Villanova University
Astronomy & Astrophysics

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This report covers the period from October 1998 to September 1999.

1. PERSONNEL

During the report period, 9/98-9/99, the staff included Assistant Professor Carol W. Ambruster, Instructor Larry DeWarf, Assistant Professor Edward L. Fitzpatrick, Professor Edward F. Guinan, Associate Professor Frank P. Maloney, Professor George P. McCook (Chairperson), Research Assistant Professor Rex A. Saffer, and Professor Edward M. Sion. Dr. Elizabeth R. Jewell served as Department Assistant.

Tara Anselowitz, Daniel Bambeck, John Bochanski, Joseph DePasquale, Paul DiTuro, Jonathan Hagis, Karen Matthews, Michele Sauer, Richard Slevinsky and David Stys served as research assistants.

2. INSTRUMENTATION

2.1 Automated Photoelectric Telescopes

The Fairborn Observatory, home of the Four College APT (FCAPT) is located in the Patagonia Mountains of AZ (Lat: +31 23 12; Long: -110 41 41). This 0.8m automated photoelectric telescope is operated by the Four College Consortium (FCC) consisting of the The College of Charleston, The Citadel, University of Nevada-Las Vegas, and Villanova University. The FCAPT is supported by NSF grant AST95-28506.

2.2 Internet Access

The department's WWW address is: phy.vill.edu/astro; 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 ZAMS Stars in our own Backyard

Ambruster, A. Brown (CASA, U. Colorado), and collaborators completed a preliminary analysis of the radio (VLA) and EUV observations (EUVE spectra and light curves) of a homogeneous sample of 6 solar neighborhood, Pleiades Moving Group, K dwarfs. These stars are essentially identical in mass, temperature (spectral class), and age (based on near-primordial lithium abundances); they differ only in rotation rate (0.38-6.9 days). The nature of EUV flare activity was found to depend on rotation rate, in the sense that the shorter the rotation period, the more frequent and energetic the flares. No significant flares were detected from those stars with rotation periods longer than about 3 days. Analysis of the EUVE lines fluxes, is continuing, as is the integration of these data into the broader, multi-wavelength study of these stars. Results were presented at the HEAD meeting of the American Astronomical Society in April, 1999.

Ambruster, A. Brown (CASA, U. Colorado), and F.C. Fekel (CFE, TN State U.) continued their analysis of the optical and HST/GHRS observations of the sample of 6 ZAMS stars. Because one of the main goals of the study is to compare upper atmospheric properties as a function of rotation for ZAMS stars, it has become clear that particular attention must be paid to understanding and minimizing possible systematic errors that could distort the comparison of derived stellar properties. For example, it was found that for two of the stars (HD 1405 and HD 82558), radii computed from the stars' luminosity and temperature (via the Stefan-Boltzmann law) are improbably low: $R/R_\odot \sim 0.64$ vs. typical values of 0.75 and 0.81 for K2 V and K0 V stars, respectively. One likely reason is that the photometric light curve maximum, V_{max} (which is used to determine the luminosity) is dimmed by extensive starspot coverage, even at light curve maximum (starspot minimum). This possibility is supported by Doppler imaging studies (Rice & Strassmeier 1998, A&A 336,972) which find extensive starspot coverage on HD 82558, one of the stars with an anomalously small computed radius. Inaccurate radii, however, affect the conversion factor used to convert the HST/GHRS observed line fluxes to surface fluxes (d^2/R^2). Inaccurate surface fluxes, in turn, would distort comparisons of chromospheric and transition region emissions among the 6 stars. On the other hand, HD 1405 and HD 82558 happen to have essentially the same rotation period ($\sim$ 1.7 d), and it may be that the high starspot filling factor indicates that some change in the nature of the magnetic dynamo within the star takes place at this rotation period. Ambruster presented these results in a talk to the Cool Star group at U. Colorado in August 1999.

3.2 HD82443

One of the 6 ZAMS stars, HD 82443, was observed by Ambruster with IUE as part of the ZAMS star project, and independently by S. Messina (U. di Catania, Italy) and Guinan with the Four College APT. The analysis of both sets of data reveals evidence for an activity cycle of 3.89 yr, and period variations which suggest differential rotation of the star. The UV chromospheric and transition region line fluxes generally correlate quite well, suggesting the presence of bright plage regions. There is also some evidence for rotational modulation, particularly in the Mg II h+k (2800 Å) flux (Messina, Guinan, Lanza, & Ambruster 1999).

3.3 IUE Data Processing

Fitzpatrick and D. Massa (Raytheon ITSS) have completed a recalibration of the absolute fluxes of low-dispersion spectrophotometry from the International Ultraviolet Explorer (IUE) satellite, as recently reprocessed for the IUE

Final Archives (''NEWSIPS''). This project was initiated by the discovery of large systematic residuals between the IUE fluxes of main sequence B stars and stellar atmosphere models. It turned out that the IUE NEWSIPS data had been improperly calibrated and that IUE fluxes deviated from those produced by the extremely well-calibrated Faint Object Spectrograph (FOS) aboard the Hubble Telescope by as much as 10-15% over most of the wavelength range covered by IUE. In addition, strong temporal and thermal dependencies were found in the NEWSIPS data. A set of corrections was derived to place IUE data on the absolute flux system of the FOS and to correct for the various systematic effects in the data. These corrections reduce the systematics in the IUE data to the 3% level – a factor of 5 improvement. A paper describing these results will appear in ApJSuppl (Massa & Fitzpatrick 2000, ''A Recalibration of IUE NEWSIPS Low-Dispersion Data''). The correction algorithms are available on request.

3.4 Stellar Astronomy

Fitzpatrick and Massa have completed the first phase of a multiyear stellar program whose goals are 1) the derivation of fundamental stellar properties for a large number of main sequence and slightly-evolved A and B stars through application of standard stellar atmosphere models and evolution theory, and 2) the application of these results to obtain a better understanding of the chemical evolution of the Galaxy and nearby galaxies by examining the systematic and random variations in the spatial distributions of elemental abundances. The technique used is to fit the observed UV/optical continua of the early-type stars with line-blanketed model atmospheres, and in so doing derive estimates of stellar effective temperature, surface gravity, general metallicity, and microturbulence velocity, as well as the wavelength dependence and magnitude of interstellar extinction. A paper describing these first results will appear in the Nov. 10, 1999 ApJ. This paper demonstrates the techniques used in the program, the degree to which the current generation of model atmospheres reproduce the observed stellar continua (namely, to a level consistent with observational uncertainties), and the method for extracting extinction information simultaneously with the stellar properties.

3.5 Interstellar Medium

In preparation for an invited review talk at the Seville Meeting: *IUE studies of interstellar extinction*, Fitzpatrick investigated the best current strategies for correcting astronomical data for the effects of interstellar extinction (''dereddening''). A paper describing these results was published in PASP, 111. This paper examines several dereddening strategies and presents estimates of the uncertainties inherent in each method. In addition, a new derivation of the wavelength dependence of an average Galactic extinction curve from the IR through the UV is presented, along with a new estimate of how this extinction law varies with the ratio of total to selective extinction in the visual region (i.e., $A(V)/E(B-V)$).

3.6 Orbital Parameters of Three New Subdwarf B Binaries

Saffer, and collaborators, Moran, Maxted, Marsh, & Livio have determined the orbital parameters of three subdwarf B (sdB) stars, PG 0101+039, PG 1432+159 and PG 2345+318. Orbital periods are found to be 13.6778 $\pm$ 0.0002,5.398 $\pm$ 0.008 and 5.7827 $\pm$ 0.0002 h, respectively. Lower limits for the mass of the companion star were calculated in each case. The authors also suggest upper mass limits for the companions to PG 1432+159 and PG 2345+318 on the basis of the maximum size of the companion allowed by the Roche lobe geometry. The nature of the companion star is discussed but cannot be determined without further observations. The previously measured period of 8.49 h for the sdB binary PG 1101+249 is confirmed.

3.7 Spectroscopic Studies of DB White Dwarfs: The Instability Strip of the Pulsating DB (V777 Herculis) Stars

Saffer and collaborators, Beauchamp, Wesemael, *et al.*, have secured optical spectra for the eight currently known variable DB, or V777 Her, stars. With the help of a new generation of synthetic spectra, spectroscopic effective temperatures are derived for these objects, as well as for 15 other DB or DBA stars above 20,000 K. The authors find that the location of the boundaries of the instability strip is sensitive to the atmospheric hydrogen abundance assumed for DB stars: the strip covers the range 22,400-27,800 K if atmospheres of pure helium are used and the range 21,800-24,700 K if undetectable traces of hydrogen are allowed for in the DB models. These determinations provide independent constraints for current seismological analyses of the V777 Her stars. More sensitive searches for weak hydrogen features in hot DB stars should help decide between the two temperature scales.

3.8 A Comparative Study of the Mass Distribution of Extreme-Ultraviolet Selected White Dwarfs

Saffer and collaborators Napiwotzki & Green present new determinations of effective temperature, surface gravity, and masses for a sample of 46 hot DA white dwarfs selected from the Extreme Ultraviolet Explorer (EUVE) and ROSAT Wide Field Camera bright source lists in the course of a near-infrared survey for low-mass companions. The analysis, based on hydrogen non-LTE model atmospheres, provides a map of LTE correction vectors, which allow a thorough comparison with previous LTE studies. Previous studies are found to underestimate both the systematic errors and the observational scatter in the determination of white dwarf parameters obtained via fits to model atmospheres. The structure of very hot or low-mass white dwarfs depends sensitively on their history. To compute white dwarf masses, theoretical mass-radius relations that take into account the complete evolution from the main sequence are used. The peak mass of the white dwarf sample is 0.59 $M_{\odot}$, in agreement with the results of previous analyses. However, a trend of peak mass with temperature reported in two previous analyses is not confirmed. Analogous to other EUV-selected samples, a lack of low-mass white dwarfs and a large fraction of massive white dwarfs is noted. Only one white dwarf is likely to have a helium core. While the lack of helium white dwarfs in the sample can be easily understood from their high cooling rate, and therefore low detection probability, this is not enough to explain the large fraction of massive white dwarfs. This feature very likely results from a decreased relative sample volume for low-mass white dwarfs caused by interstellar absorption in EUV-selected samples.

3.9 Spectroscopy of the Post-Common Envelope Binary HW Virginis

Wood & Saffer present optical spectroscopy of the post-common envelope binary HW Vir covering $\lambda 3704 - 8667$ Å. Low-resolution blue spectra are used to determine the atmospheric parameters of the sdB primary star, and medium resolution Hα observations are used to measure its radial velocity. The latter measurements determine $K_1 = 82.3 \pm 4.0$ km s^{-1} and $\gamma = 2.9 \pm 3.1$ km s^{-1}. The effective temperature, gravity and helium abundance of the sdB star are $T_{\rm eff} = 28488 \pm 208$ K, log$g = 5.63 \pm 0.03$, and $N(\rm He)/N(\rm H) = 0.0066 \pm 0.0004$. These characteristics are typical of a classical sdB star, as is the derived mass of $M_1 = 0.48 \pm 0.09 M_\odot$. The distance to HW Vir is found to be 171 ± 19 pc. The predicted value of the projected orbital velocity of the secondary star is 284 ± 21 km s^{-1}. Using previously published photometric light curves of HW Vir, the spectra were corrected to absolute fluxes, permitting extraction of the spectrum of the secondary star. This spectrum shows Hα absorption lines at phases close to the maximum of the reflection effect, with a measured radial velocity semi-amplitude of 275 ± 15 km s^{-1}. These lines are attributed to irradiation of the face of the secondary star closest to the sdB star.

3.10 The EC 14026 stars - XIII. EC 05217-3914 & KUV 0442+1416

Koen, O'Donoghue, Kilkenny, Stobie, & Saffer report the discovery of short-period oscillations in the sdB stars EC 05217-3914 and KUV 0442+1416, establishing them as members of the EC 14026 stars, a recently discovered class of sdB pulsators. The pulsation periods and atmospheric parameters for both stars are determined. The results are: periods of 218, 216 and 213 s, $T_{\rm eff} = 31{,}300 \pm 250$ K and log $g = 5.76 \pm 0.06$ for EC 05217-3914, and periods of 231, 216 and 184 s, $T_{\rm eff} = 30{,}900 \pm 400$ K and log $g = 5.72 \pm 0.1$ for KUV 0442+1416. Considerable substructure in the periods is apparent in both stars when several nights of data are combined. KUV 0442+1416 is significantly reddened. The evolutionary status of the 13 well-studied EC 14026 stars is examined. All stars except PG 1605+072 appear to be core He burning. The positions of the pulsators and the apparently constant stars are plotted in the log g – $T_{\rm eff}$ plane. Apparently constant stars mingle with the pulsators so that there is no well-defined instability strip. This poses a significant challenge to the Fe deriving mechanism of Charpinet *et al.* Five out of the 13 pulsators are obvious binaries.

3.11 Early-type Stars in the Galactic Halo from the Palomar-Green Survey II: A Sample of Distant, Apparently Young Population I stars

Rolleston, Hambly, Keenan, Dufton, & Saffer present echelle (R $\sim$ 40,000) spectroscopic observations for a sample of apparently normal, high Galactic latitude, early-type stars drawn from the Palomar-Green Survey. The metal-line spectra show evidence for rotational velocity broadening with values of $v \sin i \leqslant 300$ km s^{-1}. Using Kurucz model atmospheres, the derived stellar photospheric abundances are consistent with a Population I chemical composition; differential abundances with respect to Galactic disk Population I stars indicate no abundance differences outside the estimated errors. From a comparison of the derived atmospheric parameters with recent theoretical evolutionary models, distance and age estimates for individual stars are derived. Using kinematical considerations, the conclsions are that all these objects are 'runaway' stars, formed in the Galactic disk and subsequently ejected, possibly by supernovae explosions or dynamical interactions.

3.12 Magnetic White Dwarfs

Villanova students Tara Anselowitz and KarenMatthews, in collaboration with Richard Wasatonic, Sion and McCook examined the statistical properties, cooling ages and vector components of the three dimensional space motion UVW for the enlarged sample of 53 magnetic white dwarfs contained in the 4th Edition of *The Catalogue of Spectroscopically Identified White Dwarfs* (McCook & Sion 1999). Their cooling ages range from 2 million years to 12.6 billion years. A comparison of the total kinematical samples of magnetics and DA stars over the same luminosity range $10.0 < M_v < 16.0$ reveals a velocity dispersion σ (v) of 39 km/s for 256 DA stars compared with σ (v) = 23 km/s for 26 magnetic degenerates with space motions. These results underscore the conclusion that the sample of magnetic white dwarfs appear to be predominantly descended from a young disk stellar population subcomponent characterized by relatively small motions with respect to the Sun. This suggests links to upper main sequence Ap/Bp progenitors but possibly also massive ''near miss'' pulsar progenitors. They found preliminary evidence that the magnetic white dwarfs show a peculiar distribution in UV velocity space relative to other spectroscopic subgroups of white dwarfs.

If the magnetic white dwarfs were descended exclusively from Ap/Bp star progenitors, then one would expect a difference in velocity dispersion between the hotter magnetic degenerates with shorter cooling ages and the cooler magnetic degenerates with much longer cooling ages. This follows from the velocity inflation of a given star in galactic orbit due to increasing tidal encounters with increasing age. They found no such evidence of a difference in dispersion among the hot and cool magnetic degenerates. This may be taken as indirect evidence that the magnetics represent a sample of mixed evolutionary progeny.

3.13 IUE Archival Studies of Hot White Dwarfs

Holberg (U.AZ), Barstow (U. Leicester, UK) and Sion carried out a comprehensive survey of the IUE NEWSIPS-Porcessed spectra hot DA and non-DA white dwarfs.

3.14 White Dwarfs in Cataclysmic Variables

Sion published an invited review (1999, PASP 111) on cataclysmic variable white dwarfs. Prior to the last 15 years, the literature on cataclysmic variables contained little on the properties of the underlying white dwarf accreter other than estimates of their masses. They were regarded simply as non-descript potential wells for studies of accretion disk structure and stability. Estimates of their masses and associated core compositions were discussed but only in the context of thermonuclear runaway theory. With the advent of space spectroscopy, especially HST, IUE, EUVE and HUT, direct spectroscopic observations of exposed white dwarfs in CVs were carried out during dwarf nova quiescence or low brightness states of nova-like variables and magnetic CVs when accretion rates were very low. This review covered new insights and physical properties of white dwarfs in non-magnetic and magnetic CVs, including surface temperatures, heating and cooling measurements, rotational velocities, CV white dwarf masses (including Einstein redshift masses), photospheric chemical abundances (including composition relics of ancient novae), accretion belts, the physics of accretion heating and long term CV evolution. For an ensemble of 37 CV degenerates with secure temperatures, the average $T_{eff} = 20{,}800$K, for non-magnetic CV degenerates $T_{eff} = 24{,}100$K, for magnetic CV degenerates $T_{eff} = 16{,}400$K. The lowest T_{eff} values are associated with magnetic CVs and with systems whose orbital periods are < 2 hours. Thermal *e*-folding times of the white dwarf envelope in response to accretion heating are in the range 6 days to 600 days, photospheric chemical abundances range from moderately sub-solar to greatly above solar and rotational velocities lie within the range $50 < V \sin i < 1200$km/s. If pre-CV white dwarfs had time to cool to 10^{-3} $L_{\odot}$ prior to the onset of Roche lobe overflow, then, on average, their average lower limit lifetime is $2.5 \times 10^{+8}$ years and they have been accretion heated to an average luminosity log $(L/L_{\odot} = -1.90$ or, on average, by $\sim$ 11,000K since the end of their pre-CV evolution phase.

3.15 The Dwarf Nova OY Car

Sion, in collaboration with Cheng, Horne (U. St. Andrews, UK), Marsh (U.Southampton, UK), amd Hubeny (NASA GSFC), analyzed *HST* observations of the eclipsing dwarf nova OY Car after its 1992 April superoutburst. This data was used to isolate ultraviolet spectra (1150-2500Å at 9.2Å FWHM resolution) of the white dwarf, the accretion disk, and the bright spot. The white dwarf spectra have a Stark-broadened photospheric Lyα absorption feature, but are veiled by a forest of absorption features that we attribute to absorption by intervening disk material (a *curtain*). All of the spectral fits required supersonic turbulence in the curtain material with Mach numbers of 6 to 8. All curtain temperatures were between 10,000 K and 11,000 K. There was a curtain temperature increase $\sim$ 3 months after the superoutburst. They found that the white dwarf temperature changed from 19,700 K just 27 days after the end of the superoutburst to 18,000 K roughly 3 months after the superoutburst; the exponential (e-folding) decay time of the white dwarf temperature was 66 days. They presented evidence that the heating of the white dwarf was more extensive during the superoutburst than the normal outburst. The thermal response of the OY Car white dwarf to outburst heating is compared with WZ Sagittae, VW Hydri (the most similar dwarf nova to OY Car) and with the cooling timscales of other dwarf novae after superoutburst. The measured cooling timescales of the five systems with superoutbursts appear to be shorter, the longer the orbital period (accretion rate). There is evidence of a disk flux variation, independent of the effect of white dwarf cooling, which suggests a possible contradiction of the disk instability model. To establish this however, data is required throughout a quiescent cycle.

3.16 The Dwarf Nova RX Andromeda

Sion, in collaboration with Szkody (U.WA), Gaensicke (Gottingen), Cheng, LaDous (Sonneberg), Hassall (UK) and Holm (STScI), obtained Hubble GHRS (G140L grating) phase-resolved spectroscopic observations of the dwarf nova RX Andromeda at three times in its outburst cycle: (1) near the end of an extraordinarily deep and long dwarf nova quiescence, 3 months after the last previous outburst; (2) during the rise to outburst and; (3) near the end of a decline from outburst. The spectral wavelength range covered was 1150Å to 1425Å. All of the spectra are dominated by absorption with weak to moderately strong emission wings due to the continued presence of disk material. Uncertainties in line velocities preclude a K_1 determination or mass information. They find the T_{eff} of the white dwarf is 35,000K near the end of an unusually deep and long quiescence. The white dwarf in RX And is spinning at the globally-averaged rate of $V \sin i = 150$ km s^{-1}. Accurate abundances are complicated by line emission. They report approximate subsolar chemical abundances of Carbon and Silicon for RX And with C down by 0.05 and Si $= 0.1$ solar while other elements are at essentially their solar values. They see no evidence of thermonuclear-processed abundance ratios. If the white dwarf mass is 0.8 $M_{\odot}$ (Ritter 1999), then the cooling age is $4 \times 10^{+6}$ years and the lower limit to the age of this CV. If the peculiar line features in spectrum 3 are inverse P Cygni in nature, infall velocities of $\sim$ 2000 km/s are indicated during the decline from outburst. They compare the surface properties of the RX And white dwarf with the properties of other CV degenerates studied to date with HST, HUT and IUE.

3.17 The Ultra-Short Period Dwarf Nova WZ Sge

Villanova students Richard Slevinsky, David Stys, Sarah West, with Sion and Cheng carried out an archival IUE analysis of the whote dwarf in this system. The IUE archive offers a series of far UV spectra of ultra-short period dwarf nova WZ Sge over a long time baseline and hence the opportunity to monitor the ongoing accretion, the cooling of the white dwarf and temporal variations in the line spectra. They carried out a quantitative analysis of these spectra including model atmosphere simulations. They found an indicated cooling of the white dwarf by 5140K from 20,510K to 15,370K with a thermal e-folding time of 690 days. This cooling rate is well-represented by heating of the white dwarf by accretion of matter with angular momentum during the December 1978 outburst followed by subsequent cooling. They found that the abundance of carbon in the white dwarf photosphere is elevated above solar. This finding is consistent with the results of recent HST observations. They found marginal evidence that the C abundance was 6 x solar, close to the outburst and 2 x solar in the most recent spectra obtained 13.7 years later. Uncertainties in the abundances however did not allow any definitive conclusion regarding temporal abundance variations. The origin of the elevated carbon abundance was discussed in terms of accretion and diffusion while arguments are presented which may rule out ordinary convective dredgeup and dredgeup due to forced convection associated with shear mixing.

Their results have indicated a cooling of the white dwarf by 5000K over a time baseline of 13.7 years. The *e*-folding time of this cooling is 687 days (Sion 1999). Since the earliest quiescent IUE spectrum was secured 3 months after the return to optical quiescence following the December 1978 outburst, this amount of cooling is a lower limit. The highest T_{eff} measured for the white dwarf is 20,510K, at 0.25 years post-outburst.

The origin of the elevated C-abundance in the accreting white dwarf remains a mystery. While they have characterized the amount of cooling by the white dwarf since it was accretion-heated by the 1978 December outburst, the continued presence of C in its atmosphere during the quiescent interval since 1978 is difficult to understand. The most likely explanation offered in their paper is that the ongoing accretion at a low level brings C-enriched gas to the white dwarf surface. Intensive spectroscopic observations with HST will be required to help resolve the nature of the C-enhancement as well as to secure the mass of the white dwarf.

3.18 Magellanic Clouds

Guinan, Fitzpatrick, Maloney, DeWarf, and David Bradstreet (Eastern C.), Ignasi Ribas (U. De Barcelona), and Alvaro Giménez (LAEFF, Spain) continue their investigations of eclipsing binary systems in the Magellanic Clouds. These systems are serving as robust laboratories for studying stellar structure, evolution, and mass loss for stars with reduced metal abundances. As the study progresses, it leads to first Mass-Luminosity relationship for extra-galactic stars, and extends the parameter space in stellar interior modeling to encompass stars with chemical compositions different from Milky Way stars. Investigating massive, metal-deficient stars in the LMC and SMC is a kind of ''time machine'' for the study of low-metallicity, massive old disk O and B stars that once populated the Milky Way some 5 to 10 billion years ago. Further, these systems can serve as *standard candles*, allowing their distances to be determined to an accuracy $\sim$ 3%. This accuracy is possible because the distances so determined are principally geometric, without the need to rely upon metallicity-dependent zero-point calibrations.

This investigation began by securing IUE/SWP (1150 - 2000 Å) spectra of a sample of O/B eclipsing systems, with well-determined light and radial velocity curves. In 1996/97, HST/FOS spectrophotometry was obtained for 10 selected systems. These data are used to determine the temperatures of the stars. Since O/B stars radiate most of their energy in the UV, the character of the UV continuum and the presence of ionized elements are sensitive measures of stellar temperature. When combined with UBV (or uvby) photometry, the UV spectrophotometry can be fit to Kurucz model atmospheres with chemical abundances thought to be appropriate for the LMC or SMC. The fit provides not only accurate temperatures, but also accurate values for the extinction, surface gravity, microturbulence, and metallicity, since the spectral signatures of each one is different in the observed spectrum. With the light curves that result from the photometry, the radial velocity curves that radial velocities, and the model atmosphere that results from the HST/FOS spectra, it is possible to compute the masses, radii, temperatures, luminosities, and distances to these systems. In 1999, 4-meter telescope time at CTIO was awarded to permit high-resolution radial velocity observations of several of the binary systems without published spectra.

The first system to undergo this type of analysis is the LMC Harvard variable HV 2274. Published CCD light curves provided the temperature ratios and fractional radii (R/a, where a is the semi-major axis of the orbit). Fourteen HST/GHRS spectra, centered at 1305Å and 1335Å and covering 34Å, were obtained to provide the radial velocity curve. HST/FOS spectra were analyzed to determine temperatures, extinctions, metallicities, surface gravities and microturbulence velocities for the component stars. The surface gravities so determined were nearly identical to those found from the published CCD optical photometry and HST/GHRS radial velocity analyses. The components' temperatures, masses, and surface gravities compare quite favorably with stellar interior models from the Geneva group. Additionally, analyses of photometrically-determined times of minima show an apsidal motion consistent with the stars' internal structure parameter (k2) computed from the models. After correcting for the system's position within the LMC, the distance to the LMC was found to be $(V_0 - M)_{LMC} = 18.3 \pm 0.07$ mag.

Analyses of three more systems in the program are continuing. A progress report on HV 2226 and HV 2241 has been presented to the AAS at the January 1999 meeting, and the results from the study of HV 2226 are being readied for publication. A progress report on EROS 1044 will be presented to the AAS at the January 2000 meeting. The nine systems without high-quality radial velocity curves (all but HV 2274) will be studied with the 4-meter CTIO instrument in January 2000. HST/STIS cycle 9 time has been requested for observations of EROS 1044 as well as three other new systems, selected for their position within the LMC as well as their characteristics as distance indicators to the LMC. Analyses of these three systems, and HV 2274 already completed, should reduce the uncertainty in the distance to the

LMC to $\sim$ 2%. This degree of accuracy is critically important to many cosmological studies, since the distance scale in the universe is calibrated by Cepheid variable stars in the LMC.

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3.19 V380 Cyg

Guinan, Fitzpatrick, D. Popper (UCLA), I. Ribas (U. Barcelona, Spain), A. Giménez (LEAFF, Madrid, Spain) and D. Bradstreet (Eastern) have carried out new photometric solutions of the important eccentric eclipsing system V380 Cygni (B1.5 II-III + B2-3 V) from high-precision differential photoelectric photometry secured with the Phoenix-10 and the Four College APTs. The photometric elements obtained from the analysis of UBV light curves have been combined with the spectroscopic solution published by Popper & Guinan (1998) and have led to the absolute dimensions of the system components. The mean effective temperature has been derived by fitting IUE UV spectrophotometry to model atmospheres and compared with other determinations coming from broad-band and intermediate-band standard photometry. The values of mass, absolute radius, and effective temperature, for the primary and secondary stars are: 11.1 $\pm$ 0.5 $M_\odot$, 14.6 $\pm$ 0.3 $R_\odot$, 20350 $\pm$ 350 K, and 6.92 $\pm$ 0.25 $M_\odot$, 3.74 $\pm$ 0.15 $R_\odot$, 19600 $\pm$ 600 K, respectively. In addition, a re-determination of the system's apsidal motion rate has been made from the analysis of 11 eclipse timings obtained from 1923 to 1995. Using stellar structure and evolutionary models with modern input physics, tests of the importance of convective overshooting in the core of the more massive B1.5 II-III star of the system have been carried out. Both the analysis of the $\log g - \log T_{\rm eff}$ diagram and the apsidal motion study indicate that value of the overshooting parameter of $\alpha_{\rm ov} \approx 0.5$ is needed to reproduce the observations. Possible effects influencing this estimation have been carefully evaluated. Finally, the tidal evolution of the system (synchronization and circularization times) has also been studied.

3.20 Young Stellar Objects

DeWarf and Guinan continue intensive, long-term photometric monitoring of SU and AB Aurigae, two of the brightest archetypical classical T Tauri stars (CTTS). Photoelectric photometry of these stars is made using the Four College APT. The photometry is done using intermediate-band filters very closely matched to the Strömgren *uvby* system. SU Aur is observed to undergo rapid and dramatic light variations. Large ($\Delta V \approx \Delta y \approx 0.40$ mag) *eclipse-like* dimming events have been observed frequently, but with no predictable regularity. Referred to as ''UXor'' phenomenon after the prototype UX Ori, these light variations also appear not to be accompanied by spectral changes (i.e., veiling effects). This implies possible obscuration of the star by dust with scattering properties similar to ISM dust. Since CTT stars are pre-main sequence stars with extensive accretion disks, these dimming events could indeed be caused by concentrations of matter orbiting in the outer regions of the disk that temporarily obscure the star and the hotter central regions of the accretion disk. It is also possible that dust clouds condense from ejected matter and temporarily obscure the star. In a previous paper, DeWarf, Guinan, and Radnor High School student T. Shaughnessy derived the interstellar absorption to SU Aur (DeWarf *et al.* 1998). Combining the ISM extinction with the distance by Hipparcos provided for the determination of the absolute brightness and the color. These values place SU Aur well above the main-sequence for its respective unreddened color (or spectral type). Plotting SU Aur on PMS evolution tracks yielded an age of about 4 Myrs. Noteworthy in the currently analyzed observations for the 1998/99 season are possible short period variations in brightness that could arise from the rotational modulation of light by starspots. Several T Tau stars have their rotation periods established this way. They find a rotational period of about 2.65 days for SU Aur. The results of this analysis will be submitted for publication in 2000.

AB Aur, the probable proper motion pair of SU Aur, is observed less frequently per night and shows only small light variations ($\pm$ 0.07 mag in u and $\pm$ 0.03 mag in y). During 1999 we detected a rare UXor event lasting a few days. As far as we know, this is the first time a UXor event has been observed for this hotter early T Tauri type star. Other Young Stellar Objects that are monitored by the Four College APT are: GW Ori, V410 Tau, V833 Tau, V773 Tau, and V1331 Cyg.

3.21 The Sun In Time Program: Rotation-Activity Relations for Solar Analogs of Different Ages

Guinan and DeWarf, with M. Güdel (PSI & ETHZ, Switz.), I. Ribas (U. de Barcelona), and J.D. Dorren (Edinburgh, Scot.), continue with the *Sun in Time* project, a coordinated multiwavelenth study of several nearby, single, solar-type stars selected as proxies for the Sun at several stages in its evolution from ZAMS (Zero Age Main-Sequence) to TAMS (Terminal Age Main-Sequence). The extensive body of ultraviolet (IUE), and X-ray (Einstein and ROSAT) observations of late-type stars is employed to investigate the coronal, transition-region (TR), and chromospheric emission of spectral types close to solar. By considering only main-sequence stars in a restricted range of spectral types (F5 V - G8 V) with measured rotation periods, they focus on the role of rotation in determining activity levels. The exclusion of K stars significantly limits the range of variation of other properties such as mass, radius, temperature, and particularly convection zone depth. There is still, however, a wide spread of rotation rates ($P_{rot} \approx 1.5$ to 40 days) and ages (70 Myr to 9.5 Gyr), and consequently a wide range of magnetic activity. These stars thus constitute a test of the effect on the stellar dynamo of varying the rotation rate, keeping all other parameters approximately constant.

One aspect of this research deals with identifying solar twins. Solar twins are stars nearly identical to the Sun in mass, spectral type, color, T_{eff}, M_V, Fe/H, rotation, etc. However, in the project definition, they also require the star's age to be close ($\pm$ 1 Gyr) to the Sun's. When possible, the optically selected solar twin candidates are compared to the energy distributions and emission fluxes of the present Sun in the X-ray, EUV, FUV, and NUV wavelength regions. These emissions from the Sun arise chiefly from magnetic-dynamo activity. At the present time, the star best matching the Sun in M_V, T_{eff}, age, and chemical abundance [Fe/H] is 18 Sco. Analysis of age-magnetic activity indicators such as L_X, Ca II H&K and Mg II h+k indicate levels of magnetic activity closely matched to the Sun. These proxies of age indicate that 18 Sco is rotating within a few days of the Sun's 25.5 day rotation period. Isochronal fits to the observed values of M_v and T_{eff} were carried out and indicate an age of 4.8 $\pm$ 0.8 Gyr with an inferred mass closely matched to the Sun, $M = 1.0 \pm 0.03\ M_\odot$.

During 1999/2000 three solar type stars of different ages are scheduled to be observed by FUSE in the wavelength range of 900 − 1200Å. This study is being carried out to investigate the evolution of the TR and low corona of a solar-mass star throughout its main sequence lifetime. With FUSE they intend to study the dynamics of the lower layers of stellar atmospheres by investigating line asymmetries and line broadenings; the TR pressures will be estimated through the diagnostic density ratio of the C III (977 / 1176 Å lines). Coordinated, contemporaneous observations with XMM, and optical photometers are planned.

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4. PUBLICATIONS

4.1 Refereed

Anselowitz, T., Wasatonic, R., Matthews, K., Sion, E.M., & McCook, G.P. (1999). The Parentage of Magnetic White Dwarfs: Implications from Their Space Motions, PASP, 111, 702

Audard, M., Güdel, M., Guinan, E. F. (1999). Implications from Extreme-Ultraviolet Observations for Coronal Heating of Active Stars, ApJ, 513, L53

Beauchamp, A., Wesemael, F., Bergeron, P., Fontaine, G., Saffer, R.A., Liebert, J., & Brassard, P. (1999). Spectroscopic Studies of DB White Dwarfs:The Instability Strip of the Pulsating DB (V777 Herculis) Stars, ApJ, 516, 887

Fitzpatrick, E.L. & Massa, D. (1999). Determining the Physical Properties of the B Stars I. Methodology, ApJ, in press

Gänsicke, B.T., Hoard, D.W., Beuermann, K., Sion, E.M., & Szkody, P. (1998). HST/GHRS observations of AM Herculis, A&A 338, 933

Gänsick, B.T., Sion, E.M., Beuermann, K., Fabian, D., Cheng, F.H., & Krautter, J. (1999). TT Arietis: the low state revisited, A&A, 347, 178

Holberg, J.B., Barstow, M.A., & Sion, E.M. (1998). A High-Dispersion Spectroscopic Survey of the Hot White Dwarfs: The IUE NEWSIPS SWP Echelle Data Set, ApJ-Suppl, 119, 207

Koen, C., O'Donoghue, D., Kilkenny, D., Stobie, R.S., & Saffer, R.A. (1999). The EC 14026 stars - XIII. EC 05217-3914 and KUV 0442+1416, MNRAS, 306, 213

McCook, G.P., & Sion, E.M. (1999). A Catalog of Spectroscopically Identified White Dwarfs. ApJSuppl, 121, 1

Messina, S., Guinan, E.F., & Lanza, A. F. (1999). Photospheric Magnetic Activity in a Proxy for the Young Sun: HD 134319. Ap&SS, 260, 493

Messina, S., Guinan, E.F., Lanza, A.F., & Ambruster, C. (1999), Activity cycle and surface differential rotation of the single Pleiades star HD 82443 (DX Leo), A & A, 347, 249.

Moran, C., Maxted, P., Marsh, T.R., Saffer, R.A., & Livio, M. (1999). The orbital parameters of three new subdwarf B Binaries, MNRAS, 304, 535

Napiwotzki, R., Green, P.J., & Saffer, R.A. (1999). A Comparative Study of the Mass Distribution of Extreme-Ultraviolet-Selected White Dwarfs, ApJ, 517, 399

Ribas, I., Guinan, E.F., Fitzpatrick, E.L., DeWarf, L.E., Maloney, F.P., Maurone, P.A., Bradstreet, D.H., Gim'enez, A. & Pritchard, J.D. (2000). The LMC Eclipsing Binary HV 2274: Fundamental Properties and Comparison with Evolutionary Models, ApJ 528, in press

Rolleston, W.R.J., Hambly, N.C., Keenan, F.P., Dufton, P.L., & Saffer (1999). Early-type stars in the Galactic halo from the Palomar-Green Survey II: A sample of distant, apparently young population I stars, A&A, 347, 69

Sion, E. M. (1999). White Dwarfs in Cataclysmic Variables, PASP, 111, 532

Slevinsky, R.J., Stys, D., West, S., Sion, E.M., & Cheng, F.H. (1999). A Time-Series IUE Archival Study of the White Dwarf in the Ultrashort-Period Swarf Nova WZ Sagittae, PASP, 111, 1292

Wagner, R.M., Thorstensen, J.R., Honeycutt, R.K., Howell, S.B., Kaitchuck, R.H., Kreidl, T.J., Robertson, J.W., Sion, E.M., & Starrfield, S.G. (1999). A Photometric and Spectroscopic Study of the Cataclysmic Variable SX Leonis Minoris in Quiescence and Superoutburst, AJ, 115, 787

Wood, J.H., & Saffer, R. (1999). Spectroscopy of the post-common envelope binary HW Virginis, MNRAS, 305, 820

4.2 Conference Publications

de Boer, K.S., Drilling, J., Jeffery, C.S., & Sion, E.M. (1998). Sorting Out Nomenclature in Faint Blue Star Research, in *The Third Conference on Faint Blue Stars*, eds. A.G.D. Philip, J.W. Liebert, & R.A. Saffer (L. Davis Press), 515

Bond, H.E., Schaefer, K.G., Sion,E.M., Saffer, R.A., & Cheng, F.H. (1999). HST observations of the white dwarf in the Hyades binary V471 Tauri, in *11th European Workshop in White Dwarfs*, eds. J.E. Solheim & E.G. Mesištas (ASP Conf.Ser. 169), p. 360

Green, E.M., Liebert, J.W., & Saffer, R.A. (1998). New Evidence for Binarism in Field sdB Stars, in *The Third Conference on Faint Blue Stars*, eds. A.G. Davis Philip, J.W. Liebert, & R.A. Saffer (L. Davis Press), p. 417

Giménez, A., Guinan, E.F., & Montesinos, B. (1999)eds., *Theory and Tests of Convection in Stellar Structure*, (ASP Conf. Ser. 173)

Guinan, E. F. (1999). Comments and Summary on the Workshop on Convection in *Stellar Structure and Evolution*, *Theory and Tests of Convection in Stellar Structure*, (ASP Conf. Ser. 173), 383

Holberg, J.B., Barstow, M.A., & Sion, E.M. (1999). Elemental abusdances in hot white dwarfs, in *11th European Workshop in White Dwarfs*, eds. J.E. Solheim & E.G. Mesištas (ASP Conf.Ser. 169), p. 485

Philip, A.G.D., Liebert, J.W., & Saffer, R.A. (1998), eds., *The Third Conference on Faint Blue Stars*, (L. Davis Press)

Ribas, I., Jordi, C., Giménez, A., Claret, A., & Guinan, E.F. (1999). Test of Convective Core Overshooting Using Evolved Eclipsing Binaries, in *Theory and Tests of Convection in Stellar Structure* (ASP Conf. Ser. 173), p. 253

Saffer, R.A., Keenan, F.P., Hambly, N.C., Dufton, P.L., & Liebert, J.W. (1998). A Large Scale Spectroscopic Survey of Early-Type Stars at High Galactic Latitudes, in *The Third Conference on Faint Blue Stars*, eds. A.G. Davis Philip, J.W. Liebert, & R.A. Saffer (L. Davis Press), p. 97

Sion, E.M. (1999). Workshop Summary: The Future of White Dwarf Research, in *11th European Workshop in White Dwarfs*, eds. J.E. Solheim & E.G. Mesištas (ASP Conf. Ser. 169), p. 485

4.3 Abstracts & Misc.

Anselowitz, T., Wasatonic, R., Sion, E.M., McCook, G.P., & Aannestad, P. (1999). The Spatial Distribution and Kinematics of Cool Metallic Line White Dwarfs, BAAS, 31, 903

Bambeck, D., & Sion, E.M. (1999). An IUE Archival Study of the Hot White Dwarf in the Symbiotic Star RW Hydrae, BAAS 31, 953

Brown, A., Osten, R.A., Ambruster, C.W., Bromage, G.E., & Jeffries, R. (1999), Radio and X-Ray Coronal Activity on Nearby Young K and M Dwarfs, AAS HEAD Meeting, BAAS 31, 09.02.

DePasquale, J., Bochanski, J.J., & Guinan, E.F. (1999). Recent Light Curves and Period Study of the Contact Binary W Ursae Majoris, IBVS, no. 4752

DeWarf, L.E., Guinan, E.F., DiTuro, P., Mittal, R., Güdel, M., & Ribas, I. (1998). In Search of the True Solar Twin, BAAS 30, 1276

Fitzpatrick, E.L., & Massa, D. (1999). The UV/Optical Energy Distributions of the A Stars, BAAS 31, 1238

Fitzpatrick, E.L., & Massa, D. (1998). Modeling the UV/Optical Energy Distributions of the B Stars, BAAS 30, 1315

Guinan, E.F., DeWarf, L.E., McCook, G.P., DiTuro, P., Mittal, R., & Margheim, S.J. (1998). Stellar Evolution in Real Time: Photometry of the ’’Born Again’’ Final Helium Shell Flash Star - Sakurai’s Object (V4334 Sgr), BAAS 30, 1510

Maloney, F.P., Fitzpatrick, E.L., Guinan, E.F., DeWarf, L.E., & Bradstreet, D.H. (1998). Eclipsing Binary Systems in the Magellanic Clouds: HV 2226 and HV2241, BAAS 30, 1402

Maloney, F.P., Maurone, P.A., & DeWarf, L.E. (1998). Simulations and Experiments in Astronomy and Physics, BAAS, 30, 1385

Massa, D., & Fitzpatrick, E.L. (1998). A recalibration of IUE NEWSIPS low dispersion data, BAAS, 30, 1267

Silvestri, N.M., Oswalt, T.D., Wood, M.A., Smith, J.A., Reid, N., & Sion, E.M. (1999). White Dwarfs in Common Proper Motion Binary Systems: Mass Distribution and Kinematics, BAAS 31, 903

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