The Catholic University of America
Institute for Astrophysics and Computational Sciences
Department of Physics

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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 2001 through September 2002. IACS has three major areas of concentration a) Basic Astrophysics & Planetary Physics, b) Imaging Technology and c) Solar and Solar-Terrestrial Physics. 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), Vladimir Airapetian, Al Boggess, Tom Brown, Jeff Brosius, Peter Chen, Dana Crider, Mike DiSanti, Jack Gabel, Mike Goodman, Rosina Iping, Gunther Kletetschka, Alejandro Lara, C.-H. Lyu, Tom Moran, Leon Ofman, Charles Proffitt, Rich Robinson, Nelson Reginald, Mike Reiner, Meena Sahu, Myron Smith, Margaret Smith Neubig, O.C. St. Cyr, Dave Steyert, Mashiro Tanaka, Katya Verner, Glenn Wahlgren, Gerry Williger, and Sieji Yashiro. Other Ph.D. members of the Dept. of Physics working closely with the IACS include Pamela Clark, Neale Dello Rosso, Vladimir Krasnopolsky, and Richard Starr. Adjunct Professors of the IACS, or those working closely with it, include Mike Crenshaw, Nat Gopalswamy, Yoji Kondo, Andrew Smith, 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, Nick Collins, Rick Edwards, Joseph Goyette, Charles Hall, Ian Liska, John Nichols, 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, S. Yashiro, N. Gopalswamy (NASA/GSFC), A. Poland (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

T. Brown, with H.C. Ferguson (STScI), R.W. O'Connell (UVa), and R.G. Ohl (GSFC) has analyzed far-UV spectra of the giant elliptical galaxy NGC 1399, obtained with the *Far Ultraviolet Spectroscopic Explorer (FUSE)*. Of all quiescent ellipticals, NGC 1399 has the strongest known ''UV upturn''-a sharp spectral rise shortward of 2500 Å . It is now well established that this emission comes from hot horizontal branch stars and their progeny; however, the chemical composition of these stars has been the subject of a longstanding debate. For the first time in observations of any elliptical galaxy, these spectra clearly show photospheric metallic absorption lines within the UV upturn. The abundance of N is at 45% solar, Si is at 13% solar, and C is at 2% solar. Such abundance anomalies are a natural consequence of gravitational diffusion. These photospheric abundances fall in the range observed for subdwarf B stars of the Galactic field. Although NGC 1399 is at the center of the Fornax Cluster, they found no evidence for O VI cooling flow emission. The upper limit to $\lambda\lambda$ 1032, 1038 emission is 3.9 x 10^{-15} ergs s^{-1} cm^{-2}, equivalent to 0.14 $M_{\odot}$ yr^{-1} and less than the value predicted by simple cooling flow models of the NGC 1399 X-ray luminosity.

Bruhweiler, along with Miskey, and Smith Neubig, and Alex de Koter (Amsterdam), 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. The goals are to use UV spectra to: a.) determine the photospheric abundance patterns in the young stars of the different galaxies, b.) determine how metallicity affects the characteristics (mass loss rate and terminal velocities) of the mass outflow, and c.) derive the nature of the dust extinction laws in regions where pronounced starburst activity is observed. Two papers describing the data reduction process and the analysis of STIS 2-D spectral imagery were prepared for publication. HST/STIS two-dimensional spectral imagery have been obtained by Bruhweiler, Miskey, de Koter, Walborn, and Smith Neubig for young OB associations in Sextans A, NGC 6822, and for the core of 30 Dor in the LMC. The spectra obtained for the O and B stars in Sextans A sample the lowest metallicity O and B stars (1/30 Solar abundance) for which individual UV spectra have been obtained. This metallicity is only a factor of two higher than that of I Zw 18, which is the most metal deficient galaxy known. The spectra of the Sextans A stars show significantly weaker N V, C IV, and Si IV UV mass loss profiles than in analogous SMC stars. An analysis using sophisticated model atmospheres has commenced. Analysis of the STIS data for NGC 346 in the SMC and the core of 30 Doradus in the LMC data are well underway. These HST two-dimensional spectra yield UV through visual spectra for over 300 individual OB stars. Bruhweiler, Miskey and Smith Neubig have prepared two papers for publication that describe the newly developed spectral extraction technique for STIS 2-D data and also its application for one of the brightest H II regions in the Local Group, NGC 604 in M 33. The extraction technique has been shown to provide significantly better spectral resolution than the standard STScI pipeline processing. This has important implications for all observations using the STIS aboard the HST. Analysis of the STIS data for core of NGC 604 reveal five luminous W-R stars. The luminosities and spectral types of these stars along with other early type O stars in NGC 604 imply an age of 3-4 Myr for the most recent phase of star formation.

Williger and Liske (Edinburgh) used pixel opacities to study absorption systems toward a 1 deg field of $z>2.5$ QSOs. They confirmed the existence of the proximity effect, in which absorption systems have lower opacities in the vicinity of their backlighting QSO. They also found an example of the foreground proximity effect, in which a QSO close to the absorbers toward a higher redshift QSO several arcmin away shows decreased opacity.

Smette (Liege), Heap (GSFC), Williger, Tripp, Jenkins (Princeton) and Songaila (Hawaii) used *Hubble Space Telescope (HST)*/Space Telescope Imaging Spectrograph (STIS) spectra to measure the HeII Gunn-Peterson effect toward HE2347-4342. The softness of the UV background field varies by a factor of 70 over scales of a few Mpc, probably due to the presence of local ionizing sources.

Tripp, Jenkins, Williger, Heap *et al.* used STIS echelle data for 3C 273 to constrain the metallicities of two QSO absorbers in the Virgo cluster. A photoionization model implies an absorber thickness of 70 pc, implying pressure confinement. The Si/C ratio indicates enrichment by Type II supernovae, most plausibly provided by a galactic wind.

Williger, Campusano (U. de Chile), Clowes (U. Central Lancashire, UK) and Graham (Imperial College, London, UK) found that a large QSO group at $1.2<z<1.4$ which spans 2.5×5 degrees on the sky contains an overabundance of MgII absorbers, which in turn implies a galaxy overdensity associated with the QSOs. The MgII absorbers and QSOs correlate on a scale of 9/h Mpc, which is consistent with observed galaxy-AGN correlations.

Gabel, Kraemer, Crenshaw (GSU), Brandt (PSU), George (GSFC/UMBC), Hamann (UF), Kaiser (JHU), Kaspi (PSU/TAU), Kriss (JHU/STScI), Mather (OSU), Mushotzky (GSFC), Nandra (GSFC/USRA), Netzer (TAU), Peterson (OSU), Shields (OU), Turner (UMBC/GSFC), and Zheng (JHU) have undertaken an intensive multiwavelength monitoring campaign of the Seyfert 1 galaxy NGC 3783 to probe the intrinsic absorption associated with its AGN. This campaign involves multiple, simultaneous observations with *HST*/STIS, *FUSE*, and *Chandra* to explore the absorption in the UV, far-UV, and X-ray. Analysis of the time-averaged X-ray spectrum obtained with *Chandra* is published in Kaspi et al. (2002). The multiple *FUSE* and STIS spectra obtained for the observing campaign have been summed to produce an averaged high signal-to-noise spectrum spanning 905 – 1800 Å ; analysis of this spectrum has been published in Gabel *et al.* (2002). The averaged spectrum reveals absorption in O VI, N V, C IV, N III, C III and the Lyman lines up to Lyϵ in the three blueshifted kinematic components previously detected in the STIS spectrum (at radial velocities of -1320, -724, and -548 km s^{-1}). The highest velocity component also exhibits absorption in Si IV and metastable C III, which indicates a high density in this absorber. They also make a tentative identification of a weak, fourth absorption component in the high ionization lines and Lyα and Lyβ at a radial velocity of -1027 km s^{-1}. The Lyman lines reveal a complex absorption geometry. The strength of the higher order lines indicates Lyα and Lyβ are saturated over much of the resolved profiles in the three strongest absorption components and, therefore, their observed profiles are determined by the covering factor. They separate the individual covering factors of the continuum and emission-line sources as a function of velocity in each kinematic component using the Lyα and Lyβ lines. The covering factor of the BLR is found to vary dramatically between the cores of the individual kinematic components, ranging from 0 to 0.84. Additionally, they find that the continuum covering factor varies with velocity within the individual kinematic components, decreasing smoothly in the wings of the absorption by at least 60%. Comparison of the effective covering factors derived from the H I results with those determined directly from the doublets reveals the covering factor of Si IV is less than half that of H I and N V in the high velocity component. Additionally, the FWHM of N III and Si IV are narrower than the higher ionization lines in this component. These results indicate there is substructure within this absorber. They also find evidence for structure in the column density profiles of the high ionization lines in this component. They derive a lower limit on the total column ($N_H \geqslant 10^{19}$ cm^{-2}) and ionization parameter ($U \geqslant 0.005$) in the low ionization subcomponent of this absorber. The metastable-to-total C III column density ratio implies $n_e \approx 10^9$ cm^{-3} and an upper limit on the distance of the absorber from the ionizing continuum of $R \leqslant 8 \times 10^{17}$ cm. The decreasing covering factor found in the wings of the absorption and the extreme compactness of the C III* absorber are suggestive of a clumpy absorption gas with low volume filling factor.

Gabel and Bruhweiler have published their analysis of the starburst/LINER galaxy, NGC 4569. Through detailed population synthesis analysis, they find the compact nuclear stellar population is best described by a 5-6 Myr, approximately instantaneous starburst with subsolar metallicity. Further, the young star burst that dominates the UV emission is found to be distinct from the nuclear population of A supergiants identified in the optical spectrum by Keel (1996). They have modeled the spectral energy distribution of the stellar ionizing continuum using the spectral synthesis results and stellar atmosphere models. The Savage & Mathis (1979) extinction curve satisfies all luminosity constraints and the derived reddening is similar to the emission-line reddening. These results imply extreme conditions in the nuclear starburst, with 5 x 10^4 O and B stars compacted in the inner 9X13 arcsec region of the nucleus. Using photoionization analysis and employing all observational constraints on the emission-line gas, they find very specific conditions are required if the spectrum is generated solely by stellar photoionization. At least two spatially distinct components are required: a compact region with strong [O III] emission and an extended, low-density component emitting most of the [S II] flux. A high-density component is also needed to generate the [O I] flux. Additionally, a limited contribution from Wolf-Rayet stars to the ionizing SED is necessary, consistent with the results of the study by Barth & Shields (2000). As a physical interpretation, they suggest the multicomponent emission-line gas may arise from ambient gas (both interstellar and from the parent molecular cloud of the starburst), that may be swept up by the supernovae and stellar winds associated with the starburst.

Kraemer assisted T.J. Turner (UMBC/GSFC), R.F. Mushotzsky (GSFC), T. Yaqoob (JHU), I.M. George (UMBC/GSFC), S.L. Snowden (GSFC), H. Netzer (TAU), K. Nandra (USRA/GSFC), and D. Chelouche (TAU) in the analysis of simultaneous *Chandra* High Energy Transmission Grating and *XMM-Newton* observations of NGC 3516. They found evidence of several narrow components of Fe Kα along with a broad line. They considered the possibility that the lines arise in a blob of material ejected from the nucleus with velocity $\sim$ 0.25c. They also considered an origin in a neutral accretion disk, suffering enhanced illumination at 35R_g and 175R_g, perhaps as a result of magnetic reconnection. The presence of these narrow features indicates there is no Comptonizing region along the line of sight to the nucleus. This in turn is compelling support for the hypothesis that broad Fe Kα components are, in general, produced by strong gravity.

Kraemer, as part of a group including H. Netzer (TAU), D.M. Crenshaw (GSU), I.M. George (UMBC/GSFC), D. Chelouche (TAU), J.R. Gabel, and T.J. Turner (UMBC/GSFC), analyzed intrinsic UV and X-ray absorption in the Seyfert 1 galaxy NGC 3516, using contemporaneous observations obtained in October 2000 with the *HST*/STIS and the *Chandra*/Low Energy Transmission Grating Spectrograph. They found that The UV continuum was $\sim$4 times lower than that observed during 1995 with the Goddard High Resolution Spectrograph (GHRS), and the X-ray flux was a factor of $\sim$8 below that observed with *ASCA*. The STIS spectra showed kinematic components of absorption in Lyα, C IV, and N V at radial velocities of -376, -183, and -36 km s^{-1} (components 1, 2, and 3+4, respectively), which were detected in the earlier GHRS spectra; the last of these is a blend of two GHRS components that have increased greatly in column density. Four additional absorption components appeared in the STIS spectra at radial velocities of -692, -837, -994, and -1372 km s^{-1} (components 5-8) these may also have been present in earlier low-flux states observed by the *International Ultraviolet Explorer*. Based on photoionization models, they suggested that the components are arranged in increasing radial distance in the order 3+4, 2, 1, followed by components 5-8. They achieved an acceptable fit to the X-ray data using the combined X-ray opacity of the UV components 1, 2, and 3+4. By increasing the UV and X-ray fluxes of these models to match the previous high states, they were able to match the GHRS C IV column densities, the absence of detectable C IV absorption in components 5-8, and the 1994 *ASCA* spectrum. They concluded that variability of the UV and X-ray absorption in NGC 3516 is primarily due to changes in the ionizing flux. Analysis of the *Chandra* observations and earlier *ASCA* observations are consistent with this scenario. The X-ray data allow them to put a conservative upper limit of 60 ksec on the recombination time, which translates to a lower limit of about 2.4 x 10^6 cm^{-3} on the density of the recombining gas and an upper limit of about 6 x 10^{17} h_{75}^{-2} cm on its distance from the central source. These are the best limits obtained so far on the density and location of the X-ray-absorbing gas in a type 1 active galactic nucleus (AGN). The *Chandra* ACIS/LETGS data also reveal a strong (EW=290 eV), unresolved 6.4 keV iron line, a strong O VII 0.561 keV line, and a marginally detected N VI 0.419 keV line. The former is interpreted as originating in a large column of gas of a lower state of ionization seen in reflection and is consistent with the spectrum at high energies at all epochs. The two other emission lines are probably emitted by the gas also responsible for the line-of-sight absorption.

Kraemer worked in collaboration with a group led by I.M. George (UMBC) which analyzed the first high-resolution, X-ray image of the circumnuclear regions of the Seyfert 1 galaxy NGC 3516, using the *Chandra*. They discovered a previously unknown X-ray source, detected $\sim$ 6 arcseconds (1.1 h_{75}^{-1} kpc) NNE of the nucleus (position angle $\sim$290) which they designated CXOU 110648.1+723412. Its spectrum can be characterized as a power law with a photon index $\Gamma \sim$ 1.8-2.6, or as thermal emission with a temperature kT $\sim$ 0.7-3 keV. Assuming a location within NGC 3516, isotropic emission implies a luminosity L $\sim$ 2-8 x $10^{39} h_{75}^{-2}$ ergs s^{-1} in the 0.4-2 keV band. If due to a single point source, the object is super-Eddington for a 1.4 $M_{\odot}$ neutron star. However, multiple sources or a small, extended source cannot be excluded using the current data. Large-scale extended X-ray emission is also detected out to $\sim$10 arcseconds ($\sim$ 1.7 h_{75}^{-1} kpc) from the nucleus to the NE and SW and is approximately aligned with the morphologies of the radio emission and extended narrow emission line region. The mean luminosity of this emission is 1.5 x 10^{37} h_{75}^{-2} ergs s^{-1} arcsec^{-2}, in the 0.4-2 keV band. Unfortunately, the current data cannot usefully constrain its spectrum. These results are consistent with earlier suggestions of circumnuclear X-ray emission in NGC 3516.

Kraemer and Collins were part of a group led by T.J. Turner (UMBC/GSFC) which conducted a multi-satellite, broadband campaign on the narrow-line Seyfert 1 galaxy Ton S180 (PHL 912) performed at the end of 1999. They constrained the spectral energy distribution (SED) of the source by combining simultaneous *Chandra*, *ASCA*, and *Extreme Ultraviolet Explorer* data with contemporaneous *FUSE*, *HST*, and ground-based optical and infrared data. The resulting SED shows that most of the energy is emitted in the 10-100 eV regime, which must be dominated by the primary energy source. No spectral turnover is evident in the UV regime. This, the strong soft X-ray emission, and the overall shape of the SED indicate that emission from the accretion disk peaks between 15 and 100 eV. High-resolution *FUSE* spectra showing UV absorption due to O VI and the lack of detectable X-ray absorption in the Chandra spectrum demonstrate the presence of a low column density of highly ionized gas along our line of sight. The highly ionized state of the circumnuclear gas is most likely linked to the high luminosity and steep spectrum of the active nucleus. Given the strong ionizing flux in Ton S180, it is possible that the clouds within a few tens of light days of the central source are too highly ionized to produce much line emission. Thus, the narrow width of the emission lines in Ton S180 is due to the emission arising from large radii.

Kraemer participated in a collaboration led by D.M. Crenshaw (GSU), to use *HST*/STIS spectra of the narrow-line Seyfert 1 (NLS1) galaxy Ark 564 to investigate its internal reddening and properties of its emission-line and intrinsic UV absorption gas. They found that the extinction curve of Ark 564, derived from a comparison of its UV/optical continuum to that of an unreddened NLS1, lacks a 2200 Å bump and turns up toward the UV at a longer wavelength (4000 Å) than the standard Galactic, LMC, and SMC curves. However, it does not show the extremely steep rise to 1200 Å that characterizes the extinction curve of the Seyfert 1 galaxy NGC 3227. The emission lines and continuum experience the same amount of reddening, indicating the presence of a dust screen that is external to the narrow-line region. Echelle spectra from the Space Telescope Imaging Spectrograph show intrinsic UV absorption lines due to Lyα, N V, C IV, Si IV, and Si III, centered at a radial velocity of -190 km s^{-1} (relative to the host galaxy). Photoionization models of the UV absorber indicate that it has a sufficient column ($N_H = 1.6\text{x } 10^{21}$ cm^{-2}) and is at a sufficient distance from the nucleus (D$>$95 pc) to be the source of the dust screen. Thus, Ark 564 contains a dusty "lukewarm absorber" similar to that seen in NGC 3227.

D.M. Crenshaw (GSU) and Kraemer studied the origin of the "dusty lukewarm absorber," which they had previously identified in the reddened Seyfert 1 galaxies NGC 3227 and Akn 564. This absorber is characterized by saturated UV absorption lines (C IV, N V) near the systemic velocity of the host galaxy and is likely responsible for reddening both the continuum and emission lines (including those from the narrow-line region) from these Seyfert galaxies. From a large sample of Seyfert 1 galaxies, they find that continuum reddening (as measured by UV color) tends to increase with inclination of the host galaxy. Furthermore, reddened inclined Seyfert galaxies observed at moderate to high spectral resolution all show evidence for dusty lukewarm absorbers. They suggest that these absorbers lie in the plane of the host galaxy at distances of $>$ 100 pc from the nucleus and are physically distinct from the majority of intrinsic absorbers that are outflowing from the nucleus.

Kraemer, in collaboration with I.M. George (UMBC/GSFC), R.F. Mushotzky (GSFC), T. Yaqoob (JHU), T.J. Turner (UMBC), A.F. Ptak (CMU), K. Nandra (GSFC/USRA), D.M. Crenshaw (GSU), and H. Netzer (TAU), presented the first high-resolution X-ray image of the dwarf elliptical galaxy NGC 3226. The data were obtained during an observation of the nearby Seyfert Galaxy NGC 3227 using *Chandra*. They detected a point X-ray source spatially consistent with the optical nucleus of NGC 3226 and a recently detected, compact, flat-spectrum radio source. The X-ray spectrum can be measured up to $\sim$10 keV and is consistent with a power law with a photon index $1.7<\Gamma<2.2$ or thermal bremsstrahlung emission with 4 keV$<kT<$ 10 keV. In both cases, the luminosity in the 2-10 keV band $\approx 10^{40}$ h_{75}^{-1} ergs s^{-1}. They found marginal evidence that the nucleus varies within the observation. These characteristics support evidence from other wave bands that NGC 3226 harbors a low-luminosity active nucleus. They also comment on two previously unknown, fainter X-ray sources $<$ 15 arcseconds from the nucleus of NGC 3226. Their proximity to the nucleus (with projected distances of <1.3 h_{75}^{-1} kpc) suggests both are within NGC 3226 and thus have luminosities (approximately a few times 10^{38} to a few times 10^{39} ergs s^{-1}) consistent with black hole binary systems.

Kraemer and Gabel, with Yaqoob (JHU), McKernan (JHU), Crenshaw (GSU), George (UMBC/GSFC), Turner (UMBC/GSFC), Dunn(GSU) examined the kinematics and physical conditions in the UV and X-ray absorbers in the luminous Seyfert 1 galaxy Markarian 509, with simultaneous *Chandra*/HETG, *HST*/STIS and RXTE observations. In the X-ray spectra, strong absorption lines from He-like Ne and Mg, and from H-like N, O, and Ne were detected. The absorption-line profiles were blueshifted by $\sim$200 km s^{-1} with respect to the systemic velocity of Mrk 509, and there was a hint of another component near systemic. The soft X-ray spectrum can be described in remarkable detail with a simple, single-zone photoionized absorber. The UV spectra reveal the presence of eight kinematic components of absorption in Lyα, C IV, and N V, at radial velocities of -422, -328, -259, -62, -22, $+34$, $+124$, and $+210$ km s^{-1} with respect to an emission-line redshift of $z = 0.03440$, seven of which were detected in an earlier *FUSE* spectra. The UV components cover roughly the same velocities as the X-ray absorption profiles, but have much smaller column densities and ionization states.

Ruiz, with Crenshaw (GSU), Kraemer, G.A. Bower (STScI), T.R. Gull (GSFC), J.B. Hutchings (DAO), M.E. Kaiser (JHU), and D. Weistrop (UNLV) determined the radial velocity profile for the narrow-line region gas in the Seyfert 2 galaxy Mrk 3 out to $\sim$ 1 kpc from the nucleus. The observations consist of two data sets, both using the *HST*/STIS: (1) an [O III] slitless spectrum with the G430M grating of the inner 3" around the nucleus and (2) a long-slit observation centered on the nucleus (P.A.$=$70) by using the G430L grating and the 52X0.1 arcsecond aperture. They produced radial velocity maps of the emission-line gas, which indicate trends in the gas motion. These include blueshifts and redshifts on either side of the nucleus, steep velocity rises from systemic up to about $\pm$700 km s^{-1} taking place in the inner 0.3″ (0.08 kpc) both east and west of the nucleus, gradual velocity descents back to near-systemic values from 0.3″-1.0″, slightly uneven velocity amplitudes on each side of the nucleus, and narrow velocity ranges over the entire observed region. When fitted to kinematic models for the NLR gas, the data clearly favor one in which the gas exists in a partially filled bicone, is accelerated radially away from the nucleus, and is followed by a constant deceleration (possibly due to collision with an ambient medium). This geometry and general kinematic model are in agreement with previous work done on the NLR gas of NGC 1068 and NGC 4151.

Collins, Kraemer, Crenshaw (GSU), and Ruiz are analyzing the physical conditions in the narrow-line region (NLR) of the Seyfert 2 galaxy Markarian 3 using Space Telescope Imaging Spectrograph (STIS) low-resolution long-slit spectroscopy. The goal of the project is to determine the composition, temperature, and density of the NLR clouds observed along the line of sight as a function of distance from the hidden nucleus. Preliminary results were revealed at the 199th Meeting of the AAS in Washington, D.C., January 2002. Correcting the observed emission-line fluxes with the SMC extinction curve of Hutchings (1982) yields consistent results for both the He II 1640/4686 ratio and the Balmer decrement. An extinction gradient is detected increasing from west to east along the STIS 52X1 arcsecond slit in the NLR. Emission-lines from low-ionization potential (<50 eV) ions show a more extended morphology than those from high-ionization potential ($\sim$100eV) species ([Fe VII], [Ne V]).

2.2 Interstellar Medium

Bruhweiler, in collaboration with Maxime Bourdin (Stasbourg) have analayzed IUE data for the interstellar spectrum toward stars in the Rosette Nebula. The results indicate that the interstellar bubble produced by the winds of the embedded O stars is extremely young, approximately 50,000 yrs, while the age of the stars is 2 million years. These results are in sharp contrast with current theory. These results are being prepared for publication. Further observations for the stars in the Rosette and for the enigmatic star HD 148937 (Bruhweiler, Bourdin, Feire Ferrero (Stasbourg), and T. Gull (NASA/GSFC) are being obtained with *FUSE*. These observations are designed to further explore the physical conditions of the interstellar bubbles surrounding the stars.

Bruhweiler with graduate students, Joseph Goyette and Ian 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. Bruhweiler and Lyu are also exploring the time-dependent ionic abundances of observable interstellar species seen in the low-density local ISM.

In collaboration with T. Brage (Lund) and P. Judge (HAO-NCAR), Proffitt contributed to a recently completed STIS/HST study of the 1487.9 Å N IV hyperfine line in the planetary nebulae NGC 3918. This study yielded the first measurement of a transition probability for this class of hyperfine transitions, confirming previous theoretical calculations, and also provides a powerful new diagnostic for very low density plasmas.

Verner, along with Bruhweiler, T. Gull (NASA), S. Johannsen (Lund), and K. Davidson (Univ. Mn) have studied Eta Carinae, known to be an unusually strong radiative source with its luminosity being intermediate between the sun and a weak quasar. The very bright Weigelt Blobs, B and D, located within a light day of Eta Carinae, are uniquely rich in Fe II and [Fe II] emission. As our first step, they have focused on Fe II emission analysis of the spectrum of the BD Blobs from 1998 *HST* observations. They have used the detailed non-LTE Fe II model to bracket the physical parameters of the iron-rich plasma. Most of [Fe II] and Fe II lines that predicted by our model are in a good agreement with observations. The Fe II studies not only reveal details of physical conditions in the emitting region but also indicate shortcomings in the atomic data for Fe II ion. The initial results of this work are scheduled to appear in the Astrophysical Journal.

2.3 Stellar Physics and Astronomy

Airapetian is currently working on three projects to analyze and interpret the HST/GHRS and STIS data. He is collaborating with B. Woodgate (GSFC), D. Spicer (GSFC) and S. O'Sullivan to numerically model collimated outflows from classical T Tau and Herbig Ae/Be stars, with K. Carpenter (GSFC) and J. Aufdenberg (CfA) to interpret the GHRS and STIS observations of winds from luminous late-type stars by using the two-dimensional magnetohydrodynamic code and the radiative transfer code, PHOENIX, to compute mass-loss rates, terminal velocity and non-thermal broadening introduced by supersonic turbulence. Airapetian also proposed a model to explain the generation of surface magnetic fields and related activity in the stellar atmospheres of early-type stars. He is collaborating with M. Miesch (UCAR) to numerically simulate alpha-omega dynamos driven by inertial oscillations using a 3D MHD code to explain the generation of surface magnetic fields and related activity in the stellar atmospheres of early-type stars. He is collaborating with M. Miesch (UCAR) to numerically simulate alpha-omega dynamos driven by inertial oscillations using the 3D MHD code.

Bruhweiler and Kondo, with graduate student William Anderson, have initiated an archival IUE study of several high mass, early-type star interacting binaries. First results for U Cephei indicate a very unusual UV radial velocity curve for the subordinate lines. These results have important implications for the inferred motions for the hot gas as evidenced by C IV and S IV resonance absorption seen in the spectrum.

Proffitt (CSC/STScI), 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.

In a project led by M. Livio (STScI), Proffitt is analyzing deep STIS/CCD images that target the brightest clump in the sub-mm disk around the nearby star epsilon Eridani, with the intent of setting constraints on the dust properties and of cataloging objects visible in the field.

Proffitt, in collaboration with T. Brage (Lund) and F. Rogers and C. Iglesias (LLNL) 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.

Robinson, in collaboration with M. Smith (CSC) and G. Henry (Tennessee State University) completed a study of X-ray and optical variability of the classical Be star γ Cas. Quasi-periodic B and V band optical variations were found with a peak to peak amplitude of about 3 which varied from 55 to 93 days. As the optical intensity increased, the (B-V) color was also found to increase, suggesting that the variations originated in the massive stellar disk. Cyclic X-ray flux variations (obtained with the RXTE satellite during 2000) were also found. These varied by a factor of 2 and had a period near 70 days. Detailed comparisons with the optical variations suggests that the optical and X-ray fluxes are strongly correlated. It was suggested that both variations are driven by a magnetic dynamo operating in the stellar disk. The observations appear to be incompatible with the hypothesis that the X-rays originate from mass accretion onto a degenerate companion of γ Cas. An approx 1 solar mass companion has recently been discovered, but it has a period of 203.4 days, much longer than the timescale of the X-ray variations.

Robinson collaborated with E. Bohm-Vitense (U. Washington), K. Carpenter (NASA/GSFC/LASP) and J. Mena-Werth (U Nebraska) on a study of FUV spectra of Hyades F stars taken with the *HST* and *FUSE* satellites. Emission line fluxes for a wide range of temperatures (including Mg II, C II, C III, CIV, and O VI) all show higher emission for the early F when compared to the late F stars, with an abrupt change occurring between B-V values of 0.42 and 0.45 (near spectral type F5) where the Li surface abundances show a deep minimum. The flux levels for early and late F stars also have different dependencies on the stellar rotation rate, with the early type stars showing an increase in emission with increasing rotation velocity and the late F stars being relatively independent of rotation rate. This if opposite to the behavior observed in the older field stars, which typically show a rotational effect in the cooler stars. This suggests that there are at least two heating mechanisms operating in these stars, with one dominating in early and another in the late F stars. Further, since magnetically related heating is generally associated with a magnetic dynamo, which depends on the stellar rotation rate, they have evidence that magnetically related heating operates in the early F stars, contrary to previous expectations.

Robinson collaborated with T. Ake (CSC), A. Dupree (SAO) and J. Linsky (JILA/U Colorado) on a study of FUV observations of the active K dwarf AB Doradus obtained with the *FUSE* satellite in Oct and Nov of 1999. During a total of 29 hours of observing they observed two large flares and $>$ 10 smaller events in the FUV continuum and the integrated C III (1175) and O IV (1032/1037) line fluxes. For one of the large events the continuum increased by a factor of $>$ 100, while the line enhancement was more than an order of magnitude lower. While the continuum and C III fluxes decayed to the background level in just 6 minutes, the O VI enhancement lasted for nearly an hour. In the second event the continuum and line enhancements were compatible. Again, the durations depended upon temperature, with the continuum having the shortest and the O VI having the longest duration. The smaller flare events are much more evident in the lines than in the continuum and are of relatively long duration, lasting 5 minutes or more. This is in contract to microflare events seen in dMe stars, which typically last only 10-20 seconds.

Robinson continued a collaboration with K. Carpenter (NASA/GSFC/LASP) in determining the wind properties of cool, luminous stars. High quality Fe II line profiles of the M giants μ Gem and γ Cru (obtained with *HST*) were empirically modeled using the SEI radiative transfer code. This analysis shows a terminal velocity of 11 km s^{-1} and 19 km s^{-1}, a log mass loss rate of -10.13 and -9.3 solar masses per year and an average turbulent velocity 9 and 14 km s^{-1} for μ Gem and γ Cru respectively.

3. SOLAR PHYSICS AND SUN EARTH CONNECTION

Ofman has worked on theoretical models of waves in coronal loops (in collaboration with M. Aschwanden, LMSAL, V.M. Nakariakov, U. Warwick, R. Grappin, Obs. Meudon, T.J. Wang, MPAE), 3D MHD models of solar active region dynamics (in collaboration with B. Thompson, NASA/GSFC). The modeling effort was motivated and guided by observations of the Transition Region and Coronal Explorer (TRACE), the *Solar and Heliospheric Observatory (SOHO)* Extreme UV Imaging Telescope (EIT) and Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instruments. The combination of data and models were used to derive the physical properties of the active regions, and the physical parameters of individual coronal loops. The results of these studies shed new light on the mechanisms of wave propagation, leakage, and dissipation in the solar corona, and address the mechanism of coronal heating - the major unresolved problem in solar coronal physics.

Ofman has developed hybrid kinetic models of ion-cyclotron instability and heating of ions in the solar wind plasma (in collaboration with S.P. Gary, LANL and A. Vinas, NASA/GSFC). 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 has collaborated 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. Ofman has developed multidimensional MHD codes for these studies.

Moran is currently analyzing coronal UV spectra in a study of non-thermal ion motions above the limb in coronal holes using the *SOHO*/SUMER ultraviolet spectrograph. Minor ion line widths are proportional to the mean line-of-sight speed, which would be affected by nonthermal processes such as waves. Analysis shows that hydromagnetic, or Alfven waves, do not play a significant role in transporting the energy into the coronal hole required by the high speed solar wind. Rather, the data are consistent with the propagation of ion cyclotron or ion Bernstein waves with frequencies above the local proton cyclotron frequency. These waves are a likely mechanism to heat the coronal hole plasma and supply the power required by the fast wind.

St.Cyr and Reginald performed two spectroscopic experiments during the June 2001 total solar eclipse from Zambia. This was done in conjunction with NASA/GSFC scientists, and the results or the successful experiment measuring electron temperature and solar wind speed low in the corona are being prepared for publication. The group is also preparing for the December 2002 total eclipse, to be viewed from a site in South Africa.

St.Cyr was awarded a grant from the National Space Weather Program to study new methods of using SOHO data to predict better the probability of geomagnetic storms.

The Wind/WAVES radio observations in conjunction with the LASCO white-light observations and in-situ shock measurements have permitted progress to be made in understanding and quantifying the dynamics of CMEs in the solar corona and interplanetary medium. Reiner, M. Kaiser (NASA/GSFC), A. Vourlidas (NRL), O. C. St. Cyr, J. Burkepile (HAO), R. Howard (NRL), N. Prestage (Culgoora State Observatory) have used simultaneous ground-based and space-based radio and white-light data to study the dynamics of CMEs in the corona and interplanetary medium. By requiring consistency between these four data sets they were able to demonstrate that the solar longitude launch angle of a CME could be accurately ascertained. They also used the LASCO density measurements to demonstrate that the radio emissions most likely originated in dense coronal streamers. Using the radio data and in-situ shock parameters, Reiner and M. Kaiser were able to determine the deceleration profile of a number of CMEs. From a statistical study of these events they determined that the fastest CMEs tended to have the greater deceleration and decelerated for the shorter period of time. Although they found a statistical correlation between the CME deceleration and the conventional drag force, in a subsequent modeling effort they were able to demonstrate that the conventional drag force currently in use cannot account for the observed deceleration of CMEs in the coronal and interplanetary medium.

Reiner, M. Kaiser (NASA/GSFC) and J. Fainberg (NASA/GSFC) analyzed a unique component of low-frequency solar radio emissions observed by Wind/WAVES that turned out to be 100% circularly polarized. This radio emission component, which lasted for about 3 days, was the first such solar radio event observed in the 8 year history of the operation of Wind/WAVES. The emission source was determined to be rather far from the sun and its angular width to be quite small. It was also found to have a frequency spectrum that was quite different from the usual solar emission components. Further investigations suggested that this event my be similar to an unusual event observed more that 20 years ago by the radio experiment on the ICE spacecraft. The Wind/WAVES radio data were analyzed for a unique space weather event in April of 2002. It was found that a characteristic sawtooth behavior observed in the LANL particle data was reflected in the behavior of the Earth's Auroral radio emissions observed by the Wind spacecraft. The implications of these observations for the source of the precipitating particles is currently being investigated.

The origin and physical acceleration mechanism of solar energetic particle events is a very controversial subject; the main controversy surrounding whether they originate in solar flares or from shocks driven by coronal mass ejections. Reiner, G. Simnett (University of Birmingham), and S. Kahler (Hanscom AFB) have been investigating the the temporal and spatial relationships of solar induced ground level events with the radio observations over the entire radio spectrum to try to obtain clues as to the solar origin of these relativistic particles.

Reiner and M. Kaiser (NASA/GSFC) have demonstrated that type III radio bursts associated with the liftoff of coronal mass ejections on the sun have very unusual radio characteristics. Reiner, et. al. subsequently showed that the energetic solar electrons that produce these complex type III-like bursts originate very deep in the corona near the flare site. Reiner, M. Karlický (Astronomical Institute of the Academy of Sciences of the Czech Republic), L. Klein (Observatoire de Paris), G. Trottet (Observatoire de Paris), and M. Kaiser (NASA/GSFC) are currently trying to better understand the cause of the unusual behavior of these radio emissions by studying an event from April of 2001 during which both normal type III bursts and the complex type-like emissions occur in the same event.

Sui has been developing theoretical models and numerical codes for the interpretation of RHESSI and related observations of solar flares. Since the successful launch of RHESSI, he has been working on the application of these models to flare data to study the particle acceleration and transportation in solar flares.

4. PLANETARY SCIENCES

4.1 Planetary Astronomy

Crider continues to study the magnetic environment of Mars using magnetometer data from the Mars Global Surveyor spacecraft. Crustal magnetic fields of several hundred nT are detected at spacecraft mapping altitude, 400 km. These intense crustal magnetic fields contribute at least locally to the solar wind interaction. This research focuses on determining the extent of the contribution of crustal fields to the Martian solar wind interaction and to the structure of the Martian ionosphere. They have found that the magnetic pileup boundary is, on average, 200 km further from Mars at the terminator in the southern hemisphere than in the northern hemisphere. Because the most intense regions of crustal magnetization are in the southern hemisphere, they interpret this as a localized diversion of solar wind plasma to higher altitudes over strongly magnetized crust.

Kletetschka has been working on the interpretation of recently found magnetic anomalies by Mars Global Surveyor. His work on magnetic properties of hematite and titanohematite established that both of these minerals can be an important player in generating magnetic anomalies during the rock forming processes on planets like Mars and Earth. Other part of his work involves characterization of the magnetic signature of meteorites. Further, Kletetschka is pursuing the detection of most primitive components of magnetic fields that were recorded during the early stages of meteorite parent body development.

4.2 NEAR

Starr is an associate team member on the Near Earth Asteroid Rendezvous (NEAR) mission X-ray/Gamma-Ray Spectrometer (XGRS) experiment. NEAR arrived at Eros 433 in February 2000, and completed orbital operations in February 2001. Upon completion of the primary mission, the NEAR spacecraft made a soft landing on the surface of Eros and collected gamma-ray spectra for two weeks. Elemental compositions for a number of regions on the surface of Eros were derived from the analyses of characteristic X-ray and gamma-ray emission spectra. The XGRS science team leader is J. Trombka at GSFC. Starr will continue his work on NEAR data through the NEAR Data Analysis Program. The NEAR XGRS was part of the Inter-Planetary Network (IPN) for the detection of Gamma-Ray Bursts (GRB). The IPN incorporated GRB information from the NEAR, Ulysses, Compton-GRO, GGS-Wind, and Konus spacecrafts. The IPN has been able to determine the location of several GRBs closely enough and quickly enough to allow detection of optical and radio counterparts. Several papers have been written.

4.3 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. This is a re-flight of the GRS that was part of the instrument complement on the Mars Observer mission that was lost in August 1993. 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 really an instrument suite consisting of the GRS, a neutron spectrometer (NS) and a high-energy neutron detector (HEND). Each of these instruments/sensors are remotely mounted at different locations on the spacecraft and connect to a central electronics box. The GRS will achieve global mapping of the elemental composition of the surface and the abundance of hydrogen in the shallow subsurface. The During the first few months of observations the GRS identified two regions near the poles that are enriched in hydrogen. The data indicate the presence of a subsurface layer enriched in hydrogen overlain by a hydrogen-poor layer. The thickness of the upper layer decreases with decreasing distance to the pole, ranging from a column density of about 150 g cm^{-2} at $-42°$ latitude to about 40 g cm^{-2} at $-77°$. The hydrogen-rich regions correlate with regions of predicted ice stability. An ice abundance of $35\% \pm 15\%$ by weight, is the most likely host of the hydrogen in the subsurface layer.

4.4 MESSENGER

Fabrication of the spacecraft and science instruments for the Discovery MESSENGER mission has begun. The purpose of this mission is to collect global information on the surface, interior, exosphere and magnetosphere of Mercury. Launch will be in 2004. Two fly-bys of Mercury will be executed prior to orbital insertion in 2009. 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 will be the Johns Hopkins University. Applied Physics Laboratory. Starr is an associate team member and part of the geochemistry team that will use data from the 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.

4.5 Cometary studies

Dello Russo, DiSanti, Gibb (NRC/GSFC), Magee-Sauer (Rowan U.), and Mumma (GSFC) have continued to probe the volatile composition of comets using high-resolution ground-based infrared spectroscopy. Since 1996, eight 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 region 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 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. 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. They have measured the OPR of water in three recent comets (C/1999 H1 Lee, C/1999 S4, and C/2001 A2) and determined that the water in these three comets was last processed at about 25 K.

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).

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.

Novak (Iona College), Mumma (GSFC), DiSanti, Dello Russo, and Magee-Sauer (Rowan U.) reported absolute abundances and latitudinal variations of ozone and water in the atmosphere of Mars during its late northern spring. Long-slit maps of the singlet-delta state of molecular oxygen and HDO, an isotopic form of water, were acquired using CSHELL at NASA-IRTF. Molecular oxygen is produced by ozone photolysis, and the ensuing dayglow emission is used as a tracer for ozone. The derived rotational temperature of molecular oxygen shows a mean of 172 K confirming that the sensed ozone lies in the middle atmosphere (about 24 km from the surface). The retrieved vertical column abundance of water varies with latitude from about 3 precipitable microns at about 30 deg. S to 24 precipitable microns at about 60 deg. N.

5. INSTRUMENT DEVELOPMENT

5.1 $CdWO_4$ Scintillator

Gamma-ray spectroscopy has been used by orbital spacecraft and landed missions to determine the surface elemental abundances of planetary surfaces. The next logical step for planetary exploration is to include a GRS on a rover, but such an instrument must be light-weight, compact, and low-power because of the severe mass and power restrictions common to such missions. Starr is part of an instrument development team at Goddard that has begun work with $CdWO_4$ (CWO) scintillators. This is a relatively new scintillation material has a high Z and high density which is a requirement for gamma-ray spectrometers. Coupled to photomultiplier tubes, CWO can achieve excellent energy resolution compared to other scintillators. Preliminary results have been reported.

5.2 Schottky CdTe detectors

Schottky CdTe(Cl) type x-ray and gamma-ray detectors have attracted a lot of attention in the last several years. The reported spectral characteristics for detectors of thickness up to $1mm$ operated at $-200°C$ show excellent energy resolution and peak to valley ratios. The improved results are due to the production of homogeneous large volume single crystals. Schottky CdTe(Cl) detectors may be considered for use in interplanetary missions, which typically require long cruise periods of several years before reaching the intended target. One important requirement is the stability of the detector against the radiation of high energy protons. During missions the detectors are exposed to cosmic ray protons with a mean energy near 1GeV and solar flare protons with a mean energy around 100 MeV. Starr and co-workers at GSFC have begun testing the radiation susceptibility of these detectors. Preliminary results have been reported.

5.3 UMBRAS

Bruhweiler and Mike DiSanti working 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 free flying occulter called UMBRAS that would work in conjunction with a space telescope placed at L2, that could directly image Jovian and even 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 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 space telescope could also be used to image and study earth-like planets. Various apodization schemes for the space telescope aperture are being studied. Initial results show that apodization can improve substantially the capabilities of this two spacecraft system. This concept has been presented at several recent SPIE meetings and a more refined concept is being developed.

5.4 Additional Actvities

St.Cyr and Reginald continued to work closely with the Goddard scientists and engineering team building the COR1 coronagraph for NASA's STEREO mission.

St.Cyr began work with a Naval Research Lab team selected to design and build instruments for NASA's Solar Dynamics Observatory.

6. EDUCATIONAL OUTREACH AND OTHER ACTIVITIES

The SUNBEAMS program is now in its fifth 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 now being widely recognized as a model urban intervention technique.

The Summer Student Program in the Laboratory for Astronomy and Solar Physics is now in its 19th year, funded in part with a Research Experiences for Undergraduates (REU) grant from the National Science Foundation since 1987. During the summer of 2002, forty students worked participated in the program.

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