Villanova University
Department of Astronomy & Astrophysics

Villanova, Pennsylvania 19085

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This report covers the period from October 2001 to September 2002.

1. PERSONNEL

During the report period, 10/01-9/02, the staff included Assistant Professor Carol W. Ambruster, Instructor Laurence DeWarf, Associate Professor Edward L. Fitzpatrick, Research Assistant Professor Patrick Godon, Professor Edward F. Guinan, Associate Professor Frank P. Maloney, Professor George P. McCook (Chairperson), Research Assistant Professor Rex A. Saffer, Professor Edward M. Sion, and Research Associate Richard Wasatonic. Dr. Elizabeth R. Jewell served as Department Assistant.

Students Eric Barron, Laura Marie Barge, John Bochanski, Jessica Castora, James Davis, Michael Dulude, Scott Engle, Ryan Hamilton, Kelly Kolb, Joleen Miller, Kelly Lyons, Christopher Pilman, Jeremy Sepinsky, Jeffrey Tracey, Joel Urban and Lisa Winter served as research assistants.

2. INSTRUMENTATION

2.1 Automated Telescopes

The Fairborn Observatory, home of the 0.8 m 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 AST00-71260.

Villanova has joined the Robotically Controlled Telescope Consortium (RCT) which is refitting a 1.3m telescope located on Kitt Peak, AZ.

2.2 Internet Access

The department's WWW address is:www.astronomy.villanova.edu; 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.astronomy.villanova.edu/WDCatalog/index.html.

3. RESEARCH

3.1 Eclipsing Binary Systems in the Magellanic Clouds

Ribas, Fitzpatrick, Maloney, and Guinan, students Castora and Sepinsky, with Andrzej Udalski (Warsaw University Observatory) have completed a detailed analysis of a third eclipsing binary (EB) system in the Large Magellanic Cloud, EROS 1044 (B2 IV-V + B2 III-IV). This EB study of light and radial velocity curves with detailed modeling of the observed spectral energy distribution yields an essentially complete picture of the stellar properties of the system and a determination of its distance. The observational data exploited include optical photometry, space-based UV spectroscopy, and UV/optical spectrophotometry. The advantages of our technique include numerous consistency checks and, in the case of the distance determinations, the absence of zero-point uncertainties and adjustable parameters. We find the EROS 1044 system to consist of a pair of normal, mildly evolved 21,000 K stars, whose derived properties are consistent with stellar evolution calculations. The distance to the system is 47.5 ± 1.8 kpc. We are continuing this study by analyzing additional EBs in the LMC and SMC. With the results for the three EB systems published so far (HV 2274, HV 982, and EROS 1044) and additional systems, our aim is to explore the parameter space for stars born in chemical environments different from the Sun, and to understand the spacial structure of and distance to the Large Magellanic Cloud.

Fitzpatrick, I. Ribas (U. of Barcelona), Guinan, Maloney, and A. Claret (Inst. de Astrofisica de Andalucia) have completed analysis of a fourth eclipsing binary system in the Large Magellanic Cloud, HV5936. The approximate spectral types of the two stars in the system are $\sim B0.5$ V and $\sim$ B2 III. As in the previous studies, this analysis combines classical'' EB light curve and radial velocity curve analyses with modeling of the UV-through-optical spectral energy distribution of HV5936, to produce a detailed characterization of the system. This study also includes an analysis of the high-resolution optical absorption line spectra of the binary components. The optical spectra of the primary and secondary were extracted separately from spectra of the system via a Fourier ''disentangling'' algorithm. HV 5936 is found to be an Algol-class system, in which the masses of the primary and secondary stars have evolved via mass transfer to their current values of $11.6M_o$ and $4.7M_o$, respectively. The initial masses of the two stars were approximately $7.5M_o$ and $13M_o$, respectively. The properties of the primary star (i.e., temperature, mass, luminosity, and radius) are indistinguishable from those of a ''normal'' single star of the same current mass. The secondary is found to be overluminous for its current mass and exhibits a factor-of-2 enhancement in its surface He abundance. These results are compatible with ''Case A'' mass exchange occurring during the core hydrogen burning phase of the current secondary. A paper describing these results has been submitted to the Astrophysical Journal.

Maloney, Ribas, Fitzpatrick, Guinan, and student Laura Barge are continuing their study of the B0 IV + B2 IV SMC eclipsing binary system HV 2226. Existing B and V photometry yield light curves which, when modeled using the Wilson-Devinney code, show nearly identical stars in size, but with a temperature ratio (Ts/Tp) of 0.74. Existing spectra yield radial velocity curves which show a mass ratio (Ms/Mp) of 0.61. The combined light and radial velocity analysis yields Mp = 9.2 and Ms = 5.6. However, the uncertainties in these preliminary values are high, principally due to the uncertainties (±50 km/s) in the radial velocity data. Accordingly, new spectra have been secured using the Blanco 4-meter telescope at Cerro Tololo Interamerican Observatory. These data are presently being reduced. HST/FOS spectrophotometry of HV 2226 were secured during a Cycle 6 program to study systems in both the LMC and SMC. These data, covering 1100 - 5000 A, are fit to ATLAS9 model atmospheres, yielding temperatures Tp = 29 000K and Ts = 21 600K. With improved radial velocity data, it will be possible to determine the stellar properties of the components, the system's orbital properties, and the distance to HV 2226.

Guinan and Fitzpatrick acknowledge support from NASA HST and FUSE. FM acknowledges student support from the Delaware-NASA Space Grant College for LMB.

3.2 Sun in Time Program

Guinan in collaboration with DeWarf and Ignasi Ribas (Un de Barcelona), Manuel Güdel (PSI and ETHZ), and Graham Harper (Un of Colorado) continue to carry out a multi-wavelength study of solar analogs with ages ∼ 100 million years to 9 billion years. The data for this program are obtained with NASA and ESA satellites such as ASCA, ROSAT, XMM, Chandra, EUVE, FUSE, IUE and HST. Also, observations of most of these stars are being made with Villanova's 0.8 meter robotic telescope (FCAPT) in Arizona. The chief science goals are (1) to study the solar magnetic dynamo (with rotation as the only variable) and (2) to determine the radiative and magnetic properties of the young Sun with the purpose of constructing irradiance tables to be used to study paleo-planetary atmospheres. This study indicates that the young Sun was extremely active with large flares, strong winds, and high energy emissions up to 10,000 times stronger than now. The strong radiation and particle emissions inferred for the young Sun are expected to have major effects on the photochemistry and photo-ionization of early planetary atmospheres, and even can play an important role in the development of primitive life in the solar system. Recently they have been working with three Exo-Astrobiology groups (Graz, Austria: Madrid, Spain; and the Astrobiology Inst. at Penn State) to carry out detailed calculations and models of the effects of the young, active Sun's enhanced high energy emissions on early environments of Mercury, Venus, Earth, Mars, and Titan.

3.2.1 Observations of Solar-type Stars with FUSE

Guinan, Ignasi Ribas (Un de Barcelona), and Graham Harper (Un of Colorado) have completed the analysis of *Far Ultraviolet Spectroscopic Explorer* (FUSE) observations of six solar analogs. These are single G0–5 main-sequence stars selected as proxies for the Sun at several stages of its main-sequence lifetime from ∼130 Myr up to ∼9 Gyr. The emission features in the FUSE 920–1180 Å wavelength range allow for a critical probe of the hot plasma over three decades in temperature: $\sim 10^4$K for the H Lyman series to $\sim 10^7$K for the Fe XVIII 975A line. Using the flux ratio C III λ1176/λ977 as diagnostics, they investigated the evolution of the electron density of the transition region. The results from this study of solar proxies indicate that the electron density of the solar $\sim 10^5$-K plasma may have decreased by a factor of 30–50 since the beginning of the Sun's main-sequence lifetime. Also, they are studying the variations in the total surface flux for specific emission features that trace the hot gas in the stellar chromosphere (C II) 1037 Å transition region (C III 977 and 1176 Å), (O VI 1032/1038 Å), and corona (Fe XVIII) 975 Å . The observations indicate that the surface fluxes of the emission features strongly decrease with the increasing stellar age and decreasing rotation. The emission flux evolution with age and rotation is well fitted by different power laws, which become steeper from cooler to hotter plasma. The relationship for the integrated FUSE flux indicates that the solar FUV emissions were about twice the present value 2.5 Gyr ago and about 4 times the present value 3.5 Gyr ago. Note also that the FUSE/FUV flux of the Zero-Age Main Sequence Sun could have been higher by as much as 50 times. This analysis suggests that the strong FUV emissions of the young Sun could have played a crucial role in the developing planetary system, in particular through the photoionization, photochemical evolution and possible erosion of the planetary atmospheres.

3.2.2 Influences of the Young, Active Sun on Paleo Planetary Environments

As part of the *Sun in Time* program Guinan and Ribas are studying the radiative and magnetic properties of the young Sun. Reliable determinations of the young Sun's radiative and magnetic properties (luminosity, spectral irradiance, flare energies/frequencies, and solar winds etc.) are of crucial importance for the study of the evolution of planetary paleo-atmospheres and development of life in the solar system. Standard stellar evolutionary models constructed for the Sun, show that some 4.5 Gyr ago, the young Sun was about 200 K cooler and ∼10% smaller than today and had an initial luminosity of $L_\odot \sim 70\%$ of the present Sun. So that in the early stages of the solar system, the young Sun's total irradiance was significantly diminished. The decreased luminosity of the younger Sun, should have resulted in cooler Earth in the past. However, geological and fossil evidence indicate that the Earth's climate ∼3–4 billion years ago (when the Sun was fainter) was not significantly cooler than now and may have even been warmer. This problem has become known as the *Faint Sun* paradox. However, the study of young solar analogs (G0-5 V stars) indicates that the young Sun was rapidly rotating and correspondingly had a much more robust magnetic dynamo than assumed. The strong magnetic dynamo of the young Sun resulted in very strong coronal X-ray and EUV emissions up to several hundred times those of the present Sun and chromospheric and transition-region FUV-UV fluxes 5 to 100 times greater than present solar values. X-ray and EUV observations of the youngest solar analogs (with ages <300 Myr) indicate that the young Sun had frequent XUV flares with energies up to a thousand times (E total $10^{34}-10^{35}$ erg; more energetic than the most powerful solar flares observed today. Also, recent studies of related active stars by Brian Wood (Un of Colorado) indicate that the young Sun had strong winds with inferred plasma densities up to 1000 times the present Sun.

Ground based photometric (carried out with robotic telescopes) show that young solar-type stars are heavily spotted (5–20% surface coverage by spots) and have rotationally modulated light variations of $\sim 3-10$ percent. For comparison, the present Sun during the maximum of the sunspot cycle has dark spots typically covering 0.15–0.20% of its surface. Also, long-term studies of the young suns show that they have activity cycles similar in length to the Sun's 11 year cycle but with much larger ranges in brightness than observed today for the Sun. A review paper discussing of the effects of the young Sun's greatly enhanced dynamo generated XUV emissions, flares, and winds on the developing early solar system – in particular on the photochemical and photoionization evolution (and possible erosion) of early planetary atmospheres and ionospheres was presented at the 2nd European Workshop on Exo/Astrobiology in Graz, Austria (September, 2002). This paper will appear in the ESA Special Publication during early 2003.

3.2.3 Erosion and Sublimation Effects on Mercury's Surface

Mercury is often referred to as the ''Iron'' Planet because its iron core is very large compared to other terrestrial planets. One of several theories for this anomaly is that strong, dense, winds and very high X-ray-FUV (XUV) irradiances of the young Sun (during the first 500 Myr of its life) eroded away its early atmosphere and much of its outer mantle. Recently Guinan and Ribas (Un de Barcelona) have been working with H. Lammer, M.G. Tehrany, A. Hanslmeier and C. Kolb (Institute for Geophysics, Astrophysics, and Meteorology and the Space Research Institute - Graz, Austria) to study the effects of the young Sun's inferred strong high energy XUV radiation and strong winds on Mercury's surface. Current ground based observations of heavy constituents like Na, K and O in Mercury's present exosphere implicate a strong exosphere-surface interaction related to the particle and radiation environment of the close Sun. Recent studies on isotope anomalies in planetary atmospheres and meteorites indicate that the early Sun underwent a highly active phase after its origin. Studies of young solar proxies indicate that the particle and XUV radiation environment of the early solar system was several hundred times higher than today. Since Mercury is the closest planet to the Sun, its surface was exposed more than all other solar system bodies by such an enhanced solar wind particle and XUV radiation flux. Using the XUV data for young solar proxies, the Graz group is estimating the sputter erosion and sublimation rates of Mercury's surface during its history.

3.3 Eclipsing Binaries in the Andromeda Galaxy (M31)

Ignasi Ribas (Un de Barcelona), Guinan, and European collaborators are studying about ten 19th – 20th mag eclipsing binaries in the Andromeda Galaxy (M31). The Andromeda Galaxy, with its large and diverse stellar population and chemical history, and galactic structure similar to that of the Milky Way, is potentially an important calibrator for the Cosmic Distance Scale and thus for determining the age and evolution of the Universe. As demonstrated by the recent measures of the LMC distance (discussed elsewhere in this report), double-line eclipsing binaries can serve as excellent *standard candles*. Also, the resulting accurate fundamental properties (M, R, $T_{\rm eff}$) of the two binary components yield an empirical determination of the mass-luminosity law and permit critical tests of stellar structure and evolution models. This method proceeds in three steps: *(1)* the light curve analysis yields the orbital properties, the temperature ratio of the two stars, and their relative radii; *(2)* the radial velocity analysis yields the orbital semi-major axis and the stellar masses; and *(3)* modeling the spectrophotometry yields the stellar temperatures, metallicity, reddening, and a *distance attenuation factor*, corresponding to $(R/d)^2$. Combining this with radii determined from *(1)* and *(2)* yields the distance. Thus, the derived distances are basically geometric and essentially free from many assumptions and uncertainties that plague other less direct methods. Photometric observations providing high-precision light curves of M31 eclipsing binaries are being carried out with the Isaac Newton Telescope (INT) at La Palma. Proposals are being prepared (with Fitzpatrick) to carry out UV/optical spectrophotometry with the HST, while $\sim$10-m class telescopes (e.g., GTC) will be needed to secure good-quality spectra for the radial velocity curves due to the faintness of the target stars. The available data and the experience with the LMC indicate that the project goals are achievable. With a sample of selected eclipsing binaries we will be able to reduce the present uncertainty ($\sim$15%) of the M31 distance to better than 5%, thereby firmly calibrating the Cosmic Distance Scale.

3.4 Astrometry and the Light Travel Time Effect in Eclipsing Binaries

Guinan, Ribas, and Frederic Arenou (Meudon) have developed a method (using Hipparcos astrometry) to determine orbital properties and masses of low-mass bodies orbiting eclipsing binaries. The analysis combines long-term eclipse timing modulations (light-travel time or LTT effect) with short-term, high-accuracy astrometry. With this method, the results of a comprehensive study of Hipparcos astrometry and over a hundred years of eclipse timings of the Algol-type eclipsing binary R Canis Majoris are analyzed. A simultaneous solution of the astrometry and the LTTs yields an orbital period of $P_{12}=92.8\pm 1.3$ yr, an LTT semiamplitude of 2574 ± 57 s, an angular semi-major axis of $a_{12}=117\pm 5$ mas, and values of the orbital eccentricity and inclination of $e_{12}=0.49\pm 0.05$, and $i_{12}=91.7\pm 4.7$ 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 $a_3=18.7\pm 1.7$ AU. From its mass, the third body is either a dM3-4 star or, possibly a cool white dwarf. With the upcoming microarcsecond-level astrometric missions, this technique might be able to 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 being studied.

3.5 Photometry of Polaris - The Return of Polaris as a Low Amplitude Classical Cepheid

Under the supervision of Guinan, Astronomy students James Davis, Jeffrey Tracey, and Scott Engle have been carrying out photoelectric photometry of Polaris. Polaris ($\langle V \rangle \sim+2.0$mag; $B-V=+0.60$; F7 Ib) is a low amplitude Classical Cepheid with a pulsation period of P = 3.97 days. Polaris is one of the the nearest (d (Hipparcos)=132$\pm$8 pc) and brightest Classical Cepheids. The cepheid (Polaris A) is the luminous member of the multiple star system (ADS 1477). Over the last century amazing changes have been occurring for this famous star. The pulsation period has been increasing at a rate of dP/dt = +3.2 sec/yr. while the light amplitude has decreased from $\sim$0.12 mag (1900s) to $\sim$0.02 mag (early 1990s). A recent summary and discussion of Polaris's interesting properties is given by Evans *et al.* (ApJ, 567, 1121: 2002). New Villanova photoelectric photometry started during early 2002 and is continuing up to the present. This photometry is a continuation of the work done on Polaris by Kamper and Fernie. The Villanova photometry is being done to obtain new epochal light curves and accurate times of maximum light. From the photometry obtained in the first half of 2002, Well defined 450 nm and 550 nm light curves. From these observations accurate measures of light amplitudes of Ampl. (450 nm) =0.032$\pm$0.004 mag and Ampl. (550 nm) =0.028$\pm$0.003 mag, respectively were measured. These light amplitudes are similar (or slightly larger) to those observed during the mid-1990s. So it appears that the century long decrease in the light amplitude has halted (or at least paused). The time of maximum light found from these observations was combined with previous timings and reaffirms the continued increase in period of +3.2 sec/year. These observations lend strong support to overtone nature of Polaris's pulsations. In addition to the long-term secular increase in the Polaris's pulsation period, a detailed analysis of the O-Cs indicates $\pm$0.20 day cyclic oscillations in the apparent period with a time scale of 11-12 years. The nature of these period oscillations is being investigated. The results of this study will be presented at the January 2003 AAS Meeting. This research is supported by NSF/RUI Grant AST 00-71260 and by the Undergraduate Summer Research Assistance Program Grant from Delaware Space Grant Consortium.

3.6 Sakurai's Star

Astronomy students Jessica Castora and Lisa Winter with Guinan are completing the photometric study of the unusual variable star - Sakurai's Star (V4334 Sgr). As a *born-again* post-asymptotic giant, V4334 Sgr (Sakurai's Object) is undergoing extraordinarily rapid stellar evolution in real time. Yukio Sakurai first discovered the object in 1996 at an apparent magnitude of $m_v\sim+11.4$. Prior to its discovery the star was tentatively detected in ESO/SERC plates from 1976 close to the detection magnitude of $m_v=+21.5$. The observed rapid brightening is best explained as the star, after descending the white dwarf cooling track, underwent a final helium flash and subsequently rapidly brightened.

They are studying the photoelectric UBVRI observations of V4334 Sgr obtained with the 0.8-m FCAPT. They combined this photometry with all available photometry and spectroscopy to delineate the star's photometric and spectroscopic behavior. The photometry shows that the star reached a maximum brightness of V = +10.9 mag in 1996/97. During 1998 V4334 Sgr gradually decreased in brightness to $m_v\sim+12$ mag. In Spring 1998 V4334 Sgr showed cepheid-like light oscillations with a period of P$\sim$55d. Subsequently the star has undergone a very rapid decline in brightness reaching $m_v\sim+20.5$ mag during 1999/2000. As the star dimmed, it became very red and continued to be a strong IR source. As in the cases of the related post-AGB stars, FG Sge and V605 Aql and most R CrB stars, the rapid decrease in light is best explained by the extinction by forming circumstellar dust. At the January 2003 AAS Meeting, they will discuss the evolution of V4334 Sgr and focus on the analysis and interpretation of the stellar pulsations observed during the declining phases of the recent outburst. The star's luminosity and distance have been inferred from the its pulsation properties and compared with other estimates. This research is supported by NSF/RUI Grants AST95-28506 and AST00-71260.

3.7 Black Hole Binary Cygnus X-1

Astronomy undergraduates, Eric Barron, Joel Urban, and Jeremy Sepinsky (UDel) are working with Guinan on the analysis of the photometry and X-ray observations of Cygnus X-1. Cygnus X-1 is one of the best observed stellar black hole X-ray binaries. This 9th mag binary consists of an O9.7 Iab star and a (black hole + disk) companion. Its orbit is nearly circular and the system has a period of P = 5.6 days. At optical wavelengths Cyg X-1 shows low-amplitude periodic light variations arising primarily from the tidal distortion of the O-supergiant. Over the last three years they have been carrying out photoelectric photometry of Cyg X-1. This photometry is being conducted with the Four College 0.8m robotic telescope located in southern Arizona and the 0.4m telescope located at Villanova University. The observations are being made using UBV and Strömgren filters and a set of H-α intermediate and narrow band filters. The optical light curves show changes in shape and light amplitudes on time scales of weeks to months. Of particular interest is the investigation of the correlation of the characterisitics of the light variations with X-ray observations being made contemporaneously with the RXTE satellite. The RXTE observations of Cyg X-1 reveal that the star was mostly in a low X-ray state since its last sustained high (soft) state during 1996. However, during September 2001 the star moved into an X-ray high state and has remained high since then. Modeling of the light curves has been carried out to extract information about O-star, the accretion disk, and black hole during widely different energy states of the system. The results of this study are being presented at the January 2003 AAS Meeting. This research is supported by NSF/RUI Grant AST 00-71260 and by the Undergraduate Summer Research Assistance Program Grant from the Delaware Space Consortium. Villanova is grateful for the support from these grants.

3.8 SU Aurigae

DeWarf and Guinan with recent graduate J. Sepinsky, continue their study of the classical T Tauri star (CTTS) SU Aurigae (HD 282624; G2 IIIe; $\langle V \rangle = +9.16$ mag; $\langle B-V \rangle = +0.90$). CTTSs are believed to be pre-main sequence stars with extensive accretion disks. Intensive, long-term (since 1993) photometric observations are analyzed to determine many of its photometric and physical properties. Combining nearly 2000 Strömgren *uvby* measures obtained using the 0.8m FCAPT data, previously published photometry, and recently obtained high resolution echelle spectra has led to the determination of its effective temperature, surface gravity, luminousity, mass, age, rotation period, and absolute radius. Since the accretion disk of SU Aur is seen at a high inclination angle (i.e., nearly edge-on), this complicates the observations with significant ($\Delta V \simeq \Delta y \simeq 0.40$ mag) and apparently random, drops in observed mean light. These 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 interstellar medium (ISM). This is most likely due to the transits of protoplanetary bodies, protocomets, or associated accretion halos.

High disperson echelle spectra of SU Aur have been obtained with the 4m Blanco telescope at CTIO. One spectrum was secured during a large dimming events observed during Dec 2000. Additional VIS/NIR spectra, centered at Hα, were taken at the 1m telescope on Mt. Laguna (San Diego, CA) by collaborator P. Etzel (San Diego St. Un). Current research includes an analysis of these nearly bi-nightly observations (75 total spectra) to determine the velocity structure, temperature, and density of the accreting gas. Line widths and Doppler shifts are very sensitive signatures of the velocity dispersion due to any kind of accretion processes within these planet-forming clouds. Preliminary analysis has uncovered remarkable variability in both wings of the Hα line profile and shows changes in the core equivalent width. The team intends to investigate the nature and, if apparent, any periodicities to this dramatic spectral variability.

In addition to SU Aur, observations are being conducted of its probable proper motion pair, AB Aur. AB Aur is observed less frequently than SU Aur and shows only small light variations (± 0.07 in u and ± 0.03 in y).

3.9 GW Orionis

DeWarf and Guinan with recent graduate J. Sepinsky (Univ. of Dela.) have recently begun investigating an extensive photometric dataset of the young stellar object (YSO) GW Orionis (HD 244138; K3 Ve; $\langle V \rangle = +9.92$ mag; $\langle B - V \rangle = +0.97$. GW Ori is believed to be a single-lined spectroscopic binary ($P_{\rm orb} = 242$ d), but the properties of the unseen companion are currently unknown. It is evident from the large infrared excesses that GW Ori is surrounded by extensive circumprimary and, possibly, a circumbinary disk of material. Unlike many YSOs, the spectral energy distribution (SED) for GW Ori can be modeled with a simple two component blackbody energy distribution. They find that the observed stellar component has a temperature of $\sim$ 4300 K and the mean temperature for the circumstellar component(s?) is about 1350 K. There is photometric variability with a periodicity of about 1000 days that may be indicative of variable accretion from the circumstellar environment, magnetic activity cycles, perturbations in the circumstellar disks, or even a third stellar component.

Other YSOs that are intensively monitored by the FCAPT are: V410 Tau, V833 Tau, V773 Tau, and V1331 Cyg.

This research is supported in part by NSF/RUI Grant AST-0071260. Sepinsky would like to acknowledge the support from the Delaware-NASA Space Grant College Consortium's Undergraduate Summer Research Assistance.

3.10 M-type Giant Stars

Wasatonic and Guinan continue to conduct broad-band visual (550 nm) and narrow to intermediate-band near-IR (719 nm - 1040 nm) TiO photometry on pulsating M-type giant and supergiant variable stars. The research focuses on generating estimations of temperature, luminosity, and radii variations over time and analyzing relationships amoung these parameters. The current program stars are Alpha Orionis, Alpha Herculis, Omicron Ceti (Mira), CE Tau, TV Gem, R Leo, V CVn, XX Per, and FZ Per. Preliminary results of Alpha Orionis indicate that the observed temperature and luminosity variations are driven by localized growth and decay of hot spots or supergranulations rather than solely by radii changes. The Alpha Herculis light curve is dominated by a 350-day pulsational cycle that annually "damps" out due to multiperiodicities. Early analyses of TV Gem, R Leo, and V CVn imply that these stars are not pulsating in the fundamental mode; rather, the temperature/luminosity/ radius relationships indicate possible overtone pulsations and/or multiperiodicities. The Mira and CE Tau data has yet to be analyzed, and there is not yet enough data on XX Per and FZ Per for definitive statements to be made. Overall the behavior of the program stars has been un- expected, and warrents the need for continued observations.

Additionally, Mirtorabi (Institute of Advanced Studies in Basic Sciences, Iran), Wasatonic, and Guinan continue to conduct the V-band and near-IR TiO photometry on several bright chromospherically active spotted stars, including Lambda Andromeda and IM Pegasus. The V-band light variations were initially thought to be produced by dark starspots rotating into and out of view. However, analyses of the TiO curves with respect to V-band light curves indicate that the dark spots are not primarily responsible for the light variations. Models are being developed that indicate the visual light variations could be mainly due to bright hot-spots, such as faculae and plages, rotating into and out of view, with the dark spots having only little effect on the overall light variations.

3.11 B Stars in the Milky Way and the Magellanic Clouds

Fitzpatrick and D. Massa (Emergent IT) successfully proposed a Cycle 3 Observing Program with the Far-Ultraviolet Spectroscopic Explorer (FUSE) satellite, entitled *The Atmospheres of High-Latitude Early B Stars*. Far-UV spectra (912 - 1180 Å) will be obtained for 11 lightly reddened early B-type main sequence stars (BVs) in the galactic halo. 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. They complement observations obtained in FUSE Cycle 2 of mid- to-late B-type stars in the Orion OB associations. This combined 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. Halo targets were chosen because the early-B stars in the galactic disk are either too bright to be observed by FUSE or too compromised by interstellar absorption to allow the stellar properties to be examined in detail. This program will also allow the issue of the normalcy and origin of the halo B stars to be addressed.

Fitzpatrick, Massa, A. Fullerton (Johns Hopkins), and R. Prinja (University College, London) presented first results from a Cycle 2 FUSE program at the January 2002 meeting of the American Astronomical Society in Washington, DC (FUSE Spectra of LMC B Supergiants). The stars observed by FUSE span a narrow temperature range (spectral types B0.7 thru B1.5) but include 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 January 2002 presentation concentrated on the spectral line morphology in the far-UV region and its correspondence with spectral features in other wavelength regions.

Fitzpatrick and Massa presented a poster at the June 2002 meeting of the American Astronomical Society in Albuquerque, NM describing a technique for calibrating synthetic photometry for early-type stars (*Calibration of Synthetic Photometry for B and early-A Stars*). This project is part of a larger study of the spectral energy distributions (SEDs) of early-type stars in the UV-IR spectral region. The primary goals are to test the ability of current stellar atmosphere models to reproduce the observed SEDs and to determine how well basic stellar properties (e.g., $T_{\rm eff}$, log g, and [m/H]) can be recovered from measurements of the SEDs. The primary dataset utilized is the Final Archive of the International Ultraviolet Explorer (IUE) satellite, which contains UV spectro-photometric observations (1200 - 3200 Å) for hundreds of early-type stars over a wide range of reddenings, including eclipsing binary systems, open cluster members, and field stars. Unfortunately the wavelength range of these UV data does not include critical diagnostic information needed for determining, in particular, stellar surface gravity and the amount of interstellar extinction. These diagnostics are located in the visible and near-IR portions of the spectrum. To extract all the information available in the SEDs, the IUE data must be supplemented with optical and near-IR measurements. The most widespread body of such data are Johnson UBVRIJHKL and Strömgren $uvby$ + Hβ photometry. The June 2002 poster illustrates a procedure for calibrating synthetic Johnson and Strömgren photometry derived from stellar atmosphere models, so that it my be compared directly with observed photometry.

3.12 HST & Archival IUE and FUSE Studies of Symbiotic Variables

In collaboration with Sion, Villanova undergraduates Kelly Kolb and Joleen Miller have begun a study of the nature of the hot components in symbiotic variables and related objects. In many symbiotic systems, there is little or no evidence of an accretion disk surrounding the hot, accreting component. In fact, there is no strong evidence of a disk in any S-type symbiotic containing a white dwarf. This also appears to be true for D-type symbiotics containing a white dwarf. There is also no evidence for a far UV contribution by a nebular continuum shortward of about 1600 Å. Therefore, the far UV continuum may be contributed virtually entirely by the hot accreting white dwarf radiation up to 1800 Å. The presence of a hot accreting white dwarf in symbiotic binaries offers the possibility of studying the effect of wind accretion on the compact star.

However, there has been no direct comparison of the far ultraviolet spectra of the hot components of symbiotics with realistic models of hot white dwarf atmospheres and accretion disk models with vertical structure. Is an accretion disk really absent? Can they form in symbiotics from wind accretion or is Roche lobe overflow required? What are the model-derived properties of the accreting hot components and how do their properties compare with the results of black body fits and Zanstra techniques? What is the accretion rate onto the white dwarf based upon model fits? How do the white dwarf accreters in symbiotics compare to those in CVs? Given that the hot component radiation is detected in selected systems, is there any evidence of wind outflow (e.g., like AG Peg) and if so, is it a WD wind (like CSPN) or a bi-polar outflow via disk formation?

Their study has begun with the symbiotic systems EG And, SY Musc and UV Aur. Their work is also addressing whether, for measured red giant wind mass loss rates of 1 $\times 10^{-7} M_{\odot}$/yr, and wind accretion efficiency from 3D hydrodynamic wind accretion simulations, whether it is possible for theoretical estimates of $\dot{\rm M}$ are consistent with synthetic spectral fitting. Can the heating at this rate of accretion maintain the white dwarf surface temperature even close to what spectral modeling derives. At the surface luminosity implied by their fitting, what is the required accretion rate for steady nuclear burning and how does it compare to the $\dot{\rm M}$ derived from the observations? Is the white dwarf on its final cooling track, on the plateau of a shell flash, or steadily burning?

3.13 FUSE Studies of Dwarf Novae

3.13.1 VW Hydri

Sion, Godon, Cheng, Szkody (U.WA), Long (STScI) and Froning (CASA) have analyzed a spectrum, taken with FUSE, of the dwarf nova VW Hydri during quiescence ($\sim$11 days post-outburst) when the underlying white dwarf accreter is clearly exposed in the far UV. Their grid of models yielded a best-fitting photosphere to the FUSE spectrum with the following parameters: $T_{wd}/1000$ (K)$=26+4/-1$, log $g=8.5$, Si= 1.0 + 0.2/-0.2 times solar, C = 0.1 + 0.4/-0.1 times solar, N = 2.0 +1.8/-1.5, and V_{rot} sin i (km/s) = 400 + 100/-70. The rotation rate and chemical abundances are reasonably consistent with previous HST FOS, GHRS and STIS results but the photospheric temperature is somewhat higher than previous measurements. This may be due to a transient accretion event less energetic than a normal outburst, that took place just before or during the FUSE observation. The observations of VW Hyi show a drop from 23,000K during (a normal 3 days) dwarf nova outburst down to 19,000K during quiescence. In the simulations, they assume a $0.63M_{\odot}$ accreting white dwarf. They turn the accretion on at a rate $\dot{M}=1\times10^{-8}M_{\odot}yr^{-1}$ for 3 days, without boundary layer irradiation. The outburst temperature peaks at 23,000K while the quiescence temperature reaches 19,000K. The same results are also obtained assuming $M=0.86M_{\odot}$ and a 18,000K quiescence temperature. It is interesting to note that if one assumes an accretion rate as low as $\dot{M}=1\times10^{-9}M_{\odot}yr^{-1}$, the 4,000K jump in temperature is reproduced by including some boundary layer irradiation. However, the star (or its outer layer) would still have to rotate at a significant fraction (0.7) of its Keplerian rotation rate. The VW Hyi white dwarf spins much more slowly than this value.

If they take the 26,000K temperature from FUSE at face value, then the elevation in T_{eff} is roughly 3000K higher than previous measurement. It is possible that a transient accretion event, either just before or during the Fuse obseravtion, led to the higher than normal temperature.

3.13.2 SS Aur, RU Peg

Sion, Cheng (Hefei, China), Godon and Szkody (UWA) have analyzed the Far Ultraviolet Spectrocopic Explorer (FUSE) spectra of two U Gem-Type dwarf novae, SS Aur and RU Peg. SS Aur was observed 28 days after the last previous dwarf nova outburst and RU Peg was observed 60 days after its last outburst. In both systems the FUSE spectra (905$-$1182 Å) reveal the underlying accreting white dwarf which is clearly exposed in the far UV. Their grid of theoretical models yielded a best-fitting photosphere to the FUSE spectrum of SS Aur with the following parameters: $T_{wd}/1000$ (K)$=31+4/-1$, log $g=8.5$, Si = 1.0 + 0.2/-0.2 times solar, C = 0.1 + 0.4/-0.1 times solar, N = 2.0 +1.8/-1.5, and V_{rot} sin i (km/s) = 400 + 100/-70. For RU Peg, their model grid yielded $T_{wd}/1000(K)=49+6/-7$, log g (fixed) = 8.5, Si = 0.1 + 0.3/-0.1 times solar, C = 0.1 + 1.7/-0.1 times solar, V_{rot} sin i = (km/s) = 100 + 500/-100, Scale factor $=6.07396\times10^{-04}$.

The quality of the model fits to the FUSE spectra of the two systems is quite different. The fit to SS Aur is very much in agreement with a model white dwarf atmosphere with log g = 8.5 and $T_{eff}=31{,}000$K. This fit to the FUSE spectrum provides gratifying independent confirmation of the results of Lake and Sion (2001) who also found that the far UV IUE spectra were dominated by a hot, massive white dwarf. The T_{eff} they derive for the white dwarf in SS Aur was 30,000K. SS Aur was a dwarf nova which, during quiescence, many if not most investigators thought was dominated by its accretion disk. It was widely felt that the white dwarf in SS Aur was not exposed and could not be analyzed unambiguously. They have shown in this paper that this view was in error.

In SS Aur, it is also highly significant that there is little evidence of an additional hot component other than a single temperature white dwarf photosphere. This is in contradistinction to the SU UMa system, VW Hyi, which does show a hot component in addition to a white dwarf photosphere in the FUSE range.

Their FUSE spectrum of RU Peg likewise reveals a very hot white dwarf in agreement with the analysis of the IUE archival spectra of RU Peg in quiescence. They find that $T_{eff}=49{,}000$K for the white dwarf almost appears more complex than that for SS Aur. There is evidence for a hot component. The best-fitting single temperature, high gravity, solar composition white dwarf models reveal a 50,000-53,000K white dwarf as the dominant source of the steep far UV continuum. The scale factors for the hot white dwarf fits yield distances of 230 pc and 260 pc, both values of which are within the most probable distance range of 130 to 300 parsecs for RU Peg. As a consistency check, using flux constraints involving the far UV fractions of the bolometric luminosity radiated by the hot white dwarf, and by the disk, the hot white dwarf interpretation is still favored over a disk by a significant margin. They note, however, that although a hot single-temperature (50,000K) white dwarf agrees best with the far UV observations, they cannot rule out that the far UV continuum could be produced by a cooler, slowly rotating white dwarf and a rapidly spinning, very hot accretion belt covering a small fraction of the white dwarf surface but providing the vast majority of the UV flux.

A white dwarf as hot as 50,000K in a dwarf nova may hold important implications for the disk instability theory of dwarf nova outbursts. First, it is surprising that dwarf nova eruptions are not suppressed due to expected high ionization of the disk (Shafter *et al.* 1986). The presence of a very hot white dwarf in a dwarf nova requires consideration of the irradiation of the disk by the accreting star. Simulations of dwarf nova outbursts with the inclusion of disk irradiation by a very hot accretor are clearly needed. The accretion disk in RU Peg may be among the largest of any dwarf nova. Therefore, even with a white dwarf as hot as 50,000K, dwarf nova events would be able to occur in outer regions of the disk where the gas is not completely ionized. Accreting white dwarfs as hot as 50,000K should have an envelope thermal structure which could support thermonuclear burning.

3.14 HST Studies of WZ SGE

Sion, Gänsicke (U.Southampton, UK), Long (STScI), Szkody (UWA), Howell (UC, Riverside), Marsh and Knigge (Southampton), Welsh (SDSU), Sparks (LANL) and Starrfield (ASU) obtained director's discretionary time to observe the unexpected (ten years early) outburst of WZ Sge. WZ Sge is the widely-known, extensively-studied prototype of a group of H-rich cataclysmic variables which have extreme properties: the largest outburst amplitudes, shortest orbital periods, longest outburst recurrence times, lowest mass Roche-lobe filling secondaries, lowest accretion rates and coolest white dwarf primaries of any class of dwarf novae (Howell *et al.* 1999; Howell *et al.* 2002: see Kato *et al.* 2001 for a recent review). It is also the brightest dwarf nova and arguably the closest cataclysmic variable, with a distance of only 43$\pm$8 pc (Thorstensen 2001, private communication). Following the December 1-2, 1978 outburst of WZ Sge, its relatively clock-like outburst regularity of every 33 years was unexpectedly disrupted by a 10 year-early outburst on 23 July 2001, first reported by T.Ohshima (see Ishioka *et al.* 2001). What followed was the most thoroughly observed dwarf nova outburst in history (see, for example, Patterson *et al.* 2002, Kuulkers *et al.* 2001).

Following shortly upon the discovery of the superoutburst, two Director's Discretionary proposals with HST were approved, one proposal (GO-9287) to provide dense coverage of the outburst phase and the other proposal (GO-9304) to cover the emergence of the accretion-heated white dwarf and monitor its evolution (cooling and other properties) in response to the superoutburst. It is the results of the latter program, awarded four orbits over a 4 month time span, that Sion *et al.* have summarized.

They obtained *Hubble Space Telescope* STIS E140M spectra of the dwarf nova WZ Sge, following the early superoutburst of July, 2001. Their four FUV spectra, obtained over a time span of four months, monitor changes in the hot component of the system during the decline phase when accretion is gradually declining and cooling is occuring. The spectra cover the wavelength interval 1150 Å to 1708 Å. They reveal Stark-broadened Lyα and He II (1640) absorption and absorption lines due to metals (Si, C, N, Al) from a range of ionization states. They fit the STIS data with synthetic spectra of optically thick accretion disks, high gravity photospheres, combined disks and photospheres and two-temperature differentially-rotating composite fits combining photospheres with rapidly spinning accretion belts. They are able to rule out an optically thick accretion disk as the sole source of the far UV spectra. An optically thick accretion disk in combination with a white dwarf photosphere does not satisfactorily match the observations. Single temperature white dwarf models provide reasonable agreement with the HST spectra. Only a modest improvement in the fits to the data results when an accretion belt component is included. If the far UV spectra arise from the white dwarf alone, then they measure a cooling in response to the outburst of at least 11,000K. The absence of broad underlying absorption features due to metals at this stage suggests slow rotation. It is possible that the white dwarf has expanded due to the heating by the outburst or that the relatively narrow absorption features we observe are forming in an inflated disk atmosphere or curtain associated with the outburst.

While single temperature white dwarf models do provide reasonable agreement with the HST spectra, the September spectrum is problematic to this interpretation. It appears that there is an additional radiating component. For example, the Lyman α line does not go to zero as one expects for a white dwarf. Another point is that unless only a fraction of the white dwarf is exposed in the September data, then an increasing white dwarf radius with time is indicated as we progress to the December data. It is also possible that the system was observed during one of the optical re-brightening phases during which an additional source radiation would be evident in the September data. It seems clear that their interpretation of overall changes in the white dwarf (e.g., cooling, radius changes) hinges critically on what radiating components are contributing to the September spectrum. Among the possible sources are a circumbinary disk, ejected shell, or corona/wind structure on the scale of several WD radii. Since CHANDRA observations revealed a forest of emission lines just after outburst (Kuulkers *et al.* 2002), this may be evidence that of a large, optically thin component extending out to a few white dwarf radii.

3.15 IUE Archival & HST Studies of Dwarf Novae

3.15.1 VY Aqr, WX Ceti

Sion, Szkody (UWA), Howell (UC, Riverside), and Gänsicke (Southampton) presented the results of a multi-component synthetic spectral analysis of HST STIS spectra of the ultra-short period dwarf novae VY Aqr and WX Ceti during their deep quiescence following their last superoutburst. The white dwarf in these extremely low accretion rate systems dominates the far UV light. They find that the accreting white dwarfs in VY Aqr and WX Ceti are remarkably similar. Both systems contain white dwarfs with T_{eff} $=$13,000K to 13,500K, a rotation velocity below 800-1200 km/s and subsolar metallicity. Both white dwarfs are better fitted with a two-temperature white dwarf plus accretion-belt model in which part of the white dwarf is cooler and *slowly* rotating and part is hotter, smaller and spinning at the Keplerian speed. They discuss the implications of the surface temperatures they have derived for the white dwarfs in VY Aqr, WX Ceti and the nine other WZ Sge-like dwarf novae below the period gap which have been observed with HST.

It is of interest to compare the properties they have derived for VY Aqr and WX Ceti to other WZ Sge-related objects. In this comparison, however, it should be pointed out that unlike most of the other objects in their HST medium program, VY Aqr and WX Ceti exhibit both normal outbursts and superoutbursts while the LL And, EG Cnc, HV Vir and AL Com systems show only superoutbursts as does WZ Sge itself. Therefore, the occurrence of more outbursts on shorter timescales makes it likely that the accretion rates in VY Aqr and WX Ceti are somewhat higher than the other systems. This possibility is supported by an increased amount of emission compared with the lowest accretion rate systems in our program. Moreover, there is less prominent absorption around the Balmer lines than one sees in the other systems. The apparent presence of an accretion belt in VY Aqr and WX Ceti may be a direct result of the higher accretion. Surprisingly, the rotational velocities of VY Aqr and WX Ceti fall in the same range as the white dwarfs in LL And, SW UMa, HV Vir, BC UMa, EF Peg, EG Cnc and other ultra-short period, high outburst amplitude dwarf novae, viz., 200 to 500 km/s. The abundances of photospheric metals at sub-solar values for VY Aqr and WX Ceti, taken at face value, also appears to be a hallmark of the entire group. The evolutionary significance of the chemical abundances as well as the fate of the accreted angular momentum remain to be elucidated.

However, by far the most interesting implications arise from the effective temperatures of the white dwarfs in these two systems when they are combined with the other WZ Sge-related objects (or TOADs) in the Cycle 8 HST sample of P. Szkody and co-workers. Since all of the objects in the HST sample (BW Scl, LL And, AL Com, SW UMa, HV Vir, EG Cnc, BC UMa, EK TrA, EF Peg, WX Ceti and VY Aqr) were observed in deep quiescence, long after the last previous superoutburst, there has been sufficient time for the white dwarfs to have cooled down to essentially their equilibrium temperatures corresponding to long term compressional heating (Sion 1985), It is interesting that the white dwarfs in the above HST sample all cluster around 15,000K for orbital periods between 1.3 and 1.5 hours. Taking the surface temperatures they have derived along with the temperatures of all other white dwarfs in the HST sample (Szkody *et al.* 2002), they have 11 dwarf novae below the period gap whose average $T_{eff} = 14{,}918$K. For this T_{eff} and a 0.6 $M_{\odot}$ white dwarf ($R_{wd} = 9.16 \times 10^{8}$ cm), log ($L/L_{\odot}$) = -2.11. Using the cooling curves for different white dwarf masses computed recently by Fontaine, Brassard and Bergeron (2001), the cooling age corresponding to this average T_{eff} is $\sim 3 \times 10^{8}$ years. Of course, this age value is only a lower limit cooling age corresponding to a non-accreting white dwarf of the same T_{eff} so it is not surprising that it is much shorter than what is predicted by the standard CV evolution picture (cf. Kolb & Stehle, 1996; HRN).

The coolest white dwarf in a non-magnetic cataclysmic variable is EG Cnc with $T_{eff} = 12{,}300$K. Since the bulk of the HST sample lie very near the period minimum for an H-rich CV, the fact that no white dwarfs in dwarf novae cooler than 12,000K have been found may be manifesting the effect of long term compressional heating in keeping these objects warm compared with the cooling rates of single non-accreting white dwarfs. If they take the T_{eff} of the white dwarf in VY Aqr (14,000K), assume a 0.6 $M_{\odot}$ white dwarf, as above, and assume that the value of 14,000K is the equilibrium temperature of the white dwarf between thermonuclear outbursts (i.e., classical novae), then they can estimate the long term accretion rate corresponding to this temperature. Following Sion (1985), the fraction of the total accretion energy that goes in to compressional heating and structure changes of a white dwarf in response to long term accretion is in the range of 15% to 25%. This fraction is based upon long term quasi-static evolutionary accreting white dwarf models with realistic core thermal histories (see Iben 1982; Sion 1985). If they take a middle value in this range, say 20%, the long term accretion rate, after insertion of the values for VY Aqr, an equilibrium $T_{eff} = 14{,}000$K from compressional heating due to long term accretion corresponds to $\dot{M} = 1.2 \times 10^{-11} M\odot$/yr. This time-averaged accretion rate is almost precisely what is predicted if gravitational wave emission is driving mass transfer below the period gap (e.g., HRN). Thus, it seems reasonable to conclude that long term compressional heating due to time-averaged accretion is the mechanism responsible for the clustering around 15,000K of the surface temperatures of white dwarfs in dwarf novae below the period gap. A similar result was obtained by Townsley and Bildsten (2002) using a semi-analytic calculation which included an attempt to treat the effect of classical nova explosions on the white dwarf core temperature.

3.15.2 RX And

Sion, Szkody, Gänsicke, Cheng, C. LaDous (Germany), and B.J.M. Hassall (UK) obtained HST observations of the dwarf nova RX Andromeda near the end of an extraordinarily deep and long dwarf nova quiescence, 3 months after the last previous outburst; The spectral wavelength range covered was 1149Å to 1435Å . All of the spectra are dominated by absorption lines with weak to moderately strong emission wings due to the continued presence of disk material. Uncertainities in line velocities preclude a K_1 determination or mass information. Their best fitting model yielded $T_{wd}/1000 = 34.0 \pm 0.1$ K, log $g = 8.0 \pm 0.1$, and $V_{rot} = 600^{+200}_{-100}$ km/s. The T_{eff} value is very similar to the T_{eff} of the white dwarf in U Gem, but the rotational velocity appears to be higher than U Gem's value. They report approximate subsolar chemical abundances of Carbon and Silicon for RX And with C being 0.05 x solar and Si = 0.1 x solar while other elements are at essentially their solar values. However, accurate abundances are complicated by line emission and they cannot exclude that the abundances of all species are essentially at the 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 corresponding white dwarf cooling age, 4×10^{6} years, is a lower limit to the age of this CV. If the peculiar line features seen in the spectrum on the late decline from outburst are inverse P Cygni in nature, then infall velocities of $\sim$2000 km/s are indicated during the decline from outburst. They also compared the surface properties of the RX And white dwarf with the properties of other CV degenerates studied to date with HST, HUT and IUE, especially U Gem. These two objects are the only long-period dwarf novae with reliable surface temperature information from HST analyses. Any abundance information from the quieiscence spectrum must be viewed with caution for the reasons stated earlier. The atmospheric abundances of C and Si in RX And are likely close to solar but modestly subsolar abundances from this spectrum cannot be excluded. They do not see evidence of surface abundance ratios indicative of past CNO processing as they found for the white dwarfs in VW Hydri, and U Gem. The rotation rate of the RX And white dwarf places it in the middle range of the presently known V sin *i* distribution. Taking the mass of the white dwarf cited in Ritter (1999) at face value, the cooling age of the white dwarf is only 4×10^6 years (a lower limit to the age of RX And as a CV, in the absence of core mass loss). The line velocities corresponding to the photosphere of the white dwarf could not be measured with sufficient precision to determine a K_1 velocity semi-amplitude, due to peculiar line shapes, line blends and disk emission contamination. Therefore, they were unable to determine a reliable K_1 and gravitational redshift mass for the white dwarf.

Sepinsky (Villanova/UDel), Sion, Szkody and Gänsicke (Southampton) obtained Hubble Space Telescope far ultraviolet spectra of the Z Cam-type dwarf nova RX And during the early rise to outburst and the decline from the same outburst. The spectral wavelength range covered was 1149Å to 1435Å. The rise spectrum is dominated by strong, very broad absorption lines while the decline spectrum has strong, narrower absorption with weak to moderately strong emission wings due to the presence of disk material. They have carried out a combined model accretion disk and high gravity model atmosphere analysis of these spectra.

They have modeled the spectroscopic evolution of the RX And system during the rise to an outburst peak and during the decline from the same outburst. They have used multicomponent theoretical models combining high gravity solar composition photospheres with steady state accretion disk models with variable inclination, white dwarf mass and accretion rate. This investigation, coupled with the analysis of the RX And HST spectrum at the end of an unusually long quiescence just preceding the outburst studied here (Sion *et al.* 2001), represents, to their knowledge, the first FUV coverage of a nearly complete outburst-quiescence cycle with realistic theoretical multi-spectral component models.

The spectrum on the rise to outburst is best represented by a combined hot white dwarf (40,000K) together with a steady state disk model with solar abundances, an inclination of 41 degrees, a white dwarf mass of 0.8 $M_\odot$ and an accretion rate during the rise of 2×10^{-10} $M_\odot$/yr. The agreement between the model line profiles and the velocity-broadened absorption features associated with the inner disk confirm that the abundances in the disk cannot be very different from solar. Furthermore, They see no evidence of the extremely sharp line cores as seen during the superoutburst of VW Hydri with HST (Huang *et al.* 1996).

Their best-fitting composite model of the decline spectrum reveals the presence of a hot (45,000K) white dwarf contributing 81.4% of the flux during the decline and a remaining accretion disk component with an accretion rate during the decline of 2.85×10^{-10}, contributing 18.6% of the flux. This rate of accretion is nearly an order of magnitude larger than the rate determined by Sion *et al.* (2001) for the extended quiescence spectrum just preceeding the outburst. Without the disk contribution, they found that a single temperature white dwarf model did not fit the spectrum well (a flux excess shortward of Lyman α and poor agreement with the longward continuum). The inclusion of a disk contribution of 18% brought the observations and models into very good agreement.

The white dwarf during the decline is hotter by 11,000K than its surface temperature at the end of the long quiescence (Sion *et al.* 2001). This would indicate that the white dwarf was heated substantially by the outburst. The heating was almost certainly due to the combined effect of boundary layer irradiation (Pringle 1988), compressional heating due to the weight of the added matter (Sion 1995), and shear mixing luminosity due to the conversion of rotational kinetic energy into heat during the tangential disk accretion (Sparks *et al.* 1993). The cooling by 11,000K from the maximum heating of the white dwarf at the peak of the outburst to a lower temperature in early quiescence is consistent with the theoretical results of Sion (1995) who carried out evolutionary model sequences of white dwarfs undergoing time-variable accretion which simulated cyclic dwarf novae outbursts. New evolutionary accreting white dwarf model simulations which greatly extend the grid of time variable accretion models published by Sion (1995) are directly applicable to RX And. For a 0.8 $M_\odot$ white dwarf accreting at 10^{-8} $M_\odot$/yr for 3 days, compressional heating alone causes the white dwarf temperature to increase by 5000K. The model sequence 4h in the grid of Godon and Sion (2001) appears to be most directly applicable to the case of RX And. When boundary layer irradiation is included (with a rotational velocity of 40% Keplerian for the white dwarf), then the white dwarf temperature increases by nearly 15,000K. Since the RX And white dwarf was heated by at least 10,000K during the outburst and is rotating below 40% Keplerian, then compressional heating may be the dominant mechanism. Since boundary layer heating occurs in the much thinner and diffuse atmosphere of the white dwarf, its effects are evident on a shorter timescale than those of compressional heating. Therefore, by the time of spectrum 3, we expect the boundary layer to have significantly cooled, leaving a residual temperature increase due primarily to compressional heating.

They also note that the amount of heating of the RX And white dwarf between decline and early quiescence is remarkably similar to the elevation of temperature found with FUSE for U Gem's white dwarf (Froning *et al.* 2001) during its decline. During the decline from outburst in U Gem, Froning *et al.*(2001) found $T_{\rm eff}=45{,}000$K while in early quiescence the white dwarf had a $T_{\rm eff}=37{,}000$K.

Some of the line features in spectrum 3 appear to be longward-asymmetric (i.e., asymmetric on the *red* side) with emission on the shortward side. The impression is that disk material during the decline of the outburst has a net inward flow onto the white dwarf. If these structures do represent inverse P Cygni features, then the infall velocity of the disk-associated or outburst-associated material can be estimated from measurements of the profiles. The terminal velocity derived from the C II feature is $\sim$469 km s^{-1} while we measure terminal velocities of $\sim$781 km s^{-1} and $\sim$592 km s^{-1} from the N V and Si IV lines. It is possible that the "inward"-flowing gas was ejected by RX And through wind outflow during outburst, but may not have achieved escape velocity and, hence, is observed to be returning to the white dwarf. Similar inverse P Cygni structures were also seen in the sharp line cores in one of two HST spectra of VW Hyi's superoutburst (Huang *et al.* 1996). If the line features in the spectrum of visit 3 are really inverse P Cygni features, then they believe this is the first direct detection of actual gas infall onto the white dwarf in a cataclysmic variable.

3.15.3 EM Cyg, WW Ceti, CZ Ori, EY Cyg, CW Mon, BZ UMa

Villanova undergraduate and Goldwater Scholar Lisa Winter and Sion explored the origin of the far UV spectra of three dwarf novae using *combined* high gravity photosphere and accretion disk models. They have carried out an IUE archival comparative study of the three U Gem-type dwarf novae, EM Cyg, CZ Ori and WW Ceti. For EM Cygni, the far UV spectrum during quiescence is dominated by an accretion disk with $\dot{M}=5\times10^{-11}$ $M_{\odot}$/yr contributing 92% of the FUV light and a white dwarf with upper limit $T_{\rm eff}$ $<$24,000K contributing $<$8% of the light. For CZ Ori, the accretion disk with $\dot{M}=3.5\times10^{-10}$ $M_{\odot}$/yr contributes 99% of the FUV light while the white dwarf has an upper limit $T_{\rm eff}<$21,000K and contributes $<$1% of the light. For WW Ceti, they find that best-fitting disk models and disk plus white dwarf models yield a distance which appears far too large. A single temperature white dwarf fit with $T_{\rm eff}$ $=$22,000K implies a distance of 150 parsecs. CZ Ori and EM Cygni are dominated by the accretion disk during quiescence but with accretion rates different by over a factor of ten. In the case of EM Cygni, which has a higher inclination, it is possible that the nearly edge-on aspect of the disk may hide a much hotter white dwarf.There are now 17 analyzed dwarf nova systems with $P_{orb}<$120m and 11 systems with $P_{orb}>$180m. The average T_{eff} below the lower boundary of the period gap is $T_{eff}=$15,547K while the average T_{eff} above the upper boundary of the period gap is T_{eff} $=$31,182K. The $T_{\rm eff}$ of the white dwarfs strengthens the overall conclusion that the white dwarfs in CVs above the period gap appear to be a factor of 2 times hotter than the accreting white dwarfs in dwarf novae below the period gap.

Winter and Sion also explored the origin of the far UV spectra of an addtional three dwarf novae using *combined* high gravity photosphere and accretion disk models. They have carried out an IUE archival comparative study of the two U Gem-type dwarf novae, EY Cyg and CW Mon and a probable SU UMa system BZ UMa. Both EY Cyg and BZ UMa have very weak C IV emission and very strong N V emission, which is atypical of the majority of dwarf novae in quiescence. For CW Mon, the accretion disk with $\dot{M}=3.2$ $\times10^{-12}$ $M_{\odot}$/yr contributes 80% of the FUV light while the white dwarf has an upper limit $T_{\rm eff}<$23,000K and contributes $<$20% of the light. For BZ UMa, the far UV spectrum during quiescence is dominated by an accretion disk with $\dot{M}=3\times10^{-12}$ $M_{\odot}$/yr contributing 82% of the FUV light and a white dwarf with upper limit $T_{\rm eff}<$19,000K contributing $<$18% of the light. Possible origins of the apparently large N V/C IV emission ratio are discussed in the context of nova explosions, contamination of the secondary star and accretion of nova abundance-enriched matter back to the white dwarf via the accretion disk.

In EY Cygni, which lies above the period gap, the T_{eff} value appears to be lower than the typical 27,000 to 35,000K of other U Gem and Z Cam systems above the gap while the upper limit T_{eff} of BZ UMa is similar to the white dwarf T_{eff} in VW Hyi. Is there a connection between the lower white dwarf temperatures and, in the case of EY Cygni, higher white dwarf mass in these systems and the abundance anomaly seen in the far-UV spectra? If their true $T_{\rm eff}$ values are low, then it is possible that the abundance anomaly (excess N, depleted C) may be associated with their greater system age (longer cooling time of the white dwarf) than other dwarf novae. If indeed the white dwarf core has cooled for a longer time, then the equilibrium T_{eff} value in response to accretion is expected to be lower. This might suggest that a longer system age allows for more classical novae episodes, hence more CNO nucleosynthetic processing, consequently more contamination of the secondary's atmosphere during the brief common envelope stage of each nova. Such systems may be more likely to exhibit the apparently excess N and depleted C associated with CNO processing.

It is clear that they have not determined the true T_{eff} of the white dwarfs in EY Cygni, CW Mon and BZ UMa but only upper limits since all three systems are overwhelmingly dominated by their accretion disks during quiescence. The fact that the IUE observations of all three of these faint systems are of poor quality and underexposed lends support to acquiring better FUV spectra with FUSE and HST.

3.15.4 RU Peg

Sion and Villanova undergraduate Joel Urban presented the results of the first multi-component synthetic spectral analysis of IUE archival spectra of the long-period dwarf nova RU Peg during quiescence. The best-fit high gravity solar composition photosphere models yield $T_{eff}=50$ $-53{,}000$K with scale factor distances of $\sim$250 parsecs. Optically thick accretion disk models imply accretion rates between $1\times10^{-9}M_{\odot}$/yr and $1\times10^{-10}M_{\odot}$/yr in order to match the steeply sloping far UV continuum. However, the best-fit accretion disk models yield distances from 600 to 1300 parsecs, well beyond the estimated distance range of 130 to 300 parsecs. Using rough theoretical flux arguments and the distance estimates, they find better agreement between the observed far UV luminosity and the predicted far UV luminosity of a hot, massive, white dwarf model than with an accretion disk model. RU Peg appears to contain the hottest white dwarf yet found in a dwarf nova. They cannot rule out that the far UV energy distribution is due to a multi-temperature white dwarf with cooler, more slowly rotating higher latitudes and a rapidly spinning, hotter equatorial belt. They discuss implications of their analysis for theoretical predictions of the disk instability theory of dwarf nova outbursts. They discuss a comparison between RU Peg's white dwarf and the observed properties of other analyzed white dwarfs in dwarf novae.

A white dwarf as hot as 50,000K in a dwarf nova may hold important implications for the disk instability theory of dwarf nova outbursts. First, it is surprising that dwarf nova eruptions are not suppressed due to expected high ionization of the disk (Shafter *et al.* 1986). The presence of a very hot white dwarf in a dwarf nova requires consideration of the irradiation of the disk by the accreting star. Simulations of dwarf nova outbursts with the inclusion of disk irradiation by a very hot accretor are clearly needed. The accretion disk in RU Peg may be among the largest of any dwarf nova. Therefore, even with a white dwarf as hot as 50,000K, dwarf nova events would be able to occur in outer regions of the disk where the gas is not completely ionized.

The hot white dwarf is $\sim$15,000K hotter that the hottest white dwarfs in dwarf novae (U Gem and RX And) above the period gap. This is very significant because RU Peg's white dwarf is in the temperature regime occupied by the white dwarfs in UX UMa and VY Scl nova-like variables. These objects are in continuous outburst with some having occasional low states of little or no accretion but all being devoid of the dwarf nova phenomenon. Indeed, their accretion rates are thought to be comparable to the accretion rates of dwarf novae in outburst (Warner 1995) and therefore, the accretional heating of white dwarfs in the nova-likes should be higher than the heating in dwarf novae. Accreting white dwarfs as hot as 50,000K should have an envelope thermal structure which could support thermonuclear burning. Below the period gap, the distribution function of white dwarf temperatures is centered at roughly 15,000K with relatively little scatter. It is seen that the RU Pegasi degenerate lies to the upper right, well-separated from the other dwarfnovae white dwarfs. If, as they believe, the white dwarf is massive, then more gravitational potential energy is liberated in consequence of accretion and therefore the part of the total accretion energy going into heating is proportionately greater than in a lower mass degenerate accreting at the same time-averaged rate. Other possibilities are that the white dwarf is still young in a young dwarf nova or that the white dwarf remains hot from a ''recent'' nova outburst and is still cooling. Investigations of these possibilities with evolutionary models undergoing long term, non-magnetic accretion (e.g., Godon and Sion 2002a,b; Townsley & Bildsten 2002) are in progress and will be reported in due time.

3.15.5 DI Lacertae

Villanova undergraduate Elizabeth Moyer, Sion, Szkody, Gänsicke, Howell, and Starrfield have carried out a synthetic spectral analysis of a Hubble Space Telescope Imaging Spectrograph (STIS) observation of the old nova DI Lacertae (Nova Lacertae 1910). The spectrum, obtained with the E140M disperser, reveals a rising continuum shortward of 1560 Å, a C IV P-Cygni profile indicative of wind outflow associated with disk accretion, a deep Lyα profile, and strong N V (1238 Å, 1242 Å) and O V (1371 Å) wind/coronal absorption lines. Numerous sharp interstellar resonance lines are also present. A grid of accretion disk models, spanning a wide range of inclinations, accretion rates and white dwarf masses, was compared to three sets of de-reddened data. From the three best fits, they conclude that the most likely parameters characterizing the far-UV spectrum of DI Lac are an inclination below 18 degrees, a white dwarf mass between 0.6 and 0.8 $M_\odot$ and an accretion rate between $10^{-9.0}$ and $10^{-9.5}$ $M_\odot$/yr. The scale factors for the three best-fit disk models indicate distances between 2 and 2.5 kpc. The extreme weakness or absence of silicon features in the observed spectrum corresponds to a silcon underabundance of $\leqslant 10^{-4}$ times solar. The best-fitting high gravity photosphere model has log $g=8$, $T_{eff}=27{,}000$ K, $V \sin i = 200$ km/s and a scale factor distance (for a 0.7 $M_\odot$ white dwarf) of only 76 pc. Thus, a white dwarf photosphere cannot be contributing appreciably to the far UV spectrum.

The presence of wind outflow in DI Lac (as indicated by the C IV P Cygni profile) and its energy distribution, strongly similar to UX UMa nova-like systems, make it highly likely that DI Lac is a disk-dominated system. However, the relationship between the UX UMa systems and old novae remains unclear. The observed far UV luminosity of old novae is around 10 $L_\odot$ (Krautter *et al.* 1981). There is no apparent correlation between L_{uv} and P_{orb}, decline rate t3, or time since the last nova. If the disk luminosity L_{disk} is roughly twice the observed far-UV luminosity, then $L_{disk}=20\ L_\odot$. A representative accretion rate for old novae is therefore is 4.5×10^{-9} $M_\odot$/yr.

Their model analysis of the STIS spectrum of DI Lac indicates a strong probability that a luminous disk dominates the far UV luminosity. Adopting the most reasonable combination of disk parameters from their fitting, they believe the accretion rate of DI Lac is between 10^{-9} and $10^{-9.5}$ $M_\odot$/yr with an inclination <18 degrees and a white dwarf mass between 0.6 and 0.8 $M_\odot$. The best model fits were achieved with a reddening value $E(B-V)=0.3$. The silicon abundance appears to be sub-solar, as the (solar abundance) disk models predict strong Si II and Si III absorption which is not observed. They have determined that the extreme weakness or absence of Si absorption features in the observed spectrum implies a depletion of silicon corresponding to $\sim$0.0001 $\times$ solar.

3.16 Very Young (Pleiades-Age) Stars: the Zero-Age Main-Sequence (ZAMS)

Ambruster and collaborators A. Brown (CASA, U. Colo.) and F.C. Fekel (Center for Excellence, TN State U.) made significant progress on their study of Very Young Pleiades Age Stars during this time period. The goal of this project is to determine for the first time the nature and structure of the outer atmosphere of a cool star at the time it begins nuclear reactions in its core, i.e., the time it formally becomes a star. Observations have been obtained with HST/GHRS, ROSAT, EUVE, and IUE, as well as ground-based observations from Kitt Peak National Observatory and the VLA, as well as with the Four-College APT.

This past year saw the resolution of the major remaining interpretational problems, in particular, the causes of discrepancies in calculated stellar sizes are now understood in terms of the distinctive properties of these very young stars. The stellar size discrepancy implies that the measured brightness (luminosity) of these stars is anomalously low, lower than would result simply from typical starspot coverage. A recent, promising, theoretical result that might explain this in terms of strong magnetic fields has been identified. Calculations of stellar size suggest that it is possible that a few of the stars are a bit too large, i.e., a bit too young, for the star to have ignited nuclear reactions in its core yet.

Plots of stellar rotation vs. spectral line strength were constructed for each of 16 spectral lines measured in the Hubble Space Telescope data. The rotation activity plots are consistent with an exponential decay of spectral line strength as rotation slows, but with a fair amount of scatter. Low level flaring and other forms of atmospheric activity expected in these highly active young stars can account for the scatter, but it is also possible that differences in the functioning of the magnetic dynamo between stars on the ZAMS (hydrogen burning) and stars that are slightly pre-ZAMS (not hydrogen burning) are also present.

3.17 The Flare Star EV Lacertae

Ambruster contributed to a successful proposal written by University of Colorado collaborator Rachel Osten and collaborators at JILA, NASA/GSFC, and NOAO to obtain X-ray observations of this star with Chandra. These observations were made in Sep. 2001. Data reduction was temporarily delayed while Dr. Osten completed her PhD thesis and found a job. She is now at the University of Virginia, and data reduction is underway.

3.18 Archaeoastronomy/Archaeology

Field research in Chaco Culture National Historical Park (NM) by Ambruster in collaboration with A. B. Hull of Jet Propulsion Laboratory, California Institute of Technology has advanced considerably over this reporting period. This project has advanced well beyond the original discovery of a remarkable winter solstice sunrise (WSSR) event involving a large boulder carved with ceremonial early (18th century) Navajo rock art. Less dramatic but significant, summer solstice sunrise (SSSR) and equinox sunrises at the bases of cliffs on the horizon were also established. Interestingly, there is no mention in over 100 years of ethnography or anthopology literature that the observation of solstice or equinox sunrises was traditionally important to the Navajo, thus this site is of widespread anthropological, not just archaeoastronomical, interest in Southwest studies.

Two years ago, the further discovery was made that each of the three boulders was paired: another rock art covered boulder and/or ruin in the near vicinity views the same sunrise at essentially the same time. While this fits in well with the established importance of repetition in traditional Navajo culture, the fact that in two of the three cases, the second site of the pair is Anasazi conflicts with the commonly held view that the Navajo's well-known fear of the dead causes them to avoid prehistoric Anasazi ruins. Interestingly, both the original summer and winter solstice sites consist of 1 purely Navajo component with either a combined Navajo/Anasazi rock art panel or a small Anasazi ruin as the second part of the pair. In the past year an extensive and detailed cultural survey of the area was undertaken with the goals of: 1) clarifying the nature of the Navajo-Anasazi ruin interaction in the 18th and 19th centuries, and 2) identifying other features in the archaeological record that might correlate with a Navajo ceremonial site that involved observation of solstice and equinox sunrises. This work is being done under a research permit from the National Park Service.

The current goal of the research is to investigate the nature of the former Navajo habitation in the immediate area, compare it with the archaeological record for both Chaco Canyon and the traditional Navajo homeland in NW New Mexico (the Dinetah), searching for features (e.g., classes/density of construction or classes of rock art) that might be distinctive of this unusual ceremonial site. It is already clear that there are numerous Navajo hogan remains near Anasazi ruins, and that most rock art panels found in this survey contain both Anasazi and Navajo rock art.

The mapping survey of cultural features, both Anasazi and Navajo, currently encompasses a 1 km radius of our site, covering 200 hectares. To date, 43 rock art sites (both Navajo and Anasazi) and 34 structural remains have been identified. Future work will extend the survey area to other parts of Chaco Canyon, which will allow comparison with other Navajo sites in the Canyon (which are plentiful). In Nov. 01 and Sep. and Oct. 2002, the western 1 km of the survey was completed and work was begun on the eastern part of the survey.

4. FACULTY ACTIVITIES

Ambruster presented an invited paper on this work at Chaco Culture National Historical Park, NM at the plenary session of the 26th meeting of the American Rock Art Research Association (ARARA) in May, 2000.

Guinan presented invited papers at the following conferences: IAU meeting on Exotic Stars (Miami), AAS Meeting in New Mexico at the special session on The Future of Extreme Ultraviolet Stars, and the 6th Pacific Rim Conference held in Xi'an China. He continues to serve as President of Division V (Variable Stars) of the IAU and served on the NASA Senior Review Committee during June and July. During August he attended and helped lead the IAU and UNESCO sponsored International School for Young Astronomers, held in Argentina.

Sion presented papers at the Symposiums on Classical Nova Explosions in Barcelona, Sp., the 13th European Workshop on White Dwarfs in Naples, It., an invited paper at the Symbiotic Stars as Probes of Stellar Evolution in the Canary Islands and the 6th Pacific Rim Symposium in Xi'an, China. He also presented an invited colloquium at the National Research Institute of Astronomy and Geophysics at Helwan, Egypt. His term as associate editor of the Astrophysical Journal expired in January 2002.

5. PUBLICATIONS

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