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 1996 to 30 September 1997.

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, 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 Professors A. Harris, L. G. Mundy, and J. M. Stone; Assistant Professors D. Hamilton, E. Ostriker, J. Wang, and S. Veilleux; Associate Research Scientists K. Arnaud, M. Aschwanden, C. C. Goodrich, R. Lopez, L. McFadden, G. Milikh, E. Schmahl, S. Sharma and S. White; Assistant Research Scientists S. Balachandran and T. Golla; Research Associates W. Chen, L. Cheng, F. Finkbeiner, D. Chornay, O. Colombo, K. Fast, K. Gendreau, E. Grayzeck, M. Houdashelt, U. Hwang, N. Lame, J. Lee, C. Lisse, T. Livengood, M. Lowenstein, G. Madjeski, J. Morgan, F. Porter, A. Raugh, I. Richardson, K. Roettiger, P. Safier, C. Scharf, P. Teuben and D. Wellnitz; Instructors G. Deming and D. Theison; and Associate Director J. D. Trasco. M. Bautista, S. Dinyes, P. Ferruit, K. Issak, T. Livengood, C. Mundell, N. Pereyra, K. Rauch, J. Staguhn, M. Stark, and M. Wolfire were appointed as Research Associates. P. Chatuverdi, H. Falcke, N. Gopalswamy, F. Lemoine, E. Pavlis, F. Robinson, and R. Schulz completed short term appointments and left the department. Ph.D. degrees were awarded to J. Braatz, E. Colbert, M. Regan, and M. Thornley. An M.S. degree was awarded to L. Woodney.

V. Trimble was elected vice president of the American Astronomical Society for the term 1997-2000. She will continue to serve as Vice President of the International Astronomical Union for the same term.

3. MEETINGS

The series of Washington Area Astronomers meetings initiated in September 1981 has continued. The Fall 1996 meeting was held at the the NASA-Goddard Space Flight Center and the Spring 1997 meeting was held at the University of Maryland. Typical attendance has been 100 persons per meeting. The Maryland-Goddard Astrophysics series which started in Fall 1990 has continued. The most recent meeting ''Accretion Processes in Astrophysical Systems'' was held at the University of Maryland in October 1997. Total attendance was approximately 200 persons.

The second Maryland-Goddard Interaction Day with the objective of promoting further interaction between the researchers at UMCP and GSFC was held on February 14, 1997. This year's theme was Sun-Earth Connection.

A new program within the University's College Park Scholars Program, a residential, living- learning program for academically talented students, was initiated this year from the Astronomy Department and the College of Computer, Mathematical and Physical Sciences. The program in Science, Discovery and the Universe, is headed by faculty director, Lucy McFadden. Approximately 50 students primarily interested in the physical sciences are currently admitted in this program.

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 ten radio-dish millimeter array located in Hat Creek, California. The lab is part of the Astronomy Department and has associated with it five faculty members, one research scientist, three scientific staff, four postdoctoral fellows, and five graduate students. The faculty are S. Vogel (director), W. Erickson (emeritus), A. Harris, M. Kundu, and L. Mundy. The Associate Research Scientist is S. White. Postdoctoral fellows include P. Safier, K. Isaak, M. Choi, and J. Staguhn. The scientific staff includes M. Pound, J. Morgan,and P. Teuben. Graduate students doing Ph.D. degree work with the array include S. Donaldson, C. Lee, L. Looney, K. Sheth, and L. Woodney. M. Regan and M. Thornley completed their Ph.D. theses and assumed a Hubble Fellowship at DTM and a Humboldt Fellowship at Garching, 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 10 antennas. 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 10-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).

Expansion of the BIMA array baselines to maximum lengths of 1.4 km was completed in the Winter of 1996-97. The BIMA array is now the highest resolution millimeter wavelength array in the world. L. Mundy and L. Looney played a principle role in the expansion, designing and building the optical fiber communication links and variable delay system. The system was operated in December and January yielding excellent results; one-half arcsecond resolution images of more than a dozen young stellar systems were obtained. As a next step in expanding the array, another antenna station is being built this year at a distance of 1.2 km from the center of the main array. When completed, the maximum baseline on the array will be nearly 2 km and the spatial resolution at 2.7mm wavelength will be approximately 0.3 arcseconds.

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) is being operated in the department under the direction of M. F. A'Hearn and E. Grayzeck. A. Raugh and D. Winterfeld provide programming support. 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. Three major sets of data have now been reviewed and have been ingested into the PDS: the Comet Halley CD-ROM Archive of 24 disks produced by the International Halley Watch with SBN assistance, data sets of derived asteroid properties as well as fundamental data, and IRAS data determined to be useful for studying interplanetary dust. Most data are available through the SBN computer system interface that allows simple browsing and data requests; SBN also has a home page on WWW. Sub-nodes are actively involved in archiving spacecraft data from various missions. These data sets include data from the group of spacecraft that encountered comet Halley in 1986 and the Giotto Extended Mission to comet Grigg-Skjellerup in 1992, the Galileo experiments that collected data at the asteroid Gaspra encounter, and interplanetary dust measurements from Ulysses and Galileo. Work also continues on certain ground-based data for asteroids which supersedes the Asteroids II database and preserving IRAS data in forms suitable for investigating solar system sources. To support the customized GEM archive for comet Grigg-Skjellerup, SBN has developed techniques for CD Write Once production using networked hardware. The PDS-SBN has played a major part in the campaign to study the impact of comet Shoemaker-Levy 9 into Jupiter. Its pivotal role as communications hub during impact week contributed to the success of observing campaigns literally around the globe. The node continues to operate an electronic bulletin board which serves as an official point of contact for release of announcements by funding agencies, facilities, and scientists. PDS has also produced a CD-ROM archive of data acquired during this event.

5. RESEARCH

5.1 Extragalactic Astronomy

G. Welch, L. Sage, and G. Mitchell continue to study the molecular gas content of the dwarf companions of M31. They have found molecular gas in two (NGC 185 and NGC 205), but there is apparently no gas in either NGC 147 or M32, which are comparable in overall mass and morphological type. In addition, they have begun an unbiased search for molecular and atomic gas in SO galaxies, using a distance-limited sample.

Results from a multi-wavelength study of the prototypical barred spiral NGC 5383 by K. Sheth, M. Regan, S. Vogel, P. Teuben and J. Stone were presented at the winter AAS meeting. An analysis of the gas kinematics using the CO data obtained with the BIMA interferometer corroborated the predictions of hydrodynamic simulations by Regan and by Piner *et al.*, in particular the spray from the dust lane - ILR contact point. Comparison of the CO distribution with further numerical modeling shows the need for the inclusion of star formation in any realistic model of gas flow in a barred potential. Additionally, a remarkable correlation, better than has been observed in any other barred galaxy, is observed between the CO distribution and dust extinction morphology which may be a consequence of the lower star formation rate in NGC 5383. K. Sheth and M. Regan are also studying CO emission in several barred galaxies to determine the kinematics of gas flow in barred potentials.

CO emission from giant molecular clouds in the northern spiral arm of the Andromeda (M31) galaxy was observed with the BIMA array by K. Sheth, S. Vogel and C. Wilson (McMaster). Contrary to expectations, the region did not contain a single CO-bright GMC. The GMCs which were identifiable were far fewer than expected with low fluxes (barely above the noise) and small linewidths. These results are quite contradictory to those previously published for M31 GMCs and in stark contrast to the GMC population in the other nearby spiral galaxy M33. A more sensitive survey of a larger area of the spiral arm in M31 is underway.

S. Vogel, S. Veilleux, and R. Weymann (Carnegie Observatories) are continuing their collaboration to detect and measure the metagalactic ionizing flux at zero redshift using their newly constructed reimager with an FP system at the Las Campanas Dupont 2.5 meter telescope.

M. Regan has completed 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.

M. Thornley and L. Mundy are continuing to collaborate on a series of papers on the gas properties and dynamics of flocculent galaxies. Two papers appeared this year, one on NGC 5055 and the other on NGC 4414 (Thornley and Mundy 1997). The central results of these papers are as follows. Many flocculent galaxies show organized structures on scales larger than expected for stochastic star formation. In the case of NGC 5055, there is kinematic evidence that these structure are organized by weak spiral density waves. In general, we argue that flocculent galaxies should be viewed as disk galaxies with weak density waves and they represent the weak end density wave activity with grand design spirals at the strong end of the range. The interstellar medium in flocculent galaxies also shows strong similarities to other types of spiral galaxies. In particular, giant molecular clouds and giant molecular cloud complexes are present in the disks of flocculent galaxies.

In collaboration with T. Storchi-Bergmann (UFRGS, Brazil), L. Binette (ESO) and J. S. Mulchaey (CIW), Wilson has obtained high signal to noise optical spectra of extended, high excitation nebulosities reaching several kiloparsecs from the nuclei of five Seyfert and narrow-line radio galaxies. It is found that the conventional description of these photoionized gases - radiation-bounded (i.e. optically thick) clouds with a range of ionization parameter (U) - is unable to account for the line ratios seen. The authors propose instead that two populations of ionized clouds contribute to the line emission: a matter-bounded component responsible for most of the He II and high excitation forbidden line emission and a radiation-bounded component emitting low-to-intermediate excitation lines. component emitting low-to-intermediate excitation lines. A new sequence of photoionization calculations is thereby obtained (using the code MAPPINGS) by varying $A_{R/M}$, which is defined as the solid angle ratio occupied by the radiation-bounded component relative to the matter-bounded component. In various line ratio diagrams, the $A_{R/M}$–sequence is compared to the traditional single component U–sequence. The main success of the model is that it provides a natural explanation to the newly found correlations between the $He^{+2}/H\beta$ ratio and the [OII]/[NeV], [OII]/[OIII] and [SII]/Hα ratios. The U–sequence cannot account for these. Furthermore, the $A_{R/M}$ sequence produces much stronger high excitation lines of [NeV] and CIV $\lambda\lambda$1549 than the U–sequence, in accordance with observations.

Wilson, Storchi-Bergmann and Binette have also obtained measurements of the electron temperature at about a dozen locations in the extended emission-line regions of active galaxies. Temperatures ($T_{[OIII]}$ and $T_{[NII]}$) have been determined from both the I([OIII]λ4363)ﬁ([OIII]λ5007) and I([NII]λ5755)/I[NII]λ6583) ratios. There is a strong trend for $T_{[OIII]}$ to be higher than $T_{[NII]}$, with the difference typically being $\approx$ 5,000K. The measured values of $T_{[OIII]}$ and the differences between $T_{[OIII]}$ and $T_{[NII]}$ are very similar to those found in Galactic planetary nebulae. It is argued that the dominant form of energy input to the clouds is photoionization, but detailed modelling indicates that the temperature difference is too large to be accounted for in terms of photoionization of radiation-bounded clouds. It is proposed instead that both matter- and radiation-bounded clouds are present in the extended emission-line regions, with most of the [OIII] emission originating from a hot zone in the matter-bounded clouds and essentially all of the [NII] from the radiation–bounded clouds.

In collaboration with J. A. Acosta-Pulido (IAC), B. Vila-Vilaró (Nobeyama Radio Observatory), I. Pérez-Fournon (IAC) and Z. I. Tsvetanov (JHU), Wilson has perfomed a detailed spectral study of the extended emission-line regions of the Seyfert 2 galaxy NGC 5252. The line ratios favor a larger fraction of matter-bounded (optically thin) clouds in the extended gas than in the nucleus or an additional excitation mechanism in the nucleus, such as interaction with the radio jets. Another result favoring a contiribution from matter-bounded clouds in the extended gas is a correlation between the excitation of the gas and the emission-line brightness. A broad Hα component (FWHM $\approx$ 2,500 km s^{-1}) is detected in the nucleus. The results of the study suggest that NGC 5252 contains a partially hidden broad-line region and a more luminous nucleus than is directly observed.

C. Simpson (JPL), J. S. Mulchaey (CIW), Wilson, M. J. Ward (U. Leicester) and A. Alonso-Herrero (Madrid) have reported an optical emission-line and near infrared continuum study of the Seyfert 2 galaxy Mkn 348. The optical images reveal a well-defined region of highly ionized gas aligned approximately north-south (i.e. along the radio axis) possibly in the form of a bi-cone. In addition, there is a red linear structure in the infrared continuum, oriented perpendicular to this axis and approximately 1 kpc in extent. This latter structure may be emission from hot dust in the outer parts of the ''dusty torus'' postulated in schemes to unify the two types of Seyfert galaxy.

J. A. Morse (CASA), J. C. Raymond (CFA) and Wilson have investigated the viability of fast, photoionizing shocks as an ionization mechanism in active galaxies. They discuss how photoionizing shocks may help to resolve the UV photon deficit problem in some objects because a significant fraction of the ionizing radiation is emitted as line emission in the EUV. Also discussed are the implications of the strengths of collisionally excited UV lines, the weakness of Ca II lines, and the high electron temperatures derived from the [O III]($\lambda 4959+\lambda 5007$)/$\lambda 4363$ ratio for the ionization mechanism.

T. M. Heckman (JHU), R. Gonzalez-Delgado (STScI), C. Leitherer (STScI), G. R. Meurer (JHU), J. H. Krolik (JHU) A. Koratkar (STScI), A. Kinney (STScI) and Wilson have presented and discussed HST images and a UV spectrum plus new ground-based near-UV through near-IR spectra of the luminous type 2 Seyfert galaxy Mkn 477. The data provide direct evidence that the observed UV through near IR continuum in the nucleus of this galaxy is dominated by light from a compact (few hundred pc), dusty starburst. For example, in the space-UV, strong NVλ1240 and SiIVλ1400 stellar wind lines and other weak photospheric lines from hot stars are detected. Detailed comparison of the data to models implies that the starburst has an age of 6 Myr, was of short duration, has solar or higher metallicity and a bolometric luminosity of $\approx 3\times 10^{10}$ to 10^{11} $L_\odot$. The starburst must make a significant contribution to the overall energetics of Mkn 477, even though optical spectropolarimetry demonstrates that a powerful 'hidden' type 1 Seyfert nucleus is also present.

Recent measurements of the Circinus galaxy with ISO by Moorwood *et al.* (1996) have confirmed the extremely high excitation of the emission-line spectrum in this active galaxy. L. Binette, Wilson, A. Raga (UNAM) and T Storchi-Bergmann have interpreted these results with the help of new photoionization calculations in which all the zones of high excitation coexist within the internal structure of small matter-bounded clouds. A strong UV bump is not required to explain the line ratios in this picture. The calculations consider the effects of radiation pressure exerted by photoelectric absorption which become very important at the high ionization parameters required by the line ratios. It is proposed that the radiation pressure generates a strong density gradient within the photoionized structure and is responsible for accelerating the matter-bounded gas, explaining the systematic blueshift observed for the coronal lines.

G. A. Bower (NOAO), T. M. Heckman (JHU), Wilson and D. O. Richstone (U. Michigan) have obtained optical images of the nucleus of the nearby radio galaxy M84 (NGC 4374=3C272.1) with the Wide Field/Planetary Camera 2 (WFPC2) aboard the Hubble Space Telescope (HST). These high-resolution images reveal that the Hα+[N II] emission has three components, namely a nuclear gas disk, an 'ionization cone', and outer filaments. The major axis of the gas disk aligns with that of the dust lanes on scales of 50 pc. The radio jet and 'ionization cone' are found to align approximately perpendicular to the gas disk.

Wilson, in collaboration with Storchi-Bergmann, M. Eracleous (UCB), M. T. Ruiz (U. Chile), M. Livio (STScI) and A. V. Filippenko (UCB), has continued a study of the evolution of the broad, double-peaked Balmer lines in the nucleus of the LINER galaxy NGC 1097. When originally discovered in 1991, the red peak of Hα was stronger than the blue, while by 1994 the Hα profile had become almost symmetric. A new spectrum, taken in 1996, shows that the profile of the Balmer lines is now such that the blue peak is stronger than the red, opposite to the asymmetry observed in 1991. Various models are considered for the observed behavior, all assuming the emission lines originate in an accretion disk. A model involving a precessing, planar, elliptical accretion ring provides an acceptable fit to the line profiles. We also consider the possibility that the line profile evolution results from a precessing warp in the disk, induced by irradiation from the center, and show that the expected range of radii and precession time scales are consistent with the observations.

Stone and postdoctoral research associate K. Roettiger, in collaboration with R. Mushotzky (GSFC), have studied the hydrodynamics of an off-axis merger of two clusters of galaxies using numerical simulations. Aside from providing insight into the merger process itself, the simulations also have been applied to accounting for the peculiar X-ray properties of the cluster Abell 754. The study of the merger process is continuing by considering whether weak magnetic fields can be amplified by the merger.

In collaboration with R. W. Goodrich (Keck) and G. J. Hill (U. Texas), Veilleux recently 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 over the past four years. 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 Konigl 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 (Univ. of Hawaii), and D. C. Kim (IPAC/Caltech) have pursued their survey of ultraluminous ($\log[L_{ir}/L_{\odot}] > 12$) IRAS galaxies. Preliminary analysis of the optical spectra suggests that the fraction of optically classified Seyfert galaxies increases dramatically above $\log[L_{ir}/L_{\odot}]=12.3$. Nearly half of the galaxies with $\log[L_{ir}/L_{\odot}] > 12.3$ present Seyfert characteristics. New, recently published 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 25 μm/60 μm IRAS colors to harbor obscured broad-line regions in the near-infrared and to have large Paα-to-infrared luminosity ratios. These results suggest that the screen of dust in the warm Seyfert 2 galaxies is optically thin at 2 μm. 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.

In an effort to evaluate the impact of nuclear activity in galaxies, Veilleux, G. N. Cecil (Univ. North Carolina), J. Bland-Hawthorn (AAO), and R. B. Tully (Univ. of Hawaii) are carrying out detailed Fabry-Perot studies of 20 nearby galaxies. Results on the Seyfert galaxies NGC 4258 and Circinus were recently published. A summary of these results also appeared in a recent Scientific American article. 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.

Wolfire is continuing his collaborations with M. Greenhouse (GSFC) and M. Laming (NRL) on the IR coronal line emission from active galactic nuclei. In Greenhouse *et al.* (1977; submitted) they reported line fluxes from NGC 1068, NGC 4151, and NGC 5506. In contrast to the usual assumption that transitions with a high critical density show broad line profiles, they found that in both NGC 1068 and NGC 4151 the transitions with the highest critical density have the narrowest line profiles. With Fischer *et al.* (1996) Wolfire analyzed the ISO LWS spectrum of the colliding galaxies NGC 4038/39. They found significant emission arising from photodissociated gas consistent with moderate starburst galaxies.

5.2 Galactic Astronomy

Wilson and K. W. Weiler (NRL) have described a procedure for measuring the contribution of relativistic positrons to radio synchrotron radiation. The method relies on the fact that synchrotron radiation from particles of one sign (e.g. electrons) is circularly polarized by a small but measurable amount. If, on the other hand, there are equal numbers of relativistic positrons and electrons, the net circular polarization is zero. The method is illustrated through high accuracy mapping of the circular polarization of the Crab Nebula at 610 MHz. No significant circular polarization was detected: a very conservative limit is $< 0.05\%$, and a more realistic one $< 0.03\%$. This upper limit on the degree of circular polarization is comparable to or below that expected if only electrons radiate. Various explanations are discussed, including the possibility that relativistic positrons are present in the Crab Nebula.

L. Cheng and M. Leventhal participated as major members in the campaign of mapping the inner Galactic 511 keV positron/electron emission led by Bill Purcell of Northwestern University. Although this annihilation signal has been known for more than 20 years, more knowledge of the spatial distribution of the Galactic Center (GC) 511 keV line emission is needed to address its origin. The Oriented Scintillation Spectrometer Experiment (OSSE) (field of view: $3.8° \times 11.4°$ FWHM) on the Compton Gamma-Ray Observatory (CGRO) has completed numerous observations of the GC and Galactic plane regions. These data were combined with data from earlier wide field of view instruments to make maps of the 511 keV line distribution. The maps revealed, in addition to the previously expected GC and Galactic plane component, a surprising additional component extending approximately 10° above the GC.

Collaborating with D. Smith (UC Berkeley), G. Fishman (NASA-MSFC), and J. Tueller and N. Gehrels (NASA-GSFC), Cheng and Leventhal have finished an all-sky search for bright, transient emission lines from 300 to 550 KeV in more than 2 years (Dec 1993 and Mar 1996) of data from the Burst And Transient Source Experiment (BATSE) on the CGRO. No convincing transient has been found in the search. This result, along with a similar earlier search, calls the previous discoveries of such transients into question.

Cheng, Leventhal and Tueller have analyzed data from two 1995 Gamma-Ray Imaging Spectrometer (GRIS) balloon drift scan flights, in which the GC and Galactic plane at $l=240°$ passed through the field-of-view of GRIS. A GC 511 keV line flux that reasonably agrees with results from other instruments has been obtained. Another 511 keV source was found from the analysis, though the position of this source cannot be well determined by the data. They have been approved to use OSSE to make deep scan observations on the source region to better understand the nature of this source.

Cheng, Leventhal, Tueller and J. Naya (NASA-GSFC) have been working on an atmospheric 511 keV production model. Atmospheric 511 keV photons are produced by the annihilation of positrons, which are generated in the hadronic and electro-magnetic cascades initiated by cosmic particles injected from the top of the atmosphere. They used GEANT 3, the most popular Monte Carlo simulation package in high energy physics. The Monte Carlo atmospheric 511 keV production function agrees well with the GRIS data.

M. Isenberg, D. Q. Lamb, and J. C. L. Wang have concluded a study of how cyclotron lines form in a radiation-driven relativistic outflow. They find that narrow features for both the fundamental and higher harmonics are possible because line formation occurs primarily near the base of the outflow. The model also predicts single-peaked emission-like features which do not occur in static line forming regions. This work may be applied to Galactic halo gamma-ray burst models and possibly to the soft-gamma repeaters.

Wolfire along with collaborators D. Hollenbach (NASA/Ames), A.G.G.M. Tielens (NASA/Ames) and C. McKee (U. C. Berkeley) continued their work on the thermal phases of the Galactic interstellar medium. They calculated phase diagrams (thermal pressure P versus gas density n) for Galactic radii between 3 and 18 kpc. These were constructed by solving simultaneously for the equilibrium chemical abundances and gas temperature. The calculations were carried out in a manner similar to that of Wolfire *et al.* (1995), who constructed phases diagrams for the local medium, except that this new work accounts for the differences in physical parameters with Galactic radii. They found that thermal processes allow a multiphase equilibrium in the Galactic disk between 3 kpc and 18 kpc. The mean thermal pressure which is required ranges from about $P/k \sim 11{,}000$ K cm^{-3} at 3 kpc to $P/k \sim 1{,}000$ K cm^{-3} at 18 kpc.

5.3 Stellar Astronomy

Using data from the European Hipparcos Astrometric Satellite, V. Trimble and A. Kundu have completed analysis of the data pertaining to R Coronae Borealis variables and concluded that these evolved, hydrogen poor stars must include two rather different populations in absolute brightness, kinematics, or both, only one of which can be thick disk or bulge stars with $M_v = -4.5$ to -5.5. They have partly completed consideration of six other classes of stars included in the early-release data. Some mild surprises include the relative faintness of nova-like variable AE Aqr, the main sequence nature of one supposed FK Comae (rapidly rotating giant) star, and discordance in proper motion between T Tauri stars studied from the ground and the same stars seen by Hipparcos.

J. C. L. Wang and R. S. Sutherland (ANU) are studying low luminosity spherical accretion onto neutron stars accounting for the nonlinear coupling between accretion dynamics and nonequilibrium atomic processes. Using black body ionizing spectra, they find that steady state accretion is generally not possible owing to strong photoionization heating. They are now studying the effect of varying the ionizing spectra. This work has important implications for the detectability of old neutron stars accreting from interstellar gas.

With M. Isenberg and D. Q. Lamb, Wang has concluded a study of how line forming region geometry affects cyclotron resonant scattering lines. Their study shows that line shoulders accompanying the cyclotron fundamental are generic for moderately thick line forming regions ($\tau_{line} < \sim 10^3$). Absence of such shoulders in observed X-ray pulsar spectra suggests either line formation in very thick media on the stellar surface or in a radiatively supported layer of moderate depth in the magnetosphere.

Wang concludes from a study of RX J0720.4-3125, an unidentified soft X-ray source with an 8.39 sec spin period, that it is consistent with an isolated old ($\sim 10^9$ yrs) neutron star accreting from the ISM. If so, then spontaneous magnetic field decay must have occurred unless the star was born with both a long period ($> \sim 0.5$ sec) *and* a weak field ($< \sim 10^{10}$ G). The required long ($\geqslant 10^7$ yr) decay timescale rules out the standard picture of exponential decay over a few million years.

Cavallo (graduate student), A.Sweigart (GSFC) and Bell have studied in detail the formation of the elements C, N, O, Na, Mg, and Al around the hydrogen-burning shell (H shell) of globular cluster red giant stars. This is done by incorporating four stellar evolutionary sequences of different metallicities with a nuclear reaction network that can be varied to allow for the uncertainties in some reaction rates. This approach allows for the variation in the temperature and density around the H shell as well as the change in the structure of the star with increasing evolution.

The results show overlapping regions above the H shell in which C and then O are separately depleted. In the O-depleted zone, which is closer to the H shell than the C-depleted zone, Na and Al are produced from Ne and Mg respectively. These results are qualitatively consistent with the observations in that they predict a decrease in C and O and an increase in N, Na, and Al if non-canonical mixing were introduced to a depth near the H shell. Since the reaction rates are very temperature dependent, the variations are sensitive to the environment around the H shell which changes with evolution and is different for different metallicities. The results are consistent with the observations in that they show that the Na and Al production increases with increasing evolution and decreasing metallicity. The C, N, and O variations persist at all metallicities and evolutionary states, also in agreement with observations.

Studies of the ^{12}C/^{13}C and ^{16}O/^{17}O ratios show that the C isotopes are in the equilibrium ratio near 4 above the H shell, as seen by several observers, and the as-yet-unknown O ratio is predicted to be between 50 and 150, depending on the evolutionary status and metallicity of the star.

They are presently unable to model the large ^{24}Mg depletions seen by Shetrone (1996) in a small sample of M13 giants. There appears to be no canonical method by which this istope can be reduced, even when taking into account the latitude afforded by the uncertainty in the NeNa- and MgAl-cycle reaction rates. ^{24}Mg remains abundant, in part by formation from Na created in the NeNa cycle. This is much greater when the newer rates of El Eid and Champagne (1995) are used, instead of the more widely-used, but less certain, rates of Caughlin and Fowler (1988).

R. D. Cannon and R. A. Stathakis (AAO), Bell, F. W. Croke (Crete) and J. E. Hesser (DAO) have used FOCAP multi-object fibre optic system on the AAT to obtain spectra for a sample of more than a hundred faint stars in the globular cluster 47 Tuc (NGC 104), from the base of the giant branch to about a magnitude below the main sequence turnoff. The spectra cover the UV and the blue bands of CN and the G-band of CH. Variations in CN band strength are apparent at all magnitude levels.

The CN and CH band strengths are anticorrelated. Furthermore, the abundance pattern appears to be bi-modal, as suspected previously for much smaller samples of faint stars and similar to what was first found among the bright red giants. The main sequence stars can be divided into two approximately equal groups, one having N enhanced by a factor of ~ 7 and C depleted by ~ 0.6 relative to the other, similar to what is inferred for the red giants. No significant variations are seen in calcium abundance, consistent with the evidence from the narrowness of the giant branch that there is very little spread in the abundance of iron and other heavy elements.

The CN and CH data indicate that the stellar atmospheres contain material which has been processed through the CNO cycle but not through more advanced stages of nucleosynthesis. In the case of the evolved red giants, this could be due to the convective dredge-up of processed material. However, the standard models for low mass main sequence stars do not have deep convective envelopes, nor is there significant CNO-cycle nucleosynthesis in their interiors. Thus the main sequence C and N variations are presumably either in some sense primordial or due to a polluation mechanism. The best explanation at the moment appears to be some sort of self-enrichment process within the cluster, although no single simple explanation seems capable of explaining all of the observations. Whatever the mechanism, it seems probable that these abundance data contain important clues about the formation and early evolution of globular clusters.

Harris (McMaster), Bell and collaborators have used the WFPC2 camera on HST to obtain photometry of the low-metallicity ([Fe/H]=-2.14), outer-halo globular cluster NGC 2419. The color-magnitude diagram in (V, V -I) reaches $V_{lim} \simeq 27.8$, clearly delineating the subgiant and turnoff region about three magnitudes of the unevolved main sequence. A differential fit of the NGC 2419 CMD to that of the similarity metal-poor 'standard' cluster M92 shows that they have virtually identical principal sequences and thus the same age to within 1 Gyr. Previously published studies of many other low-metallicity globular clusters throughout the Milky Way halo show that they possess this same age to within the ~ 1 Gyr precision of measurement. The addition of the remote-halo object NGC 2419 to this list leads us to conclude that the earliest star (or globular cluster) formation began at essentially the same time everywhere in the Galactic halo throughout a region now almost 200 kpc in diameter. Thus for the metal- poorest clusters in the halo there is no detectable age gradient with Galactocentric distance.

Houdashelt, Bell and A. V. Sweigart (GSFC) improved their population synthesis models of elliptical galaxies. A new set of isochrones were calculated from Sweigart's evolutionary tracks and used to construct synthetic spectra of stellar populations having ages of 4–20 Gyr and metallicities Z=0.006, Z=0.01716 and Z=0.03. Synthetic spectra of field stars of known effective temperature, surface gravity and metallicity were used to derive the color transformations needed to put the colors measured from the synthetic spectra onto the observers' photometric systems. The newly transformed colors of the population synthesis models indicated that single, coeval, single-metallicity populations do not reproduce the colors of early-type galaxies. For this reason, work is proceeding to examine whether the addition of blue horizontal branch stars and/or decreased mass loss along the asymptotic giant branch could resolve these color discrepancies. In addition, the treatment of TiO absorption in the synthetic spectra of M giants is being refined to more realistically match the observed relationship between effective temperature and spectral type.

5.4 Interstellar Medium and Star Formation

E. Ostriker, in collaboration with J. Stone and C. Gammie (CfA), is continuing to model the evolution of dynamics and structure in star-forming molecular clouds using numerical magnetohydrodynamics in 2.5 and 3 dimensions. These simulations survey observed molecular cloud conditions by varying the amplitude of turbulence, the degree of self-gravity, and the magnitude of the mean magnetic pressure relative to thermal pressure. Results obtained indicate that the overall dynamical evolution of clouds is most sensitive to their mean magnetization, secondarily sensitive to their mass, and least sensitive to their initial turbulence. Unmagnetized model clouds, even with substantial initial turbulence, collapse after about 5 million years at typical molecular cloud densities. Clouds with moderate magnetization ($\sim 15\mu$ G) can survive for more than fifteen million years as long as their total mass does not exceed the ''magnetic critical mass.'' These results, together with results regarding the distribution of densities in model clouds of varying magnetic field strengths, support the view that the magnetic processes are crucial to maintaining the ''inefficient'' star-formation process which prevails in the present-day Galaxy.

Ostriker has investigated the acceleration and collimation of winds from accretion disks in Keplerian rotation, by the action of large scale magnetic fields. She has obtained a two-parameter semi-analytic family of wind solutions in which the asymptotic constant-density and constant-velocity surfaces are concentric cylinders. The wind collimation is achieved self-consistently by magnetic hoop stresses. These wind solutions show that it is difficult to achieve high-speed outflow and strong forward velocity direction in a self-collimated flow. This suggests that either (a) the collimation of observed ionized protostellar jets is primarily in density, not in both density and velocity, or (b) the observed protostellar jets are surrounded by a slow-moving wind which enforces the jet collimation. Ostriker has also joined faculty Vogel and Stone and student Nagar in modelling the outflow from HH111. They show that the molecular kinematics of this source are consistent with acceleration by a wide-angle protostellar wind.

With P. Teuben and graduate student J. Marshall, Ostriker has been investigating the dynamics of present-day star-forming clusters with properties similar to the extensively-observed Orion Nebula cluster. Their results, based on direct n-body simulations, have shown that the observed mass segregation and central density concentration could not have been achieved solely from two-body relaxation in a system of the presently-observed ONC mass within the known 1-2 million-year age of the cluster. This argues either for (a) an IMF which is position dependent within the cluster, or (b) significant changes in the cluster properties such as mass and density over its lifetime; further investigations will focus on the latter possibility.

M. Choi has used the BIMA millimeter array and the CSO submillimeter telescope to study the Herbig-Haro object HH 1-2. The study focused on the driving source for the outflow, and revealed a high-density, flattened core. In other work, he has completed a survey of HCO+ emission from ten Class 0 protostellar objects using the BIMA array. This provided unique information on the protostellar collapse mechanism. He is also observing several high-velocity outflows from young stellar objects using the CSO.

P. Safier has critically examined the physical basis for current magnetic-accretion models for classical T-Tauri stars. He argues that there is little observational evidence for the strong, dipolar stellar magnetic fields required by these models; also the steady-state assumed by these models is not supported by the models.

P. Safier has completed his study of the BD+41 40 star-forming region with the BIMA millimeter-array. The images reveal the structure of the associated molecular cloud, and confirm the existence of a outflow source associated with the complex. P. Safier and J. Lauroesch (NWU) are using the BIMA array at cm wavelengths in an effort to detect hydrogen recombination lines from quasars.

N. Nagar, S. Vogel, J. Stone, and E. Ostriker observed CO emission from the HH 111 optical jet with the BIMA array. Both the CO kinematics and morphology indicate a striking hollow tubular structure surrounding the optical jet. The velocity component parallel to the jet increases with distance from the central star more rapidly than the component perpendicular to the jet. The data place constraints on jet-driven models for molecular outflows. The kinematics and structure are consistent with recent wide-angle, radial-wind models.

With P. Hofner (U zu Koln), L. Mundy and S. Vogel (UMD), 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.

Xie has investigated the scaling laws and Alfvenic magnetic fluctuations in molecular clouds. Under the assumption that the observed turbulent motions in molecular clouds are Afvenic waves or turbulence, he emphasizes that Doppler broadening of line profiles directly measure the velocity amplitude of the waves. Assuming equipartition, he proposes that the observed scaling laws imply a roughly scale-independent fluctuating magnetic field, which might be understood as a result of strong wave-wave interactions and subsequent energy cascade.

T. Xie, L. Mundy, S. Vogel, and P. Hofner have been working on confinement of Ultracompact (UC) H II regions. It has been proposed recently that the small size and long lifetime of ultracompact (UC) H II regions could be due to pressure confinement if the thermal pressure of the ambient gas is higher than previous estimates. They point out that confinement by thermal pressure alone implies emission measures in excess of observed values. They show that turbulent pressure, inferred from observed nonthermal velocities, is sufficient to confine UC H II regions and explain their longevity. They predict an anticorrelation between the size of UC H II regions and the velocity dispersion of the ambient neutral gas and show that it is consistent with existing observations.

T. Xie and collaborators (Xie *et al.* 1996) proposed a new model for the confinement of ultra-compact HII regions (UCHII's). They propose that turbulence associated with the non-thermal molecular line widths in the cores of clouds acts as a pressure which balances the thermal overpressure in the ionized gas and keeps the HII regions from freely expanding into the molecular material. The model predicts a correlation between molecular line width and UCHII pressure which is consistent with the limited data currently available. Additional observations can provide further tests of the model.

S. Watt has begun studying the dust and gas distribution in and around ultra-compact HII regions with L. Mundy. The objectives of this work are to characterize the early stages of massive star formation and to understand the relationship between UCHII's, hot cores, and star formation. The complexity of this relationship is illustrated by the results of paper by G. Blake (Caltech) L. Mundy and collaborators in which it is argued that the Orion hot core is externally heated. Much of the spectacular molecular emission which characterizes the Orion hot core, and identifies hot cores in general, is argued to be arising from a layer of material being ablated from the molecular core by nearby star formation.

J. Stone's research efforts are primarily concerned with hydrodynamic and magnetohydrodynamic (MHD) studies of the ISM and star formation. Stone and graduate student K. Miller are studying the interaction of a magnetized accretion disk with the magnetosphere of the central object. In the first phase of the study, two-dimensional numerical MHD simulations have been performed to study accretion onto aligned rotators with dipole fields. Using a variety of initial field strengths, geometries, and resistivities in the disk, rapid accretion which crushes the magnetosphere to the stellar surface generally occurs. The study is being continued using three-dimensional MHD simulations of accretion disks which span many vertical scale heights to study the effect of the Balbus-Hawley instability in generating strong magnetic field in the corona above the disk through dynamo action, and to study the interaction of this field with possible stellar magnetospheric fields.

Stone and physics graduate student T. Fleming are beginning a study of the effect of microphysical resistivity on the saturation of the Balbus-Hawley instability in weakly magnetized accretion disks.

Stone has studied the nonlinear evolution and saturation of the Wardle instability in C-type MHD shocks in weakly ionized regions of the ISM. The instability saturates as thin sheets of dense gas orientated in the direction of shock propagation which anchor the field. In collaboration with D. Neufeld (JHU), Stone has computed the temperature and predicted the emission properties of unstable C-type shocks to compare to observed systems. Surprisingly, the instability has little effect on the emission properties of such shocks, primarily because most of the emission occurs from gas which is upstream of the strongest effects of the instability.

Stone, D. Proga, and J. Drew (Imperial College London) have studied the multi-dimensional structure and time-dependent evolution of radiation driven winds from luiminous accretion disks. The winds are produced by radiation pressure on Doppler-shifted spectral lines, similar to the winds from hot stars. By adopting numerical techniques, no assumptions about the geometry or time-evolution of the wind are required. In the case that the luminosity of the disk dominates that from the central star, the winds are intrinsically unsteady because the streamlines near the disk are vertical, and the vertical component of gravity increases linearly with height so that it eventually chokes the wind. On the other hand, when the luminosity of the central star dominates that of the disk, the streamlines are inclined from the vertical in a way so that gravity is decreasing, and the flow is found to be steady. The two-dimensional geometry, terminal velocity, and mass loss rate in the wind are found to be remarkably similar to the values inferred from observations of CV systems, and outflows from massive young stellar objects, strengthening the idea that radiation driven disk winds are crucial to understanding these systems.

Stone, Ostriker, and C. Gammie (CfA) are continuing to study the evolution of MHD turbulence in the cold ISM. Stone is leading the effort to perform fully three-dimensional MHD simulations of turbulence in a self-gravitating gas. Not only can the damping rate of the turbulence be measured through simulation, but the density structures which results can be directly compared to the observed structure of real clouds.

Wolfire is continuing his collaborations with various ISO observing programs. Along with C. Ceccarelli (Observatoire de Grenoble) they have presented the far infrared line spectrum of the protostar IRAS16293-2422 taken with the LWS on board ISO (Ceccarelli *et al.* 1997). They found a rich 43 μm - 197 μm molecular spectrum dominated by [O I] 63 μm and CO, H_2O, and OH rotational lines. The [O I] emission may arise from the compressional heating in the collapsing envelope.

The initial spectrum of Supernova 1993J, which exploded in M81, was classified as a type II supernova because it contained hydrogen lines. Subsequently the hydrogen lines dissappeared and its spectrum became similar to a type Ib supernova. Shortly after its first peak in optical brightness radio emission was detected from SN 1993J. W. K. Rose has developed a model for its radio emission that involves the interaction of a collisionless shock front with the stellar wind of the progenitor supergiant. This model depends on estimates of the mass loss rate of the stellar wind, the inverse Compton effect and the apparent absence of synchrotron self- absorption.

Sage, Welch, and Lanzetta have begun a search for molecular absorption along the line of sight to a blank-field radio quasar (NRAO 150); no search for molecular emission or absorption associated with known Lyman-α clouds has been successful, but they hope this completely new approach will lead to the identification of dense gas associated with structures (possibly proto-galaxies) in the early Universe.

5.5 Planetary Science

Lisse, Livengood, and A'Hearn, with colleague Lynch, analyzed MIRAC2 thermal infrared images of the P/SL-9 K impact site on Jupiter, taken $\sim$ 2 days after collision. A spectrophotometric search was made for various chemical species, and a strong signature due to silicate emission was apparently found. However, this feature is unlike the typical one found in comets, and the stellar calibration was problematic on the day of observation due to inclement skies. A new calibration procedure using the disk of Jupiter itself and Voyager 2 IRIS data is currently under trial.

T. Kostiuk (NASA/GSFC) with colleagues Lisse and Livengood studied the auroral chemical signature of the north and south poles of Jupiter in the thermal infrared. Enhanced hydrocarbon emissions from both North and South polar regions as well as their global distributions were imaged. Data are being analyzed in support of on- going studies of global stratospheric constituent distribution and of auroral morphology and intensity.

Lisse and Livengood with colleague Kostiuk and studied the rings of Saturn in the thermal infrared. The rings were clearly detectable from 8 - 13 μm. A comparison of the spectral content on the East vs. the West rings indicates a distinction in emission intensity and spectral distribution, suggesting cooling of low thermal inertia particles on the night side portion of the ring orbits. Follow-up observations are planned for late 1998 to pursue this in greater detail.

Bus along with collaborators A'Hearn, Bowell and Stern completed their study of the activity of Chiron at aphelion. They showed from archival survey plates that Chiron was clearly active at discovery as previously pointed out by others and that the activity peaked in the early 1970s, shortly after aphelion. The intrinsic amount of brightening then was a factor two more than the brightening that was widely studied on the approach to perihelion and which peaked in 1989.

5.5.1 Asteroids

Activities in the department related to asteroids focused around preparation for and analysis of data from the flyby of asteroid 253 Mathilde, a main-belt C-type asteroid with a 17.4 day rotation period, one of the slowest rates known for an asteroid. The NEAR spacecraft is on its way to asteroid 433 Eros for a year in orbit around the mission's primary target.

In preparation for the Mathilde flyby and analysis of color images in terms of possible mineralogical components, McFadden and colleagues Vilas and Jensen, convolved the spectra of potential minerals likely to be found on the surface of Mathilde to the pass-bands of the filters in the NEAR spacecraft's Multi-Spectral Imager (MSI). The authors found that a spatial unit on the surface of Mathilde must contain a minimum of some 55 asteroids and meteorites for it to be detected by the MSI.

On June 27, 1997, the NEAR spacecraft passed within 1200 km of 253 Mathilde collecting hundreds of images of this C-type asteroid. Preliminary analysis of the data are to appear in Science. With images of this asteroid, the science team, with L. McFadden a member, derived its size, 59 x 47 km, and its mean volume, 73,000 km^3. A density ranging from 1.1-1.5 g/cm^3 was derived by combination of Mathilde's mass derived from telemetry. The asteroid's visual geometric albedo is $0.036+/-0.002$. Among Mathilde's unique features, are 5 craters larger than 20 km diameter (approaching the radius of the asteroid) on the 60% of the asteroid viewed during the brief flyby.

5.5.2 Comets

Haken and A'Hearn completed their study (with Feldman and Budzien) of the variation from one perihelion passage to another in the release of water from comets based on IUE observations of OH. Using comets whose orbital periods are nearly commensurate with that of Earth to eliminate sensitivity to parameters in the models that are sensitive to geometry, they showed that the 2P/Encke varies by less than 3% (1-sigma) per perihelion passage pre-perihelion whereas 9P/Tempel 1 varies by a factor of 1.5 to 2 near perihelion from one passage to the next, apparently randomly, without a secular trend. The implications for mantle development on comets are important in that models must now explain two very different types of behavior.

A'Hearn, in collaboration with the Rosetta-Alice UV spectrometer team used the HST-FOS to study the outgassing of 46P/Wirtanen as it approached perihelion. Remarkably, while the water release, as measured by OH, increased by orders of magnitude on the approach to perihelion, the dust production, as measured by $Af\rho$, did not increase at all. The dust/gas ratio at the beginning of the observations was very high by cometary standards but by the end of the observing, a month before perihelion, the dust/gas ratio was quite low.

Meier (now at the IFA, University of Hawaii), Wellnitz, A'Hearn and Kim (now at the Kyunghee Observatory, Korea) continued their analysis of the KPNO 4-m Echelle spectra of Comet C/Hyakutake which they had taken 1996 March 26.3-26.5, at the time of closest approach of the comet to Earth. At a spectral resolution of better than 0.2 Angstroms, two line multiplets of ND were separated from an overlaying NH line forest and used to derive a 3 s upper limit for the D/H ratio in NH of 0.006, only slightly greater than the reported detections at radio wavelengths. Although photometry with an Echelle spectrometer is quite problematic, it was possible to derive absolute production rates for water (from the OH bands) and for ammonia: Q(NH3)/Q(H2O)$=$0.004. Single-cycle fluorescence models adequately describe the observed CH bands if two different rotational temperatures are introduced for the two spin-states: T(F1)$=$100 K and T(F2)$=$130 K; these temperatures are believed to be remnants of a previous dissociative excitation, there not being enough time to completely relax CH before the radical decays. The rotational temperature may thus provide clues to the identity of the CH parents. A tentative detection of S2 has been made in the spectra. This molecule had been previously noted in HST spectra taken two weeks later; the second detection suggests that S2 is a persistent outgassing product of comets.

Woodney continued her work studying sulfur chemistry in comets. The first definitive detection of OCS in a comet, Comet Hyakutake, was published by Woodney, A'Hearn, McMullin (now at NRAO), and Samarsinha (now at NOAO). This was a first step towards explaining the missing source of sulfur in comets, as H_2S and CS_2, the previously known cometary sulfur sources could not account for all the atomic sulfur observed in the UV. A minor species whose presence is difficult to explain through current chemical models of the coma, S_2, was also detected in this comet by A'Hearn *et al.*, for only the second time in a comet.

More sulfur bearing species were detected in C/Hale-Bopp than have ever been seen in any other comet, including H_2CS which was detected for the first time by Woodney, A'Hearn, McMullin and Samarasinha. Analysis of the abundances of these species in comparison to the total atomic sulfur observed should reveal whether or not we can now account for all of the primary sulfur sources in comets.

Woodney and A'Hearn were also a part of the multi-university observing team which used the BIMA array to map the comet in HCN, CS, CO and continuum at 3-mm. Preliminary comparison of HCN and CN morphology by Woodney suggests that HCN may not be the only source of CN. The BIMA array was used by the team to discover the first mm-wave cometary ion, HCO^+, in Hale-Bopp and its spatial distribution is offset and much broader than that of other species mapped in the millimeter, such as HCN; suggesting production of the species in the plasma tail of the comet.

Sherwin and A'Hearn studied the optical jets of comet 1P/Halley, using narrow band images from the International Halley Watch data archives. Removing the continuum contribution from the C_2 and CN images, they found that the ratio of CN/C_2 flux was different by about a factor of 2 for two of the jets. The third jet's CN/C_2 ratio was not significantly different from the other two. The different ratios could not be explained by projection effects, or the different scale lengths of the two species. The different CN/C_2 ratios suggest that the material from which the jets originated also had a compositional difference.

Comet C/Hale-Bopp. A'Hearn, Fernandez, Lisse, Wellnitz, and Woodney led a coordinated effort to monitor comet C/Hale-Bopp at visible, infrared, submillimeter, and radio wavelengths throughout its apparition in 1996 - 1997. Photometric and spectroscopic observations were made from telescopes at Lowell, NASA/IRTF, BIMA, CSO, and NRAO. Very large amounts of dust were found in the comet, the dustiest on record; sulfur species CS, SO, SO_2, H_2S and organic species CH_3OH, HCN, and CN were detected at extremely large production rates, with abundances $\sim$ 1% of H2O; an 11.3 hour rotation period for the brightest dust jet was found; an outflow rate of $\sim$ 0.4 km/sec was measured for the emitted dust at 1AU. Work is proceeding on measuring the effective infrared size of the nucleus, an estimate expected to improve the current 20 - 40 km radius estimate derived from HST observations of the comet (assuming a 4% geometric albedo) Fernandez, A. Kundu, Lisse, and A'Hearn used the VLA to detect the thermal radio continuum emission from a comet for the first time. Fernandez and Wellnitz obtained an occultation of the 9th magnitude star PPM 200723 by comet Hale-Bopp during an observation campaign in the American West run by the Lowell Observatory in October 1996. The shape and depth of the occultation profile constrain the size of the comet's nucleus to $\sim$ 27 km in radius, and show that the coma was optically thick out to 10-20 km from the nucleus. The comet group (what was left at home) supported the education outreach activities of the departmental observatory during the comet's perigee, during which some 3000 members of the public attended.

Comet 2P/Encke. The well studied comet 2P/Encke had an extremely close approach to the Earth in July 1997, an event happening once every 17 years. Fernandez, A'Hearn, and Lisse observed this southern comet from the CTIO/ESO telescopes in the optical and thermal infrared, in order to characterize the nucleus and dust emitted by the comet. Simultaneous infrared photometric measurements were obtained with the ISO spacecraft. Imaging returned an unresolved point like structure to the comet, suggesting little or no emitted dust and gas, consistent with Encke's known low activity. Current work is bearing on the reanalysis of the comet's size estimate, thought to be $\sim$ 2 km in radius, but potentially much smaller in an analysis of July 1997 HST images by colleague Weaver and A'Hearn.

5.5.3 Dust and Dynamics

D.P. Hamilton and colleague A.V. Krivov (St. Petersburg University) 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. Hamilton and Krivov extended the integral into three dimensions, and showed that it is related to the Tisserand's Constant of the restricted three body problem. They applied the integral to distant satellites of asteroids and were able to infer simple properties of these orbits. For example, distant prograde extend further along the Sun-asteroid line, while distant retrograde orbits extend further perpendicular to this line.

D.P. Hamilton and A.V. Krivov also continue their work on 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. Hamilton and Krivov performed detailed calculations of the number density of ring particles and compared their results to all other previous calculations. 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 continued his work on the origin of the striking black/white hemispheric asymmetry of Saturn's odd satellite Iapetus. Iapetus' orbital and spin period are equal, so it always keeps one face toward Saturn. It has long been suspected that dark dusty debris, originating from Saturn's outermost satellite Phoebe and brought inward by Poynting-Robertson drag, is responsible for Iapetus' striking albedo asymmetry. The Phoebe-dust model is very compelling because it naturally explains why the leading face of Iapetus, the side that is receiving dust from Phoebe, is dark. The model has not gained universal acceptance, however, primarily due to the following dynamical problems: i) the distribution of dark material on Iapetus does not precisely match predicted contours of constant dust flux from Phoebe, ii) there are dark-floored craters in Iapetus' high-albedo hemisphere, and iii) Iapetus' North pole is brighter than parts of the trailing hemisphere. Hamilton showed that problems are greatly reduced with the realization that Iapetus took nearly a billion years to become tidally locked to Saturn. A publication is in preparation.

With E. Grün and the Galileo dust team, D.P. 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. In addition, new concentrations of dust were discovered along the orbits of several of the Galilean satellites, notably Ganymede. The dust sensed near the Galilean satellites seems to be consistent with fragments ejected during hypervelocity interplanetary impacts of interplanetary material with the moons. Data analysis and numerical modeling efforts are underway.

Lisse, A'Hearn, and Fernandez used the Lowell and NASA/IRTF observatories to observe comet 126P/IRAS in the optical and near-IR simultaneously with our ISO GO programme. The results have been used to characterize the dust emitted by the comet as similar to that emitted by 1P/Halley with a 4:1 silicate:carbanaceous composition. Collaboration with the MPIK ISOPHOT team of Grüen and Peschke has led to an on-going study of the dust emitted by 4 other comets observed by ISO in the thermal infrared: 22P/Kopff, C/Hale-Bopp, 29P/Schwassmann-Wachmann 1, and Chiron.

Periodic comets 22P/Kopff, 81P/Wild 2, and 46P/Wirtanen were observed serendipitously in the optical and infrared by Lisse, Fernandez, and A'Hearn with colleague Hanner (JPL) while monitoring comet C/Hale-Bopp. The results of these observations will be added to a growing infrared photometric database of comets that will be used to compare the dust emitted by comets for variations by age, dynamical class, and point of origin of the comet. The 81P/Wild 2 and 46P/Wirtanen measurements will also be delivered to ESA and JPL to derive rough values for the dust production rate and history of these comets, to aid in planning the upcoming ROSETTA and STARDUST comet rendezvous missions.

Analysis in progress on MIRAC2 infrared observations of the dust emitted by comet C/Hyakutake has demonstrated the preponderance of small, slightly hot silicaceous particles in an approximately 9:1 silicate:carbanaceous composition and a dust/gas ratio of $\sim$ 2, similar to that of comet 1P/Halley.

Lisse, A'Hearn, *et al.* published their comparison of the dust emitted by the 4 comets (C/Okazaki-Levy-Rudenko, C/Austin. P/Schwassmann-Wachmann-3, C/Levy) detected by the COBE satellite. C/OLR and C/Austin were found to have most of their dust mass in large, relatively cool, dark particles, while comet Levy was more similar to comet Halley with many small, hot particles. Comet P/SW-3 was probably detected due to an excess emission of dust related to its breakup next apparition. No comet trails were found in the COBE all sky survey, although particles which would become part of a trail were emitted from Comet Austin.

A'Hearn continued his collaboration with Lamy, Toth and Weaver to photometrically isolate cometary nuclei from the coma using HST. Assuming canonical albedos, they concluded that comets P/Wirtanen and P/Honda-Mrkos- Pajdušáková were both substantially less than 1 km in radius and that they had relatively large active fractions of their surfaces (10% or greater). C/Hale-Bopp, on the other hand, had a radius near 20 km based on a similar analysis.

Lisse, Fernandez, and A'Hearn used analysis of thermal infrared images of comet C/Hyakutake during its perigee in March 1996 to search for emission from the nuclear surface. Along with the 3 km (3α) upper limit for the nuclear size found from the VLA measurements of Fernandez *et al.*, and the unusually large optical scattering observed from non-coma sources, they were able to show that the most plausible physical model for the results has a comet with a 2.4 km effective radius nucleus, a tensile strength 1×10^3 dynes/cm2, and a surrounding large cloud of slowly moving icy particles.

Lisse used the ROSAT and EUVE spacecraft to obtain photometric imaging of comet P/Encke in the extreme ultraviolet and soft x-ray. The comet was detected from 0.1 to 2.0 keV, by both spacecraft, and demonstrated an x-ray light curve similar to the one found for C/Hyakutake in 1996, with both a baseline slowly varying emission and an impulsive outburst $\sim$ 4x the low level emission. Detections of comets C/Tabur and C/Hale-Bopp with colleagues at MPE, along with archival findings by colleague Dennerl of 4 more ROSAT comets and colleague Mumma of 2 EUVE archival comets now brings the total of x-ray emitting comets to $\sim$10, and demonstrates a rough linear correlation of x-ray luminosity with optical luminosity, and establishes that x-ray emission is a universal behavior of comets. Comparison of the current observations to plausible physical models leaves the following viable x-ray production mechanisms: charge transfer between heavy solar wind ions and cometary species, bremsstrahlung scattering of energetic electrons off cometary neutrals, and solar magnetic field reconnection events.

5.6 Space Plasma Physics

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

The solar wind-magnetosphere system exhibits coherence on the global scale and such behavior can arise from nonlinearity in the dynamics. The observational time series data have been used extensively to analyze the magnetospheric dynamics by using the techniques of phase space reconstruction. Analyses of the solar wind and auroral electrojet and Dst indicates have shown low dimensionality of the dynamics and accurate prediction can be made with an input-output model. The predictability of the magnetosphere in spite of the apparent complexity arises from its being synchronized, in the dynamical sense, to the solar wind. The strong electrodynamic coupling between the different regions of the magnetosphere yields its coherent, and thus low dimensional, behavior. The data from multiple satellites and ground stations can be used to develop a spatio-temporal model that identifies the coupling between the different regions. These nonlinear dynamical models yield accurate and reliable forecasting tools for space weather.

J. A. Valdivia (former graduate student, now at NASA Goddard), A. S. Sharma and K. 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.

A. S. Sharma, J. A. Valdivia, S R. Rosa and H. S. Sawant (both from INPE, San Paolo, Brazil) studied dissipative structures and weak turbulence in the solar corona. In this work for the first time the high resolution X-ray images of the solar corona, obtained by the Yohkoh Mission, as nonlinear extended systems have analyzed. To qualify the spatio-temporal complexity in this extended system, they have introduced an asymmetric spatial fragmentation parameter computed from a matrix representing an image. Choosing different spatial scales on the same image, wave numbers are computed from the intensity contours and this yields a fragmentation spectra. This spectra is used to analyze the images of the complex transient phenomena obtained by the Soft X-ray Telescope board the Yohkoh satellite. The dynamics of the fine structures of the contours suggest the origin of the observed fragmentation to be the localized weak turbulence processes occurring in regions with complex plasma loop configuration.

A. S. Sharma and M. I. Sitnov (Moscow University, Russia) studied the role of the temperature ratio in the linear stability of quasi-neutral sheet tearing mode. Well-known linear stability criterion of the tearing mode in the magnetotail current sheet with nonzero normal component of the equilibrium magnetic field consideres the electrons to be trapped in the current sheet. This condition is significantly modified when electron-to-ion temperature ratio is small, due to the contribution of transient orbits to the perturbed electron density integrated over the flux tube. In contrast to the previous criterion marginal stability may be reached under realistic conditions in the near-Earth tail current sheet during late substorm growth phase.

K. Papadopoulos, C. C. Goodrich and R. E. Lopez have continued their work on the global modeling research. Over the last two or three years, they have made very significant advances in the understanding of the Earth's magnetosphere and those of the outer planets. These advances have resulted from three fundamental improvements in their global MHD code, written by their collaborator, J. Lyon [Dartmouth College], including extension of the range of the code to several hundred Re downstream of the Earth, incorporation of time dependent conditions on ALL of the boundaries, and implementation of a rotating dipole and semiconducting ionosphere. This work was made in collaboration with Dr. Lyon and R. L. McNutt (Johns Hopkins/Applied Physics Lab).

This group has also performed a series of global MHD simulations that may provide the key to understanding isolated magnetospheric substorms. This study has focused on the substorm event occurring at 0500 UT on March 9, 1995, which is particularly well documented by both ground based and spacecraft observations. It uses an impressive collection of ground radar, magnetometer, and other data which give a thorough ionospheric view of the substorm. Data are also available from the ISTP spacecraft, which are well placed for in situ observations. The simulation results give a global description of the substorm that is in good agreement with both the ground based and in situ measurements. They find onset occurs about 0500 UT, following a growth phase marked by thinning of the plasma sheet (PS) and heating of the PS plasma which starts around -8 Re and then progresses tailward. These results indicate onset is marked by an impulsive penetration of electric field into the central plasma sheet, and a diversion of the cross tail current, at about –10 Re. These features thereafter propagate down the tail to about –25 Re, where they engender strong reconnection, and the global magnetic topology reconfiguration characteristic of the substorm expansion phase. These results suggest a realistic model that combines the major aspects of the current leading substorm models, the Near Earth Neutral Line and Current Disruption models.

The SPP group has continued this activity in the Active Aurora Research Program (HAARP).

G. 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.

K. Papadopoulos, G. M. Milikh and J. Valdivia have continued their studies of high altitude lightning. Valdivia has worked on the problems related to this topic till spring 1997, when he graduated from the Maryland Ph. D. program. 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 —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 K. Papadopoulos, G. M. Milikh and J. Valdivia in cooperation with A. Gurevich 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 occurs at equatorial and polar latitudes.

G.M. Milikh, D.A. Usikov (Phys. Department University of Maryland) and J. A. Valdivia presented a model of infrared emission from sprites. In this model the 4.26μm infrared emission due to read sprites is considered. The model discusses generation of nitrogen vibrions due to the collisions of the nitrogen molecules with the electrons energized by the electric field from lightning, followed by transition of the nitrogen vibrions to the $CO_2(001)$ vibrational level with lifetime much shorter than that of nitrogen. The infrared photons of wavelength$=4.26$ μm radiated by the CO2(001) propagate through the optically thick atmosphere, therefore this emission could be observed mainly from the space. The model computes the infrared radiance of sprites, as well as the energy collected by the state-of-the-art space infrared detector, and estimates the signal-to-noise ratio at the detector.

G. M. Milikh and J. Valdivia in cooperation with A. Gurevich delivered a model of X-ray emission and fast preconditioning during a thunderstorm. In this paper a quantitative self-consistent model of the processes determined by the multiple runaway breakdown caused by the thunderstorm electric field is presented. It describes in detail the bremsstrahlung emission and fast charge transfer, and reaches a qualitative agreement with the earlier observations obtained during a balloon flight through a thunderstorm. The model demonstrates the exact realization of a fast charge transfer in a thunderstorm cloud. This process first predicted by Gurevich *et al.* [Phys. Lett. A 165 (1992) 364] is determined by multiple runaway breakdown. It plays an important role in the lightning triggering and has a strong influence on the development of a thunderstorm.

G. Milikh with A. Gurevich and N. Borisov (Lebedev Physics Institute, Moscow, Russia) continued their studies of the problems related to the creation of over-the-horizon radar and new types of radio communication using an artificial ionized region in the atmosphere by means of powerful rf radiation. Such a region acts like an artificial ionosphere, reflecting radio waves.

G. Milikh with G. S. Nusinovich (UMD) and B. Levush (Naval Research Lab.) 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.

J. A. Valdivia and A. Fouladi (graduate student) 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.

K. Papadopoulos with A. Drobot and C. L. 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.

D. L. Book and J. A. Valdivia 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.

5.7 Solar Radio Physics

M. R. Kundu and J. P. Raulin along with Nitta (LMSAL), Shibata and Shimojo (NAOJ) have been searching for nonthermal radio signatures in the form of metric type III bursts in conjunction with soft X-ray jets as observed by Yohkoh/SXT experiment. In contrast to Anemone-type jets where nonthermal type III bursts were always observed, they found no evidence of type III bursts in association with two-sided loop type X-ray jets. This result is consistent with the simulation results of Yokoyama and Shibata (1995), which show that anemone type jets are produced by vertical/oblique plasma flow whereas the two-sided loop type jets are produced by horizontal plasma flow.

Kundu, Shibasaki (Nobeyama) and Nitta (Lockheed) provided the first evidence of the detection of microwave emission at 17 GHz in association with coronal X-ray jets. They presented two typical cases one on the disk (1995 March 31) and the other at the limb (1992 August 25). For the disk event, they see 17 GHz emission from the upper part of the jet base (active region loop or loops), but no emission from the collimated X-ray jet itself, implying that it must be optically thin at 17 GHz. For the limb event, they see the base of the jet as well as the bottom part of the jet itself, implying that the optical depth is higher at the bottom part (obviously because of higher electron density) than at the top. They believe that the 17 GHz emission is thermal because it is gradual and unpolarized and that the heating process that gives rise to the jet X-ray plasma also results in the 17 GHz emission. The calculated 17 GHz flux densities seem to agree with the observed values within a factor of 2. This disagreement is considered to be quite reasonalbe in view of the various uncertainties involved in computing the emission in both radio and X-rays.

Gopalswamy, Kundu, Lara along with Hanaoka, Enome (Nobeyama), and Lemen (Lockheed) presented X-ray (Yohkoh/SXT) and microwave (17 GHz Nobeyama) observations of the 1993 July 10-11 CME. During this event, all the substructures of a classical CME are revealed: Frontal loop in X-rays, prominence core in microwaves, dark cavity between prominence and frontal loop in X-rays, and arcade structure beneath the prominence in X-rays.

Gopalswamy, Kundu, Hanaoka, Enome, Lemen and Akioka reported the observations of a coronal mass ejection (CME) using the Soft X-ray Telescope on board the Yohkoh Mission. The CME had the familiar three part structure (frontal loop, prominence core and a cavity). The erupting prominence was observed by the Nobeyama radioheliograph. They were able to determine the mass of the CME (2.6×10^{14} g) from X-ray observations which seems to be at the lower end of the range of CME masses reported before from white light observations. This is the first time the mass of a CME has been determined from X-ray observations. The height of onset of the CME was $0.3R_\odot$. The CME moved much faster than the erupting prominence while its acceleration was smaller than that of the erupting prominence.

Gopalswamy, Raulin, Kundu, Hildebrandt, Krüger, and Hofmann presented Very Large Array (VLA) observations of AR 7542 which demonstrate the existence of definite ring and horse-shoe structures of a sunspot in intensity (I) and polarization (V) at 8.46 GHz (3.5 cm wavelength) and compare them with model calculations of gyroresonance radiation. The VLA measurements have been made on three different days in July 1993 when AR 7542 was at three different longitudes which allows the study of the effect of viewing angle on sunspot-associated microwave emission.

Model calculations of gyroresonance radiation have been carried out using a modified dipole model corresponding to the observed photospheric magnetic field strength and average temperature/electron density distributions consistent with soft X-ray and EUV observations (for the lower atmosphere) as well as theoretical assumptions (for the corona). The calculated I and V maps were found to be generally consistent with the radio observations. They obtained information on the magnetic scale length in vertical and horizontal directions above the sunspot and about the distribution of other plasma parameters (temperature, density) inside the radio source region.

Gopalswamy, Kundu, Manoharan, Raoult, Nitta, and Zarka observed an eruptive structure on 1994 July 31, a fast (900 km s^{-1}) in X-rays, followed by a slower plasmoid (180 km s^{-1}). They were associated with a coronal mass ejection, prominence eruption, and a host of metric radio bursts. The X-ray structure seems to be a part of a white light coronal mass ejections (CME), as inferred from the white light images of July 30 and 31. A type II burst was observed at the leading edge of the X- ray eruption, while a type IV burst was spatially associated with the detached plasmoid. The type III radio bursts occurred on thin overdose structures associated with the eruption. They detected the rise of plasma levels because of mass addition to the type III burst sources as a result of the eruption. This event further clarifies the manifestation of a CME in X- rays. They identified the X-ray eruption as the driver of the coronal shock wave. This provides answer to the long-standing question regarding the origin of coronal and interplanetary shock waves. They also found evidence to support the idea that herringbone bursts are produced when the coronal shock wave crosses open magnetic field lines.

Gopalswamy, Kundu, Hanaoka, Enome and Lemen found remarkably different manifestations of a bright point flare in X-ray and radio (microwave) wavelengths, unlike previous observations. In X-rays, the BP flare was relatively simple while in radio, the bright point flare had a large scale component and a transient moving component. The large scale structure may be the radio counterpart of large scale structures sometimes seen during X-ray BP flares. The transient component was also compact and moved away from the location of the X-ray BP flare with a speed of ~ 60 km s^{-1}. The compact source also showed fast time structure which suggests nonthermal emission mechanism for the transient source. The emission peaks in the two-wavelength domains did not coincide, which suggests cool plamsa flow along the large-scale radio structure. They were able to determine the temperature and emission measure of the BP flare plasma from the X-ray data, and thus they computed the expected radio flux from the X-ray-emitting plasma. They found that the computed radio flux was much smaller than the total observed radio flux.

J. Zhang (graduate student), Gopalswamy, Kundu, E. Schmahl, and Lemen presented the measurement of magnetic field gradient in magnetic loops in the solar corona, based on the multi-wavelength Very Large Array observations of two transient microwave brightenings (TMBs) in the solar active region 7135. The events were observed at 2 cm (spatial resolution $\sim 2''$) and 3.6 cm (spatial resolution $\sim 3''$) with a temporal resolution of 3.3 s in a time-sharing mode. Soft X-ray data (spatial resoltuion $\sim 2.5''$) were available from the Soft X-ray Telescope on board the YOHKOH satellite. The three dimensional sructure of simple magnetic loops, where the transient brightenings occurred, were traced out by these observations. The 2 cm and 3.6 cm sources were very compact, located near the footpoint of the magnetic loops seen in the X-ray images. For the two events reported in this paper, the projected angular separation betwen the centroids of 2 and 3.6 cm sources come form the thermal gyro- resonance emission. The 2 cm emission is at the 3rd harmonic originating from the gyro-resonance layer where the magnetic field is 1800 G. The 3.6 cm emission is at the 2nd harmonic, originating from the gyro- resonance layer with a magnetic field of 1500 G. The estimaged magnetic field gradient near the footpoint of the magnetic loop is about 0.09 G km^{-1} and 0.12 G km^{-1} for the two events. These values are smaller than those observed in the photosphere and chromosphere by a least a factor of 2.

Gopalswamy, Zhang, Kundu, Schmahl and Lemen carried out a detailed analysis of the Very Large Array data with full time resolution (3.3 s) at two wavelengths (2 and 3.6 cm) and addressed the question of the emission mechanism of the TMBs. They find that nonthermal processes indeed take place during the TMBs. They present evidence for nonthermal emission in the form of temporal and spatial structure of the TMBs. The fast time structure cannot be explained by a thermodynamic cooling time and therefore require a nonthermal process. Using the physical parameters obtained from X-ray and radio observations, they determined the magnetic field parameters of the loop and estimate the energy released during the TMBs. The impulsive components of TMBs imply an energy release rate of $\sim$ 1.3 x 10^{22} erg s^{-1} so that the thermal energy content of the TMBs could be less than $\sim 10^{24}$ erg.

Aschwanden and Benz (ETH Zurich) investigated electron densities in solar flares. Soft X-ray emission measure observations from the Yohkoh satellite and plasma frequency measurements with the Zurich radio spectrometers allowed us to compare the electron density in soft-X-ray bright flare loops, in chromospheric evaporation upflows, and in acceleration sites of electron beams. It was found that acceleration takes place in a region of much lower density than in the flare loops, most likely located in the cusp region above the flare loops, as envisioned in magnetic reconnection models. This work represents also the first density comparison with radio and soft X-ray methods.

Aschwanden, Bynum (Oregon College), Kosugi (NOAO), Hudson (ISAS) and Schwartz (GSFC) investigated electron trapping times and trap densities in solar flare loops, using measurements from the CGRO and Yohkoh spacecraft. A systematic timing study of energy-dependent time delays of hard X-ray emission in the 20-200 keV energy range was performed. It was found that the smoothly-varying hard X-ray component revealed delays consistent with the collisional deflection time. This result was interpreted that the hard X-ray producing electrons are initially trapped in densities of $n_e \approx 10^{11}$ cm^{-3} and then pitch-angle scattered in the weak-diffusion regime into the loss-cone, from where they precipitate to the chromosphere and produce thick-target hard X-ray bremsstrahlung emission.

Aschwanden, Dennis (GSFC) and Benz (ETH Zurich) analyzed elementary time structures in solar flares, including some 10,000 hard X-ray pulses, 4000 radio type III bursts, 4000 pulses of decimetric pulsations, and 10,000 decimetric millisecond spikes. The frequency distributions of the peak fluxes of these elementary time structures were studied for each flare separately, and were found to show power-laws as well as exponential distributions. The time profiles of elementary pulses could be fitted with a logistic curve, which allows to characterize the growth and saturation time of the underlying nonlinear instability. With this logistic avalanche model, a generalized frequency distribution could be calculated, which fits exponential distributions for incoherent processes, and power-law distributions for highly coherent processes.

E. Schmahl, C. Crannell (GSFC) and C. Wald (Goddard Summer Student, Columbia U.), have investigated the extent of over resolution in solar flares using interferometers. The motivation for this investigation arose from results obtained with the Owens Valley Radio Observatory Solar Array (OVRO) and the Very Large Array. In many cases, published microwave events appear to be over resolved, sometimes with 50the 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. In a sample of over 100 flares from OVRO, we have found that flares are usually over resolved even on the shortest baseline. This indicates that large-scale structures are common in solar flares, which has important implications for proposed hard X-ray imagers.

Lee, White, and Kundu, along with A. N. McClymont (U of Hawaii) and Z. Mikic (SAIC) have completed the active region study using the state-of-the-art coronal field extrapolation technique in the analysis of high resolution microwave images of a solar active region. This field extrapolation fully takes into account the nonuniform distribution of electric currents observed in the photosphere and makes it possible to investigate the link between regions of strong currents and those of high temperature in the corona as implied by microwave images. They were able to reproduce the microwave images remarkably well with a model in which temperature is structured along magnetic field lines, depends on the current on the field line, and increases with height in a manner similar to that inferred from static heated loop models. This result implies a direct link between electric currents and coronal heating. They also used the magnetic field model to explore a technique in which depolarization of microwaves is used to infer the coronal electron density. It is shown that this technique for obtaining coronal densities is particularly sensitive to the quality of the coronal magnetic field model which, in turn, depends significantly on the amount of electric current used as a boundary condition for the field extrapolation. Such extreme sensitivity to the magnetic field model explains in part why the inference of a low density has been a common complaint of studies which have employed the potential (current-free) field models to determine the density from the depolarization condition.

As an extension of the active region study, Lee and White proposed a new diagnostic method for exploring 3-D magnetic field vectors in the corona. In the proposed method, magnetic field lines are traced in 3-D space to locate emission layers for multiple frequencies used in the observation so that a magnetic field model can be tested by looking at the correlation of the temperatures observed at different frequencies at the positions identified as the emission layers. The proposed method relies only on the well-accepted theory for coronal loop structure and does not require ad-hoc assumptions on plasma parameters.

Lee, White, and Kundu analyzed radio observations of an emerging flux region AR 7978 made using the VLA at two frequencies, 5 and 8 GHz, with high time cadence. This is the first data set that shows coronal emissions associated with emerging flux detected from the very early stage of its emergence into the corona. From spectral analysis and comparison with EUV line images (FeIX/X and FeXII) obtained from SoHO/EIT, they inferred that the emerging flux loop is, in fact, carrying heavier material inside compared with surrounding corona, which contradicts the traditional view that solar magnetic flux emergence is due to Parker's instability for magnetic buoyancy. It is also found that the radio flux increase is delayed by 1.5 hours with respect to emergence of the photospheric magnetic flux, and that the impulsive temperature increase is followed by that of density, consistent with the process known as ''chromospheric evaporation.'' Evidence for reconnection of an emerging loop to preexisting loops is also found from radio images.

5.8 Instrumentation

Working with the HEIDI (High Energy Imaging Device) team at Goddard Space Flight Center, Edward 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.

Working with B. Dennis (GSFC), E. Schmahl has produced simulations of the imaging capabilities of the proposed High Energy Solar Spectroscopic Imager (HESSI). This Small Explorer will be a rotation modulation collimator (RMC) telescope with 9 collimators resolving angular scales from 2.3 to 189 arcseconds, capable of mapping flares anywhere on the Sun. The simulations have led to a number of conclusions regarding the capabilities of HESSI for imaging/spectroscopy. Among the conclusions are that 2-s maps made of flares with at least 1000 incident photons per collimator per energy bin will show 50:1 dynamic range on spatial scales from 2.3 to 189 arcsec, and that gamma-ray (1-10 MeV) flares can be imaged with spatial resolution of about an arc minute if they are spatially complex, and of order 10 arcsec if they are comprised of isolated point sources. Spectroscopy of large (X-class) flares will provide spectral details at the 1 keV level over at least the 5-100 keV range.

5.9 Other

Trimble has begun an investigation of the development of 20th century ideas concerning star formation. The most striking feature is a period from about 1935 to 1945 when mainstream astronomical opinion denied that star formation was an ongoing process and confined it to the early period of an evolving (big bang) universe. Work continues on identifying the causes of this anomaly and the events that brought it to an end.

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