University of Maryland
Department of Astronomy
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1. INTRODUCTION

This report covers astronomical activities primarily within Maryland's Department of Astronomy but also includes some astronomical work carried out in other departments, such as the Department of Physics. The period covered is from 1 October 1995 through 30 September 1996.

2. PERSONNEL

The continuing personnel in the Department of Astronomy during the period were Professors M. Leventhal (Chair), M. F. A'Hearn, R. A. Bell, L. Blitz, J. Earl, J. P. Harrington, M. R. Kundu, K. Papadopoulos, W. K. Rose, V. L. Trimble, S. Vogel, and A. S. Wilson; Emeritus Professors W. C. Erickson, F. J. Kerr, and D. G. Wentzel; Adjunct Professors M. Hauser and S. Holt; Associate Professor L. G. Mundy; Visiting Associate Professors L. McFadden and S. Vrtilek; Assistant Professors D. Hamilton, J. Stone, J. Wang, and S. Veilleux; Associate Research Scientists K. Arnaud, M. Aschwanden, C. C. Goodrich, N. Gopalswamy, R. Lopez, G. Milikh, E. Schmahl, S. Sharma and S. White; Assistant Research Scientist S. Kim; Research Associates P. Chaturverdi, D. Chornay, O. Colombo, H. Falcke, K. Fast, K. Gendreau, E. Grayzeck, R. Kulkarni, N. Lame, F. Lemoine, C. Lisse, D. McNabb, J. Morgan, E. Pavlis, F. Porter, A. Raugh, I. Richardson, F. Robinson, K. Roettiger, P. Safier, L. Sage, P. Teuben, D. Wellnitz and T. Xie; Instructors G. Deming and D. Theison; and Associate Director J. D. Trasco. E. Ostriker was appointed as Assistant Professor. A. Harris was appointed Associate Professor and will join the department in January 1997. L. Blitz resigned. S. Vogel was promoted to Professor. Aschwanden, Arnaud, and Milikh were promoted to Associate Research Scientist. L. McFadden was appointed as Associate Research Scientist. S. Balachandran was appointed as Assistant Research Scientist. W. Chen, L. Cheng, F. Finkbeiner, M. Houdashelt, U. Hwang, F. Kazimenezhad, J. Lee, M. Lowenstein, G. Madejski and C. Scharf were appointed as Research Associates. E. Lada, D. Lengyel-Frey, P. Leonard, J. Mattox, R. Meier, J. Raulin, M. Schaefer and D. Smith completed short term appointments and left the department. Ph.D. degrees were awarded to Y. Peng, J. Rho, T. Helfer, K. Chan, J. Gallimore and R. Gruendl. M.S. degrees were awarded to Y. Fernandez, A. Kundu, S. Miller, G. Piner, S. Geier, D. Horner, and C. Xu. J. Braatz received the 1996 Pelczar Award which is given annually to the graduate student at the University of Maryland who has made outstanding contributions to his or her field. E. Colbert has won an NRC Research Associateship Award to do postdoctoral research at NASA/GSFC on X-ray imaging and spectroscopy of Seyfert galaxies.

3. MEETINGS

The series of Washington Area Astronomers meetings initiated in September 1981 has continued. The Spring 1996 meeting was held at the Space Telescope Science Institute in Baltimore and the Fall 1996 meeting was held at the NASA-Goddard Space Flight Center. Typical attendance has been 100 persons per meeting. The Maryland-Goddard Astrophysics series which started in Fall 1990 has continued. The most recent meeting ''Star Formation, Near and Far'' was held at the University of Maryland in October 1996. Total attendance was approximately 200 persons.

4. FACILITIES AND INSTRUMENTATION

4.1 Laboratory for Millimeter-Wave Astronomy

The Laboratory for Millimeter-wave Astronomy (LMA) is the organization set up by the University of Maryland to manage its participation in the Berkeley-Illinois-Maryland Association (BIMA) project, which has led to the construction of a nine radio-dish millimeter array located in Hat Creek, California. The lab is part of the Astronomy Department and has associated with it four faculty members, one research scientist, two scientific staff, two postdoctoral fellows, and five graduate students. The faculty are S. Vogel (director), W. Erickson (professor emeritus), M. Kundu, and L. Mundy. L. Blitz departed to become the Director of the Radio Astronomy Lab at Berkeley. The Associate Research Scientist is S. White. Postdoctoral fellows include T. Xie and P. Safier. E. Lada and R. Rand left to assume faculty positions at Florida and New Mexico, respectively. The scientific staff includes J. Morgan and P. Teuben. Graduate students doing Ph.D. degree work with the array include C. Lee, L. Looney, M. Regan, K. Sheth, and M. Thornley. T. Helfer, Y. Peng, and R. Gruendl completed their Ph.D. theses with the BIMA array and have assumed postdoctoral positions at Berkeley, Goddard, and Illinois, respectively.

The scientific work done with the BIMA array is outlined in the relevant sections of this report. During the past year, the array was brought to 9 antennas; the nine-element array was dedicated on June 1, 1996. New stations were added to extend the array to provide maximum baselines of 1.3 km and a resolution at 3 mm of $0.4''$, the longest baselines available with any connected-element millimeter array. Mundy, Looney, and Erickson from Maryland designed and built the optical fiber links to carry local oscillator signals to and return the astronomical signals from the long-baseline antenna pads. In addition, optical fiber fixed and variable delay systems were built to enable real time correlation of astronomical signals.

Maryland is jointly responsible with Illinois for the calibration, analysis, and image reconstruction software for the BIMA consortium. Morgan and Teuben continued the joint BIMA development of the MIRIAD data reduction package. The Maryland group focuses on antenna-based calibration routines for use with the newly expanded Hat Creek 9-element array; reduction and analysis of long-baseline interferometric data including atmospheric phase correction;

rapid time integration routines for solar flares and eclipses; holography techniques for the new antennas; observing software; analysis applications in the UV-plane; the WIP interactive graphics tool; and various X-window oriented applications.

The LMA has continued to develop its local World Wide Web (WWW) server to provide world wide access to information related to the BIMA project, observing at the Hat Creek telescope, the MIRIAD software package, and the University of Maryland Astronomy Department. The LMA has also continued its involvement with the AIPS++ software development, working on a filler for BIMA uv data.

Maryland is designated as the East Coast observing site for the array. Thirty percent of the observing time on the array is generally available to outside users (outside of the time designated for system development and tests).

4.2 Advanced Visualization Laboratory

To meet the widely perceived need for data visualization support on campus, the Department of Astronomy and the Computer Science Center jointly established the Advanced Visualization Laboratory (AVL), under the direction of C. Goodrich (Astronomy). This laboratory serves as the focal point for visualization expertise on campus providing information and demonstrations of state of the art visualization software and hardware. Their goal is to provide graphics support and innovation focusing on the types of computers generally available to researchers and students on campus. The functions of the laboratory are at three levels. At the most basic level, the AVL provides color input/output facilities on a fee-for-materials and nominal service charge basis, including paper and transparency color printing, 35mm film recording, color scanning, and SVHS/VHS videotape production and editing. At a higher level, the AVL provides faculty and students the opportunity for hands-on evaluation of a variety of visualization software on a range of computers in a friendly environment. Basic assistance in the use of visualization software and devices is available from the laboratory staff, and classes in scientific visualization are under development. Finally, the AVL actively pursues joint projects with researchers to develop custom visualization tools and works with hardware and software vendors to evaluate, test, and enhance available commercial solutions. The AVL has current research collaborations in the space sciences, mathematics, and fishery management.

4.3 Planetary Data System

The Small Bodies Node (SBN) of the Planetary Data System (PDS) continues in the department under the direction of M. A'Hearn and E. Grayzeck. A. Raugh, I. Jordan provide programming support; D. Winterfeld is a part-time consultant. Sub-nodes are operated at the U. Hawaii, U. Arizona Planetary Science Institute, and Konkoly Observatory (the European Sub-node) in Budapest, Hungary. The Sub-nodes archive relevant data for comets, asteroids, and interplanetary dust; they also distribute data once it has been reviewed by the PDS. Four major sets of data have now been reviewed and ingested into PDS: the Galileo and Ulysses Dust Detection System (DDS) data for 3 years of operation in cruise phase; the Comet Halley CD-ROM Archive of 26 disks completed to include relevant spacecraft data; data sets of derived cometary properties and fundamental asteroid data; and IRAS data determined to be useful for studying interplanetary dust. Most data are available through the SBN home page on the World Wide Web, which provides on-line browsing and a form-based utility to accept off-line data orders and special requests. Sub-nodes are actively involved in archiving spacecraft data from various missions: the NEAR mission to Eros and Mathilde; the Giotto Extended Mission to comet Grigg-Skjellerup in 1992; the Galileo experiments which collected data from asteroids Gaspra and Ida; and further interplanetary dust measurements from Ulysses and Galileo. Work also continues on certain ground-based data for asteroids which support the Gaspra/Ida Galileo data; in addition, we preserve IRAS data in forms suitable for investigating solar system sources. SBN also supports the STARDUST and ROSETTA missions which are in the planning phases of instrument definition, cometary target selection and archiving. The node operates an electronic bulletin board which serves as an official point of contact for comet and asteroid observing campaigns such as for Chiron and comet Hale-Bopp.

The PDS-SBN played a major role in the campaign to study the collision of comet D/Shoemaker-Levy 9 with Jupiter and is now assembling a CD-ROM archive of relevant data to be produced in coordination with groups at New Mexico State U. and the Jet Propulsion Lab. The first volume of this 10 disk collection, which includes the spacecraft measurements of the colliding fragments, is currently under review.

5. RESEARCH

5.1 Extragalactic Astronomy

M. Thornley has completed a study of near infrared K'-band emission in four nearby flocculent galaxies. This study reveals low-level, two-arm spiral structure in the inner disks of three out of the four sample galaxies. In the fourth galaxy, NGC 4414, more chaotic ''arm-like'' structures were observed which extended over kiloparsec scales. In collaboration with L. Mundy, M. Thornley is studying the significance of the observed near infrared structures, by comparison with the distribution of molecular and atomic gas and tracers of recent star formation. In the flocculent galaxy NGC 5055, the kinematics of HI and Hα emission provide definitive evidence of spiral density waves with streaming motions of similar amplitude to those seen in the grand design spiral M100. A similar study of kinematics in NGC 4414 shows no evidence of large-scale dynamic motions, and thus the origin of kiloparsec-scale ''arm'' features is still unknown. Further study of the distribution of recent star formation in NGC 4414 and NGC 5055 is underway, to look for variations in star formation properties with respect to structures observed in the near infrared. Studies of molecular gas in NGC 5055 and NGC 4414 using the BIMA array show structures similar to the massive Giant Molecular Associations seen in the grand design spiral M51, thus indicating that such large structures can form in a variety of galactic environments.

Stone and postdoctoral research assistant K. Roettiger, in collaboration with R. Mushotzky (GSFC) have completed a study of the systematic errors associated with using the Sunyaev-Zeldovich effect to measure the value of the Hubble constant. Because of selection effects, the brightest X-ray clusters in which the S-Z effect can be measured are generally the remnants of recent mergers. However, the assumptions of spherical symmetry and isothermality generally adopted to determine the Hubble constant for these clusters are not valid. Using a large ensemble of combined hydrodynamic and N-body simulations of cluster mergers, Roettiger, Stone, and Mushotzky (1996) demonstrated that these assumptions could lead to underestimating the Hubble constant by as much as 30%.

E. Colbert is continuing his thesis work with S. Baum (STScI) and S. Veilleux on large-scale (galactic) outflows in edge-on Seyfert galaxies. Optical and radio surveys have been completed for galaxies selected from a distance-limited sample of 22 objects. There is evidence for large-scale outflows in about 50% of the objects surveyed. Evidence includes extended Hα nebulae along the minor axis of the galaxy disk, luminous Hα nebulae located $\sim$ 5-10 kpc out of the disk, double-peaked Hα emission lines suggesting the presence of a wind blown bubble, and radio continuum emission extending one or more kpc from the nucleus. The three best candidates (NGC 2992, NGC 5506, and NGC 4438) show excellent evidence for an outflow in both the radio and optical regimes, and have extended soft X-ray nebulae which are roughly co-spatial. Follow-up work is being done to study in more detail the properties of the large-scale outflows in these three galaxies. The physics of these flows is fascinating. A plausible explanation of their origin is that they are larger scale extensions of sub-kpc nuclear outflows (e.g. jets) that are known to be present in Seyfert galaxies. Starburst driven superwinds also remain a plausible explanation in some cases.

E. Colbert, S. Baum and C. O'Dea (STScI) have obtained very deep radio continuum observations of the Seyfert/starburst hybrid galaxy Mrk 231 in order to study properties of the radio outflow. This galaxy was already known to have a galactic outflow but its origin (starburst- or AGN-driven) is not known. Data were taken with the VLA at 6 and 20 cm in all array configurations. Preliminary results show the southern extended radio feature to have diffuse structure, unlike that expected from a collimated jet. The extended radio feature is roughly cospatial with the ''tidal tail'' that is apparent in deep broad-band optical images. Mapping of the polarized flux and spectral index will be done to study the origin of the extended radio emission.

With A. Wilson and C. Simpson (STScI), H. Falcke has worked on an HST survey of Seyfert galaxies. Most galaxies show an elongated narrow line region (NLR) and are consistent with the presence of ionization cones as predicted in the unified scheme. However, it appears as if radio outflows have a significant impact on the shape of the NLR. ESO 428-G14, for example, has a spectacular jet-like NLR, with thin emission-line strands and a helical structure (Falcke *et al.* 1996c) while MK 573 shows a bowshock-like NLR around radio hotspots.

With radio observations (Effelsberg, MERLIN, and VLBI) Falcke has investigated the properties of radio-intermediate quasars (RIQ) and concluded that they most likely are relativistically boosted jets in radio-weak quasars. Relativistic jets, have so far been associated only with radio-loud quasars and hence this RIQ could hold an important clue for understanding the jet phenomenon in general and the radio-loud/radio-quiet dichotomy in quasars.

In collaboration with R. W. Goodrich (STScI) and G. J. Hill (U. Texas), Veilleux completed a search for obscured broad-line regions in Seyfert 2 galaxies. For this purpose, high-quality infrared (J, K, and L bands) spectra of 33 galaxies were acquired. It was found that a possibly large fraction (perhaps as much as 25%) of the objects in the sample present a hidden broad-line region. These results are consistent with the standard torus model if the transition zone located between the optically-thin ''throat'' of the torus and the optically-thick core is rather extended. The dusty wind model of Königl and Kartje can also explain the data. Comparisons of the broad-line and narrow-line extinctions indicate that the BLRs are considerably more obscured than the NLRs. This result agrees with the predictions of both the torus and dusty wind models, where the dust is located between the NLR and the BLR. Comparisons of the columns depths towards the BLRs with the column depths determined from X-ray data show a general tendency for the objects with detected broad recombination lines to have lower X-ray columns. The widths of broad Paβ and Brγ lie on the narrow end of the distribution for Seyfert 1 galaxies. The dereddened broad Hβ luminosities predicted from the broad infrared lines are similar to the broad Hβ luminosities of normal Seyfert 1s, and so are the ratios of the hard X-ray flux to the predicted broad Hα flux.

Veilleux, D. B. Sanders (U. Hawaii), and D. C. Kim (IPAC/Caltech) extended their survey of IRAS galaxies to a large unbiased sample of ultraluminous infrared galaxies. They confirm that the fraction of Seyferts among luminous infrared galaxies increases with infrared luminosity, reaching values of 54% at the highest observed luminosities. New near-infrared spectra reveal signs of buried quasars in most Seyfert 2 galaxies. The high quasar detection rate among Seyfert 2 galaxies bring strong support to the optical classification of these objects as genuine AGN. A tendency also exists for galaxies with warm 25μm/60μm IRAS colors to harbor obscured broad-line regions in the near-infrared and to have large Paα/infrared luminosity ratios. These results suggest that the screen of dust in the warm Seyfert 2 galaxies is optically thin at 2μm. Comparisons between warm ultraluminous infrared galaxies and optical quasars suggest that an important fraction of the bolometric luminosity in the warm objects is powered by the same mechanism as that in optical quasars.

Veilleux, J. Bland-Hawthorn (Anglo-Australian Obs.), G. Cecil (U. North Carolina), and R. B. Tully (U. Hawaii) continued their Fabry-Perot survey of the circumnuclear gas in active galaxies. The results of detailed studies of NGC 4258 and the Circinus galaxy have been recently published. The new data on Circinus show for the first time a complex of ionized filaments extending radially from the nucleus out to distances of 1 kpc. The velocity field of the filaments confirms that they represent material expelled from the nucleus or entrained in a wide-angle wind roughly aligned with the polar axis of the galaxy. Extrapolation of these filaments to smaller radii comes to within 1 arcsec of the active galactic nucleus, therefore suggesting a AGN or nuclear starburst origin to these features. The complex of radial filaments and bow shocks detected in the Circinus galaxy is unique among active galaxies. The frequency of such events is unknown since only a handful of active galaxies have been observed at this sensitivity level. The event in the Circinus galaxy may represent a relatively common evolutionary phase in the lives of gas-rich active galaxies during which the dusty cocoon surrounding the nucleus is expelled by the combined action of jet and wind phenomena.

M. Regan, S. Vogel and P. Teuben are continuing their studies of the kinematics of barred spirals. They have obtained BIMA observations of CO emission to trace the molecular gas, Palomar observations with the Maryland-Caltech Fabry-Perot to trace the ionized gas, and Kitt Peak observations for the optical and IR emission to trace stars and dust. They have analyzed the morphology of the gas and stars in the barred spiral galaxy NGC 1530. The kinematics of the ionized gas in this galaxy shows a remarkable agreement with hydrodynamic models of gas flow in barred spiral galaxies. From these observations they show that mass is flowing in along the bar dust lanes toward the nuclear dust lanes, and they determine a mass inflow rate.

M. Regan and S. Vogel have been investigating the variation of ratio of dust mass to CO emissivity using the BIMA millimeter array. They find that the central regions of most galaxies show that CO is 10 to 20 times more luminous than would be expected from the dust mass. This can lead to an overestimation of the fuel available for both starburst galaxies and AGN.

M. Regan is working on an infrared survey of a sample of Seyfert and control galaxies with J. Mulchaey (Carnegie) and A. Kundu. The goal of the survey is to determine whether the Seyfert galaxies are any more ‘‘barred’’ than the control galaxies. The survey used telescopes at Kitt Peak, Las Campanas, and Palomar observatories. The data reduction for the project is complete.

K. Sheth, M. Regan, and S. Vogel obtained O (J = 1-0), KPNO near infrared and Hα observations of the barred spiral galaxy NGC 5383. The CO emission is strongly concentrated in the nuclear region with three distinct peaks coinciding with peaks of dust emission observed via our color maps. Two of the peaks clearly correspond to the intersection of the bar dust lanes with the nuclear ring. Significant CO emission extending up to 500 pc along the dust lane is also detected.

L. Blitz and collaborators at Illinois and Berkeley have begun a survey of CO emission in Seyfert galaxies with the BIMA array. All of the ten Seyferts images so far have nuclear CO concentrations, with implied surface densities hundreds of times higher than in the disk of the Milky Way. In two LINERS, the CO avoids the nucleus, suggesting that the fueling in attenuated.

J. A. Braatz, A. S. Wilson and C. Henkel (MPIfR) completed a survey for H_2O maser emission from the nuclei of some 350 active galaxies. The sample includes all Seyfert galaxies and LINERs listed in current AGN catalogs with recession velocities below 7,000 km s^{-1} and blue magnitudes brighter than 14. Ten new H_2O megamaser sources have been detected, bringing to 16 the number of galaxies known to contain H_2O megamasers with isotropic luminosities $> 20\ L_\odot$. Most of the spectra are composed of multiple, narrow ($\leqslant$ a few km s^{-1} wide) lines, but in NGC 1052 (the only elliptical detected) the line is broad (FWHM $\simeq$ 100 km s^{-1}) and smooth. VLA measurements show the masers originate in the nuclei. The most significant discovery is that masers are detected only in Seyfert 2s and LINERs, not in Seyfert 1s. This lack of detection in Seyfert 1s indicates that either they do not have molecular gas in their nuclei with physical conditions appropriate to produce 1.3 cm H_2O masers or the masers are beamed away from Earth, presumably in the plane of the putative molecular torus which hides the Seyfert 1 nucleus in Seyfert 2s. LINERs are detected at a similar rate to Seyfert 2s, constituting a strong argument that at least some nuclear LINERs are AGN rather than starbursts, since starbursts have not been detected as H_2O megamasers. We preferentially detect H_2O emission from the nearer galaxies and from those which are apparently brighter at mid- and far-infrared and centimeter radio wavelengths. There is also a possible trend for the H_2O-detected galaxies to be more intrinsically luminous in nuclear 6 cm radio emission than the undetected ones.

The newly discovered masers have been monitored over periods of 2 - 3 years. The maser line in one of these galaxies – NGC 2639 – is found to have a systematic redward velocity drift of 6.6 ± 0.4 km s^{-1} yr^{-1}. This drift is reminiscent of the similar redward drifts of the near-systemic velocity masers in NGC 4258, and suggests that the maser line in NGC 2639 originates in gas lying on the near side of an accretion disk viewed edge-on, with the drift representing the centripetal acceleration.

T. Storchi-Bergmann (UFRGS), M. Eracleous, A. V. Filippenko (UC-Berkeley), M. Livio (STScI), J. P. Halpern (Columbia U.) and Wilson reported spectroscopic monitoring of the broad, double-peaked Balmer lines from the nucleus of NGC 1097, which appeared abruptly in 1991. Over the period 1991-1994, the integrated Hα flux has decreased by a factor of 2, the Hα/Hβ ratio has increased, and the originally asymmetric Hα profile has become symmetric. The decline of the Hα flux and the change in the Hα/Hβ ratio can be interpreted as consequences of either increased obscuration along the line of sight, or a decline in the ionizing continuum, but neither of these scenarios can account for the change in profile shapes. A model attributing the line emission to a precessing elliptical ring around a $10^6 M_\odot$ nuclear black hole can reproduce the observed profile variations. In this scenario, the line-emitting ring is the result of the tidal disruption of a star by the black hole.

G. A. Bower (NOAO), Wilson, T. M. Heckman (JHU), and D. O. Richstone (U. Michigan) have obtained spectra of the nucleus of the galaxy M81 with HST. These spectra reveal a new double-peaked broad component to the profiles of

Hα and Hβ, the FWZI of which are 14,000 and 11,000 km s^{-1} respectively. M81 and NGC 1097 are the only AGN with low radio power and in spiral galaxies known to exhibit such lines. This detection in M81 strongly supports the trend for such double-peaked broad lines to be found preferentially in galactic nuclei with LINER-like narrow emission-line spectra. It is also striking that all AGNs known to exhibit this type of line also show clear evidence for jets, even though these jets may not be luminous radio emitters. In M81, as in NGC 1097 in 1991, the red peak of the double-peaked profile is stronger than the blue peak, while the blue wing extends further from systemic velocity than does the red wing. These properties are contrary to the predictions of a model in which the line originates in a circular, relativistic disk. Either the disk is elliptical or the double-peaked lines originate in a bi-polar flow.

Wilson, with principal collaborators Bower, C. Simpson (STScI) and H. Falcke, has continued a program of imaging of the narrow line regions of Seyfert galaxies in emission lines with HST. The most recent results, for NGC 5643 and ESO428-G14, confirm that both collimation of the ionizing photons by circumnuclear tori and interactions with the radio ejecta define the structure of the narrow line region. In similar vein, Simpson, J. S. Mulchaey (CIW), Wilson, M. J. Ward (U. Leicester) and A. Alonso-Herrero (Universidad Computense) have obtained optical emission-line and near-infrared continuum images of the Seyfert 2 galaxy Mkn 348. The optical images reveal a well-defined region of highly ionized gas aligned along the radio axis, possibly in the form of a bi-cone. In addition, there a red linear structure in the infrared continuum, oriented perpendicular to this axis and approximately 1 kpc in extent. This latter structure may represent emission from hot dust in a disk or torus viewed approximately edge-on. This disk may comprise the outer parts of the ''dusty torus'' postulated in schemes to unify the two types of Seyfert galaxy.

I. Evans (SAO), A. P. Koratkar (STScI), Storchi-Bergmann, H. Kirkpatrick, J. A. Baldwin (CTIO), Heckman and Wilson have compiled an inventory of HII regions in the disks of Seyfert galaxies. These lists will find use in follow-up spectrophotometric investigations of abundances, abundance gradients and kinematics of HII regions in active galaxies, and for detailed studies of the HII region populations in these objects.

Mulchaey, Wilson and Z. I. Tsvetanov (JHU) have completed a ground-based survey of early-type Seyfert galaxies in emission lines. In order to compare the results with the predictions of unified schemes, they have performed simulations in which ambient gas is ionized by oppositely directed cones of radiation emitted from the nucleus. The images show that extended ionized gas is very common in Seyfert galaxies, with $\simeq$ 80% of the galaxies showing extension in [OIII]λ5007 and $\simeq$ 100% showing extension in Hα + [NII]. There is a strong correlation between the line fluxes of the unresolved core and the extended emission, suggesting the extended and nuclear gas are ionized by the same source. With some exceptions, the results are consistent with the scheme uniting type 1 and 2 galaxies. Continuum red-green color maps have also been made. In 40% of these maps, red (V$-$R $>$ 1.0) features are found. The majority of these red regions are unresolved structures located at the nucleus. These features are found in galaxies of all inclinations, but occur almost exclusively in type 2 Seyferts, consistent with reddening by $\approx$ 100 pc-scale dusty tori. Diffuse blue (V$-$R $<$ 0.5) features are seen in some Seyfert 2 galaxies. These blue excesses tend to be spatially coincident with the high excitation gas, suggesting an origin related to the nuclear activity, such as scattered nuclear light, star formation or shock waves.

Sage, Galletta and Sparke are investigating the molecular gas content of a sample of galaxies known to either have counter-rotating stars and (ionized) gas, or polar rings. We have found that in general there is too much gas associated with the rings to have been captured from one dwarf galaxy, which has been the preferred mechanism for producing such rings.

Welch, Sage and Mitchell are studying the molecular gas content of NGC 205, one of the dwarf companions of M31. The gas and dust are not uniformly distributed near the center of this galaxy, which is analogous to the situation found in NGC4546. This might occur because of a recent capture of gas by N205. We have found evidence for a component of gas $-$ possibly detained by passage through the disk of M31 - that is falling from the outer portions of N205 back towards its center. The first paper on this topic has been submitted to the ApJ Letters.

Sage, Mooney and Roger are examining the HI/H_2 interfaces of several molecular clouds (using the DRAO interferometer), to determine how extended that region is, and how much molecular mass is not being traced by CO emission.

5.2 Galactic Astronomy

Falcke has refined a model developed for Sgr A* in the Galactic Center and applied it to the compact radio nucleus in M81 (called M81*, Falcke 1996a). In this model a mildly relativistic radio jet is fed by an accretion disk and accelerated by its own pressure gradient beyond the sonic point. The model correctly predicts sizes and fluxes of M81* and Sgr A* with a minimum of free parameters. The model also predicts an inclination angle of $\sim$ 30 - 40 Degrees for M81*. This idea was further developed in two review papers (Falcke 1996d&e) where Falcke suggested that other compact radio cores in LINER galaxies are also due to radio jets powered by sub-Eddington accretion disks, and that at least those LINERs with bright compact radio-cores are the low-power counterparts to radio-loud quasars and radio galaxies.

F. Melia (Tucson) and Falcke have further discussed the situation in the Galactic Center and explored the physics of fossil accretion disks with wind infall. Such disks could absorb a large amount of infalling material without a large radii thus reducing substantially the amount of optical and NIR radiation produced.

Falcke and P. Teuben are using the BIMA array to monitor the flux of SgrA*, in a large collaborative observing project.

Teuben, in collaboration with L. Blitz (Berkeley), D. Spergel (Princeton), Hartman (Cambridge) and Burton

(Leiden), are studying the distribution of HVC's, based on an analysis of a number of existing HI surveys and new simulations.

Teuben is collaborating with Hut (Princeton), Makino (Tokyo), McMillan (Drexel) and Portegies Zwart (Amsterdam) on a C++ programming project to combine stellar dynamics and stellar evolution (STARLAB) and provide interfaces with the existing NEMO package.

M. Leventhal, D. Smith, L. Cheng, and graduate student R. Cavallo have been investigating the origin of Galactic positrons and the possibility that they are produced in stellar-mass black holes. Although a positron-annihilation signal from the Galactic center direction has been known for 20 years, its origin and distribution are still largely unknown. Collaborating with J. Tueller and N. Gehrels (NASA-GSFC), and G. Fishman (NASA-MSFC), they have published a search for transient bursts of positron annihilation from the entire sky between 1991 and 1993. Such events had been reported from Galactic black hole candidates and the Crab by the Sigma imager on the GRANAT spacecraft, but the Maryland survey, using the Burst And Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory (CGRO), gave uniformly negative results over a much larger data base. They are now using the BATSE data to generate a coarse (resolution about 30 degrees) map of the steady positron annihilation over the entire sky.

Cheng, Leventhal, Smith, Tueller, Gehrels, and W. Purcell (Northwestern U.), are finding the positron-annihilation distribution with higher resolution within about 30 degrees of the Galactic center using another instrument on CGRO, the Oriented Scintillation Spectrometer Experiment (OSSE). In one project, OSSE scans in Galactic longitude are being used to determine whether the annihilation is centered on the Galactic center or on the black hole candidate and ''microquasar'' 1E 1740.7-2942, about 1 degree away. In a second project, the full OSSE database is being used to generate annihilation maps by Maximum Entropy and other algorithms.

Leventhal participated with NASA-GSFC colleagues in the GRIS (Gamma Ray Imaging Spectrometer) balloon campaign in Alice Springs, Australia during the Fall of 1995. The diffuse galactic 511 keV and 1809 keV gamma ray lines and the diffuse cosmic gamma ray background were detected and studied. The 1809 keV line (26Al) was found to have a width well in excess of that expected from galactic rotation.

Smith, Leventhal, W. Heindl (UCSD), J. Swank (NASA-Goddard), F. Mirabel (CEN-Saclay), and L. Rodriguez (UNAM), has been examining 1E 1740.7-2942 and a similar source, GRS 1758-258, with the Rossi X-ray Timing Explorer (RXTE). Both objects have radio jets (hence the term ''microquasars'') and no known companions because of high extinction in the visible. Their black hole candidacy has been based on their spectra; this project examines their x-ray flickering properties, and is finding strong similarities to Cygnus X-1 and other blackhole candidates.

There is evidence that spiral galaxies such as the Milky Way contain more nonluminous dark matter than luminous mass. It has been suggested that some or most dark matter is in the form of nonbaryonic mass such as finite mass neutrinos or hypothetical massive neutrinos. During the last year W. K. Rose and S. Kainer have discussed the possibility that nonbaryonic matter can be gravitationally captured by massive black holes and thereby affect the evolution of some quasars and AGNs. They showed that only very massive (i.e. $\geqslant 2 \times 10^{10} M_{\odot}$) black holes formed from baryonic mass could capture significant amounts of cold dark matter particles and argued that large amounts of nonbaryonic dark matter have not been captured by black holes emitting relativistic jets.

5.3 Stellar Astronomy

J. C. L. Wang and R. S. Sutherland (ANU) are studying of the self-consistent structure and line emission from nebulae surrounding old neutron stars accreting from the atomic interstellar medium. In low luminosity accretion flows; the flow dynamics is coupled to non-equilibrium atomic processes. They have devised an iterative scheme to rigorously account for this coupling and applied it to spherically symmetric flows using a 1-D flow code and the MAPPINGS-II photoionization code. Initial results indicate that preheating of the accretion flow substantially reduces the mass accretion rate below the Bondi rate. This would partly explain the paucity of old accreting neutron star candidates in searches conducted to date. Spectral studies suggest highly prominent mid to far-infrared nebular lines (e.g., [NeII] 12.8μ, [SiII] 34.8μ), many of which are brighter than Hα, the strongest optical line. These lines and their distinctive ratios should help to positively identify (or reject) accreting old neutron star candidates, of which there are currently three.

With M. Isenberg (Chicago) and D. Q. Lamb (Chicago), J. C. L. Wang has concluded a study of cyclotron line formation in various line forming geometries. Using Monte Carlo methods, they studied line formation in regions characteristic of an atmosphere or an accretion column on the neutron star surface (so-called 1-1 geometry) and those characteristic of a radiatively supported layer in the magnetosphere (1-0 geometry). They find that fundamental scattering features emerging from a 1-0 geometry lack shoulders while those from a 1-1 geometry can have very prominent shoulders. Since observed cyclotron features in accretion-powered pulsars do not show strong shoulders, these results suggest that line formation can be occurring in a magnetospheric layer or in some combination of surface and magnetospheric regions. Magnetospheric line formation may explain why the field strength inferred from the cyclotron feature seen in A0535+26 is $>$ 10 times smaller than that inferred from accretion torque theory (to explain the pulsar's spin history).

C. Xu, S. D. Vrtilek, and J. C. L. Wang have concluded an analysis of spectral features in ASCA data of the low mass X-ray binary 4U1254-69. They conclude that line properties depend critically on the choice of continuum models and that ASCA's energy band (0.5-10 keV) cannot properly constrain the continuum for weak sources such as 4U1254-69.

S. White and E. Franciosini (visiting U. Md. from the University of Florence) presented data and models which appear to resolve a long-standing puzzle in stellar radiophysics: the radio polarization of RS Cvn binary systems at low frequencies. It had long been thought that the low-frequency polarization of the apparently-quiescent radio emission of these systems, which was inverted with respect to the high-frequency polarization, had to be explained with geometrically-complex gyrosynchrotron models. However, White and Franciosini argue, based on several examples, that the inverted polarization is due to a low-level but highly-polarized coherent emission which is superimposed on a largely unpolarized quiescent component. This explanation renders mnodelling of the quiescent component much simpler than was previously necessary.

R. Duncan (ATNF), White, J. Lim (BIAA), G. J. Nelson (ATNF), S. A. Drake (GSFC/USRA) and M. R. Kundu analyzed the radio outburst from the famous massive star Eta Carinae and showed that it represented the ionization of about 0.04 solar masses of previously-neutral material close to the star by a pulse of ionizing radiation. The outburst will continue to be monitored in coming years.

Lim and White collaborated on a number of stellar radio programs. They have obtained the first radio detections of stars in the Pleiades open cluster and used them to analyze the radio luminosity function for stars at the age of the Pleiades (50 million years). With O. B. Slee (ATNF), they carried out the first detection of the nearest star, Prox Cen, and showed that, somewhat remarkably, its radio flux is lower than might be expected. With S. Cully (UC-Berkeley), they studied the properties of the radio emission from the white dwarf-red dwarf eclipsing binary V471 Tau and confirmed that it does show radio eclipses, indicating that the radio source is localized between the two stars. They also used the BIMA array to search for radio emission from the massive stellar winds inferred from millimeter and infrared observations to exist on active M dwarf stars. They showed that such winds would be inconsistent with the radio properties of these stars, and also argued that coronal mass ejections could not lead to large mass rates on these stars.

R. Mewe, J. Kaastra (SRON), White & R. Pallavicini (Arcetri) used simultaneous EUVE and ASCA observations to study the corona of the active K dwarf AB Doradus. They found the surprising result that the abundance of Fe and several other heavy elements relative to hydrogen appeared to be reduced relative to their abundances in the photosphere, in contrast to the Sun where the same elements appear to be enhanced in the corona.

H. Richer (U. British Columbia), Bell and others have investigated the age-metallicity and age-Galactocentric distance relations for the 36 clusters with the most reliable age data. The clusters span Galactocentric distances from 4 through 100 kpc and a metallicity range from [Fe/H] = -0.6 to -2.3. With currently plausible choices for the relation between cluster metallicity and horizontal-branch luminosity, and α-enhancement ratios, it is found that the majority of the globular clusters form an age distribution with a dispersion σ(t) of $\sim 10^9$ yr, and a total age spread smaller than 4 Gyr. Clusters in the lowest metallicity group (Fe/H] < -1.8) appear to be the same age to well within 1 Gyr at all locations in the Milky Way halo, suggesting that star formation began throughout the halo nearly simultaneously in its earliest stages. There is no statistically significant correlation between cluster age and Galactocentric distance (no age gradient) from 4 to 100 kpc. The correlation between cluster age and horizontal-branch type suggests that causes in addition to metallicity and age are required to understand the distribution of stars along the horizontal branches in globular cluster color-magnitude diagrams.

Butler (U of California, Berkeley and San Francisco State) and Bell have checked if the relationship between pulsational and radial velocities of Cepheids varies with wavelength. Near IR (8000 Å) radial velocity curves have been obtained from one hundred absorption lines for the bright Cepheids δCep, ηAql, and X Cyg. A fiducial wavelength scale has been provided by the embedded telluric absorption lines. The relative radial velocity errors of individual stellar absorption lines have been reduced to a few hundred m/s.

The shape and amplitude of velocity curves from lines in the near IR are very similar to those from lines of the same atomic species and similar excitation observed in the visible region. For the two shorter period Cepheids in this study, the near IR and visible velocity curves differ by less than 1 km/s. The longer period (16 days) Cepheid X Cyg shows velocity differences of as much as 3 km/s.

The near IR line profile asymmetries are very similar to those observed in the visible. As in the case of the visible lines, the high excitation potential lines in the near IR appear to have a greater asymmetry amplitude than the low excitation potential lines.

Radial velocity curves and line profiles for Hα and Hβ have also been obtained. The Cepheids in this sample show a clear trend with increasing pulsation period. The Hα and H β line profiles of the shortest period (5 days) Cepheid (δ Cep), remain relatively symmetric throughout the entire pulsation cycle, and their respective radial velocity curves remain continuous at maximum infall velocity. The Hβ radial velocity curve shows only small deviations from that of the standard (Fe I) velocity curve. The Hβ line of the longer period Cepheid (7 days), η Aql, remains relatively symmetric, but Hα becomes extremely asymmetric near the phase of maximum infall. The Hα radial velocity amplitude is 57% larger than the standard Fe I velocity curve. Both the Hα and Hβ velocity curves are very sharply peaked (almost discontinuous) at maximum infall velocity, and they lag behind the standard velocity curve by 0.06 in phase. Both Hα and Hβ show extreme asymmetries. For the longest period (16 days) Cepheid, X Cyg, the Hα profile splits into two components for half the pulsation cycle. The Hα radial velocity curve is completely out of phase with the standard velocity curve, while the Hβ velocity curve remains relatively well behaved, lagging the Fe I velocities by 0.12 in phase.

Cavallo, Bell, and Sweigart (NASA/Goddard) have combined realistic stellar sequences with a detailed nuclear reaction network (from D. Arnett) to examine the details of the nuclear burning processes around the hydrogen-burning shell (H shell) of red giant branch stars. The sequences give a run of temperature and density around the H shell and enable the changes in the elements to be followed explicitly as a function of position on the color-magnitude diagram. Separate sequences mimic metallicities from the metal-poorest clusters ([Fe/H] = -2.3) to solar metallicity. The nuclear reaction rates were modified to explore the latest experimental and theoretical data for the rates involved in the CNO, NeNa, and MgAl cycles.

The results show regions in which C and O are converted to N in the CN and ON cycles above the H shell. Within the C-depletion zone, Na is enhanced from proton captures on ^{22}Ne at all metallicities at all points along the RGB. Once inside the O-depleted region, Na becomes strongly enhanced from a series of proton captures in the NeNa cycle. This is evident earlier on the RGB in the lower metallicity sequences, but does not appear until the upper RGB in the higher metallicity sequences. In addition, Al is produced from Mg inside the O-depleted zone, coming first from ^{25,26}Mg on the lower RGB in the lower metallicity sequences. For the same sequences, Al becomes greatly enhanced from a series of proton captures in the MgAl cycle. The higher metallicity sequences show enhancements in Al only towards the RGB tip and only from ^{25,26}Mg. These results are in strong qualitative agreement with the observational data.

Now that the hydrostatic models have been used to produce the elements above the H shell, a suitable mixing algorithm will be developed to bring nuclear burning products to the stellar surface and make a quantitative analysis of the abundances which can be compared to the observations.

Briley (U. Wisconsin-Oshkosh), Bell and co-authors have observed the Na lines at 8190 Å in a sample of main sequence/turn off stars in the metal rich globular 47 Tucanae. These stars had well determined photometry available and had also been observed spectroscopically in the blue, these observations yielding CN and CH band strengths. The IR spectra were summed for the CN strong and for the CN weak stars, with the result that the CN strong stars are found to have stronger Na lines than do the CN weak ones. The Ca line at 6122 Å does not show this effect.

Since the Na abundance range seen in the dwarfs is similar to that seen in 47 Tuc giants, it implies that little if any modification of Na abundances in these giants has occurred in their evolution. This is in agreement with the work by Cavallo, Sweigart and Bell, which shows that the lower temperature in the H burning shell of a metal rich globular cluster model produces Na only from Ne^{22} and not Ne^{20}. Greater production of Ne and Al occurs in more metal poor models, with higher temperatures in their H burning shells. The high Na and N abundances seen in some dwarfs may result from ejecta of material from 5-10 $M_{\odot}$ stars in the cluster, such ejecta being rich in CNO-equilibrium values and high Na, Al abundances resulting from H burning.

Cavallo, Pilachowski (NOAO) and Rebolo (IAC) have analysed the O I triplet near λ7775 Å in metal-poor field stars. The work enables them to determine the oxygen abundance in the main-sequence turn-off and subgiant branch stars. Using the triplet completes the information on O data between the main-sequence stars in which the O I triplet is normally used and the giants in which the [O I] line at λ6300 Å is typically used.

Bell and Tripicco (Hughes-STX) have compared the fluxes of solar models with different observations of the Sun. All of the calculations use an atomic and molecular line database which gives good agreement with the solar atomic line spectrum. The models give good agreement with the fluxes above 4000 Å and poorer agreement shortward of that. These calculations use the Opacity Project continuous opacities for MgI and SiI, while the FeI opacity is taken from Dragon & Mutschlecner. Further calculations have been made with the FeI opacity being enhanced by factors of 10 and 20, but the models remain brighter than the observations at some wavelengths.

Castro (Instituto Astronomico e Geofisico, Sao Paulo, Brazil), Bell and co-authors have analyzed echelle spectra of the metal-rich disk giant μLeo and the Baade's Window giant BW IV-167. It is found that μLeo and BW IV-167 have nearly identical surface gravities, effective temperatures, equivalent widths, and microturbulent velocities, with [Fe/H] = +0.46 ± 0.14 for μLeo and [Fe/H] = + 0.47 ± 0.17 for BW IV-167.

Using spectra obtained with the Lick 3-m telescope, Smith (Lick Observatory), Bell and co-authors have shown that a CN-CH band strength anticorrelation exists among a sample of six red giant members of the globular cluster M5 having absolute magnitudes in the range $-2.0 < M_V < -1.3$, while a seventh giant is found to have both strong CN and strong CH bands. Carbon and nitrogen abundances determined for five of the observed stars reveal that for the giants exhibiting the CN-CH anticorrelation (i) carbon is depleted ([C/Fe] < -0.5) by comparison with the [C/Fe] abundances of typical halo subdwarfs, (ii) nitrogen is greatly enhanced (+0.5 < [N/Fe] < +1.2) relative to the [N/Fe] abundances of typical subdwarfs, and (iii) the nitrogen and carbon abundances are anticorrelated and correlated respectively with the [O/Fe] abundances determined by Sneden *et al.* (1992). By contrast, star M5 IV-59 has [C/Fe] and [N/Fe] abundance ratios that are near the upper limits for red giants in M5. This star also appears to have an undepleted [O/Fe] abundance, despite a greatly enhanced nitrogen abundance. Similar stars to this were found in Omega Cen by Cohen (Caltech) and Bell.

M. Houdashelt, Bell and Sweigart (NASA/GSFC) began a program to study the stellar populations of galaxies through spectral synthesis. Building upon Bell's previous work, synthetic spectra were first constructed for solar-metallicity M giants; these spectra extended from 3000 Å to 5 μm. In general, the line spectra proved to be a good match to spectra of field M stars of similar effective temperature, especially in the near-infrared. Although special care was taken to model the TiO absorption accurately, the TiO bands were found to strengthen too quickly with decreasing effective temperature for spectral types later than M2. This caused the broad-band colors and spectral types measured from the synthetic spectra to differ from those observed in field M giants for effective temperatures less than 3750 K. Work is proceeding to improve the treatment of TiO in the synthetic spectra of cool stars.

The initial focus of the population synthesis models were elliptical galaxies, which were represented as coeval, single-metallicity stellar populations. The effective temperature, surface gravity distribution of these populations were described by isochrones supplied by Dorman (NASA/GSFC), to which Sweigart's horizontal-branch and asymptotic-giant-branch tracks were added. Assuming a Salpeter IMF, synthetic integrated spectra of elliptical galaxies were constructed for 6, 10 and 16 Gyr populations. At each age, models were made for [Fe/H]=+0.39, 0.00 and –0.47; the latter also had [O/Fe]=+0.23. The 16 Gyr, solar-metallicity synthetic spectrum proved to be a remarkably good match to a spectrum of the E1/S0 galaxy NGC 4472 obtained by Kennicutt. The optical colors derived from the synthetic spectra agreed well with the trends exhibited by early-type galaxies. These colors indicated that the reddest elliptical galaxies have [Fe/H] $\sim +0.25$, with bluer galaxies probably having lower metallicities rather than younger ages. In the near-infrared, the model $V-K$ and $H-K$ colors and the strength of the 2.3 μm CO band were good representations of E/S0 galaxies. However, at a given $V-K$, the $J-K$ colors of the models were redder than the galaxy trends by $\sim$0.15 mag. This is probably due to the ϕ band of TiO being too strong, thus making the J-band magnitudes too faint. Lick indices were also measured from the synthetic integrated spectra and compared to empirical measurements of elliptical galaxies. The models were able to match the observed Lick indices about as well as the models of Worthey, but the predicted metallicity and age associated with a given color or Lick index measurement differed between the synthetic spectra and Worthey's models.

W. K. Rose has reported calculations related to the formation of late-type carbon stars, non-LTE radiative transfer computations interpreting mm wavelength CO observations and calculations of infrared continuum radiation from dust particles. During the last year Rose has discussed carbon stars and elemental abundances in the light of recent observational evidence. He has argued that $^{12}C/^{13}C$ ratios depend sensitively on measured line shapes at mm wavelengths.

5.4 Interstellar Medium and Star Formation

J. Stone's research efforts are primarily concerned with hydrodynamic and magnetohydrodynamic (MHD) studies of the ISM and star formation. In collaboration with S. Balbus and J. Hawley (U. Virginia), Stone has studied angular momentum transport in accretion disks via convection. Through direct numerical simulation, Stone and Balbus have shown that convection transports angular momentum inwards, and therefore is not a viable candidate for the anomalous viscosity in disks. Through combined analytic and numerical studies, Balbus, Hawley, and Stone (1996) have been able to understand this result physically in terms of the role epicyclic motions play in mediating angular momentum transport in disks. Surprisingly, their results indicate that ANY form of hydrodynamic turbulence in an accretion disk will lead to inward transport. Magnetohydrodynamic turbulence, and large scale spiral shocks, remain viable candidates for outward transport. Stone, in collaboration with J. Hawley (Virginia), C. Gammie (CfA), and S. Balbus (Virginia) have completed a comprehensive study of the nonlinear regime of the Balbus-Hawley instability in stratified accretion disks. The study shows that local dissipative processes, rather than buoyancy, dominates the saturation mechanism. Moreover, the instability acts as a dynamo, and generates a strongly magnetized corona at high Z in the disk. This study is now being extended to model the global structure of disks in which the B-H instability is present. Stone and graduate student J. Xu have been studying the Kelvin-Helmholtz instability in non-adiabatic protostellar jet beams. With collaborator P. Hardee (U. Alabama), the growth rates of K-H modes in cooling jets have been calculated in the linear regime (Hardee and Stone 1996). There are significant differences between the growth rates of modes in adiabatic and cooling jets. Using two-dimensional hydrodynamical simulations, Stone, Xu, and Hardee (1996) have followed the growth of asymmetric modes into the nonlinear regime. Jets in which the growth rate of the sinusoidal surface wave has a maximum at a so-called ''resonant'' frequency can be dominated by large amplitude sinusoidal oscillations near this frequency. Eventually growth of this wave can disrupt the jet. On the other hand, nonlinear body waves tend to produce low amplitude wiggles in the shape of the jet, but can result in strong shocks in the jet beam. In cooling jets these shocks can produce dense knots and filaments of cooling gas within the jet. Ripples in the surface of the jet beam caused by both surface and body waves generate oblique shock ''spurs'' driven into the ambient gas. These shock ''spurs'' can accelerate ambient gas at large distances from the jet beam to low velocities, representing a new mechanism by which low velocity bipolar outflows may be driven by high velocity jets. Rapid entrainment and acceleration of ambient gas may also occur if the jet is disrupted.

Stone and graduate student K. Miller are completing a study of the interaction of a magnetized accretion disk with the magnetosphere of the central object. Initially, the study is limited to axisymmetry, and only aligned rotators with dipole fields are considered. Using a variety of initial field strengths and resistivities in the disk, rapid accretion which crushes the magnetosphere to the stellar surface always occurs.

J. P. Harrington, Lame, White, and K. Borkowski (North Carolina State) examined the dust in the planetary nebula BD+30 3639 using high-resolution HST WFPC2 and VLA images. The point-to-point map of the extinction shows a gradient across the nebula and also a large dust clump in the northeast. They found that ratio of total to selective absorption for this nebula seems much smaller than the normal ISM value. Harrington used Monte Carlo models to investigate dust properties in the substantial halo seen in the optical images.

Harrington and Lame continued analysis of the HST WFPC2 images of NGC 6543. The [O III] images were used to show that the electron temperature is fairly constant across the nebula. Emission from structures seen in the images - the caps and ansae - was isolated and compared to photoionization models.

Together with C. McKee & S. Stahler (UC-Berkeley), P. Safier developed a simple, one-dimensional model for the evolution of a dense molecular core through ambipolar diffusion. They were able to reproduce within factors of order unity numerical results from complex simulations and follow the evolution of the remnant envelope after the formation of a protostar at the center of the cloud.

Safier has continued a long-standing collaboration with A.

Königl and S. Martin at the University of Chicago to explain the origin of the CO bandhead emission in young stellar objects. The core of their efforts is a full non-LTE calculation for the excitation of the rovibrational levels of CO, which includes infrared and UV pumping.

Safier has observed the molecular cloud associated with the young stellar object BD+40 4124 in the $2 \rightarrow 1$ transition of CS with the BIMA array and has discovered high-velocity emission.

N. Nagar, S. Vogel, and J. Stone have observed the molecular outflow in Herbig-Haro 111 in CO at 6 arcsec resolution with the BIMA array. The molecular outflow is found to form a hollow parabolidal sheath around the optical jet. The observed geometry and kinematics demonstrate that the outflow velocity and acceleration is primarily in the axial direction, along the walls of the limb brightened sheath. A comparison of the fluxes and dynamic timescales of the optical jet and the molecular outflow suggest that it is possible that the molecular outflow is driven by the jet complex, though this would require the jet complex to extend further than currently observed. The observations provide strong evidence for the close connection between optical jets and molecular outflows.

L. Looney is continuing his thesis work on the circumstellar environment of young stars under the supervision of L. Mundy. Recent high resolution ($0.3''$) BIMA observations in the 2.7 mm continuum of the deeply embedded young stellar object L1551 IRS5, resolved the classic young source into a binary system with a projected separation of 50 AU (Looney, Mundy,& Welch 1996). The total flux detected in the compact source was significantly less than expected, suggestive of another structure, perhaps a circumbinary disk. In addition to the L1551 IRS5 image, high resolution observations were used to probe for compact continuum sources along the Orion Molecular Cloud ridge. Few compact sources were found, implying that the majority of the continuum emission in the Orion ridge region is from the extended structure. Continuing BIMA observations of young stellar objects at varying stages of evolution are being performed that will separate the circumstellar disk emission from the protostellar envelope emission.

With P. Hofner (U. Koln), L. Mundy and S. Vogel, Xie imaged the CS emission from the UC HII G35.2-1.74 with the BIMA array and the FCRAO 14m telescope, and found that the dynamics of the region is dominated by a massive bipolar outflow oriented East-West with the molecular gas significantly displaced from the UC HII. However, none of the existing theories for UC HIIs can satisfactorily explain the location and morphology of this source. They propose that the presence of turbulent pressure can explain the small size and longevity of UC HIIs.

Moriarty-Schieven (JCMT), Xie, and Patel (CfA) have published the first results of a project imaging 21 cm HI line and continuum emission from cometary globules in IC1396 with DRAO array ($1'$ resolution), reporting on their discovery of prominent HI tails.

Langer, Velusamy (JPL) and Xie have reported their observations of a thin disk and the inner edge of jets and outflows around IRS1 in B5 from their CO isotope images obtained with OVRO MMA. Xie has recently proposed the hypothesis that Larson's laws can be explained in terms of a scale-independent magnetic field fluctuations as a result of strong wave-wave interactions. Xie (1996) is also continuing his investigation of the so-called C/CO ratio problem as a result of mass transport in the context of magnetic turbulence.

In an effort to study the mass function of subcondensations possibly in the process of collapsing to form stars, L. Blitz and Xie have recently imaged a couple of clumps in Rosette Molecular Cloud in CO isotopes with BIMA.

With R. Snell (UMASS), P. Goldsmith (Cornell) and Lee Mundy (UMD), Xie is continuing the analysis of observations obtained with the FCRAO 14m telescope for outflow sources, such as L1448, B335 and L1455, aimed mainly at understanding the outflow activities over the full extents of the outflows.

5.5 Planetary Science

5.5.1 Asteroids

McFadden and collaborators completed and published an observational effort to find volatile emission from suspected extinct comets among the near-Earth asteroids. Searching for CN ($\Delta \nu = 0$) emission at 3880 Å, upper limits of CN emission were determined using the Haser model of molecular gas production. No emission features were detected within 3-σ for the objects observed, 4015 Wilson-Harrington, 2201 Oljato and 3200 Phaethon, the parent body of the Geminid meteorites. With these upper limits and knowledge of the size of the bodies, they determined the fractional areas active with the derived upper limits, all of which were orders of magnitude lower than the lowest activity comets. Hence, the relationship between former comets and asteroids remains at this time based on dynamical evidence alone.

L. McFadden continued her work on the NEAR mission including work on the preflight calibration and characterization of the Multi Imaging System (MIS) and the Near-Infrared spectrometer (NIS). The spacecraft was launched on February 16, 1996. It will fly-by asteroid 253 Mathilde in June, 1997 and orbit 433 Eros for one year beginning in 1999. McFadden, with F. Vilas (JSC) and others, studied the optimal filters to be used during the fast flyby of 253 Mathilde. They found that with the broad-band filters neccessitated by the high flyby speed, NEAR will be able to resolve phyllosilicate units covering 20% of the surface or more despite the distance and speed of the flyby.

C. Lisse and M. A'Hearn obtained a near-infrared rotational light curve of Phaethon in collaboration with K. Meech (U. Hawaii), who has obtained numerous optical light curves, to study the shape and rotational dynamics of this body.

5.5.2 Comets

The observational highlight of the year was the unexpected, visual discovery of two bright comets, C/Hale-Bopp and C/Hyakutake, which provided an outstanding opportunity for many observational programs carried out by members of the department. The close approach of C/Hyakutake to Earth led to intense observing near closest approach using many different telescopes over a wide range of wavelengths. Most of the programs involved numerous members of the department and many also involved collaborators elsewhere.

The most startling result was the discovery of intense X-Rays from the comet in a program led by C. Lisse and collaborators at other institutions. This breakthrough led to the subsequent discovery by others of X-Ray emission from several other comets in archival data. The explanation of the emission is unclear since most mechanisms predict too low a flux, but it is clear that the X-Rays are produced in an interaction between the solar wind and the cometary coma. The observational programs also included a program of mm-wave observations at the NRAO 12-m telescope led by L. Woodney which included the first definitive observation of OCS in a comet and leading to a significantly better understanding of how sulfur is bound up in the nucleus. There was a program to study the nucleus using the VLA led by Y. Fernández and A. Kundu and using the IRTF led by Lisse and M. A'Hearn. Preliminary analyses yield a radius of 2.5-km from the IRTF, somewhat larger than deduced from radar observations, and a somewhat larger upper limit from the VLA observations. Given the outgassing measured under various programs (see below), the nucleus must be active over an unusually large fraction of its surface.

The IRTF program also yielded CVF images of the comet which suggest significant spatial structure in the gaseous emission as well as in the dust while the VLA program yielded an upper limit on the amount of large dust in the coma, thus constraining the dust distribution when combined with the detections with radar by another group. A subsequent campaign of high-resolution spectroscopy yielded a survey of much of the near-IR spectral range with many as yet unidentified emission lines. Optical imaging at Kitt Peak led by Fernández yielded a rotational period of 6.3 hours for the nucleus but the nucleus was not directly detectable.

Spectroscopic observations included a survey at moderate spectral resolution of the entire optical region at Lowell Observatory led by L. Woodney and A'Hearn and high-resolution echelle spectroscopy at Kitt Peak led by R. Meier and D. Wellnitz. Both sets of spectra show many unidentified features. The echelle spectra have yielded upper limits for OD and other isotopic variants are still being sought in the spectra. HST spectra were taken under three programs, one led by A'Hearn and the others led by his collaborators at other institutions. These spectra showed strong emission by S_2, the second time this has ever been seen in a comet and the third time it has ever been seen astronomically. This observation rules out the hypothesis that S_2 was seen in C/IRAS-Araki-Alcock due to the anomalous orientation of the interplanetary magnetic field (which would enhance solar wind penetration into the innermost coma) and resurrects the hypothesis of origin in irradiated interstellar grain mantles. The spectra also showed anomalous populations of C_2 radicals in the ground state of the Mulliken system and these have been interpreted as showing formation by dissociation of C_2H. Abundances of several species, particularly CO and atomic S, are unusually difficult to determine because the usual emission features were very optically thick. A program with IUE, led jointly by M. Haken and A'Hearn at Maryland and M. Festou (Obs. Toulouse) and in collaboration with colleagues at other institutions, yielded the best record of the variation of total outgassing as the comet passed close to Earth, despite loss of IUE's second to last gyro shortly before closest approach to Earth. The comet was quite unusual in showing no increase in water production for an extended (several-week) period while the heliocentric distance was significantly decreasing prior to closest approach to Earth. The comet subsequently recovered and began to increase in a more normal fashion.

C/Hale-Bopp presents another rare opportunity for extensive observational programs which are still underway. These included a program of early monitoring of the sulfur compounds at large heliocentric distance led by Woodney. Far outside 2 AU, the comet was producing far more H_2S than was C/Hyakutake at 1 AU. HST observations, led by colleague H. Weaver (JHU), have yielded the only available estimate for the size of the nucleus - a radius of $\sim$20 km assuming a geometric albedo of 4%. High-resolution echelle spectra were obtained at the Keck Observatory at the very end of this reporting period to search for deuterated species and other isotopic variants. The first UV spectra of the comet were obtained at 7 AU with IUE by Haken and A'Hearn in collaboration with colleagues at other institutions, yielding a higher dust production rate than for any comet observed previously under the large spectroscopic and photometric surveys. The activity was monitored through the appearance of emission by OH using both IUE and HST.

Other comets were also observed for one purpose or another during the year. Lisse and A'Hearn were scheduled to obtain ISO observations of comet P/IRAS to study the dust distribution and gorund-based observations were also scheduled. Comet P/Honda-Mrkos- Pajdusáková was studied from IRTF by Lisse and A'Hearn and with HST by A'Hearn in a program led by P. Lamy (LAS-Marseille) and it was found to have a remarkably small nucleus with radius only a few hundred meters. X-Ray observations were also scheduled for C/Tabur.

Fernández and collaborators completed their analysis of the cometary activity of P/Wilson-Harrington, showing that the observations were consistent with the comet having a plasma tail with comparable amounts of CO^+ and H_2O^+, both of which are quite consistent with typical cometary activity, but without a significant neutral coma. The data are inconsistent with the apparent tail being due to dust. The data suggest a transient outburst of gas that was rapidly ionized or a surprising coincidence between the first observations and the cessation of cometary activity.

A'Hearn and collaborators completed their analysis of nearly two decades of cometary, narrow-band photometry. They showed, among other things, that there are two classes of comets, one with 'normal' ratios of abundances and one with depleted carbon-chain radicals (C_2 and C_3). The latter are almost exclusively Jupiter-family short-period comets and comprise about half the comets in that family. They also showed that perihelion distance appears to be a better indicator of dust-gas ratio than does actual distance at which observations are made and they suggest that the evolution of comets is dominated by the peak heating rate at perihelion rather than by the integral heating around the orbit or the number of perihelion passages. This constrains models of the evolution of cometary mantles. They also showed that, for those comets for which reliable nuclear magnitudes were available (mostly Jupiter-family comets), the observed outgassing typically implied that only a very small fraction of the surface was active, with Halley having one of the largest active fractions near 15%. The distribution at small nuclear sizes and at small active fraction is dominated by selection effects but suggests that the frequency of a given active fraction is increasing monotonically as that fraction goes to zero, thus strenghtening the suggestion that many near-Earth asteroids are really dormant or extinct cometary nuclei.

Meier and A'Hearn completed an analysis of the sulfur triplet at 1812 Å. They were able to estimate the total sulfur content of about twenty comets using data from IUE and HST and concluded that the sulfur in most comets could not be adequately explained by the known sources, H_2S and CS_2. A third source of comparable abundance to the first two was needed. OCS was proposed as a possible source and subsequently detected in C/Hyakutake (see above).

5.5.3 Dust and Dynamics

D.P. Hamilton completed a detailed study of the dynamics of dust around Mars. When the two small martian moonlets, Phobos and Deimos, are struck by interplanetary micrometeoroids, most of the impact ejecta is lofted into orbit around the red planet. Debris particles larger than several tens of microns remain in orbit for tens to thousands of years and are spread into broad rings by the action of Mars' gravity and solar radiation pressure. After investigating the orbital dynamics of the debris particles, Hamilton predicted that the rings will be azimuthally asymmetric, tilted out of Mars' equatorial plane, and that the structure of the rings will vary periodically with the position of Mars along its orbit. The rings are predicted to be very faint, and have yet to be unambiguously detected; this may change in the next few years as spacecraft carrying sophisticated dust detectors reach Mars.

Hamilton and A.V. Krivov (St. Petersburg University) have discovered a new integral of the motion which governs the evolution of planar orbits about planets when they are influenced by four perturbations: i) solar gravity, ii) planetary oblateness, iii) solar radiation pressure, and iv) electromagnetism. The formalism promises to provide an underlying and unifying framework for the dynamics of faint dusty rings. Recently, Hamilton and Krivov have shown that their integral may be extended into three dimensions. With Ph.D. student K. Watt, Hamilton has also added a weak drag force to the above suite of perturbation forces and shown the existence of an adiabatic invariant. They applied the adiabatic invariant to the motion of Phoebe dust which drifts inward to coat the leading face of Iapetus. Their results lend support to the hypothesis that dark Phoebe dust is the cause of Iapetus' striking black/white hemispheric asymmetry. Hamilton, E. Grün and M. Baguhl (MPI-K, Heidelberg) studied the motion of tiny submicron grains from the asteroid belt. They find that electromagnetic forces from the solar wind accelerate these tiny grains to escape the solar system on trajectories that take them to high ecliptic latitudes, and claim that these grains may account for the impacts sensed by the Ulysses spacecraft at latitudes of up to 80deg. With Grün and the Galileo dust team, Hamilton has continued his study of jovian dust streams: submicron-sized grains accelerated away from Jupiter by strong electromagnetic forces. Their analyses of new Galileo data and new modeling efforts further constrain possible sources and mechanisms.

5.5.4 Planets

L. McFadden and collaborators measured reflectance spectra of several SNC meteorites and initiated a comparison with the extant reflectance spectra for Mars in order to better constrain the possible sites from which the Martian meteorites were excavated.

A. Kundu, A. W. Grossman, and J. C. L. Wang are concluding their analysis of the nonthermal (polarized) 3.6 and 6.2 cm emission VLA data taken before, during, and after the impact of Comet Shoemaker-Levy 9 with Jupiter. These high spatial ($\sim 2''$) and moderate time (~ 2 hrs) resolution observations suggest the emission responds to direct impacts on magnetic field line footpoints rather than to the passage of the comet fragments through the magnetosphere. They also indicate the presence of impact-induced enhanced electron radial diffusion and pitch angle scattering.

5.6 Space Plasma Physics

A. S. Sharma and K. Papadopoulos have continued their investigation of the magnetosphere using nonlinear dynamical technique.

J. A. Valdivia (Graduate student), Sharma and Papadopoulos worked on the prediction of magnetic storms using nonlinear dynamical models. The nonlinear dynamical technique of phase space reconstruction is applied to develop nonlinear models of storms and their predictability using the NGDC database for 1964–1990. Nonlinear predictive models based on the Dst data alone were developed. These models can predict the storm evolution consistently, and can identify intense storms from moderate ones. The models based on IMF and Dst data, as well as those based on Dst alone, can be used for forecasting tools for space weather.

C. C. Goodrich, Papadopoulos, M. Wiltberger (Graduate student) and J. G. Lyon (Dartmouth College) studied energy and momentum transport from the solar wind into the magnetosphere during a substorm. They found that the propagation of the Poynting flux is determined by the dynamic state of the magnetosphere. During the substorm growth phase of this flux penetrates the magnetopause and is focused toward the central plasma sheet in a region about 6–10 RE. The Poynting flux focusing provides a natural interpretation of the observations showing the strongest substorm growth phase effects occur near 8–15 RE location. They further confirm the suggestion earlier made by Papadopoulos that the magnetosphere acts as an equivalent lens that, during a substorm growth phase, focuses the solar wind field momentum in the vicinity of 6–10 RE.

Sharma, Papadopoulos and G. S. Lakhina (Indian Institute of Geomagnetism, Bombay, India) studied helicon waves in the magnetotail. They used a two fluid plasma model of the magnetotail in order to describe the helicon mode structure. The eigenmode equation was solved by considering two regions: the outer region in which the wave polarization is that of the Alfven mode and the inner region in which the waves are helicons. Thus MHD waves entering a thin neutral sheet are mode converted into helicons. The symmetric and antisymmetric modes have strong out of the plane components and can give rise to flux ropes in the current sheet. This mode leads to current and flux transport at speeds significantly larger than the Alfven speed.

The SPP group continued their activity in the Active Aurora Research Program (HAARP). Papadopoulos is the chairman and G. Milikh is the executive secretary of the scientific committee, which objectives is the study of the scientific uses and of the wide range of applications created by the HAARP project. Currently the committee is working on the deliberation of the report ''HAARP Research and Applications.'' Recently a series of publications were devoted to the affects caused by the HF ionospheric heating. Papadopoulos, P. K. Chaturvedi in cooperation with P. N. Guzdar (UMD), and with M. J. Keskinen and S. L. Ossakow (NRL) presented a model of self-focusing instability in the presence of density irregularities in the ionosphere. This study addresses the role of preexisting density irregularities which are always present in the ionosphere. The presence of ambient irregularities results in the excitation of wave numbers, which, on the basis on homogeneous theory of self-focusing instability, should be stable. This effect can explain the puzzling observations that indicate growth of irregularities during the ionospheric heating, having a scale of the order of hundreds of meters.

Papadopoulos in cooperation with C. L. Chang (Science Application International Corp.), & with N. Borisov and A. Gurevich (Lebedev Physics Institute, Moscow, Russia) studied a direct Cerenkov excitation of waveguide modes by a mobile ionospheric heater. The model relies on transient ionospheric heating with a heater spot moving horizontally at the bottom of the waveguide with speed close to the speed of light. It is found that enhanced radiation coupling requires that the speed of the heater approaches the speed of light. For the anisotropic case such enhancement occurs independently of the direction of motion, while for the isotropic case, motion parallel to the ambient electric field is required.

Milikh and A. Gurevich (Lebedev Physics Institute, Moscow, Russia) presented a new model of the artificial airglow due to the ionospheric modification. The model is based on a recently developed nonlinear theory of stationary striations, which predicts a strong enhancement of the electron temperature inside the striations. According to this theory the neutral species can be excited by the hot electrons inside the striations, which spread both upward and downward from the source region located between the radiowave reflection and the upper hybrid resonance point. The discussed model estimates the local electron temperature inside the striations, and the intensity of red- and green-line emissions due to the excitation of O(1D) and O(1S) levels by the electron impact. These results were checked by comparison with the observations.

Papadopoulos, Sharma, H. B. Zhou (former gradient student) in cooperation with Chang (SAIC) studied the dynamic response of a magnetoplasma to an external time dependent current source in the contest of electronmagnetohydrodinamics. The results show that the electron plasma responds to a time-varying current source imposed across the magnetic field by exciting whistler/helicon waves and forming an expanding local current loop, driven by field-aligned plasma currents. The results are applied to the ionospheric generation of extremely low frequency (ELF) and very low frequency (VLF) radiation using amplitude nodulated HF heating. They found that contrary to previous suggestions the dominant radiating moment of the ELF/VLF ionospheric source is an equivalent horizontal magnetic dipole.

Papadopoulos, Milikh and J. Valdivia (Graduate student) continued their studies of high altitude lightning. Key issues addressed were modeling of so called red sprites, optical flashes located at 60–90 km above the thunderstorm, with emphasis on their fine structure, and study of the runaway discharge in the presence of the geomagnetic field. Based on the fact that lightning discharges follow a tortuous path which have been identified as a fractal structures, they developed a model of transient electric field from lightning as a fractal antenna. This model allows to obtain a spatio-temporal distribution of the optical flashes due to the lightning. They also presented a model of red sprite optical spectrum due to molecular excitation by ionospheric electrons accelerated by the electric field from lightning. The results were compared with observed red sprite spectra. Good agreement with the observations was found for values of the electric field close to the local breakdown threshold. Implications of the computations of the optical spectra to models of red sprites were also presented.

Another interesting effect related to the high altitude lightning is the runaway electron breakdown which seems to be a source of X-ray flashes generated at the height in excess of 30 km, which were recently observed by GRO observatory. However, some attempts to explain this emission neglecting the effects caused by the geomagnetic field were incorrect as commented by Papadopoulos *et al.* [Geophys Res. Lett., 23, 2283, 1996]. Thereupon Papadopoulos, Milikh and Valdivia in cooperation with A. Gurevich (Lebedev Physics Institute, Moscow, Russia) proceeded with a new model, which generalizes the theory of the electron runaway discharge to the case of a laminar electric field at an arbitrary angle to the magnetic field, and derives the relevant threshold conditions. They showed that the conditions of runaway process depend on the angle between the of electric and magnetic fields, and the ratio of their magnitudes. In fact, the geomagnetic field hinders the development of runaway breakdown in the atmosphere. They revealed that one can expect a significant difference in the properties of high altitude discharges that occur at equatorial and polar latitudes.

Milikh with Gurevich and Borisov (Lebedev Physics Institute, Moscow, Russia) prroduced a book ''Physics of Microwave Discharges and Artificially Ionized Regions in the Atmosphere'' (Gordon and Breach Publishers, UK). The book is devoted to studies of the problems related to the creation of over-the-horizon radar and new types of radio communication using an artificially ionized region in the atmosphere by means of powerful rf radiation. Such a region acts like an artificial ionosphere reflecting radio waves.

Milikh with G. S. Nusinovich (UMD) and B. Levush (NRL) discussed removal of halocarbons from air with high-power microwaves. They consider the destruction of halocarbons caused by free electrons produced in a freely localized discharge initiated in the air by a focused microwave beam. After fast cooling, the electrons can attach to halocarbon molecules and destroy them. Operating regimes and their efficiencies were analyzed in the paper, and the corresponding parameters of microwave sources were specified. They also discussed the availability of microwave sources for such processes.

Sharma and Milikh have continued their studies of the structure and dynamics of inner cometary plasmas. A model of the cometary plasma consisting of water group ions, bulk electrons and energetic electrons produced mainly by photoionization has been presented. The dominant losses in the inner coma are the radiation from the excitation of vibrational levels of water molecules. The electron energy losses due to these processes peak near 4000 K, and at temperatures higher than this value a localized cooling leads a thermal instability. The resulting increase in recombination leads to an ion density depletion, and the estimates for this depletion at comet Halley agree with the observations. The effects caused by diffusion and thermal conductivity has been studied.

Valdivia and A. Fouladi (graduate students) introduced and implemented a new method of period control of chaotic systems based on optimization. An error function, which is a measure of deviation from the desired time evolution, is constructed. The error function is then minimized along the trajectory in order to stabilize an unstable periodic orbit. The process of optimization is not arbitrary but constrained to the dynamics. No specific knowledge of the desired state of the system is required. They also demonstrated how orbits of ''high'' period are similarly controlled.

Papadopoulos with A. Drobot and Chang (both Science Application International Corp.) studied the physics of current collection by the tethered satellite system which was deployed from the space shuttle ''Columbia'' on February 24, 1996. Data collected revealed a host of new physics phenomena concerning the current collection by charged bodies in space moving at orbital velocities. In fact, the current collected was significantly larger than expected by space charged limited flow in magnetized and even unmagnetized plasmas. The ongoing physics analysis of the observed phenomena was presented.

Papadopoulos and D. Book in cooperation with the experimentalists from the Hebrew University (Israel) headed by A. Zigler, continued their studies of the current response of an electrically biased magnetoplasma to a short photoionizing laser pulse. It is found that the behavior in the approach to the asymptotic state varies from monotonic to oscillatory, depending on the ratios of the collision frequency to the cyclotron frequency for the carriers. Of particular interest is the case equivalent to a critically damped oscillator, which allows the photonic pulse to be mapped to a short electric pulse, independently of the carrier lifetime. This corresponds to transient breakdown of the magnetic insulation during the photoionization time.

Book and Valdivia (graduate student) proposed that the differential rotation of the Earth's inner core, which was recently deduced, is due to a combination of the deacceleration of the Earth's rotation and the viscous drag between the Earth's inner and outer cores. The proposed model allows to estimate the dynamic viscosity in the inner core of the Earth as 104 poise. Besides providing a novel way of determining the viscosity of the core, this model suggests some new tests and shows how astronomical effects can influence geological phenomena.

Book studied a suppression of the Rayleigh-Taylor instability through accretion. He obtained that the nonlinear growth of the Rayleigh-Taylor instability in an accelerated shell can bereduced by arranging for the shell to sweep up materials as it moves. Momentum conservation preferentially slows the thinner ''bubble'' portions of the perturbed shell, which lead to the ''spikes.'' Results were presented from calculations based on the spherical thin-shell model.

Book with L. Wang and J. Orloff (both UMD) and T. Tang (Xián Jiaotong University, China) developed a new method for calculating theaxial potential due to space charge in electrostatic optics. In this method the charge density and potential are expanded in powers of r and z and the Poisson equation is solved term by term. The method could be useful for modern high-resolution focused ion beam systems.

Book studied high-frequency electrostatic models in non-neutral plasmas. He employed a fluid description to derive the dispersion relation for cyclotron models in a cylindrical non-neutral plasma confined by a uniform magnetic field inside a chamber with conducting walls. The eigenvalues are found, as well as the eigenfrequencies for high-frequency electrostatic models.

5.7 Solar Radio Physics

N. Gopalswamy and M. Kundu are involved in an international collaborative effort to study the onset phase of coronal mass ejections using prominence eruptions observed by the Nobeyama radioheliograph. By comparing the radio data with Yohkoh soft X-ray data, they found that a coronal volume much larger than the erupting prominence participates in the eruption, similar to coronal mass ejections observed in whitelight.

Gopalswamy and Kundu, in collaboration with Hiraiso Solar terrestrial research Center in Japan and the WIND/WAVES group at NASA/GSFC are studying the origin of coronal and interplanetary shocks. Preliminary results suggest that the coronal shocks, originating from solar flares may not propagate all the way to the interplanetary medium. They found a population of interplanetary shocks with no correspondence with the coronal shock population. This result strongly suggests that the coronal and interplanetary shocks are independent and have different origin.

Gopalswamy and Kundu are investigating X-ray signature of type II and type IV radio bursts in collaboration with M.

Pick and Manoharan (Meudon) and N. Nitta (Lockheed-Martin). In one case they found a coronal disconnection event associated with a type IV burst and a sudden X-ray ejection associated with a type II burst. These data provide new insight into the near surface mass motion that may be responsible for particle acceleration needed to produce non-thermal radio emission.

Gopalswamy, Zhang and Kundu are investigating the time structure in the Transient microwave brightening discovered earlier (Gopalswamy *et al.*, 1994). This analysis is important in determining whether the transient microwave brightenings are thermal or nonthermal. Preliminary results show that there are short (several seconds) and long time scale structures in the time profiles of TMBs. This suggests that both nonthermal and thermal radio emission occur from which we infer that both heating and acceleration take place even in extremely weak energy releases such as TMBs.

Lara, Gopalswamy and Kundu have completed their investigation of active region evolution using VLA, Nobeyama, Yohkoh/SXT data. This is is the first time a detailed comparison is made using probes that correspond to various levels in the solar atmosphere - from the transition region to high corona. Several properties of the active regions have been conformed and new results have been obtained. They found no center to limb variation of microwave emission at least over the several days period they studied.

J. Lee, White, Gopalswamy, and Kundu analyzed high resolution microwave maps of AR6615 obtained using the VLA to demonstrate the ability to identify coronal currents from their signatures in microwave images. In this new approach, the potential-field (i.e., current-free) extrapolations of the photospheric magnetic fields are compared with microwave images to locate regions where the potential extrapolation fails to predict the magnetic field strength required to explain the microwave images. The positions of the coronal currents are then compared with those of the photospheric currents obtained from the curl of the transverse fields to reveal the 3-D structure of the electric currents and its association with magnetic fields in the active region.

Lee, White, Gopalswamy, and Kundu have detected mode-conversion and depolarization of microwaves emitted from AR6615 and interpreted the observation based on the general magnetic properties of the high corona of a bipolar active region. It is suggested that the magnetic topology in a multi-spot active region changes with height depending on relative magnetic fluxes of the spots underneath, and that this topological change is responsible for the observed microwave polarization. They exploited this property to diagnose the intrinsic magnetic fluxes of strong fields at spot centers to which Babcock-type magnetograms are insensitive.

Lee, White, Gopalswamy, and Kundu are currently working with McClymont (U. of Hawaii) to bring out nonlinear force-free field extrapolation from the Stokes polarimeter data of a solar active region. A main goal of this study is to address the physical consequences of the presence of the coronal currents with use of the up-to-date extrapolation technique that takes into account nonuniform electric currents in an active region.

J.-P. Raulin, Kundu, Nitta and Raoult have reported the detection of a metric continuum burst source at the top of a coronal loop observed in soft X-rays. The continuum burst was probably a flare continuum which lasted more than 1 hour. This is the first observation of such metric continuum emission produced by energetic electrons with high spatial resolution imaging instruments in both X-rays and radio. The nonthermal radio emission appears to be associated with the rupture of a part of the loop-top and the ejection of soft X-ray plasma at the top of the coronal loop. We have also identified X-ray coronal structures in which type III emitting electron beams propagate. The metric continuum is most likely due to second-harmonic plasma emission and the electron density in the soft X-ray structure where type IIIs are observed is close to the critical plasma density derived from radio observations.

Raulin, White, Kundu, Silva, and Shibasaki have studied millimeter observations of a B5.6 solar flare. The BIMA interferometer and the Nobeyama radioheliograph observed both the impulsive and the thermal phase of the flare emission. The 3.5 millimeter maps obtained with BIMA allowed the determination of the location of the radio source and its properties at different phases of the flare evolution. Hard X-rays (BATSE) and soft X-rays (Yohkoh) were also available for this event. With the available data set it was possible to characterize the nonthermal electron distribution responsible for X-rays and microwave/millimeter emissions. The comparison of the temporal evolution of the flare emission observed in a large frequency domain, also allowed the authors to discuss the relevance of the millimeter flare emission in the context of flare models.

Kundu, Raulin and Nitta have studied the nonthermal counterpart of two-sided-loop soft X-ray jets. These jets arise in the solar corona when newly emerging magnetic flux reconnect with the ambiant horizontal magnetic field in an active region. Contrary to the anemone-type jets for which nonthermal counterpart has already been observed in the form of type III radio bursts, no similar signature has been detected in association with two-sided-loop soft X-ray jets. Despite that the same physical processes are involved in the formation of both type of jets, the difference lies in the reconnection model. The two-sided-loop soft X-ray jets are expected to be formed by hot ejected plasma along horizontal magnetic field lines where there will be no density gradient, and therefore no favorable conditions for the production of fast drifting nonthermal radio bursts.

Working with the HEIDI (High Energy Imaging Device) team at Goddard Space Flight Center, E. Schmahl has developed a method for making quantitative characterizations of bi-grid Rotating Modulation Collimators (RMCs) that are used in a Fourier Transform X-ray imager. The team applied the method to the RMCs on the HEIDI balloon payload in its preflight configuration. The results indicated the 25'' X-ray imaging optics on HEIDI are capable of achieving images near the theoretical limit and are not seriously compromised by imperfections in the grids.

Kundu and Schmahl completed a study which shows that the microwave flux from sunspots generally dominates the flux of solar active regions at certain frequencies. This makes it possible to determine the effective sunspot area from total power observations without any spatial resolution. From this study they generated a useful five-frequency proxy for the 9-year irradiance variations observed by the ACRIM experiment aboard the Solar Maximum Mission (SMM) satellite. This proxy correlates with irradiance at the 95% level.

Schmahl, Crannell (GSFC) and Trattner (Goddard Summer Student, Harvard), are investigating the extent of over resolution in solar flares using interferometers. The motivation for this proposed investigation arose from results obtained with the Owens Valley Radio Observatory Solar Array and the Very Large Array. In many cases, published microwave events appear to be over resolved, sometimes with 50% of the total power being measured with the correlated fluxes. Even the simplest event requires an additional, larger component, the flux from which is a factor of about 2 larger than the resolved component.

Nerney, Suess (MSFC) and Schmahl have used the solutions to the steady state MHD equations they found previously to show the shape and structure of the magnetic field lines as they are carried into the heliopause region by the outflowing solar wind. They have computed the magnetic reversals in the solar wind and their patterns as mapped onto the heliopause.

S. White, M. Kundu, K. Shibasaki, S. Enome (NRO), T. Sakao, T. Kosugi and T. Sakurai (NAOJ) looked for radio emission at 17 GHz from the soft X-ray transient brightenings in active regions discovered by the Soft X-ray Telescope on the Yohkoh satellite. At this frequency radio emission was detected from these brightenings, but with properties very similar to the observed soft X-rays, suggesting that it (the radio emission) was purely thermal in origin. The detection of nonthermal radio emission would suggest that these brightenings are simply mini-flares.

M. R. Kundu, N. Nitta (Lockheed), S. M. White, K. Shibasaki, S. Enome (NRO), T. Sakao, T. Kosugi and T. Sakurai (NAOJ) studied the radio emission from two flares which showed pronounced signatures of emission from both footpoints in hard X-ray images from the Yohkoh satellite. They found evidence for stronger hard X-rays at the footpoint with the weaker magnetic field, while the radio emission was stronger from the stronger-magnetic field footpoint, in line with expectations from a trap model for the coronal configuration of the flaring loop.

A. Silva (UC-Berkeley), S. White, R. P. Lin, I. de Pater (UC-Berkeley), K. Shibasaki (NRO), H. S. Hudson (U. Hawaii), and M. R. Kundu presented the first true high-resolution images of a solar flare at millimeter wavelengths. The images were made using data from the BIMA array, and demonstrated the future potential of this instrument for imaging flare studies.

Silva, White, M. Kundu and a number of collaborators published one of the most comprehensive multi-wavelength studies of a solar flare ever assembled. The soft and hard X-ray imaging, microwave and millimeter imaging, optical imaging and soft X-ray spectral information together build a portrait of a relatively small event showing many complexities, including a soft X-ray loop arching over the top of a delta sunspot and a long-range connection from the main flare site to a distant active region.

Aschwanden, Hudson (ISAS), Kosugi (NAOJ), and Schwartz (GSFC) compared for the first time an electron time-of-flight distance measured from hard X-ray timing delays using the Compton Gamma Ray Observatory (CGRO) with the geometry of a flare loop imaged in soft X-rays and hard X-rays by the Yohkoh spacecraft. For this solar flare on 1992 January 13, which became famous for Masuda's discovery of an above-the-loop-top hard X-ray source, the site of particle acceleration was found to be located about twice as high than Masuda's above-the-loop-top source, according to the electron time-of-flight measurements.

Aschwanden and Schwartz conducted theoretical calculations of the timing of hard X-ray emission, by convolving time-dependent electron injection spectra with the Bethe-Heitler bremsstrahlung cross-section and the instrumental response fucntions of BATSE/CGRO and HXRBS/SMM. These calculations enable an accurate inversion of the electron time-of-flight distance from hard X-ray time delay measurements.

Aschwanden, Wills (CfA), Hudson (ISAS), Kosugi, and Schwartz applied the measurements of electron time-of-flight distances and flare loop geometries to the 8 largest flares commonly observed with the Compton Gamma Ray Observatory (CGRO) and Yohkoh spacecraft. The main result was that the electron flight path was found to be a factor of 1.3 $\pm$ 0.2 longer than the flare loop half length.

Aschwanden, Kosugi, Hudson, Wills, and Schwartz extended the measurements of electron time-of-flight distances and flare loop geometries to all flares commonly observed with CGRO and Yohkoh and corroborated the scaling law between the electron time-of-flight path length l and the flare loop half length s, i.e. $l/s = 1.4 \pm 0.3$, suggesting that the particle acceleration source is located above the flare loop.

Aschwanden analyzed the timing of electron acceleration in DC electric fields and stochastic acceleration scenarios and could show that the resulting energy-dependent timing is not consistent with the recently discovered hard X-ray delays, which were found rather to be consistent with electron time-of-flight differences (published in AIP 374).

Aschwanden investigated whether the energy-dependent timing of $\geqslant$ 20 keV hard X-rays in solar flares could be consistent with protons, as proposed in a model by G. Simnett. However, the measured HXR time delays are fully consistent with electron time-of-flight differences and electron trapping times, and thus, rule out protons as primary generators of $\geqslant$ 20 keV HXR emission (published in ApJ Letters).

Aschwanden discusses the recently discovered hard X-ray time delays in solar flares under the aspect whether they support magnetic reconnection models, considering various problems involved in the quantitative interpretation in terms of electron time-of-flight differences, i.e. the asymmetry of conjugate magnetic footpoints, loop geometries, electron pitch angles, and magnetic field line twist (published in Bath Proc.).

5.8 Instrumentation

R. Weymann (Carnegie), S. Vogel, and H. Epps have built a reimager for the duPont 2.5 m telescope at Las Campanas Observatory in Chile. The instrument has a 25′ field of view. The reimager can be used, in collaboration with S. Veilleux, with the Maryland 70mm Fabry-Perot etalon in the collimated beam. The instrument was designed for wide-field imaging, with a particular interest in detection of faint, diffuse emission. First observations were made in April 1996. A primary goal is to measure the metagalactic ionizing flux at zero redshift. The uncertainty in this flux is a major uncertainty in interpreting neutral hydrogen observations of gas which is not optically thick in the Lyman continuum. This includes Ly-alpha clouds, whether most of the $z=0$ baryonic matter is in ionized form, and the structure and extent of HI disks. Also, a measurement of the ionizing flux would constrain models for ionization sources, including quasars, blue star-forming galaxies, and massive decaying neutrinos. The ionizing flux can be measured by observing H-alpha emission from an HI cloud which is optically thick in the Lyman continuum and which does not contain local ionizing sources. The primary target is HI 1225+01, an extended HI cloud near the Virgo cluster.

S. Vogel, in collaboration with P. Shopbell and S. Kulkarni (Caltech), has modified the Maryland-Caltech Fabry-Perot for use at the Cassegrain focus of the Palomar 200″ telescope. First observations were made in August 1996.

5.9 Other

V. Trimble has completed an investigation of the papers and citations to those papers resulting from data collected at large optical telescopes throughout the world. There are 39 such telescopes (of 2-meters or larger diameter) located in 10 countries. On average, 20 papers per year report results from each, and each paper is cited about 3.5 times per year a few years later, but the range in both quantities is more than an order of magnitude. Some correlations are no surprise; you don't learn much from a telescope at a rainy site or one that you cannot afford to maintain. Thus the Russian 6-meter is much less productive than the 2.1-meter at Kitt Peak. There were also some surprises. The most productive telescope in both papers and citations is the Anglo-Australian Telescope. Tied for second place (depending on whether you count papers or citations) are the Canada-France-Hawaii Telescope and the CTIO 4-meter. All are four meters or smaller in diameter. All draw observers from more than one country (but they have quite different total potential numbers of users), and all are rather difficult to get to for their main users, perhaps providing some self-selection of people who are used to working hard and know and love their particular favorite facilities.

Trimble is currently investigating the history of our understanding of the processes of star formation. Star formation (and solar system formation) were regarded as a legitimate, if somewhat speculative, part of astronomy through the 19th and early 20th century. Curiously, there was a period from about 1930 until shortly after World War II when most astronomers seem to have been persuaded that all stars (including the Sun, and Earth) were about 2 Gyr old, the same as the expansion time scale of the universe (as understood when Hubble's constant was 500 km/sec/Mpc) and, therefore, that stars had formed as part of the same processes in the early universe that produced galaxies. During this period, suggesting that there might be very young stars or stars currently in the process of formation was not respectable.

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