University of Maryland
Department of Astronomy
College Park, Maryland 20742

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This report covers the period 1 October 1998 to 30 September 1999.

1. PEOPLE

The teaching and research staff consisted of Full professors: Marvin Leventhal (Chair), Michael A'Hearn, James Harrington, Mukul Kundu, Lee Mundy (new promotion), Dennis Papadopoulos, William Rose, John Trasco (associate director) , Virginia Trimble (visiting), Stuart Vogel, and Andrew Wilson.

Associate professors: Andrew Harris and James Stone.

Assistant professors: Douglas Hamilton, Stacy McGaugh, Coleman Miller (new appointment), Eve Ostriker, and Sylvain Veilleux.

Instructors and teaching specialists: Grace Deming, Beth Hufnagel, Ramon Lopez, and David Theison.

Professors emeriti: Roger Bell, James Earl (from 1 January), William Erickson, Frank Kerr, and Donat Wentzel.

Senior research scientists: Charles Goodrich (new promotion) and Surjaial Sharma (new promotion).

Associate research scientists: Keith Arnaud, Suchitra Balachandran (new promotion), Lucy-Ann McFadden, Gennady Milihk, Edward Schmahl, and Stephen White.

Assistant research scientists: Wan Chen, Thejappa Golla, Tilak Hewagama, Timothy Livengood, Michael Loewenstein, Grzegorz Madjeski, Chee Ng, and Mark Wolfire (new promotion).

Research associates and assistants: John Cordes, Siobhan Dinyes, Edwin Grayzeck, Carole Mundell (moving on to a Royal Society Fellowship in Liverpool, UK), Alexander Nindos, Marc Pound, Kevin Rauch (moving on to a Davis Fellowship at Johns Hopkins University), Anne Raugh, Leslie Sage, Patrick Shopbell, Mikhail Sitnov, Phillip Sprangle, Johannes Staguhn, Peter Teuben, Neal Turner, Gretchen Walker, Dennis Wellnitz, and Friedrich Wyrowski.

A PhD was earned by Arunav Kundu (now a postdoctoral fellow at University of Virginia) and MS degrees by Wayne Baumgartner, Xi Shao, and James Marshall.

2. SERVICE AND RECOGNITION

Asteroid 4958 Wellnitz was named for Dennis Wellnitz in July, 1999. It joins Asteroids A'Hearn and McFadden among those named for department members.

Assistant professor Douglas Hamilton received the 1999 Harold C. Urey Prize of the Division of Planetary Sciences of the American Astronomical Society. Assistant professor Sylvain Veileux received a Cottrell Scholarship for integrated teaching and research innovation and an NSF five-year CAREER award. Graduate student Kartik Sheth was named Alumni Scholar by Grinnell College. Intramural research awards went to Assistant Professor Eve Ostriker and Professor Andrew Wilson. Graduate student Laura Woodney held a NASA graduate fellowship. Medals and group achievement awards from NASA, NSF, and the Navy went to: Lucy McFadden (NEAR Project Team), Ramon Lopez (Global Geospace Science), Johannes Staguhn (research in Antarctica), and Edward Schmahl (High Energy Solar Spectroscopic Imager Team).

The Deep Impact cometary mission, with Professor Michael A'Hearn as principal investigator, was selected as part of the NASA Discovery Program. Co-Investigator Lucy McFadden will coordinate outreach activities as well as serve on the spectroscopy team. New Assistant Professor Stacy McGaugh was among the department members who also received new grants during the year.

Eve Ostriker has been part of the Theory and Computation Panel of the Astronomy Decadal Survey, and Virginia Trimble part of the panel on Benefits to the Nation from Astronomy. The department was represented on advisory and users' committees for SIRTF; the NASA Planetary Protection Task Force, the Near-Earth Orbit Program Office, Space Telescope Science Institute, AXAF (now Chandra), the NASA Structure and Evolution of the Universe Subcommittee, the NSF Active Galaxies Proposal Review Board, SOFIA, the NASA Submillimeter program and other NASA review panels, SOFIA, National Radio Astronomy Observatory users and visiting committees, and committees of the American Astronomical Society, the American Physical Society, and a number of other professional organizations by Michael A'Hearn, Andrew Wilson, Andrew Harris, Stephen White, Beth Hufnagel, and Virginia Trimble.

A'Hearn continued a term as President of Division III (Planetary Systems Sciences) of the International Astronomical Union, and Trimble continued terms as vice-president of the IAU and of the American Astronomical Society and as council member of the American Physical Society. Departmental participation in organization of conferences and presentation of invited lectures, colloquia, and seminars was too extensive to list completely, but included talks by graduate students Sven Geier, Kartik Sheth and Jie Zhang, instructors Ramon Lopez and David Theison, and research associates Neal Turner, and Dennis Wellnitz.

Andrew Harris was part of the editorial board of *Experimental Astronomy*, and other department members helped out with the *Journal of Astrophysics and Astronomy, Scientometrics*, and other professional publications. Research associate, Leslie Sage, provided a regular column for the *Journal of the Royal Astronomical Society of Canada*, and other department members wrote for *Sky and Telescope* and other pro-am journals.

The department hosted the Ninth Annual October Astrophysics Conference, jointly organized with Goddard Space Flight Center. The 1998 topic was the universe at redshifts $\gtrsim$ 2-5, ''After the Dark Ages: When Galaxies were Young.'' The 1999 topic will be Cosmic Explosions.

3. EDUCATION AND OUTREACH

More than 1600 students passed through departmental courses for non-majors during the year. Thus more than a third of University of Maryland graduates have taken at least one astronomy course. The University Observatory was, as always, open to the public two nights a month, and about 2000 people attended, hearing talks by graduate students, research staff, and faculty, and star gazing on the relatively rare occasions when weather permitted.

Professor Emeritus Donat Wentzel continued to coordinate the program of IAU Teaching for Astronomy Development, directing projects in Vietnam, Central American, and Morocco. He also chaired the SOC for a joint IAU-COSPAR-UN education workshop in Capacity Building in astronomy and space science. Patrick Shopbell is part of a US-Japanese collaboration whose goal is to permit a group of high school students from both countries to work together operating a 24-inch telescope on Mt. Wilson. They will have access both to real-time data and to archives from HST and the Sloan Digital Sky Survey.

David Theison was named the Outstanding Instructor within the College of Computer, Mathematical, and Physical Sciences for 1998. He was also one of the ten Lilly-Center for Teaching Fellows who organized the first campus-wide Undergraduate Research Symposium in spring 1999. Lee Mundy received the Dean's Award for Excellence in Teaching in 1999 from the College of Computer, Mathematical, and Physical Sciences. Ramon Lopez received a Scientist in Education Achievement Award from the Space Science Institute.

Lucy McFadden is a co-founder-director of the Explore-it-all Science Center, a hands-on, mobile experience for residents of the greater Washington area. She also completed her second year as director of the College Park Scholars program, for academically talented freshmen and sophomores who combine special seminars and other academic experiences with some teaching, research, and outreach of their own with middle school and high school students.

Grace Deming and Beth Hufnagel were part of a collaboration for astronomy education, which produced the first validated questionaire for undergraduate, non-major astronomy courses. Hufnagel also served on the Committee on Astronomy Education of the American Association of Physics Teachers and on an AAS astronomy education research panel.

New assistant professor Cole Miller gave a series of lectures on astronomy within the adult education program of the Adler Planetarium and another for gifted high school students. Other department members spoke to community groups and amateur astronomers at locations coast to coast.

4. GRADUATE STUDENT RESEARCH

Yan Fernández successfully defended his PhD dissertation, directed by Prof. A'Hearn, on the physical nature and evolution of the nuclei of **comets**. A better understanding of the ensemble properties of cometary nuclei, which have remained mostly pristine since their formation 4.5 Gyr ago, can lead to the ''Holy Grail'' of comet sciences: the properties and collisional history of the planetesimals that formed the planets of the Solar System. Based on measurements of the thermal continuum and scattered sunlight, he has addressed the problems of characterizing the size, reflectivity, rotation state, and thermal properties of several nuclei. These are often difficult to study – there are well-determined sizes for only about a dozen of the thousand-plus comets known – but recent advances in infrared detector arrays and image processing techniques have improved our ability to study the nuclei, and the coming years will see a rapid increase in the rate of new data. Fernández is continuing his work by looking at the thermal behavior of the nucleus of Comet Hale-Bopp, using, among other data, the first-ever interferometric microwave detection of a cometary nucleus.

Amy Fredericks is completing a research project, directed by Dr. Balachandran, on the abundance of' **lithium** in the stars of open cluster IC 4651, whose age is about 2.4 billion years. The amount of depletion of lithium in main sequence stars of different ages, masses, and rotation rates is an important probe of how convection and mixing works in these stars.

Kayhan Gultekin is completing a project with colleagues at his undergraduate institution on thermal dust emission from the disk and envelope surrounding the high-mass protostar L1206A. Such **protostellar disks** may be the sites of planet formation.

Don Horner is involved in two projects concerning **X-ray emitting clusters and groups of galaxies**. A worldwide collaboration called the Wide Angle ROSAT Pointed Survey (WARPS) is a study of sources serendipitously detected in ROSAT pointed observations. Much of Horner's work has been in obtaining and analyzing optical images and spectra of the candidate sources. He is also working with Richard Mushotzky of Goddard Space Flight Center on the relationships among X-ray luminosity, gas temperature, and total mass of the clusters, to extend the relationships down to groups of galaxies. The combination of the surveys and correlations will permit a measurement of the local distribution of masses of clusters and groups, which in term feeds into the total local mass density of the universe and cosmological models.

Woong-Tae Kim has completed a second year research project with Dr. Ostriker investigating magnetic shear and buoyancy instabilities in rotating, cylindrical flows, such as magnetized protostellar winds, accretion disks, and so forth. He is beginning a new (probably thesis) investigation with Drs. Ostriker and Stone and Charles Gammie (Univ. of Illinois) which will study the internal dynamics and formation of **molecular clouds** using direct numerical simulations.

Kip Kuntz is persuing three topics in **X-ray astronomy**, with Steven Snowden, Fran Verter, and other astronomers at Goddard Space Flight Center. The first is a search for fluctuations in the diffuse soft X-ray background on scales from five arcminutes to a few degrees. The goal is to try to identify the component of diffuse, hot, intergalactic gas, which may contain most of the ''missing baryons'' in the universe. The second is a decomposition of the spectrum of that background into thermal and non-thermal components coming from different parts of the interstellar gas and from beyond the Milky Way. The third aims to measure masses of molecular clouds in the Milky Way which absorb the X-ray backgrounds.

Kristen Miller is carrying out global computer simulations of the **accretion disks around neutron stars and black holes** under the direction of Dr. Stone. There are two goals. The first is to look for non-axisymmetric phenomena which affect the evolution of disks and can be seen only in global calculations, not local ones. The second will be an attempt to determine whether convection plays an major role in the transport of angular momentum in the disks. It does not in the disks around young stars, and if it turns out to be ineffective in these simulations as well, then convection will effectively be eliminated as a source of transport in any astronomical disk.

Scott Miller is working on a thesis with Dr. Veilleux to try to understand the **diffuse ionized gas** in the halos of nearby, edge-on **spiral galaxies**. The first step was a survey at Hα to find out the range of gas morphologies that occur. Phase two is spectroscopy of those galaxies with prominent, extended emission. Emission line ratios will help in finding out where the gas came from and how it is ionized. The final step will be mathematical modeling of the gas aimed at reproducing the observed line ratios.

Neil Nagar is well along on a thesis with Prof. Wilson and Dr. Falcke (a former research associate) tracking down ‘‘dead’’ **quasars**. Using radio observations, particularly from the VLA and VLBA interferometric arrays, they are looking at a number of nearby bright galaxies which host low-luminosity active nuclei. The goal is to determine whether there are black holes and accretion disks in these nuclei, and, if so, to estimate the black hole mass and try to figure out why the current luminosities are low. This putative evolutionary link between very luminous quasars and seemingly normal galaxies has important implications for how galaxies must have formed.

Rob Piontek is working on a **stellar atmosphere code**, intended to incorporate the minimum amount of physics needed to produce model atmospheres and synthetic spectra. It should be useful in advanced undergraduate and beginning graduate courses.

Kartik Sheth's thesis project with Dr. Vogel is a study of the distribution of **molecular gas in nearby spiral galaxies**, based on a survey (BIMA SONG) with the BIMA array. The survey maps the inner three arcminutes of 44 galaxies in the CO (J = 1-0) emission line. The goal is increased understanding of star formation in barred spirals, where comparison of the molecular gas distribution and kinematics with the amount of recent star formation may clarify how, when, and why star formation occurs. Barred galaxies have three different regions: the bar ends, the bar, and the circumnuclear regions, which are known to differ in star formation activity. Sheth and Vogel hope to distill common threads which tie together the phenomena and environments of star formation.

Keith Watt is working with Charles Misner (physics department) to calculate the waveforms of **gravitational radiation** emitted by coalescing binary neutron stars. The waveforms are determined using a scalar theory of gravity, which is much more amenable to numerical methods than is full general relativity, but which still generates results which are a reasonable approximation to those found using GR. The results will help to develop gravitational wave templates for use by LIGO, the Laser Interferometry Gravitational-Wave Observatory.

Laura Woodney's thesis project with Dr. A'Hearn is a study of **cometary chemistry** observed at multiple wavelengths. Comet Hale-Bopp is the first for which there are simultaneous high resolution images in the light of the parent-daughter pair HCN and CN, permitting an examination of how they are related. The key result is that HCN and CN in jets are closely related, but neither is well correlated with the dust. Thus HCN is probably the main source for the CN jets, though there could be a small contribution from dust or CHON particles of sizes that don't show up in either optical or radio emission. The most exciting result from the radio images is that not all jets have the same ratio of CS to HCN. This means that the nucleus must have formed from material in the early solar system that was not chemically homogeneous and that the comet managed to bring together material originating at different distances from the sun or in different azimuthal zones.

Jie Zhang is looking, along with Prof. Kundu and Dr. White, at the **statistics of coronal bright points**, emphasizing evolution or time variability, spatial distribution, and the range of total energies involved. They are also examining the variations of coronal structures and energetics during the rising phase of sunspot cycle 23. These studies will help in understanding the complexity and dynamics of the solar corona.

5. FACULTY RESEARCH

Each member of the teaching and research faculty was asked to provide a paragraph description of the research project about which s/he is currently most excited. About two-thirds of the department members were able to participate.

5.1 Education, Sociology, and History

Dave Theison's continuing research interests include developing innovative teaching and learning strategies to engage non-science majors in the study of science. The interdisciplinary classes he has created for the University Honors Program include ‘‘The Cultural Significance of Astronomy,’’ ‘‘The Science in Science Fiction,’’ and an honors version of introductory astronomy that is video-based and structured around real-life observational experiences with binoculars. At present, Theison is also restructuring the department's ‘‘Life in the Universe’’ class to reflect more fully the new and rapidly developing interdisciplinary field of astrobiology. Linked to this was his creation of ‘‘The Mars Room,’’ an interactive and multidisciplinary exhibit accessible to the entire campus in our undergraduate library.

Virginia Trimble has waded into two historical problems. First is the development of professional astronomical societies and journals. The biggest surprise so far is that, although the numbers of astronomers and published papers has increased by a factor 100 or so through the 20th century, the range of journals in which they are published has contracted by a factor of about 10. Power is thus concentrated in a decreasing number of editorial hands. Second is the proto-history of gravitational lensing, where the least-known fact is just how often lensing was independently rediscovered, from about 1800 to the mid 1950s. Einstein and Zwicky come somewhere near the middle of the list of discoverers, not at the beginning or end.

5.2 The Solar System and the Sun

Lucy McFadden and Dennis Wellnitz prepared for the Near-Earth Asteroid Rendezvous mission but ended up analyzing data from a flyby after the spacecraft's main engine shut down seconds after a scheduled burn and before completion of the necessary trajectory correction to place it in orbit around 433 Eros. They are preparing again for orbit this year, with better knowledge of the shape of Eros and confirmation of albedo variations gleaned from ground-based observations.

The Deep Impact mission, PI Michael A'Hearn, was selected by NASA as the eighth Discovery mission in July. This mission will recreate a meteorite impact into a cometary nucleus in order to excavate a large crater. The goal is to study the material deep below the surface of the nucleus with optical imaging and near-infrared spectroscopy. The mission will provide information on the density, porosity, and strength of the surface layers, the depth to which the surface layers are differentiated by evolution, and the compositional heterogeneity both horizontally and radially in the cometary nucleus. The primary target is 9P/Tempel 1, with launch in January 2004 and impact in July 2005. The events associated with the impact will be observable from a wide variety of Earth-based telescopes and should even be visible with binoculars.

Ed Grayzeck and M. Martin (JPL) continued work with Digital Versatile Disk (DVD) media as storage for scientific (NASA) data. Along with J. Hyon (JPL) they are preparing a white paper for the Planetary Data System, which has adopted this medium for archival purposes. Preliminary findings have been presented at working group meetings and symposia.

Early in the history of the Solar System's formation, Jupiter is predicted to have been a 10 Earth-mass rocky protoplanet accreting gas from the primordial solar nebular, the disk of dust and gas surrounding the young Sun. Over several million years, Jupiter slowly acquired its massive Hydrogen and Helium atmosphere directly from the primodial gas disk. Doug Hamilton and a former student, Heather Fleming, have recently calculated the influence of Jupiter's mass growth from a 10 Earth mass core to its current 330 Earth masses on the orbits of the Trojan asteroids, objects that currently reside in Jupiter's orbit and oscillate stably around the Lagrange points 60 degrees ahead and behind the giant planet. They find, with both analytic and numerical methods, that Jupiter's 30-fold mass increase has a stabilizing effect on Trojan orbits, systematically driving their *libration amplitudes* down by about a factor of 2.5. The libration amplitude is defined to be the angular extent of the oscillation around the Lagrange points. The shrinking of Trojan orbits acts to stabilize them against perturbations from the other planets; many early Trojans are drawn into orbits that are stable over the age of the Solar System. This effect may be responsible for the current extremely large number of Trojans asteroids in comparison to other asteroid populations. Fully one-third of all asteroids are Trojans and are locked in a special 1:1 resonant relationship with Jupiter. Hamilton and Fleming are currently assessing other dynamical mechanisms likely to have been important in the early Solar System in order to test their hypothesis for the origin of the Trojan asteroids.

Edward Schmahl has been working with Goddard and UC Berkeley scientists in developing the High Energy Solar Spectroscopic Imager (HESSI), which will be the first arc-second class imager and 1-keV resolution spectrometer to observe solar and cosmic X-ray and gamma-ray bursts, starting in July 2000. The prime goal of HESSI is to determine the physical mechanisms of particle acceleration on the Sun and in the cosmos. A number of innovative techniques were used to align and test the subcollimator grids to the micron level during construction of the imager, completed in October, 1999. The telescope will use Fourier imaging techniques like those of radio astronomy, and several new mapping methods and methods of analysis have been implemented to permit PCs and small workstations to map bursts in real time as a function of time and energy during the projected 3-year mission.

Using the two-component temperature model of the sun's corona, based upon the spectral lines observed by SOHO/EIT, Jie Zhang (graduate student), Mukul Kundu, and Stephen White have been studying the question of reconciliation of active region radio brightness temperatures computed from EUV coronal spectral lines with the observed values obtained with the VLA. They find that reconciliation is easily obtained if the coronal iron abundance is higher by a factor of about 5 than the commonly accepted value. They have also been studying the solar cycle variation of the coronal EUV intensity: they find that there may be two components - a base corona which changes little and an enhanced corona which seems to be magnetically controlled and thus varies with the solar cycle. Zhang and Kundu have been doing a statistical study of EUV Coronal Bright Points (EBPs) and comparing them with X-ray Bright Points (XBPS). Alexander Nindos, White and Kundu have been working on a flare model using simultaneously obtained VLA data at 2 and 6 cm wavelengths. Kundu, Nindos, White and others have started a general study of the relationship of soft X-ray emission and gyroresonance microwave sources, primarily using the Nobeyama 17 GHz imaging data and Yohkoh soft X-ray imaging data. Kundu and White have been studying the evolution of microwave active regions and their flare productivity, with particular reference to the interaction between loops as the flare trigger. Kundu and White have started to use certain flares observed by BIMA and the Nobeyama radioheliograph to determine if the millimeter burst emitting electrons at 86 GHz form a different population than the energetic electrons responsible for common microwave burst emission.

The main unresolved issue in type III burst physics is the identification of the nonlinear mechanisms responsible for electron beam stabilization, and conversion of Langmuir waves into escaping radiation at the fundamental and second harmonic of the electron plasma frequency. One can address this by using the in-situ observations of waves associated with local type III bursts. Thejappa Golla and colleagues have identified several local type III bursts in the Ulysses Unified Radio and Plasma Experiment (URAP) data. They have analyzed the high time resolution $\sim$ 1 millisecond data during these type III events, which show that the Langmuir wave packets, i.e., localized electrostatic plasma waves with frequencies near the local electron plasma frequencies, occur as broad intense peaks with time scales ranging from 15 to 90 milliseconds (6-27 km). They show that the normalized peak energy densities of the broad Langmuir wave packets, which are of the order of 10^{-5} are well above the estimated modulational instability threshold of $\sim 10^{-8}$. They have measured the spatial scales L of these wave packets and have shown that they range from 1 to 5 Langmuir wavelengths as expected of the oscillating or envelope solitons. One of the potentially interesting results of this study is that the physical width of these packets scales with the square root of the wave energy. This is the scaling predicted for 1D envelope solitons. By solving the Zakharov equations, they have obtained the solution in the form of envelope solitons for typical solar wind conditions. They show that the observed widths of these broad Langmuir wave packets compare very well with the theoretically calculated widths of envelope solitons. Thus, they have demonstrated that most probably the broad Langmuir wave packets observed during several local type III events correspond to Langmuir envelope solitons, which are the main signatures of strong Langmuir turbulence. This presents the first observational evidence for the generation of Langmuir envelope solitons in the source regions of solar type III radio bursts. The solitons appear to be formed by electron beams which excite either the modulational instability or oscillating two-stream instability (OTSI). These observations indicate that strong turbulence processes, such as the modulational instability or the OTSI play important roles not only in stabilizing the electron beams that produce type III bursts, but also in converting Langmuir waves into electromagnetic waves at the fundamental and second harmonic of the electron plasma frequency.

5.3 Star Formation and Nebulae

To shed light on the early phases of high-mass star formation, Friedrich Wyrowski and colleagues use the BIMA array in three complementary approaches:
With the new BIMA 1mm capabilities, the chemical and physical conditions of hot molecular cores associated with ultracompact HII regions are explored.

High-mass protostars without any free-free emission, meaning that no Ultra-Compact HII region has formed yet, are studied. Several hot cores are found indicating that the embedded sources are heating their circumstellar environs.

Cold, collapsing condensations within a new population of infrared dark clouds (IRDCs) are observed. The IRDCs appear to be a population of extremely large, dense molecular clouds harboring cores in the earliest stages of probable high-mass star formation.

J. P. Harrington continues to work on planetary and proto-planetary nebulae in collaboration with K. J. Borkowski (N. Carolina State). They completed a search for jets in planetary nebulae using the Hubble Space Telescope (HST), and conclude that true jets are rare in mature (as opposed to proto-) planetary nebulae. Their most convincing jet, aside from NGC 6543 (the Cat's Eye), is IC 4593. On the other hand, ''cometary structures,'' with a dense clump facing the star, are not uncommon – NGC 2392 (the Eskimo) is an outstanding example of a PN with such features.

Harrington and Borkowski have now observed the proto-planetary nebula He-3-1475 with the STIS spectrograph of HST. From these spectra they obtain a detailed velocity map of its spectacular jets, which are conical in shape and converge to knots at their tips. The flow first accelerates to a maximum of $\sim \pm 900$ km/s, then slows somewhat toward the apex of the cone; finally there is an abrupt deceleration of over 500 km/s when the flow hits the knot. It will be a challenge to construct a model of this behavior.

They are also using the HST to obtain further data on the young PN BD+30°3639. This nebula is known to be chemically inhomogeneous: C-rich in the inner zones and O-rich in the outer neutral envelope. STIS spectra will allow mapping of the C/O ratio at the 0.1 arcsec resolution of HST, which should reflect the rapid chemical evolution of the central star.

The first phase of the ''PDR Toolbox'' came on-line. This WEB page developed by Drs. M. Wolfire, L. Mundy, M. Pound and S. Lord (IPAC) provides diagnostic contour plots from Photodissociation Region (PDR) models. Using a set of infrared line and continuum observations users can determine the gas density, gas temperature, and UV field illuminating the PDR gas. The WEB page was developed under a NASA ADP grant (PI Wolfire) and can be accessed through the URL http://dustem.astro.umd.edu or from a link on the IPAC home page.

5.4 High Energy and Theoretical Astrophysics

The extreme nature of neutron stars and black holes means that they can be used as unique probes of strong gravity and dense matter. The advent of a new generation of high energy resolution X-ray satellites such as Chandra, XMM, and Astro-E, plus planned high-area missions such as Constellation-X, produces optimism that with careful modeling and comparison with these new data we will be able, for the first time, to make quantitative tests of general relativity in a strong gravity regime. We may even be able to constrain the equation of state of matter at supranuclear densities to tighter precision than is now possible from terrestrial experiments. In anticipation of these data Cole Miller is beginning a program of modeling and simulation in collaboration with scientists at Goddard Space Flight Center and elsewhere. He is concentrating on the kilohertz oscillations in the brightness of neutron-star low-mass X-ray binaries, both in their persistent, accretion-powered emission and in their bursting, thermonuclear-powered emission. Preliminary modeling of the waveforms from thermonuclear burst oscillations suggests that a future large-area X-ray timing mission could strongly constrain the high-density equation of state, and that a combination of spectral and timing information could provide redundant self-consistency checks of the predictions of general relativity in strong gravity. He plans to expand the simulation software greatly, by including effects such as frame-dragging, scattering, and Comptonization.

Collaborating with D. S. Main and D. M. Smith (UC Berkeley), W. A. Heindel (UCSD), J. Swank (NASA/ GSFC), and I. F. Mirabel (CEN/SACLAY), Marv Leventhal has contributed to the long term X-ray monitoring of the galactic bulge black hole candidates 1E 1740.7-2942 and GRS 1758-258 using data from the Proportional Counter Array on the Rossi X-ray Timing Explorer (RXTE). During the three year study, the flux of each object has varied by up to a factor of 3 and the indices of the enercy spectra have varied by no more than 0.4. The power spectra are similar to other black-hole candidates: flat topped noise, breaking to a power law. Each object has exhibited a brightening that lasted for several months and we have found lags between the power law index and the flux, which are about 90 degrees out of phase.

In accretion disks which fuel black holes in active galaxies, the energy density in photons may greatly exceed that in the thermal motions of the gas. How this disk material loses angular momentum and spirals towards the black hole is not known. When photon energy density is low, angular momentum can be transferred by the magneto-rotational or Balbus-Hawley instability. With James Stone, Neal Turner is developing numerical methods to investigate the case where photons dominate the total energy of a fluid threaded by magnetic field. The magneto-rotational instability may also have made accretion possible in the part of the proto-Solar nebula within the Earth's present orbit. This region was a poor conductor of electricity. With P. Bodenheimer (UC Santa Cruz) he is examining how dissipation of magnetic field and accompanying heating modify the instability, and how magnetic buoyancy effects may lead to ejection of magnetized material from disks and generation of winds and jets like those of many young stars today.

Eve Ostriker, in collaboration with J. Stone and C. Gammie (U. Illinois), is continuing to model the evolution of dynamics and structure in star-forming molecular clouds using numerical magnetohydrodynamics in two and three dimensions. Analysis of these simulations has led to an increased understanding of observed velocity and density structure in Giant Molecular Cloud Systems; explaining, for example, weak variation of linewidth with size scale for ''pressure-confined clumps'' as due to foreground and background contributions within the cloud. In addition, analysis of simulations indicates that polarization maps may be used to discriminate mean field strengths in clouds.

Ostriker has worked with student W.-T. Kim on studying axisymmetric and nonaxisymmetric instabilities in magnetized, rotating winds and disks. In addition to large-scale expansion-mode instabilities, both poloidal-field dominated and toroidal-field dominated winds may suffer from bouyancy instabilities analogous to the Parker instability, with the centrifugal force playing the role of gravity. The magnetorotational (Balbus-Hawley) instability, however, is suppressed in cold winds, due to strong compressibility. Large scale modes may lead to the conversion of jets to wide-angle winds, whereas small-scale modes may lead to radial mixing.

Stone, in collaboration with graduate students K. Miller, T. Fleming, C. Lee, and postdoctoral research associate N. Turner continues to study the dynamics of magnetized accretion disks and outflows primarily using numerical methods. Using large scale simulations on massively parallel supercomputers, global three-dimensional simulations which span up to two decades in radius and which are evolved for thousands of orbital times are now possible. Such calculations can be used to test the most fundamental aspects of accretion disk theory, for example whether the resulting accretion flow can ever be described by a steady-state approximation (e.g., is the accretion rate constant with radius?). Both geometrically thin and thick accretion flows are being studied. In the latter case, we have begun to study the nonlinear stage of MHD turbulence in a radiation dominated fluid in order to study the dynamics of accretion flows around compact objects such as black holes and neutron stars.

In previous research, William K. Rose has presented models for compact and extended radio sources. More recently Rose has examined how the nature of these models should depend on redshift. This work provides explanations for the observed steepening of the average spectral index of radio sources with redshift and also for the observed smaller dimensions of high redshift sources. It also predicts that the number of strong compact radio sources such as radio loud quasars should decrease with redshift more rapidly than the corresponding number of radio quiet sources.

5.5 Extragalactic Astronomy, Including Active Galaxies

In collaboration with Vera Rubin (DTM), Stacy McGaugh has been measuring high resolution optical rotation curves of low surface brightness galaxies to supplement existing radio data. Precision rotation curves of dark-matter-dominated, low-surface-brightness galaxies provide maps of the halo mass distribution. These can be used to test cosmological structure formation models, leading to strong limits on cosmological parameters like the total and baryonic mass densities and the Hubble constant.

Sylvain Veilleux, D. B. Sanders (Univ. of Hawaii), and D. C. Kim (ASIAA) are continuing their imaging and spectroscopic survey of a large sample of ultraluminous ($\log [L_{IR}/L_{\odot}] > 12$) IRAS galaxies. Much of the spectroscopic portion of this survey was recently published in the Astrophysical Journal. The main effort now focuses on completing the analysis of the imaging data and combining these data with the results of the spectroscopic analysis to look for a possible evolutionary link between these objects and optical quasars.

In collaboration with J. Bland-Hawthorn (AAO), G. N. Cecil (Univ. of North Carolina), S. T. Miller (Univ. of Maryland), R. B. Tully (Univ. of Hawaii), and S. Vogel (Univ. of Maryland), Veilleux is carrying out a comprehensive study of the warm ionized medium on the outskirts of nearby disk galaxies. The physical state, distribution, and velocity structure of this material are relevant for understanding large-scale galactic winds (''superwinds'') and fountains in active and normal galaxies, quasar absorption-line systems, the baryonic content of the universe, the formation and evolution of galaxies, and for measuring the mass and distribution of dark matter in galaxies. The distribution of the line-emitting gas in a complete sample of nearby galaxies is being mapped down to unprecedented flux levels using state-of-the-art optical Fabry-Perot interferometers and recently developed observational techniques. Part of this work will constitute S. Miller's Ph.D. thesis at Maryland.

As part of Andrew Wilson's group, Patrick Shopbell is preparing to analyze X-ray imagery of 10 of the most important active galaxies. The data will be taken this fall with the new Chandra X-ray Observatory (CXO) and will provide us with by far the best X-ray images ever obtained of active galactic nuclei, galactic jets, and extended hot galaxy halos. With a spatial resolution 10X any previous X-ray observatory, the images will be comparable to optical images taken from the ground and with the Hubble Space Telescope, allowing us to make a highly detailed analysis of the very hot, energetic gaseous components of active galaxies.

Motivated by the success of observations of the quasar MR2251-178, we have embarked on further observations of extended ionized gas in a number of quasars and active galaxies, using the TTF instrument. Initial indications are that these observations will prove successful, allowing us to understand the extent of previously unseen gas in the surroundings of galaxies, as well as the influence of galactic nuclei on these extended environments. Such observations are important when one starts to consider larger issues such as galaxy formation and the propagation of heavier elements throughout the Universe.

Andrew Wilson, in collaboration with A. L. Roy, J. S. Ulvestad, J. A. Braatz (NRAO), E. J. M. Colbert (GSFC), K. A. Weaver (JHU), C. Henkel (MPIfR), M. Matsuoka, S. Xue (RIKEN) and N. Iyomoto (U. Tokyo), completed an investigation of absorbing material towards the nucleus of the LINER galaxy NGC 2639. This galactic nucleus exhibits water vapor megamasers, so plausibly posseses an edge-on viewed accretion disk and the results are relevant to the physical state of this disk. VLBA radio maps at three frequencies and an ASCA X-ray spectrum were obtained to search for free-free and photoelectric absorptions, respectively. The radio observations reveal a compact ($<$ 0.2 pc) nuclear source with a spectrum that turns over sharply near 5 GHz. The X-ray spectrum appears to show a low energy cut-off due to photoelectric absorption by an equivalent hydrogen column of $\simeq 5 \times 10^{23}$ cm^{-2}. Assuming the low frequency radio cut-off is a result of free-free absorption, the ratio $\int n_e^2 dl / \int n_H dl$ may be determined. The resulting ionization fraction is discussed in terms of models in which molecular and atomic gas is ionized by a nuclear source.

Pierre Ferruit, Wilson and J. S. Mulchaey (OCIW) continued a program of emission-line and continuum imaging Seyfert galaxies with the Hubble Space Telescope. Results were obtained for 14 galaxies, including the nearby galaxy NGC 3516 which is known from ground-based observations to show an extended, bi-polar nebulosity. By combining images in emission-lines and an image of the obscuration, it is shown that gas to the southwest (northeast) lies on the near (far) side of the galaxy stellar disk. The consequences of this geometry for the kinematics of the ionized gas are discussed.

N. Nagar, Wilson, Mulchaey (OCIW) and J. F. Gallimore (MPIFEP) completed a VLA survey of a complete sample of about 50 early-type Seyfert galaxies. Emission-line ([OIII] and Hα+[NII]) and continuum (green and red) imaging of this sample has been presented in an earlier paper. It is found that the nuclear radio structures of Seyfert 2.0's in the early-type sample tends to be aligned with the [OIII] and H α+[NII] structures even though the radio extents are smaller than the [OIII] and Hα+[NII] extents by a factor of $\sim$ 2 to $>$ 5. This alignment, previously known for individual Seyferts with 'linear' radio sources, is here shown to be characteristic of early-type Seyfert galaxies as a class. Seyfert 2.0's in the early-type sample also show a significant alignment between the emission-line ([OIII] and Hα+[NII]) axes and the major axis of the host galaxy. These alignments are consistent with a picture in which the ionized gas represents ambient gas predominantly co-planar with the galaxy stellar disk. This ambient gas is ionized by nuclear radiation that may escape preferentially along and around the radio axis, and is compressed in shocks driven by the radio ejecta. An investigation of a larger sample of Seyferts reveals the unexpected result that the Seyfert 1's with the largest radio extent ($\geqslant$ 1.5 kpc) are all of type Seyfert 1.2. It appears that classification as this type of intermediate Seyfert depends on some factor other than the relative orientation of the nuclear obscuring torus to the line of sight.

Nagar and Wilson have used the difference (δ) between the position angles of the nuclear radio emission and the host galaxy major axis to investigate the distribution of the angle (β) between the axes of the nuclear accretion disk and the host galaxy disk in Seyfert galaxies. They emphasize that biases in the distribution of inclination translate to biased estimates of β in the context of the unified scheme. When this effect is taken into account, the distributions of β for all Seyferts together, and of Seyfert 1's and 2's separately, agree with the hypothesis that the radio jets are randomly oriented with respect to the galaxy disk. Seyfert nuclei in late-type spiral galaxies may favor large values of δ (at the $\sim$ 96% confidence level), while those in early-type galaxies show a more or less random distribution of δ. This may imply that the nuclear accretion disk in non-interacting late-type spirals tends to align with the stellar disk, while that in early-type galaxies is more randomly oriented, perhaps as a result of accretion following a galaxy merger.

A model in which the narrow line regions (NLRS) of Seyfert galaxies are photoionized ''in situ'' by fast (300 – 1,000 km s^{-1}), radiative shock waves driven into the interstellar medium of the galaxy by radio jets from the active nucleus has been investigated by Wilson and Raymond (CfA). Such shocks are powerful sources of soft X-rays. The authors compute the expected ratio of the count rates in the ROSAT PSPC and Einstein IPC detectors to the [OIII]λ5007 flux as a function of shock velocity, and compare these ratios with observations of type 2 Seyferts. If most of the observed soft X-ray emission from these galaxies originates in the NLR and the absorbing hydrogen column is similar to that inferred from the reddening of the NLR, a photoionizing shock model with shock velocity $\simeq$ 400 – 500 km s^{-1} is compatible with the observed ratios. High angular resolution observations with the Chandra X-ray Observatory are needed to isolate the X-ray emission of the NLR and measure its absorbing column, thus providing a more conclusive test.

K. A. Weaver (JHU), Wilson, C. Henkel (MPIFR) and J. A. Braatz (NRAO) have completed a study of the 0.6 - 10.0 keV X-ray spectrum of the bright nuclear LINER galaxy NGC 1052, one of two elliptical galaxies known to contain a luminous H_2O maser. The observed 2.0-10.0 keV spectrum is unusually flat (photon index $\Gamma \simeq 0.2$) and is best described as intrinsically power-law shaped nuclear flux that is either (1) attenuated by a complex absorber with 70% of the nuclear flux absorbed by a column density of $N_H \sim 3 \times 10^{23}$ cm^{-2} and 30% absorbed by a column density of $N_H \sim$ 3-5 $\times 10^{22}$ cm^{-2} or (2) reprocessed, with the nuclear source blocked and the X-rays Compton reflected in our direction by high column density ($\geqslant 10^{24}$ cm^{-2}) gas. The moderate equivalent width of the Fe Kalpha line favors the dual absorption model as the most likely scenario. The 0.1-2.0 keV spectrum does not resemble the few times 10^{6-7} K thermal emission typically found in other elliptical galaxies, but instead is best described as nuclear X-rays leaking through a patchy absorber or scattered in our direction by low-density, ionized gas plus a 15%-20% contribution from a thermal component, which is most likely due to the galaxy.

J. S. Ulvestad, J. M. Wrobel, A. L. Roy (NRAO), Wilson, H. Falcke, T. Krichbaum, and A. Zensus (MPIFR) have used the NRAO VLBA to image the milliarcsecond-scale 15-GHz radio emission from the Seyfert galaxies Mrk 231 and Mrk 348 at two epochs separated by about 1.7 yr. Both galaxies contain parsec-scale double radio sources, whose components have brightness temperatures of 10^9–10^{11} K, indicating that they are generated by synchrotron emission and probably associated with radio jets. The nuclear components of both galaxies are identified by strong variability between epochs, implying that the double sources are apparently one-sided jets. In Mrk 348, the relative component speed is $0.074 \pm 0.035c$ at a separation of 0.5 pc, while the apparent speed in Mrk 231 is $0.139 \pm 0.052c$ at a separation of 1.1 pc (using $H_0 = 65$ km s^{-1} Mpc^{-1}). The lack of observed counterjets is probably due to free-free absorption by torus gas having ionized densities $n_e > 2 \times 10^5$ cm^{-3} within a parsec of the nuclei. This gas density is consistent with X-ray absorption measurements for both galaxies, and also is similar to that inferred in H_2O megamaser galaxies. Except for radio power, the overall properties of the Seyfert radio sources are similar to compact symmetric objects, whose one-sided jets also could be due to free-free absorption by gas having $n_e \sim 5 \times 10^4$ cm^{-3} on scales of 5–10 pc.

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