

The Catholic University of America Institute for Astrophysics and Computational Sciences
Department of Physics
Washington, District of Columbia 20064

The following report covers the astrophysical research activities of the Institute for Astrophysics and Computational Sciences (IACS) and other closely related research activity in the Department of Physics for the period from September 2003 through September 2004. IACS has three major areas of concentration a) Basic Astrophysics & Planetary Physics, b) Imaging Technology and c) Solar and Solar-Terrestrial Physics. The Institute has a well-developed educational and public outreach component as well. The IACS was established in October 1996 to a) develop strong research and educational programs in the areas of astrophysics and computational sciences at CUA, and b) promote closer cooperation between The Catholic University of America (CUA) and government agencies and with industry. This has been done to take advantage of CUA's proximity to major laboratories and its existing collaborations with government and private enterprise. The ultimate goal is to enhance research, educational, and employment opportunities for CUA faculty, research staff, and students over what is typically offered in the academic environment. The IACS operates within the Department of Physics at CUA.

1. PERSONNEL

The Ph.D. faculty and research staff that are directly affiliated with the Institute are: Fred Bruhweiler (Director), Steve Kraemer (Associate Director), Arthur Aikin, Al Boggeess, Jeff Brosius, Peter Chen, Dana Crider, Sergei Ipatov, Vladimir Krasnapolsky, Duilia de Mello, Neale Dello Rossa, Jeffrey Hayes, Rosina Iping, Stefan Ivarsson, Gunther Kleetschka, Alejandro Lara, Don Michaels, Tom Moran, Krister Nielsen, Norman Ness, Leon Ofman, Charles Proffitt, Rich Robinson, Nelson Reginald, Mike Reiner, Myron Smith, Johannes Staghun, Richard Starr, Dave Steyert, Mashiro Tanaka, Katya Verner, Glenn Wahlgren, Gerry Williger, Sieji Yashiro, and Hong Xie. Other Ph.D. Adjunct Professors of the IACS, or those working closely with it, include Ed Colbert, Mike Crenshaw, Michael DiSanti, Jack Gabel, Nat Gopalswamy, Ted Gull, Yoji Kondo, Andrew Smith, Chris St. Cyr, and Carol Crannell. Non-Ph.D. research and support staff, who work directly in the IACS, includes Cherie Miskey and George McCabe, as well as the graduate students, Bill Anderson, Bryan Armentrout, Nick Collins, John Corriera, Rick Edwards, Ian Liska, Steve Nunes, Ana Rosas, Jose Ruiz, Ed Wassell, and Linhui Sui. Within IACS, in addition to the curriculum in Astrophysics, the Center for Solar Physics and Space Weather (CSPSW) offers an educational curriculum in the area of Space Weather. The members of CSPSW include A. Lara Sanchez, T. Moran, O.C. St. Cyr (NASA/GSFC), S. Yashiro, N. Gopalswamy (NASA/GSFC), R.A. Howard (NRL), S. Jordan (NSAS/GSFC), D. Rust (JHU/APL), J. Green (NASA/GSFC), D. Sibeck (JHU/APL), and C. Crannell (NASA/GSFC).

2. ASTROPHYSICS

2.1 Galaxies and Extragalactic Astronomy

Bruhweiler, along with Miskey, Alex de Koter (Amsterdam/Netherlands), Nolan Walborn (STScI), and Thierry Lanz (GSFC/AURA) continue to use Hubble Space Telescope spectra to study the effects of metallicity on properties of massive stars and starburst activity in galaxies of the Local Group. A two-dimensional data reduction scheme has been developed for the G230L and G430L long slit and slitless spectroscopy for the star forming regions of both NGC 346 in the Small Magellanic Cloud and the 30 Doradus region in the Large Magellan Cloud. The largest problem in this reduction was removing the large nebular emission line contributions in the G430L data that affected the entirety of the slitless spectral images. Using the reduced and calibrated data, we have shown the complete STIS spectra for B and late O main sequence stars from 1150 to 5700Å are matched almost perfectly by the model atmosphere flux distributions of appropriate metallicity of Lanz & Hubeny (2003) using a common interstellar extinction law for NGC 346. In the case of NGC 346, there are complete datasets extending from 1150 through 5700Å for 110 stars extending down to spectral type B2 on the main sequence. The slitless G230LB and G430L data provide roughly a factor of two more usable stellar spectra. The situation is similar in the 30 Doradus region. The data reduction has been far more complex in the 30 Dor region where the stars are much more concentrated. Although the results are still preliminary for 30 Dor and NGC 346, they indicate that at a Salpeter type IMF can well-represent the stellar populations in both regions, even though they represent two different metallicities. Bruhweiler and Liska, are performing theoretical studies of the expansion of supershells both in our own galaxy and in dwarf ellipticals. Work is concentrating on both the evolution of these large interstellar structures and how they trigger star formation. Work with Liska has concentrated upon what parameters, mass ranges, mass concentration, gas to star ratios, and stellar birth rates that lead to ejection of interstellar gas from the galaxies. This work has important implications for understanding evolution of dwarf galaxies in the early Universe. de Mello is currently working with Jonathan Gardner (GSFC), Yogesh Wadadekar (STScI), Swara Ravindranath (STScI), and Stefano Casertano (STScI) on the analysis of the deepest U-band images ever taken with the Hubble Space Telescope during the Ultra Deep Field campaign in January 2004. More than 400 galaxies are seen in the WFPC2 U band and are also detected in the multiwavelength ACS/GOODS images. Analysis of their morphology, sizes, and redshift distribution are in progress. de Mello continued working with Gardner and the Great Observatories Origins Deep Survey (GOODS) team in the analysis of the Hubble Space Telescope data released in December 2004. A series of papers summarizing their results was published in

the Astrophysical Journal Letters special issue which was dedicated to GOODS in January 2004. de Mello worked with Emanuele Daddi (ESO) and the K20 team on the analysis of the VLT composite spectrum of near-infrared luminous galaxies to search for the epoch of formation of massive galaxies. They found evidence of high metallicity, together with high masses, high star formation rates, and possibly strong clustering, which well qualify these galaxies as progenitors of local massive elliptical galaxies. de Mello worked with Theresa Wiegert and Cathy Horellou (Onsala Space Observatory, Sweden) on a paper summarizing the main results of the Master's thesis of Mrs. Wiegert which has been accepted for publication by the Astronomy and Astrophysics journal. They have used the Hubble Deep Field South images to assess the galaxy population out to $z=2$. They used two methods of templates fitting of the spectral energy distributions to obtain photometric redshifts and classify the objects. Analysis of the rest-frame colour distribution shows a bimodality out to $z=1.4$. Although in low numbers, a population of early-type galaxies (or heavily obscured low redshift galaxies) is seen out to $z=2$. de Mello, Gardner and collaborators began examining archival data from GALEX and HST to study the UV properties of moderate redshift galaxies as a function of HST morphology. P. Francis (ANU), P. Palunas (Texas), H. Teplitz (IPAC), Williger and B. Woodgate (GSFC) used narrowband Ly α images over a 0.5° field to identify a filament at $z=2.38$ spanning $80h^{-1}$ comoving Mpc ($h=0.7$), and encompassing several voids $\sim 5-10h^{-1}$ comoving Mpc voids. The observed structure implies larger voids than predicted by current structure formation models. They then used the AAT+2dF to take spectra of 37 candidate emission line galaxies in the filament. Of the 14 brightest candidates with flux $\geq 5.0 \times 10^{-17}$ erg cm $^{-2}$ s $^{-1}$ arcsec $^{-2}$, 12 of them were confirmed to be in the filament. Six fainter candidates also belong to the filament, and a foreground cluster of QSOs at $z=1.65$ was identified. The field has also been recently observed with Chandra, and is a site of active investigation about the size and nature of extremely large structures at high redshift. Francis and Williger took high resolution spectra of a QSO whose sight line passes through the halo of a pair of elliptical galaxies in the same filament. This pair of galaxies probably lies at the center of a galaxy protocluster and is embedded in a luminous extended Ly α nebula. The QSO sight line intersects two small gas clouds within this halo. These clouds have properties similar to those of high-velocity clouds seen in the halo of the Milky Way. The gas is in a cool ($< 2 \times 10^4$ K) and at least 20% neutral phase, with metallicities in the range $-3.0 < [Fe/H] < -1.1$ and neutral hydrogen column densities of $\log N(HI)=19.5$. The origin of these clouds is unclear. The presence of low-metallicity gas within this possible protocluster implies either that the intracluster medium has not been enriched with metals at this redshift, or the clouds are embedded within a hot, ionized, metal-rich gas phase. B. Wood, J. Linsky (Colorado), G. Hébrard (IAP/JHU), Williger, H. W. Moos and W. Blair (JHU) used FUSE to measure the D/H ratio toward two distant subdwarfs, JL 9 and LSS 1274. Their values of $(1.00 \pm 0.37) \times 10^{-5}$ and $(0.76 \pm 0.36) \times 10^{-5}$ support a tendency for low D/H values at

large distances (590 ± 160 pc and 580 ± 100 pc, respectively). The low D/H measurements would be consistent with D being preferentially depleted onto dust grains relative to H, and that longer sight lines beyond the Local Bubble sample more depleted material. W. Zheng, W.V. Dixon, J. Kruk, Williger, Moos (JHU), G. Kriss, S.D. Friedman (STScI), J.-M. Deharveng (Marseille), J. M. Shull (Colorado), M.L. Giroux (E. Tennessee St.) and D.C. Morton (HIA) used FUSE and VLT data to study the properties of the intergalactic medium at $2.0 < z < 2.9$. They compared HI and HeII absorption, and found that the ratio $\eta \equiv N(HeII)/N(HI)$ varies over $\sim 1-1000$, with $\langle \eta \rangle = 62$ and a distribution consistent with the dominant ionization field coming from quasars. Their results also imply contributions from softer sources such as star-forming regions and obscured AGN. At $z > 2.7$, the large but finite increase in opacity τ_{HeII} suggests that this is near the end of reionization which began at higher z . The Doppler parameter distribution suggests turbulent broadening. At HI column densities $N(HI) < 3 \times 10^{12}$ cm $^{-2}$, the Ly α forest declines relative to a power law, and becomes negligible at $N(HI) < 10^{11}$ cm $^{-2}$. Verner in collaboration with B. Peterson (Mt. Stromlo observatory, Australia) used Sloan Digital Sky Survey Data to analyze Fe II/Mg II emission ratio. Interpretation of the Fe II(UV)/Mg II emission ratios from quasars has a major cosmological motivation. Both Fe and Mg are produced by short-lived massive stars. In addition, Fe is produced by accreting white dwarf supernovae somewhat after star formation begins. Therefore, the Fe/Mg ratio is expected to gradually decrease with redshift. They have used data from the Sloan Digital Sky Survey to explore the dependence of the Fe II(UV)/Mg II ratio on redshift and on luminosity in the redshift range of $0.75 < z < 2.20$, and they have used predictions from 830-level model for the Fe II atom in photoionization calculations to interpret their findings. They have split the quasars into several groups based upon the value of their Fe II(UV)/Mg II emission ratios, and then checked to see how the fraction of quasars in each group varies with the increase of redshift. They next examined the luminosity dependence of the Fe II(UV)/Mg II ratio, and they found that beyond a threshold of Fe II(UV)/Mg II = 5, and $M_{2500} < -25$ mag, the Fe II(UV)/Mg II ratio increases with luminosity, as predicted by their model. They interpret the observed variation of the Fe II(UV)/Mg II ratio with redshift as a result of the correlation of redshift with luminosity in a magnitude limited quasar sample. Verner, Bruhweiler, D. Verner (CUA), S. Johansson (Lund), T. Kallman (GSFC/NASA), and T. Gull (GSFC/NASA) explored how Fe II emission in quasars is linked to physical conditions and abundance. They have constructed a 830-level Fe II model atom and investigated through photoionization calculations how Fe II emission strengths depend on non-abundance factors. They have split Fe II emission into three major wavelength bands, Fe II (UV), Fe II(Opt1), and Fe II(Opt2), and explored how the Fe II(UV)/Mg II, Fe II(UV)/Fe II (Opt1) and Fe II(UV)/Fe II (Opt2) emission ratios depend upon hydrogen density and ionizing flux in broad-line regions (BLR's) of quasars. Their calculations show that: 1) similar Fe II(UV)/Mg II ratios can exist over a wide range of physical conditions; 2) the

Fe II(UV)/Fe II (Opt1) and Fe II(UV)/Fe II (Opt2) ratios serve to constrain ionizing luminosity and hydrogen density; and 3) flux measurements of Fe II bands and knowledge of ionizing flux provide tools to derive distances to BLR's in quasars. To derive all BLR physical parameters with uncertainties, comparisons of model with observations of a large quasar sample at low redshift ($z < 1$) is desirable. Bergeha with Colbert and Tim Roberts (Leicester) is studying ULXs using Chandra data. A sample of 51 ULXs were compared with 20 "normal" XRBs by studying their X-ray spectral properties. The results from fitting the spectra with an absorbed power-law model, show that there is a significant difference between the two samples. Many ULXs have the photon index $\Gamma \sim 1.8$ while the comparison sample shows a broad distribution between 1.4 and 2.8 and has a higher average (~ 2.2). By fitting the spectra with a two-component model consisting of a power-law with fixed slope at $\Gamma \sim 1.8$, and a multi-color disk black body model, we obtained evidence for soft disk temperatures more frequently in ULXs than the comparison sample. This suggests that at least some ULXs could be Intermediate Mass BHs. Preliminary results were presented at the 204th Meeting of the AAS in Denver, CO, June 2004. In order to get better statistics we are currently expanding both samples with new data from Chandra. Collins, Kraemer, Ruiz, and Bruhweiler, with D.M. Crenshaw and R. Deo (Georgia State Univ (GSU)), used Hubble Space Telescope/Space Telescope Imaging Spectrograph (HST/STIS) longslit low-resolution spectroscopy from 1150Å to 10,300Å to study the physical conditions in the narrow-line region (NLR) of the Seyfert 2 galaxy Markarian 3. They find from the HeII 1640/4686 line ratio and the Balmer decrement that the extinction within Markarian 3 along the line-of-sight to the NLR is best characterized by a Large Magellanic Cloud (LMC) type extinction curve. The extinction gradient increased from west to east along the STIS slit in both line and continuum emission, indicating that the host galaxy disk is tilted towards the observer in the east: the line-of-sight to the eastern emission-line cone intersects more dust in the plane of the galaxy than that to the western cone. They model the observed continuum as a combination of reddened host galaxy light from an old stellar population, reddened H and He recombination continua, and less reddened scattered light from the central engine. They estimate that the amount of intrinsic non-ionizing UV continuum scattered into our line-of-sight is 0.04%, consistent with our estimate of the scattering fraction for broad CIV 1548,1551 emission. Kraemer, Armentrout, and T.J. Turner (UMBC) are in the process of re-analyzing XMM-Newton spectra of Seyfert galaxies. The purpose is to 1) determine the physical conditions in the X-ray emission-line gas and 2) provide the highest quality dataset for testing and upgrading the photoionization code CLOUDY. The latter effort is in coordination with G.J. Ferland and R. Porter (U.Ky). Kraemer is assisting Crenshaw (GSU) and M. Dietrich (GSU) in the analysis of optical spectra of Narrow-Line Seyfert 1 galaxies obtained at Cerro Tololo International Observatory. They find that the emission-line spectra of the narrow-line regions are similar in Narrow and Broad Line Seyfert 1 galaxies. Therefore, there is no strong evidence for different

ionizing continua in these two classes of Seyfert 1s. Kraemer, with a group led by Crenshaw (GSU), analyzed ultraviolet spectra of the dwarf Seyfert 1 nucleus of NGC 4395, obtained with the Far Ultraviolet Spectroscopic Explorer and the Hubble Space Telescope Space Telescope Imaging Spectrograph. They confirm their earlier claim of C IV absorption in low-resolution UV spectra and detect a number of other absorption lines with lower ionization potentials. In addition to the Galactic lines, they identify two kinematic components of absorption that are likely to be intrinsic to NGC 4395. Possible origins of the absorption include the interstellar medium of NGC 4395, the narrow-line region, the outflowing UV absorbers, and the X-ray "warm absorbers." Component 1, at a radial velocity of -770 km s^{-1} with respect to the nucleus, is only identified in the C IV 1548.2 line. It most likely represents an outflowing UV absorber, similar to those seen in a majority of Seyfert 1 galaxies. Kraemer, with a group led by J.S. Kaastra (SRON), observed the Seyfert 1 galaxy NGC 5548 for a week with Chandra using both the HETGS and LETGS spectrometers. In a study of the time variability of the continuum radiation, they report that the source showed a gradual increase in flux over four days, followed by a rapid decrease and flattening of the light curve afterwards. Superimposed upon these relatively slow variations several short duration bursts or quasi-periodic oscillations occurred with a typical duration of several hours and separation between 0.6-0.9 days. The bursts show a delay of the hard X-rays with respect to the soft X-rays of a few hours. They interpret these bursts as occurring due to a rotating, fluctuating hot spot at approximately 10 gravitational radii; the time delay of the hard X-rays from the bursts agrees with the canonical picture of Inverse Compton scattering of the soft accretion disk photons on a hot medium that is relatively close to the central black hole. Kraemer, with I.M. George (UMBC), Crenshaw (GSU) and Gabel (U. of Colorado (UC)), explored the relationship between the [O III] $\lambda 5007$ and the 2-10 keV luminosities for a sample of broad- and narrow-line Seyfert 1 galaxies (BLSy1s and NLSy1s, respectively). They find that both types of Seyfert galaxies span the same range in luminosity and possess similar [O III]/X-ray ratios. The NLSy1s are more luminous than BLSy1s when normalized to their central black hole masses, a fact attributed to higher mass accretion rates. However, we find no evidence for elevated [O III]/X-ray ratios in NLSy1s, which would have been expected if they had excess extreme-ultraviolet (EUV) continuum emission compared to BLSy1s. While the simplest interpretation is that, like BLSy1s, a large EUV bump is not present in NLSy1s, they show that the [O III]/X-ray ratio can be lowered as a result of absorption of the ionizing continuum by gas close to the central source, although there is no evidence that intrinsic line-of-sight absorption is more common among NLSy1s, as would be expected if there were a larger amount of circumnuclear gas. Kraemer, with G.J. Ferland (U.Ky) and Gabel (UC), examined the effects of low-temperature, or $\Delta n=0$, dielectronic recombination (DR) on the ionization balance of the Fe M shell (Fe IX-Fe XVI). Since $\Delta n=0$ rates are not available for these ions, they derived estimates based on the existing rates for the first four ionization states of the CNO sequence

and newly calculated rates for L-shell ions of third-row elements and Fe. For a range of ionization parameter and column density applicable to the intrinsic absorbers detected in ASCA, Chandra, and XMM-Newton observations of Seyfert galaxies, we generated two grids of photoionization models, with and without DR. The results show that the ionization parameter at which the population of an Fe M-shell ion peaks can increase in some cases by a factor of more than 2 when these rates are included. More importantly, there are dramatic changes in the range in ionization parameter over which individual M-shell ions contain significant fractions of the total Fe (e.g., $> 10\%$) in the plasma. These results may explain the mismatch between the range of Fe ionization states detected in the X-ray spectra of Seyfert galaxies, identified by the energies of the M-shell unresolved transition array, and those predicted by photoionization models of the X-ray absorbers that reproduce lines of second- and third-row elements. The results suggest that care should be taken in using third- and fourth-row ions to constrain the physical conditions in photoionized X-ray plasmas until accurate DR rates are available. This underscores the importance of atomic physics in interpreting astronomical spectroscopy. Kraemer assisted T.J. Turner (UMBC) and J.N. Reeves (USRA/GSFC) in the analysis of XMM-Newton spectra of several Seyfert galaxies. These data have revealed a new type of X-ray spectral feature, one that appears to offer important new insight into the black hole system. XMM revealed several narrow emission lines redward of Fe $K\alpha$ in NGC 3516. Since that discovery the phenomenon has been observed in other Seyfert galaxies, e.g., NGC 7314 and ESO 198-G24. They present new evidence for a redshifted Fe line in XMM spectra of Mrk 766. These data reveal the first evidence for a significant shift in the energy of such a line, occurring over a few tens of kiloseconds. This shift may be interpreted as deceleration of an ejected blob of gas traveling close to the escape velocity. Kraemer, with a group led by P. Romano (Ohio State Univ.), assisted in the analysis of the intrinsic spectral energy distribution (SED) of the narrow-line Seyfert 1 galaxy (NLS1) Ark 564, constructed with contemporaneous data obtained during a multiwavelength, multisatellite observing campaign in 2000 and 2001. They compare this SED with that of the NLS1 Ton S180 and with those obtained for broad-line Seyfert 1 galaxies to infer how the relative accretion rates vary among the Seyfert 1 population. Although the peak of the SED is not well constrained, in their parameterization most of the energy of this object is emitted in the 10-100 eV regime, constituting roughly half of the emitted energy in the optical/X-ray ranges. This is consistent with a primary spectral component peaking in the extreme-UV/soft X-ray band and with disk-corona models, hence high accretion rates. Kraemer collaborated with a group led by H. Netzer (TAU) in the detailed spectral analysis of the data obtained from the Seyfert 1 galaxy NGC 3783 during the period 2000-2001 using Chandra. This analysis, along with the measured equivalent widths of a large number of X-ray lines and photoionization calculations, lead them to the following results and conclusions. (1) NGC 3783 fluctuated in luminosity by a factor of ~ 1.5 during individual observations (most of which were of 170 ks duration). (2) On

a longer timescale (20-120 days), they find the source to exhibit two very different spectral shapes. The main difference between these can be well-described by the appearance (in the ‘‘high state’’) and disappearance (in the ‘‘low state’’) of a spectral component that dominates the underlying continuum at the longest wavelengths. NGC 3783 seems to be the first active galactic nucleus (AGN) to show this unusual behavior. (3) Photoionization modeling indicates that a combination of three ionized absorbers, each split into two kinematic components, can explain the strengths of almost all the absorption lines and bound-free edges. All three components are thermally stable and seem to have the same gas pressure. Thus, all three may coexist in the same volume of space. Turner (UMBC) and Kraemer presented results from a 20 ks XMM-Newton observation of Mrk 231. The European Photon Imaging Camera (EPIC) spectral data reveal strong line emission due to Fe $K\alpha$, which has rarely been detected in this class, as broad absorption line quasars (BAL QSOs) are very faint in the X-ray band. The line energy is consistent with an origin in neutral Fe. The width of the line is equivalent to a velocity dispersion $\sim 18,000 \text{ km s}^{-1}$, and thus the line may be attributed to transmission and/or reflection from a distribution of emitting clouds. If, instead, the line originates in the accretion disk, then the line strength and flat X-ray continuum support some contribution from a reflected component, although the data disfavor a model in which the hard X-ray band is purely reflected X-rays from a disk. Crenshaw (GSU), Kraemer, and Gabel (UC) studied the host galaxy morphologies of narrow- and broad-line Seyfert 1 galaxies (NLS1’s and BLS1’s) based on broadband optical images from the Hubble Space Telescope archives. They find that large-scale stellar bars, starting at $\sim 1 \text{ kpc}$ from the nucleus, are much more common in NLS1’s than BLS1’s. Furthermore, the fraction of NLS1 spirals that have bars increases with decreasing full width at half-maximum of the broad component of $H\alpha$. These results suggest a link between the large-scale bars, which can support high fueling rates to the inner kiloparsecs, and the high mass accretion rates associated with the supermassive black holes in NLS1’s. Kraemer collaborated with a group led by Gabel (UC) in the analysis of HST/STIS spectra of the Seyfert 1 galaxy NGC 3783. They report the first detection of an intrinsic absorber with decreasing outflow velocity in the Seyfert 1 galaxy NGC 3783. These results are based on measurements from 18 measurements, obtained between 2000 February and 2002 January. In two intervals separated by ~ 13 and 9 months, the absorption lines in the kinematic component with highest outflow velocity exhibited mean redward velocity shifts of ~ 35 and 55 km s^{-1} , respectively. The rate of velocity decrease was 2.2 ± 0.6 times more rapid in the second interval. No variations in absorption velocities were detected in the other kinematic components. They explore potential interpretations of the observed velocity shifts: radial deceleration of the UV absorber due to a change in either the speed or direction of motion of the outflow, and the evolution of a continuous flow across our line of sight to the emission source. Kraemer assisted a group led by Turner (UMBC) in the analysis of Reflection Grating Spectrometer data from an XMM-Newton observation of the Seyfert 1 galaxy NGC

3516, taken while the continuum source was in an extremely low flux state. This observation offers a rare opportunity for a detailed study of emission from a Seyfert 1 galaxy, as these are usually dominated by high nuclear continuum levels and heavy absorption. The spectrum shows numerous narrow emission lines ($\text{FWHM} < 1300 \text{ km s}^{-1}$) in the 0.3-2 keV range, including the H-like lines of C, N, and O and the He-like lines of N, O, and Ne. The emission-line ratios and the narrow width of the radiative recombination continuum of C VI indicate that the gas is photoionized and of fairly low temperature ($kT \sim 0.01 \text{ keV}$). The availability of emission lines from different elements for two isoelectronic sequences allows them to constrain the element abundances. These data show that the N lines are far stronger than would be expected from gas of solar abundances. Based on photoionization models, they find that nitrogen is overabundant in the central regions of the galaxy, compared to carbon, oxygen, and neon, by at least a factor of 2.5, and suggest that this is the result of secondary production of nitrogen in intermediate-mass stars and indicative of the history of star formation in NGC 3516. Kraemer, with a group led by Crenshaw (GSU), presented new UV spectra of the nucleus of the Seyfert 1 galaxy NGC 5548, which obtained with the Space Telescope Imaging Spectrograph at high spectral resolution, in conjunction with simultaneous Chandra X-Ray Observatory spectra. Taking advantage of the low UV continuum and broad emission-line fluxes, they have determined that the deepest UV absorption component covers at least a portion of the inner, high-ionization narrow-line region (NLR). They find nonunity covering factors in the cores of several kinematic components, which increase the column density measurements of N V and C IV by factors of 1.2-1.9 over the full-covering case. For the first time, they have simultaneous N V and C IV columns for component 1 (at -1040 km s^{-1}) and find that this component cannot be an X-ray warm absorber, contrary to our previous claim based on nonsimultaneous observations. They find that models of the absorbers based on solar abundances severely overpredict the O VI columns previously obtained with the Far Ultraviolet Spectroscopic Explorer and present arguments that this is not likely due to variability. However, models that include either enhanced nitrogen (twice solar) or dust, with strong depletion of carbon in either case, are successful in matching all of the observed ionic columns.

2.2 Interstellar Medium

Bruhweiler, in collaboration with Rubens Feire Ferrero (Stasbourg/France) is analyzing Far-UV data acquired with FUSE of stars in the Rosette Nebula and the central star of NGC 6164-5 (HD 148937). The data are being combined with both IUE and HST spectra in an attempt to understand the dynamics of the shells of expanding gas surrounding the central stars of the Rosette and HD 148937. Both regions are represented by central apparently, empty cavities, which appear to be interstellar bubbles blown by the embedded stars. However, in both cases, the ages for the stars are much older (although still less than 2 Myr) than the inferred ages of the expanding shell structures around these bubbles. The situation is further complicated in that the

ejecta of NGC 6164-5 show evidence of O and C deficiency (presumably CNO-processed). Bruhweiler continues to probe the evolution of stellar wind/supernovae driven shells and how their expansion and subsequent rise in column density in the shells lead to star-formation. Results indicate that much of the structure of Lindblad's Ring and Gould's Belt can be explained by star formation triggered by a single expanding shell complex driven by the kinematics of a star cluster some 50 million years ago near the Sun.

2.3 Stellar Physics and Astronomy

Grady, Woodgate (GSFC), Torres (Itajubá, Brazil), Henning (MPIA, Heidelberg), Williger et al. investigated the environment of the nearest Herbig Ae star, HD 104237, using a multiwavelength approach from the far-UV through the optical to the mid-IR. They find that two of the stars within $15''$ of HD 104237 have IR excesses, potentially indicating the presence of circumstellar disks, in addition to the Herbig Ae star itself. They derive a new spectral type of A7.5Ve-A8Ve and calculate an age of $\sim 5 \text{ Myr}$. HD 104237 is driving a bipolar microjet termed HH 669, making it the second, older Herbig Ae star now known to have a microjet. The presence of the microjet enables us to constrain the circumstellar disk to 70 AU. With the high spatial density of disks in this group of stars, proximity, and minimal reddening, HD 104237 and its companions should serve as ideal laboratories for probing the comparative evolution of planetary systems. Nielsen has in collaboration with Gull (GSFC), Bruhweiler, and Verner been investigating the UV/NUV spectrum of the LBV star $\eta \text{ Car}$ and its circumstellar gas. The analysis has revealed the spectrum to be a composite of spectral features from different parts of the $\eta \text{ Car}$ nebula including absorption spectra with blue-shifts corresponding -146 and -513 km s^{-1} . These velocity components are, based on their stellar characteristics, shown to exhibit different excitation conditions and located at vary different distance from the the central star. The spectrum and its variability is investigated to gain understanding of the nature and geometry of the $\eta \text{ Car}$ system. The Gallium abundance in HgMn stars has been reported to be dependent on what spectral range that is used in the analysis. Nielsen has in collaboration with Wahlgren and Proffitt pursued this problem from a line blending perspective. Proffitt, in collaboration with S. Adelman (the Citadel), G. J. Peters (USC), and G. Wahlgren (Lund), continues work using coadded IUE spectra to study very heavy elements in both normal and chemically peculiar B stars. Improved techniques for the coaddition of IUE high dispersion spectra have been developed, as have procedures for generating detailed spectral atlases of the best observed narrow lined stars. Proffitt continues theoretical work on the radiative acceleration of heavy elements in stellar envelopes and atmospheres. Improved techniques for radiative acceleration calculations in stellar atmospheres are also being developed, and large scale model atoms of gallium and other very heavy elements are being implemented for use in non-LTE calculations. Proffitt, in collaboration with K. Venn (Macalester), is studying Hubble Space Telescope spectrographic observations of boron in early-B stars with the goal of testing models of envelope mixing induced by stellar rotation. This data will also be

used to measure iron abundances in these stars. The cycle 13 HST-SNAP program 10175 (PI Proffitt) was designed to greatly expand the number of stars for which boron abundances are derived, but unfortunately only two targets were observed before the STIS instrument failed. Analysis of Far Ultraviolet Explorer (FUSE) spectra of the highly magnetic Ap star 17 Com A is ongoing. The very strong magnetic field in this star is expected to result in very non-uniform distributions of surface abundances. Proffitt is studying the variation of the spectrum with rotational phase in an attempt to determine the nature of the opacity changes over the surface of this star. Rettig (U. Notre Dame), Brittain (U. Notre Dame), Simon (U. Hawaii), Kulsea (U. Arizona), DiSanti, and Dello Russo obtained infrared observations of CO in preplanetary disks around Herbig AeBe stars (AB Aurigae and HD 141569). The CO spatial profiles constrained the location of the gas to a distance of less than 50 AU from both stars. The CO emission from the disk of AB Aurigae shows at least two temperature components suggesting an inner and outer disk of gas. The more evolved HD 141569 implies a single temperature distribution indicating the inner disk has been cleared of CO out to a minimum of about 17 AU. The residual mass of CO suggests the inner disk of HD 141569 is not in an active phase of planet building but does not rule out the possibility that giant planet building has previously occurred. Verner, Bruhweiler and Gull have studied the variability of ionization structure of surrounded nebulosities of Eta Carinae. The greatly expanded atmosphere of Eta Car and the surrounded nebulosities enshrouds the stellar system lying deep within. The X-ray emission of Eta Car exhibits a 5.54 year period, which is also seen in the modulation of the nebular emission lines. Through photoionization modeling, they find that the radiation field from the more massive B-star companion supports the low ionization structure throughout the 5.54 year period. The radiation field of an evolved O-star is required to produce the higher ionization emission seen across the broad maximum. This emission region is identified with slow-moving condensations, photoionized by the O star, in the extended mass flow emanating from the B star primary. Comparison between the models and observations reveals that high ionization lines belong to a region, physically distinct ($n_H = 10^7 \text{ cm}^{-3}$ and $T_e \sim 10^4 \text{ K}$) from the BD Blobs ($n_H = 10^6 \text{ cm}^{-3}$, $T_e \sim 7000 \text{ K}$). While they obtained the following important abundances for H; He; C; N; O; Ne; Mg; Si; S; Ar and Fe, more work is needed for the rest of ions. The results of this work are scheduled to appear in the *Astrophysical Journal*.

3. SOLAR PHYSICS AND SUN EARTH CONNECTION

Brosius, in collaboration with Stephen White (University of Maryland), analyzed coordinated observations of the large sunspot in NOAA Region 8539 obtained on 1999 May 9 and 13 with the Very Large Array (VLA) and three instruments (Coronal Diagnostic Spectrometer [CDS], Extreme-ultraviolet Imaging Telescope [EIT], Michelson Doppler Imager [MDI]) aboard the *Solar and Heliospheric Observatory* (SOHO) satellite. The EUV observations reveal a plume in the sunspot umbra on both observing dates. The plume ap-

pears brightest in emission lines formed at temperatures between 1.6×10^5 and 5.0×10^5 K. Radio emission from the sunspot umbra is dominated by thermal gyroemission from the plume, which accounts for radio brightness temperatures $< 1 \times 10^6$ K in the umbra on both dates, as well as umbral brightness temperature depressions in the 4.5 and 8.1 GHz observations on May 13. A compact 14.7 GHz source persists near the umbra/penumbra boundary during our observing period, indicating a long-lived, compact flux tube with coronal magnetic field strength of at least 1700 G. It occurs in a portion of the sunspot that appears very dark in EUV emission. Brosius continued analyzing coordinated EUV and radio observations of solar active regions obtained as part of SOHO's Joint Observing Program (JOP) 100 to extract information about the strength and structure of the coronal magnetic field. He devised and carried out a new campaign to obtain coordinated observations of an active region at the solar west limb in order to measure the height dependence of the coronal magnetic field. Brosius, in collaboration with Ken Phillips (NRC Senior Research Associate), analyzed EUV and X-ray light curves and Doppler velocity measurements for a GOES class M2 solar flare observed in NOAA Region 9433 on 2001 April 24 at high time resolution with SOHO's CDS (9.83 s) and with the Bragg Crystal Spectrometer (BCS) and Hard X-ray Telescope (HXT) aboard the *Yohkoh* satellite (9.00 s). Coordinated imagery with SOHO's EIT and the TRACE satellite reveal that the CDS slit was centered on the flare commencement site; coordinated magnetograms from SOHO's MDI are consistent with this site being the foot point of a flare loop anchored in positive magnetic field near the outer edge of a sunspot's penumbra. CDS observations include the preflare quiescent phase, two precursors, the flare impulsive and peak phases, and its slow decline. We find that (1) the average wavelengths of O III, O IV, O V, Ne VI, and He II lines measured during the preflare quiescent phase are equal (within the measurement uncertainties) to those measured during the late decline phase, indicating that they can be used as reference standards against which to measure Doppler velocities during the flare; (2) the EUV lines of O III, O IV, O V, and He II exhibit upflow velocities $\sim 40 \text{ km s}^{-1}$ during both precursor events, suggestive of small-scale chromospheric evaporation; (3) the Fe XIX EUV intensity rises and stays above its preflare noise level during the second (later) precursor; (4) the maximum upflow velocities measured in Fe XIX with CDS (64 km s^{-1}) and in Ca XIX (65 km s^{-1}) and S XV (78 km s^{-1}) with BCS occur during the flare impulsive phase, and are simultaneous within the instrumental time resolutions; (5) the Fe XIX EUV intensity begins its impulsive rise nearly 90 s later than the rise in intensities of the cooler lines; (6) hard X-ray emission arises nearly 60 s after the cool EUV lines begin their impulsive intensity rise; (7) the EUV lines of O III, O IV, O V, and He II exhibit downflow velocities $\sim 40 \text{ km s}^{-1}$ during the flare impulsive phase, suggesting momentum balance between the hot upflowing material and the cool downflowing material. Our observations are consistent with energy transport by nonthermal particle beams in chromospheric evaporation theory. Reginald and Brosius, in collaboration with J. M. Davila (GSFC) and O. C. St.Cyr

(GSFC), presented measurements of electron temperature and bulk flow speed low in the solar corona derived from white-light spectra obtained during the total solar eclipse of 21 June 2001. Observations were obtained at two locations in the solar corona, one within a helmet streamer at the east limb and the second in a streamer cluster in the southwest. Both points were at an altitude of about $1.1 R_{\odot}$ from the solar center. The east limb and southwest locations yielded electron temperatures of 0.96 ± 0.05 MK and 1.2 ± 0.2 MK and bulk flow speeds of $72.0_{-72.0}^{+281.0}$ km s⁻¹ and $257.0_{-257.0}^{+443.0}$ km s⁻¹, respectively. These measurements are unique in that they simultaneously provide both the electron temperature and its bulk flow speed; few previous measurements of electron parameters in the corona are available. These results demonstrate the potential for this technique: if the instrument were used with a coronagraph it would provide routine synoptic maps of electron temperature and bulk flow speed. Brosius contributed to the science definition and E/PO planning for the Normal-incidence EXtreme Ultraviolet Spectrograph (NEXUS), a pending NASA SMEX mission (J. M. Davila, PI). He also contributed to science and observing plans for GSFC's Extreme Ultraviolet Normal Incidence Spectrometer (EUNIS) sounding rocket experiment (Douglas Rabin, PI). He also collaborated with Jeff Kuhn (University of Hawaii), Reginald, Davila, R. J. Thomas (GSFC), and St.Cyr to develop plans for the new Multi-Aperture Coronal Spectrometer (MACS) instrument to be installed on the SOLARC coronagraph at Mees Solar Observatory on Haleakala. Brosius continued ongoing collaborative EUV spectroscopy work with Thomas, Davila, and F. P. Keenan (The Queen's University of Belfast, Northern Ireland). Comparisons between emission line intensity ratios measured with GSFC's Solar EUV Research Telescope and Spectrograph (SERTS) sounding rocket experiment and those derived from theoretical calculations generally reveal good agreement between theory and observation. Ions studied most recently include Si VIII, Fe XV, and Fe XI. Accurate atomic physics calculations enable us to (1) reliably identify lines in solar and stellar spectra, (2) use line intensity ratios to derive the density of the emitting plasma, (3) use lines formed at different temperatures to derive the differential emission measure of the emitting plasma, and (4) verify or modify the relative radiometric calibration of satellite instruments via density- and temperature-insensitive line intensity ratios. Ofman has worked on theoretical models of coronal heating and solar wind acceleration and developed two-dimensional three-fluid model of the fast solar wind accelerated and heated by a spectrum of waves. The model allows to investigate the interaction between the waves, the protons, and the heavy ions in the solar wind, and compare to spectroscopic observations. The three fluid model was also applied to the study of the slow solar wind in coronal streamers. Ofman has collaborated with CUA postdoc J. Terradas (now at U. Balears, Spain) on three-dimensional MHD models of coronal loops and waves in solar active regions. They showed how wave activity can affect the properties of loops, and used as a diagnostic tool of the physical parameters of the coronal plasma. Ofman collaborated with Xie and Lawrence (now at Royal Observatory, Belgium) on the development of empiri-

cal models of coronal mass ejection (CME'). By estimating better the velocities and the arrival time of these solar disturbances, the models can potentially improve space weather forecasting. Ofman continued his work on hybrid kinetic models of ion-cyclotron instability and heating of ions in the solar wind plasma in collaboration with H. Xie, S.P. Gary (LANL) and A. Vinas, (NASA/GSFC). New multi-ion models were developed using one-dimensional and two-dimensional hybrid codes. These studies were motivated by recent *SOHO* Ultraviolet Coronagraph Spectrometer (UVCS) observation of large temperature anisotropy, and preferential acceleration of minor ions in coronal holes, suggesting that the ion-cyclotron waves energize and accelerate the minor ions in the fast solar wind. Ofman continued his collaboration with E. Sittler (NASA/GSFC), S. Gibson (HAO), and T. Holzer (HAO) on semi-empirical, and self-consistent MHD modeling of solar wind flow in multi-streamer coronal structures. Moran developed a technique to create three-dimensional reconstructions of coronal mass ejections (CMEs) using polarized exposures recorded by the *SOHO*/LASCO coronagraphs. These reconstructions show that CMEs expand radially from their source regions and have a loop arcade structure which remains connected to the sun at multiple locations for the duration of the observations (Moran and Davila 2004). As part of this work, Moran characterized the polarization properties of the LASCO coronagraphs by measuring the polarization angles of electron-scattered light at the solar limb. Since the true angle is tangential to the limb, deviations from tangentiality provide the information needed to correct for instrumental effects. Moran developed correction algorithms for the C2 coronagraph, which acts as a partial circular polarizer, and for the C3 coronagraph, which has a small asymmetric component of polarized stray light at the focal plane (Moran *et al.*, 2004, to be submitted to Solar Physics). Sui, with G. Holman (GSFC/LASP) and B. Dennis (GSFC/LASP), has been studying solar flares mainly using the hard X-ray observations from the Ramaty High Energy Solar Spectroscopic Imager (RHESSI). Sui found that the RHESSI observations of three homologous flares that occurred between April 14 and 16, 2002, provided strong evidence for the presence of a large-scale current sheet above a flare loop, which is the basis of standard flare models. The most convincing finding is the presence of the temperature distribution of a separate coronal source above the flare loops: the hotter part of the coronal source was located lower in altitude than the cooler part. Together with the fact that the hotter flare loops are higher than the cooler loops, the observations support the existence of a large-scale current sheet between the top of the flare loops and the coronal source above. Sui also found some hard X-ray features which are beyond the predictions of the standard flare models: the downward motion of flare loops in the early impulsive phase of each flare, and an initially stationary coronal source above the loops. In particular, the downward loop motion seems to be a common phenomenon in flares, suggesting the necessity for modifications to the existing standard flare models.

4. PLANETARY SCIENCES

4.1 Planetary Astronomy

Crider is using her model of the migration of water vapor to lunar polar cold traps to estimate the atmospheric content of water vapor and its dissociation products. These calculations are then used to determine specs for orbital instruments that would search for these products in the lunar exosphere. T. Breus (Russian Academy of Sciences), A. Krymskii (Rostov State University), and Crider have studied the relationship between ionospheric scale height and the martian magnetic anomalies. They have found that there is evidence of heating near regions of locally vertical magnetic field. These are presumably magnetic cusps, where solar wind plasma has direct access to the ionosphere. The solar wind deposits some of its energy there in the form of heat. This increases the ionospheric scale height above what is observed elsewhere in the martian ionosphere. Krymskii and Crider are investigating magnetic flux ropes in the martian ionosphere. When the magnetic field magnitude is low, an instability allows the magnetic flux to wrap up into flux ropes. This phenomenon is also observed in the ionosphere of Venus, at the Earth's magnetopause, and in the solar wind. At Mars, flux ropes are not observed in the southern hemisphere where crustal magnetic sources are present. Crider is analyzing MGS ER data for information on ionospheric clouds at Mars. Parcels of plasma with photoelectron spectra, characteristic of the martian ionosphere, are observed at higher altitudes by MGS. These parcels of plasma either are detached from the ionosphere or represent bumps in the ionosphere or result from temporal fluctuations in the ionopause position. Many models of the solar wind interaction with Mars show detaching ionospheric plasma, which then travels downstream and is lost from the system. The extent to which this mechanism contributes to atmospheric loss from Mars is yet unknown. Kletetschka along with M. H. Acuna (GSFC), T. Kohout (Academy of Sciences, Czech Republic), P. J. Wasilewski (GSFC), and J. E. P. Connerney (GSFC) reached an extremely significant finding, namely that there is a simple linear relationship between the intensity of a TRM (normalised by easily obtainable magnetic parameters) and that of the magnetizing field that transcends both magneto-mineralogy and domain-state. Our work is describing one of the most important recent discoveries in rock magnetism. A general relationship of thermoremanent magnetization they found allows link of all of the magnetic materials (natural/artificial) under one simple theoretical equation in their paper Kletetschka *et al.*, (2004a). Kletetschka, along with J. E. P. Connerney, N. F. Ness (U. of Delaware), and M. H. Acuna, studied a Pressure effects on Martian crustal magnetization near large impact basins. In their paper (Kletetschka *et al.*, 2004b) they studied an effect of impact on natural magnetic minerals and compared their results with magnetic modeling of Martian magnetic anomalies near large impact basins. They were able to detect a magnetic region that has signature of extremely high magnetic coercivity that can be explained only by presence of high coercivity mineral like hematite and/or pyrrhotite. This suggests involvement of water during the crustal formation associated with large magnetic signatures. Kle-

tetschka, N. F. Ness, P. J. Wasilewski, J. E. P. Connerney, and M. H. Acuna, they analyzed all possible magnetic minerals that could cause magnetic anomalies on Mars. In their paper, Kletetschka *et al.*, (2003a) they demonstrate the magnetic strength of natural minerals in correlation with natural occurring rocks and discuss the thermoremanent and chemical magnetic acquisition mechanisms. Kletetschka, T. Kohout, and P. J. Wasilewski designed a new paleointensity technique published in Kletetschka *et al.*, (2003b) and applied this technique to detect paleomagnetic information in Murchison meteorite. They discuss their findings in light of possible generation of aminoacids, the building blocks of life on Earth. They rule out an electric discharge as a significant mechanism forming the aminoacids in the parent body of Murchison meteorite. Kletetschka, Kohout, T. M. Kobr, P. Pruner, and P. J. Wasilewski are actively involved in examining the magnetic contamination of meteorites both chemical and isothermal. Their lab allows them to run complex chemical/magnetic experiments that deepen their understanding how meteorites change magnetic properties during their terrestrial residence. Kletetschka studied magnetic interactions and showed that significant errors can be reported when estimating paleomagnetic intensities in archeomagnetic samples. An intriguing pattern resulting from magnetic interaction can be used to achieve a required precision in archeomagnetic paleointensity estimates. Krasnopolsky completed a study of Martian dayglow. The O₂ dayglow at 1.27 μ m is a sensitive tracer of Mars photochemistry. Maps of the dayglow intensity at four seasons on Mars were observed using a high-resolution spectrograph CSHELL at the NASA Infrared Telescope Facility on Hawaii. Diurnal, latitudinal, and seasonal variations of the dayglow are revealed and discussed. The results provide the observational basis for chemical-dynamical modeling of Mars atmosphere. Krasnopolsky, with J. P. Maillard (CNRS), and T. C. Owen (U. of Hawaii) reported on the first detection of methane in the Martian atmosphere. A spectrum of Mars at the P-branch of the strongest methane band at 3.3 μ m was observed with resolving power of 180,000 using the Fourier Transform Spectrometer at the Canada-France-Hawaii Telescope. Summing up the data for 15 strongest lines, the absorption of martian methane was revealed at a 3.7 sigma level. The observed absorption results in a methane mixing ratio of 103 parts per billion. It is the smallest species ever detected on Mars. Its lifetime is 340 years on Mars, and methane production is 270 tons per year. Mean deliveries of methane by comets and meteorites are 2% and less than 4% of this value, respectively. Outgassing from Mars is weak, the latest volcanism is at least 10 million years old, and thermal emission imaging from Mars Odyssey does not reveal any hot spots on Mars. Hydrothermal systems can hardly be warmer than the room temperature at which production of methane is extremely low. Therefore, methanogenesis by living subterranean organisms is a plausible explanation of this discovery. The suggested estimated show that the martian biota may be extremely scarce and Mars may be generally sterile except for some oases. Mumma (GSFC), Novak (Iona College), DiSanti (GSFC), Bonev (U. of Toledo/GSFC), and Dello Russo conducted a sensitive search for methane in the atmo-

sphere of Mars. Long-slit maps of methane and water, were acquired using CSHELL, Phoenix (Gemini-south), and NIRSPEC.

4.2 Mars Odyssey 2001

Starr is a Participating Scientist on the Mars Odyssey 2001 Gamma-Ray Spectrometer (GRS) experiment; principal investigator is W. Boynton of the University of Arizona. The Mars Odyssey spacecraft was launched in April 2001, arrived at Mars in October 2001, and began mapping the surface of the planet in February 2002. The GRS is an instrument suite consisting of a gamma-ray spectrometer, a neutron spectrometer (NS) and a high-energy neutron detector (HEND) (Boynton *et al.* 2004). The GRS measures the elemental composition of the surface and the abundance of hydrogen in the shallow subsurface. During the first few months of observations the GRS identified a region of hydrogen enrichment near the south pole. The data indicated the presence of a subsurface layer enriched in hydrogen - most likely water-ice - overlain by a hydrogen-poor layer (Prettyman *et al.* 2004). Subsequent observations have identified a similar region of water-ice at the north pole. Two years of observations have allowed the Mars Odyssey GRS team to generate global maps of H, Si, Fe, Cl, K, and Th all with spatial resolution 500 km. Publication is expected later this year.

4.3 MESSENGER

The Discovery MErcury Surface, Space ENvironment, Geochemistry, and Ranging mission (MESSENGER) was launched on 3 August 2004. The purpose of this mission is to collect global information on the surface, interior, exosphere and magnetosphere of Mercury. During more than six years of cruise, MESSENGER will execute one Earth fly-by, two Venus fly-bys and three Mercury fly-bys. The orbital portion of the mission, beginning in March 2011, will last one Earth year. The principal investigator is S. Solomon of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The lead institution for the spacecraft and mission operations is the Johns Hopkins University/Applied Physics Laboratory. Starr is part of the geochemistry team that will use data from the MESSENGER x-ray, gamma-ray, and neutron spectrometers to determine the surface composition of Mercury. Starr is also the instrument scientist for the MESSENGER X-ray spectrometer experiment.

4.4 Interplanetary matter

Ipatov, together with J.C. Mather, A.S. Kutyrev, S.H. Mosely (GSFC), G.J. Madsen, and R.J. Reynolds (University of Wisconsin-Madison), has developed a set of self-consistent dynamical models of the Zodiacal cloud, following the orbital evolution of dust particles under the gravitational influence of planets, radiation pressure, Poynting-Robertson drag, and solar wind drag (Ipatov *et al.* 2004). Three populations were considered, originating from the Kuiper belt, asteroids and comets. Using the models developed, we investigated how the solar spectrum is changed by scattering by the zodiacal cloud grains, what brightness is

due to different distances and velocities, and what is the distribution of migrating dust particles in the Solar System. For each particles population different scattering functions were considered. With improved and more extensive observations it will be possible to distinguish the sources of dust and impose constraints on the particle size distribution. This should result in a self-consistent 3D model of Zodiacal cloud density and velocity particles distribution.

4.5 Cometary studies

Dello Russo, Gibb (NRC/GSFC), Magee-Sauer (Rowan U.), DiSanti (GSFC), Mumma (GSFC), and Bonev (U Toledo/GSFC) have continued to probe the volatile composition of comets using high-resolution ground-based infrared spectroscopy. Since 1996, twelve Oort cloud comets have been observed with the high-resolution spectrometers CSHELL at NASA-IRTF and NIRSPEC at Keck 2 on the summit of Mauna Kea, Hawaii. Comparison of the volatile species reveals compositional differences between these comets that may suggest the regions in the early solar nebula where they formed. The spectral grasp of NIRSPEC allowed an almost complete spectral survey in the 2.9 - 3.6 μm region of comet C/1999 H1 Lee in August 1999. A spectral atlas is being prepared to catalog the hundreds of features seen in this spectral region. Dello Russo, Gibb, Magee-Sauer, DiSanti, Mumma, Bonev, Tennyson (UCLondon), and Barber (UCLondon) Have continued and extended their studies on water production in comets to the 2.9 μ spectral region, where there are many lines. Fluorescence models for water hot-bands were developed, and applied to data obtained on comet 153P/Ikeya-Zhang (C/2002 C1). Production rates and rotational temperatures were determined. In addition to cometary composition, determination of the nuclear spin temperature of water from the ortho-to-para ratio (OPR) may be a way to probe the temperature of comet forming regions. We have measured the production rate, rotational temperature, and OPR for water in three recent comets (C/1999 H1 Lee, C/1999 S4, and C/2001 A2) using our recently developed fluorescence models. DiSanti, Dello Russo, Magee-Sauer, Gibb, Mumma, Reuter (GSFC), and Xu (U. New Brunswick) studied the volatile oxygen chemistry in Oort cloud comets, concentrating on the chemically-linked molecules CO, formaldehyde, and methyl alcohol. Their relative abundances may test the efficiency of hydrogen addition reactions to CO on the surfaces of icy-mantled grains prior to their incorporation into the nuclei of comets. Current models suggest that the formation of methanol is particularly sensitive to temperature in the range of interest ($\sim 10 - 30$ K). Gibb, Mumma, Dello Russo, DiSanti, and Magee-Sauer studied methane production and release in comets. Fluorescence models for methane were developed and applied to eight Oort-cloud comets. Abundances of methane/water are compared among our existing sample of comets, in the context of establishing their place of origin. In addition, methane is compared to native CO, another hypervolatile species, and no correlation is found among the comets observed. Krasnopolsky reported on advanced observations of x-ray spectra of two comets using the Chandra X-ray Observatory have been processed in the same way to compare x-rays from

those comets. Despite the different observing conditions and properties of the comets, efficiencies of x-ray excitation relative to the solar wind flow are equal for both comets thus confirming the excitation by charge exchange between the solar wind heavy ions and cometary species. Lines of multiple charged ions of O, C, Ne, Mg, and Si are identified in the spectra. Some ion ratios and temperature are extracted and discussed. Krasnopolsky discovered a significant error in a paper by Podolak *et al.* regarding whether the D/H ratio in the comet coma equal to the D/H ratio in the comet nucleus, which adversely affects all conclusions of that paper. Krasnopolsky, with J. P. Greenwood (UCLA) and P. C. Stancil (U.of Georgia), is studying X-ray and extreme ultraviolet emissions from comets. Significant progress has been achieved in both observations and theory of x-ray and EUV emissions from comets since the discovery of this phenomenon eight years ago.

4.6 Miscellaneous Activities

Kletetschka, V. Zila (Charles Univ., Czech Republic), and P. J. Wasilewski examined environmental effects of traffic pollution near Washington Baltimore Parkway and described a strange pattern of magnetic signature around the tree trunks near the highway. Magnetism on the side of the tree trunks facing the highway is much less than facing away from the highway. They explain this observation by applying the atmospheric circulation model driven by nearby traffic.

5. INSTRUMENT DEVELOPMENT

5.1 James Webb Space Telescope

Kletetschka is actively researching the magnetic properties of the microshutters for James Web Space Telescope. His work allow the production team to come with the best recipe to built this complex devices allowing much better detection of light coming from the deepest corners of the universe. His work along with T. T. King, M.A. Jah, M.J. Li, M.D. Jhabvala, L.L. Wang, R.F. Silverberg, D. Rapchun, D.S. Schwinger, G.M. Voellmer, S.H. Moseley and L.M. Sparr, stirred the microshutter design in new direction allowing better performance and reliability.

5.2 UMBRAS

Bruhweiler and Mike DiSanti continue to work closely with A. Schultz, H. Hart, & I. Jordan (all at STScI/CSC), and with J.M Hollis and R. Lyon (NASA/GSFC) to develop a spacecraft system for detecting terrestrial extrasolar planets. This effort has centered around the development of a free flying occulter called UMBRAS that would work in conjunction with a large 4m-class space telescope placed at L2, that could directly image Jovian and earth-sized planets. The present design makes use of existing technology and is an outgrowth of an original idea by Lyman Spitzer. The current UMBRAS design has been further defined from earlier work. Ideas have been presented on how it could be mated to a launch vehicle. Moreover, a mission operations concept has also been developed. This system consists of a Solar-Powered Ion Driven Eclipsing Rover (SPIDER) attached to

an occulter. Details and papers describing this proposed spacecraft can be found at <http://www.umbras.org> The UMBRAS is designed to enable an astronomical space observatory, either a 1-m to image Jupiter-sized planets with 5 A.U of the central star at distances out to or possibly greater than 30 pc. A much larger 4-m space telescope could also be used to image and study earth-like planets. This concept has been presented in a technology development proposal to NASA and at several recent SPIE meetings and a more refined concept is being developed.

5.3 Additional Activities

Reginald is currently involved in building an advanced white-light spectrometer to be attached to the SolarC coronagraph at the Mees Solar Observatory in Haleakala, Hawaii for coronal diagnostic study to determine the coronal electron temperature and its speed simultaneously and globally on the solar corona. Chen continued collaboration with R. Oliverson (NASA GSFC) on the development of lightweight mirrors and system concepts for a Life Finder type mission. A study was made to investigate the use of autonomous robots and wireless power transmission for unmanned exploration of lunar polar craters (led by M. Comberiate, NASA GSFC). Work has commenced on the development of lightweight mirrors with ultra-smooth surfaces for the Stellar Imager mission (PI K. Carpenter, NASA GSFC)

6. EDUCATIONAL OUTREACH AND OTHER ACTIVITIES

The SUNBEAMS program is now in its seventh year as an exciting and successful educational partnership between NASA Goddard Space flight Center and the District of Columbia Public Schools. Crannell continues as Principal Investigator for the program which is widely recognized as a model urban intervention technique. The Summer Student Program in the Laboratory for Astronomy and Solar Physics is now in its 21st year, funded in part with a Research Experiences for Undergraduates (REU) grant from the National Science Foundation since 1987. During the summer of 2004, thirty-five students participated in the program. Michaels along with Charles Montrose (Physics/CUA) and Sally Pickert (Education/CUA) were Teachers of Physical Science (TOPS!). The goal of the TOPS! program is to improve the preparation of Washington area K-8 General Education teachers in basic physical science. Content of the program is teaching of basic physical science, brought out and illustrated at every step through the wealth of solar imagery provided by active space observatories, particularly SOHO. Solar observations serve as both a hook, to catch student interest, and a teaching aid to illustrate physical concepts. This has been a collaboration between members of IACS, the Department of Physics, and the Dept. of Education at CUA. An expansion of scope this coming year introduces to TOPS! a collaboration with the departments of Engineering and Education at University of District of Columbia, with whom IACS and CUA are participating in a NASA-funded MUC-ERPI program (Minority University Collaboration for Edu-

cation and Research Program Initiatives) for strengthening the Space- Related physical science program of that institution.

PUBLICATIONS

The publication list includes all papers published or submitted between September 2003 and September 2004 by the permanent staff.

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