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This report covers the period from 9/96-9/97.

1. PERSONNEL

During the report period, 9/96 - 9/97, the staff included Assistant Professor Carol W. Ambruster, Instructor Larry DeWarf, Professor Edward F. Guinan, Associate Professor Frank P. Maloney, Professor George P. McCook (Chairman), and Professor Edward M. Sion. Dr. Edward L. Fitzpatrick joined the department as Assistant Professor in August 1997. Post-Doctoral Fellows Dr. Min Huang and Dr. Fu Hua Cheng worked with Dr. Sion. Dr. Ulysses J. Sofia was Research Associate; Dr. Rex Saffer was Research Assistant Professor.

Tara Anselowitz, Dirk Fabian, Kenneth Guerin, J. Erich Jay, Todd Mahler, Jamison Maley, Karen Matthews, Steven Margheim, Nicholas Morgan, Michele Sauer, Richard Slevinsky, David Stys, Sarah West and Steve Wright served as research assistants. Dr. Elizabeth R. Jewell served as Department Assistant.

2. INSTRUMENTATION

2.1 Automated Photoelectric Telescopes

The Fairborn Observatory, home of the Four College APT, has been moved to an new site located in the Palagonia Mountains of AZ (Lat: +31 23 12; Long: -110 41 41). The 0.8-m automated photoelectric telescope is operated by the Four College Consortium(FCC) consisting of The College of Charleston, The Citadel, University of Nevada-Las Vegas, and Villanova University, the FCC-APT is supported by NSF grant AST95-28506. The 0.8M APT is equipped with *UBVRI* wide-band filters as well as *uvby*, Hβ and Hα narrow- and wide-band interference filters.

2.2 Internet Access

The Astronomy & Astrophysics WorldWideWeb (WWW) address is: www.phy.vill.edu/astro. Our email address is: astronom@ast.vill.edu. Experimental laboratory work for non-science majors can be found at: http://astro4.ast.vill.edu. This project is supported by the Pew Charitable Trusts.

3. CURRENT RESEARCH

3.1 Interstellar Clouds

E.L. Fitzpatrick and the late Lyman Spitzer, Jr. (Princeton University) continued their multi-year study of the physical properties of individual interstellar clouds with a detailed examination of the line of sight towards the star HD 215733 in the Galactic halo. Analysis of data from the *Goddard High Resolution Spectrograph* ($\lambda/\delta\lambda \simeq 85000$) and the Kitt Peak Coudé Feed spectrograph ($\lambda/\delta\lambda \simeq 200000$) reveals an exceedingly complex line of sight, with more than 20 individual absorption components identified in the low-ionization species. Most of the gas seen towards HD 215733 is cold, with temperatures of order 100 K. Five different electron density diagnostics are available, based on collisional excitation equilibrium of C^+ fine structure levels, and ionization equilibrium of C^0/C^+, Mg^0/Mg^+, S^0/S^+, and Ca^+/Ca^{++}. The various ionization equilibrium diagnostics are found to have systematic discrepancies of up to 1 dex, in the sense that the values involving the neutral species tend to be larger than those derived from the Ca^+/Ca^{++} ratio. The values derived from Ca are consistent with the observed C^+ excitation in the cold clouds if the free electrons come primarily from ionization of the metals. The gas pressures P/k implied by this condition are reasonable, in the range 1000–5000 cm^{-3}K. The reason for the discrepancy among the ionization equilibrium diagnostics is not known. Future studies will seek to establish the systematic behavior of these discrepancies. A paper describing these results was published in the ApJ, 475, 623.

3.2 Gas Phase Abundances

Fitzpatrick analyzed the pattern of interstellar gas-phase abundances of the elements Si, S, Mn, Cr, Fe, and Zn for about 30 individual interstellar clouds along the sightlines toward the Galactic disk star HD 68273 and the halo stars HD 93521, HD 149881, and HD 215733. The gas-phase abundance of S relative to H in these clouds appears indistinguishable from the solar value. For the other elements, well-defined upper limits are found in the gas-phase abundances at significantly subsolar values. For Fe, Mn, and Cr (and probably Ti) there are no convincing cases where the relative gas-phase abundances exceed ~ -0.5 dex, i.e., these elements have not been seen in interstellar gas with an abundance greater than about 1/3 solar. For Si the limit is ~ -0.15 dex, and for Zn a constant abundance of -0.13 dex is found from seven clouds along one halo sightline. These subsolar maximum abundances have two possible interpretations: (1) they indicate the presence of an essentially indestructible component of interstellar dust, which contains about 2/3 of the Ti, Mn, Cr, and Fe and about 1/3 of the Si (assuming that the intrinsic interstellar abundances are solar) or (2) they indicate that the true total abundances of these elements are substantially less than in the Sun. The complete results from this analysis were reported in ApJL, 473, L55.

3.3 Mg II in the ISM

Fitzpatrick derived an empirical estimate of the oscillator strengths of the far-UV Mg II $\lambda\lambda$1239,1240 lines. The strong near-UV Mg II $\lambda\lambda$2796,2803 lines are generally highly saturated along most interstellar sightlines outside the local ISM and usually yield extremely uncertain estimates of Mg^+ column densities in interstellar gas. Since Mg^+ is the dominant form of Mg in the neutral ISM and since Mg is expected to be a significant constituent of interstellar dust grains, the far-UV lines are critical for assessing the role of this important element in the ISM. This study consisted of complete component analyses of the absorption along the lines of sight toward HD 93521 in the Galactic halo and ξ Per and ζ Oph in the Galactic disk, including all four UV Mg^+ lines and numerous other transitions. The three analyses yield consistent determinations of the $\lambda\lambda$1239,1240 f-values, with weighted means of $6.4\pm0.4\times10^{-4}$ and $3.2\pm0.2\times10^{-4}$, respectively. These results are a factor of $\sim$2.4 larger than a commonly used theoretical estimate, and a factor of $\sim$2 smaller than a recently suggested empirical revision. The effects of this result on gas- and dust-phase abundance measurements of Mg are discussed. These results were reported in the ApJL, 482, L199.

3.4 Interstellar Matter (Abundances)

Sofia continues as a member of the Interstellar Medium Absorption Profile Spectrograph (IMAPS) Science Team. Sofia, Jenkins (Princeton U. Obs.) and Sonneborn (NASA/GSFC) are calibrating data from IMAPS successful flight on the Space Shuttle ORFEUS-II mission last Fall. Sofia is proceeding with his studies of the neutral interstellar medium (ISM). Sofia and Jenkins are studying the abundance and depletion of argon in the neutral ISM using data from the first Space Shuttle flight of IMAPS. The abundance of Neutral Ar can be used to gauge the partial ionization interstellar clouds.

Sofia, Meyer (Northwestern U.) and Matthews (Villanova) are continuing their studies of heavy elements in the ISM, particularly tin and cadmium. The different processes by which the heavy elements are formed combined with the measured ISM abundances gives information about the stellar processes producing the elements and the efficiency of injection of the species into the ISM.

Sofia, Massa (Hughes STX) and Sembach (JHU) are studying chemical gradients within the Galaxy with HST data. These studies will provide information about nucleosynthetic enrichment of the Galaxy, and the efficiencies of vertical and radial mixing of the ISM.

3.5 Interstellar Matter (Dust)

Sofia, Joseph (Rutgers University) and Fabian (U. Wisc.) are using far UV absorption data from IMAPS in order to study the incorporation of P, Si, and Fe into dust grains and the implications for grain destruction in=20 interstellar clouds.

Sofia is using data from the Hubble Space Telescope to empirically determine the oscillator strengths for the Mg II 1240 A doublet. This important value is needed in order to find the mineralogy of interstellar silicate grains.

3.6 Planetary Atmospheres

Sofia and Wolff (SpSciInst) are using data from the Faint Object Spectrograph and the Wide Field Planetary Cameras on the Hubble Space Telescope in order to determine reliable ozone abundances in Mars' atmosphere as a function of season and latitude.

3.7 White Dwarfs in Cataclysmic Variables

Sion with Cheng, Huang (Villanova), Paula Szkody (U.WA), Warren Sparks (LANL), Boris Gansicke (Gottingen), and Janet Mattei (AAVSO) obtained Hubble GHRS medium resolution (G160M grating) phase-resolved spectroscopic observations of the prototype dwarf nova U Geminorum during dwarf nova quiescence, 13 days and 61 days following the end of a narrow outburst. The spectral wavelength ranges were centered upon three different line regions: N V (1238Å, 1242Å), Si III (1300Å) and He II (1640Å). All of the quiescent spectra at both epochs are dominated by absorption lines and show no emission features. The Si III and He II absorption line velocities vs. orbital phase trace the orbital motion of the white dwarf but the N V absorption velocities appear to deviate from the white dwarf motion. They confirmed their previously reported low white dwarf rotational velocity, V sin $i=$ 100 km s^{-1}. They obtained a white dwarf orbital velocity semi-amplitude $K_1=107$ km s^{-1}. Using the gamma velocity of Wade (1981) they obtain an Einstein redshift of 80.4 km s^{-1} and hence a carbon core white dwarf mass of 1.1 $M_\odot$. They reported the first subsolar chemical abundances of C and Si for U Gem with C/H $=$ 0.05 times solar, almost certainly a result of C depletion due to thermonuclear processing. This C-depletion is discussed within the framework of a weak TNR, contamination of the secondary during the common envelope phase, and mixing of C-depleted white dwarf gas with C-depleted matter deposited during a dwarf nova event. Remarkably, the T_{eff} of the white dwarf 13 days after outburst is only 32,000K, anomalously cooler than previous early post-outburst measurements. Extensive cooling during an extraordinarily long (210 days) quiescence followed by accretion onto an out-of-equilibrium cooled degenerate could explain the lower T_{eff}.

Cheng, Sion, Szkody and Huang presented *Hubble Space Telescope* Goddard High-Resolution Spectrograph G140L spectra of the white dwarf in WZ Sge, exposed during quiescence. Their spectra, covering the wavelength interval 1237.1 Å to 1523.1 Å and obtained at orbital phase 0.143 – 0.686, reveal strong, broadened photospheric C I absorption features centered at 1356 Å, 1433 Å and 1464 Å, and N I centered at 1494 Å. The spectra also showed the Stark-broadened Lyα red absorption wing, H_2 quasi-molecular Lyα ''satellite'' absorption lines, and Si IV $\lambda\lambda$1393, 1402 absorption lines. Their best fitting synthetic spectra yielded a rapidly rotating white dwarf with velocity V_{rot} sin i $=1{,}200^{+300}_{-400}$ km s^{-1}, white dwarf effective temperature T_{wd} $=$ 14,800 K, the gravity log g $=$ 8.0, the chemical abundances with 3σ error-bars, in number relative to solar, C, $5.0^{+2.0}_{-2.0}$; N, $3.0^{+1.0}_{-1.0}$; Si, $<$0.1; and all other metals, 0.01. They also re-examined previous *HST* Faint Object Spectrograph G130H spectrum reported by Sion and coworkers, and obtained rotational velocity V_{rot} sin i $=$ $1{,}100^{+400}_{-400}$ km s^{-1}, T_{wd} $=$ 14,800 K, the gravity log g $=$ 8.1, the chemical abundances, C, $2.0^{+5.0}_{-1.5}$; N, $1.0^{+3.0}_{-1.0}$; Si, $<$0.1; and all other metals, 0.01. The discovery of a rapidly rotating white dwarf supports Patterson's model of the origin of $\sim$ 28 s oscillations in WZ Sge. The oscillation is thus identified with rotational modulation of a bright accretion region on the white dwarf. They did not detect a measurable line shift in their observed spectra, due presumably to the extreme low mass of the companion.

Cheng, Sion, Horne (U. St.Andrews, UK), Hubeney (NASA), M. Huang, and Vrtilek (CfA) re-examined two archival *HST* FOS G130H spectra of the prototype dwarf nova U Geminorum obtained during its quiescence 13 days and 70 days after a *wide* outburst. Using synthetic spectral fitting with two flux-emitting components, a slowly rotating white dwarf photosphere and a rapidly spinning accretion belt ($V_{rot} \sin i = 3200$ km s^{-1}) significantly improves the spectral fit but does not provide a unique solution. They found clear evidence for the cooling of the white dwarf, confirming earlier results, and evidence for the cooling of the accretion belt or gas in Keplerian motion as well. If an accretion belt is really present, then for the white dwarf and belt respectively, 13 days post-outburst, we find $T_{wd} = 37{,}000\text{K} \pm 400\text{K}$ and $T_{belt} = 45{,}000K \pm 2{,}500\text{K}$ while at 70 days post outburst, They found $T_{wd} = 33{,}500K \pm 700\text{K}$ and $T_{belt} = 37{,}500K \pm 4{,}000\text{K}$. These results were compared with their *HST* GHRS G160M observations obtained 13 days and 61 days after a *narrow* outburst of U Gem. These results, viewed comparatively with their analysis of *HST* GHRS G160M observations obtained 13 days and 61 days after a *narrow* outburst of U Gem where the accretion belt is far less prominent, indicates empirically for the first time the difference in heating, angular momentum, chemical abundance and mass accretion into the white dwarf, between a *wide* and a *narrow* plausibly expected when matter with angular momentum shears onto the surface of a white dwarf in a dwarf nova during outburst (Kippenhahn & Thomas 1978; Sparks *et al.* 1993). Since matter accretes tangentially at the equator and does so every several weeks, an equilibrium state may be established such that the equatorial region spins rapidly while the higher latitudes and polar regions do not. The controlling parameter for this equilibrium state is the Richardson number (Kippenhahn & Thomas 1978), which implies a differential rotation going both inward into the white dwarf and poleward along the white dwarf surface. The spectroscopic detection of such accretion belts would represent an important milestone in our understanding of accretion physics.

3.8 VW Hydri

Sion, Cheng, Sparks (LANL), Szkody (U.WA), and Huang presented Hubble Space Telescope GHRS G160M spectra of the white dwarf in VW Hydri, exposed during quiescence, 1 month after the end of a normal dwarf nova outburst. Their spectra, covering the wavelength interval 1236Å to 1272Å, were obtained at orbital phase 0.06 – 1.60, revealed strong photospheric S II λλ1260, 1264 absorption features and a previously unidentified broad feature centered around 1250 Å. This feature is due to a blend of phosphorus lines. From line-shift measurements they determined a gravitational redshift of 58 ± 33 km s^{-1} yielding a white dwarf mass $M_{wd} = 0.86^{+0.18}_{-0.32}$ $M_{\odot}$ (only the second gravitational redshift determined for a cataclysmic variable white dwarf), white dwarf radius $R_{wd} = 6.5^{+3.1}_{-1.5} \times 10^8$ cm, and gravity log $g = 8.43^{+0.31}_{-0.54}$. Their best fitting synthetic spectra yielded white dwarf effective temperature $T_{wd} = 22{,}000$ K, a rotational velocity $V_{rot} = 400$ km s^{-1}. The chemical abundances relative to solar are: C 0.5, N 5.0, O 2.0, Fe 0.5, Si 0.1, P 900, and all other metals 0.3. The abundance of phosphorus being 900 solar, coupled with the elevated aluminum abundance reported by Sion *et al.* (1995b), suggested nucleosynthetic production of these odd-numbered nuclei through a hot CNO bi-cycle thermonuclear runaway (TNR) on the white dwarf. If their interpretation is correct, then they have found the first direct spectroscopic link between a dwarf nova and a classical nova by using the white dwarf surface chemical abundance. It is clear that the white dwarf has undergone a runaway sometime in the past, the first such evidence of a TNR in a dwarf nova. A TNR on a slowly accreting 0.86 $M_{\odot}$ white dwarf should produce a classical nova explosion. This is also the first direct evidence of proton capture-processed material in the atmosphere of a white dwarf. Nova explosions on more numerous, lower mass C-O white dwarfs may therefore account for some fraction of the short-lived radionuclide ^{26}Al in the Galaxy. This nuclide is observed from its galactic gamma-ray line emission and is postulated to have an important role in the heating of small bodies in the solar system.

3.9 White Dwarfs: WZ Sge & OY Car

Cheng worked with Catalan (UK) *et al.* on the curtain absorption in cataclysmic variables WZ Sge, Z Cha and V2051 Oph using HST/FOS G160L observations. They found that the white dwarf spectra in all three objects are veiled by a large number of Fe II and other element features to varying strengths which they attribute to absorbing disk material along the line of sight to the white dwarf, possibly located in the upper atmosphere (chromosphere) of the disk.

Cheng and Sion also worked with Welsh (U. Tex.) *et al.* on the UV oscillations in WZ Sge. Their HST/GHRS observations discovered 28.1s ultraviolet oscillations in the cataclysmic variable WZ Sge; the strength of the oscillations is strongly wavelength dependent: the oscillation amplitude decreases rapidly from wavelength ~1500 Å to ~1250 Å. This decrease is explained as an indication that the spectrum of the oscillations contains a broad Lymanα absorption line. This implies that the white dwarf photosphere is the origin of the oscillation signal. Whether it is due to white dwarf pulsations or magnetically channeled accretion onto a rapidly spinning white dwarf remains unknown.

Cheng and Sion worked with Horne (UK) *et al.* on the cooling of the white dwarf in OY Car. Their HST/FOS G160L observations discovered white dwarf temperatures changing from 19,700 K just 27 days after the start of the superoutburst to 18,000 K around 3 months after the superoutburst; the exponential decay time of white dwarf temperature was 66 days. The curtain temperatures were between 10,000 K and 11,000 K, and appeared to rise ~3 months after the superoutburst. The surface density of the outer disk, the electron density and the velocity dispersion of the intervening disk material are positively correlated with the curtain temperature while the path length and column density were anti-correlated. The path length of the intervening disk material was less than one white dwarf radius.

Research on white dwarfs and CVs during the report period was supported by several grants from NASA and NSF.

3.10 LMC X-4

Cheng worked with Vrtilek (CfA) *et al.* on simultaneous HST/ASCA observations of LMC X-4. Their ASCA observations covered roughly 1.12 binary orbits (1.58 d) and the HST observations were centered on this for roughly 0.4 orbital phase coverage (0.56d). The GHRS data are the highest resolution (both temporal and spectral) ultraviolet spectra ever taken of LMC X-4. With generally-accepted parameters for the sources, fits to the UV continuum (using a model that incorporates X-ray heating of the companion star and the accretion disk) yield a mass accretion rate $M=4.0\times10^{-8}M_{\odot}$; the X-ray luminosity implied by this value is consistent with the X-ray flux measured during simultaneous observatioans (3.2×10^{-10} ergs cm^{-2} s^{-1}). The model accurately predicts observed B magnitude and ultraviolet variations over both orbital and long-term periods. The ultraviolet P-Cygni lines show dramitc changes with orbital phase, with strong broad absorption near X-ray eclipse and narrow absorption when the X-ray source is in the line-of-sight. They interpret this as a result of X-ray photoionization of the stellar wind; when the neutron star is in front of the normal star, the wind absorption disappears and mainly the photospheric absorption lines are visible. The X-ray pulse period measured during our observations, 13.5090 ± 0.0002s, is consistent with steady spin-down over the past 10 years. No pulsations were detected in the ultraviolet observations with upper limits to the pulsed fraction around N V and C IV of 1.8% and 2.7% in the continuum and 12.4% and 7% in the absorption troughs.

3.11 Pulsating Hot Subdwarf Stars

In collaboration with M. Billeres, G. Fontaine, P. Brassard, S. Charpinet (U.Montreal), J. Liebert (Stew. Obs.), and G. Vauclair (Obs. Midi-Pyrenees), Saffer participated in the discovery of multiperiodic luminosity variations in the hot B subdwarf PG 1047+003. At least five periodicities are seen in the light curve, from 104.2 s to 161.9 s, but others are also present at lower amplitudes in that interval. The largest oscillation has an amplitude $\sim$9.2 millimag in white light and a period of 142.2 s. With atmospheric parameters $t_{eff}\sim$ 34,370 K and log$g$ 5.7 for PG 1047+003, these variations are identified with low-order radial and nonradial (p and f) pulsation modes. The similarity of periods and derived stellar parameters indicate that PG 1047+003 is a genuine member of the EC 14026 class, the latest and newest family of pulsators in the field of asteroseismology. However, the star shows no evidence of a binary companion, implying that the mechanism for driving pulsations is internal to the star. The survey which discovered the stellar pulsations continues to search for additional sdB pulsators.

3.12 High-Resolution Spectroscopy of Early-Type Halo Stars

Together with N.C. Hambly, W.R.J. Rolleston, F.P. Keenan, and P.L. Dufton (Queen's U. Belfast), Saffer analyzed high-resolution spectroscopic observations of early-type stars drawn from a complete sample of targets identified by low-resolution spectroscopy in the Palomar-Green Survey by Green, Schmidt, & Liebert. Qualitatively, the metal-line spectra are sharp and are therefore indicative of extremely low projected rotational velocities. Hence the objects are characterized as members of an old, evolved population (for example, blue horizontal branch or post–asymptotic giant branch). By careful choice of Population I Galactic disk B stars, differential abundances were computed between the targets and their main-sequence analogs. The CNO abundances from model-atmosphere analyses suggest the presence of nucleosynthesis dredge-up products in the stellar photospheres. With one exception, the stars all have [Fe/H] abundances consistent with their progenitor objects being metal deficient. Some conclusions were drawn as to the previous evolution (red giant branch, horizontal branch, or asymptotic giant branch) of the stars.

3.13 Post-AGB A and F Supergiants as Standard Candles

In collaboration with H. Bond, L. Fullton, and A. Saha (STScI), Saffer computed synthetic colors in support of the calibration of a photometric system to detect A and F post-AGB stars. Low-mass stars leaving the asymptotic giant branch (AGB) and passing through spectral types F and A should make excellent Population II standard candles. Theoretically, they should have a very narrow luminosity function: the upper limit is set by the much shorter lifetimes of the more luminous post-AGB (PAGB) stars, and the lower limit corresponds to the turnoff mass of the oldest progenitors. Moreover, PAGB A-F stars are readily recognized because of their enormous Balmer jumps. They should be found in the halos of spiral galaxies where internal absorption is minimized and also in elliptical galaxies. The search is ongoing in old populations of Local Group galaxies. A hybrid CCD photometric system is employed that combines the Gunn u filter with Johnson-Kron-Cousins BVI. Kurucz/Hubeny model atmospheres and stellar emergent spectra are used along with filter transmission functions and instrument sensitivity curves to generate synthetic photometric indices that can be parameterized in terms of stellar $T_{\rm eff}$ and log g. To date, several Local Group galaxies have been calibrated in this manner. The derived distances agree well with a number of other methods.

3.14 Blue Stragglers in Globular Cluster Cores

In collaboration with M.M. Shara and M. Livio, Saffer analyzed HST Faint Object Spectrograph observations of a Blue Straggler Star (BSS) in the globular cluster 47 Tuc. These hot, young stars are observed by HST to exist in the cores of many, if not all, of the very old globular clusters. Theory maintains that these stars must be more massive than hydrogen-burning cluster members as old as the clusters themselves. For the first time, this theoretical claim has been verified by directly measuring the mass of a globular cluster core blue straggler. The derived mass, $M=1.7\pm0.4\ M_{\odot}$, is almost twice that of the oldest primordial hydrogen-burning cluster star. Furthermore, the star is found to be rotating rapidly, with a derived projected rotation velocity of $v\sin i = 155 \pm 55$ km s^{-1}. This large value for the rotation velocity tends to support the binary mass-transfer/merger hypothesis for blue straggler formation, rather than the physical stellar collision/merger hypothesis.

3.15 Kinematics of Hot Subdwarf Stars

In collaboration with P. Thejll, C. Flynn, and R. Williamson, Saffer analyzed radial velocity and proper motion data on a sample of hot subdwarf and white dwarf stars, with the aim of determining to which stellar population sdB stars (in the V magnitude range 10.5 to 14.5) belong. The sample is the largest of hot subdwarf proper motions measured to date. The kinematic analysis suggests that the parent population of these hydrogen-rich sdB stars is as old or older than the old disk. The absolute magnitude of the sdB stars in the field is measured as $M_{\rm V} = 4.5$, providing independent confirmation of absolute V magnitude estimates for these stars from clusters and spectroscopic analyses. Provided it can be shown that the sdO stars evolve from the sdB, then the sdO absolute V magnitude distribution is about 1 magnitude brighter than for the sdB, and 1 magnitude wider.

3.16 The Double Degenerate Progenitors of Type Ia Supernovae

In collaboration with M. Livio (STScI), Saffer analyzed radial velocity observations of a large sample of apparently single white dwarfs (WDs) in an effort to discover close, double-degenerate (DD) pairs which might comprise viable Type Ia Supernova (SN Ia) progenitors. The WD sample was augmented with a previously observed sample of apparently single subdwarf B stars, which are believed to evolve directly to the WD cooling sequence after the cessation of core helium burning. A number of candidate velocity variables were identified, as well as two new confirmed short-period subdwarf B/white dwarf pairs. The observations appear to be in general agreement with the predictions of the theory of binary star evolution. Further observations are planned to solve for the orbital parameters of the candidates, from which it will be possible to place meaningful observational constraints both on DDs as SN Ia progenitors and, more generally, on the theory of binary star evolution.

3.17 Faint B Stars in the Galactic Halo

With K. Mitchell and S. Howell, Saffer analyzed a new sample of 31 faint B and A0 stars, 30 of which comprise a complete sample within the limits $(U-V) < 0$ and $10.0 < B < 18.0$. The sample is based on low- and intermediate-resolution spectrophotometry of color-excess objects selected in the US survey. Atmospheric parameters for the stars have been derived through the use of synthetic colors, Balmer-line strengths, and atmospheric-model fitting. The atmospheric parameters and preliminary metallicity estimates indicate that most of the stars are distributed along the blue horizontal branch with low metallicities ([Fe/H] = −1.0) and with both the first and second Newell gaps present. However, nine of the B/A0 stars can be identified as candidate main-sequence stars based on evidence of high metallicities ([Fe/H] = 0) and/or derived effective temperatures and surface gravities which place them close to the main-sequence relation. The completeness characteristics of the sample have been discussed, and its surface density has been compared to that of other recently isolated B-star samples. The sample exhibits a shallow integral number-count slope. This new sample will help provide increased statistical coverage of the B-star population in the Galactic halo through its relatively faint magnitude-completeness limits and its relatively red color-completeness limits.

3.18 Young Stellar Objects: SU & AB Aurigae

DeWarf and Guinan, with T. Shaughnessy (Radnor High School, Radnor, Pennsylvania), continue intensive, long-term photometric monitoring of SU and AB Aurigae, which are two of the brightest classical T Tauri stars (CTTS). Differential photoelectric photometry (Strömgren *uvby*) is made using the 0.8m Automatic Photoelectric Telescope (APT), located at the Fairborn Observatory, AZ. The recently determined distance from Hipparcos confirms that both SU and AB Aur are members of the Taurus-Aurigae star-forming complex. Furthermore, since both have nearly identical parallaxes and similar proper motions, it appears that they are physically linked - perhaps a common proper motion pair, or are members of the same local star forming region. Using the Hipparcos parallax, they computed the absolute magnitudes of both SU Aur and its probable companion AB Aur. These values place SU and AB Aur well above the main-sequence for their respective unreddened colors (or spectral types). The two stars can be satisfactorily placed on PMS evolution tracks for a common age of about 4 Myrs.

Noteworthy in the currently analyzed results of SU Aur for the 1993/94 observing season, is a large ‘‘eclipse-like’’ drop in light that occurs starting around JD = 2449370 (Jan. 17, 1994) and ending about 40 days later. Also evident are smaller light variations that occur on shorter time-scales and a possible long-term, low amplitude undulation in brightness with time. There is a strong wavelength dependence during this large dimming event. For example, the light decrease is 0.8 and 0.4 mag in u and y, respectively. No significant variations are seen in the Strömgren reddening-independent $[c_1]$ and $[m_1]$ indices during the dimming event. This behavior indicates that the light decrease arises from the obscuration of the star by dust with scattering properties similar to ISM dust. Since CTTS have accretion disks, the dimming event could be caused by a concentration of matter orbiting in the outer regions of the disk that temporarily obscures the star and the central (hotter) regions of the accretion disk. It is also possible that a dust cloud condenses from ejected matter and temporarily obscures the star. This work will be submitted for publication during 1998.

3.19 Evidence of Angular Momentum Loss in the Eclipsing Binary VW Cephei

Guinan, Bradstreet (Eastern Coll.), Z. Glownia (Palomar Coll.) and Eastern undergraduate M. J. DeVita worked on angular momentum loss. VW Cep is one of the brightest and longest observed short-period (P = 6.67 hours) W UMa type binaries. It consists of G5V and K0V components in contact with their Roche surfaces. They investigated complex period changes based upon eclipse timings from the past 70 years. In addition to the well-known 30 year light time effect caused by the presence of a third star in the system, there is now evidence for a long term decrease in the orbital period of dP/dt = -0.02 sec/yr. This decrease in period could arise from angular momentum loss from the binary or mass exchange between components. From these timings, they have refined the properties of the tertiary component and redetermined its mass and orbital parameters. After correcting the O-C's for the third body and the steady decrease in Keplerian period, they uncovered small systematic deviations in the residual O-C's and are studying these second order period variations, possibly arising from mass loss in winds and/or mass flow between components, to determine if they correlate with known cycles of spot and surface activity.

3.20 Magellanic Clouds

Guinan, Maloney, DeWarf, Fitzpatrick and Maurone worked with Bradstreet (Eastern Coll.) I. Ribas (Un. of Barcelona) and A. Giménez (LAEFF, Sp.) in the study of selected detached, hot eclipsing binaries in the Magellanic Clouds, begun with IUE and now being continued with the Hubble Space Telescope. The chief purposes of the UV studies of these binaries is the determination of accurate temperatures, reddenings, and chemical abundances of the component stars. Twelve systems were observed with IUE during 1993-1995, chiefly with the SWPLO camera (115-200nm). During 1996/97, HST/FOS observations were secured of ten of these systems that cover 115-480nm. HST/GHRS medium resolution spectra of two systems (HV 2274 and HV 12634) were made near the quadratures of their orbits to measure radial velocities so that stellar masses could be obtained. The results obtained from the UV are being combined with radii and masses of the stars obtained from ground-based photometry and spectroscopy. This is yielding the first directly determined Mass-Luminosity relation for stars outside of our Galaxy. Moreover, these eclipsing bianaries can serve as ''standard candles,'' providing direct, independent and accurate distances to the LMC and SMC.

3.21 HST Observations of Mira AB Wind Accreting Binary System

Guinan and M. Karovska (CfA), continued work on the Mira AB system. The Mira AB system belongs to a class of detached binaries in which a compact object accretes mass from the wind of a cool giant or supergiant. This system provides a unique laboratory for detailed study of the characteristics of the wind accretion processes because it can be spatially resolved with the HST and the components can be studied individually at UV and optical wavelengths.

They resolved the components of this binary using the HST FOC camera images and obtained spectra of each component separated for the first time. The multiwavelength FOC images combined with the spectra provide a unique perspective of this accreting system and its components at wavelengths ranging from 150 nm to 550 nm. They determined the spectral energy distribution of each component unambiguously at UV and optical wavelengths and obtained the first high spatial resolution images of Mira A and Mira B at UV wavelengths. They detected significant asymmetries in the giant's atmosphere and found evidence for possible interaction with its companion.

Guinan, Karovska, Mahler, and Wasatonic used IUE and APT data to study accretion flux in the Mira AB system. In addition, Wing TiO near IR photometry was started during 1996. Shortward of about 300nm the flux of the accreting companion dominants the spectrum so that the IUE provides unique insights into the properties of the Mira B. The UBV and TiO band light curves are dominated by the light variations of the red giant except during minimum light. However, near the times of the minimum light of Mira, the U-band photometry is dominated by the light of Mira B. There is strong evidence from the IUE and the U-band photoelectric photometry of large systematic variations of the accreting star on nearly all time-scales. Also seen from the IUE data is evidence for sharp increase in Mg II h+k 280nm emission, occuring about 120-135 days after the maximum light of the red giant. This periodic appearance of relatively strong and narrow Mg II emission probably arises from a shock front in the cool star's atmosphere.

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3.22 CM Draconis: Properties of the Binary System

Guinan, McCook, Villanova student S. Wright, Bradstreet(Eastern Coll.), and and D. Saumon (Vanderbilt) have been studying the orbital and physical properties of the eclipsing binary CM Draconis. CM Draconis is the lowest mass eclipsing binary known. From the analysis of the radial velocity curve (from Metcalfe *et al.* 1996) and the light curves obtained by us, the orbital properties and the physical characteristics of the dM4.5 + dM4.5 components are now known to high precision.

The dM4.5 stars of CM Dra are important because they provide crucial data points for the Mass-Luminosity-Radius Relation for low mass stars with fully convective envelopes.

Because of the well determined masses, radii, and temperatures, it is possible to compare the observed physical properties with theoretical models of low mass stars. Models computed by Saumon (Vanderbilt) were used. Generally the models give good fits to the observations. The fractional helium abundance (Y) was found from the modeling that yielded mean value of $Y(1+2)=0.24\pm0.03$. The error is still too large to be very useful for cosmological questions. Further modeling is planned with more physically realistic models. In addition, the light curves will be re-analyzed with more sophisicated modeling methods. A redetermination of Y is planned. The recently determined metal abundance for CM Dra by Viti *et al.* (IAU JD 10; 1997) of $[M/H]=-0.7\pm0.1$ will be used as a ''fixed'' parameter in the modeling.

3.23 CM Dra: Planetary Transit Eclipse

Guinan, McCook, Wright and Bradstreet report further on the possible photometric detection of a planetary transit eclipse for the dM4.5+dM4.5 (P=1.268d) eclipsing binary star CM Dra. CM Dra was selected as a target for a planetary transit search because its orbital plane is seen almost exactly edge-on and its component stars radii are small. A planet orbiting the binary in the plane of its orbit would transit across the disks of the stars, producing a decrease in brightness proportional to the relative areas of the planet to the stars.

Photoelectric photometry of CM Dra has been conducted from Arizona from 1995-1997 using the Four College Consortium 0.8m APT. As reported in IAUC No.6423, during a 3.5hr interval on 01 June 1996 UT, CM Dra was fainter by 0.08 mag in the I-band. Modelling results of the observed light decrease when assuming a planetary transit eclipse of the limb-darkened ($x = 0.45$) dM4.5 stars. Good fits of the light loss were obtained for a planet with a diameter $= 0.94 \pm 0.04$Dj and having an orbital period of $P = 2.2 \pm 0.4$ yrs. This estimated orbital period is close to the elapsed time interval of 2.01 yrs between the transit event reported here and that reported by Martin and Deeg (IAUC No. 6425). Upper limits of the mass of this possible planet of Mp<5Mj were made by searching for systematic variations of the eclipse arrival times of the eclipsing binary that would occur from the presence of a massive planet or brown dwarf. Observations of additional photometric transits are needed to confirm the presence of a planet in the CM Dra system.

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3.24 Eclipsing Binary Systems as Astrophysical Laboratories: B-star Components of V380 Cygni

Guinan in collaboration with D. Popper (UCLA), D. Bradstreet (Eastern Coll.) I. Ribas (U. of Barcelona), A. Giménez (LAEFF, Madrid, Sp.) and FitzPatrick (Villanova) have investigating the orbital and physical properties of the eccentric eclipsing binary V380 Cygni (P=12.462; e =0.22). New spectroscopic and photometric solutions have been carried out on the important B1.5 II-III + B2-3 V eclipsing system from high signal-to-noise CCD spectroscopy obtained by Popper and high precision photoelectric photometry obtained with the APTs from Arizona. New, improved masses, radii and temperatures of the stellar components were determined. The temperatures were obtained by fitting U,B,V observations and IUE observations to Kurucz models using techniques developed by Fitzpatrick and D. Massa.

An accurate determination of the V380 Cygni's apsidal motion rate was made from the analysis of eclipse timings obtained from 1923 to 1996. Using the recent stellar structure and evolutiona models of Claret and Giménez, the internal structure of the more massive star was determined and tests of the importance of convective overshooting in the core of the more massive B1.5 II-III star of the system was carried out by chiefly Ribas and Giménez. Also, the values of the fractional helium abundance (Y) of both stars were made and compared to other Helium abundance determinations. In addition, the evolutionary age and luminosities of V380 Cyg were were found. The results of this study are being prepared for publication.

3.25 The Sun in Time: Coronal and Chromospheric Properties of Optically Selected Solar Analogs and Twins

Guinan, Güedel (PSI/ETHZ), and DeWarf continue the study of the X-ray, EUV, FUV, and UV properites of optically selected analogs of the Sun. The optical selection of solar analogs and twins comes chiefly from spectral and photometric criteria such as spectral types, *B-V* (or *b-y*) indices, and absolute magnitudes with parallaxes determined from Hipparcos. In selecting stars as analogs of the Sun, known members of interacting binaries are excluded, but stars that are members of wide (non-interating) binary or multiple star systems (such α Cen A and 16 Cyg A&B) are included.

For the most part the solar proxies in our sample have spectral types that range from about G0V to G5V (or $B-V$ indices between about +0.60 and +0.70). For comparison, the Sun's $B-V = +0.648 \pm 0.005$. Several of these stars (the solar twins) appear in lists of stars well matched to the Sun - including the well known nearby ''solar twin'' candidates - HD 44594 (=HR 2290), 18 Sco, 16 Cyg A & B, and Alpha Cen A. When possible, the stars are compared to the energy distributions and emission fluxes of the present Sun in the X-ray, EUV, FUV, UV, and also in the microwave (coronal) region in a few cases.

Stars that appear well matched to the Sun in the optical, sometimes show stronger coronal and chromospheric emissions than the Sun. This enhanced coronal and chromospheric activity arises from more rapid rotation due to younger ages. However, the study of time-dependence of solar activity using solar proxies with known ages and rotation rates provides a ''time machine'' to investigate and understand the past, present, and expected future behavior of the Sun and solar magnetic activity. It also puts tighter constraints on the present Sun's place among solar-type stars.

At the present time, the star best matching the Sun in M_v, T_{eff}, age, and chemical abundance, [M/H] is 18 Sco (see Porto de Mello & daSilva, ApJ 482,L89). Analysis by us of age/magnetic activity indicators such as L_x, CaII H+K and Mg II h+k indicate levels of magnetic activity closely matched to the Sun. These proxies of age and rotation show 18 Sco to be rotating within a few days of the Sun's 26 day rotation period. Isochronal fits to the observed M_v and T_{eff} of 18 Sco were carried out by Ignasi Ribas (U. of Barcelona) and indicate an age of 4.9 ± 0.8 Gyr and a mass nearly $1.0 \pm 0.02\ M_\odot$. These measures support Porto de Mello's contention that 18 Sco is so far the best match to the Sun.

The new Hipparcos parallax for the former ''solar twin,'' HD 44594, shows it to be more distant and more luminous than originally assumed. This star now appears to be significantly more evolved than our Sun with an age estimate of 8.0 ± 1.0 Gyr. 16 Cyg A and B are even more evolved with ages near 9 Gyr and masses near 1.0 $M_\odot$ and 0.96 $M_\odot$, respectively.

3.26 Near IR and TiO-Band Intermediate-Band Photometry of α Ori , 1996-1997

Alpha Orionis (Betelguese, HD 39801, M2Iab) is the brightest star in the infrared sky. It is also one of the closest, with the recent Hipparchos Survey updating its distance estimate to 131±30 pc. The star's relative proximity, coupled with its semi-regular variability and advanced evolutionary age, has made it an attractive target for a number of studies. Despite these studies, α Ori remains an enigmatic object.

From September 1996 to April 1997, α Ori was observed at the Wasatonic Observatory (Allentown, PA) as part of the ongoing program between the Wasatonic and Villanova Observatories to study cool giants and supergiants. Photometry was conducted on a total of 23 nights using an uncooled Optec photometer attached to a 20-cm Schmidt-Cassegrain telescope. The detector employed was a silicon PIN-photodiode. Differential photometry was conducted with both the V-band and Wing near-IR three filter intermediate band system to measure TiO (Wing 1992). α Ori showed an average effective surface temperature of 3500 K. The maximum and minimum physical surface temperatures were 3550 K and 3440 K, corresponding to TiO indicies of 0.568 and 0.706, respectively. These temperature values agree well with Dyck's *et al.* (1992) interferometric estimated surface temperature of 3520±85 K.

It is uncertain whether the luminosity changes are due to uniform, global pulsations of the star, or whether they are restricted to local hot-spot growths on the surface. In 1994, Goldberg concluded from radial velocity data that the visual brightness variations are probably not global in nature. However, Dupree *et al.* (1987) asserts that the regularity of α Ori's variability argues against the erratic variability associated with the emergence of convective cells. Under the assumption that the luminosity variations are global in nature, the radius of α Ori was computed for each observation. α Ori exhibited an average radius of 1040 $R_\odot$ with gradual changes of about 30 $R_\odot$ over the observation period as the star became fainter. This value is slightly larger than interferometric observations of α Ori's radius in TiO wavelengths. These results, however, represents the first findings of α Ori's radius using intermediate infrared observations. For this research, we utilized the SIMBAD database, operated by CDS, Strasburg, France. This work was supported in part by NSF grant AST-9528506, which we gratefully acknowledge.

3.27 ZAMS K Dwarfs

C. Ambruster continued work on a multi-wavelength study of the atmospheres of cool Zero-Age-Main-Sequence (ZAMS) stars. Observations with HST(GHRS), EUVE, IUE, ROSAT, the VLA, and the KPNO coude feed are now complete for an unusual sample of six Zero-Age-Main-Sequence (ZAMS) Pleiades Moving Group K0-K2 dwarfs in the solar neighborhood. Several independent lines of evidence establish these stars as Pleiades age: near primordial lithium abundances, high activity levels, and space motions consistent with the Pleiades Moving Group. All six stars have essentially the same mass and temperature (spectral types K0 V - K2 V), and are confirmed single (although HD 17925 may be an unresolved SB2 on the basis of low-amplitude radial velocity variations). Most are within 20 pc. This sample removes, age, mass, and temperature as variables, leaving rotation (true rotation periods from photometric variability) as the only significant difference between the stars.

The GHRS data contain both low (G140L)- and medium-resolution spectra. The final reduction of the G140L spectra was done by Ambruster in summer 1997. During 1996, in order to test the sensitivity of measured line properties to different measurement procedures, Ambruster and Fabian reduced the GHRS spectra using two different methods: 1) a Gaussian-fitting algorithm (developed by B. Wood (CfA)), and 2) a direct integration algorithm (developed by G. Harper (CASA, U. Colo.)) where errors are determined by a Hermite-Gauss Quadrature routine. Agreement between the two methods was generally good, in that fluxes usually agreed within 1σ. Ultimately, method 2 (direct integration) was chosen for the low-resolution GHRS spectra, where the S/N is good. This method was not as reliable for the lower S/N medium resolution spectra and method 1 (Gaussian fitting) was used for them. By 1997, improvements to the Hermite-Gauss Quadrature error calculation routine of Method 2 (direct integration) necessitated the remeasurement of all the G140L spectra, which was completed in August 1997. Analysis of the medium resolution Ly-α profiles for each star enabled us to apply a very small correction for interstellar reddening to all the measured fluxes.

As part of the attempt to understand uncertainties affecting the final fluxes, the measured fluxes were converted to surface fluxes by two different, but not completely independent, methods. The two methods were: a) the Barnes-Evans relation for (B-V), and 2) d^2/R^2, with distances, d, from Hipparcos (for 5 of the 6 stars), and stellar radii, R, from the Stefan-Boltzmann relation (where temperature is known from spectral classification of KPNO coude feed spectra of the six stars by colleague F.C. Fekel (COE, TN St. U.), and luminosity from the absolute magnitude). Surface fluxes calculated from the Barnes-Evans relation are consistently 10-20% lower than by the d^2/R^2 method; the reason(s) for this are being investigated.

Rotation-activity relations were constructed for both the transition region (using the C IV λ1550 surface fluxes), and the chromosphere (using the O I λ1304+1306 surface fluxes which, unlike Mg II h+k and O I λ1302, are unaffected by interstellar absorption). For both O I and C IV, fluxes are probably saturated for the three stars where $P_{rot}<2$ days; for longer periods surface flux is a (linear) function of rotation rate (on a log-log plot). The slope of the linear part of the C IV rotation-activity relation is steeper than for the O I relation, consistent with current understanding that fluxes from lines formed in hotter regions decay faster as rotation slows than cooler lines. However, the rotation-activity relation for the chromospheric Mg II h+k fluxes (from G270M spectra) is essentially saturated out to $P_{rot}=6.9$ d, the rotation rate of the slowest rotator of the group. A similar result was obtained earlier from IUE LWP-Hi spectra. Correction of the Mg II surface fluxes for interstellar absorption and reddening almost certainly will not result in a slope as steep as that of O I, i.e., the slopes of the two chromospheric lines are significantly different. O I is believed to be radiatively excited by H Ly-β; if so, its emissions echo the fact that H Ly-β is collisionally formed in a hotter environment than Mg II. O I, then, reflects the fact that H Ly-β is no longer saturated.

These results were presented in a paper by C. Ambruster and collaborators A. Brown (CASA, U. CO), F.C. Fekel Jr. (COE, TN State), G.H. Harper (CASA, U.CO), D. Fabian (U. Wisc.), B. Wood (CfA), and E.F. Guinan (Villanova) at the Tenth Cambridge Conference on Cool Stars, Stellar Systems, and the Sun, held in Cambridge, MA in July 1997.

Data reduction for some of the other data sets is continuing: the SWP-Lo IUE data obtained during the last 4 years are being systematically reduced by colleague T.R. Ayres (SWP-Lo); the same procedure was used to reduce some 50 SWP-Lo spectra obtained earlier for the six stars. The last 4 years of IUE LWP-Hi and LWP-Lo spectra are being reduced by Villanova seniors Matthews and Margheim.

Still in the process of final analysis are data sets from EUVE, ROSAT, and the VLA. The fluxes will finally be used to construct volume emission measure (VEM) models of the upper atmospheres of cool ZAMS stars.

3.28 Archaeoastronomy

Ambruster and colleague A.B. Hull continue their investigation of a site in eastern Chaco Canyon National Culture Historical Park that offers comprehensive evidence that at least some Navajo marked the solstices and equinoxes with horizon observations. Only three of a dozen or so large boulders at the base of a talus slope have significant rock art panels (deeply incised Gobernador-phase Navajo). Each defines an observing point for watching the sun rise at the base of three different cliffs on a relatively featureless eastern horizon at Equinox, Winter and Summer Solstice. Conversely, boulders lacking significant rock art also lack alignment with distinctive horizon features at the Equinox or Solstice sunrise positions. The rock art from at least two of the three boulders suggests an associated season: incised plants appear only on the boulder marking the observing point for summer solstice sunrise; the traditional constellations for November and December are drilled into the boulder participating in a dramatic winter solstice sunrise event. There are tight constraints on the observer's position at all three boulders. A drawing of the rock art on the Equinox and Winter Solstice boulders appears in the report of the Simpson expedition of the U.S. Army in 1849: some very obvious features are not seen, suggesting that a Navajo sunwatching tradition persisted here for at least 100 years. These results were presented at the 50th annual Pecos Archaeological Conference held in Chaco Canyon, NM in August 1997.

4. CONFERENCES & APPOINTMENT

Guinan was elected president of the IAU Commission 42 (Close Binary Stars) through 2000; he was reappointed chairperson of the AAS Committee on Careers and Employment, appointed Assistant Secretary of the IAU International School of Young Astronomers (ISYA) for 1997-2000 and visiting lecturer for the ISYA held at Zanjan, Iran in July 1997. He organized and chaired the IAU Joint Discussion *Stellar Evolution in Real Time* at the IAU General Assembly in Kyoto, Japan (August 1997).

Sion was the featured speaker at the 11th Guo Shoujing Summer School of Astrophysics on Cataclysmic Variables and Binary Evolution held at the University of Science and Technology of China in Hefei, (Anhui Province), People's Republic of China and a Visiting Scholar, sponsored by the Chinese Academy of Sciences, at the Shanghai Observatory where he presented a series of invited lectures and at the Sir Robert Black College of the University of Hong Kong. He was also an invited speaker at the Pacific Rim Conference on Stellar Astrophysics at the Hong Kong University of Science and Technology, the 13th North American Workshop on Cataclysmic Variables and X-Ray Binaries, the AAVSO Spring Meeting on *New Frontiers in Variable Star Research* held in Sion and St.Luc, Switzerland. Sion continued as a Scientific Editor of The Astrophysical Journal and is on the Scientific Organizing Committee of the 14th European Workshop on White Dwarfs to be held in Norway during the summer of 1998.

Ambruster served on the editorial committee for the refereed publication from the Fifth International Archaeoastronomy conference held in Santa Fe, NM in August 1996. Sofia received the DARA ASTRO-SPAS Award for contributions to the ORFEUS-SPAS 2 mission.

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