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This report covers the period October 1994 through September 1995.

1. INTRODUCTION

The Johns Hopkins University Center for Astrophysical Sciences (CAS) again put astronomer Sam Durrance in orbit in 1995. Below, we sketch the participation of the Hopkins Ultraviolet Telescope (HUT) in the Astro-2 mission. Many Hopkins astronomers spent weeks in Huntsville, Alabama, in an extraordinarily successful second flight of HUT.

Participation in major NASA missions has been the foundation stone of the growth of astronomy and astrophysics research activity at Hopkins. This growth continued in 1995 with the selection of CAS Director Holland Ford as principal investigator for the Advanced Camera for Surveys project for the *Hubble Space Telescope*. At press time, the Hopkins Ultraviolet Background Explorer project (HUBE), has advanced to the final round in the NASA MIDEX selection process.

Another major space mission that passed a major milestone was the Far Ultraviolet Spectrograph Explorer (FUSE), which has been substantially restructured, but which now is on track for implementation by NASA, with launch in 1997.

However, a foundation stone, by itself, does not a building make; below you will find the details of a very broad and vigorous program in astronomy and astrophysics that includes strong contributions to theory, observation, and experiment.

2. PERSONNEL

G. Bowers, M. Martinez, A. Naim, and S. Regan are new Post Doctoral Fellows to CAS. J. C. Mihos begins his Hubble Fellowship at CAS in October 1995. W. Oegerle comes to CAS as a Research Scientist to work on the FUSE mission. S. Friedman and J. Murthy are now research scientists. Davis Fellow Boqi Wang left JHU during the summer of 1995 to accept a position with a major Wall Street investment firm. M. Vogeley and Hubble Fellow C. Mark Voit are leaving JHU to accept positions at STScI.

Other permanent staff are: P. J. Dagdigian, A. F. Davidsen, J. P. Doering, P. D. Feldman, H. C. Ford (Director, CAS), R. Giacconi (Director, ESO), T. M. Heckman, R. C. Henry (Director, Maryland Space Grant Consortium), B. R. Judd, C. W. Kim, J. H. Krolik, H. W. Moos (Chair, Physics and Astronomy) C. A. Norman, D. F. Strobel, A. Szalay, and R. Wyse, Professors; D. Neufeld, Associate Professor; S. Lubow, Assistant Research Professor; W. P. Blair, R. Griffiths, and G. A. Kriss, Associate Research Professors; Wm. G. Fastie, Adjunct Research Professor; M. Finkenthal, Visiting Professor; S. T. Durrance, Principal Research Scientist; R. Burg, S. McCandliss, S. Friedman, and A. Uomoto, Research Scientists; M. Allen, R. Buss, A. Connolly, B. Espey, D. Golimowski, D. Hall, C. Holmes, E. Kaiser, J. W. Kruk, Y. Pei, K. Ratnatunga, D. Sahnow, Z. Tsvetanov, and W. Zheng, Associate Research Scientists; J. Daniels, R. Della Ceca, G. Meurer, L. Neuschaefer, Post Doctoral Fellows; K. S. Long, Associate Astronomer (STScI)/Adjunct Research Professor (JHU/CAS); P. Madau, M. A. McGrath, and H. A. Weaver, Assistant Astronomers (STScI); H. C. Ferguson, Hubble Fellow (STScI); and F. Paresce, Senior Astronomer (ESA/STScI).

3. THE ASTRO-2 MISSION

One of the highlights of the past year was the extremely successful flight of the Hopkins Ultraviolet Telescope (HUT) as part of the Astro-2 space shuttle mission aboard *Endeavour* (STS-67). HUT is the brainchild of principal investigator Arthur F. Davidsen, and it grew out of the JHU sounding rocket program in the late 1970's. HUT's first flight was in December 1990 as part of the nine day Astro-1 mission (STS-35) on *Columbia*. In contrast, the Astro-2 mission was nearly twice as long, with launch occurring at 6:38 GMT on 1995 March 2. Once again, payload specialist and JHU principal research scientist Samuel Durrance was aboard along with six other astronauts who operated the observatory around the clock for the next 16 days as part of this dedicated astronomy mission. HUT was the only one of the three primary telescopes in the Astro payload to have undergone substantial improvements since the first mission. New optical coatings and a new spectrograph resulted in 2.3 times higher sensitivity achieved during Astro-2.

The operational phase of the Astro-2 mission went very smoothly, and HUT operated almost flawlessly. The mission ultimately stretched out to 16.5 days, the longest shuttle mission to date. Supporting the astronauts was a large contingent of scientists, engineers, and support people at NASA's Marshall Space Flight Center in Huntsville, Alabama, including about 30 JHU/CAS scientists, staff, and students and personnel from the JHU Applied Physics Laboratory in Laurel, Maryland.

A tremendous wealth of astronomical data was obtained and is in the process of being analyzed and published by the HUT team, which includes seven groups of Guest Investigators selected by NASA in 1993 to participate in Astro-2. Increased observation time, coupled with technical improvements to HUT and the Instrument Pointing System, and improved mission planning procedures, enabled HUT scientists to gather roughly five times more data than they did during Astro-1. In all, HUT was used to make 385 science pointings at 260 unique astronomical targets for over 20 different key science programs during Astro-2. Nearly 20 presentations of early HUT results were made at the Pittsburgh AAS meeting in 1995 June, and a special issue of *The Astrophysical Journal (Letters)* for 1995 November 20 will be dedicated to results from HUT on Astro-2, less than nine months after the launch. These results really only amount to the proverbial ‘‘tip of the iceberg,’’ and many more results are in process at this writing.

To facilitate access to scientific and technical information about the HUT project and its scientific results, a World-Wide-Web site was established, accessible at the URL http://praxis.pha.jhu.edu/hut.html. There, information about the instrument, the science programs and the science results is provided at both a general and technical level. (Many of our technical publications, for instance, are available on-line.) We will continue to update these pages with new science results as they become available.

The Astro-2 Mission exceeded the most optimistic expectations held for it by members of the HUT team. Based on the quantity and quality of the unique new scientific data gathered on this flight, Astro-2 must be judged an unqualified scientific success. We thank the many NASA personnel at headquarters, MSFC, KSC, and JSC whose input and hard work were so important to the successful execution of this mission.

4. RESEARCH AND ACTIVITIES

Marsha Allen continues to work with R. C. Henry's group (with J. Murthy) on preparations for the upcoming launch of the *MSX* spacecraft in early 1996. She has been testing data analysis software, writing documentation, and assisting the calibration team.

William P. Blair is an associate research professor in the Department of Physics and Astronomy and is deputy project scientist for the Hopkins Ultraviolet Telescope (HUT) project. With the successful two-week flight of HUT on the Astro-2 space shuttle mission (STS-67) in 1995 March, HUT duties have dominated this year's activities, from preparations for the flight (first half of the reporting period) to initial data reductions and paper writing (second half). With Blair's involvement in revamping the mission planning process for Astro-2 over the last several years, he was particularly gratified to see this process run so smoothly over the course of the Astro-2 mission. Initial results already in press include the first ultraviolet detections of the galactic supernova remnants Puppis A and SN 1006 (with J. C. Raymond, SAO; and K. S. Long, STScI), a comparison of Astro-1 and Astro-2 HUT spectra of U Geminorum (also with Long and Raymond), and the FUV spectra of two novae (with B. Greeley, JHU; and Long). Many more results are in progress from the exceptional performance of the HUT on Astro-2.

In addition, Blair has continued independent research on galactic and extragalactic supernova remnants using both ground-based telescopes and space-based instruments. *Hubble Space Telescope* imagery of the supernova remnant N132D in the Large Magellanic Cloud, a member of the ‘‘oxygen-rich’’ class of remnants, was carried out this year. These images show the structure of the nebulosity in exquisite detail and demonstrate the stratification of the supernova ejecta and the interaction of the blast wave with the surrounding interstellar medium. These data have been followed by Faint Object Spectrograph (FOS) observations of three filaments (just obtained), which will be analyzed in the coming year.

Blair, O. Vancura (CfA), and Long published FUV spectra of the Vela supernova remnant obtained with the *Voyager* ultraviolet spectrometers. The data for two positions showed the presence of O VI emission lines for the first time in this object, but at a weaker level than had been seen previously in the Cygnus Loop. This paper laid the ground work for HUT spectroscopy during Astro-2. With J. Saken (STScI), Long, and P. F. Winkler (Middlebury), optical and *ROSAT* data on the galactic remnant 3C 400.2 were used to rule out a ‘‘multiple supernova’’ picture for this remnant; rather, an interaction of the blast wave with an inhomogeneous ISM is more likely to explain the observed characteristics of the object.

In the time approaching Astro-2, several remaining Astro-1 results were published. With C. W. Bowers (GSFC) and other HUT team members, a paper on the high excitation planetary nebula NGC 1535 was published. The HUT spectrum of the 70,000 K central star surprisingly shows deep absorptions due to molecular hydrogen, presumably due to a relic shell surrounding the visible nebula. The fact that molecular hydrogen had not been seen in infrared observations demonstrates the great sensitivity of the ground-state-connected transitions in the HUT range for detecting small amounts of this molecule.

Gary A. Bower, in collaboration with J. Mulchaey (Carnegie Obs.), A. Wilson (U. Maryland), T. Heckman, J. Krolik, and G. Miley (Leiden Observatory) published their analysis of *HST* imaging of the Seyfert galaxy NGC 2110. Analysis of similar images of NGC 5930, the interacting companion of the Seyfert galaxy NGC 5929, was published by Bower and Wilson.

Bower, Wilson, J. Morse (STScI), R. Gelderman (GSFC), M. Whittle (U. Virginia), and J. Mulchaey completed their investigation of Seyfert galaxy Mkn 1066, resulting in a paper which is in press in the ApJ (20 Nov 1995).

Bower, Wilson, D. Richstone (U. Michigan), and Heckman are continuing their investigation of the stellar dynamics in AGNs. Our HST spectroscopic observations of M81 show preliminary evidence of rapid rotation and high velocity dispersion within 5 pc of the nucleus. Although such kinematic features are expected if a $\sim 10^7 M_\odot$ black hole exists at the nucleus, additional HST observations are required to confirm this suggestive result.

Bower, R. Elston (CTIO), Heckman, Richstone, and M. Franx (U. Groningen, Netherlands) initiated a study of the stellar dynamics in the nearby dusty AGNs Centaurus A and NGC 4945. Imaging and spectroscopic observations at near-infrared wavelengths have been obtained. Such observations allow for the nucleus to be viewed through the prominent dust lanes which obscure the nuclei of both galaxies at optical wavelengths.

Richard H. Buss, Jr. participated in the training, mission planning, and satellite operations of the HUT Astro-2 mission. He conducted spectral FUV observations of Galactic stars and nebulae, ensuring successful data acquisition. Analyzing these data for publication in a special *Astrophysical Journal Letters* issue, Buss verified that hot stars in the FUV are matched by existing stellar atmospheric models and, with

J. Kruk and H. Ferguson (STScI), compiled a variety of useful stellar FUV spectra in an atlas. Buss presented at the January AAS, the results of the first observations of FUV molecular hydrogen fluorescence from the HUT Astro-1 mission, with J. Kruk and JHU undergraduate K. Ennico. The FUV spectrum shows much higher excited vibrational states than previously known from longer wavelength data. Also with Kruk, Buss completed the analysis of the general FUV flux calibration by intercomparing HUT and *Voyager* spectra, finding that the FUV calibrations agree. The results of a study of a young stellar disk were published in the ApJ with JHU graduate student T. Brown. We found evidence for the alteration of the disk composition by the central star. Finally, Buss completed a paper with T. Snow (U. Colorado) and others on the origin of interstellar diffuse absorption bands, whose strengths depend on the ionization state of the nebular environment.

Istvan Csabai works with A. Szalay on the SDSS science archive. The Sloan Digital Sky Survey, a multi-color digital mapping of the northern sky will result in a complex archive of about 20 terabytes data of parameters, spectra and images of galaxies. The maintenance of an archive of such a massive size and the need to support various queries for effective usage present major design challenges. Building this complex archive will use methods of computational geometry and object oriented database techniques.

Julian Daniels, post-doctoral fellow and Space Grant Fellow for the Maryland Space Grant Consortium, continues his work on producing a full-blown model of the ultraviolet sky: the first elements of which were presented interactively using NASA Goddard's SkyView (a virtual astronomical observatory) at the ADASS 94 conference.

Daniels was heavily involved as assistant project scientist for phase 1 studies of the Hydrogen Recombination Radiation Experiment; he led a team of 15 students from Hopkins, the Applied Physics Lab, and Morgan State University in the area of science and data processing.

In a collaboration with L. Smith (Morgan State U.), level-4 software to validate the calibration of *MSX* (Midcourse Space Experiment) ultraviolet and visible instrumentation is under development.

Daniels, in collaboration with J. Murthy, is conducting a study of dust and gas in the Coalsack Nebula using infra-red, radio, optical and ultraviolet data.

In a JHU-MSU (Morgan State U.) collaboration, NASA JPL's Surveyor Software (a powerful software package for the visualization and animation of 3D data sets) has been successfully applied to the scientific and educational display of astrophysical data for the first time: using data from an integrated (over 5 by 5 galactic degrees) ultraviolet starlight model.

In a further JHU-MSU collaboration, Daniels has been assigned project scientist for MSU's participation in the Environmental Monitoring of Chesapeake Bay with specific emphasis on the correlation between bay grass growth and blue crab yields using hyperspectral imaging data from a NASA Stennis airplane fly-over and possibly from the forthcoming Lewis and Clark satellite project.

Arthur F. Davidsen continues in his role as principal investigator of the Hopkins Ultraviolet Telescope project, and has collaborated with other members of CAS and students on a variety of topics addressed with HUT. His primary interest has been the measurement of the He II opacity of the intergalactic medium, which has been the main scientific goal for HUT ever since it was first proposed to NASA in 1978. A successful measurement was made on the Astro-2 mission toward the quasar HS 1700+64 at $z=2.74$. The He II opacity at a mean redshift of 2.4 was found to be 1.00 (± 0.07). Most of this opacity arises from intergalactic gas with very low neutral hydrogen column densities, less than those associated with the widely studied Lyman alpha forest lines. This low density intergalactic gas has a He II/ H I ratio of order 100, producing a much larger He II Gunn-Peterson effect than the corresponding H I absorption. This result was presented in an invited paper at the AAS meeting in June 1995 and is described in a forthcoming paper by Davidsen, Kriss, and Zheng.

Davidsen has continued to serve on the NAS/NRC Committee on Astronomy and Astrophysics.

S. D. Doty joined CAS as a postdoctoral fellow in January, 1995. Recent work, in collaboration with D. A. Neufeld, has concentrated on the detailed modeling of the radiative transfer, chemistry, and thermal structure of dense cloud cores. Utilizing an ALI code written by Doty, simulated observations are produced with the intent of comparing model results with upcoming *SWAS* and *ISO* observations. Doty also continues his collaboration with C. M. Leung (Rensselaer Poly. Inst.), where they find that detailed treatments of the radiative transfer in dust, and photodissociation of CO and H_2 match observations of IRC +10216 much better than any previous models.

Brian R. Espey's main work this year involved participation in the Astro-2 flight of the Hopkins Ultraviolet Telescope. In his role as guest investigator on the mission using both the HUT and Wisconsin Ultraviolet PhotoPolarimeter (WUPPE) instruments, Espey obtained good data for a sample of eight symbiotic stars from the Lyman limit imposed by our Galaxy to 3200 Å. In addition, supporting ground-based and *IUE* data were obtained which will considerably enhance the usefulness of the space-borne data. During the mission the symbiotic systems CH Cyg and AG Dra were observed during their outburst phase (Espey *et al.* 1995a). The observation of CH Cyg occurred only one week after the first reported ejection event; the first ever FUV data showing P-Cygni profiles in low ionization ions were obtained of this phenomenon. The first paper from the mission, reporting the observation of Raman-scattered O VI in RR Tel using a combination of Astro-2 and ground-based data, is currently in press (Espey *et al.* 1995b). A subsidiary paper discussing emission line diagnostics based on FUV Ne lines is nearly ready for submission. Espey's symbiotic work also forms part of the calibration effort for the HUT and he is also a collaborator on a number of other Astro-2 projects involving observation of the UV and FUV observation of Active Galactic Nuclei (AGN). Other duties involve supporting the guest investigators on the HUT team for the Astro-2 mission.

Espey has continued his collaborations with faculty at the University of Pittsburgh where he has an adjunct position as research assistant professor. Work with D. Turnshek (U. Pitt) has led to the submission of a paper on the metallicity of Broad Absorption Line QSOs in which metallicity estimates are made taking account of the influence of the intrinsic ionizing spectrum on these determinations. Further work on the analysis of *HST* data on the ''Cloverleaf'' gravitational lens is in progress.

As part of the Pittsburgh AAS Summer meeting, Espey organized a well attended special session on metallicity in the environment of AGN which was well attended. The session examined questions of the origin and evolution of metals pertinent to cosmic evolution models. The meeting drew together a number of strands of research and permitted comparisons between results from different sub-fields.

Work also continues in collaboration with A. J. Cooke (IfA, Edinburgh), and R. F. Carswell (IoA, Cambridge) on a maximum likelihood determination of the intergalactic ionizing background at high redshifts. Preliminary results of this work were presented at the Space Telescope Science Institute meeting on the Lyα forest in June 1995. The main result of this work is that the background is nearly constant over $2.0<z<4.5$ and has an intensity similar to those found by previous determinations. A paper detailing the method and results is nearly ready for submission.

Paul D. Feldman directs the NASA supported sounding rocket program, which has as its main focus the development of new instrumentation for far- and extreme-ultraviolet astronomy. He has also continued an *IUE* comet program (in collaboration with M. F. A'Hearn of the University of Maryland) and his collaboration with H. A. Weaver (Applied Research Corporation) in a program of *HST* observations of comets both of which included the newly discovered comet Hale-Bopp. He collaborated with M. A. McGrath (JHU/STScI), D. T. Hall, and D. F. Strobel in *HST* observing programs of Jupiter, Titan and the Saturn ring plane atmosphere, and with A. Vidal-Madjar (IAP) in *HST* studies of CO and atomic carbon in the gaseous disk surrounding β-Pictoris. During March 1995, as part of the HUT team during the Astro-2 mission (described above in this report) he was responsible for planning the solar system observations that acquired far-ultraviolet spectra of Io, the Io plasma torus, Jupiter's equator and aurora, Venus and Mars. During the mission, simultaneous HUT spectroscopy and *HST* WFPC2 imaging of Jupiter's north polar aurora were obtained. He is currently a member of the HST Users Committee, NASA's Small Bodies Science Working Group and Sounding Rocket Users Group, and served on the bilateral Rosetta Science Working Group through March 1995.

Holland Ford, in collaboration with Ball Aerospace and colleagues from JHU, the STScI, the University of Arizona, the University of California Santa Cruz, and Leiden University, won the NASA contract to build an Advanced Camera for the *Hubble Space Telescope*. The Advanced Camera for Surveys (ACS) will have three cameras: a $200'' \times 200''$ wide field camera (4096×4096 CCD) optimized for maximum sensitivity at 800 nm, a 1024×1024 CCD high-resolution ($0.025''$ per pixel) camera with sensitivity optimized between 200 nm and 300 nm, and a 1024×1024 solar-blind photon-counting array optimized for maximum sensitivity at 121.6 nm. The WFC ''discovery efficiency,'' defined as the product of the area and quantum efficiency at 800 nm, will be ten times higher than the discovery efficiency of the WFPC2. Progress on the CCDs and design of the ACS is excellent.

In collaboration with W. Jaffe and F. van den Bosch (Leiden Univ.), R. O'Connell (Univ. Virginia), and JHU graduate student L. Ferrarese, Ford used the *HST* to image and study a complete sample of 14 E/S0 galaxies in the Virgo cluster. The observations show that early-type galaxies are divided into two types by shape and luminosity profile. Type I galaxies, the bright classical ellipticals ($M_B<-20$), have luminosity profiles in their centers which can be fitted by a double power law. The cores have shallow power laws which continue into the innermost measurable radius ($\sim0.2''=14$ pc), and relatively low central surface brightnesses (typically $17 > \mu_V > 16$ mag arcsec-2). In contrast, the Type II galaxies have power-law brightness profiles which rise steeply into the very center, giving a high central surface brightness. These flattened galaxies often have a small ($r\sim100$ pc), thin ($r<25$ pc) stellar disk in their centers. We conclude that the dynamically cold stellar disks and highly flattened structures of Type IIs imply they formed during conditions when gaseous dissipation was important and specific angular momentum was high. The persistence of the extremely thin, cold disks with scale heights less than 25 pc suggests these galaxies have not undergone major dynamical disturbances since their creations. Alternatively, the galaxies have not undergone major dynamical disturbances since the disks formed. Understanding the dichotomy in E/S0 galaxies undoubtedly will tell us a great deal about galaxies formed.

Ford and colleagues continue to pursue a vigorous program of searching for massive black holes in the centers of galaxies. They have new *HST* observations of the center of M87 using the FOS $0.086''$ aperture. The velocities in the gaseous disk, which are being analyzed, continue to rise on the smallest observable scales. FOS observations of the nuclei of both M31 and NGC 4261 strongly suggest that these galaxies also have massive black holes in their nuclei.

Scott D. Friedman is the Hopkins project scientist for the Lyman Far Ultraviolet Spectroscopic Explorer (FUSE) mission. FUSE will make observations in the critical 910–1195 Å region at a spectral resolving power of approximately 30,000. FUSE will address problems such as the abundance of primordial light elements, including the deuterium/hydrogen ratio and the distribution of intergalactic helium, the composition and dynamics of galaxies, and the origin and evolution of stars and stellar systems.

Along with A. Uomoto, S. Smee, and P. Feldman, Friedman is also designing and constructing two fiber-optic spectrographs as part of the Sloan Digital Sky Survey. Each spectrograph will record the spectra of 320 separate objects over a wide field of view. The spectrographs are expected to be completed by the end of 1995, and will then be delivered to the dedicated 2.5-meter telescope at Apache Point Observatory in New Mexico.

David Golimowski is an associate research scientist attached to the Extrasolar Planet Search program headed by *HST* Guaranteed Time Observers W. G. Fastie and D.

Schroeder (Beloit College). The search for faint, low-mass companions to 18 nearby stars using *HST*'s Planetary Camera (PC) began in earnest in early 1994 and will continue until June 1996. The first results of the program, observations of the very-low-mass star GL 105C, will appear in an October issue of *The Astrophysical Journal*.

Golimowski continues his ground-based search for substellar companions to nearby stars along with collaborators S. Kulkarni, T. Nakajima, and B. Oppenheimer (all at Caltech). The circumstellar environments of over 100 nearby stars have been observed using the Palomar 60-inch telescope and JHU's Adaptive Optics Coronagraph (AOC). The first success of the program occurred in late 1994, when a faint, very red companion to the astrometric binary GL 105A was detected. Based on the companion's intrinsic brightness, it is estimated that its mass is 8%–9% that of the Sun—just above the minimum mass needed to sustain hydrogen burning.

Richard Griffiths is principal investigator for the *HST* Medium Deep Survey, a Key Project which has continued into Cycle 5 of the *HST* General Observer program. The JHU team includes K. Ratnatunga, L. Neuschaefer, M. Im, A. Naim and S. Casertano (also at STScI). The conclusions from the Medium Deep Survey so far are as follows:

(i) Hubble-type morphological classification has been routinely achieved to $I_{\rm band}=22$ (Griffiths *et al.* 1994, Driver et al. 1995, Glazebrook *et al.* 1995). Spectroscopy is in progress for large subsets of these galaxies.

(ii) Statistical properties of galaxies are measured to $I=25$. For the pre-refurbishment WF/PC images, the structural parameters of about 13,000 objects have been presented by Casertano *et al.* (1995), using data taken from about 112 fields. Sizes, magnitudes, colors and crude classifications are based on two-dimensional model fitting to undeconvolved images. For galaxies with $I\leqslant22$ in WFPC2 data, the maximum-likelihood fits have been found for combined disk-plus-bulge models of all galaxies.

(iii) The universe is dwarf-rich at $z=0.3$–0.5. The marginal distribution of size vs. magnitude can be compared with the predicted distributions based on various galaxy evolution models such as the no-evolution model, the merger model, and the dwarf-rich model. The data are consistent with the dwarf-rich models and a dwarf luminosity function with a steep faint-end slope.

(iv) The excess number counts are only partially explained by "giant" spirals or ellipticals, which are observed to have little cosmological evolution (Driver *et al.* 1995, Glazebrook *et al.* 1995), size vs. redshift, or structural parameters (Phillips *et al.* 1995): the bulk of the local giant population was apparently in place at half the Hubble time. Furthermore, this population has either undergone relatively little merging (about 10%) since $z\sim0.7$, or else the mergers have been of the "minor" kind (with gas-rich dwarfs) and have not caused major disruptions (Driver *et al.* 1995). For those galaxies which do show evidence of merger activity, photometry shows bluer colors and thus increased star formation (Forbes *et al.* 1995).

Spiral galaxies are, however, slightly bluer in the past when their K-corrections are taken into account; their apparent (V-I) color does not change between $I=18$ and $I=22$. The bulk of the microJansky radio population may be identified with these spiral galaxies with enhanced star formation, especially with the MDS galaxies showing evidence of interaction (Windhorst *et al.* 1995).

The two-point correlation function (all galaxies, irrespective of morphology) shows a constant slope down to arcsec scales, with no evidence for the excess galaxy pairs that might result from a high rate of "major" mergers. The deepest of the MDS fields and the deeper *HST* surveys indicate, however, that mergers of galaxy components may have been common at epochs which are presumably earlier (i.e., at $z\gtrsim1$).

(v) The excess number counts in V and I *are* largely explained by the high fraction of irregulars/peculiars and compact objects, including dwarf (dE, Im) candidates and galaxies or protogalaxies with starburst knots. These combined objects show a steeply rising number count with magnitude. Multiple, high surface-brightness cores are evident within about 30%–40% of the irregulars. The irregular/peculiar population comprises great morphological diversity, however, including galaxies in various stages of maturity, some with superluminous starburst regions or knots.

(vi) If the dwarf candidates are identified by their exponential luminosity profiles, round shapes, blue colors and small sizes ("small exponential ellipticals"), the characteristics of dEs or Ims, then these constitute about 20% of all galaxies at $I=20\sim21$. Taken together with the irregulars, these appear to be responsible for the excess number counts in the bright magnitude range of the MDS (Im *et al.* 1995b). At this brighter end of the MDS distribution, such objects may be the evolved versions of the dwarf irregulars at higher redshift. Low surface brightness galaxies (some nucleated) are common amongst this population.

(vii) To $I=25$, there is some evidence that the small excess in the number of pairs of galaxies with separations less than $3.''0$ is predominantly caused by "satellite" galaxies which are fainter than the "primaries" by at least 1 or 2 mags. (Neuschaefer *et al.* 1995b). Such observations may constitute strong evidence in support of the "minor merger" hypothesis.

(viii) There is a population of unresolved nuclei within those galaxies fitted simultaneously with disk and bulge components ($I_{814}\leqslant 22$); these galaxies show narrow emission lines in the spectroscopic follow-up program. *HST* photometry indicates that these stellar nuclei have the colors of moderately redshifted Seyfert I galaxies. About 6% of field galaxies at $z\lesssim0.5$ may therefore contain AGN which are 3–4 magnitudes fainter than the host galaxies (Sarajedini *et al.* 1995).

(ix) There is evidence for "weak shear" lensing, as evidenced by the preferential orientation of background field galaxies ($I=22$–24), in the vicinity of foreground galaxies ($I=18$–22). Also, the first HST-discovered "Einstein cross" type of gravitational lenses have been found in archive and MDS data; such objects would not have been discovered in ground-based data and are the first lenses centered on relatively bright elliptical galaxies with well understood properties; such objects may eventually be powerful cosmological tools.

Griffiths is also a co-investigator on the science team for WFPC2. The behavior of WFPC2 in orbit has been well characterized in order to support the detection and measurement of the faintest possible sources. In collaboration with other members of the WFPC2 team, Griffiths has begun investigations into the nature of starburst galaxy nuclei.

XMM is an ESA cornerstone mission scheduled for launch in 1999, supported on the Science Working Team by Griffiths as one of two U.S. Mission Scientists. Griffiths is supported in this role at JHU by R. Della Ceca. As well as carrying out simulations of the XMM observations, Della Ceca works on the luminosity functions of extragalactic X-ray sources, using data from the Einstein Observatory and the Deep Surveys with *ROSAT*, for which Griffiths is principal investigator. The *ROSAT* Deep Surveys have been carried out in collaboration with co-Investigators in the U.K., and have been used to show that the X-ray Background at 1 kev is dominated by AGN, but with important contributions from star-forming and other galaxies. In collaboration with Heckman and Della Ceca, Griffiths has obtained data from the Japanese X-ray astronomy satellite *ASCA* on dwarf starburst galaxies, and has shown that these galaxies contain compact binary X-ray sources and hot, outflowing winds. These winds, implying the loss of interstellar gas, may be very important to the fading of dwarf galaxies at moderate and high redshift. The fading of these galaxies is responsible for the fact that there are far more blue dwarf irregular galaxies in the past than there are in the local universe.

Timothy Heckman and collaborators have continued their studies of the galactic ''superwind'' phenomenon: the galaxy-scale outflows associated with starburst galaxies and presumably driven by the collective effect of the energy and momentum input from massive stars and supernovae. He and M. Lehnert (Leiden) are analyzing spectra of the interstellar NaI D doublet in a large sample of starbursts. Outflows of gas (seen in absorption) are common among very luminous starbursts. The outflow speeds are typically a few hundred km s^{-1} and the associated kinetic energy represents a significant fraction of the energy injected by supernovae.

Heckman and Lehnert have also analyzed long-slit optical spectra and deep H-α images of a sample of 50 of the nearest and brightest starbursting disk galaxies oriented such that their large-scale stellar disks are seen nearly edge-on. This orientation is the most favorable one for studying the superwind as it flows out along the minor axis of the galaxy. They find evidence that outflows are occurring in most if not all of the galaxies in their sample. Faint emission-line loops and bubbles extend far out into the galactic halo in many cases. The gas projected along the optical minor axis (halo gas plus disk gas seen in projection) is much more kinematically disturbed than the gas along the major axis (pure disk gas). While the gas along the major axis has emission-line ratios implying it is photoionized by OB stars, the gas along the minor axis has emission-line ratios consistent with shock-heating by the superwind (e.g., strong emission in lines like [S II] and [O I]). The measured gas pressures in the galactic halos are far larger than in normal galaxies, and agree with the predicted ram pressure of the superwind. The inferred outflow velocities and the size of region affected by the outflow both increase with the starburst luminosity.

Heckman and collaborators L. Armus (Caltech), M. Dahlem (STScI), G. Fabbiano (Harvard-Smithsonian), D. Gilmore (STScI), M. Lehnert (Leiden), J. Wang (JHU), and K. Weaver (JHU and GSFC) have continued their analysis of *ROSAT* HRI and PSPC data for a sample of a dozen starburst galaxies spanning a broad range in starburst luminosity. In all cases studied to date, the keV X-ray emission is spatially-resolved, and can be detected out to radii of tens-of-kpc (e.g., well beyond the optical isophotal radii). In the case of the edge-on galaxies, the X-ray emission is preferentially extended along the optical minor axis, strongly suggesting that much of the X-rays are produced by a galactic ''superwind.'' The Fe-L emission complex has been detected in a few cases, demonstrating that much of the keV X-ray emission comes from hot gas with a temperature of several million K. There is also spectroscopic evidence for a much harder component that can be fit as either thermal emission with kT $>>$ few keV or as a hard powerlaw. One interesting byproduct of the X-ray survey was the discovery of a highly unusual variable X-ray source in the center of NGC3628. It is either a very unusual AGN or the most luminous-know X-ray binary. Multiphase 1-D numerical hydrodynamical simulations of superwinds conducted with collaborators V. Berman (STScI), D. Balsara (Illinois), A. Suchkov (STScI) reproduce many of the properties of the X-ray data and suggest that the X-rays arise primarily from cloudy gas that is shock-heated by supernovae inside the starburst and then carried out by the wind.

In a related project, JHU graduate student A. Marlowe, Heckman, R. Wyse, and R. Schommer (CTIO) discovered evidence for a qualitatively similar starburst-driven outflow phenomenon in a sample of 20 dwarf galaxies undergoing bursts of star formation. About half the galaxies studied have kpc-scale ''superbubbles'' seen in deep Fabry-Perot H-α images. Long-slit echelle spectra show that these structures are expanding at about 100 km s^{-1} (comparable to the escape velocity from these galaxies). *ROSAT* X-ray images of the prototypical dwarf starburst galaxy NGC1569 provide additional evidence that the expanding superbubbles are being inflated by hot gas supplied by the central starburst. These observations provide key observational support for models of the evolution of dwarf galaxies which posit that starburst-driven mass loss is the fundamental mechanism that governs the evolution of such galaxies. This has received additional support from *ASCA* observations of NGC 1569 and NGC 4449 (with JHU collaborators R. Della Ceca and R. Griffiths). These show that the soft X-ray emission is dominated by gas at a temperature far above the virial temperature in these small galaxies.

Heckman has also participated in several other studies of starburst galaxies. Heckman and Lehnert have emission-line images and rotation curves of their sample of starburst galaxies to show that: 1) the observed correlation between dust temperature and IR surface brightness is consistent with a simple foreground screen model for the dust; 2) starbursts have a maximum surface-brightness, suggesting that some type of feedback is occurring between the massive stars and the interstellar medium; 3) the starburst is located within the central region of the galaxy where the rotation curve indicates solid body rotation; 4) typical starburst galaxies have masses ranging from a few percent to about 100% that of the Milky Way. 5) In some extreme cases, starbursts appear to be forming stars at the maximum rate allowed by causality (viz. turning all the gas into stars in one orbital time).

C. Robert (U. Laval), C. Leitherer, and Heckman have constructed synthetic ultraviolet spectra of starbursts for a wide range in initial mass functions and star-formation histories. These models were compared to *IUE* spectra of starbursts with roughly solar composition. The data are well fit by models in which stars have been forming for at least 10 Myr, with an IMF that extends at least as high as 60 solar masses (contrary to some other published claims of a deficiency of very massive stars in starbursts). Together with collaborators A. Kinney (STScI) and D. Garnett (U. Minnesota) they are extending their analysis to *HST* FOS data on three starbursts. The superior signal-to-noise and spectral resolution of these data have allowed them to compare the predicted and observed stellar wind lines in detail. The data also reveal strong, broad, and blueshifted interstellar absorption lines, indicating large column densities of turbulent, outflowing gas spanning a wide range in ionization states (C I to N V).

With Leitherer, H. Ferguson (STScI), and J. Lowenthal (Lick), a small sample of starburst galaxies were observed below the Lyman break with the Hopkins Ultraviolet Telescope on Astro-2. The upper limit on the fraction of the ionizing radiation produced in the starburst that ''leaks'' out into the intergalactic medium is less than a few percent, a result that suggests that quasars probably dominate the ionization of the IGM. Similar observations with *HST* of more distant starbursts are being analyzed by Heckman and Meurer, while Heckman and Lowenthal are attempting to measure the escaping fraction of starburst ionizing photons by deep H-α imaging of H I clouds near starbursts.

B. Wang (JHU/STScI) and Heckman have used optical, space-UV, and far-IR data to study the dependence of dust opacity on galaxy luminosity for normal late-type disk galaxies. They find that opacity increases with luminosity. Simple models of plane-parallel slabs of intermixed stars and dust are able to reproduce the observed correlations, provided that the total dust optical depth is proportional to the square-root of galaxy luminosity and is roughly unity for a typical Schecter L* spiral galaxy. The luminosity dependence of opacity probably results from the correlations of luminosity with both metallicity and surface mass density in disk galaxies. They show that the opacity-luminosity correlation should have interesting implications for the form of the optical galaxy luminosity function, for the Tully-Fisher relation, and for the interpretation of the faint blue galaxy population. With D. Calzetti, R. Bohlin, and A. Kinney (all at STScI), Heckman has considered the likely heating sources for the warm dust in starbursts and has concluded that the non-ionizing radiation is crucial.

Heckman has continued to investigate the environments of high-redshift quasars. He and collaborators J. Lowenthal (Lick), M. Lehnert, and J. Elias (CTIO) obtained optical continuum (B or V), and near-IR continuum (K) images of two samples of radio-quiet quasars (one at $z=1$ and one at $z=2$ to 3). In contrast to their earlier results on radio-loud quasars at these redshifts, the radio-quiet quasars are all spatially-unresolved. The host galaxies of these radio-quiet quasars are therefore fainter by at least two magnitudes than are either the host galaxies of radio-quiet quasars or powerful radio galaxies at similar redshifts. Lowenthal and Heckman are also using deep Ly-α and multicolor images of fields around high redshift radio-loud and radio-quiet quasars to search for galaxies at the same redshift as the quasar. Heckman, Lehnert, Miley (Leiden), and van Breugel (IGPP/LLNL) have recently obtained *HST* images of high-z quasars, and these often show complex ''knotty'' UV morphologies. These may represent starbursting companion galaxies, dusty clouds that are scattering quasar light, or foreground galaxies responsible for Mg II absorption.

A. Koratkar (STScI), S. Deustua (IGPP/LLNL), Heckman, A. Filippenko (Berkeley), L. Ho (Berkeley), and M. Rao (STScI) have used *ROSAT* to study the X-ray emission from a sample of low-luminosity AGNs. They find that the X-ray emission is dominated by the nucleus in all cases and the X-ray spectrum in the *ROSAT* band is similar to that observed for much more powerful type 1 Seyfert nuclei. These low-luminosity AGNs extend the correlation between the luminosity of the X-rays and the Broad-Line Region downward by another order-of-magnitude. These galaxies appear have genuine AGNs (albeit of very low power). Whether there exists some fundamental lower limit to the luminosity of a true AGN is still not clear.

A. Wilson (Maryland), Heckman, G. Bower, J. Mulchaey (Carnegie), J. Krolik (JHU), and G. Miley (Leiden) have analyzed *HST* images of the ionized gas in the central-most regions of several Seyfert galaxies. These images show evidence for ''ionization cones'' produced as ionizing radiation from a hidden AGN shines out through the poles of a central ''obscuring torus.'' The ionized gas bears a surprisingly strong morphological relationship to the nonthermal radio jets, suggesting that these latter may play some role in the heating and/or redistribution of the interstellar gas near the Seyfert nucleus.

Heckman has also studied a sample of mid-IR, optical, and radio data for Seyfert nuclei and used them to test the popular model of an ''obscuring torus.'' In agreement with the predictions of this model, he finds that type 1 Seyfert nuclei are on-average several times brighter in at 10 microns than are type 2 Seyfert nuclei with the same radio and [O III]5007 luminosities. On the other hand, with collaborators Calzetti, Kinney, Koratkar, Krolik, Meurer, Robert, and Wilson, he showed that no more than about 20% of the ultraviolet continuum in Seyfert 2 galaxies (as measured in 10×20 arcsec *IUE* aperture) can be scattered light from a hidden type 1 Seyfert nucleus. After considering several possible alternative explanations, they concluded that the most likely origin for this light was a dusty circumnuclear starburst. If true, this would make such starbursts an energetically significant part of the Seyfert phenomenon. Ultraviolet *HST* imaging and spectroscopic observations are underway to test these ideas.

Richard C. Henry conducts research on the interstellar medium, cosmology, and ultraviolet background radiation. A proposal to obtain *HST* observing time to study the ration of deuterium to hydrogen in the local interstellar medium was successful (28 orbits); Deputy PI is W. Landsman, and Co-Investigators include J. Murthy and J. Linsky among others. Several lines of sight will be investigated to obtain the abundance ratio, especially any evidence for variation of the abundance ratio with direction. This will extend earlier work, which began with sounding rockets, and extended through *Copernicus* and *IUE* observations. An *ApJ Letter* is in press presenting Henry's analysis of the lunar albedo in the far ultraviolet, measured using HUT on the Astro-2 Mission. The Hopkins Ultraviolet Background Explorer (HUBE) has been submitted as a MIDEX proposal; the result of preliminary NASA selection is expected shortly. Work continues on study of the HUBE as a joint US/Argentina project in the SAC-D mission planned for early in the next millennium. Finally, planning continues for the Cosmic Background experiments on the Department of Defense *Midcourse Space Experiment* (*MSX*), which is now scheduled for launch in 1996 March. With Murthy, Henry continues to work on *Voyager* diffuse ultraviolet background radiation data that appear to be of very high quality and that certainly are of very extensive quantity; concrete results should be reported over the coming year. Henry continues as Director of the Maryland Space Grant Consortium.

Gerard A. Kriss is an associate research professor in the Department of Physics and Astronomy. As project scientist for the second flight of the Hopkins Ultraviolet Telescope, the highlight of 1995 was the enormously successful Astro-2 mission in March. As detailed elsewhere, HUT performed extremely well and returned a wealth of far-UV spectral data extending down to the Lyman limit on a wide variety of astronomical objects. Of particular interest to Kriss were observations of more than a dozen AGN, including six observations of NGC 4151 at intervals of 2–3 days, and two observations of NGC 3516 that were simultaneous with X-ray observations made with the Japanese satellite *ASCA*.

The six observations of NGC 4151 show significant flux variations in the lines and the continuum as well as correlated variability in the strong UV absorption lines, including the Lyman lines of neutral hydrogen. On average, the UV continuum was five times brighter than observed on Astro-1, and all high ionization absorption lines show a dramatic increase relative to Astro-1. The Lyman lines are also stronger, but the inferred column density is lower—the increase appears to be due entirely to a substantial increase in the turbulent velocities broadening the lines. These variations should prove fruitful in building a consistent model of the UV and X-ray absorbing gas in NGC 4151. A useful tool in this regard will be the warm absorber models developed over the past year by Krolik and Kriss, which will also be applied to the simultaneous UV and X-ray observations of NGC 3516.

Jeffrey W. Kruk is the deputy project scientist for instrumentation for the Hopkins Ultraviolet Telescope project. During the past year he has been involved in developing operating and observing procedures for use by the astronauts during the Astro-2 space shuttle mission, in serving as one of the team leads in the Payload Operations Control Center at Marshall Space Flight Center during the mission, and then with postflight instrument calibration and data analysis.

Kruk is collaborating with D. Finley (Eureka Scientific), R. Kimble (GSFC), and D. Koester (Kiel) in the analysis of spectra from eight hot DA white dwarfs. Two of these stars are being used for purposes of instrument calibration, the rest for tests of refinements to model atmosphere codes. Preliminary results are noted in the reference section below.

Spectra of five PG 1159 stars were also obtained with HUT, which are being analyzed in collaboration with K. Werner (Potsdam). Preliminary results were presented at the Bamberg Conference on Hydrogen Deficient Stars. One immediate result is a much clearer demonstration than heretofore possible of the absence of He in the atmosphere of H1504+65. Detailed modeling of this and the other PG1159 stars is presently in progress.

Kruk and collaborators G. Kriss, A. Davidsen, and W. Zheng are analyzing HUT spectra of extragalactic objects for absorption by hot gas in the galactic halo. Preliminary results for Markarian 421 were presented at the AAS meeting in Pittsburg.

Kruk is also collaborating with T. Lanz (GSFC) on the analysis of hot sdO stars observed with HUT, and with R. Buss, H. Ferguson (STScI), and JHU graduate student T. Brown on the analysis of sdB and hot main sequence stars.

S. Lubow together with P. Artymowicz (Stockholm) have continued investigations of the nature of disks around young stars. They determined the long-term evolution of a young binary's semi-major axis and shown that it depends mainly on global properties of the disk. More results have been obtained about the eccentricity evolution, using a semianalytic approach. The results show that disks rapidly cause binary eccentricity to increase to at least 0.1, for typical parameters. They have also found that circumbinary disks can transfer mass via gas streams to the binary, under certain circumstances. A semianalytic description of the gas stream was found. The gas stream mass flux is modulated on an orbital timescale. Various predictions of observational signatures are underway.

S. Lubow and H. Spruit (MPI) have completed a study of the stability accretion disks supported by poloidal magnetic fields. The main effect is that matter is subject to an interchange instability in the radial direction, if the field strength increases sufficiently inwards. However, the effects of shear are important in limiting the extent of the instability. Strong growth of disturbances is possible only if the growth rate calculated in the absence of shear exceeds the shear rate.

Lubow and J. Pringle (IoA) investigated a possible model for giant molecular clouds, based on the picture that they are composed of clumps and are supported by MHD turbulence. To form stars, the gas must lose magnetic flux. They investigated the viability of a model for flux loss based on magnetic reconnection, as opposed to the usual mechanism of ambipolar diffusion. Since random motions in the cloud are in virial equilibrium with the magnetic field, the model indicates that magnetic reconnection can achieve high enough efficiencies to be an important source for creating low flux matter matter.

Lubow continued his investigations of superhump models for CVs. A likely model to explain the slight period shift observed in superhumps is that they are due to an eccentric, precessing disk. A possible source of eccentricity which has been discussed in the literature is the gas stream. Lubow investigated the dynamical effects of the gas stream in generating eccentricity using an analytic model. The result is that the gas stream is very inefficient in generating eccentricity, although it does disturb the disk. The main problem is that eccentricity is efficiently generated by disturbances that are stationary in the inertial frame, while the gas stream tends to generate disturbances that are stationary in the frame of the binary, even for variable mass transfer rates.

Lubow, Papaloizou (QMW), and Pringle (IoA) investigated the possible configurations of a magnetized accretion disk which removes its angular momentum through a centrifugal wind over a large range of radii. The magnetic field is assumed generated outside the disk and advected inward by the accretion flow. Three solutions were found: one corresponding to a purely vertical field with no accretion, one corresponding to bent field lines like that discussed by Blandford and Payne, and the last with highly bent field lines. They argued that the last solution is unphysical because the mass loss is too rapid, while the middle solution is unstable, and the first solution is stable. Based on these results, it appears that the actual solution which produces jets likely involves only a local mechanism near the disk center and may involve a dynamo generated field.

Stephan R. McCandliss is engaged with preparing two NASA sounding rockets (NSR) for launch. The first NSR 36.132/.136 UG is a mission to observe the core of the LMC nebula 30 Dor with a long slit ($200'' \times 12''$) FUV spectrometer (912–1300 Å) at a resolving power of 100. The mission goals of this dual flight are to determine the extinction toward the 30 Dor core and account for its stellar content, while serendipitously searching for nebular emission. The work is being carried out with J. McPhate and Paul Feldman. The second NSR 36.115 is a mission to simultaneously image atomic and molecular hydrogen UV emissions from the Jovian aurorae with $1''$ resolution. The f/24 telescope for the Jupiter mission uses a curved LiF prism for the dispersing element and a thinned backside charged and illuminated SITE (formerly Tektronics) CCD as the imaging device. This work is being carried out with JHU graduate student P. Morrissey and P. Feldman. In a paper with Morrissey and Feldman it is shown that a UV-flooded SiTE CCD has a QE of $\sim$ 40% in a bandpass spanning 1200–2500 Å and that the number of e^- per detected photon at 1216 Å was approximately twice that in the visible.

A third NSR currently in the development stage will use a high ruling density (5800 l/mm) holographically recorded Rowland circle grating ($R = 635$ mm) with an ion-etched blaze profile provided by Jobin-Yvon through a collaboration with A. Vidal-Madjar (CNRS/IAP). This grating will be coupled with a small pixel CCD ($\sim 12 \mu$m) and used for high dispersion studies of hot stars around 1026 Å . This mission will test whether the high contrast of UV to visible intrinsic to unreddened hot stars along with the low scatter of the holographic grating can mitigate problems with red leak in UV observations with CCD's.

McCandliss has a contract with JPL to work on methods of windowless vacuum UV CCD calibration techniques. He has recently been awarded a NASA research grant, along with J. Kruk to develop windowless vacuum UV calibration lamps. He continues to work on various hot star topics such as: a two-dimension classification of WN type Wolf-Rayet stars; (with R. Buss); determining the interstellar absorption of molecular H in the FUV extinction in OB star pairs observed by HUT on the Astro missions; and the time variability of line profiles in OB and Wolf-Rayet stars (with Massa *et al.* [1995]).

Gerhardt R. Meurer is a postdoctoral associate working with T. Heckman. Meurer, Heckman, and collaborators C. Leitherer, A. Kinney (STScI), C. Robert (Laval), and D. Garnett (U. Minnesota) finished a detailed analysis of ten ultraviolet ($\lambda_c \approx 2320$ Å) images of starburst galaxies obtained with the Faint Object Camera on *HST*. They find that the typical starburst structure is a cloud(s) of diffusely distributed high mass stars with an effective radius of 100 to 1000 pc. Embedded in the cloud(s) are luminous young clusters which on average comprise 20% of the total ultraviolet luminosity. The formation of clusters is thus an important and efficient mode of star formation in starbursts. Most starbursts occupy a very narrow range of effective ultraviolet surface brightnesses. This suggests that a negative feedback mechanism is limiting the star formation intensity of starbursts. A strong correlation between the ultraviolet to far-infrared flux ratio and ultraviolet spectral index is well modeled by dust in a simple foreground screen geometry. Thus much of the extincted ultraviolet flux can be recovered by deshrouding this screen.

Meurer showed that the clusters within starbursts have sizes and luminosities consistent with the hypothesis that they are proto-globular clusters. This is despite the form of their luminosity function, a power law of slope -2, which is very different from that of Galactic globular clusters which have a Gaussian luminosity function. The difference can be explained by the fact that Galactic globular clusters are old and essentially coeval, while the clusters in starbursts are young and have a significant age spread.

Warren Moos is the chair of the Department of Physics and Astronomy. He is also the principal investigator for the Lyman Far Ultraviolet Spectroscopic Explorer (FUSE) astronomy satellite. Also participating in this activity at the Center are: A. F. Davidsen, P. D. Feldman and S. Friedman as co-investigators, C. Holmes and W. Oegerle as operations scientists, D. Sahnow as instrument scientist, and M. Martinez as a postdoctoral fellow. Warren Moos also participates as a co-investigator in the definition of the Space Telescope Imaging Spectrograph; M. E. Kaiser is the STIS calibration scientist. Moos is also principal investigator of the DOE-supported ''XUV Diagnostics Based on Layered Synthetic Microstructures for Magnetically Confined Fusion Plasma.'' M. Finkenthal is principal research scientist and S. Regan a postdoctoral fellow on this grant.

Jayant Murthy is analyzing archival *Voyager* data to investigate the ultraviolet radiation field. He is also involved with planning for the *MSX* spacecraft which is due to launch in March 1996. Other projects include the HUBE satellite which is currently under consideration for the NASA MidEx program and *Hubble Space Telescope* observations of the local interstellar medium.

Abraham Naim conducted statistical studies of the morphology and evolution of normal and peculiar galaxies in the local universe and at high redshifts. These studies use B-band photographic plates for nearby galaxies, and I- and V-band CCDs for MDS galaxies at redshifts of 0.1–0.7. Following the successful application of techniques, such as artificial neural networks, to morphological classification of galaxies, Naim is seeking to apply these methods to other problems of a similar multivariate nature. Studies of dwarf galaxies and their relation to normal galaxies are underway using multicolor CCD photometry of dwarf elliptical galaxies.

David Neufeld's research efforts remain primarily in the theoretical study of the interstellar medium and of fundamental physical processes that operate there. With S. Lepp (UNLV) and G. Melnick (SAO), Neufeld modeled the radiative cooling of molecular astrophysical gas over a wide range of temperatures and densities. Their model for the radiative cooling of molecular gas included a detailed treatment of the interstellar chemistry that determines the abundances of important coolant molecules, and a detailed treatment of the excitation of the species H_2, CO, H_2O, HCl, O_2, C, O, and their isotopic variants where important. They obtained results for the total radiative cooling rate and for the cooling rate due to individual coolant species, as a function of the gas temperature, density and optical depth. They also computed the individual millimeter, submillimeter and far-infrared line strengths that contribute to the total radiative cooling rate, and obtained example spectra for the submillimeter emission expected from molecular cloud cores. Many of the important cooling lines will be detectable using the *Infrared Space Observatory* (*ISO*) and the *Submillimeter Wave Astronomy Satellite* (*SWAS*).

With P. Maloney (JILA), Neufeld has continued to model the physical and chemical conditions expected within molecular gas close to an AGN. Neufeld and Maloney constructed a specific model for the warped molecular disk in the active galaxy NGC 4258. Modeling this system as a viscous accretion disk that is illuminated obliquely by a central X-ray source, they were able to obtain an estimate for the mass accretion rate through the disk, based upon the observed X-ray luminosity and the observed extent of the water maser emission detected from the disk. The resulting estimate for the mass accretion rate was $7\times10^{-5}\alpha$ solar masses per year, where α is the dimensionless viscosity parameter, a value which implies that the active nucleus must convert rest mass energy into 2–10 keV X-rays with an efficiency $0.01\alpha^{-1}$. They also investigated how the properties of molecular circumnuclear disks are expected to depend upon the mass and luminosity of an active galactic nucleus: the results suggested the possible existence of extragalactic water masers that are several orders of magnitude more luminous than any observed to date.

With former JHU graduate student M. Kaufman (now at NASA/Ames), Neufeld has completed a comprehensive model which predicts the molecular emissions that are expected to result from magnetohydrodynamic interstellar shock waves. The results suggest strongly that such shock waves are the source of submillimeter water maser emissions that have recently been detected in star-forming interstellar regions. This study also indicates that non-masing far-IR water emissions will carry most of the luminosity that is emitted by dense molecular shock waves in star-forming regions. Model predictions for the far-infrared spectrum will guide *ISO* observations of shock-excited water to be carried out in collaboration with M. Harwit. With JHU graduate student W. Chen, Neufeld has carried out analogous studies of molecular emissions from outflows from oxygen-rich late-type stars, another astrophysical environment in which far-infrared water emissions are expected to dominate the radiative cooling. The results suggest that previous studies, which were based upon overestimates of the likely gas temperature in the emission region, have yielded predictions for the water rotational line strengths that are too large by an order of magnitude or more. Once again, model predictions for the emitted water spectrum will be confronted with *ISO* observations to be obtained in collaboration with M. Harwit.

Neufeld continues to work as a co-investigator on the *Submillimeter Wave Astronomy Satellite* (*SWAS*) project, a Small Explorer mission which will fly an orbiting radiometer capable of detecting line emission from cold interstellar water, molecular oxygen, atomic carbon, and warm carbon monoxide.

Yichuan Pei, with Z. Tsvetanov, H. Ford, and G. Kriss, has been examining new *HST* (post-COSTAR) spectroscopic observations of the nucleus of M31. Previous *HST* (pre-COSTAR) observations indicate that one of the double peaks in the center of M31 hosts a nuclear black hole. Unfortunately, these observations have missed some of the important aperture positions covering the very center of the nucleus. New *HST* observations will then allow them to complete the kinematic measurements in these positions and to confirm the existence of the nuclear black hole in the center of M31. This work is in preparation to be submitted for publication.

Pei, with S. M. Fall (STScI), has proposed new models for cosmic chemical evolution, applicable to comoving volumes large enough to contain many damped Lyα systems and hence to be representative of the universe as a whole. The damped Lyα systems, identified by strong H I Lyα absorption in the spectra of quasars, are usually interpreted as the progenitors of present-day galaxies and thus represent the best hope of tracing the evolution of ordinary galaxies at high redshifts. The models presented here are intended to be illustrative rather than definitive. Nevertheless, they agree remarkably well with all available data of damped Lyα systems and are consistent with the average properties of present-day galaxies. The models illustrate a consistent picture for histories of star formation, gas consumption, and metal production in ordinary galaxies at high redshifts. One specific prediction in Pei and Fall's models of chemical evolution is that the damped Lyα systems experience rapid star formation at relatively low redshifts. This work will appear in the 1995 November issue of the *Astrophysical Journal*.

Darrell Strobel has focused his research on the photochemistry and vertical transport in Io's atmosphere and the vertical temperature structure of Pluto's atmosphere in collaboration with colleagues M. Summers (NRL) and X. Zhu (JHU). During the last six months he has devoted considerably theoretical effort to understanding the interaction of the Io plasma torus with Europa thin molecular oxygen. With Meudon colleague E. Lellouch, millimeter wave observations of Io this past summer lead to the discovery of SO in Io's thin atmosphere.

Alan Uomoto continues building the two fiber-optic spectrographs for the Sloan Digital Sky Survey. This survey will use a dedicated 2.5-m telescope at Apache Point Observatory to image 1/4 of the sky in five bandpasses and measure one million galaxy redshifts during a five year observing period.

His other interests include work with K. Davidson (U. Minnesota), G. MacAlpine, S. Lawrence (U. Michigan), and W. Blair on imaging and spectroscopy of the Crab Nebula, polarization imaging of Seyfert nuclei with R. Antonucci (UC Santa Barbara) and JHU collaborators, and continuing observations of faint broadband photometric standard stars with A. Landolt (LSU).

Kim Weaver is currently studying iron K-α fluorescence lines in Seyfert galaxies using data from *ASCA* with collaborators J. Nousek (Penn State), T. Yaqoob, R. Mushotzky (GSFC), C. Otani, F. Makino, I. Hayashi, and K. Koyama (Japan). The Seyfert 1.9 galaxy, NGC 2992, possesses a narrow line with a FWHM of less than 6,600 km s^{-1}. The line flux lags decreases in the continuum flux by $\sim$10 years implying a distance of $\sim$3.2 pc to the reprocessor. This suggests that the iron line is the X-ray signature of the "obscuring torus" expected within the context of unified models. The Seyfert 1.9 galaxy, MCG-5-23-16, possesses a remarkable iron K-α line which consists of two distinct components. The primary feature is narrow (similar to NGC 2992), while the secondary feature is very broad with a FWHM of $\sim$90,000 km s^{-1}. The broad line contains significant photons at energies higher than 6.4 keV and suggests a "double-horned" profile expected for an accretion disk approaching an edge-on view.

R. Wyse, together with G. Gilmore (Cambridge, England) and J. B. Jones (Cardiff, Wales) completed the analysis of the chemical abundances of their (Wyse and Gilmore) sample of faint F/G stars in the thick disk. This involved the derivation of a new technique specifically designed to extract chemical abundance estimates for spectra obtained with fiber spectrographs (Jones, PhD thesis). This provided the first true iron abundance distribution for a well-understood sample of F/G stars 1–3 kpc above the disk plane; there is essentially no vertical metallicity gradient in the thick disk, which constrains its origins, arguing against a dissipational settling. JHU graduate student A. Ferguson's thesis research demonstrated the existence of diffuse ionized gas in many of the nearby spiral galaxies in her sample for which she has deep H-α images. The available evidence suggests that the source of this gas lies in ionizing photons which leak out from H II regions. Thus one must be careful to include the diffuse emission when making an inventory of ionizing photons from which to infer a massive star-formation rate.

Wei Zheng devotes most of his work to the Astro-2 mission, mainly in the science planning, data evaluation and analyses. Among the first Astro-2 results, he and other HUT team members report the far-UV spectral properties of Fairall 9. The UV continuum may be extrapolated to the soft X-ray band, forming a weak UV bump. The weak O VI emission strength in Fairall 9 supports an earlier claim that the intensity of this high-ionization line is correlated to the X-ray strength. Based on a major Astro-2 result, i.e., the measurement of the He II Gunn-Peterson optical depth, he uses simulated spectra to argue that forest lines can only produce up to a half of the observed He II opacity, hence the observations indicate the contribution from the long-sought intergalactic medium.

As part of the archival studies of the *HST* data, he and his colleagues construct a composite *HST* spectrum of quasars. The very high S/N level enables to reveal many new features, such as several very weak emission lines, the detailed profiles of emission lines, and the turnover of the power-law continuum.

Zheng also joins a collaborative work to study the optical spectra of radio galaxy 3C 390.3 between 1974 and 1990. The study confirms the variability of narrow lines in periods as short as four months. It is suggested that the narrow-line region in this object must be exceptionally compact and probably linked to the broad-line region.

In cooperation with Lipari (U. Cordoba) and Tsvetanov, Zheng studies the broad-band properties of several quasars with exhibit extremely strong optical Fe II emission. They find that these objects show strong broad absorption in the UV range, suggesting a transition phase between starburst and AGN phenomena.

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PUBLICATIONS

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