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

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The following report covers the astrophysical research activities of the newly-formed Institute for Astrophysics and Computational Sciences (IACS). However, activities of non-Institute members in the Department of Physics at the Catholic University of America (CUA), who work closely with the Institute are also included. The period of this report covers from September 1997 through September 1998.

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 that are directly affiliated with the Institute are: Fred Bruhweiler (Director), Al Boggess, Peter Chen, Mike Crenshaw, Mike DiSanti, Nat Gopalswamy, Scott Johnson, Steve Kraemer, C.-H. Lyu, Charles Proffitt, Rich Robinson, Myron Smith, 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 Richard Cecil, Tena DuBerry, Cherie Miskey, and Brendan Smith, as well as the graduate students, Jack Gabel, Craig Harbuck, Charles Hall, Theo Hadjimichael, Ian Liska, Jose Ruiz, and Scott Weingarten. This is in addition to undergraduate and talented high school students who do research with members of the Institute.

2. RESEARCH ACTIVITIES

2.1 Cosmic Background Radiation

Johnson (GST) has been using balloon flight data in the infrared to characterize foreground to the cosmic background radiation in a frequency range of 19 GHz to 675 GHz. The goal of the study is to better understand the cosmic background radiation anisotropy in this frequency range.

2.2 Galaxies and Extragalactic Astronomy

Bruhweiler, Miskey, and 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 applied the new UV spectral library developed as part of the dissertation work of Smith Neubig in an attempt to determine age, slope of the Initial Mass Function, and metallicity of the bright starbursts in nuclear ring of starbursts in NGC 1068. Synthetic UV spectra have been produced using the theoretical evolutionary tracks in conjunction with the spectral library, which consists of IUE spectra of stars in the Galaxy, the LMC, and the SMC. Results soon to be published, show that the ages of the starbursts are quite young, $\approx$ 5 Myr and the metallicity appears to be roughly twice solar. These results are consistent with previous findings for the elemental abundance for the Narrow Line Region of the active galactic nucleus of this Seyfert 2 galaxy. Preliminary results were presented at the American Astronomical society meeting in San Diego.

Data reduction and analysis is proceeding on new STIS data obtained for NGC 604, the bright H II region-OB association in M33. Recent data obtained by STIS show 30-40 UV spectra of OB stars in a single slitless exposure. Bruhweiler, Miskey, and Smith Neubig are using thes data to better determine where these stars are in the H-R diagram in that galaxy and compare the findings on mass loss and metallicity with the Galaxy, LMC, and SMC.

Smith Neubig and Bruhweiler just completed an analysis of roughly 300 ultraviolet spectra obtained by the IUE of O and B stars in the Large and Small Magellanic Clouds. This work has appeared or have been submitted in two papers by Smith Neubig and Bruhweiler during this period.

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 continue to work on the intrinsic absorption lines in active galaxies. A STIS echelle spectrum of NGC 5548 was presented at the AAS meeting in San Diego. Lα, N V, and C IV show five high-ionization absorption components at radial velocities from $-$ 185 to $-$ 1090 km s^{-1}, relative to the systemic velocity. Lα also shows absorption components at lower velocities, which may be associated with the interstellar medium of the host galaxy. The same kinematic components were present in GHRS spectra of C IV and N V obtained two years earlier. Strong variability was detected in the column density of one of the components (at $-$ 520 km s^{-1}). The possibility of weaker variations is being investigated. Crenshaw and Kraemer have

also completed a paper on a survey of intrinsic absorption in Seyfert galaxies observed by HST.

Kraemer, Crenshaw, and Ruiz are working to explore the differences in the narrow-line regions (NLRs) of active galaxies. The physical conditions in the inner narrow line region (NLR) of the Seyfert 2 galaxy, NGC 1068, were examined using ultraviolet and optical spectra and photoionization models. The spectra are *Hubble Space Telescope* (*HST*) archive data obtained with the Faint Object Spectrograph (FOS). Spectra of four regions, taken through the 0.3″ FOS aperture and covering the full FOS 1200 Å to 6800 Å waveband, were selected. Each region is approximately 20 pc in extent, and all are within 100 pc of the apparent nucleus of NGC 1068. The spectra show similar emission-line ratios from wide range of ionization states for the most abundant elements. After extensive photoionization modeling, it was determined that each region includes a range of gas densities, which were included in the models as separate components. Supersolar abundances were required for several elements to fit the observed emission line ratios. Dust was included in the models but apparently dust to gas fraction varies within these regions. The low ionization lines in these spectra can be best explained as arising in gas that is partially shielded from the ionizing continuum. New long-slit observations with STIS will permit a more detailed examination of the physical conditions in NGC 1068.

Kraemer, Turner (USRA), Crenshaw, and George (USRA) have explored the effect of UV absorbing material on the shape of the EUV continuum radiation emitted by the active galactic nucleus and the relative strengths of emission lines formed in the narrow line regions of Seyfert galaxies. Within a sample of Seyfert 1.5 galaxies, objects with flatter soft X-ray slopes tend to have lower values of He II λ4686/H β, which implies a correlation between the observed spectral energy distribution of the ionizing continuum and the narrow emission line strengths. Since those objects with the flattest soft X-ray continua appear to be heavily intrinsically absorbed, it is most plausible that the differences in relative narrow emission line strengths among these galaxies are an indication of the size of the columns 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 emitted ionizing continuum and the resulting variations in the conditions in a typical narrow line cloud. The results indicate that the presence of a UV absorber with large covering factor will indeed produce the narrow line ratios and soft X-ray spectral characteristics observed in several Seyfert 1.5 galaxies. The results also suggest that, based on the narrow line and soft X-ray data, the presence of low ionization UV absorption may be more common than currently believed.

2.3 Interstellar Medium

Bruhweiler is continuing work with Holberg (Univ. Arizona) and Barstow (Leichester) to use the Extreme Ultraviolet Explorer, IUE, and HST to study the physical processes both in the photospheres of hot white dwarfs, and in the local ISM. This work has focussed upon recent HST/STIS observations of the white dwarf, REJ 1032+532. These results show that, although the photospheric abundances for carbon and silicon mathc 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.

Bruhweiler, and Lyu are also continuing their theoretical calculations in modeling the time dependent ionization in the Local ISM. They 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.

Bruhweiler, Meena Sahu (AURA/GSFC), Crenshaw, and Kraemer are studying the interstellar lines produced in the Galactic Halo seen in the UV echelle spectrum of NGC 5548 obtained with STIS aboard the HST. Several velocity components are seen through the halo. The lack of absorption from C II λ1335 originating from an excited fine-structure level indicates that the density is quite low over much of the pathlength through the halo.

2.4 Stellar Physics and Astronomy

Bruhweiler in collaboration with Schultz (STScI/CSC) are 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.

Bruhweiler and Lyu, have further pursued model suggesting that tidal interactions produce spiral shocks in young forming planetary systems. The signal 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 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 far-UV spectral data from the Far Ultraviolet Spectral Explorer (FUSe), due to be launched in early 1999. Time-resolved spectra will be obtained of very hot white dwarfs displaying hydrogen-like O VIII emission.

Kondo continued his appointment as NASA Project Scientist for the International Ultraviolet Explorer (IUE) satellite observatory, which was formally terminated at the end of September 1997. The IUE Final Archive, which contains over 100,000 astronomical spectra, is available to the scientific community through the Space Telescope Science Insti-

tute and ESA. More than 3,500 articles have been published in refereed journals from IUE observations that were obtained over its 18 years and 8 months of operation. He also served as Project Scientist for the Extreme Ultraviolet Explorer (EUVE) launched in 1992; the operation of EUVE has been transferred to UC Berkeley.

With G. McCluskey of Lehigh University, Kondo analyzed HST observations of a strange cataclysmic-like binary V Sge, in which hot emission features had once been observed red-shifted by several hundred kilometers per second. With F. Bruhweiler, C.H. Lyu and A. Boggess, he completed an analysis of the high-resolution HST spectra of the protoplanetary system candidate star beta Pictoris. The new results are consistent with the possibility that a Jupiter-sized object is causing shock-waves as it ploughs through the extended gaseous envelope of the star; the present results are not consistent with the hypothetical proposal that millions of comets are presently falling into beta Pictoris.

Proffitt together with D. S. Leckrone (NASA/GSFC), G. M. Wahlgren, J. Brandt (U. Colo.) and T. Brage (Univ. of Lund) has continued to work on HST/GHRS spectra of the chemically peculiar stars χ Lupi and HR 7775. This work includes extensive non-LTE and radiative force calculations for mercury and other heavy elements, and has lead to improved understanding of the causes of line profile anomalies observed in these stars.

Proffitt is also engaged in a study of the B III resonance line in early B stars, using HST/GHRS and IUE data. Using our GHRS data, we have determined boron abundances and isotope ratios for the early-B stars γ Pegasi and HD 35299. The $^{11}B/^{10}B$ isotope ratios found are similar to that found for solar system material. The star ζ Cassiopeiae was found to be strongly depleted in boron.

Robinson and Carpenter completed a study comparing the atmospheric properties of the K5 giant α Tau with the hybrid star γ Dra, which has the same spectral type but quite different wind properties. The goal was to characterize the atmospheres of each of these objects and to search for differences which would explain the different wind properties. These two stars were found to be remarkably similar in the photosphere and lower chromosphere and differ only in the upper chromosphere, where the high speed wind of the hybrid is initiated. This led to the suggestion that the winds in the hybrid star were generated by low frequency waves which propagate through the inner parts of the atmosphere with very little effects.

Carpenter and Robinson also completed a detailed study of the K5 supergiant star λ Vel. The purpose was to characterize the atmosphere and wind properties of this star and to compare them with those of other cool stars. A particularly important part of the study involved a comparison of the SEI computer code, which is used to determine the wind characteristics of a star from centrally reversed spectral lines, with a more exact radiative transfer code. There is also a comparison of mass loss rates determined by spectral analysis with those determined through radio observations.

One of the most promising mechanisms which has been proposed to drive the winds of cool giant and supergiant stars involves Alfven waves which are generated by the convective motions at the stellar surface. To study this process Airapetian and Robinson are adapting a fully non-linear MHD computer code which was originally developed for the study of MHD waves in solar coronal holes. The preliminary calculations are very promising and are able to qualitatively account for many of the observed properties of these winds, including the large mass loss rates, the small terminal velocities and the large turbulence.

Robinson, in collaboration with Bohm-Vitense and Carpenter, are using FUV spectra obtained with the GHRS to search for white dwarf companions to Ba stars. The project is designed to test the theory that the chemical peculiarities of these objects arise from mass transfer during the evolution of the white dwarf progenitor. A white dwarf companion was found for all but one of the stars observed. However, the deduced temperatures of the white dwarfs are much smaller than expected, indicating that they are older than previously thought. In several cases the deduced ages of the white dwarfs is longer than the post-main-sequence lifetime of the companions, suggesting that the transfer took place while the primary was still on the main sequence. This seems unlikely, since there are no known main sequence Ba stars.

Smith and Robinson investigated UV continuum variations observed in HST/GHRS and IUE observations of the classical Be star γ Cas. These variations occurred over timescales of hours and had an amplitude of $\sim 1 - 2\%$ at 1400 Å and more than 5% near 1200 Å . They are closely related to variations in the stellar X-ray luminosity and it was proposed that they are caused by the rotational modulation of dense, clouds of cool material suspended above the surface and forced to co-rotate with the star.

3. SOLAR PHYSICS AND SUN-EARTH CONNECTION

Andretta has been investigating, with S. Jordan and H. Jones (NASA/GSFC) the problem of the formation of the helium spectrum in the solar atmosphere. By means of numerical radiative transfer modeling, this investigation has indicated several tests for discriminating the different mechanisms proposed to justify the anomalous high intensity of helium lines in much of the solar atmosphere. In order to test the model predictions, an observational campaign involving SOHO instruments (mainly CDS, SUMER, EIT) and several ground-based observatories (Kitt Peak, Sacramento Peak, German Vacuum Telescope in Tenerife, Coimbra Observatory) has been organized. Some of the preliminary results seem to point to a rethinking of the role of coronal radiation in exciting the helium spectrum in the quiescent solar atmosphere.

Andretta, Kucera and Poland have explored the origin of EUV absorption features associated with prominences. In several instances it has been possible to determine that continuum (bound-free) absorption, mainly in the hydrogen and helium resonance continuum, is the main operating mechanism. From a relatively simple model of the absorption process, a technique has been devised to infer column densities of both hydrogen and helium from SOHO/CDS spectra.

Gibson is studying the role of the large-scale solar coronal magnetic field in both stable and dynamic coronal structures.

She has worked with coronal observations from SOHO, SMM, and the Mk-III K-coronameter, and is currently involved in preparing for the upcoming Spartan telescope mission, due for its fifth launch from a space shuttle in October, 1998. Gibson continues to develop computer models of the large scale corona, designed to satisfy the MHD equations as applied to coronal structures such as coronal streamers, coronal holes, and coronal mass ejections, in collaboration with B. C. Low (HAO/NCAR), A. Fludra (RAL, U.K.), F. Bagenal (CU, Boulder), and Guhathakurta. The application of these models to solar observations has led to the development by Gibson and P. Charbonneau (HAO/NCAR) of advanced ''genetic algorithm'' data analysis techniques for these coronal problems that better incorporate an extensive range of observations.

Gibson, along with D. Biesecker (SAC/NASA GSFC) and Andretta, continue to coordinate multi-instrument observations and their analysis, via the ''Whole Sun Month'' (WSM) campaigns. The goal of these campaigns has been 1) to quantify the physical properties (i.e. density, temperature, magnetic field, and velocity) of the 3-dimensional, large scale, stable solar minimum corona; and 2) to test and use this information with models connecting the corona to in situ observations of the solar wind. The first WSM campaign coordinated observations from the SOHO satellite with other satellite and ground-based observations, and occurred Aug. 8–Sept. 10, 1996. This campaign has led to two workshops at NASA Goddard Space Flight Center, special sessions at both the 1997 and 1998 Spring American Geophysical Meetings, a special WSM issue of the Journal of Geophysical Research, and the invitation for a set of WSM papers to be submitted to Science magazine. The second WSM was reduced to two weeks (Aug. 10 - 25, 1998) by the unfortunate loss of communications with the SOHO satellite, but nevertheless coordinated multiple ground-based observations with space-based telescopes such as the Yohkoh and TRACE satellites. Gibson, along with Guhathakurta and R. Fisher (NASA/GSFC), are also developing an observing campaign including the Spartan and TRACE telescopes. The goal of this campaign will be to connect the lower emission line corona seen by TRACE to the large-scale white light corona seen by ground-based telescopes and Spartan, and to consider these connected coronal structures in the context of the coronal magnetic field. These studies will focus particularly on the onset of coronal mass ejections.

Gopalswamy, Nitta (Lockheed), Manoharan (Ooty), Raoult and Pick (Meudon) studied the changes in the vicinity of a disappearing solar filament (DSF) that occurred on 1993 April 30. The DSF was associated with a long duration X-ray event (LDE) observed by the GOES and Yohkoh spacecraft. A detailed analysis of the X-ray images obtained by the Yohkoh Soft X-ray Telescope revealed that the X-ray manifestations of the eruption were wide-spread: (i) X-ray enhancement over a coronal volume several times larger than that of the eruption region, probably the X-ray counterpart of a halo coronal mass ejection (CME), (ii) X-ray Ejecta accelerating to 670 km s^{-1} into the corona, and (iii) quasi-stationary X-ray loops as in long decay events (LDEs) were observed. It was found that the X-ray ejecta was fast enough to drive a coronal shock consistent with the shock speed obtained from type II radio burst to within 10%.

Gopalswamy, Hanaoka (Nobeyama) and Hudson (ISAS, Japan) studied the 1997 December 14 prominence eruption event that was accompanied by eruptive signatures in X-rays, EUV and white light: coronal dimming, X-ray arcade formation, X-ray brightenings, EUV eruption, and a white light CME. The data used were obtained by the Nobeyama Radioheliograph, Yohkoh Soft X-ray Telescope (SXT) and SOHO/LASCO and EIT. Various substructures of the eruption and their inter-relationships could be clearly identified. It was found that the pre-disruption swelling of the equatorial streamer was caused by the outward displacement of the coronal material around the prominence eruption. The dynamical behaviors of the CME and the accompanying eruptive prominence seem to be very different.

Gopalswamy and Kaiser (NASA/GSFC) have begun a work to identify the drivers of coronal and interplanetary shocks so that they can be used effectively for forecasting space weather. This is done by analyzing more than two dozen type II radio bursts obtained by ground based radio instruments and the Wind/WAVES experiment in conjunction with data on coronal mass ejections (CMEs), flares and prominence eruptions from SOHO and Yohkoh missions and from the Nobeyama Radioheliograph. For the first time, actual coronal densities (from the solar surface to 30 solar radii) derived from coronagraphic data and flow speed shall be used to determine the speed and starting height of coronal and interplanetary shocks. This analysis will produce a set of geoeffective solar events that can serve as useful reference that can greatly influence future data acquisition, analysis and forecasting of space weather.

Gopalswamy, Lara (UNAM, Mexico) and Shibasaki (Nobeyama, Japan) 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. Using the intensity and polarization images of active regions, it was found that the coupling constant is typically $> 10^3$ corresponding to a weak coupling regime. We determined the mean value of the transition frequency to be $\sim 5.3\times 10^{11}$ Hz, below which the weak coupling effect is important. For all the active regions studied in this paper, 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.

Gopalswamy, Hanaoka (Nobeyama), Kaiser, Gurman (NASA/GSFC), and Hudson (ISAS, Japan) studied the birth place of the 1998 January 21 halo coronal mass ejection (CME). The CME was launched from high southern latitudes in association with a filament disappearance observed by the Nobeyama Radioheliograph. Signatures of the initial destabilization of the filament were observed by the Extreme-ultraviolet Imaging Telescope (EIT) on board the SOHO spacecraft and by the Soft X-ray Telescope (SXT) on board Yohkoh. The Wind/WAVES experiment observed a type II burst in the 600-300 kHz range. The data coverage for this

event is unusually high the origin and evolution of the eruption could be studied well. In particular, it was possible to determine: (i) relation between filament eruption and X-ray arcade formation beneath the filament, (ii) comparison between the hot arcade formation in X-rays and EUV, (iii) relation between the filament eruption and the white light CME, (iv) relation between the CME and the interplanetary shock inferred from the WAVES data. This study established that the CME-driven shock formed only at a heliocentric distance of about 8 $R_{\odot}$.

Guhathakurta's research has been directed towards the synthesis of a number of multi wavelength observations, ranging from the radio to the extreme ultraviolet, for the purpose of exploring the Sun-Earth connection and the distinguishing properties of the source regions of the slow, moderate and high speed solar wind. She has been involved in multi-spectral photometric solar data analysis, image processing, and physical interpretation with the goal of characterizing the large scale magnetic field of the solar corona, the large and small scale density and temperature structures of the solar corona and then apply these high quality observational constraints towards solar wind modeling to understand the coronal heating process.

Guhathakurta's recent work involves characterizing the coronal magnetic field topology from SOHO observations and associating these structures with the source regions of fa st and slow solar wind. She has been the project scientist (1/1/93-current) for the Spartan 201 white light coronagraph which is preparing for its fifth flight in October, 1998. Presently she is a PI on a 3 year NASA grant involved in developing suitable mathematical tools for tomographic inversion of (single spacecraft or solar rotation tomography and multiple spacecraft) quasi-stationary white light observations of the solar corona from Skylab, SMM, Spartan, Mk III K-coronameter and SOHO to obtain both a necessary and sufficient three-dimensional density model of the solar corona. The results of this ongoing interpretive model can be and are being used as a planning tool for the Solar Stereo Mission and would be instrumental in the analysis and interpretation of data from this mission. She is currently involved in a study to estimate solar coronal brightness as seen from the vantage point of the Solar Probe and to relate these estimates to typical instrument sensitivities which would be extremely important for designing imaging remote sensing instruments. She is also a co-I on NSF funded eclipse expeditions with the goal of taking quantitative observations of the solar corona. She participated in a SAO/NSF/GSF C eclipse expedition to Guadaloupe in February, 1997. She has been a team member of the science definition team of NASA towards defining the scientific goals for the Solar Stereo mission. She has been a participant in the science definition team of NASA proposed Solar Probe mission.

3.1 Planetary Astronomy

Krasnopolsky observed Mars at 1212-1218 Å with the HST Goddard high-resolution spectrograph and detected, among other emissions, Lyman-alpha emission of terrestrial deuterium. He constructed a model for H_2, H, HD, and D at 85 to 500 km which agrees with the observed intensity of D. D is formed by photolysis of HDO and in reactions of HD with O, O^+, and $O(^1D)$. The model shows that escapes of H and D are diffusion limited and isotope fractionation factor is 0.5.

Krasnopolsky (with L. W. Esposito, J. L. Bertaux, V. I. Moroz, and L. V. Zasova) reviewed findings in the chemical composition of Venus' atmosphere and its modeling for the last fifteen years. They considered basic principles of this modeling and demonstrated that the assumption of thermochemical equilibrium is inapplicable to many chemical processes in the atmosphere.

Krasnopolsky, on request from the editorial board of Encyclopedia of Astronomy and Astrophysics, wrote an article on sixteen Russian spacecraft missions to Venus, with short descriptions of the instrumentation and scientific results.

Krasnopolsky (with M. J. Mumma and G. R. Gladstone) observed Mars at 1212-1218 A with the HST Goddard high-resolution spectrograph and detected Lyman-alpha emission of atomic deuterium. They developed a photochemical model for H_2, H, HD, and D at 80 to 250 km on Mars. The model data were used as input data to a radiative transfer code which resulted in the measured D intensity for HD/H_2 smaller by an order of magnitude than HDO/H_2O. This means that fractionation of deuterium between water and molecular hydrogen is controlled thermodynamically, not kinetically. H_2 is strongly depleted in deuterium relative to water on Mars because of the very long lifetime of H_2 (1200 years). The derived isotope fractionation corresponds to an estimate of a planetwide reservoir of water ice about 5 meter thick that is exchangeable with the atmosphere.

Krasnopolsky developed a new method of analytic solution for the equation of hydrodynamic flow from an atmosphere which improves by an order of magnitude the errors in the equation for the McNutt approximation. Structure of Pluto's upper atmosphere was calculated by this method at various solar activity. Hydrodynamic flow of N_2 varies from 1.2×10^{27} to 3.6×10^{27} s^{-1}. Pluto's atmosphere is restricted to 3000-4500 km which makes possible a close flyby of future spacecraft.

3.2 Cometary Studies

Krasnopolsky (with M. Mumma, M. Abbott, B. Flynn, D. Yeomans, P. Feldman, K. Meech, and C. Cosmovici) observed comet Hale-Bopp using the Extreme Ultraviolet Explorer (EUVE) and detected emission of He 584 A for the first time in comets. Helium appears in comets due to charge exchange of solar-wind alpha-particles with cometary neutrals, a process which is essentially similar to that which excites X-ray. They also obtained the first sensitive upper limit to neon in comets. This limit shows that cometary neon is depleted relative to the solar abundance by more than factors of 25 and 200 for cometary gas and gas plus dust, respectively. This means that cometary ices formed at or experienced temperatures higher than 25 K.

The same authors reported the detection of X-rays in comet Hale-Bopp, and Krasnopolsky (with M. J. Mumma and M. Abbott) also detected X-rays in comets Hyakutake and d'Arrest while comet Bradfield was below the detection limit. Along with ROSAT observations, EUVE observations

demonstrated that X-ray emission from comets is a general phenomenon and exceeds the level expected for scattering and fluorescence of solar X-rays by three orders of magnitude. Comparison of X-ray intensities, brightness distributions, and brightness maximum offsets from nuclei in four comets favors charge transfer of solar wind heavy ions to cometary neutrals as a dominant process for X-ray excitation.

Krasnopolsky reanalyzed the ROSAT observations of comet Hyakutake and concluded that the mean X-ray intensity exceeded that of ''slow varying component'' by a factor of 3 and agreed with the EUVE observations. He proved that bremsstrahlung and electron impact excitation which were previously claimed as the basic processes of X-ray generation in comets, may produce about 1% of the observed emission. Spectral index for scattering of solar X-rays by so-called attogram dust disagrees with the measured spectral index, and this does not favor this process as well. Therefore, charge transfer of solar wind heavy ions should be a dominant process for X-ray excitation in comets.

4. INSTRUMENTAL DEVELOPMENT

Chen, in collaboration with C.W. Bowers, S.G. Neff, R.S. Polidan (NASA GSFC) and R.Romeo (CMA), continued the development of ultra lightweight mirrors for space astronomy. Significant accomplishments include the fabrication of a 0.6 m diameter thin facesheet mirror with mass 0.9 kg (areal density 2 kg/sqm). This is far lighter than glass (63 kg) or beryllium (6 kg) mirrors of the same size. Active figure control to correct astigmatism has been demonstrated in the laboratory. Current work is aimed at demonstrating diffraction limited operation at visual wavelengths. In collaboration with R. Keski-Kuha (GSFC Optics branch), several graphite cyanate ester mirrors have been coated with silicon carbide by ion beam deposition. The two materials have been found to be compatible, as determined by reflectance measurements over a one year time span. This development is very encouraging, as it promises to make possible very lightweight, large aperture telescopes with good reflectivity below Lyman alpha. A core reinforced 0.9m mirror has been made for ground-based astronomy and lidar applications. At a mass of 4 kg, this mirror can be carried by hand. A normal 0.9 m glass mirror weighs close to 200 kg. Progress results were presented at meetings of the SPIE, AAS, NASA NGST Technology Challenge Conference, UV Space Astronomy Beyond the HST Conference, and other professional forums. Plans are being made to field test several ultra lightweight composite mirrors on expeditions to observe lunar and asteroidal occultation of stars.

Chen, in collaboration with R.J. Oliversen and Y. Kondo, continued to develop and refine a new concept lunar observatory. A new high temperature superconductor bearing has been designed and is under construction. New developments in low cost trajectories has made it possible to compute launch to the weak stability boundary with very few launch window constraints. An elegant solution has been found to solve problem of providing power for nighttime observations without radioactive thermal generators. A new idea of using world wide participation to simplify communications with telescopes on the Moon is being studied. The study so far has shown that it is possible to deploy a 1 m uv/vis/ir telescope on the Moon within the budget of a SMEX class mission ($40-50M). With a MIDEX budget ($60-100M), it is possible to deploy a 2x1m optical interferometer pair with a baseline of up to a kilometer. Progress reports have been given at a meeting of the IAU and at the UV Space Astronomy Beyond HST Conference. A manuscript is currently being prepared for publication.

5. EDUCATIONAL OUTREACH & OTHER ACTIVITIES

Research Experiences in the Laboratory for Astronomy and Solar Physics: This summer student program, administered by CUA for NASA Goddard Space Flight Center, had an outstanding summer with 23 students participating. The students' projects spanned the full range of research pursued by the laboratory, including solar physics, infrared astronomy, and Hubble related science. Just before summer began, one of our former summer students, Jonathan Winkler was named a Rhodes Fellow. This was cause for much celebration both at Goddard and at NASA Headquarters. Jonathan has spent three summers at Goddard, the first of which was with Dr. Frederic L. Lang in the Solar Physics Branch.

SUNBEAMS, a New Teacher/Student Workshop: Students United with NASA Becoming Enthusiastic About Math and Science (SUNBEAMS) was initiated at Goddard Space Flight Center in partnership with the District of Columbia Public Schools as model space-science program for middle school teachers and students. It is an adaptation and amplification by Crannell and her GSFC colleagues of a highly successful science and mathematics program, BEAMS, developed by the Thomas Jefferson National Accelerator Facility where she spent her most recent sabbatical. During summer workshops at GSFC, teacher/mentor partners developed lesson plans incorporating hands-on, inquiry-based, cooperative-learning. During this school year, each of the teachers will bring their students to GSFC for one week of total immersion in these lessons that reflect the process and excitement of space science. The GSFC mentors will maintain contact with their teacher partners during the year, participate in the student workshops, and attend SUNBEAMS Family Nights at their respective schools.

Gopalswamy is a member of the Organizing Committee of IAU Commission 10 for 1997 - 2000.

Johnson (GST) is currently involved in developing educational software to use as web-based applications. The goal is to create physics, astronomy, and math applications that encourage students to seek answers to basic questions. Johnson is the web curator of the IACS web page.

Kondo completed his tenure as President of International Astronomical Union (IAU) Division V (Variable Stars), which consists of IAU Commissions 27 (Variable Stars) and 42 (Close Binary Stars). He continues to serve as IAU representative to International Astronautical Federation (IAF).

Other members of the IACS, have regularly visited elementary and intermediate schools to lecture and assist teachers in astronomy and physics presentations.

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