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1. INTRODUCTION

This report describes research performed from September 1995 through September 1996 by astronomers at the Computer Sciences Corporation (CSC).

Research in astronomy at CSC is primarily performed by members of the Science Programs, System Sciences Division. The Science Programs include two operations and two science support groups. The operations groups work with the International Ultraviolet Explorer (IUE) satellite and the Hubble Space Telescope (HST) at the Space Telescope Science Institute (STScI). The science support groups work with the ASTRO Ultraviolet Imaging Telescope (UIT), and staff the Goddard High Resolution Spectrograph (GHRS) Science Support Center. Dr. P. Perry is the Director of Science Programs, Dr. C. Wu heads the CSC operations at STScI, Dr. B. Turnrose oversees the IUE operation, and Dr. T. Ake leads the GHRS work. In addition to their support work, CSC astronomers are active in a wide range of research activities supported by NASA and NSF contracts.

Astronomers and research assistants at CSC during this reporting period were D. Adler, V. Airpetian, T. Ake, R. Arquilla, W. Baggett, V. Balzano, J. Baum, J. Bedke, A. Berman, M. Bielefeld, R. Bradley, M. Bullock, J. Caplinger, D. Chance, G. Chapman, P. Chen, K. Clark, D. Crenshaw, R. Dempsey, T. Ellis, M. England, L. Evans, G. Fireman, D. Fraquelli, M. Garhart, E. Giovane, M. Goodman, A. Groebner, F. Hamilton, H. Hart, W. Hathaway, J. Hershey, A. Holm, C. Imhoff, R. Jackson, A. Johnston, D. Jones, D. Kaufmann, D. Kenny, W. Kinzel, M. Kochte, S. Kraemer, V. Laidler, H. Lanning, C. Loomis, O. Lupie, D. MacConnell, L. Marochnik, B. McCollum, G. Menchaca, J. Nichols, R. Parise, S. Parsons, A. Patterson, P. Perry, P. Pitts, R. Pitts, K. Plett, C. Proffitt, L. Rawley, K. Reinhart, R. Robinson, J. Rose, W. Safley, J. Sandoval, F. Schiffer, A. Schultz, M. Schlegel, J. Scott, W. Sears, S. Slowinski, M. Smith, S. Snell, D. Steinberg, C. Sturch, D. Swade, D. Taylor, T. Teays, R. Thompson, B. Turnrose, G. Wahlgren, T. Walker, E. Wells, A. Welty, M. Wenz, K. Wittenburg, W. Workman, C. Wu, J. Younger, D. Zak, and L. Zimmerman.

2. RESEARCH

2.1 Solar System

Berman with J. Lissauer (SUNY), Y. Greenzweig (Tel Aviv U.), and David Kary (UC Santa Barbera) completed their study of analytic and numerical calculations of planetary rotation and accretion rates for the case of a planet on an eccentric orbit. The results have been accepted for publication in Icarus. The analytic studies show that nongravitating planets on eccentric orbits accrete the same specific rotational angular momentum as planets on circular orbits in disks of planetesimals with eccentric orbits. Further, planetesimal inclinations reduce the specific angular momentum accreted by nongravitating planets by 25 – 65 %. The dependence of accretion rates on planetary and planetesimal eccentricities can be reduced to a single parameter, and the extent of a planet's single-pass feeding zones (in the limit of small planetary mass) depends only upon the sum of the eccentricities of the planet and the planetesimals and their mutual inclination. The numerical simulations tracked the motions of the planetesimals until the point of their closest approach to the protoplanet. Berman calculated the rotation rates as a function of protoplanet radius normalized to the size of its Hill sphere. This way, one can apply the results to any chosen protoplanet density and semimajor axis. They found that a gravitating planet on an orbit with eccentricity $e_0 \ll 1$ in a disk of planetesimals with circular orbits obtains the same rotation rate as a planet on a circular orbit in a disk of planetesimals which have eccentricity $e = e_0$. They also found that when the initial eccentricity of the planetesimals is equal to that of the planet, planetesimals with periapses close to that of the planet dominate the population of accreted bodies. This is because they have a small velocity relative to the planet. This leads mainly to retrograde rotation, provided the Hill eccentricities are not too large and inclinations of the particles are small. Planetesimal inclination typically reduces the magnitude of planetary rotation; however when the eccentricity of the planet and planetesimals are nearly equal, the inclusion of inclination can turn retrograde rotation into prograde rotation by reducing the accretion cross-section advantage of planetesimals with low relative eccentricities.

Schultz and Hart with F. Bruhweiler, M. DiSanti (CUA), K. Reinhard (Doane College) and G. Schneider (Steward Obs.) have obtained HST Wide Field Planetary Camera 2 (WFPC2) images of the southwest and northeast extensions of the disk about the protoplanetary candidate β Pictoris. The disk was imaged in PC1, while the core of the Point Spread Function (PSF) was positioned in WF4. Pairs of exposures through the F555W and F675W filters were obtained. Due to the physical properties of the WFPC2 pyramid, the inner 5.0 arcsec ($\sim$80 AU) was not imaged. α Pic was observed in identical fashion, and was used to model both the PSF and light scattering for scaled subtraction from the corresponding β Pic image. Preliminary analysis of the F555W data indicates the disk is more edge-on than implied from ground-based imagery.

Schultz, Hart, Hamilton, Fraquelli, and Swade with F. Bruhweiler, M. DiSanti (CUA), K.P. Cheng (CSU Fullerton), K. Reinhard (Doane College), and C.D. Keyes (AURA/STScI) have obtained HST Faint Object Spectrograph (FOS) spectra of the disk about the protoplanetary candidate β Pic. Reductions are in progress.

Wells, B. Zellner (Georgia Southern), B. Flynn (UC Berkeley), J. Gradie (Hawaii), R. Johnson (Virginia), D. Pascu (USNO), A. Stern (Southwest Research), and P. Thomas (Cornell) used the Hubble Space Telescope to obtain the first spectra of the leading and trailing sides of Jovian inner satellites Amalthea and Thebe. The objects are very red indicating the probable effects of sulfur-bearing compounds. For both objects the leading sides are 1.4 times brighter than the

trailing sides demonstrating the important effects of the satellites orbital environment.

Wells, B. Zellner (Georgia Southern), B. Buratti (JPL), D. Currie (Maryland), K. Seidelmann (USNO), D. Pascu (USNO), and A. Storrs (AURA/STScI) used the Hubble Space Telescope to obtain spectra of 4 inner satellites of Uranus from 0.25 to 0.80 microns. Miranda and Puck have reflectivities that are bluer than the Sun suggesting the presence of some type of frost on the surface, probably water frost. Satellites Portia and Juliet were detected, but the strong scattered light from Uranus will make the determination of reflectivities very difficult.

Wells, B. Zellner (Georgia Southern), R. Binzel (MIT), M. Gaffey (RPI), P. Thomas (Cornell), and A. Storrs (AURA/STScI) used the Plantary Camera of the Hubble Space Telescope to obtain 78 images of asteroid 4 Vesta at six rotational epochs in May 1996. The images were made near a perihelic opposition when the apparent diameter was 0.61 arcseconds. This gave significantly improved resolution over HST images made in 1994. The images show spectacular morphological features near the South Pole of Vesta and strong albedo variations. Observations were made in bandpasses at 0.439, 0.673, 0.791, 0.953, and 1.042 microns. Much improved mineralogical mapping of the surface should be possible with this data.

2.2 Stellar Astronomy and Astrophysics

Wu, Schiffer, and Crenshaw are creating an ultraviolet spectral atlas of standard stars from the low dispersion spectra in the IUE Final Archive. This atlas will comprise approximately 550 stars with thorough coverage of spectral type-luminosity class combinations. The stars have been selected to minimize the effects of duplicity, variability and classification errors. Most of the observations were taken specifically to create the comprehensive atlas. By using the IUE Final Archive products, the atlas will provide higher signal-to-noise ratios, better photometric and wavelength accuracy, and more uniform processing than previous spectral atlases. The IUE Final Archive processing accounts for and corrects, where possible, all of the known limitations in the original IUE data. The calibrations have been expanded and revised to the best known values. All sensitivity variations, both with time and temperature, have been corrected during the processing.

Dempsey has continued to investigate the outer layers of late-type binaries using the ROSAT All-Sky survey as well as IUE, HST and EUVE. This has included a multi-instrument, multi-wavelength, multi-national observation campaign anchored by 41 hours of uninterrupted HST observing.

Goodman developed a series of two dimensional, steady state, resistive MHD models with flow to support the proposition that a major source of heating for the middle chromosphere is resistive dissipation of large scale electric currents driven by a convection electric field. The currents are large scale in that their scale heights range from hundreds of kilometers in the network to thousands of kilometers in the internetwork. The current is carried by protons, and flows orthogonal to the magnetic field in a weakly ionized, strongly magnetized hydrogen plasma. The flow velocity is mainly parallel to the magnetic field. The relatively small component of flow velocity orthogonal to the magnetic field generates a convection electric field which drives the current. The magnetic field is the sum of a loop shaped field and a stronger, larger scale potential field. Solutions indicate that magnetic loops with horizontal spatial extents of 1000 – 5000 km may be confined to, and heat, the middle chromospheric network. Other solutions indicate that magnetic loops with horizontal spatial extents of 10,000 – 30,000 km may span and heat the middle chromospheric internetwork over the interior of supergranules, and may be the building blocks of the chromospheric magnetic canopy.

McCollum, England, Rawley, and Schlegel, with C. Grady (Eureka Scientific), searched for accreting gas in A-shell stars using new and archival high-dispersion IUE images. The survey found evidence of high-velocity, accreting gas in 2/3 of the 12 stars sampled. This suggests that such accretion may be physically connected with the A-shell phenomenon and β Pictoris is not unique among A stars in having such activity. The same team also made the first detection of accreting, circumstellar gas in a λ Bootis type star, 131 Tauri.

McCollum and Teays are continuing their analysis of VY Pyxis, for which the light curve suggests may be an overtone BL Herculis star. They are currently refining their studies of the hydrogen lines on spectra obtained at CTIO.

Parsons continued work on UV classification and UV-optical flux fitting for over 120 binary systems containing luminous cool stars with hot main-sequence secondaries. Relevant ground-based data have been compiled for comparison. Sources for spectral types have been checked, and it was found that many such references are not included or are not correct in the SIMBAD database retrievals. The best fit of IUE fluxes and Johnson-system photometry to a grid of intrinsic stellar fluxes provides new values for each system's interstellar reddening, difference in visual luminosity between components, temperature classes of the components, and the wavelength at which flux dominance crosses over between hot and cool components.

Robinson and K. Carpenter (NASA/GSFC) completed a study of the turbulence and flows in the atmosphere of the M supergiant α Ori. This study revealed a turbulence of 30 – 35 km/s which is anisotropically distributed, with velocity directed primarily along or perpendicular to the radial direction. The stellar wind is initiated high in the chromosphere and reaches a maximum outward velocity of 7 km/s. There is no indication of deceleration of the wind at large distances from the star.

Robinson, Airapetian, S. Maran (NASA/GSFC) and Carpenter used GHRS observations to study the active RS CVn star HR 1099. The spectra contain lines formed in the chromosphere (O I, C I), transition region (O V) and corona (Fe XXI). These lines show an increase in the macroturbulent velocity from about 30 km/s in the chromosphere to 200 km/s in the transition region and then a decrease to $<$ 65 km/s in the corona. The profiles also suggest that this turbulence is anisotropically distributed, with motions directed primarily along or perpendicular to the radial direction.

Robinson with T. Brage, Carpenter and G. Harper (JILA) has analyzed GHRS spectra of the symbiotic star RR Tel. The spectra consist of numerous emission lines, many from forbidden transitions, which are superimposed on a weak continuum. Many of the lines have important astrophysical applications. The main purpose of the project is to determine basic atomic parameters for these transitions, including electron collision strengths, branching ratios and recombination rates.

Robinson, Airapetian, B. Woodgate (NASA/GSFC) and Carpenter examined the dynamics of stellar flares on the dMe star YZ CMi, observed during a multi-wavelength observing campaign in Dec 1994. The campaign included the HST, IUE and EUVE satellites as well as radio observations from the VLA and Australia Telescope and optical spectroscopy from the 3.9m Anglo-Australian Telescope and the Lick 120'' telescope. The flares appear to fall into two distinct classes; long duration events which have plasma at temperatures over 10^7 K, and much shorter events in which the temperatures are restricted to values $<$ 200,000 K.

Schultz, Hart, Hamilton, and Kochte in collaboration with J.C. Brandt (LASP/Colorado), F. Benedict (McDonald Obs.), F. Bruhweiler (CUA), J. Caldwell, C.C. Cunningham (York), O.G. Franz (Lowell Obs.), and C.D. Keyes (AURA/STScI) have initiated a direct detection search for faint companions about the nearby stars using the FOS onboard HST in coronagraphic mode. Five of six targets have been observed. New orbital elements were derived for the calibration target Wolf 424AB.

Smith and collaborators have concluded a long-term monitoring program of variability in the three M supergiants α Ori, α Sco, and α Her. This program began in 1985 as a radial velocity monitoring program. In 1989 an IUE component was added to follow the UV flux and spectral variations of α Sco and α Her. During the past few years these efforts have been joined by collaborators who have been obtaining optical photometry (E. Guinan and R. Wasatonic, Villanova), K-line fluxes (S. Baliunas, CfA), and spectropolarimetry (K. Nordsieck, Wisconsin). At least four types of variability are apparent in the optical radial velocity data of these supergiants: stochastic variations on a timescale of a month, periodic $\sim$ 1-year variations attributable to radial fundamental pulsation, a ''long period'' of several years, and Hα variations on a timescale of a few months to years. The ''long period'' in α Ori can now be said to be irregular, a result consistent with the other two stars studied as well. Moreover, the long period for α Sco is currently six years, at variance with earlier historical results. The long-term behavior of α Her's velocities is quite erratic but a 4-year period can be found in its Hα velocity and K-emission. There is a positive correlation between the Hα velocity and K-line emission in all three stars that is suggestive of solar-like granulation.

Smith and colleagues have published results on a study of the physics of atmospheric instabilities in the B2e star λ Eridani. First, working with G. Basri (UC Berkeley) and J. Aufdenberg (Arizona State), Smith and Plett compared simultaneous HeI line data from five observatories. They found that dimple-shaped features that often appear for a few hours at a time in the 6678 Å line are also present in the blue higher members of both singlet and triplet series. Their visibility indicates that exospheric structures responsible for these features contain more material than had been thought. At 10^{-12} M_{solar}, these structures rival the weakest detectable circumstellar disks that sometimes are expelled from this star. Smith suggests that because the mass released into these structures is so high, the difference between a Be star being in an inactive and active state may be merely the open versus closed loop topology of its atmospheric magnetic field. These authors have also found evidence that dimple features are present in He I lines of five mild Be stars in addition to λ Eri.

In a related study of λ Eri, Smith and Plett, with D. Cohen, J. MacFarlane (Wisconsin), I. Hubeny (USRA), G. Basri (UC Berkeley), and C. Johns (Texas) have found that the appearance of transient emission in the 6678 Å singlet line within the photospheric absorption profile is matched by transient emission of similar strength in the analog 5876 Å triplet line. In order to interpret how transient He I emission is produced in front of the stellar disk in this proportion, Smith's group has simulated model slabs having various properties and suspended over the star. They find that the illumination of high energy (EUV/X-ray) flux sources such as flares depletes the He I column density, rendering He I features undetectable. Detectable features can be produced when the model slab has a high density ($\sim 10^{12}$ cm^{-3}) and a moderately large optical depth in the optical He I lines. The key to producing this emission is for the slab to feel its own Lyman continuum radiation. This condition causes the 584 Å line to partially depopulate the ground state and overpopulate the first few excited states and excite the $n=2$ state. A second necessary ingredient is a high density. This insures efficient cascading of recombining electrons to excited states. The combination of these two processes operates as a kind of ''Lyman-pumped recombination'' because it relies on the Lyman continuum being marginally optically thick. These results are consistent with He I studies of planetary nebulae, symbiotic nebulae, and AGNs, and may have bearing on other ''detached atmospheres'' problems as well.

In another study on λ Eri, Smith, Murakami (ISAS, Japan), and Anandarao (PRL, India) have completed an optical/UV/X-ray study consisting of ground-based, IUE, Voyager 2, Rosat, and ASCA satellite data taken in March 1995, when the star was at the peak of its mass ejection phase. Although λ Eri exhibited an X-ray flare in 1991, no flares were recorded in the 1995 campaign. However, several marginally significant X-ray excursions were obtained in March which were not observed in a secondary campaign in September. Moreover, unusual activity, which appears not to be correlated with the X-ray fluctuations, were observed in H α, He I 6678, He II 1640, C IV 1548-52, and C III 977 Å (Voyager). The helium line activity suggests that a mass ejection occurred at the base of the wind whereas the carbon line behavior imples that shock interactions occurred in the wind flow. The Voyager UltraViolet Spectrometer also observed a ''ringing'' in the far-ultraviolet light curve of λ Eri which decayed over three 3-hour cycles. The amplitude of these fluctuations was 50 % at 1000 Å, decreased rapidly with wavelength, and faded to nondetection at 1300 Å. These

fluctuations appear to be due to a time-dependent flux deficit in the 950-1200 Å region, possibly attributable to time-variable absorption by the C I edge in a medium above the star alternately heated and cooled. Finally, Smith and collaborators drew attention to an increase in Hα emission that occurred at about the time the far-UV ringing started. This increased emission hints that $\sim$ 50,000 K plasma near the star's surface can influence the circumstellar disc 12 R^* away by its increased Lyman continuum flux.

Smith and Robinson carried out a large optical/UV/ X-ray campaign on the prototypical B0.5e star γ Cas in January and March of 1996. In the first of these campaigns optical spectroscopy was obtained on several sites around the globe along with UV spectroscopy from the IUE satellite. In March the HST/GHRS and RXTE/PCA instruments monitored this star for 14 orbits. Results of the HST data, while still prelimary, show the existence of at least two spots having cooler temperatures on the star's surface. Additionally, the complicated variation of the strength of the Si IV 1394-1403 Å lines seems to require the presence of enhanced Si-rich (2-3 X) patches on the surface as well; these spots and patches are not cospatial. Preliminary analysis of the discrete absorption components from the wind flow also suggests that efflux of wind from the surface occurs in occasional staccato-like bursts. Analyses of these data are still ongoing.

Teays, in collaboration with N. R. Evans (CfA), Taylor, J. B. Lester (Toronto), and R. B. Hindsley (USNO), completed a study of the temperatures of Cepheids and non-variable supergiants, based on comparisons of energy distributions with model atmospheres. The energy distributions included ultraviolet spectrophotometry from IUE and visual/IR, ground-based photometry (UBVRIJHK). The final color-temperature relation is similar to the Kraft (1961) relation.

2.3 Nebulae and Interstellar Matter

Wu, Crenshaw, A. Hamilton (Colorado), R. Fesen (Dartmouth), M. Leventhal (Maryland), and C. Sarazin (Virginia) have obtained a far-ultraviolet spectrum (1150 – 1600 Å) of a hot subdwarf star behind the remnant of SN 1006 with the FOS on HST. The high-quality spectrum is used to test previous identifications of the strong absorption features discovered with IUE. These features have FWHM = 4200 ($\pm$ 300) km/s and are *not* at the rest wavelengths of known interstellar lines, as opposed to the broader ($\sim$ 8000 km/s FWHM) Fe II lines from the remnant centered at zero km/s in near-UV FOS spectra. The broad absorption features are principally due to redshifted Si II, Si III, and Si IV lines, which are centered at a radial velocity of +5100 ($\pm$ 200) km/s.

2.4 Galaxies and Extragalactic Astronomy

Baggett, with S. Baggett (AURA/STScI) and K. Anderson (NMSU), continues to study the nature of inner-truncated spiral galaxy disks. The bulge-disk decomposition of 659 brightness profiles has been completed, and work continues to analyze statistically meaningful samples of objects from the set of fits. Conclusions from the various preliminary reports continue to be supported by the well-defined samples.

Crenshaw, in collaboration with S. Maran (NASA/ GSFC) and A. Boggess (CUA), has obtained a number of GHRS and FOS spectra of Seyfert galaxies with HST. These spectra indicate that the incidence of intrinsic absorption is much higher than previously suspected. The absorption lines are typically characterized by high ionization (C IV, N V), have radial velocities in the range 0 to -1000 km/s relative to the emission lines (indicating outflow), and are moderately broad (FWHM $\approx$ 100 – 300 km/s). The group is investigating the origin of the absorption lines, their connection to the emission-line regions, and their similarity to associated metal-line systems and broad absorption lines in QSOs. The group is also also working with R. Mushotzky (NASA/ GSFC) to investigate the possibility that the UV absorption is related to the warm absorbers seen in the X-ray spectra of many active galaxies. Crenshaw, Kraemer, and F. Bruhweiler (CUA) are planning to obtain echelle spectra of several Seyfert 1 galaxies with the Space Telescope Imaging Spectrograph (STIS) over the entire UV wave band, to determine the column densities and radial velocity structure of intrinsic absorption lines that span a wide range in ionization.

Kraemer, Crenshaw, and Wu are working to explore the differences in physical conditions, reddening, and kinematics in the extended narrow-line regions (NLRs) amongst Seyfert galaxies. This pursuit is important for understanding the nature of the NLR clouds and ionizing continuum source, testing unified theories of active galaxies, and understanding the link between nuclear activity and the host galaxy. Currently, the group is concentrating on the unusually compact NLRs in the Seyfert 2 galaxy I Zw 92 and Seyfert 1 galaxy NGC 5548, and is planning to study the physical conditions and velocity field as function of position in extended NLRs, by obtaining long-slit UV and optical spectra with Kraemer's guaranteed time on STIS.

Crenshaw continues his work with the International AGN Watch (led by B. Peterson, Ohio State). The goal of the collaboration is to probe the size and structure of the broad emission-line region and the nature of the continuum source in active galaxies through intensive, multi-wavelength monitoring campaigns. The IUE, HST/FOS, and ground-based monitoring campaigns revealed that the broad-line region is 3 – 10 times smaller than predicted by previous photoionization models, the broad-line region shows pronounced radial ionization stratification, and that accretion disk models have trouble accounting for the observation that there is no detectable time lag between the UV and optical continuum light curves. Current efforts are concentrating on UV and optical profile variations, to determine the kinematics of the broad-line region, and multi-wavelength (optical to X-ray) campaigns, to discriminate between accretion disk and reprocessing models for the central source.

Schultz in collaboration with K. Borne (Hughes STX) continues to study collision-induced starburst activity in ring galaxies. HST WFPC2 images of the Cartwheel galaxy have been obtained. The blue-band (F450W) and I-band (F814W) images have been analyzed. Fine structure is observed down to the resolution limit of the images and very young compact objects (perhaps massive young clusters) are found through-

out the star forming regions. Borne presented this work at the HST Science workshop held in Paris, December 4-8, 1995.

2.5 General Interest

Crenshaw, O. Bruegman (Omitron), R. Johnson (Hughes STX), and M. Fitzurka (CUA) have analyzed six sky-background images obtained with IUE to identify camera artifacts in high-dispersion point-source spectra observed through the large aperture. The camera artifacts are artificial emission features that are apparent in all IUE spectra with exposure times longer than about one hour. The positions of the strong artifacts in each order and plots of the sky background spectra were published to aid scientists in the identification of artifacts in their spectra.

Teays, with the assistance of Caplinger and the staff of the IUE Operations Control Center (AlliedSignal), taught a course for college and high school students in spacecraft operations and astronomy. The students were trained to conduct routine science operations with the IUE satellite. At the end of the course they were able to run a shift by themselves. In addition to the operations training the students also received lectures on spacecraft hardware and astronomy, especially concerning the nature of the targets that they observed.

Thompson, Caplinger and Teays continued work on a multi-year project to make OAO3 (Copernicus) and Voyager data more readily available to the astronomical community. Software was written to coadd contemporaneous U1 Copernicus scans in a production mode and to create database tables describing the available Copernicus data sets. The coadded scan files, as well as the raw data sets, spectral atlas files, and documentation will be available to users via the World Wide Web. The web page will also allow users to search the Copernicus databases, download requested data sets in FITS format, and display plots of flux versus wavelength for the coadded scans.

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