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1. INTRODUCTION

This report describes research performed from September 1997 through September 1998 by astronomers at the Computer Sciences Corporation (CSC).

Research in astronomy at CSC is primarily performed by members of Science Programs, part of the Civil Group in CSC's Federal Sector. Dr. C. Wu is the Director of Science Programs. Science Programs staff members provide Hubble Space Telescope (HST) operations support and Multi-mission Archive at Space Telescope (MAST) support at the Space Telescope Science Institute (STScI), as well as science support to NASA's Goddard Space Flight Center (GSFC). 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. Airapetian, T. Ake, M. Allen, S. Anderson, R. Arquilla, W. Baggett, V. Balzano, J. Baum, J. Bedke, M. Bielefeld, J. Caplinger, D. Chance, G. Chapman, D. Christian, K. Clark, T. Ellis, M. England, L. Evans, D. Fraquelli, E. Giovane, M. Goodman, A. Groebner, F. Hamilton, H. Hart, W. Hathaway, J. Hershey, A. Holm, C. Imhoff, R. Jackson, D. Jones, I. Jordan, D. Kaufmann, D. Kenny, W. Kinzel, M. Kochte, V. Laidler, H. Lanning, C. Loomis, O. Lupie, D. MacConnell, L. Marochnik, G. Menchaca, J. Mo, R. Parise, S. Parsons, A. Patterson, P. Pitts, R. Pitts, C. Proffitt, M. Reinhart, R. Robinson, J. Rose, J. Sandoval, F. Schiffer, A. Schultz, K. Scollick, J. Scott, M. Smith, D. Steinberg, S. Streit, C. Sturch, D. Swade, D. Taylor, T. Teays, R. Thompson, B. Turnrose, T. Walker, E. Wells, A. Welty, C. Wu, J. Younger, and D. Zak.

2. RESEARCH

2.1 Sun and Solar System

Goodman developed an electrically driven, steady state, dissipative MHD model with flow to study the structure and heating mechanisms of the solar transition region (TR). The model includes the complete Ohm's law for a collision dominated plasma. The model makes several important predictions. First, the thermo-electric current density, which is almost always neglected in MHD modeling of the solar atmosphere, can nearly cancel the conduction current density. Second, the electron pressure gradient, which is also usually neglected, can make the dominant contribution to the generalized electric field that drives the conduction current density. Third, the contribution to TR heating of the dissipation of electric currents on spatial scales greater than or on the order of 10 km is insignificant. Fourth, the electron heat flux from the corona can provide all of the energy required to heat the TR. Fifth, the thermoelectric component of the electron heat flux, which is driven by the generalized electric field, flows from lower to higher temperatures, and can cancel a large fraction of the familiar temperature gradient

driven electron heat flux which flows from higher to lower temperatures. The total heat flux flows from higher to lower temperatures, as required by the second law of thermodynamics.

Goodman developed a cylindrically symmetric, electrically driven, steady state MHD model with flow and an energy equation to study the effects of classical transport processes on MHD equilibria. The transport coefficients, which are functions of number density, temperature, and magnetic field strength, are computed self consistently as a function of radius. By analogy with laboratory fusion plasmas in confinement devices, the plasma in the inner region is confined plasma, and the plasma in the outer region is unconfined plasma. The solutions studied demonstrate that the thermoelectric current density, driven by the temperature gradient, can make the main contribution to the current density by one or more orders of magnitude, and that the thermoelectric component of the electron heat flux, driven by an effective electric field, can make a large contribution to the total heat flux. These solutions also demonstrate that the electron pressure gradient and Hall terms in Ohm's law can make dominant contributions to the radial electric field. These results indicate that the common practice of neglecting thermoelectric effects, and the Hall and electron pressure gradient terms in Ohm's law is not always justified, and can lead to large errors. The model may be applied to any fully ionized, two component, electron-ion, collision dominated plasma for which the ion cyclotron frequency is much larger than the ion-ion Coulomb collision frequency, such as the plasma in magnetic flux tubes in the solar interior, transition region, and possibly the lower corona.

2.2 Stellar Astronomy and Astrophysics

Hershey and Chance studied the low-mass binaries Ross 614A,B and L722-22A,B using the HST Faint Object Spectrograph (FOS). These binaries are much too close for acquiring separate spectra from the ground. The four spectra and masses form a sharply defined spectral-type-mass relation which implies that M-dwarf spectral subtypes 6 and later are at or below the minimum mass for reaching the main sequence.

Hershey and L. Taff (Johns Hopkins) used Fine Guidance Sensor (FGS) astrometry taken over four years to determine the individual masses in L722-22, a pair of M dwarfs suggested to be near the mass limit for hydrogen-burning stars. The orbital motion of the binary was used to estimate the masses with an error level of a few percent, far higher accuracy than possible from ground-based observations on these faint objects. The masses were found to be well above the limit for substellar objects.

Hershey, with G. Schneider (Arizona) and M. Wenz (Allied Signal), examined HST guide star acquisition data to search for double stars. From the study of 14,000 guide-star

acquisitions on nearly 5000 stars in a time-span of 22 months, over 5% of the guide stars have been found double with a high degree of certainty and many more are likely doubles. The guidance interferometers, as used for guide-star acquisitions, detect double stars in the range of 40 to 800 milliarcseconds. A catalog of 269 doubles was compiled.

Lanning, with M. Meakes (STScI), continues his analysis of the Sandage two-color (U,B) survey of the galactic plane. Plates taken with the 48-inch Oschin Schmidt telescope at Palomar Observatory are being scanned to identify objects bright in the UV. These often include white dwarf candidates, CVs, B shell stars, etc. The fourth in the continuing series of catalogs of UV-bright sources was published, with two additional lists of objects in progress.

MacConnell continues to collaborate with R. F. Wing (Ohio State), E. Costa (U. Chile), and Hershey on analysis of near-IR, 8-color photometry and spectroscopy obtained at CTIO and CCD spectra from CTIO, Las Campanas, and La Silla of about 1500 K and M galactic supergiant candidate stars found on southern, near-infrared, objective-prism plates. About 220 cool supergiants have been identified thus far including some which may be 5-6 kpc from the Sun. The second paper in a series, presenting new supergiants in the sector $208 < l < 248$ deg, is being prepared for publication.

MacConnell and K.V.K. Iyengar (Indian Inst. Ap.) examined M spectral types determined by DJM for about 10,000 IRAS Point Sources along the southern galactic plane. They studied the correlations of IRAS colors with the M spectral types finding that the color indices increase with later type and that they are always larger at a given type for the faint M stars than for a control set of M stars.

MacConnell and R. Williamson (STScI) continued to work on the determination of proper motions of astrophysically interesting stars in the magnitude range $12 < V < 18$. They are preparing a paper on motions of nearly 300 northern halo stars from the Beers-Preston-Schechter survey.

MacConnell is the PI on an HST project to determine the proper motion and parallax of the brown dwarf, PPL 15, in the Pleiades. This was the first low-mass star in which Li I absorption was found, and it has recently been shown to be binary. The present astrometric observations, made over two years with the Planetary Camera of the Wide Field Planetary Camera (WFPC2), were recently completed and are being analyzed.

Parsons completed a study on IUE spectral classifications and UV-optical flux fitting for 131 binary systems comprised of evolved late-type primaries and upper main-sequence secondaries. It was found that 10 percent of the systems show anomalous interstellar extinction, but that their fluxes may all be fit by adjusting the strength of the 2200 Å feature via the Seaton algorithm. Effective temperatures of the components estimated from their spectral classes along with the V mag differences from flux fitting allow fitting each system to isochrones. This work is now in progress to provide mass, age, luminosity and distance estimates.

Parsons and O. Franz (Lowell Obs.) obtained HST observations of the G4 II star HD 173764 with FGS3 in TRANS/POS modes in order to resolve the secondary stellar component and determine both components' masses. The secondary

has a spectral class of B9, from IUE, and a difference in visual luminosity of about 3 mag. Isochrone fitting yields estimates of 5 and 2.5 solar masses for the G4 and B9 components, and 0.023 arcsec for the projected semi-major axis of the system from the spectroscopic period of 832.5 days. This combination of separation and magnitude difference pushes the current limits of HST astrometry, but the system should have been resolvable near apastron. However, no consistent solution of the TRANS data has been achieved. This implies that the binary system is farther away than estimated, and the Hipparcos parallax confirms the greater distance. Analysis of the POS data for reflex motion is in progress.

Schultz, Hart, Hamilton, Hershey, and Kochte, in collaboration with J.C. Brandt (LASP, Colorado), F. Benedict (McDonald Obs.), F. Bruhweiler (Catholic), J. Caldwell, C.C. Cunningham (York) O.G. Franz (Lowell Obs.), and C.D. Keyes (STScI) have completed a direct detection search using the FOS aboard HST for faint companions about the nearest star to the Sun, Proxima Centauri. A feature which may correspond to a substellar companion within 0.5 arcsec of Proxima Cen was identified. An infrared observing program using the Near Infrared Camera and Multi Object Spectrometer (NICMOS) Camera 1 aboard HST is in progress to image Proxima Centauri for confirmation of the tentative FOS result.

Schultz and Hart, with F. Bruhweiler and M. DiSanti (Catholic), K. Reinhard (Doane Coll.), and G. Schneider (Steward) have obtained HST 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 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 (~ 80 AU) was not imaged. α Pic was observed in identical fashion, and was used to model both the PSF and light scatter for scaled subtraction from the corresponding β Pic image.

Smith participated in the international conference "Ultraviolet Astrophysics: Beyond the IUE Final Archive" held in Seville, Spain, in November 1997 by giving an invited review of the contributions of the International Ultraviolet Explorer satellite to the study of variability in B/Be stars.

Smith, Robinson (Catholic), and Corbet (USRA) completed the analysis of a large optical/UV/X-ray campaign on the prototypical B0.5e star γ Cas. In the first of these campaigns optical spectroscopy was obtained at several sites around the globe along with UV spectroscopy from the IUE satellite. In March the Hubble Goddard High Resolution Spectrograph (GHRS) monitored the SiIV doublet near 1400 Å and surrounding continuum nearly continuously for over 21 hours while the RXTE satellite also monitored it for 27 hrs. A UV continuum flux curve from the GHRS spectra shows two light dips separated by about 10 hours and amplitudes of about 1%. The RXTE data show two timescales of modulations, of which one is the rotational timescale of near 1.125 days. The UV flux curve shows undulations with emission peaks which coincide with the occurrence of the dips in the UV flux curve. The X-ray flux show fluctuations called "shots" on rapid timescales from several minutes to perhaps

a second. Close examination shows that these shots are loosely clustered, and their incidence and amplitudes are correlated with the UV flux dips. The rapid evolution of shots implies that the plasma density of the X-ray emitting sites is very high, of order 10^{14} cm^{-3} . Contemporaneous ASCA data by Corbet, Murakami, and colleagues together with the RXTE data suggests that the X-ray undulations repeat with a period of 1.125 days.

In a related study of γ Cas, Smith, Robinson, and Hatzes (Texas) showed that the UV light curve dips could be phased from the HST epoch to 33 IUE observations obtained two months earlier if the dips arise from modulation with a slightly modified rotational period of 1.123 days. They also showed that the light curve dips could not come from structures corotating on the surface of γ Cas but rather must be formed within transparent clouds corotating over the star. Color curves constructed from the IUE continua of the star showed a steep wavelength dependence of the dip amplitudes near 1200 \AA which they were able to model with cool clouds having a temperature of only $\sim 7000 \text{ K}$.

Smith and Robinson, using GHRS data of γ Cas, found ubiquitous absorption line variations on timescales of minutes to several hours. From Hubeny model atmosphere codes, they found that these features are optically thick and that they arise in one of three thermal regimes: cool ($< 10,000 \text{ K}$), warm ($10,000\text{--}18,000 \text{ K}$), and hot ($> 30,000 \text{ K}$) plasma. The cool/hot plasma lines vary in phase with the light curve determined from the GHRS/IUE continuum study whereas the warm ions lead this curve by 3 hours. All these lines exhibit either of two kinematical behaviors: (1) blue-to-red motion in wavelength consistent with plasma trapped in corotating clouds or (2) uniform motion of hot plasma over several hours at either low or high velocity (up to $+1500 \text{ km/s}$). The existence of cool/hot plasmoids above γ Cas implies the importance of surface magnetic processes in this region which are probably responsible for ejection of material both from the star and toward the star from its circumstellar disc.

Steinberg continues to create a comprehensive catalogue of the NICMOS pure parallel observations, with particular attention paid to brown dwarf candidates. One target found in this project is a very convincing low mass candidate, most likely a very late M dwarf or brown dwarf. Copies of the NICMOS spectrum were circulated, and confirmation is being sought through ground-based and Space Telescope Imaging Spectrograph (STIS) observations. Many more brown dwarf and low mass star candidates are likely to be found during the continuation of this project.

Wu, Mo, D. Crenshaw (Catholic) and collaborators continued to work on a comprehensive ultraviolet spectral atlas of standard stars based on the low dispersion spectra from the IUE Final Archive. This atlas will have close to 550 stars from O3 to M7 which are widely distributed across the HR diagram.

2.3 Galaxies and Extragalactic Astronomy

Baggett, with S. Baggett (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 published and the analysis of well-defined samples of objects drawn from the fits is in progress. The analysis continues to support the preliminary findings, including that the inner-truncation appears strongly correlated with the presence of a bar.

Wu, with J. Ponder, D. Burstein (ASU) and other collaborators, studied HST FOS observations of four globular clusters in M31 and the cores of six elliptical galaxies. Continuum and line indices were measured from the FOS data for these objects and compared with the same indices based on IUE observations of dwarf elliptical M32, Galactic globular clusters, and Galactic stars.

2.4 Instrumentation

Schultz, in collaboration with the STScI NICMOS group, presented a review of the on-orbit characteristics of the HgCdTe detectors aboard NICMOS at the SPIE's International Symposium on Astronomical Telescopes and Instrumentation, 20-28 March 1998, Kona, Hawaii. A rigorous treatment of the dark current as a function of exposure time for the HgCdTe array detectors indicates darks consist of three independent components, a constant component which is the true dark current, an "amplifier glow" component, and a "shading" component well known in HgCdTe detectors. Once fully characterized, "synthetic" dark current images can be generated to match the detectors' performance for calibration purposes.

Working with the MAST team, Smith has evaluated the quality of high-dispersion IUE data processed through NEWSIPS software in two studies. The first study is a cross-correlation of various dependences of the apparent radial velocities of bright stars with camera, time, wavelength, and aperture as well as differences with other UV space-borne missions. Spectra obtained through the IUE's small and large science apertures show small differences in apparent velocity for all three cameras as well as residual (-5 km/s) differences of short-wavelength data compared to data from the two long-wavelength cameras. In general, NEWSIPS data are to be preferred over older IUESIPS-processed data for radial velocity accuracy because of the greater stability of the wavelength calibrations of the former system over the 18 year history of the IUE mission. A surprising and interesting discovery in this study was the finding that velocities from NEWSIPS short-wavelength data differ from both earlier IUESIPS-processed data and data from the Copernicus mission for the standard star τ Scorpii. Smith showed that the apparent radial velocity difference is robust and is likely to arise from a 1990 revision of the laboratory wavelengths of the PtNe calibration source used by the IUE (NEWSIPS) and the HST spectrograph GHRS. This fact means that UV wavelengths before and after this date may show variations of a few km/s in the far-UV when taken from a variety of satellite missions.

In a second study, Smith examined the reasons for a reported time-dependent error in the background fluxes in the region of Lyman α of τ Scorpii, as reported by D. Massa (priv. comm.). He showed that the zero-flux ("null surface") of images obtained with the short-wavelength camera has spatial distortions which change markedly and nonuniformly

with time. These changes accelerated with the onset in 1990–91 and might be due to solar-maximum activity at that time. The evolution of the shape of the null surface causes a progressive change in the background fluxes extracted by NEWSIPS for images observed at different times (generally, late-epoch images give more correct results). A secondary, but still significant, effect of these changes is on the “gross” fluxes with time because the Intensity Transfer Function calibrations used to convert instrumental to linear fluxes were obtained only once in the mission.

3. ACKNOWLEDGMENTS

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