Villanova University
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This report covers the period from October 2000 to September 2001.

1. PERSONNEL

During the report period, 10/00-9/01, the staff included Assistant Professor Carol W. Ambruster, Instructor Laurence DeWarf, Assistant Professor Edward L. Fitzpatrick, Research Assistant Professor Patrick Godon, Professor Edward F. Guinan, Associate Professor Frank P. Maloney, Professor George P. McCook (Chairperson),Fulbright Fellow Dr. Ignasi Ribas, Research Assistant Professor Rex A. Saffer, Professor Edward M. Sion, and Research Associate Richard Wasatonic. Dr. Elizabeth R. Jewell served as Department Assistant. Mr. Taghi Mirtorabi of the Institute for Advanced Studies in Basic Sciences (Zanjan, Iran) arrived in August, 2001, as a pre-doctoral fellow.

Students John Bochanski, Jessica Castora, Joseph DePasquale, Michael Dulude, Scott Engle, Colleen Henry, Joshua Lake, Kelly Lyons, Ira Nadalin, Christopher Pilman, Jeremy Sepinsky, Michael Stump, Jeffrey Tracey, Joel Urban and Lisa Winter 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 (FC) 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 and AST-0071260.

2.2 Internet Access

The department's WWW address is: phy.vill.edu/astro; email address is: george.mccook@villanova.edu. Laboratory work for non-science majors can be found at: astro4.ast.vill.edu. This project is supported by the Pew Charitable Trusts. The Villanova White Dwarf Catalog can be found online at:www.phy.villanova.edu/astro/WDCatalog/index.html.

3. CURRENT RESEARCH

3.1 B Stars in the Milky Way and the Magellanic Clouds

Fitzpatrick and D. Massa (Emergent IT) successfully proposed a Cycle 2 Observing Program with the *Far-Ultraviolet Spectroscopic Explorer (FUSE)* satellite, entitled *A Study of the Atmospheres of the Main Sequence B Stars*. Far-UV spectra (912 – 1180 Å) will be obtained for 15 mid- to late B-type main sequence stars (“BVs”) in the Orion OB1 association. These data will be part of a comprehensive investigation of the ability of current model atmosphere calculations to reproduce the observed properties of the BVs, including their spectral energy distributions and detailed absorption line spectra. This study will provide a benchmark and a “reality check” for studies of more exotic early-type objects, since the BVs are the hottest and most luminous stars whose atmospheres can be modeled with the simplifying assumptions of LTE, plane-parallel geometry, and hydrostatic equilibrium. The targets span a T_{eff} range of 11,000-17,000 K, have *vsini* values from 50 km s^{-1} to 400 km s^{-1}, are lightly reddened to minimize the impact of the ISM on the observed spectra, and are located in a relatively small volume of space to minimize differential extinction effects. The sample is large enough to allow general conclusions to be drawn and to distinguish individual peculiarities from general trends. These data will be ideal for evaluating the success of current stellar atmosphere calculations and examining the effect of rapid rotation on the far-UV energy distributions of the BV stars. Nine of the 15 targets were observed by *FUSE* in early January 2001. Fitzpatrick and Massa presented the results from an initial examination of these data at the June 2001 meeting of the American Astronomical Society.

Fitzpatrick, D. Massa (program P.I.), A. Fullerton (Johns Hopkins University), and R. Prinja (Univ. Coll., London) successfully proposed a Cycle 2 *FUSE* program entitled *CNO Abundances in Large Magellanic (LMC) Cloud BN and BC Supergiants*. In this program, far-UV spectra of 10 luminous stars in the LMC will be obtained. This sample of stars spans a narrow temperature range (spectral types B0.7 thru B1.5) but includes objects with a variety of chemical composition anomalies (involving carbon, nitrogen, and oxygen) as well as apparently normal objects. By carefully matching the normal and anomalous stars, the relative strengths of various stellar wind features in the far-UV spectra can be used to determine the *relative* carbon, nitrogen, and oxygen abundances among the different groups. By employing a simplified model for the origin of carbon, nitrogen, and oxygen abundance enhancements (basically, assuming that the anomalous abundances result from a mixture of normal gas and gas with carbon/nitrogen and oxygen/nitrogen ratios fixed by nuclear processing), the relative abundances can be converted into *absolute* abundances. The ultimate scientific goal of this program is to help elucidate the origins of composition anomalies in massive stars, in particular the BN/BC phenomenon. The observations for this program have not yet been performed.

3.2 Eclipsing Binaries in the Large Magellanic Cloud (LMC)

Fitzpatrick, I. Ribas (U. of Barcelona), Guinan, DeWarf, Maloney, and D. Massa (Emergent IT) completed a study of the LMC eclipsing binary (EB) system HV982, and currently have a paper describing the results in press with the ApJ. This investigation is part of an ongoing research program whose goals are: 1) to derive essentially complete descriptions of the stellar properties of detached, B-type EB systems (e.g., temperature, mass, radius, and luminosity) for testing and constraining stellar evolution theory; and 2) to measure precise individual distances for the systems, from which the general LMC distance can be derived. Because of its role as a fundamental calibrator for distance indicators which reach far beyond the Local Group of galaxies, the LMCs distance is a particularly important factor in determining the size scale of the Universe.

The study of HV982 incorporated ground-based spectroscopy and photometry and space- based spectrophotometry from the Hubble Space Telescopes Faint Object Spectrograph (FOS) and Space Telescope Imaging Spectrograph (STIS). The ground-based spectra were ‘‘velocity-disentangled,’’ revealing the details of the optical spectrum of each member of the binary system. These results, plus an analysis of the systems photometric light curve and spectral energy distribution, reveal HV982 to be composed of a pair of entirely normal, slightly evolved, early-B stars, whose observed properties are consistent with results from stellar atmosphere and structure theory. The normalcy of the HV982 system allows a precise estimate of its distance, which is 50.2 ± 1.2 kpc. This distance is substantially larger than that found for the previously analyzed system HV2274. The interpretation of these results is ambiguous. If they represent independent measures of a uniquely defined quantity, i.e., the distance to the LMC, then they are only marginally consistent with each other. Alternatively, the results may indicate that the spatial distribution of LMCs stellar population is more complex, and has a much greater line-of- sight depth, than the usually assumed inclined disk. Such complexity would call into question the LMCs value as a calibrator of the cosmic distance scale.

Maloney, Ribas, Fitzpatrick, Guinan, and DeWarf, together with students Jessica Castora and Jeremy Sepinsky, completed analysis of another LMC EB system, EROS1044, and presented the results at the June 2001 meeting of the American Astronomical Society (Pasadena, CA). The analysis was virtually identical to that applied to HV982, as described above, and revealed the EROS1044 system to be composed of a pair of normal, mildly evolved B2 stars. The distance derived for the system is 46.3 ± 1.4 kpc. EROS1044 is located in the *Bar* of the LMC as is the system HV2274. These two systems yield completely consistent results, and indicate a distance to the center of the LMCs *Bar* of 46 kpc. These results are in marked contrast to that for HV982 and suggest that the latter is located significantly behind the *Bar*. Analysis of additional systems is proceeding and will focus on mapping out the spatial distribution of the LMCs early-type stellar population.

3.3 LMC Eclipsing Binary Systems with Cepheid Components

Guinan, Ribas, Fitzpatrick, Maloney, and DeWarf continue their work on the Cosmic Distance Scale with Douglas Welch, David Lepischak (Can.)and Andrzej Udalski (Pol.). The distance to the LMC and the Cepheid P-L law form the backbone of the Cosmic Distance Scale and the determination of H_o. In spite of concerted efforts of many investigators, the zero-point of the Cepheid P-L law and the LMC distance remain controversial and uncertain to $\sim 10-15\%$. To help resolve this problem, the group is continuing the HST Cycle 10 program to determine the physical properties and distances of two rare, recently discovered LMC long period eclipsing binaries (EBs) that contain Cepheid components. The HST/STIS observations of these extraordinary systems could hold the key to determining simultaneously the Cepheid P-L zero-point and LMC distance. The two systems are a 17.3 mag LMC EB (SC 21-40876) with $P_{orb} = 801$d, which contains a classical Cepheid with $P = 2.03$d, and a 14.5 mag LMC EB (SC16-119952) with a $P_{orb} = 397$d with a 4.97d Cepheid. The HST Cycle 10 program (22 orbits) of HST/STIS low dispersion (115-900nm) spectrophotometry will be used to determine T_{eff}, [Fe/H], and ISM extinction while the radial velocity variation of the Cepheids will be measured from STIS medium dispersion spectroscopy. They have requested STIS medium resolution spectroscopy in the UV and near-IR to obtain accurate double-line orbital radial velocity curves of the component stars. These RVs will be combined with light curves from OGLE and MACHO programs and spectrophotometric T_{eff} and $A(\lambda)$ that will yield accurate stellar masses, radii, luminosities, and distances. The HST observations of these key EBs offer the opportunity to probe the LMC distance, and ‘‘self-calibrate’’ the Cepehid P-L relation and to determine directly the fundamental physical properties of Cepheids themselves.

3.4 The Interstellar Medium

Fitzpatrick and D. Welty (U. Chicago) published a study of time-variable interstellar gas absorption towards the Milky Way halo star HD219188. Although interstellar absorption lines were first recognized as such by their invariance in the spectra of binary stellar systems, recent investigations have provided an abundance of examples of temporally-variable line strengths and velocities. Such variations may arise due to motions of the background stars on whose spectra the interstellar lines are impressed, or motions of the interstellar gas clouds themselves, or changing physical conditions within the interstellar clouds, or any combination of these effects. In many instances, the time variability is likely related to small-scale spatial structure in the interstellar medium. Determining the scale and nature of such structure is crucial to understanding the overall topology of the interstellar medium. Towards HD219188, Fitzpatrick and Welty observed the appearance – and continued strengthening – of a new strong, narrow Na I absorption feature at a velocity of 38 km s^{-1}. It appears that, due either to motions of HD219188 or the interstellar medium, a relatively cold, quiescent cloud has moved into the HD219188 line-of-sight. Estimates of the physical conditions have been derived and suggest the hydrogen must be partially ionized within the cloud. Continued monitoring of HD219188 will help refine estimates of the clouds properties and allow its structure to be probed as it sweeps across the HD219188 line-of-sight.

3.5 Young Stellar Objects: SU Aurigae

DeWarf and Guinan, with students J. Sepinsky and S. Engle, continue their study of the classical T Tauri star (CTTS) SU Aurigae (HD 282624; G2 IIIe; $<V> = +9.20$ mag; $<B-V> = +0.90$). CTT stars are pre-main sequence stars with extensive accretion disks. Photometric observations have been made using the 0.8 m Four College Automatic Photoelectric Telescope (FCAPT), utilizing intermediate-band filters very closely matched to the Strömgren *uvby* system. These concentrated (nightly) observations began in Oct 1993 and continue to the present. SU Aur is observed to undergo rapid and dramatic ($\Delta V \approx \Delta y \approx 0.40$ mag) light variations (see DeWarf, Guinan & Shaughnessy , 1998, *IBVS* 4551). The light variations appear not to be accompanied by significant spectral changes, which implies possible obscuration of the star by dust with properties similar to the intersteller medium (ISM). This is most likely due to dust clumps around low mass companions (accreting protoplanets) either warping the circumstellar disk, or exciting tidal waves which would heat and puff the disk up locally when dissipating shocks. High dispersion echelle spectra of SU Aur have been obtained with the 4 m Blanco telescope at CTIO. One spectrum was secured during a large dimming event observed during Dec 2000. Current research includes an analysis of these spectra to probe the velocity structure, temperature, and density of the accreting gas. In addition, they are conducting a systematic search, spanning decades of ground-based photometry, for regularities in these planet-induced obscurations.

The light variations of SU Aur, like many CTT stars, are complicated. In addition to the short-term ‘‘dips’’ in the light curve, the star also varies on time scales of days, months, and years. Recently analyzed APT observations, especially the short period variations in brightness caused by rotational modulation of light by starspots, yielded a rotational period of about 1.7 days (Nadalin, DeWarf & Guinan, 2000, *IBVS* 4987). SU Aur is observed nearly edge-on, therefore combining the rotation period with the projected rotational velocity ($v \sin i$) resulted in a stellar radius of about 2.2 $R_\odot$. The star spot/plage sizes are currently being modeled using the software package Binary Maker 2.0 (Bradstreet, 1993, Contact Software, Norristown, PA) to determine the extent of coverage as an estimate of the magnetic field strength or accretion rate in this early-type object. Preliminary results indicate that spot coverage can be over 1% greater on one side of the stellar surface than on the other, with an average spot hotter than the photosphere by a factor of 10%. This research is supported in part by NSF/RUI Grant AST-00 71260. Sepinsky and Engle would also like to thank the Delaware Space Grant College Consortium for their generous support through the Undergraduate Summer Research Assistance program.

In addition to observing SU Aur, differential photometry of its probable proper motion pair, AB Aur, is conducted at the same time. AB Aur is observed less frequently per night and shows only small light variations ($\pm$ 0.07 in *u* and $\pm$ 0.03 in *y*). Other Young Stellar Objects that are intensively monitored are: GW Ori, V410 Tau, V833 Tau, V773 Tau, and V1331 Cyg.

3.6 ZAMS K Dwarfs

Ambruster and collaborators F.C. Fekel (Ctr of Excellence, Tenn.St.U) and A. Brown (CASA, U. Colo.) continued work on a small, homogeneous group of solar neighborhood, zero-age main-sequence (ZAMS) stars, focussing on implications for the evolutionary status of these stars. The six stars, supplemented by AB Dor, are all single (with 1 possible exception), have spectral classes of K0-K2 V, near-primordial lithium abundances, and space motions consistent with the Pleiades Moving Group. The only significant variable is rotation: rotation periods range from about 8 hours to 7 days.

Constraints from high quality optical data suggest that several of the stars have radii that are 0.1-0.2 $R_\odot$ larger than the main sequence radius expected from their spectral type, and thus might still be slightly pre-main-sequence. Radii were calculated in three ways and compared: 1) the Barnes-Evans relation; 2) the Stefan-Boltzmann law; and 3) $R \sin i$.

Alternatively, very recent theoretical work (Mullen & McDonald, ApJ, Sep. 20, 2001) has shown that, for active M dwarfs, strong magnetic fields can alter the physical conditions underlying the onset of convection, causing stars to appear slightly cooler and less luminous than in the non-magnetic case. The resulting distorted V and (B-V) values, and possibly spectral types, could skew radius calculations that depend on V and (B-V) as input, for example, the Barnes-Evans or Stefan-Boltzmann relations. Thus, if the effects of strong magnetic fields in K dwarfs parallels that for M dwarfs, the stars of our sample might be slightly earlier (and more massive) than their spectral classes indicate, and already on the ZAMS.

Since the derived $R \sin i$ values are independent of V and (B-V), they should be reliable lower limits to R^*. In fact, for five of the K dwarfs, $R \sin i$ values exceed the main sequence radius of a K0 V star (0.81 $R_\odot$).

Thus there are now two ways to interpret the $R \sin i$ radii: 1) the spectral classes are accurate, the historically brightest (non-flare) V measurement for each K dwarf, V_{max}, and its (B-V) counterpart, reflect a minimally spotted photosphere undistorted by strong magnetic fields, and the stars are slightly above the main sequence; or 2) strong magnetic fields cause a slight distortion in both the spectral classes and V_{max}, the stars are actually slightly earlier (and more massive) stars disguised as K dwarfs, and are actually on the ZAMS.

3.7 Starspots and Plages on the Active G8 IV-III Star λ Andromedae from Wing Near-IR TiO band Photometry

Wing near IR TiO and V-band photometry of the bright chromospherically-active star, λ And (G8 III-IV; V $\sim +3.82$; B-V $= +1.08$, d (Hip) = 25.8 pc; $P_{rot} \sim 54.5$ days) is being carried out by Richard Wasatonic (Wasatonic Obs.), Guinan and M. T. Mirtorabi (Inst. for Advanced St., Zanjan, Iran). λ And is a long-period RS CVn star and has sinusoidal-like light variations with periods that range from 53-57 days. These light variations are relative large (V-amp $\sim 0.10-0.25$ mag) and are believed to arise from the uneven (and changing) distribution of large dark starpots on its differentially rotating surface. Like other RS CVn variables, λ And is a moderately strong coronal X-ray source and also has strong transition region and chromospheric line emissions.

The Wing near-infrared TiO and V-band photometry of λ And was conducted during 1996 - 2001 with small telescopes located in Zanjan, Iran and Allentown, Pa. Also, over 20 years of nearly continuous intermediate-band Strömgren and UBV photometry was carried out at Villanova University Observatory. The Wing narrow-band 3 filter system (Wing, JAAVSO, 1992, 21,42) uses 3 filters centered on the TiO γ (0,0) bandhead at 719 nm, and two filters centered on essentially line-free spectral regions at 754 nm and 1040 nm, respectively. A photometric TiO-index (that measures the strength of the TiO molecular absorption) is formed from the observations. The index is calibrated with temperature (T_{eff}) by observations of standard stars having spectral types that range from G0 to M9. Because starspots are cool regions they should have strong temperature-dependent TiO absorptions and the TiO photometry can provide measures of the fractional starspot coverage (fill-factor). Also, as the star rotates, the variations in the TiO-index light curve can yield information on the distribution of starspots over the star's photosphere. Combining the TiO light curves with continuum 550 nm and the near-IR light curves makes it feasible to investigate the contributions of white light plages and dark starspots to the continuum light curves. In the case of λ And, they find strong evidence that the observed light variations arise primarily from bright plage regions. This is contrary to the widely held view that the light variations of λ And and those of most RS CVn stars arise exclusively from the rotational modulation in brightness from dark (cool) starspots.

This research is sponsored in part from NSF/RUI Grant No. 00-71260 and a Small Research Grant from the American Astronomical Society to Wasatonic.

3.8 HD 209458: An Eclipsing Star-Planet Binary System

Exosolar planets now have been detected around more than 80 nearby solar type stars. The discoveries of these planets were primarily made through high precision spectroscopic observations of the small reflex motions of the host stars that are produced by the weak gravitational pull of the planets. The analysis of these observations yields the orbital period (P), semi-major axis (A), and the product of the planet's mass (Mp) and the sine of its orbital inclination Mp sin(i). The majority of these exosolar planets have masses a few times that of Jupiter. In one of these systems, HD 209458 (G0V, V-mag = +7.64 mag, B-V = +0.58), the inclination of the planet's orbit is seen nearly edge-on so that the orbiting planet transits across the projected disk of the star. This produces a small decrease in the light received from the star as the transit takes place. Recently Charbonneau *et al.* (2000) and Henry *et al.* (2000) have reported observing planetary transit events for HD 209458 that lasts ~3.5 hrs and with a light loss of ~1.6%. Modeling of these data yields the inclination of the orbit and the radius and mass of the planet.

Guinan, McCook, Ribas and student Michael Stump have carried out *uvby* photoelectric photometry of HD 209458 during several transit events. The observations were made with the 0.8 m Four College Automatic Photoelectric Telescope (FCAPT). The light curves were modeled with the Wilson-Devinney program and excellent fits were made to the data. From the observations the radius of the orbiting planet was found to be Rp = 1.51 Rjup. The orbital period of the system was refined by computing a new period by combining our transit times with the previous transit times. Now the period is known to a precision of ±30 sec.

Using the recent evolutionary codes of Schaller *et al.*, the mass and evolutionary age of the G0 V host star was computed. The input parameters for these model fits were its absolute magnitude, temperature, and solar-type metallicity. HD 209458 was found to have an age of ~4.5±0.4 Gyr and a mass of 1.10 $M_\odot$. Remarkably, the age of HD 209458 is nearly identical to the age of our Sun and solar system of 4.58±0.06 Gyr.

This research is supported by a NSF/RUI Grant AST-0071260 which we gratefully acknowledge.

3.9 A Low Mass Tertiary Companion of R Canis Majoris

Ribas, Guinan, and Arenou (Meudon) have developed a method to determine orbital properties and masses of low-mass bodies orbiting eclipsing binaries. This method combines long-term eclipse timing modulations (light-travel time or LTT effect) with short-term, high-accuracy astrometry. As an illustration of the method, a comprehensive study of Hipparcos astrometry and over a hundred years of eclipse timings of the low-mass Algol eclipsing binary R Canis Majoris has been caried out. A simultaneous solution of the astrometry and the LTTs yields an orbital period of $P_3 = 93.2 \pm 0.8$ yr, an ''light-time''(LTT) semiamplitude of 2561±114 s, an angular semi-major axis of $a_{12} = 116 \pm 5$ mas, and values of the orbital eccentricity and inclination of $e_3 = 0.47 \pm 0.03$, and $i_3 = 93.6 \pm 5.0$ deg, respectively. Adopting the total mass of R CMa of $M_{12} = 1.24 \pm 0.05\ M_\odot$, the mass of the third body is $M_3 = 0.34 \pm 0.02\ M_\odot$ and the semi-major axis of its orbit is $a_3 = 18.8 \pm 0.4$ AU. From its mass, the third body is either a dM3−4 star or a white dwarf. With the upcoming microarcsecond-level astrometric missions, this technique can be successfully applied to detect and characterize long-period planetary-size objects and brown dwarfs around eclipsing binaries. Possibilities for extending the method to pulsating variables or stars with transiting planets are also being tested.

3.10 Brown Dwarf Companion to V471 Tau

Guinan and Ribas have carried out an analysis of about 160 eclipse timings spanning over 30 years of the Hyades eclipsing binary V471 Tauri that shows a long-term quasi-sinusoidal modulation of its observed eclipse arrival times. The O−Cs have been analyzed for the ''light-time'' effect that arises from the gravitational influence of a tertiary companion. The presence of a third body causes the relative distance of the eclipsing pair to the Earth to change as it orbits the barycenter of the triple system. The result of the analysis of the eclipse times yields a light-time semi-amplitude of 137.2±12.0 s, an orbital period of $P_3 = 30.5 \pm 1.6$ yr and an eccentricity of $e_3 = 0.31 \pm 0.04$. The mass of the tertiary component is $M_3 \sin i_3 \simeq 0.0393 \pm 0.0038$ M$_\odot$ when a total mass of 1.61 ± 0.06 M$_\odot$ for V471 Tau is adopted. For orbital inclinations $i_3 \gtrsim 35°$, the mass of the third body would be below the stable hydrogen burning limit of $M \approx 0.07$ M$_\odot$ and it thus would be a brown dwarf. IWhen these astrometric measurements are available (covering half of the orbital period) they will unambiguously yield the orbital inclination and the semi-major axis with an error below 0.5 mas, corresponding to a few percent uncertainty of the tertiary object's mass. This will represent the first direct dynamical mass determination of a brown dwarf with known age, chemical composition, and distance. Moreover, in the next several years it should be feasible to image directly V471 Tau C in the IR (using coronographic observations made with adaptive optics or observations made from space) as it moves toward maximum angular elongation from the eclipsing pair. Once these observations are carried out, and if V471 Tau C is indeed confirmed to be a brown dwarf, it will make an excellent benchmark for understanding the properties and evolution of these objects. Astrometry with the HST Fine Guidance Sensor is being carried out during 2001/02.

3.11 Optical and X-ray Observations of the Black Hole X-ray Binary System Cygnus X-1

Guinan, McCook, Villanova students Christopher Pilman, JOel Urban and Jeremy Sepinsky, and I. Ribas (Un. de Barcelona) are studying Cygnus X-1, one of the best studied variable X-ray sources. About 30 years ago this strong X-ray source was identified with a 9th mag spectroscopic binary (HDE 226868) having an orbital period of P = 5.60 days. This binary system shows complicated, low amplitude ellipsoidal light variations, and consists of a O9.7 Iab star and a probable 7-10 M$_\odot$ black hole companion with an x-ray emitting accretion disk. Long-term X-ray and radio observations of the system show it to change on times scales of seconds (flickering), minutes-hours (flares), days (orbital), months (low/hard states and high/soft x-ray states). Some of the long-term x-ray and radio variations appear to be related to the semi periodic changes in the accretion disk and also may arise from a precessing disk and jet.

Strömgren *uvby* and Hα narrow and intermediate band photometry of Cyg X-1 is being carried out with the Four College Consortium 0.8m Automatic Photometric Telescope (FCAPT). The observations started in September 2000 and are continuing through the Fall 2001. Light curves have been formed from the photometry, and show to the first approximation, the 5.60 day low amplitude cos 20(y-amp = 0.045 mag) light variations expected to arise from the tidal and rotational distortion of the luminous supergiant. However, during phase 0.20P to 0.35P persistent brightness enhancements of 0.02-0.03 mag are frequently observed. (Zero phase is the time when the O9 star is at the orbital conjunction, nearest to the observer.) The least active orbital phases occur near 0.45 - 0.65P. Also present are apparently random light variations of about 0.01 mag. These most likely arise from small light variations (non-radial pulsations) of the O9 supergiant. The Hα photometry reveals a weak variation of the line emission/absorption as a function of orbital phase. The ongoing X-ray observations of Cyg X-1 are being carried by RXTE satellite have been combined with the optical photometry to search for correlations. An analysis of the light curves using the Wilson-Devinney Binary Code is being conducted to compute new values of the orbital inclination and mass ratios. In addition, an examination and analysis of the IUE observations of Cyg X-1 are being conducted. The results of the modeling of the optical, x-ray, and uv observations are being prepared for publication. An integrated model of the system has been constructed in which the light enhancements observed near 0.3 phase appear to arise from the impact of the stellar wind on the accretion disk.

This research is supported by NSF/RUI Grant 00-71260 and by the Undergraduate Summer Research Assistance Program Grant from the Delaware Space Grant College Consortium.

3.12 The Sun in Time: EUVE and FUSE Observations of the Solar Analogs with Different Ages

Guinan, Ribas and Graham Harper (CASA) are studying Extreme Ultraviolet Explorer satellite (EUVE) and the Far Ultraviolet Spectroscopic Explorer (FUSE) observations of an homogenous sample of single G0V - G5V stars with well known rotation periods and ages. The program stars are nearby and range in age from ∼130 Myr to ∼8.5 Gyr and with corresponding rotation periods that range from ∼2.5d to ∼35d. This program is part of a comprehensive study of the *Sun in Time* across the electromagnetic spectrum that started in 1988. The EUVE observations cover the wavelength region from 80 Å to ∼400Å – a spectral region that is rich in important coronal line emission that cover coronal temperaturs from ∼1MK to ∼20MK. FUSE covers a much shorter wavelength range of 910-1190Å but this wavelength contains several important transition region (TR) and coronal line emissions. The EUVE and FUSE observations fill a critical wavelength and energy gap in the *Sun in Time* program and complement observations of the same stars in the X-ray region (corona) made with ROSAT, SAX, ASCA, XMM, and Chandra, in the UV-NUV (TR and chromosphere) made using IUE and HST, and at cm-radio wavelengths (non-thermal corona) obtained with the VLA. In addition, optical photometry of stars in the program has been carried out for over 10 years (using robotic telescopes). The photometry permits the rotation periods, activity cycles, and starspot fill-factors and differential rotation of the program stars to be determined. Overall, the *Sun in Time* program is important for the understanding of the evolution of magneto-dynamic atmosphere phenomena, and the associated high energy emissions of the Sun and of solar type stars.

From the stars in the sample, the crucial question of the influence of the young Sun's observed strong X-ray, EUV and FUV emissions have on the developing planetary system – in particular on the photochemical and photoionization evolution (and possible erosion) of early planetary atmospheres and ionospheres. To this end, spectral irradiance tables for the Sun at different ages (flux at 1.0 AU; 1Å to 5500Å) are being constructed. The group is studying the implications that the young Sun's greatly enhanced high energy radiation (which includes energetic flaring) may have had on the formation and development of life on Earth over ~3.5 billion years ago.

This research is supported by NASA FUSE Cycle 1 & 2 Grants NAG 5-8985 and NAG 5-10387 and EUVE Mini-grant SA2085-26310 which we gratefully acknowledge.

3.13 The Sun in Time: Short-term and Long-term Solar Forcing on Earth's Climate - Past, Present and Future

Guinan and Ribas are studying variations of the Earth's climate with time and investigating the effects that the Sun's nuclear and magnetic evolution have on global climate. Standard evolutionary models constructed for the Sun, show that the Zero-Age Main Sequence (ZAMS) Sun, some 4.6 Gyr ago, was slightly cooler and smaller than today and had an initial luminosity of $L_\odot$ of ~72 % of the present Sun. So that in the early stages of the solar system, the young Sun's irradiance and ''Solar constant'' were significantly diminished. While on the main sequence, as the pace of nuclear fusion increases, the Sun's luminosity increases. Calculations indicate that as early as 1.0 Gyr from now, the nuclear aging of the Sun should significantly warm-up the Earth making it inhabitable for most current terrestrial life forms. Of course, in the distant future some 5.5 Gyr from now, the Sun exhausts its hydrogen fuel and rapidly expands and cools to become a red giant. During red giant stage, the Sun's atmosphere expands beyond the Earth's orbit, thus incinerating the Earth but possibly creating temporary life zones further out in the solar system.

On the other hand, studies of solar analogs (G0-5 V stars) with different ages show that the young Sun was rotating more than 10 times its present rate of $P_\odot$~25.5d and had correspondingly strong UV chromospheric and transition-region and X-ray and EUV coronal emissions that are produced by a vigorous magnetic dynamo. Despite its lower luminosity, the studies of these young suns from orbiting X-ray and UV satellites show that the young Sun had very strong X-ray and UV emissions up to several hundred times stronger than the present Sun. From the study of solar type stars with different ages, it is shown that the Sun loses angular momentum with time via magnetized winds (magnetic breaking). In response to slower rotation, the solar dynamo strength decreases with time causing the Sun's UV and X-ray emissions also undergo significant decreases. Through photochemical and photoionization processes, the strong X-ray and UV emissions of the young Sun could have had a major influence in the evolution of the atmospheres, ionospheres and the climates of the terrestrial planets, including the Earth.

This research is supported by NASA FUSE Grants NAG 5-8985 & NAG 5-10387 and EUVE Mini-grant SA2085-26310 which we gratefully acknowledge.

3.14 The Sun ~4.5 Billion Years Ago: A Multi-frequency Study of the Young Solar Analog HD 129333 (= EK Dra)

Guinan, Ribas, McCook, Villanova students John Bochanski and Joseph DePasquale, Güdel(ETHZ) and David Dorren (Scotland) continue work on EK Draconis (HD 129333; V = 7.50 mag; G1 V; B-V = +0.61) which is a very young (near ZAMS), single solar type star with a rotational period of rotating P~2.7 days. The U,V,W space motions of EK Dra show it to be a probable member of the Pleiades Moving Group implying an age of ~70 Myr. Providing a look-back of the Sun shortly after its arrival on the Zero-Age Main Sequence some 4.5 Gyr ago, EK Dra is one of the youngest stars solar-type stars on our *Sun in Time* Program. Appropriate for its youth and related rapid rotation, EK Dra has very high levels of coronal X-ray and EUV emissions and strong FUV-UV transition-region and UV-NUV chromospheric line emissions that are generated from a robust magnetic dynamo. For example, its average X-ray luminosity of $L_x = 9\times10^{29}$ ergs/s is several hundred times larger than that observed for the present Sun (P_{rot}=25.6d; Age = 4.58 Gyr).

Photometry of EK Dra has been carried out since 1983. The photometry shows relatively large rotationally induced brightness variations (V-Ampl. from 0.05 - 0.09 mag) with periods that range from 2.55d to 2.80d. These light variation have been modeled with dark starspots that have been found to cover up to 15 percent of the stellar surface. The apparent variation in the observed period is explained by the effects of differential rotation in which starspot groups form at different stellar latitudes having different rotation rates. The photometry also shows a long-term cyclic variation in the star's brightness which is a manifestation a ~12 year starspot cycle. This is remarkable similar to present Sun's activity cycle length of 11 years. However, the luminosity variations observed for EK Dra are much larger than the present Sun which varies only about 0.2 percent over an average activity cycle. For EK Dra, the maximum and minimum brightness occurred during 1994 and 2000. However, the variation in light between maximum and minimum brightness is large: the difference in brightness between minimum and maximum is 0.120 mag at 350nm and 0.079 mag at 550nm. X-ray observations carried out over the same time by ROSAT and XMM show corresponding large variations in the star's coronal X-ray flux.

3.15 The Photometric Programs Conducted by Villanova University with the Four College Automatic Telescope: 2000 - 2001

Guinan and McCook continue to coordinate the observations of different types of variable stars with the 0.8m Four College Automatic Photometric Telescope (FCAPT). Undergraduate students from Villanova University and Eastern College are participating in several of these FCAPT programs. Most stars are observed with filters matched to the UBVRI or the Strömgren *uvby* systems. Some objects are also observed with Hα or Hβ narrow and intermediate-bands filters. Some representative Villanova FCAPT projects are: (1) ''The Sun in Time'' - photometry of about 15 solar-type stars of different ages to determine star spot coverages, rotation periods, activity cycles, (2) ''Stellar Evolution in Real Time'' that includes photometry of Nova Aql 1999b, and the rapidly evolving post-AGB stars - Sakurai's Object and FG Sge, (3) ''Eclipsing Binaries as Astrophysical Laboratories'' - the systems observed during 2000/01 include the high-mass eclipsing binaries: μ_1 Sgr, V380 Cyg, VV Cep, and Y Cyg and the low mass systems: CM Dra, CU Cnc, V471 Tau. Results of searches for the light-time effect in the eclipse arrival times of the eclipsing binary V471 Tau revealed the presence of a possible brown dwarf companion . (4) ''Chromospherically Active Single and Binaries'' - the study of starspots and activity cycles of the following stars: V711 Tau, UX Ari, lambda And, IM Peg, FK Com, and the dMe flare star AD Leo. (5) ''Photometry of T Tauri Stars'' - which includes SU and AB Aur and V410 Tau and a few other PMS stars. (6) ''Stellar Prototypes'' - this program includes long-term photometry of the pulsating AGB star Mira, the bright Be star ω Ori, and observations of the X-ray (black hole candidate) binary Cygnus X-1.

In addition to these programs several other different types of variable stars are also being observed with the FCAPT. Coordinated observations of some of the program stars are being carried out with FUSE, Chandra, XMM, and HST. Several undergraduates have participated in this program during 2000/2001. They are John Bochanski, Joseph DePasquale, Paul DeTuro, Jonathan Hargis (Eastern College), Joshua Lake (Eastern College), Joel Urban, Ira Nadalin, Jeremy Sepinsky and Jeffrey Tracey.

3.16 Analysis of the dM4.5+dM4.5 Eclipsing Binary CM Draconis

Guinan, Ribas, Bradstreet (Eastern), and Hargis (Eastern) have also analyzed 85 times of minimum light of the eclipsing binary CM Draconis (dM4.5+dM4.5, P=1.268 days, Vmax=11.5 mag) obtained between 1995 and mid-2000. With the possibility of planetary transits in this system (see IAUC 6423), I-band photometry has been carried out with particular attention being paid to observing the primary and secondary eclipses. In addition to searching for transit events, the eclipse minima have been monitored to look for evidence of the ''light-time'' effect. The observed - computed (O-C) timings (from a linear ephemeris) determined from the analysis of the eclipse minima show evidence of small 10-20 s) variations on different time scales. The magnitude of the short-term variations appears to be correlated with the presence of wave-like disturbances in the outside eclipse portions of the light curves. These quasi sinusoidal light variations are attributed to the presence of star spots on these two rapidly-rotating dM4.5 stars. Simulations generated using Binary Maker show that the observed time of minimum light can be displaced typically by $\sim 10-15$ seconds from an uneven distribution of star spots on the surface of the cool stars. The preliminary results of this study were presented at the 197th AAS Meeting (Hargis *et al.* 2000).

3.17 Nova Aquilae 1999-2

Eastern Univ. researchers D. Bradstreet, F. Jewett and D. Steelman have been tracking the nova Aquilae (1999-2) together with Guinan, McCook and Villanova student J. Tracey. Nova Aquilae 1999-2 (V1494 Aql) reached a maximum brightness of V = +3.8 on 03 December 1999 making it one of the brightest novae observed in the northern hemisphere. Photoelectric photometry began at Villanova University on 08/09 December 1999 and continued in March 2000 in Arizona using the 0.8m APT. The APT photometry was done using Strömgren *uvby* and Hα narrow/wide filters. This photometry was continued through the end of 2000 when the star became too faint to observe. A visual light curve was constructed from all the available photometry. From the rapid decline in brightness, the system is classified as a *fast* nova. From March-August 2000 quasi-periodic oscillations were detected in the light curve up to 0.5 mag in amplitude with a characteristic timescale of several days. The nature of these oscillations is being investigated. Several long observing runs were undertaken at this time to search for underlying binary eclipse signatures, and although small variations were detected, they were not periodic.

In July 2001 V1494 Aql was reported to exhibit eclipses at approximately V = +14 mag (IAUC Nos. 7665 & 7674). In August 2001, the team resumed monitoring of the star using unfiltered CCD photometry. So far they have obtained 25+ nights of observations, primarily using the 40-cm reflector at Eastern University. This photometry confirms the presence of a deep (0.6 mag) eclipse with a period of 0.1346186 days. Thus V1494 Aql is a cataclysmic variable (CV) in which the eclipse occurs as the cooler companion eclipses the accretion disk surrounding the white dwarf. The light curve varies continuously in brightness even outside of eclipse, as well as exhibiting night-to-night variations in its shape. Although the light curve is variable, it shows persistent features that include a maximum in brightness prior to and immediately following the eclipse, and at times a secondary minimum at $\sim$0.5P. They are attempting to model the light curves to determine the properties of the disk and accretion effects (hot spot/gas stream) and will present the results at the AAS meeting in January 2002. In addition they are searching for optical evidence of the 40-min x-ray oscillations recently found from CHANDRA (Starrfield 2001, priv. comm.)

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3.18 The Villanova Catalogue of Spectroscopically Identified White Dwarfs – Online

McCook and Sion continued work on the Villanova White Dwarf Catalog. The online version (phy.villanova.edu/astro/WDCatalog/index.html) allows full access to the features found in the print copy with the addition of convenient links between catalog sections. In addition, all references are linked to the ADS abstract service for online viewing of articles. The WD stars are linked to SIMBAD for coordinate update and star fields. The front page of the online catalog provides access to the preface, references, notes and the cross-reference sections from a drop down menu. The formats of these sections have been changed from the print version (ApJS 121, 1999) to a more user-friendly format with the addition of hyperlinks. Clicking on the appropriate WD number or any of the names for a given star accesses the catalog data. These are displayed in the left and right frames of the front page respectively. WD numbers can be displayed in order of R.A. or can be grouped by spectral class or binary nature.

Plans are underway to develop a reliable system for making corrections and additions to the online catalog on an ongoing basis. At the present time corrections are being made as they are discovered.

3.19 Dwarf Novae: White Dwarf Properties, Accretion Physics, Accretion Rates & Tests of Disk Instability Theory

Astronomy major Michael Stump and Sion carried out a high gravity, solar composition model atmosphere and model accretion disk study of the U Gem-type dwarf nova UU Aql. They identified the far UV signature of the underlying white dwarf for the first time. Their best fit model atmosphere to the observed far UV spectrum in quiescence is 27,000K $\pm$1000K. The solar abundance high gravity photosphere provides a consistent explanation for the sharp absorption lines due to metals in the white dwarf's atmosphere. This interpretation is also consistent with the predicted 20-30,000K small, hot, far UV source (smaller than an accretion disk) proposed by Patterson & Raymond (1985). Model accretion disk fits do not account for the sharp absorption lines and continuum slope. The best-fit accretion disk corresponds to $M_{wd}=0.8$ M$\odot$, $i=18$ degrees and $\dot{M}=10^{-9.5}$ M$\odot$/yr. Optically thick disk models at accretion rates lower than $1\times10^{-9.5}M_{\odot}$/yr are ruled out due to marked flux deficiency shortward of 1400Å . They presented theoretical arguments which rule out accretion rates as high as $1\times10^{-9.5}M_{\odot}$/yr during dwarf nova quiescence. While the they can rule out the quiescent disk as being a significant UV flux contributor, they believe the heated white dwarf accounts for most of the far UV flux. Patterson and Raymond (1985) included UU Aql in their tabulation of dwarf novae showing evidence of ''pseudo-white dwarfs.'' Their estimate of the temperature and fractional area f of the source of radiation in the far UV was 20-30,000K and 0.1 to 1.0, respectively. Stump and Sion found that the surface temperature of the UU Aql white dwarf to 27,000K$\pm$1000K. The photosphere fits they carried out are also consistent with the presence of sharp absorption features due to metals.

Astronomy major Ira Nadalin and Sion studied the dwarf novae TY Psc and V436 Cen, both systems being below the CV period gap. For TY Psc, the short-period dwarf novae TY Psc and V436 Cen are SU UMa systems with very similar orbital periods, similar recurrence times for normal outbursts ($\sim$23 days) and superoutbursts ($\sim$340 days) and nearly identical outburst amplitudes. They applied the Massa-Fitzpatrick (2000) flux calibration correction to the archival IUE NEWSIPS SWP spectra of these two systems, obtained during dwarf nova quiescence. They carried out high gravity model atmosphere fits using the codes TLUSTY, SYNSPEC, ROTIN and accretion disk synthetic spectra from the grid of Wade & Hubeny (1998). The best-fitting stellar model spectrum, from spectral slope and line fitting, is a white dwarf photosphere having $T_{eff}=25{,}000$K, log g = 8 and essentially solar chemical abundances while the best-fitting optically thick accretion disk model, from spectral slope fitting, has $M_{wd}=0.55$ M$\odot$, $\dot{M}=10^{-9.5}$ M$\odot$/yr and an inclination $i=18$ degrees. The implied accretion rate is almost certainly too large for dwarf nova quiescence, the inclination is far lower than previously reported values and the disk model does not reproduce the sharp absorption lines as well as a photosphere model. The predicted fluxes using parameters from the photosphere and disk spectral slope fitting models reveal enormous differences compared with the observed luminosity using a reasonable distance estimate. For TY Psc the predicted accretion disk luminosity is 100 times too luminous while the stellar luminosity is too luminous by a factor of 10. For V436 Cen, the best-fit high gravity model photosphere, from spectral slope fitting, yields $T_{eff}=24{,}000$K, log g = 8 and essentially solar abundance while the best-fit accretion disk models, from spectral slope fitting, yield 0.8 M$\odot$, $i=75$ degrees and an accretion rate 10^{-10} M$\odot$/yr. The presence of broad, absorption troughs at unusual wavelength positions suggests the presence of an absorption curtain (upper disk atmosphere) in V436 Cen. The temperatures they have for TY Psc and V436 Cen are higher than normal for the accreting white dwarfs in dwarf novae below the period gap. This could be indicating that the systems were not in the deepest level of quiescence when they were observed.

Joshua Lake (Eastern College) and Sion have carried out high gravity model atmosphere and accretion disk synthetic spectral fits for the U Gem-type dwarf novae during quiescence. For UZ Ser, they find that the far UV spectrum is best-fit with a log g = 8, $T_{eff}=27{,}000$K photosphere with abundances near solar. The best-fit accretion disk model for UZ Ser has $M_{wd}=1.0$ M$\odot$, disk inclination $i=75$ degrees and $\dot{M}=10^{-9}$ M$\odot$/yr. For SS Aur, the best-fit model photosphere has $T_{eff}=30{,}000$K, log g = 8 and solar composition abundances while the best-fit accretion disk model has $M_{wd}=1.0$ M$\odot$, $i=41$ degrees and $\dot{M}=10^{-10}$ M$\odot$/yr. Fortunately, there is a very recently measured parallax (497 mas) for SS Aur from observations with the HST FGS (Harrison *et al.* 1999). Using the radius which Lake and Sion calculated from the scale factor and the parallax distance, the radius is clearly that of a compact object, a white dwarf, not an accretion disk. Therefore, they believe that they have identified the white dwarf in the far UV and have correctly characterized its surface temperature. However, it is possible that other explanations may account for the small radius, for example, a thin ring. Taking this radius value as indicative of a white dwarf source, this would serve to strengthen the interpretation that the white dwarf may be the dominant source of far UV radiation during the quiescence of many dwarf novae above the period gap. These accretion rates are discussed in connection with the critical accretion rates predicted by the disk instability theory. Whether a white dwarf or a disk accounts for the far UV spectra, they must be quite hot. If indeed the white dwarf dominates the far UV light, then UZ Ser and SS Aur add two important temperatures in support of the conclusion that the accreting white dwarfs above the period gap are a factor of 1.5 to 2 times hotter than the accreting CV degenerates in systems below the period gap.

Astronomy major Colleen Henry and Sion carried out an IUE archival comparative study of the two U Gem-type dwarf novae, VW Vulpecula and X Leonis. The spectrum of X Leo does not show any C IV, a feature normally seen in the vast majority of other dwarf novae. For VW Vul, a single temperature high gravity photosphere does not produce a consistent fit. The best-fit accretion disk model corresponds to $M_{wd}=0.55$ M$\odot$, $i=41$ degrees, and $\dot{M}=10^{-9}$ M$\odot$/yr. For X Leo, they find a white dwarf model with $T_{eff}=33{,}000$K gives the best-fit to the far UV spectrum. However, a model accretion disk with parameters 0.80 M$\odot$, $i=60$ degrees and $\dot{M}=10^{-10}$ M$\odot$/yr also gives a satisfactory fit to the far UV continuum. However, the accretion rate derived for VW Vul is within a factor of three of the critical value such that dwarf nova while the accretion rate of X Leo is within a factor of 60 of the critical rate. If they have identified the accreting white dwarf in X Leo, then it strengthens the overall conclusion that the white dwarfs in CVs above the period gap appear to be a factor of 1.5 to 2 times hotter than the accreting white dwarfs in dwarf novae below the period gap.

Sion, F. Cheng, P. Szkody (U.WA), B. Gaensicke (Goettingen), W. Sparks (LANL) and I. Hubeny (NASA Goddard) analyzed HST spectra of the white dwarf in the dwarf nova VW Hydri. Hubble STIS observations of VW Hydri 2 days and 7 days after the end of a superoutburst reveal a heated white dwarf with deep broad Lyman α, narrow metallic absorption features and evidence of a hotter Keplerian-broadened component. They confirm the existence of enhanced abundances of odd-numbered nuclear species P, Mn and Al as well as a N/C ratio indicative of CNO H-burning thermonuclear processing. Our best single temperature white dwarf reduced χ^2 fit to the first spectrum reveals (1) a DAZQ white dwarf with $T_{\rm eff}$ = 22,500$\pm$ 500 K, log g = 8, and photospheric abundances C = 0.3 solar, N = 3.0 solar, O = 3.0 solar, Si = 0.3 solar, Al = 2 solar, Fe = 0.5 solar, Mg = 3.0 solar, Mn = 50 solar, Ni = 0.3 solar, P = 15 solar and Ti = 0.1 solar. The best-fit white dwarf + accretion belt composite model yields a large improvement in the χ^2 value. The accretion belt temperature is 32,000K and covers a fractional area of 3% contributing 11% of the flux. The second spectrum 5 days later reveals slightly increased metal abundances except that P is elevated to 20 times solar while Fe has declined to 0.05 times solar. The white dwarf has cooled by $\approx$1000K, the belt temperature is 32,000K and the fractional area and flux contribution of the belt are 5% and 20% respectively. These STIS observations confirm that a past (prehistoric?) thermonuclear runaway has occurred on the white dwarf in VW Hyi. It is expected that the thermonuclear runaway would be strong enough to produce a nova outburst. Therefore, these two classes of close binaries, namely dwarf novae and classical novae, are linked and can overlap.

3.20 Theoretical Studies of Accretion Physics

P. Godon and E.M. Sion have continued multi-D theoretical evolutionary simulations of the physics of accretion onto white dwarfs in close interacting binaries. The central accreting degenerate star in cataclysmic variables and related systems has been revealed in many systems by direct observation during the quiescences of dwarf novae or low states of nova-like variables, when the inner accretion disks are less prominent or absent. Multiwavelength spectroscopic observations (HST, IUE, ROSAT, EXOSAT, EUVE, ASCA, ORFEUS, HUT) have revealed that the white dwarfs in dwarf nova systems above the period gap have temperatures (22,000K to 40,000K), a factor of 1.5 to two times hotter than the white dwarf temperatures below the gap (9,000K to 24,000K). The nova-like variables on the other hand all appear to have $T_{eff}>40{,}000$K. They have been carrying out evolutionary model simulations with *time-variable accretion* which include a heat source shining inward (boundary layer irradiation) into the white dwarf envelope as well as compressional heating. Their goal is two-fold: (1) to account for and theoretically interpret the distribution of CV white dwarf temperatures for various CV subtypes and; (2) to obtain a quantitative answer to how much the cooling rate of CV white dwarf with a surface heat source shining inward as well as compression by the weight of the added matter, differs from the cooling evolution of a single, non-accreting white dwarf. All previous studies of accretion onto white dwarfs have assumed a constant rate of accretion, have not included both boundary layer irradiation *and* compression and have focussed upon the effect of accretion on the timescale to thermonuclear runaway. Only two studies (Pringle 1988, MNRAS; Sion 1995, ApJ) have addressed the effect of accretion heating on the white dwarf in the time intervals between classical nova explosions. None of the studies has adressed the long term effect of accretion heating on the cooling rate and envelope thermal structure of the white dwarf.

They have nearly completed, during the report period, the construction of a large grid of white dwarf evolutionary models undergoing time variable accretion, using the accretion rate, white dwarf mass, initial T_{eff} and the outburst timescale and quiescence timescale as free parameters. These physical insights will carry important implications in the broader context of (equatorial) accretion flows onto central compact objects and test theoretical models of accretion disk/boundary layers in cataclysmic variables, T Tauri stars, X-ray binaries, disk- accreting symbiotic binaries and possibly even disk accretion physics in AGNs.

They have just published the first quasi-static evolutionary model sequence with time variable accretion in which the combined heating effect of boundary layer irradiation (including stellar rotation) and compressional heating on the underlying white dwarf accretor has been included. This initial exploration followed the thermal evolution of a $0.6M_\odot$ white dwarf in a dwarf nova, over many dwarf nova accretion cycles. Accretion rates of $\approx 10^{-8}$ $M_\odot$ yr^{-1} for outburst duration of days to weeks, are followed by a shut off of the radial infall during dwarf nova quiescence. The matter is assumed to accrete 'softly' with the same entropy as the white dwarf outer layers, but a fraction of the energy liberated in the boundary layer is assumed to be absorbed by the outer layer of the star (boundary layer irradiation). Accretion is resumed and shut off repeatedly at intervals of months to simulate the thermal evolution of the white dwarf in typical dwarf novae. The timescale of the white dwarf cooling is such that after a complete (outburst + quiescence) cycle, the surface of the white dwarf has not yet completely cooled down - thus the star has not yet reached hydrostatic equilibrium. When the evolution of the white dwarf is followed for 125 cycles (about 8 years), the temperature (T_{eff}) of the white dwarf increases as a function of time (t) like $Log(T_{eff}) = 3DaLog(t)$, where $a > 0$. They find that a itself decreases with increasing temperature. The inclusion of the boundary layer irradiation has no detectable effect on the results over the timescale studied here. During quiescence the outermost layer of the star quickly radiates away the energy absorbed during outburst. The overall fraction of the outer layer of the star thermally affected by the compressional heating is of the order of the mass accreted, namely $\approx 10^{-8} M_{\odot}$ during a complete run (8 years). These results indicate that after a long evolution time of many accretion cycles, the effective surface temperature of the white dwarf will increase substantially. They discuss the application of the sequence to HST studies of the observed heating of white dwarfs in dwarf novae. They also examine the effect of compressional heating on the deep interior structure which directly demonstrates that there is a significant heating effect. They suggest that the envelope thermal structure resulting from compression and irradiation should be a crucial component in understanding the envelope structure of a pre-nova white dwarf.

3.21 Magnetic Cataclysmic Binaries

Astronomy major Joe DePasquale and Sion studied the presence of absorption lines due to accreted metals in the photosphere of the magnetic (28 MG) white dwarf in the prototype polar AM Herculis. They applied the Massa-Fitzpatrick (2000) flux calibration correction to the archival IUE NEWSIPS SWP spectra of AM Herculis, obtained during the optical low states when the accretion rate is very low and emission due to thermal bremstrahlung and cyclotron processes is essentially absent. They examined low state spectra at the same UV maximum phase ~ 0.6 (main accreting pole most directly exposed to the observer) and UV minimum phase ~ 0.1 (line of sight perpendicular to the magnetic field). They used the model atmosphere codes TLUSTY, SYNSPEC and ROTIN to determine the surface temperature of the white dwarf at each UV phase during quiescence and the chemical abundance of detected metal species. They found that the abundances of metals in the photosphere of the accreting magnetic degenerate in AM Her range between 0.05 times solar to 0.001 times solar. These are the first photospheric metal abundances to be determined for any accreting magnetic white dwarf in a magnetic cataclysmic variable. Their preliminary results indicate: (1) no correlation between the time since the last high state and either the surface temperature or the chemical abundance and; (2) the metal abundances do not appear to be significantly different between spectra obtained at UV maximum and UV minimum. This implies that, based upon the limited sample of spectra presented here, the abundance of metals may be similar across the stellar surface. This would result if sideways diffusion and spreading of material from the small polar cap accretion regions had occurred.

3.22 Symbiotic Variables

Sion, former Villanova student Dan Bambeck, Joanna Mikolawjewska (Warsaw) and T. Dumm (Zurich) have carried out an ultraviolet spectroscopic study of the hot white dwarf in the eclipsing S-Type symbiotic variable RW Hydra ($P_{\rm orb} = 370.2$ days). Their study used orbital-phase resolved IUE archival low resolution and high resolution spectra and HST archival spectra, including all available images obtained at inferior conjunction (when the accreting hot white dwarf is in front of the red giant). This system is one of less than a handful of symbiotic variables in which the photospheric continuum from the hot white dwarf is the dominant source of light in the far ultraviolet. They found N V features characteristic of an outflow with velocity of approximately 170 km/s, almost certainly associated with outflow from the white dwarf, as they are present only in those phases in which the white dwarf is visible. They also performed the first model atmosphere synthetic spectral fit to the WD-dominated far UV continuum, and found that the best fit was provided by a model with solar abundances, a log*g* of 8, and a temperature of 41,000 K, considerably cooler than estimates of the temperature based on Zanstra techniques. They cannot exclude the possibility that the hot component is hidden by an accretion curtain and their temperature does not characterize the accreting white dwarf's true photospheric temperature. For a measured wind red giant wind mass loss rate of $1 \times 10^{-7} M_{\odot}$/yr, a wind accretion efficiency of 7%, then $\dot{M} = 37 \times 10^{-9} M\odot$/yr. The heating at this rate of accretion cannot maintain the white dwarf surface temperature even close to what they derived. At the surface luminosity implied by their fitting, the required accretion rate for steady nuclear burning is a factor of 20 lower than the above accretion rate. Based on these results, they conclude that the hot component of RW Hya is a young (lower limit age of 1.6 million years), accretion-heated white dwarf, very likely with nuclear shell burning, on its final cooling track.

3.23 The Hyades Pre-Cataclysmic, Post-Common Envelope Binary V471 Tauri

Sion, H.E. Bond (STScI), D. J. Mullan (Bartol), and M.S. O'Brien (STScI) completed HST spectroscopy of the Hyades member V471 Tauri, an eclipsing system consisting of a hot DA white dwarf (WD) and a dK2 companion in a 12.5-hour orbit. It is the prototype of the pre-cataclysmic binaries. The late-type component is magnetically active, due to its being constrained to rotate synchronously with the short orbital period. During their UV spectroscopy of V471 Tau, carried out with the Goddard High Resolution Spectrograph (GHRS) onboard the Hubble Space Telescope, they serendipitously detected two episodes in which transient absorptions in the Si III 1206 Å resonance line appeared suddenly, on a timescale of < 2 min. The observations were taken in a narrow spectral region around Lyα, and were all obtained near the two quadratures of the binary orbit, i.e., at maximum projected separation ($\sim 3.3 R_{\odot}$) of the WD and K star. They suggest that these transient features arise when coronal mass ejections (CMEs) from the K2 dwarf pass across the line of sight to the WD. Estimates of the velocities, densities, and masses of the events in V471 Tau are generally consistent with the properties of solar CME's. Given our detection of 2 events during 6.8 hr of GHRS observing, along with a consideration of the restricted range of latitudes and longitudes on the K star's surface that can give rise to trajectories passing in front of the WD as seen from Earth, they estimate that the active V471 Tau dK star emits some 100-500 CME's per day, as compared to 1-3 per day for the Sun. The K dwarf's mass-loss rate associated with CMEs is at least $(5-25) \times 10^{-14}$ $M_{\odot}$/yr, but it may well be orders of magnitude higher if most of the silicon is in ionization states other than Si III.

Sion, S. O'Brien (STScI), and H. E. Bond (STScI used the GHRS onboard the HST to obtain Lyman α spectra of the hot white-dwarf (WD) component of the short-period eclipsing DA+dK2 pre-cataclysmic binary V471 Tauri, a member of the Hyades star cluster. Radial velocities of the WD, combined with ground-based measurements of the dK velocities, eclipse timings, and a determination of the dK star's rotational velocity, yield dynamical masses for the components of $M_{(WD)}=0.84$ and $M_{(dK)}=0.93$ $M_{\odot}$. Model-atmosphere fitting of the Ly-α profile provides the effective temperature (34,500 K) and surface gravity (log g=8.3) of the WD. The radius of the dK component is 18% larger than that of a normal Hyades dwarf of the same mass. This expansion is attributed to the extensive coverage of the surface by starspots, causing the star to expand in response. The WD radius, determined from a radiometric analysis and from eclipse ingress timings, is 0.0107 $R_{\odot}$. The position of the star in the M-R plane is in full accord with theory for a degenerate CO WD. The high temperature and mass of the WD present an evolutionary paradox: the WD is the most massive known in the Hyades, but also the hottest and youngest. They suggest that the explanation is that the WD is indeed very young, and is descended from a triple consisting of a blue straggler and a more-distant dK companion. They estimate that the common-envelope efficiency parameter, α_{CE}, was of order 0.3-1.0, in good agreement with recent hydrodynamical simulations.

3.24 The Nature of Mira B in the Mira AB System

Sion and senior astronomy student John Bochanski demonstrated that the companion to Mira A is a white dwarf surrounded by a swirling disk of gas produced by powerful stellar winds from Mira itself. They presented the results of their computer modeling of the bizarre Mira companion at the 198th meeting of the American Astronomical Society in Pasadena, CA. Their result is very important because it establishes that an accretion disk can form from the capture of a stellar wind by the gravity of a compact companion star. This has important implications for explaining many types of binary star systems with compact companion stars in which it was never clear whether a disc could form from stellar wind capture by the compact star. For example, many of the uncertainties about the formation of disks around white dwarfs, neutron stars and black holes with stellar wind-emitting giant companions may now be resolvable from studies of the Mira binary system.

The nature of the companion has been a mystery for decades. Astronomers could not explain the strong high energy radiation associated with it. With the first observations from space in 1979 with the International Ultraviolet Explorer, the first hints emerged of what the companion might be.

It was thought, but never proven, that a white dwarf with an accretion disk was the source of the companion's light. Astronomers B. Warner (South Africa), D. Reimers (Germany), A. Cassatella (Italy) and M. Livio (USA) all proposed that a disk and white dwarf probably explain the companion's light. In 1997, using the Hubble Space Telescope, Margarita Karovska of the Harvard-Smithsonian Center for Astrophysics and her team revealed separate images of the two objects, the red supergiant and the companion light.

In spring of 2001, Sion and Bochanski created computer models which provided an explanation of the ultraviolet light seen in archived spectra obtained with the International Ultraviolet Explorer spacecraft and, therefore, the true nature of the mystery companion. Their computer models revealed that this mysterious companion star consists of a white dwarf with a surface temperature of only 10,000 degrees enshrouded by a swirling disc of gas formed from the powerful stellar wind leaving the red super giant. Despite the veil the disc produces, Sion and Bochanski determined the white dwarf is not invisible after all. Indeed, stellar wind matter flowing outward from a red giant star, can carry enough angular momentum to create a disc around a compact companion. Sion and Bochanski find that the swirling gas disk provides the the ultraviolet radiation seen by orbiting telescopes at the shortest wavelengths while the white dwarf star shines through and provides the light at the longest ultraviolet wavelengths. Mira A itself is too cool to contribute much ultraviolet light. They find that the material in the disk is replenished by the stellar wind at a rate equivalent to one billionth of the sun's mass per year. This is enough to provide the intense light energy from Mira B. Their successful computer modeling of the ultraviolet observations has important implications for explaining many types of binary star systems in which it was never clear a disc could form from a stellar wind. Sion and Bochanski's results provide new insight into the intricate problem of disc formation from a wind accreting onto a compact companion star.

Research on white dwarfs and cataclysmic variables by E.M.Sion and collaborators was supported by NSF grant AST99-01955, NASA/AURA Hubble Grants GO-08103.01, GO-08319.01, GO-09304.01, GO-06558.01, GO-06700.01, a NASA FUSE Cycle 2 grant, NASA Database Grant NAGW5-9408 and summer undergraduate research support from the Delaware Valley Space Grant Consortium.

3.25 UITBOC 1574: A Very Distant Helium-poor Subdwarf O Star

Saffer with Mark Seibert , Pierre Meurer and Ralf Napiwotzki((Johns Hopkins Un.)) have obtained the optical spectrum (3750-7500) and ultraviolet fluxes at 1521 and 2260Å for the quasar candidate UITBOC 1574. The optical spectrum shows strong Balmer absorption lines through at least n=9 and the He II line at 4686Å . Thet compared the optical spectrum with non-LTE stellar atmosphere models and find

T_{eff} = 46,900 ± 3,000 K, log g = 5.6 ± 0.3, and helium abundance log(He/H) = −2.0 ± 0.4. They classify the object as a hot subdwarf O star (sdO). With its high effective temperature and low helium abundance, UITBOC 1574 may be considered as belonging to the hot end of the subdwarf B population. The location of this object on the theoretical $T_{\rm eff}$-log g diagram suggests that it is most likely in a post-extreme horizontal branch evolutionary stage. However, they cannot exclude the possibility that UITBOC 1574 may be a low-mass helium white dwarf precursor. They estimate a spectroscopic distance of 5.6 ± 1.7 kpc with a height of 2.7 ± 0.8 kpc above the Galactic plane if it is a helium-poor sdO. The heliocentric radial velocity of the star is 89 ± 18 km s^{-1}.

Based on observations obtained with the Apache Point Observatory 3.5 m telescope, which is owned and operated by the Astrophysical Research Consortium.

3.26 On the Origin of Subdwarf B Stars and Related Metal-Rich Binaries

Saffer with Elizabeth Green and James Liebert (Un. of AZ) Have been studying the origins of Subdwarf B stars. Mounting evidence from subdwarf B (sdB) stars in the galactic field and their recently discovered counterparts in old open clusters indicates that at least two thirds of local disk sdB stars are binaries. Their recent radial velocity survey showed that binary sdB stars naturally divide into two groups with contrasting spectroscopic and kinematic properties. Those with detectable spectral lines from a cooler companion invariably have periods longer than a year. A larger number with periods on the order of hours or a few days have essentially invisible companions.

They suggest that the long period sdB binaries must have been produced by Roche lobe overflow/mass transfer from low mass, metal-rich giants near the first red giant branch tip, without forming a common envelope. The same process should also occur at slightly lower red giant luminosities, producing a wide binary with a helium white dwarf instead of an sdB star. They present new evidence that most short period sdB's result from a common envelope following subsequent Roche lobe overflow of the initial secondary onto one of these white dwarfs. Rare post-common envelope sdB + main sequence (MS) binaries also exist, but available data suggest that most such systems involving lower MS companions probably merge. The two known MS survivors in short period sdB binaries have small and nearly identical masses, implying that the MS secondary must have lost a large fraction of its initial mass along with the envelope of the red giant sdB progenitor. This work was supported by NSF grant AST97-31655.

3.27 The Search for Variability Among Cool Blue Degenerates

Villanova student John Bochanski held a NSF-REU fellowship at Florida Institute of Technology. With T.D. Oswalt and N.M. Silvestri (FIT), he investigated cool white dwarfs in the solar neighborhood for photometric variability. White dwarfs are the primary end product of stellar evolution; they are the final state of 90% of all stars. These stars occupy the low luminosity blue section of the HR diagram. As the degenerate cores of their main sequence predecessors, these stars are defined by a simple mass-temperature relationship, as determined by the equation of state. Similarly, with no internal nuclear burning, these stars simply cool, defining a temperature-time relation, known as a "cooling curve." Recently, two independent models have predicted specific cooling characteristics of these stars (Hansen 1999; Saumon & Jacobsen 1999). The oldest and coolest (T < 4000 K) of these stars should have a blue infrared color, and this has been observationally verified on multiple occasions (Oppenheimer 2001). The spectra of these stars exhibit a large depression in the infrared continuum, attributed to collision-induced absorption by molecular hydrogen (H_2) (Hansen 1999). In response to this depression, the peak of the spectral energy distribution shifts to the blue, hence the name, cool blue degenerates. They have selected these stars for monitoring of possible pulsational instability because of this large opacity (i.e., absorption). Precedence of this instability lies in other regions of the white dwarf cooling sequence, with large opacities due to hydrogen (DA Variables, McGraw 1979) and helium (DB Variables, Winget 1982) leading to pulsation-induced variations. Thus, selecting a wide range of intrinsic colors and magnitudes, they have begun a systematic search for a strip of pulsational instability among these cool blue degenerates. A preliminary report will be presented at the American Astronomical Society Meeting in January 2002.

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