Rice University
Department of Space Physics and Astronomy
Houston, Texas 77005

The following report covers the Department activities from October 1995 through October 1996. Updated information can be accessed through our URL, http://spacsun.rice.edu.

1. INTRODUCTION

In 1963 Rice University took a bold step into the exploration of mankind's newest frontier with the establishment of the first Department of Space Science in the United States. Today, as the Department of Space Physics & Astronomy, it strives for excellence in graduate education and research across a broad spectrum of topics in physics & astronomy ranging from the Earth's climate to Cosmology.

2. PERSONNEL

2.1 Academic and Research Staff

Seventeen personnel constitute the primary resident academic and research staff. For the 1996/97 academic year, Professors were P. A. Cloutier, R. J. Dufour, A. A. Few, Jr., J. W. Freeman, R. C. Haymes, E. P. Liang, F. C. Michel, C. R. O'Dell, P. H. Reiff (*chair*), J. C. Weisheit, and R. A. Wolf. Assistant Professors were A. A. Chan and P. M. Hartigan. Distinguished Faculty Fellows were T. W. Hill and K. A. Smith. T. S. Ledley was a Senior Faculty Fellow. In 1996 July, F. R. Toffoletto joined the department as a Faculty Fellow.

Affilitated Faculty (from other University departments) were Professors F. B. Dunning (physics), D. Heymann (geology), and G. K. Walters (physics). Adjunct faculty were Adjunct Professors D. Black (LPI), W. C. Horton, Jr. (U. Texas, Austin), J. D. Winningham (SWRI), and D. T. Young (SWRI); and Adjunct Associate Professors T. F. Stepinski (LPI) and J. H. Newman (NASA-JSC). W. E. Gordon was a Distinguished Professor Emeritus. J. W. Chamberlain, A. J. Dessler, and R. F. Stebbings were Professors Emeritus.

R. W. Spiro was a Senior Research Scientist; C. Law and I. A. Smith were Research Scientists. Postdoctoral Research Associates were X. Hu, Z. Huang, P. Krisko, B. Lindsay, H. Straub, and W. Wu.

2.2 Students

At the beginning of the 1996/97 academic year, 28 students were enrolled in full-time graduate study and two part-time. Of these, four joined the department for graduate study in 1996 August. In addition, seven junior and senior undergraduates were enrolled in our ''Space Physics & Astronomy Option'' study program towards obtaining a B.A. degree in Physics.

During our May 1996 Commencement, four Ph.D. and five M.S. degrees were awarded. The Ph.D. recipients and dissertation titles were Xihai Hu for ''High Velocity Flows and Shocks in the Star-Forming H II Region: The Orion Nebula,'' Vincent E. Kargatis for ''Continuum Spectral Evolution of Gamma-Ray Bursts,'' Colin C. Law for ''Currents and Magnetic Field Structures in the Dayside Solar Wind Interaction with Venus and Mars,'' and Mauricio Reyes-Ruiz for ''Magnetic Fields in Protoplanetary Disks.''

3. FACILITIES

The department is located in the Space Science and Technology Building on the Rice campus. In this building are engineering and shop facilities for the production of laboratory equipment and flight hardware for satellite, rocket and balloon-borne experiments. Professors K. Smith, F. Dunning, and G. Walters have laboratories for experimental atomic and molecular physics studies and R. Haymes has a laboratory for gamma-ray telescope development.

Most faculty and staff offices occupy the second floor of the building, which also includes our computational and data analysis facilities. Several Sun sparcstations (including a server, ''spacsun''), a Vax cluster, X-terminals, and Macintosh computers are networked together with other campus-wide systems and the world-wide internet.

Undergraduate and graduate students have the opportunity to use a variety of telescopes in education and research, ranging from small instruments located on the roof of Fondren Library, to computerized 14- and 36-inch telescopes at the George Observatory, located in Brazos Bend State Park, 35 miles southwest of the campus. In addition, students use facilities at the Lunar and Planetary Institute in nearby Clear Lake City, as well as the laboratories for space instrumentation development at the Southwest Research Institute in San Antonio, Texas.

4. RESEARCH

4.1 Space Science

4.1.1 Earth and Atmosphere

Professor A. Few's research interest is atmospheric physics with a special emphasis on atmospheric electricity and Earth system science. In the experimental area he has data from a suite of instruments that operated at the South Pole for a three-year period; these measurements monitor the total global thunderstorm activity, a parameter strongly influenced by global warming. Few is also active at the national level in global change or Earth system science education. He is an author-participant in the Global Change Instruction Program (NSF and NCAR), and in the Earth System Science Education Program (NASA and USRA). These programs share the goal of developing undergraduate courses and teaching materials in the interdisciplinary areas of global change or Earth system science.

Senior Faculty Fellow T. Ledley's recent work has emphasized understanding the role of the polar regions in shaping global climate on a wide range of time scales by examining the possible mechanisms of climate change. The polar regions of the Earth can have a large impact on global climate despite the fact that they occupy a small percentage of its total area. The main feature of the polar regions that make them different from others is the presence of snow and ice. The impact of snow and sea ice on the climate of the polar regions and globally has been examined with a coupled energy balance climate-thermodynamic sea ice model that includes a hydrologic cycle. The modeling studies show that snow and sea ice have a large impact on the energy exchange between the atmosphere and ocean, and that changes in that interaction affect climate.

Ledley's work has led to current research on the shorter time scales, which involves examining the effect of various atmospheric and oceanic processes on the sea ice regime of the Ross Sea and the subsequent impact on the climate system. On the longer time scales she is examining the mechanisms that produce the large scale glacial/interglacial cycles recorded in the geologic record, and has recently incorporated a dynamic ice sheet model into the coupled system in order to study the interactions between the different components of the climate system on the ice age time scales.

4.1.2 Earth's Magnetosphere and Space Weather

Over a period of many years, Professor R. A. Wolf and collaborators have developed a computer code called the Rice Convection Model, which has proved to be an effective research tool for studying the dynamics of the Earth's inner magnetosphere. A group led by Professors J. W. Freeman, R. A. Wolf, and Senior Research Scientist R. W. Spiro has more recently developed a streamlined, data-driven version of the Rice Convection Model that is designed to run from real-time space and ground data. This real-time model, called the Magnetospheric Specification Model, can thus provide an up-to-date picture of the state of the inner magnetosphere. It now runs routinely at the U. S. Air Force's space forecast center, and it is also proving to be a useful tool for the scientific analysis of space data. It was recently used to demonstrate that bursts of enhanced magnetospheric convection are responsible for the injection of new ring current particles in a magnetic storm, and that the magnetic reconfigurations involved in magnetospheric substorms play a relatively minor role.

As part of the National Space Weather Program, Distinguished Faculty Fellow T. W. Hill (PI) in collaboration with R. W Spiro, F. R. Toffoletto and R. A. Wolf plan to couple the Rice Convection Model with the open magnetosphere model. The coupled code will provide a unique capability for self-consistent multifluid numerical simulation of global, time-dependent magnetospheric convection with a minimum of input parameters, primarily the solar wind ram pressure, the vector interplanetary magnetic field (IMF), and an independently specified model (empirical or theoretical) of magnetotail substorm variations. They plan to then use this capability to simulate specific geomagnetic storms, using solar-wind data as input and magnetospheric data to validate the model results.

Professor P. Reiff's group is active in studies of the Earth's magnetosphere and ''Space Weather.'' As a Co-I on the Polar spacecraft, launched in February 1996, she and graduate student Andrew Urquhart and an undergraduate student are investigating the detailed response of the magnetosphere to changes in the Interplanetary Magnetic Field, particularly in times where the IMF is nearly parallel to the Earth's field near the boundary. Graduate student Ben Boyle is analyzing Dynamics Explorer and DMSP data to create empirical models of the reaction of ionospheric electric fields to changes in the solar wind. Graduate student Shan Xue is creating quantitative models of the ion injection from the solar wind to the magnetosphere (entering at the cusps, where Earth's field becomes connected to the IMF). Postdoctoral associate Paula Krisko is analyzing Dynamics Explorer particle data to create a numerical model of electron loss from the ring current, important or modeling efforts at Rice and elsewhere. Reiff is also a Co-Investigator for the ''IMAGE'' mission, recently selected by NASA as its next MIDEX. Using new techniques such as neutral atom imaging and radio sounding, IMAGE will for the first time be a remote sensing tool for the entire magnetosphere. Her students will be working with the theoretical group as well as with the hardware and spacecraft design.

Assistant Professor A. A. Chan is continuing a theoretical study of the effects of anisotropic plasma pressure and kinetic effects on MHD equilibrium and stability in the Earth's magnetosphere. Anisotropy can significantly lower both the wave eigenfrequency and the instability threshold for ballooning modes (pressure-gradient-driven MHD modes). Resonant wave-particle instabilities are also considered. These studies use linear gyrokinetic theory (a self-consistent kinetic theory of low-frequency waves and instabilities in plasmas). Theoretical results are compared with spacecraft measurements of wave and particle properties.

Chan and graduate student Karen Klamczynski have made test particle calculations of the nonlinear dynamics of ring current ions in magnetospheric hydromagnetic waves. The primary motivation for this work comes from recent spacecraft observations of intense sub-auroral ion precipitation. Chan and Klamczynski are investigating whether a bounce resonance with hydromagnetic waves is responsible for the ion precipitation.

Chan is the principal investigator on a project to model the so-called ''killer electrons,'' relativistic electrons which can cause significant damage to scientific and communications spacecraft. The project is part of the National Space Weather Program. Chan and graduate student Karsten Braaten have developed a preliminary simulation model based on the Magnetospheric Specification and Forecast Model. The preliminary model simulates the proton radiation belts during a large magnetic storm. Chan and graduate student Hee-Jeong Kim are studying the fully-adiabatic response (all three adiabatic invariants conserved) of relativistic electrons during magnetic storms.

Chan and R. Denton, E. Belova, and M. Hudson at Dartmouth College, are developing a hybrid MHD-gyrokinetic computer code to calculate the self-consistent nonlinear evolution of magnetospheric hydromagnetic waves and the induced particle transport. He is also collaborating with L. Chen at the University of California at Irvine, in developing general equations for the transport of mass, momentum and energy across the dayside magnetopause due to low frequency waves. Chan and C. Z. Cheng and J. Johnson at Princeton University continue studies on kinetic effects on MHD modes in the Earth's magnetosphere.

Faculty Fellow F. R. Toffoletto and R. A. Wolf have started a collaboration with J. Birn of Los Alamos National Lab and M. Hesse of Goddard Space Flight Center to develop the first self-consistent computational model of a substorm, by coupling the physics of the inner magnetosphere and the ionosphere (as represented by the Rice Convection Model) and the physics of the tail (as represented by the Los Alamos/Goddard MHD model of tail dynamics). A third essential element is an equilibrium code that has been developed through a Los Alamos/Goddard/Rice collaboration. The fully merged Tail-MHD/RCM model will be a useful tool for testing substorm ideas for theoretical consistency and for making precise theoretical predictions that can be compared with observations. Graduate student M. Hojo, R. A Wolf, R. Spiro and F. R. Toffoletto are also collaborating with J. Lyon of Dartmouth College to include the Rice Convection Model in a Global MHD Code.

Toffoletto and T. W. Hill have continued work on the development of their open magnetosphere model. At the 1996 Geospace Environment Modeling Snowmass workshop they participated in the joint session on model comparisons with Synoptic Weather Maps. They used their open magnetosphere model to derive polar cap convection patterns and open/closed boundary locations. The model in several cases was able to reproduce the convection patterns reasonably well. The model was also used by Terry Onsager who used the magnetic and electric fields derived from the open model to trace particles from the magnetosheath to the polar cap. Using the model, he was able to show that the soft electron zone in the polar cap was magnetosheath origin particles that entered the magnetosphere along open field lines. Furthermore the combined model was able to provide a possible explanation for a dropout of particle fluxes in the polar cap as a natural consequence of model geometry. Postdoctoral associate Cheng Ding and Graduate student Jinwen Song are preparing a new version of the open magnetosphere model for distribution on the internet.

4.1.3 Solar System Plasmas

Professor P. A. Cloutier and his students continue their analysis of 14 years of Pioneer-Venus data. Recent work includes the discovery of a magnetic field rotation at the dayside Venus ionopause which correlates with the boundary between post-shock solar wind flow and Venus thermal ions. This discovery has led to diagnostic tools for interpretation of the planned Mars Global Surveyor magnetometer experiment, for which Cloutier serves as a Co-Investigator.

Professors T. W. Hill and R. A. Wolf continue their study of rotationally driven magnetospheric convection at Jupiter. This work involves numerical simulation of the outward transport of plasma from the centrifugally unstable Io plasma torus. They are also developing a simulation model of inner magnetospheric perturbations induced by the July, 1994 impacts of the Comet Shoemaker-Levy-9 fragments. The aim of this work is to account for the low-latitude ultraviolet aurora observed by HST after the K fragment impact, and the frequency-dependent enhancements of decimetric synchrotron emissions observed after the impacts.

4.2 Galactic Astronomy

4.2.1 Young Stellar Objects

Assistant Professor P. Hartigan continued his studies of young stellar objects, jets and shock waves. Some of the most interesting results came from analysis of deep HST images of the stellar jets HH 111 and HH 47. In these systems it is possible to identify the actual location of shocks in the outflows by comparing emission line images taken in Hα with images in [S II]. A paper about HH 47 featured on the cover of the *Astronomical Journal* was published in 1996 October, and a paper on the HH 111 results is being prepared for publication. Our group has been granted time in the next HST Cycle to reobserve these systems and measure proper motions. These new observations will allow us to compare the motion of the shocks in the jet with those predicted from numerical simulations.

Hartigan completed a study of the molecular bubble observed in Cepheus A. This region of high mass star formation has both high velocity shocks that excite optical lines and low velocity shocks that heat H_2. The molecular bubble surrounds the optical HH objects, but lies within the confines of the CO outflow observed at radio wavelengths. A series of small H_2 knots exists along the interior portion of the bubble, perhaps arising from cooling instabilities in the flow.

Hartigan and graduate student Parviz Ghavamian are working with J. Raymond (CfA) to model the free-free and synchrotron radiation expected from radiative shocks at high densities. We hope to be able to explain the observed radio characteristics of bow shocks in stellar jets with these models, and may apply the models to supernovae remnants. As part of his senior thesis, undergraduate Jason Tumlinson has been exploring the use of Ne V as a diagnostic in astrophysical shocks. The goal is to identify regions of Ne V emission by carefully comparing narrow-band images taken in the line and adjacent continuum with a blue-sensitive CCD camera. Observations of Ne V will help to quantify the shock velocities in the target objects.

4.2.2 H II Regions

Professor C. R. O'Dell and his students continue to intensively study the Orion Nebula with the HST and ground telescopes. Together with graduate student Shui Kwan Wong, he completed and published the results of a survey of the stars and compact emission line sources (1996, AJ, 111, 846.), the latter being circumstellar disks photoionized by the Trapezium stars. His student, Xihai Hu, completed his Ph.D. dissertation in 1996 May and has had accepted for publication (AJ) a study of the kinematics of the Orion HH objects. O'Dell also collaborated with M. J. McCaughrean of the Max Planck Institute for Astronomy in Heidelberg on a paper presenting detailed observations of the circumstellar disks around young stars that are seen in silhouette against the Orion Nebula (1996, AJ, 111, 1977.). A summary of the HST Orion results is in press in the Proceedings of the Paris

HST Science-II Conference held in 1995 December. This work was also summarized in an article on Orion by James B. Reston, Jr. which appeared in the 1995 December issue of the National Geographic Magazine. During the 1996/97 academic year, O'Dell is on sabbatical leave at MPIA, Heidelberg, as a recipient of an Humboldt Senior Research Fellowship.

Hartigan, with C. R. O'Dell and J. Morse (U Colo), has been reducing an extensive set of Fabry-Perot images of the Orion Nebula in the lines of Hα, [N II], [S II] and [O III]. These data should isolate the high velocity flows from the background photoionized gas clearly for the first time in Orion. Together, the FP data and HST images hold the key to understanding the dynamics of a typical H II region.

Professor R. J. Dufour has been pursuing several projects related to imagery and spectroscopy of Galactic H II regions. He and O'Dell are collaborators among a group, led by R. H. Rubin of NASA-Ames, which have obtained HST observations (WFPC, WFPC2, FOS, & GHRS) of the Orion Nebula in three observing cycles aimed at detailed model analyses of physical conditions and abundances. Papers on two aspects of the studies: formation of the low-ionization lines of [O I] and [Fe II] (1996, ApJ(Lett), 468, L115) and the gaseous-phase Fe-abundance from the UV [Fe IV] 2837Å line (Rubin *et al.* 1996, ApJ(Lett), in press) have been completed. Additional papers on temperature and density diagnostics (and fluctuations thereof), the UV-optical extinction curve, and abundances of CNONeSiFe in the Orion Nebula are being prepared. New observations of the spatial variation of UV-optical emission lines across ionization fronts, possible wind-shock fronts, and protostellar objects in the Orion Nebula have been proposed using STIS with HST during Cycle 7. In addition to this, Dufour has acquired echelle spectroscopy and interference filter imagery of several H II regions using telescopes at San Pedro Martir Observatory in Baja. In collaboration with M. Peimbert and R. Costero of IA/UNAM (Mexico) and D. Walter (South Carolina St.), he is studying O and N abundances from faint recombination lines and the spatial variation of temperature across the nebulae. Recently (1996 July), he and H. Castañeda of IAC (Spain) imaged M8 and M17 with the 1m telescope at La Palma to extend the T_e-mapping studies.

4.2.3 Planetary Nebulae

O'Dell is also using the HST to study the Cometary Knots seen in the nearest planetary nebula, the Helix Nebula. Together with graduate student Kerry P. Handron, he determined that there are about 3500 of these objects and that their characteristic masses are a few times that of the Earth. They are in radiative and possibly dynamic equilibrium with the central star and will probably survive ablation by photoionization. The results of this study have also been published (1996, AJ, 111, 1630).

Dufour has been active in studies related to abundances and temperature variations in planetary nebulae. He is collaborating with S. Torres-Peimbert, M. Peimbert, and M. Peña of IA/UNAM on HST imagery and spectroscopy of two halo PN, DDDM-1 and M2-29. Lucy deconvolved WFPC imagery of M2-29 taken in 1992 with HST indicated the presence of a jet emanating from M2-29. FOS UV-optical spectra taken in 1995 indicated that the N and O abundances in this PN are higher than previously believed and that it is not likely to be a member of the halo. He is also collaborating with astronomers in Mexico and Spain in a program of interference imagery of bright PN in the lines of [O III] and [N II] to map the electron temperature distribution across these objects. He is also collaborating with R. Rubin (NASA-Ames), P. Harrington (U. Maryland), S. Colgan (NASA-Ames), and D. Levine (IPAC) on a comprehensive UV(HST)-optical(SPM)-IR(ISO) spectroscopic study of abundances in bright PN from comparisons of both T_e-sensitive and T_e-insensitive emission lines of identical ions.

4.2.4 Supernova Remnants

Michel is active in theoretical work concerning the properties of neutron stars and their evolution. The primary work here is to simulate the particle motion about a rotating neutron star with an inclined magnetic field, and extension of earlier work with Jurgen Krauss-Polstorff now being undertaken with Ian Smith and graduate student Peter Thacker.

Professor F. C. Michel is involved with the analysis of HST images of the Crab Nebula which show major variations in the so-called ''wisps'' on times scales a short as a week, in collaboration with a group headed by Jeff Hester at Arizona State University. Initial results were presented during the 1996 June AAS meeting in Madison.

In collaboration with LLNL, the University of Michigan, Arizona and Colorado, Professor E. P. Liang is part of an effort to establish a laser plasma astrophysics initiative at LLNL to simulate astrophysical phenomena with the big lasers at LLNL. The idea is to train new plasma students who will be fluent in both laser plasmas and astrophysical plasmas. The first two projects are to simulate the Rayleigh-Taylor instabilities in a supernova and the pending interaction of SN1987A with its circumstellar ring. Experiments will be conducted on the Nova laser and the future NIF laser.

Dufour is PI on a program of HST FOS spectroscopy of condensations ejected by the supermassive star Eta Carinae last century. In 1995/6 FOS spectra covering the 1150-8500Å wavelength range were taken of ten locations in the ejecta surrounding Eta Carinae. Graduate student Tim Glover analyzed the 1995 spectra and reported the results for the ''S'' condensations located SW of the central object. We found that N/O and C/O are enhanced in these ejecta by factors of >1000 over ISM values near the sun. In addition, the UV emission lines of nitrogen are seen in four ionic states (N II, N III, N IV, and N V) and are indicative of radiative shocks with velocities $\sim$120-150 km s^{-1} for a gas that is N-rich and correspondingly depleted in C & O. Additional results on these regions, the homunculus, and recently obtained spectra of the NE jet were presented by Dufour and Glover at the 1996 October Luminous Blue Variables meeting in Kona, HI. Collaborators on this study include J. Hester (Arizona St.), D. Currie (U. Maryland), and D. van Orsow (STScI). As ''satellite'' investigations to the primary FOS observations, parallel WFPC2 imagery of regions in the Carina Nebula were obtained with HST and the results reported at the 1996 January and June AAS meetings.

4.2.5 Stellar Plasmas and Neutron Stars

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In collaboration with an international team of observers, Research Scientist I. A. Smith has been making significant progress in a program of multiwavelength observations of the quiescent counterparts to the Soft Gamma-Ray Repeaters The three known sources produce brief intense outbursts of low energy gamma rays, and it appears they are completely new manifestations of neutron stars. The discovery of quiescent infrared counterparts to two of them has been a significant breakthrough, but one which has pointed out our complete lack of understanding of these objects. In contrast, a counterpart to the third source has only been detected in X-rays. We have been making detailed spectroscopic and photometric observations of all three sources in the optical and near-infrared at the USNO, CTIO, and KPNO at 10μm using TIMMI on the 3.6-m at ESO, in the far-infrared using IRAS and ISO, in the submillimeter using the JCMT, and in the millimeter using BIMA and SEST.

Research Scientist Ian Smith and collaborators have been performing multiwavelength observations of Galactic black hole candidates. SEST observations of the region around GRS 1739-278 found a variable radio source, although it is uncertain whether this is the counterpart. Radio observations were made at Narrabri of GX 339-4 during its recent transition to the X-ray high state, in conjunction with our CGRO gamma-ray observing run: a preliminary analysis of the radio data promise surprising results. A search for an infrared stellar counterpart to 1E 1740.7-2942 was made using the IRTF: the data is currently being analyzed. We are currently setting up multiwavelength observing campaigns to coincide with our CGRO and XTE observations of GRS 1758-258 and GRS 1915+105 in 1997.

For many years, it was believed that the magnetic fields of isolated neutron stars decay as they age, although this has recently been challenged. To test this, Research Scientist Ian Smith developed Monte Carlo pulsar evolution codes; the results of these can be compared with the observed pulsars. New observations have shown that some pulsars are born with much higher velocities than was previously believed, and a popular model for the gamma-ray burst sources uses high velocity neutron stars in an extended Galactic halo. By adding a population of high velocity neutron stars to the isolated radio pulsar evolution simulations, it was found that a surprisingly large number of these high velocity pulsars could be seen. This means that any correct model for the gamma-ray bursters must also be consistent with the radio pulsar observations.

Professor J. Weisheit and his former graduate student, Michael Murillo (now at Los Alamos), have submitted to Physics Reports their comprehensive survey of atomic and plasma physics issues germane to the problem of ionization in hot, dense plasmas. The necessity of using dynamic screening models is established, and the competing effects of continuum lowering (which tends to increase ionization rates) and coulomb screening (which tends to decrease them) are shown in several numerical examples. Weisheit and graduate student David Geller are investigating modifications to the Rutherford formula for e-ion scattering in strongly magnetized plasmas. This work, which has applications to transport coefficients in, e.g., magnetic white dwarf stars and inertial fusion plasmas, shows that deflection is inhibited even in small impact parameter events, and hence that the usual replacement of the Debye length by the cyclotron radius in the Coulomb logarithm is not a good approximation.

4.2.6 High Energy Astrophysics

Professor R. C. Haymes is a member of the international team conducting a sky survey with the OSSE on NASA's Compton Gamma Ray Observatory. He and graduate student Michael Moss have been analyzing OSSE data on the Galactic black hole candidates GRS 1009-45 and GRS 1716-249. Both the energy spectra and light curves for radiation in the 50 - 150 keV energy interval are being investigated. The analyses are in progress and are expected to form the basis of the Ph.D thesis for Mr. Moss.

Liang continues research in high energy astrophysics in collaboration with Research Scientist Ian Smith, graduate students Anthony Crider, Chuan Luo, Mike Moss, summer student Sameer Sheth, visiting student Julia Dobrinskaya, and former students Vince Kargatis (now at Hughes STX) and Hui Li (now at Los Alamos) and Dr. Masaaki Kusunose of Japan.

Liang and Kargatis discovered a new property of gamma ray burst spectral evolution: for clean long smooth pulse decays, they find that the spectral break energy (where most of the power comes out) decreases exponentially, not as a function of time, but as a function of photon fluence (time integral of flux). More recently, Crider, Liang and coworkers found additional unique signatures of the evolution of the low energy power law below the break. Together these two properties suggest that the basic emission mechanism may be saturated Compton upscattering of soft photons with a decreasing Thomson depth.

Liang and collaborators further propose that the soft photons are self-emitted synchrotron photons in a weakly magnetized plasma with a field around 0.1-10G. This model also predicts that the ratio of the source distance to the emission region size should be of the order 10^{12} cm. In addition to explaining most of the known properties of gamma ray burst spectra and spectra evolution, this model makes numerous quantitative predictions that are currently being tested with BATSE data.

Luo and Liang found new transonic accretion disk solutions around black holes that can naturally explain the multicomponent spectra and multi-state transitions of Galactic black holes. Liang and students are currently completing the analysis and modeling of black hole spectral data from CGRO, RXTE, ASCA and other satellites. They have also performed time variability analysis and found QPOs in many cases.

Together with Hui Li and Masaaki Kusunose, Liang and students are now developing a state-of-art Monte Carlo radiation code coupled to Fokker-Planck particle transport code for the modeling of emission from compact objects. Liang is a guest investigator on CGRO, RXTE, and ASCA.

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4.3 Extragalactic Astronomy

Dufour, in collaboration with D. Garnett and E. Skillman at Minnesota and G. Shields of U. Texas at Austin, continues to study the most metal-poor star-forming galaxy known −I Zwicky 18 using HST. The results of WFPC2 imagery has been reported in several meetings and conference publications and is currently being written up for publication in the AJ. The imagery results show that I Zw 18 and a second Im galaxy located 15 arc sec to the NW are both resolved into stars and the second galaxy could be as near as 2 kpc to the starbursting main body. If so, this companion could have affected, even triggered the current starburst in I Zw 18. While the stars in I Zw 18 are no older than 30-50 Myr, evidence for stars at least as old as several 100 Myr are seen in the WFPC2 images of the companion and thus it could have an effect on the chemical evolution of the system. To determine in the distance of the companion, Dufour, C. Esteban, and H. Castañeda (both IAC, Spain) obtained a long-slit spectrogram of the brightest Hα knots in I Zw 18 and the companion with the 4.2m William Herschel telescope in La Palma in 1996 February. It was found that the radial velocities of the two knots were identical within errors of measurement and that the ionized gas surrounding I Zw 18 may have been tidally disturbed by the companion galaxy. The results have been accepted for publication in ApJ Letters and new observations are planned in early 1997.

Dufour, again in collaboration with Garnett, Skillman, & Shields, are studying the UV spectra of extragalactic H II regions using FOS on HST in a variety of galaxies. FOS spectra of two H II regions in I Zw 18 have been acquired and confirmed earlier suspicions that C/O is higher by about 0.3 dex compared to several other very-metal-poor irregular galaxies (1996, ApJ, in press). FOS spectra of H II regions in the spiral galaxies M101 and NGC 2403 are currently being acquired and will be used to study the C-abundance gradient in such galaxies for the first time. Dufour and Garnett have submitted a Cycle 7 proposal to do comprehensive UV-optical spectral studies of bright H II regions in the Magellanic Clouds using the new STIS on HST in 1997. Graduate student Cindy Kurt is completing a comprehensive study of the UV-optical spectrum of the peculiar dusty H II region in the SMC N88A based on FOS and CTIO spectra. All of these studies, taken together, should provide a good picture of the evolution of the CNO element group, and potential depletion effects by dust, in the ISM of star-forming galaxies for the first time.

Dufour is also analyzing parallel HST WFPC2 images of fields in the disks of M101 and NGC 2403 as a scientific spinoff of the primary HST spectroscopy studies previously mentioned. Images were taken in Hα, [O III] 5007Å, and F547M continuum bandpasses and will be used to study the detailed morphology and ionization structure of H II regions in the two galaxies at a spatial resolution of about ten times better than possible from the ground.

Weisheit and undergraduate student Kenneth Rines, are exploring the autocorrelation function ξ(r) for galaxies in clusters. Through a series of numerical experiments involving various power-law and polytropic mass distributions, they hope to segregate differing forms of ξ(r) for relaxed (virialized) and non-relaxed simulations of galaxy clusters, and thereby probe the question of whether or not the clusters Zwicky classified as ''irregular'' are bound, equilibrium systems.

4.4 Instrumentation Development

Haymes and graduate student M. Moss have been building a balloon-borne gamma-ray telescope called the Prometheus All Sky Survey (PASS.) The primary objective of PASS is to map the entire sky, and throughout the 0.1-10 MeV gamma-ray energy interval, for the locations and spectra of all persistent astronomical sources, with an angular resolution of 0.5 degrees, down to a limiting flux for spectral lines of 2×10^{-5} photons cm^{-2} sec^{-1}. The angular resolution of PASS is adequate to resolve even the most closely spaced candidates – the several objects that have been nominated as responsible for the gamma-ray spectral lines observed to be emanating from the Galactic Center Region. The PASS flux limit is fainter than any existing data. It is expected to resolve the discrepant spectral results reported by OSSE and COMPTEL for the Cas A supernova remnant.

PASS is be conducted with the Rice-developed balloon-borne gamma-ray telescope named Prometheus II. PASS achieves improved sensitivity through lowered instrumental background. Prometheus's position-sensing gamma-ray detector eliminates the instrumental background components arising from instrumental activation and to neutron interactions. Its coded aperture measures the background from all around the source direction, at the same time that it measures the source. This eliminates the systematic error otherwise introduced by offsetting the pointing direction for background observations.

For the PASS, Prometheus II will be suspended from unmanned, Long Duration Balloons (LDBs). The altitude of each balloon will be about 120,000 feet, which is less than one gamma-ray mean free path in from the top of Earth's atmosphere. During flight, Prometheus II will be continually spun in azimuth, at a fixed zenith angle. Earth's rotation will each day cause the entire accessible celestial hemisphere to pass through the coded viewfield of Prometheus II. The spectral, positional, and timing data, together with housekeeping information, will be stored on board. After the termination of each balloon flight the payload will be recovered. Upon recovery the stored data will be downloaded into Rice computers, while the payload is refurbished for reflight.

Two sequential flights of NASA-furnished LDBs are planned. The first one is to be launched from Alaska. The second mission, referred to as PASS-2, is to be launched from either Antarctica or Australia. Each of the two-week balloon flights is expected to fully circle the globe once, at a roughly constant latitude. NASA's National Scientific Balloon Facility is to conduct the launches, mission operations, and payload recoveries. Further information on PASS may be found at its website, ''Prometheus All Sky Survey (PASS).'' The URL address is, http://spacsun.rice.edu/ moss/ pass.html

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