The Catholic University of America
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The following report covers the astrophysical research activities of the Institute for Astrophysics and Computational Sciences (IACS). This report also includes activities of non-Institute members in the Department of Physics at the Catholic University of America (CUA), who work closely with the Institute. The period of this report covers from September 1998 through September 1999.

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 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 in the Department of Physics at CUA.

1. PERSONNEL

The Ph.D. faculty and research staff directly affiliated with the Institute are: Fred Bruhweiler (Director), Vincenzo Andretta, Al Boggess, Peter Chen, Mike Crenshaw, Mike DiSanti, Mike Goodman, Nat Gopalswamy, Rosina Iping, Scott Johnson, Steve Kraemer, Alejandro Lara, C.-H. Lyu, Charles Proffitt, Rich Robinson, Myron Smith, Margaret Smith Neubig, and Glenn Walgren. Other Ph.D. members of the Dept. of Physics working closely with the IACS include Pamela Clark, Neale Dello Rosso, Sarah Gibson, M. Guhathakurta, Vladimir Krasnopolsky, Fred Lang, Michael Smith, Richard Starr, and Carl Werntz. Adjunct Professors of the IACS, or those working closely with it, include Yoji Kondo, Andrew Smith, and Carol Jo Crannell.

Non-Ph.D. research and support staff, who work directly in the IACS, are Tena DuBerry, and Cherie Miskey, as well as the graduate students, Jack Gabel, Craig Harbuck, Charles Hall, Theo Hadjimichael, Ian Liska, John Nichols, Steve Nunes, Jose' Ruiz, and Scott Weingarten. This is in addition to undergraduate students (Timothy Maloney (CUA), Kathyrn Holz-Donohue (CUA), Annie James (CUA), Mike Salem (Case Western Reserve University), Joseph Gordon (University of Pennsylvania), Howard Eaton (US Naval Academy), Samantha Stevenson (W. Conn. Coll.), and James Tanlyi (US Naval Academy) and talented high school students (Margaret Heitmanchek, Matt Lemmon, and Mark Pitts) who have done research with members of the Institute during this period. Also, during this period, Craig Harbuck received his Ph.D. under Bruhweiler's direction.

Within IACS, a Center for Solar Physics and Space Weather (CSPSW) has recently been established to promote education and research in collaboration with scientists at NASA/GSFC, the Naval Research Laboratory (NRL), the Applied Physics Laboratory of Johns Hopkins University (JHU APL) and Air Force Research Laboratory (AFRL). The CSPSW is headed by Nat Gopalswamy. The advisory committee consists of R. Fisher (NASA GSFC), R. Howard (NRL), S. W. Kahler (AFRL VSBS) and D. Rust (JHU APL). The core members of CSPSW are N. Gopalswamy (IACS), A. I. Poland (NASA GSFC), S. Jordan (NASA GSFC), D. Rust (JHU APL), J. Green (NASA GSFC), M. Guhathakurta (CUA Physics), C. J. Crannell (GSFC), A. Lara Sanchez (IACS), and V. Andretta (IACS).

2. RESEARCH ACTIVITIES IN ASTROPHYSICS

2.1 Galaxies & Extragalactic Astronomy

Bruhweiler, Miskey, and Smith Neubig continue to use Hubble Space Telescope spectra obtained with the GHRS and STIS to study the effects of metallicity on properties of massive stars and starburst activity in nearby galaxies. They have been awarded additional HST observing time to use the two-dimensional capabilities of the Space Telescope Imaging Spectrograph (STIS) to obtain spectra of individual OB stars in the star formation regions of galaxies in the Local Group. Observations will include stars of M31, NGC 6822, and the most metal deficient galaxy in the Local Group, Sextans A. Observations are scheduled.

Miskey and Bruhweiler have been working closely with other members of the STIS Instrument Definition Team at GSFC to develop sophisticated optimal extraction software to extract individual spectra from the 2-D spectral images of OB stars in the crowded stellar fields of the bright nearby starburst H II region NGC 604 in the galaxy M33. This software uses a 2-D line-spread-function, which is a function of wavelength and y-position on the detector). This LSF was derived as part of this work. These were derived using STIS calibration data. Using this software, they have successfully extracted high quality spectra of 15 OB stars from a single STIS exposure. This work is being prepared for submission to the Astronomical Journal.

Bruhweiler, Smith Neubig, along with students Holz-Donohue, Eaton, and Tanlyi have analyzed all the available HST spectra of the O and B stars of the Magellanic Clouds and have derived more quantitative diagnostics for determining effective temperature and luminosity. They have found that the derived UV spectral types are in good accord with those derived previously by Smith Neubig and Bruhweiler (1997,1999). These results are being prepared for publication. A second paper is also being prepared analyzing the spectra extracted using this software. These results show a significant number of stars showing He II λ1640 emission characteristic of W-R stars. Many stars appear to be quite young, with ages less than 2 Myr.

These spectra are to be included in an evolving UV spectral library of O and B stars that has been developed to de-

termine age, slope of the Initial Mass Function, and metallicity of the bright starbursts in nearby galaxies. Synthetic UV spectra have been produced using the theoretical evolutionary tracks in conjunction with the spectral library, for data obtained by the International Ultraviolet Explorer (IUE) and spectrographs aboard the HST. In most cases good spectral fits have been obtained, but many starbursts have strong spectral features that are too strong to be fit by the modeling. This suggests that some starbursts have metallicities higher than the solar neighborhood.

Gabel, with Bruhweiler, Kraemer and Crenshaw and Miskey have recently completed a photoionization modeling study of the nearby LINER galaxy NGC 1052. These results show that photoionization modeling, without the need for shock ionization, provides excellent fits to ''all'' the observed emission lines in the UV through optical spectrum in this object. This agreement was achieved using the deduced intrinsic spectrum based upon the observed radio through X-ray flux distribution. The results of this work will appear in the Astrophysical Journal (Gabel *et al.*) This work is part of a Ph.D. dissertation by Gabel.

Gabel and Bruhweiler are also modeling the starburst/ LINER galaxy, NGC 4569, using the inferred flux distribution characteristic of a starburst. The inferred flux from stars appears insufficient to produce the observed optical emission lines in this galaxy. Further modeling efforts are focusing on incorporating photoionization by X-ray binaries and shocks from supernovae both produced by massive stars. At this point it is unclear if the observed emission requires the presence of a AGN.

Also, Bruhweiler and Boggess plan to use a significant portion of their remaining guaranteed observing time associated with The Space Telescope Imaging Spectrograph aboard the HST to probe active galactic nuclei and starburst galaxies.

Crenshaw and Kraemer have obtained the first observations of a Seyfert galaxy with the echelle gratings on the Space Telescope Imaging Spectrograph (STIS). Five kinematic components of absorption are present in Lα, C IV, and N V at radial velocities of $-$ 160 to $-$ 1060 km s^{-1} with respect to the emission lines. Photoionization models were calculated to match the UV column densities from each of the five components associated with the nucleus. In four of the components, the ionization parameters (U = 0.15 – 0.80) and effective hydrogen column densities (N_{eff} = 6.0 x 10^{18} cm^{-2} – 2.8 x 10^{20} cm^{-2}) cannot produce the O VII and O VIII absorption edges seen in the X-ray warm absorber. The remaining component is more highly ionized (U = 2.4, N_{eff} = 6.5 x 10^{21} cm^{-2}) and the model of this component matches the previously observed X-ray absorption columns. This component is therefore likely to be responsible for the X-ray warm absorber. It also has the highest outflow velocity and showed the largest variations in column density.

Crenshaw, Kraemer, Boggess, Maran, Mushotzky (GSFC), and Wu (CSC) have published a survey on intrinsic absorption in Seyfert galaxies, based on previous HST observing programs and HST archive data. The fraction of Seyfert 1 galaxies that show intrinsic absorption associated with their active nuclei is more than one-half (10/17), and there is a one-to-one correspondence between Seyferts that show intrinsic UV absorption and X-ray ''warm absorbers.'' The intrinsic UV absorption is generally characterized by high-ionization: C IV and N V are seen in 10 Seyferts, whereas Si IV is present in only four of these Seyferts, and Mg II absorption is only detected in NGC 4151. The absorption lines are blueshifted with respect to the narrow emission lines, indicating that the absorbing gas is undergoing net radial outflow. At high resolution, the absorption splits into distinct kinematic components that show a wide range in widths (20 – 400 km s^{-1} FWHM) The strong absorption components have cores that are much deeper than the continuum flux levels, indicating that the regions responsible for these components lie completely outside of the broad emission-line regions. The covering factor of the absorbing gas in the line of sight, relative to the total underlying emission, is $C_{los} \geqslant 0.86$, on average. The global covering factor, which is the fraction of emission intercepted by the absorber averaged over all lines of sight, is $C_{global} \geqslant 0.5$. The individual absorption components show a wide range in C IV column densities (0.1 – 14 x 10^{14} cm^{-2}), and the ratio of N V to C IV column density varies significantly from one absorption component to the next, even in the same Seyfert galaxy.

Kraemer, Ho (Carnegie), Crenshaw, Shields (Ohio U.), and Filippenko (UC Berkeley) have combined *Hubble Space Telescope*/Faint Object Spectrograph, ground-based, and *Infrared Space Observatory* spectra of the nucleus of NGC 4395, the least luminous and nearest known type 1 Seyfert galaxy. The spectra show emission lines from a wide range of ionization states and critical densities. They have generated multicomponent photoionization models of both the broad and narrow emission-line regions (BLR and NLR) to investigate the physical conditions in the emission-line gas and test the proposition that the source of ionization is the non-stellar continuum radiation emitted by the central source. With a minimum of free parameters, the model predictions match the observed emission-line intensity ratios quite well. The elemental abundances appear to be subsolar, with even greater underabundance of nitrogen. From the size of the BLR predicted by the models, they estimate a central mass of a few x 10^5 $M_\odot$, in reasonable agreement with estimates from the stellar kinematics. Finally, the results suggest that the covering factor of the emission-line gas is close to unity, and that the observed UV to X-ray continuum is absorbed by intervening NLR gas. This suggests that a high covering factor is responsible for the apparent flattening of the Baldwin relation in low-luminosity active galactic nuclei.

Kraemer, Turner (UMBC), Crenshaw, and George (USRA) have explored the effects of UV absorbing material on the shape of the EUV continuum radiation emitted by the active galactic nucleus, and on the relative strengths of emission lines, formed in the narrow line regions of Seyfert galaxies, excited by this continuum. Within a sample of Seyfert 1.5 galaxies, objects with flatter soft X-ray slopes tend to have lower values of He II λ4686/Hβ, which implies a correlation between the observed spectral energy distribution of the ionizing continuum and the narrow emission line strengths. Objects with the flattest soft X-ray continua tend to possess high column density UV absorption and it is plau-

sible that the differences in narrow emission line ratios among these galaxies are an indication of the effects of absorbing material internal to the narrow line region, rather than intrinsic differences in continuum shape. A set of photoionization models were generated to examine the effect of a range of UV absorbers on the ionizing continuum and, hence, the resulting conditions in a typical narrow line cloud. The results indicate that a low ionization UV absorber with large covering factor will indeed produce the combination of narrow line ratios and soft X-ray spectral characteristics observed in several Seyfert 1.5 galaxies. These results also suggest that low ionization UV absorption may be more common than currently believed.

2.2 Interstellar Medium

Bruhweiler, with Sahu (AURA/GSFC) and other investigators, have determined the D/H ratio in the local ISM through an analysis of a high spectral resolution echelle spectrum of the nearby, hot white dwarf, G191-B2B. These results, based upon a detailed analysis of the Lyman-α of the white dwarf spectrum, indicate D/H = $1.6\text{x}10^{-5}$. This result suggests that there is no variation in the D/H ratio in the local ISM, in contrast with previous results based upon GHRS/HST data. Further reanalysis of the GHRS data for G191-B2B indicate that the previously derived ratio was influenced by uncertainties in the scattered background in the GHRS spectrograph. These effects are much better characterized in the two-dimensional STIS MAMA detector. This leads to the more accurate D/H results for this object.

Bruhweiler and Sahu, along with Holberg (Arizona) and Barstow (Leichester) are continuing their analysis of the interstellar spectrum of the other ions seen in G191-B2B. Detailed Voigt profile fitting show that the STIS spectrum can be fit by two interstellar components.

Bruhweiler is continuing work with Holberg and Barstow to use the Extreme Ultraviolet Explorer, IUE, and HST to study the physical processes both in the photospheres of fiducial lines-of-sight toward hot white dwarfs in the the local ISM. These white dwarfs have been observed with the Extreme Ultraviolet Explorer (EUVE) and are the only objects for which good constraints on the column densities of H I, He I, and He II in the ISM have been found. Recent publications describing the analysis of recent HST/STIS observations of the white dwarf, REJ 1032+532 have appeared in the Astrophysical Journal (Holberg *et al.* 1999a,b). These results show that, although the photospheric abundances for carbon and silicon match those predicted from radiative levitation models, the abundance of nitrogen exceeds predictions by a factor of 50. This makes this object one of two nitrogen-rich white dwarfs known. The analysis of the interstellar medium for the line-of-sight toward this white dwarf is equally intriguing. The presence of Si III is indicative of gas that is almost essentially ionized ($\approx$ 95%) and cannot be produced in the local cloud in which the sun is embedded. The velocity difference between Si III and the other lower ionized species further reinforces that conclusion. Reduction and analysis of STIS data are continuing on several other white dwarfs.

Bruhweiler, and Lyu are also continuing their theoretical calculations in modeling the time dependent ionization in the Local ISM. Recent results finding radioactive ^{60}Fe in the deep ocean crust by a German group confirm their predictions of a recent supernovae event in the solar vicinity within the past few million years (Lyu & Bruhweiler 1997). Bruhweiler and Lyu are also exploring, with the assistance of Gabel and Margaret Heitmanchik (a high school student), in understanding where and how the high ionization gas giving rise to Si III, originates. This is requiring a systematic analysis of the archival HST spectral observations for lines-of-sight in the Local ISM.

Bruhweiler, Meena Sahu (AURA/GSFC), Crenshaw, and Kraemer, as well as a high school student, Matt Lemmon, continue analyzing the interstellar spectrum produced in the Galactic Halo seen in the UV echelle spectrum of NGC 5548 obtained with STIS aboard the HST. Five velocity components are seen through the halo. The lack of absorption from C II λ1335, over a wide velocity range, originating from an excited fine-structure level indicates that the density is quite low over much of the pathlength through the halo. The H I and S II column densities have been derived. Much effort has gone to software that provides theoretical fits to the complicated velocity structure of the interstellar spectrum.

2.3 Stellar Physics and Astronomy

Bruhweiler in collaboration with Schultz (STScI, CSC) is continuing to use HST to search for sub-stellar objects around nearby stars and study the circumstellar disk of Beta Pictoris. As a follow-up of previous published work to search for a companion to the nearest star to the Sun, Proxima Centauri, Bruhweiler and Schultz are using the infrared capabilities of NICMOS aboard the HST to search for a brown dwarf companion that was suggested to be present in previous HST imagery using the FOS barred aperture. Observations have recently been obtained for other stars.

Bruhweiler and Lyu, have further pursued a model suggesting that tidal interactions produce spiral shocks in young planetary systems. The signature of these shocks can be seen in a temperature peaks in gaseous infall in β Pic, and possibly in other similar stars, and even in Herbig Ae/Be stars. This is an outgrowth of recent work (Bruhweiler, Lyu, Kondo, and Boggess), which detected a double peaked temperature profile from HST data of β Pic. A new model is proposed that does not directly require infalling cometary bodies to explain the variable infall.

Bruhweiler, with Holberg (Arizona), Barstow (Leichester), and Ivan Hubeny (AURA/GSFC) were selected to obtain early observations using the recently launched Far Ultraviolet Spectral Explorer (FUSE). Time-resolved spectra will be obtained of very hot white dwarfs displaying hydrogen-like O VIII emission.

Bruhweiler, with Sahu, Holberg and Barstow is also studying the very high resolution STIS echelle photospheric spectrum of the DA white dwarf, G191-B2B. These observations reveal very sharp ''interstellar-like C IV features at $\lambda\lambda$1548,1550 in addition to the corresponding photospheric features. However, these features cannot be produced in the local ISM. Modeling by Bruhweiler and the absence of the Si IV resonance doublet at the same velocities indicate that these features must arise in the immediate vicinity of G191-

B2B, most likely in the gravitational well of the star. The redward- displaced photospheric C IV features are then displaced due to the gravitational redshift of the white dwarf.

Bruhweiler and Walter Feibelman (GSFC), are studying the recently acquired HST/STIS spectra of the ultra-hot prewhite dwarfs, Sand 3 and NGC 6905. The data reveal spectra rich in very high ionization emission lines characteristic of temperatures far in excess of the stellar effective temperature (T$\approx$ 100-150x10^3 K). Results are only preliminary and detailed analyses are planned.

Proffitt in collaboration with P. J'ónsson (Lund), U. Litzén (Lund), J. C. Pickering (Imperial College London), and Wahlgren completed a study of the B III resonance doublet in the early-B stars HD 35299 and HD 886, finding ^{11}B/^{10}B isotope ratios consistent with the 4:1 ratio seen in the solar system. Work continues on a study of the B III lines in IUE spectra of early-B stars. This latter work demonstrates that a substantial fraction of early-B main-sequence stars are depleted in boron.

Proffitt, together with David Leckrone (GSFC), Glenn M. Wahlgren, Jack Brandt (Colorado), and others continued working on radiative acceleration and non-LTE calculations for HgMn stars, especially the stars χ Lupi and HR 7775 for which high resolution and S/N Goddard High Resolution Spectrograph (GHRS) data exist. A annotated UV spectral atlas of the GHRS observations of χ Lupi (Brandt *et al.* 1999) and a detailed summary of the scientific results derived from these data (Leckrone *et al.* 1999) were published. Proffitt has prepared an on-line version of the Brandt *et al.* (1999) χ Lupi atlas, which is now available through the HST archive page at http://archive.stsci.edu/. Proffitt also initiated a new project on the radiative acceleration of very heavy elements in stellar envelopes in collaboration with F. Rogers and C. Iglesias (LLNL).

Robinson, in collaboration with Carpenter (GSFC) and Percival (U. Wisconsin) completed work on a study of microflare activity from the classical dMe flare star, YZ CMi. This work used high time resolution UV photometric time sequences obtained with the High Speed Photometer aboard the Hubble Space Telescope using the F240W filter, which is centered near 240 nm and has a 80 nm bandwidth. During 2.5 hours of observations a total of 54 flare and microflare events were detected, ranging in integrated flux from 2.0 $\times$ 10^{28} to 3.0 $\times$ 10^{30} ergs. These events are superimposed on a relatively strong background which shows non-flare like variations in flux with amplitudes up to 50% on timescales ranging from 10 minutes to several hours. The occurrence distribution of microflare events is very similar to that determined for flare events observed from the ground. However, a statistical analysis of the background suggests that it may be composed of unresolved nano-flare events with a much steeper distribution than for the resolved events. This is consistent with previous results.

Robinson worked on the analysis of high quality STIS spectra of the dMe flare star AU Mic, taken as part of the GTO program of Linsky (JILA). In collaboration with Pagano (Catania Astrophysical Observatory) a study was carried out to investigate a high quality, medium resolution (R =20,000) quiescent spectrum of the star in the 1150-1730 Å region. A total of 142 emission lines from 28 atomic species were identified in this spectrum, covering a temperature range from the chromospheric C I and O I lines to the coronal Fe XXI line at 1354 Å. Emission measures were determined from the line fluxes and the transition region line profiles were found to have extremely broad winds with a centroid which is offset slightly from a much narrower core, suggesting a multi-component atmosphere. The atmospheric density was derived from flux ratios of the density sensitive O IV] intercombination lines. It was difficult to reconcile these densities with emission measures derived from other atomic species and a model was proposed which involved emission from both dense, flare related plasma and relatively low density plages.

The STIS data set which was used to study the quiescent properties of AU Mic was obtained using the time-tagged mode of observation, which tagged each detected photon with its time and location. Using this data it was possible to develop a spectral time sequence and thereby study the flaring activity on AU Mic. Robinson examined these data and found four relatively large flares during a total of $\sim$ 3 hours of on-source observing. These flares had overall durations lasting from 3 to 7 minutes and were primarily detected in the FUV continuum and the Si IV and C IV resonance lines. An emission measure analysis of the time averaged flare spectrum showed a pronounced peak near 10^5 K, with emission measures falling off towards both high and low temperatures. Enhancements of the Fe XXI line formed at 10^7 K were seen during the initial phases of two of the strongest flares, but only lasted for a few seconds. There was no evidence of proton beams associated with any of the major flare events.

Myron Smith and Rich Robinson carried out investigations of several aspects of activity seen in the classical Be star γ Cas. In one study they investigated variations in the UV spectrum near the Si IV resonance lines at 1400 Å. These observations consisted of a 22 hour spectral time series obtained using the GHRS and having a spectral resolution of 10,000 and a time resolution of 1 second. The data indicate the presence of clouds of plasma having temperatures ranging from 10,000 to more than 35,000 K within the circumstellar environment. In some cases these clouds were tied to the surface of the star, presumably by magnetic fields, and forced to co-rotate with the star. In other cases the clouds moved away from or towards the star with velocities up to 1500 km/s. It was suggested that this activity points to an interaction between magnetic loops from the surface of the star and the dense, equatorial disc. γ Cas also shows strong, blueshifted absorption features seen in the wing of the Si IV line. These are normally referred to as Discrete Absorption Components (DACs). These were investigated by Smith and Robinson in collaboration with Cranmer (CfA) using the data set described above. In addition to the 'time-averaged' DAC feature, which was found to be optically thick in Si IV, they also found a substantial amount of fine structure which varied on a time scale of several hours to the full 27 hour rotation period of the star. It is speculated that this variable fine structure is associated with sources of X-ray emission which are tied to the surface of the star and rotate with re-

spect to the stationary DAC structures. Finally, Smith and Robinson completed a study of an X-ray time sequence of γ Cas which was obtained with the RXTE satellite. This time sequence shows short duration bursts superimposed on a slowly varying background and the object of the program was to search for rotational modulation of the background, thereby proving that the X-rays originate from the Be star rather than from a hypothetical degenerate companion. While earlier observations showed variations in the background on time scales of 10 hours, this data set had variations on time scales of 1 hour or less, which is much too rapid to be caused by rotation (the period for the star is 27 hours). These rapid variations masked any rotation effects which might have been present.

3. SOLAR PHYSICS AND SUN-EARTH CONNECTION

In collaboration with S. Jordan (GSFC), Andretta continues to investigate the problem of the anomalously strong helium spectrum in the Sun. By using data from the campaigns organized in 1997 and 1998 with SOHO and ground-based instruments, evidence has been found that non-equilibrium processes may contribute to the observed enhancement. An analysis of SERTS (Solar EUV Rocket Telescope and Spectrograph) profiles of the He II Lyman-α line at 304 Å, with S. Jordan and J. Brosius (GSFC), is adding more information on the effect of the dynamical behavior of the solar transition region on the EUV helium spectrum.

In collaboration with T. Kucera and A. Poland (GSFC), Andretta is extending a new diagnostic technique based on continuum absorption of hot coronal lines ($T > 10^6$ K) by relatively cool prominence material The initial work was done considering only lines observed by SOHO/CDS in the range 310–380 Å and 510–640 Å. Andretta has been working on extending this technique to the emission spectrum observed by both SOHO/CDS and SOHO/EIT in the range $\lambda > 150$ Å. Such an extension will allow a substantially more accurate determination of column densities in prominences.

Gopalswamy reviewed the X-ray and microwave signatures of coronal mass ejections (CMEs). X-ray and microwave imaging of structures associated with CMEs have provided a wealth of new information towards a better understanding of solar eruptions. The review concentrated on the recent research based on microwave imaging from the Nobeyama Radioheliograph and X-ray imaging from the *Yohkoh* Soft X-ray Telescope. He discussed the advances made towards understanding the near surface manifestations of CMEs best observed in X-rays and microwaves. In particular, the following issues were considered: (i) observability of CMEs in X-rays and microwaves, (ii) coronal dimming, (iii) relation between CME substructures, (iv) heating and expansion of eruptive prominences, (v) timing of flare, CME and prominence eruptions, and (vi) CME mass estimates from non-optical observations.

Goplaswamy, Yashiro (Tokyo University), Kaiser, Thompson (GSFC) and Plunkett (NRL) reported on the near-surface and outer coronal manifestations of the 1998 January 25 coronal mass ejection (CME) using white light, EUV, X-ray and hectometric radio data which reveal the three dimensional structure and long term evolution of the CME. They found that (i) the substructures of the CME (prominence core, cavity, frontal structure and the arcade formation) are clearly observed in X-ray and EUV wavelengths. (ii) The filament heats up early on and is observed as a backbone in X-rays. (iii) The filament also expands considerably as it erupts. (iv) The CME is observed through direct leading edge signature as well as through dimming process in X-rays and in EUV.

Using the observed relation between speeds of coronal mass ejections (CMEs) near the Sun and in the solar wind, Gopalswamy, Lara, Kaiser, Lepping (GSFC), Berdichevsky (ITSS) and St Cyr (CPI) estimate an ''effective'' acceleration acting on the CMEs. This study quantifies the qualitative results of Gosling [1997] and numerical simulations that CMEs at 1 AU with speeds closer to the solar wind. A linear relation between the global acceleration and the initial speed of the CMEs has been found. The absolute value of the acceleration is similar to the slow solar wind acceleration. This study naturally divides CMEs into fast and slow ones, the dividing line being the average solar wind speed. These results have important implications to space weather prediction models which need to incorporate this effect in estimating the CME arrival time at 1 AU. This study also shows that the arrival times of CMEs at 1 AU are significantly different from the zero acceleration case.

Gopalswamy, Kaiser, Burlaga, Thompson, Szabo (GSFC), Lara, Vourlidas (George Mason University) and Yashiro (Tokyo University) studied a set of 25 solar eruptive events associated with radio bursts in the decameter-hectometric wavelength regime. They identified the global characteristics of these events based on multiwavelength multispacecraft and ground based data. Their findings are as follows: (i) Each of the radio-rich events is associated with a white light CME; these CMEs seem to be wider and faster: On an average the width (160deg) of the radio-rich events is much larger than the typical width of white light CMEs ($\sim$ 45deg). There is a longitudinal dependence of measured speeds suggesting projection effect. (ii) A third of the events studied did not have metric type II bursts. In the rest of the events, the relationship between the metric and longer wavelength type II bursts is highly complex. A careful study of the three dimensional nature and long-term evolution of the CMEs and the shocks driven by them is needed to understand this relationship. (iii) Presence of a shock seems to be essential to produce an SA event; the energetic electrons seem to be accelerated in the shock front rather than from near the solar surface. (iv) For most of the shocks detected in situ, there was associated kilometric emission highlighting the importance of shock waves in producing radio emission at all heliocentric distances. (v) A significant number of shocks detected *in situ* (without drivers) were from limb CMEs suggesting that shocks have a greater longitudinal extent than CMEs. (vi) Spectroheliograms obtained by SOHO/EIT at 195 Å had a definite signature for each of the eruptive events near the solar surface consisting of one or more of EIT waves, dimming and global enhancement; the global

enhancement may be the earliest form of the CME itself.

Gopalswamy, Hanaoka (NAOJ) and Hudson (ISAS) have made first detection of coronal dimming in microwaves associated with the 1998 March 29 coronal mass ejection (CME). The dimming was observed by the Nobeyama radioheliograph at 17 GHz as a reduction in thermal free-free emission from the corona due to the displacement of coronal structures during a coronal mass ejection. The dimming was also observed in X-rays confirming the microwave observations. A low brightness feature within the white light CME could be identified that corresponds well with the microwave and X-ray dimmings. The dimming appeared drastically different in extreme ultraviolet probably due to the combined effect of coronal displacement and temperature change.

Gopalswamy, Lara and Kaiser (GSFC) compared the near-Sun and near-Earth manifestations of solar eruptions that occurred during November 1994 to June 1998. They compared CMEs, metric type II bursts and EIT waves (near the Sun) with interplanetary (IP) signatures such as magnetic clouds (MCs), IP ejecta and IP shocks. They performed a two way correlation study: (i) Look for counterparts of metric type II bursts that occurred close to the central meridian. (ii) Look for solar counterparts of IP shocks, MCs and ejecta. They used Wind and SOHO data along with metric radio burst data from ground based solar observatories. Preliminary analysis shows that (i) Most of the metric type II bursts did not have IP signatures. (ii) Most of the IP events (MC, Ejecta) did not have metric counterparts. (iii) A significant number of IP shocks without drivers were detected. In all these cases, the drivers (CMEs) were ejected transverse to the Sun-Earth line suggesting that the shocks have much larger extent than the drivers. These shocks also had good type II radio burst association.

Gopalswamy, Shibasaki (Nobeyama), Thompson, Gurman (GSFC) and DeForest (Stanford) studied the microwave enhancement and its variability in the elephant trunk coronal hole observed during the Whole Sun Month campaign (August 10-September 09, 1996) using the Nobeyama Radioheliograph images and the magnetograms and EUV images obtained simultaneously by the Michelson Doppler Imager (MDI) and the Extreme Ultraviolet Imaging Telescope (EIT) on board the SOHO spacecraft. The combined data set allowed them to understand the detailed structure of the microwave enhancement in the spatial and temporal domains. They find that the radio enhancement is closely associated with the enhanced unipolar magnetic regions in the coronal hole. When a minority polarity is present within the coronal hole, the resulting dipole is associated with a bright-point-like emission in coronal EUV lines such as the Fe XII 195 A. On the other hand, the lower temperature line emission (304 A) and the microwave enhancement are associated with the unipolar magnetic flux elements in the network. They found strong time variability of the radio enhancement over multiple time scales, consistent with the initial results obtained by SOHO instruments.

Based on the physical properties of coronal holes, Gopalswamy, Shibasaki (Nobeyama), Thompson, Gurman (GSFC) and DeForest (Stanford) attempted to constrain the region in the solar atmosphere in which the microwave enhancement originates. The brightness temperature range in which the enhancement occurs seems to be around 10,000 K. This temperature is close to the upper chromopsheric temperature. Therefore, they think that the enhancement takes place in the upper chromosphere of the coronal hole. Microwave emission from the quiet Sun is optically thick thermal bremsstrahlung from the upper chromosphere. Therefore, the optically thick layer in the coronal hole chromosphere must be hotter than the corresponding layer in the quiet chromosphere. They analyzed microwave and SOHO observations and found support for this idea. They calculated the emission measure and hence the expected optical depth of the corona in the coronal hole and found it to be negligibly small. They also invoked the result that any transition region with reasonable filling factor would produce a high brightness temperature which is never observed. Thus they conclude that the enhancement points to a difference in the upper chromosphere in the coronal hole as compared to that in the quiet Sun.

Gopalswamy and Salem (undergraduate research student from Case Western Reserve University) searched for coronal holes in the SOHO EIT data and identified 71 well defined holes during 1996 January to 1998 June. These dates correspond to the launch of SOHO and its temporary disability in June 1998. They are in the process of obtaining statistical results on area, life time, brightness temperature and variability in these holes.

Guhathakurta's recent work focuses on inferring difficult to measure coronal magnetic field strength and its topology in the corona-interplanetary medium. She along with Sittler (GSFC) has developed a two dimensional semi-empirical MHD model of the corona-interplanetary medium. This model for the first time produces an empirical heating function of the corona by using observational constraints. The model is also able to predict both qualitatively as well as quantitatively the source regions of the quasi-steady fast and slow solar wind.

Guhathakurta and Nunes are continuing to develop suitable mathematical tools for tomographic inversion of quasi-stationary white light observations of the solar corona such as coronal streamers and plumes from spacecraft measurements such as SOHO and Spartan 201 to accurately model the three-dimensional coronal density distribution.

Guhathakurta, Davila (GSFC) and Reginald (University of Delaware) took part in an expedition of the total solar eclipse of August 11, 1999. This experiment was sufficiently different from all the other eclipse observations of the past. Instead of imaging the corona they took spectroscopic observations at multiple points in the corona. The focus of this experiment was to determine the radial and latitudinal profiles of the coronal temperature and the solar wind speed.

Lara, Gopalswamy, Pérez-Enríquez (UNAM), and Shibasaki (Nobeyama) studied the development of microwave polarization of a group of active regions for a period of 10 days during April, 1993 using data obtained by the Nobeyama radioheliograph. The observed sense of polarization at 17 GHz, changed with the active region position on the solar disk. This change of polarization can be explained by the mode coupling theory, according to which a weak coupling

between the ordinary and extraordinary electromagnetic modes takes place when the radiation traverses a region of strong transverse magnetic field and results in a polarization reversal. Since the strength of the mode coupling depends on the physical parameters (and their gradients) of the quasi-transverse region, observations of polarization changes can be used to obtain key values magnetic field and field gradient in the active region corona. Using Yohkoh/SXT and 17 GHz intensity and polarization images of active regions, it was found that the coupling constant is typically $> 10^3$ corresponding to a weak coupling regime. The mean value of the transition frequency was found to be $\sim 5.3 \times 10^{11}$ Hz, below which the weak coupling effect is important. In all the active regions studied, there seems to be a similarity in the position on the solar disk where the mode coupling effects become important. The polarization reversal always occurred when the active regions were farther than the 500 arc sec mark from the disk center.

Lara, Gopalswamy and DeForest (Stanford) studied the magnetic flux changes in the source regions of a large number of coronal mass ejections using the longitudinal magnetograms obtained by the Michelson Doppler Imager of the SOHO mission. Magnetic field changes associated with CMEs have been elusive for a long time. It was found that when the source region is divided into small subregions then the flux showed remarkable changes at the times of coronal mass ejections. The eruptive activity is usually centered around the interval when there is substantial change in the magnetic flux. The changes seem to be on time scale much larger than the time scale of individual eruptions. It is planned to extend this work using magnetograms of high cadence in order to identify the exact feature that results in an eruption.

Lara, Gopalswamy, and Kaiser (GSFC) are analyzing the radio spectral evolution of a number of eruptive flares in the range 50 MHz to 17 GHz. All these events involved coronal mass ejections and energetic particles. They include spatial information of the flares from Yohkoh/HXT images in determining the spectral evolution. They also study the timing of long wavelength radio bursts observed by Wind/WAVES experiment to determine all possible sources of energetic particles. They compare and discuss the relationship between the hard X-ray, radio and energetic particle spectra in order to understand the acceleration process during these eruptive events.

4. PLANETARY SCIENCES

4.1 Planetary Astronomy

To study thermal structure and hydrodynamic escape in Pluto's upper atmosphere, Krasnopolsky suggested two limiting models of Pluto's atmosphere. He found that heating by the UV absorption of CH_4 (previously neglected) is even stronger than the EUV heating by N_2. He proved the existence of hydrodynamic flow of N_2 and developed a method of analytical solution for the equation of hydrodynamic flow. Structure of Pluto's upper atmosphere was calculated by this method at various solar activity. The models show that escape on Pluto disagrees with the classic theory and is case of a slow hydrodynamic escape. Pluto's atmosphere is restricted to 4000 km, which makes possible a close flyby of future spacecraft.

Krasnopolsky and Cruikshank developed a photochemical model of Pluto's atmosphere and ionosphere. This model is based on a set of the continuity equations for 44 neutral and 23 ion species and includes 191 chemical reactions. Altitude profiles, column abundances, escape and precipitation rates were calculated for each species. The model results are addressed to the basic aspects of Pluto's atmospheric composition, chemistry, and evolution.

4.2 NEAR

Clark and Starr are associate team members on the Near Earth Asteroid Rendezvous (NEAR) mission X-ray/Gamma-Ray Spectrometer (XGRS) experiment. They support operations during the cruise and orbital phases of the mission and will have lead roles in data analysis. NEAR will arrive at Eros 433 in January 2000, and will remain in orbit around the asteroid for 1 year. The rendezvous was delayed by about one year because of a failed rendezvous burn maneuver on December 20, 1998. A successful rendezvous burn maneuver was accomplished on January 3, 1999. The XGRS will collect thousands of X-ray and gamma-ray spectra while in orbit around Eros. These observations will be used to obtain elemental composition maps of the surface of Eros. These mapped compositions will be compared to known meteorite compositions in order to determine whether Eros has the characteristics of any of these meteorite types. The maps will also be of importance in determining the nature of formation and evolution of the Eros. The XGRS science team leader is Jacob Trombka at Goddard Space Flight Center.

Observations of solar spectra by the XGRS solar monitors on board the NEAR spacecraft during high activity periods have been obtained. These spectra show both continuum and discrete line calcium and iron emissions. Information on gamma-ray detector activation due to cosmic rays has been obtained. The NEAR XGRS has been included in the Inter-Planetary Network (IPN) for the detection of Gamma-Ray Bursts (GRB). The IPN now incorporates GRB information from the NEAR, Ulysses, Compton-GRO, GGS-Wind, and Konus spacecraft. The precision of the timing of the NEAR XGRS GRB detection system has been determined by using the detection of the GRB-associated optical transient GRB 990510. The delay between the arrival time at NEAR and at Konus was both measured and then calculated. The one-sigma difference in arrival time between measurement and calculation was found to be about 100 milliseconds. This difference then corresponds to a possible difference in location of the GRB of about one half arc-minute when 1.5 AU separates the spacecraft. This is well within the two arc-minute requirements for locating position of GRB's in the IPN network. Effects of long-term radiation exposure have been observed in the gamma-ray/X-ray detectors and the mechanism producing this degradation is understood. The results of these have been published. A number of students from both universities and high schools have participated in developing significant parts of the NEAR XGRS data management acquisition analysis processing system.

Clark and Starr are currently in the process of creating a master meteoritical information database from a variety of sources, including Jarosewich (the Smithsonian), Mittlefelhdt (JSC), Kallemeyn (from Wasson's group, chondrites), and the Japanese (Antarctic meteorites), which includes elemental abundances (for major, minor, and radioactive elements including Mg, Al, Si, Ca, Ti, Fe, S, K, Th, U, P, Cr, Mn, Zn, Cu, and Ni), ratios, and useful ancillary information, including methodology, laboratory, class, nature of sample, weathering information, and reference for each analysis. They are developing a range of IDL and EXCEL based tools to allow them to determine intrinsic variations in geologically significant elemental abundances and ratios associated with major meteorite classes and components. Products they can generate include spreadsheets, mean and standard deviation, histograms, density plots, and statistically significant populations associated with each class using cluster analysis. They also have interactive capability to pull up all the information for any point on the plot. They will use the database to exclude variations which result from instrumental or laboratory biases and to identify the most useful ratios which can be derived from their spectral XGRS data and used to determine the nearest meteorite analogue and differentiation history of Eros. Thus, they are focusing on data from meteorites which are the most likely analogues, including chondrites, stony irons, and achondrites.

Clark and Starr have established a systematic relationship between their observed spectra from the solar monitor and the level of solar activity as determined by the GOES solar X-ray instrument in orbit around the Earth. They have verified that their solar model data closely matches their observations. They have also determined that increase in the level of solar activity is not correlated with increased in high energy charged particle induced background. Increases in background are associated with solar mass ejections that are generally associated with, although they do not occur in every case for very energetic solar flares. They are now establishing a record of changes in background for the detectors during cruise, and will verify causes for each shift in background. On the basis they have generated inputs for the NEAR analytical software (quicklook) for treating and interpreting their measurements according to level of solar activity. Information on typical means and standard deviations for each element for major meteorite classes and components generated from their interactive meteorite database are now being used to generate model spectra under a range of solar conditions anticipated during the mission. Plots of XRF intensity ratio versus concentration ratio, with realistic error bars from their interactive database, will be used to determine which ratios will be most useful in interpreting their results. The predicted results will be used as tools for planning their observations and developing data treatment software.

4.3 Lunar Data Analysis (Lunar Prospector Mission)

Starr is a Principal Investigator and Clark a Co-Investigator in the Lunar Data Analysis Program. Clark has used quantitative (sensor fusion) techniques to combined data from Clementine spectral reflectance and Apollo gamma ray spectra derived iron and titanium variation on the Moon. By using this approach, they have optimized the utility of measurements from each data set. In their approach, gamma-ray measurements are used to provide bulk abundances for these two elements (based on calibration to bulk soil abundances), in the case of spectral reflectance measurements, recalibrating published Ti and Fe data (on the basis of soil bulk abundances and mineralogy) to represent Fe and Ti in minerals which absorb most efficiently at the selected wavelengths, namely Fe in pyroxene and Ti in ilmenite grains. They are developing this approach, and a classification matrix based on parameters derivable from near infrared, X-ray, and Gamma-ray spectral measurements, for use in both the analysis of recently obtained gamma-ray observations of the Moon (Lunar Prospector) and for other planetary surfaces with more limited ground truth, in particular for the asteroid Eros which we will encounter on the NEAR mission. Establishing this relationship between near infrared observations, which have been used to classify asteroids on the basis of mineralogy, and high energy spectral data, from which bulk elemental abundances can be derived, can also be useful in the interpretation of ground-based near infrared spectral measurements in terms of their geochemical, as well as mineralogical, significance.

4.4 Mars

Michael Smith is an associate member of the Mars Global Surveyor Thermal Emission Spectrometer (TES) science team. The Mars Global Surveyor has been in orbit around Mars since September 1997 and has been in its primary mapping mission since April 1999. Smith has led an investigation of the ubiquitous dust aerosols that are in the Mars atmosphere. TES has observed several large regional dust storms (including the large November 1997 Noachis Dust Storm), numerous local dust storms, and has monitored the seasonal and geographical variations of the background dust activity. Smith has also led the development of retrieval algorithms to separate the contributions of the atmosphere and the surface from TES spectra. These algorithms are being used to identify and to map mineralogical units on the surface of Mars.

4.5 Cometary Studies

Krasnopolsky, Mumma, and Abbott continued their study of soft X-rays in comets with the EUVE by observing post perihelion Hale-Bopp and analyzing observations of comets Encke, Mueller, and Borrelly from the EUVE archive. Five of eight observations in their EUVE database show the detectable X-ray emissions. Correlation of the X-ray luminosities with the gas production rates favors charge transfer from the solar-wind heavy ions as an excitation mechanism. However, the EUVE observations of Hale-Bopp, its nondetection with the ROSAT, and its high X-ray luminosity observed with the BeppoSAX require a substantial contribution from the attogram dust scattering of the solar X-rays.

5. INSTRUMENTAL DEVELOPMENT

5.1 MS2001

Starr is a Participating Scientist on the Mars Surveyor 2001 Gamma-Ray Spectrometer (GRS) experiment. 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 Surveyor spacecraft is planned for launch in February 2001 and arrival at Mars nine months later. The Principal Investigator is William Boynton of University of Arizona. The detector will be a large volume high purity Ge detector that is being supplied by URSYS in France. It will be passively cooled to cryogenic temperatures by a cooler designed and built by A. D. Little. Calibration of the detector system will be a joint responsibility of the University of Arizona and GSFC. Prototype models have been constructed and are under test. The flight systems are now being constructed.

5.2 MESSENGER

A Discovery proposal for a Mercury orbiter mission called MESSENGER has been selected by NASA Headquarters to begin in 2000. The purpose of this mission is to collect global information on the surface, interior, exosphere and magnetosphere of this least explored of the terrestrial planets. Launch will be in 2004. Two flybys of Mercury will be executed prior to orbital insertion in 2008. 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 will have a key role in the development, test, and calibration of the X-ray, gamma-ray, and neutron spectrometers that will fly on board the MESSENGER spacecraft.

5.3 New Concepts

Bruhweiler is working closely with A. Schultz (STScI, CSC), D. Schroeder (Beloit), I. Jordan (STScI, CSC) and others to develop a free flying occulter called UMBRAS that would work with the future Next Generation Space Telescope (NGST). The current UMBRAS design consists of two separate spacecraft, a Solar-Powered Ion Driven Eclipsing Rover (SPIDER) and one or possibly two metrology platforms along with the NGST. The UMBRAS is designed to enable the NGST to image faint sources as close as 0.15‘‘ from target stars. Giant Jupiter-sized planets could be imaged as close as 5 AU from stars at a distance of 30 pc. This concept has been presented at a recent SPIE meeting and a more refined concept will be presented at the NGST meeting on Cape Cod in Sept. ’99.

Remote X-ray spectroscopy is used to obtain elemental composition maps from condensed bodies in our solar system. The major excitation source for remote X-ray fluorescence experiments is solar X-rays. X-rays in the energy range 1 to 10 keV are very soft and so they sample only the topmost layer of a planet’s surface. X-ray line emission from Mg, Al, and Si may be observed even during periods of little solar activity. When the sun is active, higher energy lines from Ca, Fe, and Ti may be produced with sufficient statistics to allow abundance measurements of these elements, also. Detector areas of 25 cm^2 or greater are needed for K-shell X-ray planetary remote sensing systems in order to obtain the best spatial resolution. Proportional counters have been developed and flown on space flight missions successfully, but the energy resolution is very poor and cannot resolve, for example, the Mg, Al, and Si lines. Under the Planetary Instrument Definition and Development Program (PIDDP) program, room temperature silicon strip detector systems are being developed with resolution better than proportional counters. These detectors promise significant improvements in energy resolution and reduced mass. Detector areas of about 1 cm^2 are now produced with good energy resolution. Studies have just begun on developing mosaics of these detectors in order to obtain the desired 25 cm^2 area. Starr is supporting this PIDDP effort and will be responsible for test and calibration of newly developed detector systems.

6. EDUCATIONAL OUTREACH & OTHER ACTIVITIES

Guhathakurta has been detailed since November of 1998, on an Intergovernmental Personnel Act (IPA) assignment at the Office of Space Science (OSS), NASA, Headquarters to assume the responsibilities of the program scientist for the solar and heliospheric physics branch. As an IPA Guhathakurta is working on solar physics issues of importance to understanding the field as a whole and the role it has in the study of the Sun-Earth Connection within the solar system. She is in charge of management and outreach of solar physics flight programs now operational. She is also assigned the task of program scientist for the upcoming solar and heliospheric missions, STEREO and Solar Probe.

The IACS strongly encourages the participation of graduate and undergraduate students as well as capable high school students in scientific research. IACS personnel directly supervising these students have been Bruhweiler, Chen, Crenshaw, Gopalswamy, Gabel and Kraemer. Bruhweiler and Crenshaw serve as official Mentors for the Montgomery County and Prince George County school system in Maryland. Bruhweiler and Gabel have regularly visited elementary and intermediate schools to lecture and assist teachers in astronomy and physics presentations and been judges for school science fairs. Bruhweiler has also served as a lecturer for the Space Telescope Science Institute Lecture Series and also for the Smithsonian Associates Lecture Program. Bruhweiler also gave the keynote address for the Blair High School Mentor Award Ceremony (Montgomery County, MD).

SUNBEAMS (Students United with NASA Becoming Enthusiastic About Math and Science) is now in its second year as a pilot program. This effort is headed by Carol Jo Crannell. The number of teachers participating in the 5-week summer workshops, increased from 9 to 18, and the number of participating mentors increased proportionately. The first of the 18 classes to come to Goddard for a full week of total immersion in math and science will be at Goddard on October 4 and the enthusiasm for the program is increasing

throughout the District of Columbia Public Schools. Efforts to replicate the program are underway in Philadelphia and Boston.

The CUA/GSFC summer student program in the Laboratory for Astronomy and Solar Physics, in its ninth year of funding with an NSF/REU site grant, had a record number of students (55) participating in our seminars and other activities. The students ranged from high school seniors to graduate students and worked in discipline areas ranging from Atmospheric Sciences to Solar Physics, Astronomy, and Astrophysics.

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