran and F. Vilas (NASA JSC) conducted a study of a randomly selected group of asteroids in the UV/blue bandpass using the Large Cassegrain Spectrograph on the 2.7 m Harlan Smith telescope. This was a pilot project to determine if they could detect diagnostic crystal-field absorption features with this instrument. They showed that weak features (2-5% depth) could be detected and yield information on the crystal structure of the surfaces of asteroids.

A. Cochran led a team of researchers, including E. Barker, W. Cochran and D. Lambert, in obtaining high spectral resolving power (both R=60,000 and R=200,000) observations of comet Hale-Bopp. The highest resolving power observations will be used to concentrate on studies of line widths as probes of the outflow of the coma gas and will also be used for isotopic studies. The R=60,000 data will be used to characterize the coma gas and for some isotopic studies. In all, data were obtained on 21 nights, 9 at the highest resolving powers.

A. Cochran and M. Combi (U. Michigan) collaborated on a study of the gas outflow of the coma of comet Hyakutake (1996 B_2). Line widths from emissions of the molecules NH_2, C_2, and CN were studied, along with lines from atomic (O ^{1}D) and H α. It was shown that the narrowest line widths are those of the NH_2 and arise from a pure outflow. The other species show the coma gas outflow in addition to the excess energy from the dissociation. This is the first time line widths have been measured well for NH_2 and C_2.

The Hubble Space Telescope Astrometry Science Team continued to monitor the nearby stars Proxima Centauri and L726-8AB for low-mass companions (investigation lead by G. F. Benedict). Five new data sets for Proxima Centauri were acquired this year. After removing proper motion and parallax signatures, they continue to analyze the (now sixty-nine) astrometric residuals for the signature of a companion. Present companion mass detection limits for Proxima Cen vary from one down to 0.25 Jupiter mass for periods ranging 50 to 600 days. A final report is in preparation.

3.3.3 Stars and Stellar Systems, Stellar Ejecta:

The University of Texas McDonald Observatory Supernovae Search Team (UTMOSST) M. Adams, A. Howell, M. Ward, W. Wren, L. Wang and J. C. Wheeler discovered its first supernova in an Abell cluster, SN 1997cq, a member of the class of narrow Balmer line Type II supernovae. In addition, the UTMOSST team began a new program using the prime focus camera on the 0.8 m telescope to look for optical counterparts for cosmic gamma ray bursts. Several upper limits were established.

A. Clochiatti (CTIO), J. C. Wheeler and a large number of collaborators completed a study of the Type Ic supernova SN 1983V. Though old, much of this data had never been reduced and analyzed. SN 1983V is important because it has a light curve very similar to SN 1993J and the Type Ib prototype SN 1983N, but a much higher velocity. The latter is a conundrum if all these events have a similar energy.

R. Wilhelm has begun a spectroscopic investigation of blue, horizontal-branch, candidate stars in the vicinity of several globular clusters. The goal of this investigation is to search for a halo field component with kinematics similar to the clusters themselves. This stellar component, along with the neighboring cluster, are expected to be leftover debris from a galactic satellite accretion event. Observations of a field four degrees away from the cluster M30 have been successful in identifying several stars with cluster-like, line-of-sight velocities. Future observations are planned to check the statistical significance of this possible signal and to extend the search to other clusters.

C. Sneden, J. Cowan, D. Burris (U. Oklahoma), and J. Truran (U. Chicago) have explored the UV spectra of three metal-poor field giant stars using the HST GHRS. In a recently completed study, detections are reported of very heavy ''3^{rd} neutron-capture peak'' elements Os, Pt, and Pb in the very metal-poor ([Fe/H] ~ -2.7) yet neutron-capture-element-rich star HD 115444. It is argued that these detections mean that the general shape of rapid neutron-capture nucleosynthesis output from early Galactic supernovae can now be defined for elements in the range $56 \leqslant Z \leqslant 82$. This allows one to predict with more confidence the relative amount of the radioactive element Th that was also produced in these supernovae, thus strengthening the use of Th as a cosmochronometer in ultra-metal-poor stars.

For metal-poor ([Fe/H] ~ -2) relatively unevolved stars, C. Sneden, I. Ivans, C. R. James, and B. Carney (U. North Carolina) are beginning a large-sample study of metal-poor stars known to have orbits that take them to large galactocentric distances. This is a followup study to their discovery that the halo field dwarf star BD+80 245, although quite metal-poor ([Fe/H] $\simeq -1.9$), unlike nearly all other such stars is relatively deficient in α-capture elements: [Mg, Si, or Ca/Fe] $\simeq -0.2$. This collaboration, along with similar studies being completed by e.g. Nissen & Schuster (preprint) is pursuing the notion that the α-poor stars of the halo may be an entirely separate population, perhaps not native to our galaxy but present in our galactic halo as a result of later accretion.

C. Sneden, C. Pilachowski, R. Joyce, and K. Hinkle (KPNO/NOAO) began a study of the carbon isotope ratios in field metal-poor giant stars, with the aim to identify the luminosity along the giant branch where the anomalous additional mixing of CNO-cycled material first affects surface abundances. This point will be signaled through witnessing an abrupt drop in the carbon isotope ratio. Only a few stars were analysed in a proof-of-concept study from our first observations with the PHOENIX high resolution IR spectrometer on the KPNO 2.1 m reflector; observations are continuing with PHOENIX on the KPNO 4m.

C. Sneden, R. Kraft (UCSC), E. Langer (Colorado Coll.), and C. Pilachowski (NOAO/KPNO) have ongoing collaborations to derive light element abundances from echelle spectra of large stellar samples (typically $\geqslant 10$) on the upper red giant branches (RGBs) 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 occur in many globular clusters. Positive correlations of N, Na, and Al abundances, all of which are anticorrelated in some way with the C, O, and Mg abundances, lead directly to the conclusion that high-temperature proton-capture nucleosynthesis has caused the abundance variations. 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. This past year they have determined the chemical compositions of 18 giant stars of the very metal-poor ([Fe/H/] ~ -2.3) cluster M15, showing that not only are the light element abundances quite varied from star-to-star, but so are the neutron-capture elements Ba and Eu. The variations in the ''r-process'' element Eu indicates that some ''primordial'' (supernova) nucleosynthesis occurred in this cluster before the presently-observed stars were born. They also studied 6 giants of the the outer halo cluster NGC 7006. Only mild variations in the light-element abundances are seen in this cluster, suggesting a link between the amount of mixing of proton-capture nucleosynthesis products and the morphology of horizontal branches in globular clusters. Highlights of present investigations include large giant-star samples in M22 (a cluster alleged to have internal Fe-metallicity variations) and M4 (a ''CN-bimodal'' cluster; this is the Masters' project of I. Ivans).

A. Hatzes investigated how spectral line bisectors and precise stellar radial velocity (RV) measurements could be used to study low-amplitude nonradial pulsations in stars. In collaboration with D. Gray (Univ. of Western Ontario), Hatzes demonstrated that, for the star 51 Peg, both the radial velocity and spectral line bisector variations found by Gray

(Nature, 385, 795, 1997) could be explained by an m=2 nonradial spheroidal mode. The implications of this result is that 51 Peg may not have a planetary companion. Observations at McDonald observatory are in progress in an effort to confirm the spectral variability initially reported by Gray.

A. Hatzes and W. Cochran searched for variability in the spectral line profiles of τ Bootis in an effort to confirm the planet hypothesis for this star. They analyzed a total of 34 high resolution (0.026 Å) and high signal-to-noise ($S/N \approx 400$) spectra taken with the 2dcoudé spectrograph of the McDonald 2.7 m Harlan Smith Telescope. Changes in the line shape were quantified using spectral line bisectors and line residuals. They detected no variations in either of these quantities above the level of the noise in the data. Comparisons of the data to the bisector and residual variations expected for nonradial pulsations allowed them to exclude those sectoral nonradial modes having $m > 2$ and all sectoral modes with $k > 1$, where k is the ratio of the horizontal to vertical velocities for the pulsations. The lack of line shape variability and the 469 m sec^{-1} radial velocity amplitude is still consistent with nonradial sectoral modes $m = 1$, and possibly $m = 2$, but with $k \approx 1$, which is at least 3 orders of magnitude less than the predicted value given the 3.3 day period of τ Bootis. Such low values of k can probably be excluded given the lack of photometric variations for this star. Although the measurements presented here do not prove, without any doubt, that τ Boo has a planetary companion, they do add significantly to the increasing body of evidence in favor of this hypothesis.

A. Hatzes and W. Cochran used high resolution ($R = 200,000$) data to examine the spectral line shapes of the K giant star Aldebaran ($=\alpha$ Tau). They found variations in the bisector velocity span with a period of 50 days which was interpreted as arising from a nonradial m=2 mode. No spectral variability was found with the 654-day period of the radial velocity measurements for this star (Hatzes & Cochran 1993, ApJ, 413, 339.) This gives some support to the planet hypothesis for the radial velocity variations, although an m=2 mode can still account for the RV variations without producing measurable changes in the spectral line shapes.

A. Hatzes continued his Doppler imaging studies of active late-type stars. In collaboration with S. Vogt, A. Misch (UCO/Lick Observatories), and M. Kuerster (ESO), Hatzes finished a 12-year long Doppler imaging study of the RS CVn star HR 1099. This study established that the polar spot morphology often found on late-type stars is very long-lived. The sequence of 22 Doppler images for HR 1099 was used to measure directly the surface differential rotation. The rate on this star is a factor of 50 less than on the Sun, and in the opposite sense, i.e. the poles of the star rotate faster than the equator. Marginal evidence was also found for a 3 year cycle in the polar spot area.

C. Johns-Krull and A. Hatzes derived Doppler images for the classical T Tauri star Sz68 under the assumption of solid-body rotation as well as allowing for differential rotation. Assuming solid-body rotation, they found evidence for a large, cool polar spot similar to those found previously on naked T Tauri stars. Allowing for substantial amounts of anti-solar differential rotation caused the bulk of the polar spot to disappear, although several small spots remained at high (+60 deg) latitude. Evidence of rotational modulation was also found in the Hα emission line, which is formed primarily in an accretion flow. These results were interpreted within the framework of magnetospheric accretion models for classical T Tauri stars.

A. Hatzes and A. Kanaan started the first program of its kind to use precise stellar radial velocity measurements to study pulsations in Ap stars. An investigation of the rapidly oscillating Ap star γ Equ showed an RV amplitude that depended on both the line strength and the atomic species: weaker lines and those due to chromium and titanium had a much higher amplitude (by factors of 10–100) than stronger lines and those due to iron. The interpretation of this phenomenon was that the differences in amplitudes arose from the inhomogeneous distribution of elements on the stellar surface. Elements (chromium and titanium) that are concentrated at the magnetic poles should have a high RV amplitude because their pulsational motion is parallel to the magnetic field lines. On the other hand, elements that are concentrated near the magnetic equator (iron) have a lower RV amplitude because their motion is perpendicular to the magnetic field lines. Hatzes and Kanaan are applying this technique to several other Ap stars.

J. Fernley (ESA-Vilspa), T. Barnes and six collaborators completed their program on the distance scale of field RR Lyrae stars using data from the Hipparcos satellite. They used the methods of statistical parallax and trigonometric parallax to show that the mean absolute magnitude of field RR Lyrae stars is Mv $=0.73\pm0.14$ mag at [Fe/H] $=-1.53$. This value is in good agreement with the Baade-Wesselink distance scale for RR Lyraes and in disagreement with the Cepheid distance scale, as intercompared using Cepheids and RR Lyraes in the Large Magellanic Cloud.

T. Barnes, J. Fernley (ESA-Vilspa) and four collaborators have published in PASP an extensive photometric study of 22 galactic Cepheid variables in the bandpasses BVRIJHK. These data provide complete light and color curves for 16 variables.

A detailed study has been made by E. Bakker and co-workers of the chemical abundance of the photosphere of post-AGB stars. The selected post-AGB stars are carbon rich and enriched in s-process elements. A survey of ultra high resolution ($R=200,000$) spectroscopy of molecular absorption lines in optical spectra of post-AGB stars has resulted in the detection of complex line profiles and isotopic bands. A paper has been submitted to ApJ presenting a discussion of the ^{12}CN/^{13}CN ratio in the line of sight to HD 56126.

E. Bakker and co-workers studied Hα emission from HR 4049. The result clearly shows that Hα emission is periodic with the orbital period of the binary system. They propose a model in which Hα emission originates from a hot spot in the circumbinary disk.

While carrying out astrometric monitoring of Proxima Centauri (a known flare star, V 645 Cen) for planetary mass companions with *Hubble Space Telescope* Fine Guidance Sensor 3 (FGS 3), G. F. Benedict and co-workers obtained photometry and astrometry for several significant and several minor flare events. For one major flare that produced a

$\Delta V \sim -0.6$, time-resolved astrometry (effective 1 Hz rate) indicates a detonation at a distance 5.2 ± 2.4 stellar radii from the center of Proxima Cen. A complete report will appear in the Proceedings of the Tenth Cool Stars Meeting.

G. F. Benedict, in collaboration with O. Franz (Lowell Observatory) and T. Henry (Harvard-SAO) has instigated a program of radial velocity measurements of low-mass binary stars. These data, once combined with HST astrometry, will permit a full, three-dimensional characterization of the orbits, and a very precise determination of masses and mass-ratios for these objects. The primary goal is to firm-up the lower main sequence mass-luminosity relationship. The secondary goal is to sift for additional low-mass companions

L. Wang and J. C. Wheeler have continued their program of supernova polarimetry. They found that a classic Type Ia supernova was polarized at nearly the 1 percent level prior to maximum light. This is more than anticipated from models and may be enough to raise concerns about the isotropy of the luminosity and the affect on Type Ia to measure distance scales. They also found that a Type Ic supernovae was highly polarized, in excess of 1 percent. This suggests that the asymmetry may be associated with the process of core collapse itself.

L. Wang investigated the ring structure of SN 1987A combining HST data with that from the European Southern Observatory.

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

H. Dinerstein, C. Pulliam, and D. Garnett (Univ. of Minnesota) have been studying oxygen abundances in planetary nebulae using faint optical emission lines produced by recombining O^{++} ions. In principle, these lines should yield more reliable measurements of O/H than the standard method, which relies on intrinsically brighter but highly temperature-sensitive collisionally excited [O III] lines. Previous investigators had reported puzzlingly high O/H values from the O recombination lines in two planetary nebulae. Using the McDonald Observatory 2.7 m telescope, Dinerstein, Pulliam, and Garnett measured O recombination lines in 12 additional nebulae, and found systematically high O/H values, most greater than 1×10^{-3}. If these results are to be reconciled with the observed intensities of the forbidden [O III] lines in the same nebulae, physical conditions in the nebular gas must be highly inhomogeneous. Alternatively, an overlooked physical mechanism might be enhancing the strengths of the O recombination lines.

3.3.5 Extragalactic:

H. Dinerstein is a team member on the Infrared Space Observatory (ISO) Key Project on ''The Interstellar Medium of Normal Galaxies.'' This project is surveying a dozen nearby, spatially resolved, disk galaxies, and about 60 distant galaxies that sample a wide range in morphological types and infrared luminosities. The ISO observations include mid-infrared imaging and spectroscopy of the thermal dust emission, and measurements of far-infrared emission lines from ionized and photodissociation regions. The overall goal is to better understand the characteristics of global star formation activity among different types of galaxies. Preliminary measurements of 30 galaxies reveal that the strength of the [C II] 158 μm line decreases relative to the infrared dust continuum emission as the infrared continuum gets stronger and is indicative of a hotter dust temperature. In a recently submitted paper (Malhotra *et al.* 1997), the Key Project team has suggested several possible interpretations of this effect. Among the more likely explanations is that this behavior results from the expected decrease in the gas heating efficiency for more intense UV radiation fields, which will be present in galaxies with higher levels of recent star formation activity.

In a related project, H. Dinerstein, C. Pulliam, and collaborator D. Hunter (Lowell Observatory) are obtaining optical emission-line measurements of H II regions in the galaxies in the ISO sample. The purpose of these observations is to obtain an estimate of the metallicity of the ISM in order to examine relationships among elemental composition, ISM properties, and star formation in these galaxies.

G. Shields completed a study of the chemical composition of H II regions in the spiral galaxy NGC 2403 with D. Garnett, E. Skillman, S. Sagan (U. Minn.) and R. Dufour (Rice U.) Abundances of O, N, S, Ne, and Ar were estimated from new spectra of twelve H II regions analyzed with the aid of a new method for combining different temperature indicators. The effective yield for oxygen is higher in M33 than NGC 2403, despite similar structural properties. The O/H gradient per unit disk scalelength is similar among a sample of unbarred spirals including NGC 2403, but the relation between disk surface brightness and metallicity depends on galaxy luminosity.

G. F. Benedict, along with I. Jørgensen, A. Howell, B. Smith (CalTech) and J. Kenney (Yale University), obtained 5 orbits (UBVI and H-α bandpasses) of WFPC-2 data of NGC 4314 on 29 December 1995. All data have been reduced and analysis if the images is nearly completed. The goals include: exploiting the HST resolution to explore the nucleus for a cusp or a nuclear bar; modeling the underlying stellar distribution to obtain intrinsic colors for all regions of past recent star formation in (and just exterior to) the nuclear ring; integrating galaxy photometry with galaxy dynamics - which stars came from where, and how? Preliminarily, they find that profiles through the nucleus modeled with a Nuker function (Lauer *et al.* AJ, **110**, 2622, 1995) imply stellar densities in excess of 5000 $L_{\odot}$ pc^{-3}, within a few pc from the center. A nested ellipse model (Jørgensen *et al.*, AP&SSS, **95**, 489, 1992) subtracted from the original data provides a residual map yielding dust and new star formation (cluster) distributions. UBVI photometry results in preliminary age for clusters in the nuclear ring of 3 My, consistent with active H II regions seen in the Hα image. The outer nuclear ring (OILR) shows no Hα. The color of excess light above the nested ellipse model implies an age $\sim$300 My for the OILR.

I. Jørgensen and B. Milvang-Jensen (Copenhagen University) have continued the study of elliptical and lenticular galaxies in nearby clusters. They have analyzed large samples of galaxies in the clusters Coma and Hydra I. Mean ages and abundances of magnesium and iron have been derived for the galaxies. A strong relation is found between age and magnesium abundance. It is also found that very massive galaxies have rather homogeneous stellar populations, while less massive galaxies populate a broad range in mean ages and mean metallicities.

I. Jørgensen and H. Jønch-Sørensen (Copenhagen University) have studied the poor nearby galaxy cluster S639. The elliptical and lenticular galaxies in this cluster contain surprisingly young stellar populations – some 40% younger than those in galaxies of similar mass in the Coma cluster.

I. Jørgensen and G. Hill have obtained redshifts for 340 faint galaxies in the central part of the Coma cluster, 220 of which had no previous measurements. The measurements will be used together with other available redshift data and new photometry to establish the luminosity functions for galaxies in this cluster, in four different passbands.

M. Bergmann, along with I. Jørgensen, has started a study of morphology of elliptical and lenticular galaxies in the cluster CL0024+16 at a redshift of 0.4.

G. Shields began a study of chemical abundances in the outflowing gas of Broad Absorption Line (BAL) QSOs, in collaboration with V. Junkkarinen and others at UCSD. The study involves HST spectroscopy of BALQSOs with low or or moderate redshifts to study the heavy element absorption lines with a minimum of interference from the Lyman alpha forest. The goal is to test observations and theories of very high metal abundances in the BAL gas, including selective enhancements of Al and P (Shields ApJL, **461**, L9, 1996, and references therein).

In collaboration with A. Laor (Technion, Israel), B. J. Wilkes (Harvard-Smithsonian Center for Astrophysics), G. Ferland (Univ. Kentucky), D. Wills and M. Brotherton (LLNL), B. Wills is investigating relations of UV and optical broad emission lines, absorption lines, and continua, with the ROSAT Xray 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, & McDowell 1997, ApJ, 477, 93). Observations are essentially complete and data reduction half complete. When finished, this work will provide a valuable comparison with samples of different luminosity, radio and Xray and infrared selection criteria. Two objects with high ionization ultraviolet absorption lines have been used in combination with ASCA 'warm absorbers' to discuss physical conditions in the ionized absorbing gas (Laor, I. George (LHEA, Goddard Space Flight Center) & collaborators).

D. Grupe, B. Wills, D. Wills, and K. Beuermann (Georg-August Univ. Goettingen) surveyed the optical polarization of Grupe *et al.* (1997)'s sample of bright ROSAT soft-Xray-selected AGN. Besides the well-known examples NGC 1068 and IRAS 13349+2438, another Xray 'warm absorber' IRAS 12397+333 was discovered by its high optical reddening but lack of corresponding cold Xray absorption. They discuss the relationship between reddening and scattering polarization, and the prevalence of warm absorbers among AGN with high reddening and scattered-light polarization.

K. Leighly, L. Kay (Columbia Univ.), B. Wills, D. Wills, & D. Grupe presented the results of ASCA analysis of the warm absorber, and spectropolarimetry of the Xray bright AGN, IRAS 17020+4544, and showed there is a relationship between optical polarization and the column density of ionized gas ('warm absorbers') in AGN.

M. Brotherton (LLNL), B. Wills, A. Dey (KPNO), W. van Breugel (LLNL), and R. Antonucci (Univ. California at Santa Barbara) have investigated the 'edge-on' extremely red quasar 3CR 68.1 by means of Keck spectropolarimetry, confirming the scattered-light continuum and broad emission line spectrum and discovering strong associated absorption in Mg II and Fe II (see also Aldcroft, Bechtold, & Elvis 1994, ApJS, 93, 1).

D. Grupe, K. Beuermann, K. Mannheim (Goettingen) and H.-C. Thomas (MPE Garching) have completed a paper on Grupe's dissertation work on the IR-Xray spectral energy distributions of a sample of bright soft-Xray selected ROSAT AGN, finding that the optical and Xray spectral indices are inversely correlated and explaining this in terms of emission from hot accretion discs around low-mass black holes. These authors continued further work on the relationships among optical spectroscopic and Xray properties of this sample.

E. Zink has obtained infrared images of quasars and radio galaxies with the IRCAM on the 2.7 m Smith telescope and has investigated the separation of their AGN from the host galaxies.

M. Yuan, with B. Wills and H. Tran (LLNL) are completing an investigation of the secular variation of degree and angle of optical polarization in a sample of BL Lac objects and blazars, using data from the literature, and from McDonald Observatory. D. Wills has continued his investigation of rapid polarization changes in the BL Lac object, OJ 287.

G. Hill, K. Thompson (Royal Greenwich Observatory), and R. Elston (University of Florida) continued their work on the properties of very high redshift QSOs. Infrared spectroscopic observations with the CTIO and KPNO 4 m reflectors of 12 QSOs with redshifts between 3.2 and 4.7 have been combined to study the Fe II emission around Mg II in the rest UV. Comparison with composite spectra of low redshift QSOs reveals very little difference in the emission line properties. The similar Fe II emission implies high Fe abundance in QSOs very early in the universe, and constrains the cosmology because Fe is enriched through Supernova Ia explosions with a characteristic timescale of 1 Gyr.

G. Hill, S. Rawlings (University of Oxford) and other Oxford researchers have detected the largest structure in the universe. It is traced by 7C radio galaxies and is $>80\times60\times75$ Mpc in size and lies at $z=0.25$. This appears to be an example of a very rare supercluster resulting from a $>3\sigma$ fluctuation in the primordial density field. The existance of such structures places constraints on structure formation theories. Further follow-up with McDonald Observatory telescopes and the HET is planned.

3.3.6 Theory:

A. Khokhlov, E. Oran, A. Chechtelkovna (Naval Research Laboratory), and J. C. Wheeler completed a general numerical study of the interaction of a shock wave with a flame as part of their ongoing research into the propagation of combustion in Type Ia supernovae.

V. Gamezo, J. C. Wheeler, A. Khokhlov, and E. Oran (Naval Research Laboratory) completed a study of the instability of detonations in the context of Type Ia supernovae. They found that the unstable structure occurs on three essentially decoupled lengthscales of carbon, oxygen, and silicon burning, respectively. For densities less than about 10^7 g cm^{-3}, the silicon burning length scale becomes comparable to the size of a white dwarf and hence the inhomogenities associated with unstable detonation fronts may leave an imprint on the ejecta.

P. Höflich has adapted his code to compute the three-dimensional, nonLTE radiative transfer to run on a Cray T3E machine. This code will be used to explore the origin of polarization in supernovae.

P. Höflich, J. C. Wheeler and A. Khokhlov (Naval Research Laboratory) completed a study of the γ-ray emissivity of a large suite of models for Type Ia supernovae and discused the detectability of various models with the Compton Gamma Ray Observatory and future proposed gamma ray missions. They point out that if any Type Ia events arise from explosions of helium layers surrounding carbon/oxygen cores that the exposed Ni^{56} from the burned helium should give rise to a strong prompt γ-ray signal from anywhere in the Virgo cluster. Failure to see such a signal would rule out this class of model.

P. Höflich, J. C. Wheeler and F. Thielemann (University of Basel) completed a study of the effect of changing composition on the photometric and spectroscopic properties of Type Ia supernovae. Variation of metallicity and of white dwarf carbon/oxygen ratio with progenitor mass, and hence age, may lead to systematic changes in the light curve brightness decline rate relation that could impose systematic errors in the use of high redshift Type Ia supernovae to measure cosmological parameters. These effects may be calibrated by study of nearby supernovae in a range of environments.

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.

Y. Stein (Hebrew University of Jerusalem) and J. C. Wheeler continued to explore the multi-dimensional aspects of the process of quasi-static carbon burning in carbon/oxygen white dwarfs near the the Chandrasekhar limit.

W. Hix, J. C. Wheeler, A. Khokhlov (Naval Research Laboratory) and F. Thielemann (University of Basel) completed a study of 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.

R. Gearhart, J. C. Wheeler, and D. Swartz (Marshall Space Flight Center) completed a reexamination of the production of carbon-monoxide in SN 1987A using a full radially dependent model for the supernova structure and the associated radiative transfer. They were unable to produce as much CO as previous studies. The reasons for this are under investigation.

S.-W. Kim, S. Mineshige (Kyoto), and J. C. Wheeler continued to study time-dependent irradiated disk models for black hole Xray transients. Of particular interest are the question of whether black hole sources undergo less self-irradiation than neutron stars since the irradiation comes from the surface of the disk rather than the surface of the central star. Another major issue is to understand how fully time-dependent Keplerian disks merge into the inner regions that are strongly suspected to be dominated by nearly radial advective flow.

M. Moscoso, along with J. C. Wheeler, 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. They have developed wind solutions and are investigating critical point structure of annhilation dominated pure pair wind flows.

I. Yi (Institute for Advanced Study), E. Vishniac, and J. C. Wheeler continued to develop a theory for the newly discovered symmetry in spin up and spin down of accreting Xray pulsars. 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. The theory gives constraints on the magnetic field of the neutron star.

J. Scalo and D. Chappell used two-dimensional simulations of spatially coupled one-zone star formation models to demonstrate that local spatial couplings can lead to large-scale coherent, and even synchronized, patterns of star formation without any explicit propagation or any separate organizing agent, such as galaxy encounters, spiral arms, or bars. The local model allows star formation when the gas velocity dispersion falls below a threshold, cools the gas by a model dissipation function, and injects energy from star formation events into their neighborhood, increasing the velocity dispersion and inhibiting further star formation. Several distinct types of behavior, or ''phases,'' of the spatially-coupled system were identified, including, with decreasing density, a spatially homogeneous steady state, oscillatory ''islands,'' traveling waves of star formation or global synchronization, and scattered ''patches'' of star formation activity. The results suggest that phases such as these, which depend mostly on the denstiy, may occur in different ranges of galactocentric distance within individual galaxies, and that galaxies as a whole may evolve through different phases as the gas is gradually depleted by star formation, or because the transient time to settle into a given phase may be very large. In particular, the time for large-scale synchronized global oscillations to develop is of order 1 Gyr, so this phenomenon could be important in the interpretation of star formation rates in galaxies at intermediate and large redshift, producing a long ''latency'' period without the need for any external trigger (e.g. galaxy collisions) or inhibitor (e.g. the metagalactic ultraviolet radiation field).

J. Scalo, with E. Vazquez-Semadeni (UNAM), D. Chappell, and T. Passot (Obs. Nice), have begun an approach to the the numerical simulation of hydrodynamics of gas in galaxies that concentrates on identifying and understanding the underlying physics. The approach uses numerical simulations that systematically reduce the number of physical processes included and the dimensionality, and so the method is called ''reductive simulations.'' A pilot study concerning the form of the one-point probability distribution function (pdf) of density for the interstellar (and integalactic) medium has been completed. Two-dimensional simulations of supersonic turbulence which include star formation energy injection, cooling, self-gravity, magnetic fields, and rotation are the highest-level simulations; similar simulations without the magnetic fields and rotation are at the second level; and two-dimensional simulations of decaying Burgers (pressureless) turbulence are the third level. All levels show similar general filamentary morphology and evidence for a power-law regime in the density pdf with logarithmic slope around -1.7, suggesting that these are the signature of the nonlinear advection operator, the only physical process in common to the different levels of simulation. The power law behavior does not agree with previous claims about the density pdf based on simulations. A series of one-dimensional simulations of forced supersonic polytropic Navier-Stokes turbulence (the fourth level) is used to resolve the discrepancy, finding that the lognormal pdf only occurs when the effective polytropic index is very close to unity. Published cooling functions and different heating sources are used to evaluate this polytropic index for conditions relevant to the cool interstellar medium and the predicted behavior of the density pdf discussed. Implications for the derivation of the stellar initial mass function (which they claim is not possible from the density pdf), the predicted size distribution of expanding shells or superbubbles, and cosmological simulations were considered.

J. Scalo and D. Chappell have generated a large number of two-dimensional finite difference simulations of a model galactic system in which hydrodynamic advection acts on shells expanding away from young star clusters that form according to a threshold prescription on the column density of the filamentary structures. The simulations are pressureless (effective polytropic index zero), and so correspond to a situation in which ram pressure dominates. This model may also be viewed generically as a ''reaction-advection'' system, or as a driven Burgers turbulence with mass conservation. The main purpose is to understand the phenomenology of fluid advection in a very compressible excitable (i.e. star-forming) medium. The dependence of the behavior on initial conditions and on the assumed values of parameters is studied. The general morphology is found to be a ''turbulent'' network of shell fragments covering a range of scales, with a tendency for self-organization into large-scale complexes, even though there is no self-gravity in the simulations. Coherent regions of star formation form, disperse, and wander throughout the simulation as the collective action of many ''propagation'' events, typically involving interactions between shells; self-organization occurs even though self-gravity is absent. The global star formation rate is found to show only rather small temporal fluctuations, except when the average star formation rate is small or the time delay between collapse and energy injection is large, in which case bursts develop.

J. Scalo and D. Chappell studied an interpretation of 2-dimensional reaction-advection simulations of galactic star formation based on the well-known Oort coalescence model for cloud evolution. The simulated system generally evolves by shells merging and fragmenting during shell interactions, and new shells being generated by young stars that form when a threshold criterion is met, very similar to the Oort model. In past studies of coagulation models, the mass spectrum was derived by integrating a kinetic equation whose solution depends on the assumed form of the cloud collision cross section, the relation between cloud density and size, and the velocity distribution of the clouds. It is generally believed that the solution is a power law at large masses, with a power law index between -1.5 and -2, but the exact value depends on the assumed quantities. In the simulations no assumptions need to be made about such quantities, since they evolve self-consistently from solutions of the hydrodynamic equations. The masses of ''clouds'' in the simulations are found by applying a simplified form of the ''structure tree'' image skeletonization approach of Houlahan and Scalo. It is found the the high-mass end of the cloud mass spectrum is a power law of index close to -1.5, close to the classical value, for a broad range of simulation parameters. These results are compared with the mass spectra inferred from molecular line observations.

J. Scalo and D. Chappell also used their simulations of 2-dimensional reaction-advection models for galactic hydrodynamics and star formation to investigate the probability distribution function (pdf) of gas velocities in star-forming regions. A large number of simulations were examined. The overall velocity distribution, either weighted by mass or not, was well-fit by a gaussian core with broad non-gaussian tails. Identification of the filaments in the simulation (which would be shells in 3D), using a new and effective filament-finding algorithm, is used to demonstrate that these tails are primarily due to the gas in the filaments. The velocity pdf of the matter only in the filaments is shown to be extremely non-Gaussian, although the form depends somewhat on the simulation parameters, with the fits varying from exponentials to power laws. The form expected from a number of physical processes and simple models for the shell-shell interaction system is discussed, and a comparison is made with the velocity pdfs estimated for high-mass star formation regions by Miesch and Scalo.

J. Scalo, E. Vazquez-Semadeni (UNAM), D. Chappell, and T. Passot (Obs. Nice) are using the reductive simulation approach, which systematically reduces the number of physical processes included and the dimensionality of the simulations, in order to understand the physics behind the velocity probability distribution of interstellar gas, especially the origin of the broad tails seen in some observed molecular clouds with massive star formation activity.

J. Scalo and D. Chappell examined the linewidth scaling behavior predicted for models of interstellar clouds and galactic and extragalactic giant H II regions that are powered by internal star formation. A balance between energy injection rate and a model dissipation rate leads to a simple scaling relation between velocity dispersion, the flux of kinetic energy from the power source, and the mean density of the region. Two-dimensional pseudo-hydrodynamic simulations of star formation-driven advection, in which threshold star formation drives expanding shells which are advectively distorted by the interaction with other shells, were used to test the predictions of the simple model, and surprisingly good agreement was found. The predicted scaling relation is compared with available data for molecular clouds and extragalactic giant H II regions. In the former case there is insufficient data for a comparison, although such a comparison is feasible. In the latter case the predicted dependence of linewidth on source luminosity (after a consideration of the scaling between kinetic energy injection rate and luminosity for a population of stars) is probably too steep compared to observations, suggesting that virialization models are a better description of the physics.

J. Scalo and P. Kornreich proposed that galactic shocks propagating through interstellar density fluctuations provide a mechanism for the intermittent replenishment, or ''pumping,'' of the supersonic motions and internal density enhancements observed pervasively within cool atomic and molecular interstellar structures, without necessarily requiring the presence of self-gravity, magnetic fields, or young stars. The shocks are assumed to be due to a variety of galactic sources on a range of scales. They studied the process of shocks passing through interstellar density fluctuations, or ''clouds,'' in the case where such shock-cloud encounters do not disrupt the cloud nor induce gravitational collapse. The new features of this study are the consideration of clouds with internal density gradients and the analytical approach taken. It is shown that when a shock encounters a stratified cloud, the variation in post-shock velocity along the shock line induces vortical and compressional velocity perturbations within the cloud. The induced internal velocities are initially a significant fraction of the shock speed divided by the square root of the density contrast, accounting for both the observed linewidth amplitudes and the apparent cloud-to-cloud linewidth-density scaling. The induced vortical energy should quickly be converted to compressible and MHD modes, and so would be difficult to observe directly, even though it would still be the power source for the other modes. The transformation of the vortical modes to compressible modes will be accompanied by the production of new supersonic density fluctuations in the cloud. This shock pump should lead to nested shock-induced structures, providing a cascade mechanism for supersonic ''turbulence'' and a physical explanation for the fractal-like structure of the cool interstellar medium. The average time between shock exposures for an idealized cloud in our Galaxy is estimated and found to be small enough that the shock pump is capable of sustaining the supersonic motions against readjustment and dissipation, except for the smallest structures, suggesting an explanation of the roughly spatially uniform and nearly sonic linewidths in small coherent cores.

J. Scalo is examining a model for star formation and the initial mass function based on the finding of Kornreich and Scalo that interstellar structures should be intermittently ''pumped up'' with internal kinetic energy by the passage of galactic shock waves due to a variety of galactic sources on a range of scales. In this model the kinetic energy powering the linewidths of ''clouds'' and suppressing star formation is free to decay between shock encounters, but is intermittently boosted by shock encounters. Since the decay time is smaller for smaller clouds, the probability of attaining a small enough velocity dispersion for star formation varies inversely with the cloud size. Assuming that in this way the avoidance of shock pumping is necessary for a localized region to form stars, the dependence of the frequency of turbulence decay below a star formation threshold on the cloud size, and hence mass, and other parameters is studied by viewing the intermittent shock pumping and subsequent decays as a stochastic process. The result will be a predicted theoretical initial mass function that increases to smaller masses (because of the dependence on decay probability on cloud size), but quantifying the functional form of this IMF is difficult. Complications involve modelling the frequency distribution of shock speeds at various scales, the effect of a distribution of cloud densities at a given size, and the inclusion of the possibility that a shock encounter will either disrupt the cloud or lead directly to collapse.

J. Scalo and E. Vazquez-Semadeni (UNAM) are investigating simple models, involving recursive expansion-contraction systems, for understanding the sensitivity of hydrodynamic behavior on the effective polytropic index, as well as incorporating detailed cooling functions for molecular interstellar gas into the existing MHD hydrodynamics simulation code.

G. Shields and D. Husfeld (Munich U. Obs.) continued work on the energy distribution and polarization of thermal continuum from accretion disks around supermassive black holes in AGN. A promising model by Blaes and Agol (1996, ApJL, **469**, L41) for an observed, abrupt rise in the polarization in the Lyman continuum (Koratkar *et al.* ApJ, **450**, 501, 1995) fails when the relativistic transfer function is taken into account. A model with an abrupt rise in polarization at 912Å in the rest frame of the orbiting gas gives a good fit and provides a potential way for measuring the angular momentum of the black hole and the inclination of the disk. Graduate student E. Fierce is adding a non-LTE treatment of the ionization of H and He to Shields' disk atmosphere code.

P. Shapiro, H. Martel, and M. Owen (OSU and Lawrence Berkeley Livermore Labs) continued the development and application of their new anisotropic version of Smoothed Particle Hydrodynamics (SPH), called Adaptive SPH (ASPH), for cosmological gas dynamics. The method was tested in 2D and 3D against a variety of problems, including the Sedov blast wave, the interaction of two blast waves, the cosmological pancake collapse, and problems involving collapsing and shearing disks. These tests demonstrated that the method consistently outperforms the standard isotropic SPH, by exhibiting higher spatial resolving power at fixed initial particle number per dimension, while maintaining an adequate level of global conservation of energy and linear and angular momentum. Owen applied a version of this method in 3D to simulate the formation of an Xray cluster, the ASPH entry in the Santa Barbara Cluster comparison paper on cosmological numerical gas dynamics methods, which demonstrated that ASPH gives reasonable results in comparison with other methods currently in use, even when using only a relatively smaller number of particles and running only on a desktop workstation, rather than a supercomputer. Shapiro and Martel experimented with a modification of their original algorithm for the evolution of the anisotropic smoothing kernels of ASPH, designed to eliminate the problems which can result when strong shear occurs in the simulated flow. In addition, new algorithms for the nearest-neighbor particle search were developed based upon an oct-tree, a step towards parallelizing the ASPH method. Finally, the Particle Mesh gravity solver of the original ASPH/PM method was replaced in 3D by a Particle-Particle/Particle-Mesh (P3M) gravity solver.

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

H. Martel and P. Shapiro generalized the comoving variables which Shandarin had first introduced for matter-dominated cosmological models in 1980, to the cases of cosmological models in which there is a nonclumping background of energy density (e.g. cosmological constant), in addition to baryonic and dark matter. In terms of these variables, which Martel and Shapiro refer to as supercomoving variables, fluid properties for an ideal gas with ratio of specific heats equal to 5/3 are stationary in the absence of perturbations, and fluid equations are identical to the fluid equations for noncosmological gas in a nonexpanding background. This property makes the variables extremely useful for solving problems in cosmological structure formation, by allowing the known solutions and techniques of noncosmological gas dynamics to be applied immediately in a straightforward way.

H. Martel and P. Shapiro solved the problem of the collapse of spherical top-hat density perturbations, well-known for matter-dominated cosmological models, in the more general models in which a nonclumping component of energy density is present (e.g. cosmological constant), in addition to the standard baryonic and dark matter.

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

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

E. Vazquez-Semadini (UNAM) and P. Shapiro modified a numerical gas dynamics code, based upon a pseudo-spectral method, for application to the growth of cosmological structure from primordial density fluctuations. The original method was developed in 2D and 3D to study turbulence in the interstellar medium. This work, the first to apply pseudo-spectral methods to cosmology, has revealed the inherent difficulty which such methods have in accurately and stably evolving a gas in which density fluctuations of wavelength much larger than the Jeans length collapse gravitationally at supersonic speeds, leading to strong shocks of very high Mach number and extremely high density contrasts.

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

H. Martel, in collaboration with P. Premadi and R. Matzner (Center for Relativity, University of Texas), has designed a new, state-of-the-art, ray-tracing algorithm for studying the propagation of light in inhomogeneous universes, for the purpose of using QSO lensing properties to constrain the possible cosmological models. This algorithm uses a P3M N-body code to simulate the formation and evolution of large scale structure in the universe. The length resolution of the simulations is extended to sub-Megaparsec scales by using a Monte-Carlo method for locating galaxies inside the computational volume according to the underlying distribution of background matter. This algorithm constitutes a major improvement over previous methods, which either neglected the presence of large-scale structure, neglected the presence of galaxies, neglected the contribution of distant matter (matter located far from the beam), or used the Zel'dovich approximation for simulating the formation of large-scale structure. In addition, this algorithm takes into account the observed morphology-density relation when assigning morphological types to galaxies, something that was ignored in all previous studies.

The distribution of galaxies generated by the P3M algorithm was also used to investigate a totally different problem: the morphological evolution of galaxies. The goal was to determine whether the morphological type of galaxies is primarily determined by the initial conditions in which these galaxies form, or by evolutionary processes (such as mergers or tidal stripping) occurring after the galaxies have formed, which eventually alters their morphology. The main technique consisted of comparing the environments in which galaxies are at the epoch of galaxy formation with the environment in which the same galaxies are at the present. H. Martel and co-workers compared the galaxies that form in low density environments, but end up later in high density environments, to the ones that form also in low density environments, but remain in low density environments. The first group contains a larger proportion of elliptical and S0 galaxies than the second group. These results suggest that about 3/4 of the elliptical and S0 galaxies observed at present formed as such, while the remaining 1/4 of these galaxies formed as spiral galaxies and underwent morphological evolution. These results are consistent with recent observations by HST (the deep field) that show an excess of spiral galaxies at high redshift compared to the present.

3.3.7 Laser Ranging:

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

The McDonald Laser Ranging Station (MLRS) is a fundamental station in the world-wide laser ranging network. It consists of a 0.76-m reflecting telescope and a very short pulse, frequency-doubled, 532-nm wavelength, neodymium-YAG laser, with ancilliary computer, electronic, and timing hardware. The station is located at McDonald Observatory on Mt. Fowlkes, to the north-east of Mt. Locke in west Texas and shares the mountain top with the Hobby*Eberly Telescope. With a two-crew observing operation, laser ranging is carried on to a large number of artificial satellites (Fizeau, ERS-2, Tips, ADEOS, Starlette, Stella, Diadem-C, Diadem-D, Meteor-3, Ajisai, TOPEX/Poseidon, LAGEOS-1, LAGEOS-2, Etalon-1, Etalon-2, GPS-35, GPS-36, and several GLONASS targets) as well as the Moon. The MLRS continues to be the only lunar capable laser ranging station in the United States and only one of two lunar capable stations in the world. By measuring the time it takes for a laser pulse to leave a ground station, bounce off a targeted reflector array, and return to the ground station, one measures very precisely the distance between the station and the reflector array. Comparing a series of measurements (almost 30 years of lunar laser ranging observations have now been accumulated, together with almost 15 years of artificial satellite data), scientific results are obtained in four broad areas: solar system ephemeris development, general relativity and gravitational physics, lunar science, and geodynamics.

Lunar and artificial satellite laser ranging observations were obtained with the MLRS at record setting levels for the 8th straight year, as personnel cooperated with colleagues around the world, making maximum use of the data type for Earth, Moon, and solar system related dynamics. Principal research activity includes monitoring the exchange of angular momentum between the solid Earth and its atmosphere, the principal geopotential terms, plate tectonic activity, tidal dissipation in the lunar orbit, the lunar free libration, and the equivalence principle of general relativity. In a service capacity the project also serves as Observing Center and Analysis Center in the International Earth Rotation Service (IERS), obtaining millisecond accuracy estimates of the constant of precession, coefficients of nutation, polar motion, and Earth rotation. This constitutes the only near-real-time source of this information that includes the lunar laser ranging data type.

3.3.8 Astrometry:

The Hubble Space Telescope Astrometry Science Team is based at the University of Texas. Local members include G.

Fritz Benedict (Deputy P.I.), R. Duncombe (Aerospace Engineering), W. Jefferys (P.I.), B. McArthur, A. Whipple (now at Allied-Signal Aerospace Company), P. Hemenway (now at University of Rhode Island), E. Nelan (now at STScI), P. Shelus, and D. Story (now at Goddard Spaceflight Center). The team continued obtaining, reducing and analyzing data bearing on planet searches (see Solar System, above), HIPPARCOS-quasar reference frame tie-in, and parallaxes of astrophysically interesting objects (Delta Cephei, RR Lyrae, Feige 24, the central star of the planetary nebula NGC 6853, RW Tri, TV Col, the Hyades, and low-mass M-dwarfs). All data are obtained with Fine Guidance Sensor 3 aboard HST. We continue to obtain 1–2 milliarcsecond precision per measurement.

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

P. Shelus, J. Györgey-Ries, and A. Whipple continued their astrometric observations of faint solar system objects. This effort employs a CCD using the Prime Focus Corrector (PFC) on the McDonald 0.76-m reflector. The total astrometric system continues to be 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. Addiitonal observations were made of the satellites of Jupiter, Saturn, Neptune, and Uranus. Many of these objects that are now observed have, in the past, been grossly underobserved and orbit refinements require that a continuous set of precise and accurate positional observations be maintained.

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