Boston University
Department of Astronomy
Boston, Massachusetts 02215

This report covers the major activities in the department over the period from approximately September 1994 through August 1996. Much of the research of department personnel is carried out through the Center for Space Physics (CSP) at Boston University. Further information about the department can be obtained via its World Wide Web page (http://bu-ast.bu.edu/astro.html).

1. PERSONAL

The staff of the department currently consists of Professors Thomas Bania, Kenneth Brecher, Supriya Chakrabarti, Theodore Fritz, W. Jeffrey Hughes, Kenneth Janes, Alan Marscher (Chairman), and Michael Mendillo; Professor Emeritus Michael Papagiannis; Research Professors Jules Aarons, Nancy Crooker, and George Siscoe; Associate Professors Dan Clemens, James Jackson, and Roger Yelle; Associate Research Professor John Mattox; Assistant Professors Teresa Brainerd, Lynne Deutsch, Robert Kerr, and Harlan Spence; Assistant Research Professors Timothy Cook, Daniel Cotton, and Gary Erickson; Adjunct Associate Professors Eileen Friel and Adair Lane; and Postdoctoral Research Associate Leslie Young.

Graduate students currently in the program include Mohamed Al-Othman, Yan Betremieux, Jyotimoyee Bhattacharjya, Alberto Bolatto, Athanasios Boudouridis, Andrew Byrne, Valerie Coffey, Shantanu Desai, Markos Georganopoulos, Sherri Godlin, Gina Gugliotti, Jeremy Hallum, Melissa Hayes, Karen Hirsch, Maohai Huang, Jim Ingalls, Anders Jorgensen, Kathleen Kraemer, Redgie Lancaster, Matthew Lister, John Noto, Candace Oaxaca, Charles Paxson, Daniel Pierkowski, Leah Schechter, Sheela Shodhan-Shah, Andrew Stephan, Melissa Weber-Dryer, and Eftyhia Zesta.

New additions to the faculty and research staff during the reporting period were Friel in 1994, Brainerd and Yelle in 1995, and Cook, Cotton, Deutsch, Mattox, and Young in 1996. Postdoctoral research associates who departed include Elizabeth Moore (to Rutgers University), José Luis Gómez (to IAA, Granada, Spain), and Richard Chamberlin (to the Caltech Submillimeter Observatory).

Boston University joined the Universities for Space Research Association (USRA). It is also a member of the Association of Universities for Research in Astronomy (AURA).

Aarons was named the 1996 Appleton Lecturer, awarded each year to a distinguished ionospheric physicist by the IEE (UK).

Bania is a Trustee of the Northeast Radio Observatory Corporation (NEROC) which operates Haystack Observatory. He remains as one of the Harlow Shapley Lecturers of the American Astronomical Society. Bania was on sabbatical leave in spring 1996 at the National Radio Astronomy Observatory in Green Bank, WV.

Brecher, who is director of the university's Science and Mathematics Education Center, is chair of the Space Telescope Astronomy Education Committee and a member of the editorial committee of the *Annual Reviews of Astronomy & Astrophysics*. His educational projects include ''On Growth and Form'' and ''The Random Universe.'' He has continued his involvement (at Harvard U.) in the development of the ''MicroObservatory'' project: Five 2nd-generation models of the automated 6'' telescopes, each equipped with a CCD, with pointing control and image processing by a Macintosh computer, have been completed. Software is being written to place them on the World Wide Web for remote use by students, amateur astronomers, and museums. Brecher continues to write entries for *Encyclopaedia Britannica* and *World Book Encyclopedia*.

Chakrabarti is a member of NASA's Ultraviolet, Visible, and Gravitational Astrophysics Management and Operations Working Group (MOWG).

Clemens continued to serve as a member of the Haystack Committee on Operations and Plans (time allocation committee) as well as the Time Allocation Committee for the Five College Radio Astronomy Observatory 14 meter telescope (1995-96). Clemens is co-chair of the Legacy Program sub-committee of the SIRTF Community Task Force.

Crooker served as a member of the AGU Waldo E. Smith Medal Committee in 1992-94 and chairs the Boundary Layer Working Group (NSF/GEM Program) Task Force.

Friel resigned her position as director of the Maria Mitchell Observatory to become a program officer in the Division of Astronomical Sciences of the National Science Foundation.

Hughes is director of the Center for Space Physics at Boston University, a research unit with close ties to the Astronomy Department. He is chairman of the steering committee for the NSF's Geospace Environment Modelling (GEM) program. He served on the American Geophysical Union's Meetings Committee (1992-96) and currently serves on their Budget and Finance Committee.

Janes continued as the Boston University representative to the Association for Research in Astronomy (AURA), initially as a member of the Board of Directors, and following its reorganization in 1996, as a member representative. In addition, Janes became a member of the Board of Directors of the Fund for Astrophysical Research.

Marc Kassis (Willamette College) spent the summers of 1995 and 1996 in the department as an NSF REU student working with Janes and Friel.

Kerr is currently on the NSF CEDAR Scientific Steering Committee. He also served on the AGU Space Physics Awards Committee 1992 - 1994. Kerr leads a panel to plan atmospheric science uses of the Gregorian Upgrade at Arecibo, and serves as the chair of a Personnel Committee at that facility. 1996 was the final year of Kerr's Presidential Young Investigator Award, which began in 1991.

Marscher served on the AUI Visiting Committee for the

National Radio Astronomy Observatory, chairing the committee in 1995. He also sits on the *Compton* Gamma Ray Observatory Users Committee.

Mendillo is chair of the NSF CEDAR (Coupling, Energetics & Dynamics of Atmospheric Regions) Science Steering Committee.

Siscoe chairs the Geospace General Circulation Model Campaign as part of the NSF GEM program, co-convened the 1996 GEM Space Weather Workshop, and is a member of the NASA Roadmap Panel and the NOAA Advisory Committee to the National Centers for Environmental Predictions.

Spence continued his National Science Foundation (NSF) Young Investigator award during 1994-1996. He continues to serve as a member of the National Academy of Science's Space Studies Board Committee on Solar and Space Physics. Spence is also a member of the National Science Foundation Geospace Environment Modeling (GEM) Program Steering Committee, is the bi-annual GEM Workshop coordinator, and co-chairs GEM Substorm Campaign Working Group 2. He is also a member of NASA's Science Definition Team for the proposed Geospace Multiprobe Mission.

Yelle served as a member of NASA's Outer Planet Science Working Group (OPSWG), the Pluto Express Science Definition Team, and the Solar System Roadmap development team. He was also a member of the Icarus editorial board and COMPLEX, the National Research Council committee on Planetary and Lunar Exploration.

2. INSTRUMENTATION

2.1 Spaceflight Design/Fabrication

2.1.1 TERRIERS: A Satellite in the STEDI Program

USRA selected a Boston University satellite, TERRIERS (Tomographic Experiment using Radiative Recombinative Ionospheric EUV and Radio Sources) for flight under its educational satellite program (STEDI), a pilot program to assess the efficacy of developing small, low cost space flight missions that rely heavily on student participation. Cotton is the PI of TERRIERS, while Chakrabarti is the Chief Scientist, Cook is the Project Manager, and Mendillo is a co-I. TERRIERS is a small satellite designed to map the ionosphere on a global scale for the first time using tomographic (CAT-scanning) techniques. Although the project is small, the TERRIERS satellite has 10 instruments including 5 single element imaging spectrographs (SEIS), and a Gas Ionization Solar Spectral Monitor (GISSMO). The SEIS design provides the necessary sensitivity (100$\times$ more sensitive than previously flown instruments) to carry out the tomographic measurements. GISSMO is a new optics-free solar spectrograph designed to monitor the solar EUV over long time periods without degradation. TERRIERS will be the maiden flight for the SEIS spectrographs and the first satellite demonstration for GISSMO.

The primary mission of TERRIERS is to map the ionosphere in three dimensions using the 911Å $O+$ recombination line. This diagnostic provides an optically thin electron density tracer which TERRIERS will use to establish the 3-D structure of the ionosphere. By measuring the solar flux (with GISSMO), TERRIERS will be able to determine how ionic structures react to the changing solar-terrestrial environment. While carrying out its primary mission of mapping the ionosphere, the satellite will collect data in both the upward and downward directions. The upward dataset will provide an opportunity to assemble the first all-sky three-color survey at far ultraviolet wavelengths.

Another aspect of this student explorer project is the educational program it contains. Not only are undergraduate (J. Vaillancourt, V. Taylor, J. Weida, D. Noyes, F. Beile, and M. Galpin are among nearly twenty individuals who have contributed) and graduate students (A. Stephan, F. Kamalabadi, J. Vickers, and P. Dell) taking on critical roles including testing and calibrating the instruments, developing the scientific data base to store the data, and designing the electronics systems and analysing the data, but key outreach programs are being run at the K-12 and public education levels. In fact, TERRIERS will have on-board a high-school instrument developed by AeroAstro in conjunction with Cleveland Heights High School; this will measure the solar Ly α flux and measure the thermal properties of several materials in space. TERRIERS is scheduled for launch in August, 1997.

2.1.2 CAMMICE and CEPPAD Instruments on the POLAR Satellite

NASA's POLAR satellite, successfully launched in February 1996, carries several instruments designed, developed, and calibrated by Boston University faculty. During 1994-1995, Spence, CSP Research Associate R. Sheldon, graduate students Jorgensen and Hirsch, and undergraduate students S. Thompson and K. Fishbaugh worked with Fritz's group (W. Spjeldvik, visiting scholar from Weber St. U., and Research Assoc. J. Chen, both of the CSP) on final calibrations of CEPPAD (Comprehensive Energetic Particle and Pitch Angle Distribution) and CAMMICE (Charge and Mass Magnetospheric Ion Composition Experiments). Fritz is PI and Spence is co-I of CAMMICE, while both are co-I's on CEPPAD. Since activation in March, the CEPPAD and CAMMICE instruments have returned spectacular data of the energetic particle populations in the Earth's magnetosphere. For CEPPAD, Fritz's group (including Boston U. Physics professor J. Sullivan, CSP Senior Research Assoc. D. Matthews, and Sheldon, and students Al-Othman, S. Braginsky, A. Contos, Weber-Dreyer, Gugliotti, Hirsch, Jörgensen, G. Levine, and L. Sanchez) was responsible for the design, testing, and calibrations of two of the three sensor systems: HIST (High Sensitivity Telescope) and IES (Imaging Electron Spectrometer). HIST is designed to make a clean definitive measurement for the first time of the trapped energetic (0.5–10 MeV) electron component within the magnetosphere. The IES sensor system utilizes a very novel, compact, low mass, and low power design using an integrated circuit device developed for pulsed particle accelerators. It incorporates a stobing function which is different from classical nuclear spectroscopy and pulse height analysis. The IES sensor was also included in the scientific payload of each of the four CLUSTER satellites (see below) as part of the RAPID [Research with Adaptive Particle Imaging Detectors] experiment.

Spence was named POLAR science liaison to the NASA Midex ''IMAGE'' mission, and will provide hardware guidance to that team based on lessons being learned from similar POLAR instrumentation.

2.1.3 CIRCLE Experiment on Champollion

Yelle was chosen as the PI for the CIRCLE experiment on the Champollion lander on the ESA's Rosetta mission to comet Wirtanen. CIRCLE consists of visible cameras which obtain high resolution images of the comet's surface, a microscope, which obtains higher resolution images of a subsurface sample, and a multichannel IR spectrometer for compositional studies. Yelle leads a team of scientists from JPL (where CIRCLE will be built), as well as a number of universities in the US and abroad. Yelle, in collaboration with B. Sandel and R. H. Brown (U. Arizona), L. Soderblom (USGS), and colleagues at JPL, continued development of lightweight/low power instrumentation for space missions including the Pluto Integrated Camera Spectrometer (PICS), developed as a prototype for NASA's Pluto Express Mission and a flight model of MICAS (Minature Integrated Camera and Spectrometer), developed for the DS1 mission in the New Millenium Program.

2.1.4 CLUSTER

The CLUSTER satellites were destroyed with the failure of the Ariane 5 rocket on its initial launch from French Guiana in June 1996. Since that failure, Fritz has been working with the ISTP project and the RAPID PI, B. Wilken of the German Max-Planck-Institut für Aeronomie, to incorporate an IES sensor as part of plans to launch the CLUSTER flight spare in 1997 (''CLUSTER 5''). Modifications to the IES were incorporated into the spare unit [IES#6], with subsequent testing supported by Braginsky, Matthews, and Sheldon.

2.1.5 EPD on the Galileo Spacecraft

Fritz is co-I of the EPD (Energetic Particle Detector) experiment on the Galileo spacecraft currently in orbit around Jupiter. This instrument has measured fluxes of energetic particles accelerated along the magnetic flux tube connected to Io.

2.1.6 SPINR Sounding Rocket Program

SPINR (Spectrograph for Photometric Imaging with Numeric Reconstruction) is a sounding rocket experiment being designed and constructed by Taylor and Cook to map the variation of the ultraviolet reflection and absorption spectrum of interstellar dust in reflection nebulae and star forming regions. The instrument is simple and efficient, using a SEIS system to record the spectrum of a wide field while imaging in the cross dispersion direction. The system is spun about its optical axis and a tomographic reconstruction algorithm is used to deconvolve the 2-D image of the field. This technique yields a full 3-D data cube (i.e. RA, Dec, and wavelength), which can be used to study both the spectrum of multiple objects in the field as well as light from the diffuse background. The experiment will be able to map the relationship between dust grain size and composition, ultraviolet flux, and morphology across the region. These data should yield new insights into the processes of dust formation and destruction in the region. The data will be useful both as a catalog of a large number of stars scattered throughout the field that can be used for absorption studies and as a measure of the ultraviolet scattering properties of the nebula. It is likely that this dual approach of measuring both the scattering and absorption properties of the interstellar medium will prove more productive than either method would independently.

2.1.7 SCARI

The SCARI (Self Compensating All Reflective Interferometric) spectrometer was designed to constrain models of the structure of the outer heliospheric region and study the interaction of interstellar H I with the solar wind, using precise measurements of the H I velocity distribution within a few AU of the sun. These goals will be accomplished with high spectral resolution measurements of solar Lyα photons resonantly scattered from interstellar H atoms that have penetrated the solar system. From these data, the nature of the interaction between the solar system and the surrounding interstellar cloud can be determined, including the filtering of this H I population in the heliosphere region and the modulation of the velocity distribution of this population in the heliopause region and within the solar system. Since the experiment will be conducted from a relatively low altitude ($\sim$300 km), concomitant data on the hydrogen in the earth's upper atmosphere (which extends to over 10^5 km altitude) can be collected. This gas (the H geocorona) glows when exposed to solar Lyα emission. These data can be used to study the escape of H in the earth's atmosphere. The SCARI effort is being aided by a NASA graduate fellowship to Godlin.

2.1.8 SADIE

The next generation of orbiting astronomical telescopes and planetary probes will be smaller, lighter, and cheaper while at the same time demanding higher resolution, and larger formats. SADIE (the Silicon Anode Detector with Integrated Electronics) is being developed to meet these challenging requirements. The system uses VLSI technology to fabricate a position-sensitive photon counting readout instead of the traditional printed circuit board technologies. As a result, the SADIE anodes have finer detail, 3-D structures, and lower noise. In addition, since the anode is fabricated with IC technology, it is a straightforward procedure to incorporate the readout electronics directly on the anode, thereby making a light, very low-power detector.

2.1.9 Hi-TIES

Former student J. Vaillancourt, Senior Research Assoc. J. Baumgardner (CSP), and Chakrabarti have developed a novel high resolution echelle spectrograph (without the customary cross-disperser) for wide-field studies. Order sorting is achieved by employing a mosaic of interference filters placed over selected spectral features. This allows a complete flexibility of wavelength selection in the entire visible region as well as choice of the features to be measured simultaneously while maintaining high spectral resolution.

2.2 AST/RO (Antarctic Submillimeter Telescope and Remote Observatory)

The exceptionally cold and dry atmosphere over the South Pole makes it the best observing site on Earth at submm wavelengths. A small consortium including Boston University operates a 1.7 m aperture submm-wave telescope at the NSF Amundsen-Scott South Pole Station. The AST/RO instrument was fabricated at the Scientific Instrument Facility at Boston University and tested extensively during the winter of 1993-94 at an on-campus test site. AST/RO was installed during the 1994-95 Austral summer and is now beginning its third season of operation. AST/RO is highly automated and has a $\sim$100 arcsec resolution at 600 μm with high beam efficiency. It is a general purpose submm-wave telescope and is ideal for large-scale studies of galactic structure. As part of the AST/RO Consortium, Bania, Jackson, and Lane are co-investigators in CARA (Center for Astrophysical Research in Antarctica), an NSF Science and Technology Center.

2.3 CEDAR Imager (Coupling, Energetics, and Dynamics of Atmospheric Regions)

An NSF sponsored facility, the CEDAR Program's CLASS-1 CCD Imager was designed and built at Boston University and now operates at the Haystack Observatory/Millstone Hill complex in Westford, MA. The imager operates in all-sky (180-degree field of view) mode to record emissions from the ionosphere associated with solar-terrestrial disturbances, as monitored by the Millstone Hill Incoherent Scatter Radar. The Boston University optical site at the Haystack Observatory has been expanded into a CEDAR Optical Tomography of the Ionosphere Facility (COTIF).

Kerr has designed, constructed, and placed in service a transportable, multiple etalon Fabry-Perot Spectrometer. That instrument provides high spectral resolution spectroscopic data from the visible to the near infrared using GaAS PMT, CID array, and Germanium IR detectors. The Fabry-Perot, based at the Haystack Observatory Millstone Hill Optical Facility, has been used on Wake Island to measure thermospheric winds and at Arecibo Observatory to measure the infrared metastable helium emission.

2.4 MACCS (Magnetometer Array for Cusp and Cleft Studies)

MACCS collects high time resolution (1 sec) magnetic field measurements at 12 sites in the eastern Canadian arctic. The array is funded as part of NSF's GEM Program, and is run jointly by Boston University and Augsburg College. The magnetometer sites span about 5 hours in magnetic local time and magnetic latitudes from 74° to 82°. The primary purpose for the array is to study waves and perturbations associated with the magnetopause and magnetospheric cusp and boundary layers. Ongoing collaborative observations include studies with the spacecraft of the International Solar-Terrestrial Program (GEOTAIL, WIND, POLAR) as well as with the SuperDARN array of HF ionospheric radars and with other magnetometer arrays.

2.5 Planetary Environment Imaging Spectrograph and Monochromatic Imager

These imaging systems provide 6° fields of view and are used to search for large-scale, faint emissions associated wtih solar system bodies. To date, they have been used to describe the extended sodium atmospheres of Jupiter and the Moon. In 1994, these facilities were incorporated into a new Boston University Station on Mt. Locke at the McDonald Observatory. An 18-foot dome was constructed, together with a control room, to house a new 20-inch Richey-Cretian telescope to conduct searches for extended planetary comas.

2.6 Optical-Infrared Instrumentation

Clemens, Deutsch, Jackson, Bania, and Yelle have been awarded a NASA grant to conduct a detailed instrument design study in support of their concept for a far-infrared imaging photometer and polarimeter for the upcoming airborne observatory SOFIA. The instrument, called IMPP, will be capable of background-limited deep imaging simultaneously at two wavebands or high-precision imaging polarimetry of magnetic fields in warm dust clouds. Clemens, Deutsch, and Janes have embodied their optical polarimetric and photometric experiences into the design of a modern CCD-based imaging polarimeter and multi-object spectrophotometer, which they hope to build and then use in galactic studies.

2.7 Associations with National Observatories

One of the ten stations of the transcontinental Very Long Baseline Array (VLBA) radio interferometer operated by the National Radio Astronomy Observatory (NRAO) is located at Boston University's Sargent Camp near Hancock, NH. Each station has a 25-m diameter radiotelescope and associated computers and electronics. The VLBA operates at wavelengths as short as 7 mm and produces images of quasars and other compact objects with resolutions as fine as $0\rlap{.}''00015$.

Boston University is a member of the Northeast Radio Observatory Corporation, which operates the Haystack Observatory in Westford, MA. Haystack is a 43-m diameter radiotelescope that is used for sensitive cm- and mm-wave spectroscopy and very long baseline interferometry.

3. RESEARCH

3.1 Interstellar Medium

Bania, D. Balser (NRAO), R. Rood (Virginia), and T. Wilson (Max Planck Institut) continued their studies of the abundance of $^3He^+$ in the interstellar medium. Balser (Ph.D. 1994) is constructing sophisticated numerical models for $^3He^+$ sources. The group has made spectral line and continuum observations of a sample of 23 Galactic H II regions at 3.46 cm wavelength during the past 14 years as part of a program to measure the abundance of $^3He^+$ in the Milky Way interstellar medium. Determining the ^3He:H abundance ratio requires not only accurate measurements but also realistic models for the ionization and density structure of the sources. The observations needed to model the sources were made with the NRAO 140 Foot, VLA, and MPIfR 100 m telescopes. Based on H II region models they derive abundances in the range ^{3}He:H = 1–5$\times 10^{-5}$. The abundance differences among the sources appear to be real, the consequence neither of observational error nor of the source modeling. For a sample of six Galactic planetary nebulae they derive abundances ^{3}He:H less than about 0.1–1$\times 10^{-3}$ by number. These abundances are a factor of ten larger than those found in Galactic H II regions and are consistent with standard stellar models. When combined with other light element abundances their present limits on the $^3He^+$ abundance begin to either challenge Standard Big Bang Nucleosynthesis models or call into question some of the standard assumptions concerning the chemical evolution of $^3He^+$. For example, the observed abundance pattern across the Milky Way cannot be easily explained by existing chemical evolution models.

The AST/RO group is making C I and CO surveys of selected regions such as the Galactic center, the Magellanic Clouds, portions of the fourth quadrant of the Galaxy, and particular high latitude regions. Such extensive comparative studies provide important tests for theories about the relationship between the atomic and molecular constituents of the interstellar medium, the metallicity dependence of these species, and their relationship to star formation and galactic evolution. AST/RO is observing star-forming clouds, nearby galaxies, and the envelopes of mass-losing stars as directed summer projects. Stratospheric ozone and CO concentration is also being measured as a function of altitude and time at regular intervals throughout the year.

Ingalls, Bania, and Jackson are studying atomic and molecular interfaces in high latitude galactic clouds (HLCs) using the CO molecule and the 492 GHz fine-structure transtion of [C I]. In a study of the nearest molecular cloud MBM-12, they reported the first detection of [C I] emission from a high-latitude cloud. More recently they have used AST/RO to detect [C I] in a sample of eight southern hemisphere HLCs. The C/CO column density ratio ranges from 0.4 to 2.5, and is similar to the values previously measured in the high latitude clouds MBM 12 and HD 210121. For all ten HLCs observed in [C I], C/CO averages $\sim$1.2 and decreases with increasing total gas column density N_H, as predicted by translucent cloud models. Quantitative comparison with chemical models of homogeneous clouds is unsatisfactory, however, and they conclude that the clumpy structure of clouds must be taken into account in order to interpret the data properly.

Marscher and Moore continued a scheme to use time variability of molecular absorption lines to detect AU-scale structure in molecular clouds. Changes in the λ 6 cm absorption line profile of H_2CO were verified toward NRAO 150 and 3C 111 and measured at the 4σ level toward BL Lac with the VLA. This result indicates that diffuse molecular clouds are clumpy from light-year to AU size scales. Given the velocity width of the features in the difference spectra, the clumpiness of the cloud appears to result from supersonic (consistent with magnetosonic), compressible turbulence in the cloud with an inner scale smaller than 1 AU.

3.2 Star Formation

By using novel probes of the densest gas, Jackson, T. Paglione (Ph.D. 1996), and colleagues have been examining the dense gas content of galactic nuclei. The primary tools are spectral lines of molecules such as HCN, HCO^+ and CS that require high densities for excitation. The group has detected several of these lines (HCN 4-3, HCO^+ 4-3, CS 1-0) in external galaxies for the first time. An analysis of the excitation shows that there is a large difference in gas density among galaxies, with those galaxies undergoing nuclear starbursts having the highest gas densities. A survey of HCN and CO emission from the center of the Galaxy shows that most of the dense gas is confined to a few massive clouds. Comparison between the Milky Way and starburst nuclei at the same spatial resolution shows that starburst galaxies have larger masses of dense gas, larger average gas densities, and larger regions of enhanced gas density than the Milky Way. Jackson's group has also imaged HCN emission from the starburst galaxy NGC 253 at high angular resolution. The individual molecular cloud complexes are much denser and more massive in NGC 253 than in the Milky Way. Apparently, star formation activity has a profound effect on the global properties of the interstellar medium in galactic nuclei.

Jackson's group has also been examining the effects of massive star formation on nearby Galactic molecular clouds. The primary laboratory for this study has been the NGC 6334 molecular cloud/star forming complex. Images of NH_3 (3,3) lines with the VLA have revealed maser emission associated with the shocks induced by stellar outflows. The group also discovered a massive (2000 $M_\odot$) molecular disk associated with the O star NGC 6334 A. They suggest that the disk is spawning a proto-star cluster and that all clusters may form from such large-scale molecular structures.

B. Kane (now at Phillips Lab) completed his PhD dissertation concerning the structure and magnetic nature of starless Bok globules, under the direction of Clemens. Kane observed a sample of 14 small Bok globules using high angular and spectral resolution mm-wave spectral line mapping and analysis of optical imaging polarimetry. The spectral line data established the rotation rates of each cloud and the projected directions of the cloud momentum vectors. The optical polarimetry of stars background to the small clouds was used to create maps of the projected magnetic field directions in the peripheries of these clouds, with typically 100 stellar samples per cloud. These maps were further analyzed to establish the mean field directions and directional dispersions. In comparing the cloud rotation directions with their magnetic field directions, Kane established a clear link between the kinematics and magnetic nature of these simple clouds.

Polarization maps continue to be analyzed, with a new emphasis on star-forming Bok globules. Undergraduate researchers J. Wright and P. Ilardi, working under the direction of Clemens, have improved upon the analysis tools used by Kane and applied them to observations of the outer regions of B335. Their magnetic field map contains almost 300 stars, more than an order of magnitude more than in any previous study of this cloud. One of the outstanding problems concerning the small Bok globules, that of establishing their distances, has recently been addressed in the work of undergraduate D. Peterson, under the direction of Clemens. Using IRAF analysis of deep optical images containing Bok globules, collected at the SDSU 1.05 meter telescope, she has shown that broadband photometry can identify M-dwarf stars in front of, and just behind, the globules. Estimates of the extinctions and intrinsic spectral types of these stars constrains globule distances to much higher precision than ever before.

Jackson, Bania, and Bolatto have used AST/RO to observe the $^3P_1 \rightarrow {}^3P_0$ fine structure [C I] transition of neutral carbon toward two star forming regions in the Large Magellanic Cloud: N159 and 30 Doradus. They find that the $I_{[C\,I]}/I_{CO}$ luminosity ratio in N159 is enhanced by a factor greater than about 2 with respect to the same ratio in the Galaxy, a result that they attribute to the lower metallicity of the Large Magellanic Cloud. Low heavy element abundances and low dust-to-gas ratio characterize the metal-poor interstellar medium and produce enlarged photodissociation regions, where C^0 is the dominant form of carbon.

Clemens and J. Yun (U. Lisbon) plus undergraduate researchers M. Cushing, D. Donovan, D. Hill, and J. Cook are continuing their project to produce a catalog of all protostars observed with the *IRAS* satellite, based on a strategy developed by Yun in his PhD dissertation research involving star formation in small Bok globules.

3.3 Stars and Stellar Evolution

Janes, Friel, R. Phelps (Carnegie Obs.), J. Heasley (U. Hawaii), R. Zinn (Yale U.), and other colleagues and students, have continued to study the history of the galaxy using star clusters as dated artifacts and, via stellar evolution, using them as stellar laboratories. In a continuation of a study of the old open clusters, they have obtained new photometry of a number of clusters. The new photometry has confirmed the extreme age for the cluster Berkeley 17, which could be in excess of 10 Gyr. Another previously unstudied cluster, Berkeley 66, is similar in age to the well-known old cluster M67. Improved photometry for several more old clusters (Melotte 66, NGC 2204, NGC 2477 and Berkeley 39) has been completed. Friel and her NSF-REU students from the Maria Mitchell Observatory continued to analyze spectroscpic data for cluster red giants obtained at CTIO and KPNO. The new results confirm that there has been a significant systematic increase in the metallicity of the galactic disk in the past 8–10 Gyr.

Friel, in collaboration with MMO students J. Finlay (Alfred U.) and L. Hsu (Johns Hopkins U.) and MMO visiting scientist A. Noriega-Crespo (IPAC), has begun a study of the galactic orbits of several old open clusters. Orbital calculations in a realistic gravitational potential indicate that these clusters must survive many passages through the disk. N-body simulations are underway to determine the most influential structural and orbital characteristics that lead to the survivability of these long-lived clusters.

Janes, Zinn, Heasley, and others have nearly completed reduction of HST observations of globular clusters near the Galactic center and are in the process of estimating their ages. The goal of the project is to learn whether the clusters near the Galactic center differ in age from those nearby the sun, to probe the early evolution of the Galaxy. The preliminary indications are that the metal-poor clusters are almost identical in age to the halo cluster M92.

The potential of ultra-high precision photometry for application to several astronomical problems is the subject of a new program by K. Janes and collaborators. By taking advantage of the high angular density of stars in a cluster, it may be possible to do differential photometry sufficiently well to monitor the effects of stellar activity cycles in stars of known ages, or even to detect the occasional transits by Jupiter-size planets in front of the parent star. Janes, working with K. Yoss and (U. Illinois) and Grant Miller (SDSU and Southwestern Col.), has obtained an extensive series of observations of the open clusters NGC 188, NGC 6819 and NGC 7789 to search for indications of stellar activity as a function of stellar age, and to explore, in general, the limits to ultra-high precision photometry. If sufficiently high-precision differential photometry can be acquired through a suitable choice of observing site, it may be possible to detect the p-mode oscillations of solar-type stars. Heasley and Janes have published an analysis of the South Pole as a site for asteroseismology; the prospects appear good for detecting stellar oscillations at the South Pole.

Deutsch's current research focus is the study of the processing of interstellar matter through the cycle of stellar evolution. Of particular interest are the circumstellar environments and gas and grain populations in objects in the early and late stages of stellar evolution, such as Galactic and extragalactic star forming regions and planetary nebulae. In order to advance her observational program of near- and mid-infrared imaging and spectroscopy, Deutsch is actively developing new infrared instrumentation for ground-based and airborne observatories. She continues to observe with the UA/SAO MIRAC2 (Mid-Infrared Array Camera) as an original team member in collaboration with colleagues W. Hoffmann (UA), J. Hora (UH/IfA), and G. Fazio (SAO). Deutsch is currently designing a mid-infrared camera system with both spectroscopic and imaging capabilities to be built at Boston University over the next two years.

3.4 Quasars

Marscher, Moore, Georganopoulos, undergraduate student A. Young, and collaborators monitored γ-ray bright blazars at a number of wavebands, combining multi-frequency VLBI, mm- and submm-wave, and infrared observations with space-based X-ray (*ROSAT* and *RXTE*), and γ-ray (*CGRO*) measurements. Early results of VLBI monitoring using the VLBA suggest that the γ-ray bright blazars have higher apparent speeds and greater Doppler beaming than the general population of bright flat-spectrum radio sources. Marscher and former student J. Travis calculated the multiwaveband spectrum expected from synchrotron self-Compton (SSC) emission from relativistic jets, showing that the observed spectra of several sources can be explained by this model. Former student S. Bloom (Ph.D. 1994) and Marscher determined that 2nd-order SSC emission cannot in general explain the γ-ray emission from blazars—it must be 1st-order. In addition, the relativistic electron energy distribution must flatten or cut off at energies below about 100 MeV. The May 1994 TeV γ-ray flare of Mkn 421 (D. Macomb of NASA/GSFC was the leader of the collaboration) had no IR-submm counterpart but did coincide with an X-ray flare; this can be explained if the only physical variation was in the upper cutoff to the electron energy distribution.

Mattox has been studying blazars with CGRO. He obtained a spectacular result for PKS 1622$-$297: the flux in the high-energy γ-ray band was observed to be five times brighter than that of any previous blazar, and twice as bright as that of the Vela pulsar, normally the brightest source in this band. Also, the flux was observed to double in less than 4 hours, placing severe constraints on models of γ-ray emission. Marscher and Mattox are monitoring this and the blazar CTA 26 with the VLBA in search of new radio-jet components corresponding to the γ-ray flares. A follow-up multiwavelength observation campaign is scheduled for August 1997.

Mattox will use the EGRET instrument aboard CGRO to search for high-energy γ-ray emission from X-ray novae within our Galaxy that are observed to have superluminal jets. These observations provide a means to confirm the report from the HEGRA observatory of the detection of TeV γ-rays from X-ray nova GRS 1915+105.

Marscher is collaborating with Gómez and J.M. Martí and J.M. Ibáñez (U. Valencia) on a project that simulates time-variable relativistic jets using relativistic hydrodynamics. The synchrotron emission is calculated at both optically thin and optically thick frequencies. Variations in the velocity or energy density of the otherwise steady flow causes shock waves and rarefactions to form and propagate down the jet, which in turn causes the appearance of knots moving at superluminal speeds, as observed by VLBI.

Georganopoulos and Marscher calculated both the steady-state and time-variable spectrum expected in the accelerating inner jet model. The range of properties of the spectra of BL Lac objects can be explained by a combination of the effects of viewing angle and a distribution of magnetic fields among different objects. An increase in magnetic field increases the energy losses of electrons injected at the base of the jet, thereby steepening the spectrum as it rises. These types of variations are expected when the electric vector of the polarization is perpendicular to the axis of the jet, whereas the shock model developed by Marscher and W.K. Gear (Royal Observatory Edinburgh) should be applied when the vector is parallel to the axis.

Lister and Marscher are investigating the statistics of relativistically beamed flat-spectrum radio sources. When one takes into account the luminosity function and other effects, the observed distributions of redshift, apparent velocity, and other observed parameters, are reproduced for models in which low bulk Lorentz factors are more prevalent than high ones. The Lorentz factor can be either independent of or correlated with the luminosity, but cannot be anti-correlated.

3.5 Cosmology

Brainerd, R. Blandford (Caltech), and I. Smail (Univ. of Durham) used deep imaging data from the Hale 5-m telescope to investigate statistical gravitational lensing of cosmologically distant galaxies by forground galaxies. Their work reports the first positive detection of this effect and concludes that field galaxies have gravitational potential wells consistent with circular velocities of 220 km s^{-1} and physical radii in excess of $20h^{-1}$ kpc. Using data from the Hubble Deep Field and flanking fields, Brainerd, Blandford, D. Hogg (Caltech), and T. Kunic (Caltech) are continuing to investigate this effect and its potential for constraining both the physical properties of the dark matter halos and the redshift distribution of faint field galaxies.

Brainerd, I. Smail, and J. Mould (Mt. Stromlo) used deep imaging data from the Hale 5-m telescope to investigate the angular clustering of faint field galaxies to $r\sim26$, corresponding to maximum redshifts of order 1. The observed clustering is extremely weak, in agreement with eariler investigations carried out at brighter limiting magnitudes. Although weak, the clustering is significantly non-zero. The observed clustering strength, combined with an assumption of a growth rate of clustering comparable to the predictions of linear theory, supports the scenario in which the high number density and low clustering amplitude of faint galaxies are produced by star-forming dwarf galaxies at modest redshifts that are clustered similarly to local low surface brightness galaxies. Brainerd, Smail, and Hogg are currently investigating the clustering properties of even more distant galaxies, $z\sim1.5$, using high-quality, multi-color imaging data obtained with the Keck-I 10-m telescope.

Brainerd has begun a collaboration with S. G. Djorgovski (Caltech) to measure the large-scale angular clustering of local galaxies and clusters of galaxies from the Palomar-STScI Digital Sky Survey (DPOSS). The survey will contain ~3 times the number of galaxies as the APM survey and will include data from 3 photometric bands (calibrated to Gunn g, r, and i). The results of this investigation will provide stringent constraints on theories of structure formation in the universe.

Brainerd and J. V. Villumsen (MPIfA) use N-body simulations of the formation of cosmic structure to test theories of structure formation against the observed large-scale structure of the universe. The most recent results include a test of the redshift-space power spectrum of galaxies in a standard Cold Dark Matter universe. Compared to the power spectrum of IRAS galaxies, there is excellent agreement between the theory and observation. However, through further study in collaboration with B. C. Bromley (CfA), M. S. Warren (LANL), and W. H. Zurek (LANL), Brainerd has found that the agreement between observation and theory is most likely serendipitous and, in particular, that the redshift-space power spectrum of galaxies on scales less than $\sim30h^{-1}$ Mpc is essentially independent of the normalization of the CDM model and, hence, constitues a poor model discriminant.

Under Brainerd's direction, undergraduate D. Goldberg (now a graduate student at Princeton University) performed N-body simulations of the formation of rich clusters of galaxies. This work shows clearly that the typical infall distances to rich clusters of galaxies in standard Cold Dark Matter universes is of order $15h^{-1}$ Mpc and that material as distant as $20h^{-1}$ Mpc at $z=30$ is found within the cluster at the present epoch. This result suggests that typical simulations of cluster formation, which are significantly smaller than this length scale, are missing a large fraction of the infall of material into the deep cluster potential wells over the formation history of the clusters. Hence, at least in the case of standard CDM, the results of previous high-resolution simulations of cluster formation are called into question due to an artificial lack of late-time infall.

3.6 High-Energy Astrophysics

In collaboration with J. Halpern and M. Ruderman (Columbia U.), Mattox will use EGRET to time the rotation of the radio-quiet pulsar Geminga. Although the existence of high-energy periodicity was initially established with X-ray data from the ROSAT satellite, the primary means of timing Geminga is with high-energy γ-rays. It is possible to account for each of the 700,000,000 rotations of this pulsar that have occurred since CGRO was launched. Mattox will ultimately attempt to link the rotation phase between the EGRET observations and earlier observations with the COS-B and SAS-2 satellites. A coherent analysis over this 24-year baseline would produce a very precise ephemeris to support future studies at other wavelengths. Also, it would allow for a precise characterization of the timing noise and possibly allow the braking index to be measured.

Paglione, Marscher, Jackson, and D.L. Bertsch (NASA/GSFC) calculated the γ-ray emission expected from cosmic-ray interactions in the nuclear region of the starburst galaxy NGC 253. The observed upper limit γ-ray emission by EGRET is consistent with production of cosmic-rays in supernovae, given the supernova rate in NGC 253, but the galaxy should be detectable with a somewhat more sensitive instrument.

Brecher has carried out several theoretical studies concerned primarily with the physics of neutron stars. One examined the properties of collapsed objects whose radii lie inside their own photon spheres (‘‘gray holes’’). Another focussed on models of asymmetric pulsar radiation that could lead to runaway pulsars as possible candidate sources for the origin of γ-ray bursts. Brecher also continued to examine the astrophysical implications of historical records of supernovae, particularly concerning their reappearance.

3.7 Planetary and Cometary Atmospheres

In preparation for the Galileo Probe measurements of the Jovian Atmosphere, Yelle, L. Young, and collaborators at U. Arizona and NASA/ARC reanalyzed a wide array of data on the thermal structure of the Jovian upper atmosphere. The temperature profile derived from this reanalysis predicted fairly well the temperature profile measured by the Galileo Atmospheric Structure Instrument (ASI). The shape of the temperature profile suggests that dissipation of gravity waves is responsible for the high thermospheric temperature on Jupiter. Yelle, L. Young, R. Young, and A. Sieff continue investigation of this hypothesis through analysis of the wave structure evident in the ASI data and theoretical models for the propagation of gravity waves and their effect on thermal structure.

Yelle has continued investigation of the effects of the impact of comet Shoemaker-Levy 9 on the atmosphere of Jupiter through analysis of UV spectra obtained with HST. Atomic, ionic, and molecular emission lines were analyzed in collaboration with M. McGrath (STScI) and K. Carpenter (NASA/GSFC). Work on the analysis of molecular sulfur absorption lines seen in the atmosphere continues.

Yelle, in collaboration with J. Stansberry (Lowell Obs.) and others, has investigated the emissivity of nitrogen ice at far-infrared wavelengths. The N ice emissivity is a critical factor in the thermal balance of Pluto’s surface. It is found that the emissivity changes sharply at the alpha-beta phase transition at 35.6 K. Because of this the atmosphere of Pluto may not freeze out as it approaches aphelion, as previously believed. Yelle, in collaboration with Stansberry and others, also developed a model to explain the large abundance of methane in Pluto’s atmosphere. The model relies on the existence of pure patches of methane on the surface in addition with that methane that is in solid solution with N.

Mendillo and J. Baumgardner (CSP) have continued their studies of Jupiter’s sodium magneto-nebula, concentrating recently on variability aspect, modelling of source mechanisms, and characterization during NASA’s Galileo spacecraft mission. J. Wilson recently joined their group as a post-doctoral research associate to work on modeling areas.

Studies of the lunar atmosphere, as revealed during total lunar eclipses, were continued by Mendillo and Baumgardner using observations conducted on 4 April and 26 September, 1996. The April event was conducted at the site of Italy’s new TNG (Telescopio Nationale Galileo) in La Palma, Canary Islands, in collaboration with C. Barbieri and G. Cremonese (U. Padova). The September event was observed with the Boston University Planetary Environment Imaging Spectrograph and Monochromatic Imager.

3.8 Magnetospheric Physics

Spence has continued theoretical modeling studies of the global structure of magnetospheric particles and fields. Spence and Hirsch completed the synthesis of a theoretical model of plasma transport in the Earth’s geomagnetic tail with a complementary model developed by an external collaborator. The principal model, developed initially by Spence and M. Kivelson (UCLA), describes the transport and bulk plasma parameters of the magnetotail plasma sheet using bounce-averaged drift theory in model magnetic and electric fields. The merger with the T. Onsager model (a field-aligned, particle transport code developed at UNH) has provided insight on the low-altitude signature of particle transport from the magnetotail to the ionosphere. Hirsch and Spence are using these models in connection with the fresh data provided by the POLAR spacecraft to explore such new topics as the role of inductive electric fields in plasma sheet convection.

Using archival spacecraft data, Spence has continued research of inner magnetospheric dynamics during auroral substorms. He and Jorgensen used multiple spacecraft studies, with observations made on the ground, the ionosphere, and in the magnetosphere, to establish the global response and processes responsible for particle acceleration and field-line mapping during substorms. This study clearly established a surprising mapping of auroral phenomena to the near-Earth magnetospheric equatorial plane.

Spence, Jorgensen, Hughes, and collaborators at the Aerospace Corporation, are constructing comprehensive empirical models of the particles and fields of the inner magnetosphere. Built on a foundation of archival data sets, these formative models will elucidate global aspects of the inner magnetosphere including the role of plasma pressure gradients in the ring current during magnetic storms and the near-tail current sheet during substorms.

In addition to these continuing efforts, Spence and his group have been busy analyzing data from the recently launched POLAR spacecraft. Three major areas are already providing much excitement: Polar Energetic Particles (PEPs), Energetic Neutral Atom (ENA) imaging of the magnetosphere, and a new magnetic storm model. PEPs are a newly discovered class of energetic particles that occur at high magnetic latitudes near the POLAR apogee at $\sim 9 R_E$. Spence and co-workers conclude that PEPs are the signature of magnetic reconnection between the interplanetary and Earth's magnetic fields when the interplanetary field has a strong component either in the direction of the ecliptic normal or radial, or both. Early analysis reveals the first compelling evidence for the strong control of reconnection at these latitudes with the radial component. POLAR instrumentation is able to measure not only energetic charged particles *in situ* but also energetic neutral atoms produced through the charge exchange of hot magnetospheric plasmas with the cold extended hydrogen geocorona. These ENAs travel along a line of sight from their source region near the magnetic equator and can be imaged by POLAR when it is at apogee. These techniques are producing the first global images of the Earth's ring current made from the north ecliptic pole looking down toward the Earth. More excitingly, the ENA technique is also being used to image the injection of energetic ions into the near-Earth nightside region of the Earth's magnetosphere during substorms. This unexpected observation will allow Spence and collaborators to constrain substorm models which are only poorly constrained with other techniques. Finally, the POLAR energetic charged particle data from the ring current and radiation belt regions are being used to study the sun-Earth connection during magnetic storms. POLAR and complementary data sets are being used to track coronal disturbances as they leave the sun, follow them as they travel through interplanetary space, record their arrival as they impinge upon the Earth's magnetosphere, and measure their global response in space and on the ground. New observations from POLAR are revealing the important role that parallel electric fields may play in the ring current formation during magnetic storms.

Hughes, D. Murr (CSP), Zesta, and several undergraduate students operate the MACCS magnetometer array in northern Canada. Zesta and Hughes are studying traveling convection vortices (TCV's), which are signatures of filamentary field-aligned currents linking the ionosphere and magnetopause. The 2-D MACCS array allows them to monitor the growth and decay of these currents as well as their motion. They are also studying the relationship between these transient currents and events in the solar wind that trigger transient magnetopause processes. Further studies of TCV's are ongoing, especially projects that combine MACCS data with ionospheric radar and spacecraft observations. Undergraduate M. Kowalewski and Hughes are studying the ion cyclotron wave bursts seen at high latitudes and their association with TCV's. MACCS data is also being used in the study of ULF waves, largely in collaboration with M. Engebretson and others at Augsburg College, and for monitoring substorm currents.

Recent activities of Erickson have centered on quantitative descriptions of magnetic field-aligned currents that couple Earth's magnetosphere to the ionosphere. He determined the cause of field-aligned currents flowing out of the nightside auroral ionosphere along the reversal of the north-south component of the ionospheric electric field, known as the Harang discontinuity. Since the low-latitude extension of the Harang discontinuity locates the onset of geomagnetic substorms, he has suggested a mechanism by which the associated currents play a decisive role in destabilizing Earth's magnetic field configuration. He recently co-authored a paper describing a previously unknown polarization electric field effect in steady-state, magnetic-mirroring, collisionless plasma. Currently, Erickson is involved in extending the self-consistent model of quasi-static convection to three dimensions. Complementary to the theoretical investigation of substorm onset, he is engaged in interpretation of electric and magnetic field measurements from satellites at high altitude near times of substorm onsets.

As the dataset from CRRES (Combined Release and Radiation Effects Satellite - launched in July 1990) matures, it provides a rich resource for studies of the inner magnetosphere. Near apogee, CRRES is ideally situated for observing substorms near the inner edge of the plasma sheet, a region now realized to be crucial for understanding substorms. Hughes is using CRRES data in conjunction with magnetometer data from geosynchronous spacecraft and ground-based observatories to examine the magnetic field configurations during the growth and expansion phases of substorms. As part of a GEM collaboration, Hughes is coordinating a study of substorms that combines data from CRRES and many other sources. Careful timing of signatures observed in different locations is being used to find where a substorm is triggered. Hughes and H. Singer (NOAA Environmental Research Laboratory) have used CRRES magnetometer data to map the magnetic perturbations caused by the ring current in the inner magnetosphere. Through the use of Ampere's Law, they recreate average current distributions in the ring current region. This work is continuing in collaboration with Spence and Jorgensen, who are combining data from different spacecraft to obtain golbal patterns. Hughes has also developed a means of using ULF field line resonances to sense remotely plasma distributions along magnetic flux tubes, a technique now being used by Bhattacharjya to study plasma distributions in the inner magnetosphere.

A series of older datasets from the ISEE satellites, the ATS-6 satellite, and the NOAA/TIROS-N satellites have been recovered and used for a number of studies and presented papers. Gugliotti, D. Matthews (CSP), and Fritz completed a study of energetic particle signatures at substorm onsets to place the satellite data with respect to the substorm acceleration region, thereby showing that these events were consistent with the concept of a near-Earth neutral line. Al-Othman modeled the behavior of the high latitude >40 keV electron trapping boundary [HLTB] using data from satellite Injun 3 to demonstrate that many of the features of the variation of the HLTB with local time are explained by the drift of these electrons while conserving their first two adiabatic invariants. Undergraduate student D. Patel characterized the HLTB using both energetic electron and proton data from the NOAA/TIROS-N low altitude polar-orbiting satellites. This work has laid the ground work for a study of simultaneous data from the high altitude ISEE 1 and 2 satellites with the low altitude NOAA/TIROS satellite data, which try to determine how regions map from the outer magnetosphere on the night side to the high latitude low altitude auroral ionosphere. This is a critical unknown in much of the work on the magnetospheric substorm. This work involves students Gugliotti and undergraduate C. Sullivan as well as Fritz, Matthews, Sheldon.

3.9 Exospheric Studies

B. Bush (CSP) and Chakrabarti developed a radiative transfer model using spherical geometry in a non-isothermal atmosphere and applied it to H and He Lyα emission at 1216 and 584 Å, respectively, in the geocorona. This model also included partial frequency redistribution during the photon scattering. After comparing the model results to other similar models, they applied these to resonance emission observed from a 600 km altitude, polar orbiting spacecraft at local noon. Comparison of the model results with the spectroscopic data suggested specific updates to the presently used atmospheric and solar irradiance models.

3.10 Atmospheric and Ionospheric Studies

J. Vickers (CSP) and Chakrabarti investigated the use of inversion algorithms to obtain ionospheric O^+ density distribution from O II 834 Å airglow emission. This radiation is produced primarily by photoionization of atomic oxygen in the thermosphere. The initial photons thus produced are resonantly scattered by O^+. It was found that by using only the airglow intensities and their angular variations, one cannot obtain ionospheric densities (using a three parameter model distribution) accurate to better than 10%, as has been claimed by other studies. However, using other independent measurements, it might be possible to obtain these parameters to within 50% uncertainty.

Chakrabarti's ultraviolet (UV) group is investigating many different applications of tomography to the deconvolution of remotely sensed UV emission. These include the deconvolution of spin-scanned 911Å emission for the TERRIERS mission (by F. Kamalabadi and Stephan), and the deconvolution of SPINR data for the analysis of that mission (Stephan, Betremieux, and Cook).

Equatorial and high latitude data from 20 Global Positioning System stations are being used by Aarons and Mendillo to study the dynamics of the development of ionospheric irregularities. Equatorial data have revealed extremely high altitudes of irregularities over the magnetic equator during a series of magnetic storms. The occurrence of varying altitudes of equatorial plumes has been noted using the NSF MISETA radar data set of September–October 1994. At auroral and polar latitudes, phase fluctuation observations during storms reveal the penetration of middle latitudes by irregularities at GHz frequencies of GPS.

Mendillo and Baumgardner have achieved a major advance in optical remote sensing of the ionosphere-thermosphere system through tomographic analysis of coordinated observations from their NSF-sponsored COTIF network of meridional imaging spectrographs in New England. J. Semeter's (CSP) Ph.D. dissertation deals with the inversion theory required for this new technique, as well as the science yield from the resultant altitude profiles of emission, a measurement previously available only via sounding rocket flights.

Kerr leads a research group using multifrequency diagnostics to study coupling of the thermosphere, ionosphere, and exosphere in the earth's upper atmosphere. The scope of this research includes studies of the mechanisms controlling the escape of light gases from planetary atmospheres. The research is primarily observational, using visible photometers, interferometers, and the incoherent scatter radars at the Arecibo Obervatory, The Haystack Observatory Millstone Hill Facility, and the Sondre Stromfjord Greenland Incoherent Scatter Radar Facility. Kerr has designed, constructed, and placed in service a transportable, multiple etalon Fabry-Perot spectrometer. That instrument provides high spectral-resolution spectroscopic data from the visible to the near-infrared using a variety of available detectors (GaAS PMT, CID array detector, and Germanium IR detector). The Fabry-Perot has been used on Wake Island to measure thermospheric winds, at the Arecibo Observatory to measure the infrared metastable helium emission, and is based at the Haystack Observatory, Millstone Hill Optical Facility. Kerr has recently made measurements of the metastable $\underline{1083}$ nm helium emission in the earth's atmosphere that demonstrate that recombination from He^+ is an important nonthermal source of the metastable neutral population, and has detected the IR signature of middle atmospheric NO from the ground. Kerr has established a new technique to derive the altitude profile of atomic hydrogen density on earth from 300 km to 10,000 km. Kerr will fiber-optic couple his Fabry-Perot to the 61″ Catalina telescope outside Tuscon AZ in winter 1996-1997 to search for suprathermal sodium in the atmosphere of Mercury. In spring 1997, Kerr tranports the Fabry-Perot to Sondre Stromfjord, Greenland for assessment of the role NO plays in cooling the middle atmosphere there.

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