Villanova University Department of Astronomy & Astrophysics

Villanova, Pennsylvania 19085

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This report covers the period from October 2003 to September 2004.

1. PERSONNEL

During the report period, 10/03-9/04, the staff included Assistant Professor Carol W. Ambruster, Instructor Laurence E. 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), Professor Edward M. Sion, Visiting Professor Chun-Hwey Kim (Inst. for Basic Research, Chungbuk National Univ.) and Research Associates Dr. Robert Koch(University of Pennsylvania), Richard Wasatonic and Scott Engle. Dr. Elizabeth R. Jewell served as Department Assistant.

Students Laura Marie Barge, Eric Barron, Joseph Drescher, Michael Dulude, Ryan Hamilton, Kelly Kolb, Sarah Lakatos, Michael Lesniak, John Marcy, Joleen Miller, Rebecca Percy, Vanessa Pettiford, Adric Riedel, FIT student Laura Seward, Scott Stegman, Elysse Voyer, and Joel Urban served as research assistants.

2. INSTRUMENTATION

2.1 Automated Photoelectric Telescopes

The department has installed a new 14‘‘ automated telescope in the main campus observatory. 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 a Consortium of the College of Charleston, The Citadel and Villanova University. The FCAPT is supported by NSF grants AST95-28506 and AST-0071260.

The Robotically Controlled Telescope (RCT) 1.3m telescope on Kitt Peak is now completing its final testing phase. The Research Consortium includes Villanova, Western Kentucky, South Carolina State, Francis Merion and the Planetary Science Institute.

3. RESEARCH

3.1 Interstellar Medium

Fitzpatrick prepared a review article on the properties of extinction by interstellar dust grains in the Milky Way galaxy. The article concentrated on the current state of our understanding of the wavelength dependence of the dust absorption and scattering. Dust extinction is a particularly important process in interstellar space since it greatly modifies the properties of electromagnetic radiation traversing the galaxy and affects the observability of many astronomical objects. Characterizing the wavelength dependence of extinction can shed light on the properties of the dust grains themselves and better enable the removal of its effects from observations. Of chief concern in the review article was the issue of Milky Way ‘‘extinction curves’’ as a 1-parameter family, characterized by their value of $R_V \equiv AV/E(B-V)$. Based on analysis of new (i.e., *2MASS)* and old (i.e., *IUE*) data for $\sim$100 sightlines, it was shown that the UV, optical, and IR wavelength regimes do display coherent variations, but with too much intrinsic scatter to be considered truly correlated. A 1-parameter family can be constructed which illustrates these broad trends, but very few individual sightlines are actually well-reproduced by such a family and disagreement with the mean trends is not a sufficient condition for considering a sightline to be ‘‘peculiar.’’ Only a very small number of extinction sightlines stand out as truly peculiar. The article concludes that simple variations in the mean grain size from sightline to sightline are responsible for much of the coherent variability seen in Galactic extinction, and might also explain the ’’peculiar’’ extinction long-noted in the Magellanic Clouds. This paper appeared in the ASP Conference Series, Volume 309.

3.2 Apsidal Motion: DI Her

Maloney, Guinan, and student L. Barge have re-examined the puzzling eclipsing binary system DI Herculis. This system is rare among main sequence stars in that its apsidal motion is dominated by the effects of General Relativity. The GR contribution to its theoretically predicted apsidal motion is 2.34°/100 y., whereas the theoretically predicted classical contribution (due to tidal and rotational deformation of the component stars) is 1.93°/100 y. The interesting fact is that the observed apsidal motion, determined from timings of the stars’ mutual eclipses, is anomalously low: $\sim$1°/100 y., well below the combined theoretical expectation of 4.27°/100 y.

Since Rudkjǿbing’s (1959) announcement of the special nature of DI Her, observers have been measuring light curves and radial velocity curves to determine the orbital parameters of the system and the stellar properties of its components. DI Her consists of two main sequence stars (B5V and B6V) in a 10.55 day eccentric orbit ($e = 0.489$). Observations of times of minima reveal the system’s apsidal motion, computed from the changing displacement of the secondary eclipse from the primary eclipse. Four decades of photoelectric measurements show that the observed apsidal motion remains below that predicted. Various explanations for this discrepancy have been offered, with the most promising involving the presence of a third component of the system. In a highly inclined orbit, the third body would diminish the rate of apsidal advance of the close pair. Adding photometry recently taken with the 0.8 m Four College Automatic Photoelectric Telescope, they have recalculated the apsidal motion for DI Her, 1.39±0.30°/100 y. They are also examining a new formalism for studying three-body interactions by Mardling in the DI Her system.

This research is supported by NSF/RUI grant AST00-71260, which is gratefully acknowledged.

3.3 LMC: Eclipsing Binary HV 2241

Maloney, student L. Barge, I. Ribas (IEEC, Spain), DeWarf, Fitzpatrick, and Guinan are investigating the LMC eclipsing binary HV 2241 as part of a larger project directed toward the determination of the physical properties of LMC stars and the distance to the LMC. HV 2241 is a semi-detached system, consisting of an $\sim O7$ III primary component and an $\sim$B0 III secondary (filling its Roche equipotential surface) in a 4.34 d orbit. The datasets being analyzed consist of previously published CCD photometry (Strömgren u, Cousins Ic, and V), HST/FOS 110-480 nm spectrophotometry, and newly acquired 400-530 nm echelle spectroscopy using the Blanco 4-meter telescope at CTIO. Preliminary values for the temperature ratios of the components, the stellar radii and masses, and the inclination of the stars' orbits are used to model the system with the Wilson-Devinney eclipsing binary code. Analyses of the spectrophotometry yield surface temperatures of the stars and the amount of interstellar reddening. The resulting stellar properties for the primary star (radius, temperature, and mass) are compared with stellar evolution models for consistency. The distance to HV 2241 is computed from a knowledge of the stars' radii and temperatures as well as the amount of reddening.

Preliminary results reveal the stellar properties (P = Primary, S = Secondary components) and orbital parameters: $T_P = 33{,}000 \pm 1500$K, $T_S = 25{,}500 \pm 1000$K, $M_P = 27.2 \pm 3\ M_\odot$, $M_S = 13.3 \pm 1.5\ M_\odot$, $R_P = 13.9 \pm 0.7 R_\odot$, $R_S = 12.0\ R_\odot$, Period = 4.342365 d, Inclination $= 84.1 \pm 0.6$ deg., a $= 38.5 \pm 1.5\ R_\odot$.

They gratefully acknowledge financial support from the NASA - Delaware Valley Space Grant consortium, and from the National Science Foundation through HST grant GO-06683. They are grateful for the skilled assistance of the CTIO staff during their January 2000 observing run.

3.4 Analysis of the Active Contact Binary CE Leo

Visiting Astronomer, Dr. Chun-Hwey Kim, with Young Woon Kang, Hee-Won Lee, Kyeong Soo Hong and Guinan have studied the chromospherically active contact binary CE Leonis. They secured VRI light curves of the system and carried out detailed photometric solutions, as well as an analysis of its period variations. A total of 73 times of minima over 50 years, including our observations, were used for the period study. The complex period variation can be sorted into a linear period improvement, a period of P=0.30342771 days, a secular period increase at the rate of $\dot{P}/P = +3.05 \times 10^{-7}$ days yr^{-1}, and a 22.6$\pm$0.5 yr periodic component. The $\sim$22.6 yr periodic variation in the O-C residuals most likely arises from the light-travel time effect from a low-mass ($m_3 \sim 0.3 M_\odot \sin i$) dM tertiary companion moving in an eccentric ($e' = 0.61 \pm 0.04$) orbit. However, it is also possible that this periodic variation arises from the effects of a magnetic activity cycle, known as the Applegate mechanism. The light curves show asymmetries in the two different maxima. The 1998 light curves show that primary maximum was 0.042, 0.038, and 0.038 mag brighter than secondary maximum in V, R, and I, respectively. The relative depth of primary minimum was found to vary between 1.20 and 1.32 mag. They have analyzed the light curves from the three epochs using the 1993 version of the Wilson-Devinney differential corrections computer code to find a unique solution for CE Leo. The corresponding spectral type of the secondary star from the colors and effective temperature is $\sim$ dK2. The asymmetric light curves can be best explained by the effects of starspots. They find that the light curves are best fitted by employing a cool spot on the cooler, larger component of the system.

3.5 A Program to Determine a Direct and Accurate Distance to M31 from Eclipsing Binaries

I. Ribas (IEEC, Spain), Guinan, C. Jordi (UB, Spain), F. Vilardell (UB, Spain), and R. W. Hilditch (St. Andrews, UK) have continued their work on the Andromeda Galaxy (M31) aimed at the discovery and analysis of eclipsing binaries and Cepheid variables. M31 is potentially a crucial calibrator for the Cosmic Distance Scale, and thus for determining the age and evolution of the Universe. Yet, currently the M31 distance is known to no better than $\sim$15%. Previous work in the LMC carried out by the Villanova University team led by Guinan demonstrated that double-line eclipsing binaries can serve as excellent ''standard candles.'' Distances derived from eclipsing binaries are basically geometric and essentially free from many assumptions and uncertainties that plague other less direct methods. The present project represents the extension of the program of using eclipsing binaries as standard candles to determine an accurate distance to M31. The photometric observations that yield the light curves have recently been completed with the 2.5 m Isaac Newton Telescope at the ING (La Palma, Spain). Approximately 300 eclipsing binaries and a similar number of Cepheids have been reported in the studied 32'$\times$32' field. The time-series photometric measurements contain a total of 250 individual observations in each of the B and V filters. Spectroscopic observations of a selected sub-sample of eclipsing binaries and Cepheids (with magnitudes $V \sim 19-20$) were carried out during the 2004B observing season with the Gemini-N GMOS spectrograph. Based on the previous experience, the expectations are to reduce the uncertainty of the M31 distance to better than 5%, thereby firmly calibrating the Cosmic Distance Scale. Also, the project will provide the first direct determinations of masses and radii of stars in M31, thus allowing for an unprecedented test of stellar structure and evolution using stars that have evolved in a medium much different from that of the solar neighborhood.

3.6 Variable Giant Stars

Guinan and Wasatonic are conducting long term V-band and Wing near-IR TiO photometry of late-type variable red giant and super- giant stars. The primary objectives of these investigations are to characterize radii, luminosity, and effective temperature variations throughout their pulsational cycles and to determine general pulsation features such as oscillation modes and multi- periodicities. Secondly, relationships between variations in V- band magnitudes, near-bolometric magnitudes, and TiO absorption band strengths at 719 nm with these changing physical properties are being analyzed.

The program stars are the SRc supergiants Betelgeuse, α Her, TV Gem, and the Perseus double-cluster members XX and FZ Per. Giant stars being observed are the Mira-type variables *o* Ceti and R Leo, and the SRa variable V CVn.

Analysis of the R Leo observations indicates a fairly tight anti- correlation effect between T_{eff} and luminosity increases with decreasing radii, and vice-versa. This can be indicative of of fundamental mode pulsation. At R Leo maximum brightness its average T_{eff}, luminosity, and photospheric radius are 3200K, 7300 $L_{\odot}$ and 260 $R_{\odot}$, respectively. At R Leo minimum brightness, its average T_{eff}, luminosity, and radius are 2100 K, 3300 $L_{\odot}$, and 460 $R_{\odot}$, respectively.

Preliminary observations of other program stars are yielding interesting results. Beat periods of about 180 and 190 days were found in V CVn and the existence of shock waves propagating through the atmosphere are also postulated based on preliminary analyses of V-band, near-IR, and TiO strength curves. TV Gem exhibits a long-term period of approximately 2000 days upon which smaller periodicities are superimposed. The V-band light curve of α Her is characterized by a 350-day periodic major ‘‘pulse’’ with an average amplitude of 0.6 magnitude followed by pulses with gradually decreasing amplitudes that eventually ‘‘damp out’’ throughout a given observing season. Detailed results of all observations will be ascertained as both archived and continual, newly acquired data is analyzed.

3.7 Chromospherically Active Stars

Guinan and Wasatonic are carrying out a pilot program of V-band and Wing near-IR TiO photometry of the chromospherically active spotted stars λ And (G8 IV-III) and IM Peg (K1.5 II-IIIe). Current thought is that the V-band magnitude variations are due to relatively large starspots rotating into and out of view, which would be characterized by mirror-imaged V-band magnitude and TiO absorption strength curves. However, the observations on both stars to-date show only sporadic anti-correlation effects between the V-band and TiO curves. It is thus speculated that the V-band variations are caused by bright spots such as plages and white light faculae that rotate into and out of view rather than dark spots. Both bright and dark spot models have been developed by T. Mirtorabi (Iran) that are needed to confirm or refute this theory.

3.8 Young Stellar Objects

DeWarf and Guinan continue their intensive long-term photometric monitoring of Young Stellar Objects (YSOs) with the 0.8m Four College Automatic Photoelectric Telescope (FCAPT). Some YSOs that are currently monitored are: AB Aur, SU Aur, V1331 Cyg, GW Ori, V410 Tau, V833 Tau, and V773 Tau. Some current projects include:

GW Orionis: Over 12 years of *UBV* observations have been obtained with FCAPT. GW Ori (HD 244138; K3 - G5 (?) Ve; $\langle V \rangle = +9.92$ mag; $\langle B\text{-}V \rangle = +0.97$) is possibly a single-lined spectroscopic binary ($P_{\rm orb} = 242$ days). Unfortunately, the physical properties of the secondary component remain unknown. It is evident from large infrared excesses that GW Ori is surrounded by an extensive circumprimary and possibly circumbinary disk of material. The spectral energy distribution in the optical and near-infrared wavelengths has been preliminarily modeled utilizing a simple two-component (Kurucz stellar atmosphere + blackbody) energy distribution. Their procedure (*see* DeWarf *et al.* 2003, ApJ, 590, 357) will determine many observational and physical properties of the star, including temperature, mass, radius, surface gravity, and age of the primary star, average temperature of the circumstellar component(s), along with extinction to the system. Visible wavelength spectra recently obtained by collaborator A. Pugach (Main Astronomical Observatory of NASU, Kiev) should provide key information vital to the completion of this stage of the project.

GW Ori’s rotation period remains uncertain. In general, rotation periods can be determined from the low-amplitude, short-term modulations in brightness due to the presence of starspots. The difficulty in obtaining the rotation period in this manner is due to the complex nature of starspot activity – spots are (relatively) quickly created, destroyed, and are free to migrate about the stellar surface. Standard period analysis routines often lead to non-detections, or even misleading values, due to these slight changes in period (migration/differential rotation) and random phases (creation/destruction). Current efforts involve developing a specially modified Lomb-Scargle periodogram method employing a segmented-averaging approach. Though still in the ‘‘testing’’ stage, it is believed that this procedure will be ideally suited for finding these subtle periodicities in temporally large photometric datasets.

SU Aurigae: Their long-term FCAPT photometry of SU Aur (HD 282624; G2 IIIe; $\langle V \rangle = +9.16$ mag; $\langle B-V \rangle = +0.90$) shows that its brightness varies on time scales of days, months, and years, and the star often displays dramatic ‘‘dips’’ that most likely are caused by obscurations by dust clumps around low mass companions (accreting protoplanets, protocomets, and/or associated halos). The accretion disk of SU Aur is therefore most likely in the process of forming embryonic planets. Recently approved (but not yet carried out) Cycle 5 *FUSE* observations should provide excellent data on the hot plasmas at various temperatures, compositions, dynamics, ionization states, and electron densities in the stellar chromosphere, transition region, and corona, along with the hot inner regions of the circumstellar disk. These observations should greatly improve their understanding of the complex inflow, accretion, and outflow dynamics that occur during this stage of evolution and possibly provide new insights into the nature of the ‘‘eclipse-like’’ events.

3.9 ‘‘The Sun in Time’’

Guinan & DeWarf continue with their comprehensive study of the evolution of the corona (x-ray; *Einstein, ROSAT, ASCA, XMM, Chandra*), transition region (FUV; *IUE, FUSE*), and chromospheric (FUV-UV; *IUE*) emissions of single solar-type stars with a wide range of ages and corresponding magnetic activity. They use a sample of solar analogs, narrowly confined between spectral types G0-5 V that vary only by their (reasonably) well determined ages and rotation periods, and hence magnetic activity. In this sample, however, there is still a wide spread of rotation rates and ages, ranging from about 1.5 to 37 days, with corresponding ages from 100 Myr to 8.5 Gyr respectively. This has given them an excellent cross section of both age and rotation period, with a resulting wide range of magnetic dynamo induced activity. These stars thus constitute a test of the effect of varying rotation rates (and age) on the stellar dynamo, keeping all other stellar parameters approximately constant. Their selection of solar-like stars (which should have similar convective zone depths) significantly limits the range of variation of stellar properties. Their studies show that the Sun's L_X has *decreased* by 1000× since its young, more active ZAMS days. In essence, they use a 1 $M_\odot$ star as a laboratory to study the effects of the stellar dynamo by varying the only free parameter, P_{rot}.

The Solar Twin: One of the particularly interesting stars in the ''Sun in Time'' program is 18 Sco, which has been identified as the ''Closest Ever Solar Twin'' (Porto de Mello & da Silva 1997, ApJ, 482, L89). This nearby G2 V star has M_V, T_{eff}, [Fe/H], $R/R_\odot$, inferred age and mass that are closely matched to the Sun. Also, its magnetically-related chromospheric activity is very similar to the Sun. Recent studies of Ca II HK indicate a solar-like (~10 year) magnetic activity cycle. With student R. Hamilton, the team will combine *FUSE* and *XMM* observations with other datasets, providing nearly complete spectral coverage spanning the x-ray to visible wavelengths. 18 Sco will provide an important check on the behavior of our present Sun. For example, is our Sun ''normal'' for its age and mass? If confirmed as a precise match to our Sun, 18 Sco would be important for follow-up studies in astroseismology, extrasolar planet searches, and could serve as a surrogate for the ''nighttime Sun'' as a standard star.

15 Sge: Guinan, DeWarf, and McCook, with I. Ribas (IEEC, Spain) and Villanova graduate M. Dulude are currently researching the two billion year-old solar proxy 15 Sge. Recently, 15 Sge was discovered to host a dim, cool L6 ± 1.5 brown dwarf companion with a mass of ~58-71 M_j and a distance of ~14-21 AU from the host star (see Liu *et al.* 2002; Bocccaletti *et al.* 2003). 15 Sge (HR 7276; G1V; V = +5.80 mag; π (Hipp) = 56.6 mas) has been on the Villanova ''Sun in Time'' program for over 15 years. As part of this program, this young solar proxy has been observed at x-ray, EUV, FUV-NUV, and optical wavelengths to study its coronal, chromospheric, and starspot activity. Its rotation period of 13.9±0.4 days is well determined from photometry (light variations of starspots) and from Mt. Wilson Ca II HK studies. From their Age-Rotation-Activity relations, its age is 1.9±0.3 Gyrs. This value agrees well with an age of 2.0 ±0.5 Gyr estimated from recent stellar evolution codes. 15 Sge is extremely critical because of its age. It serves as an important proxy for our Sun at a time in the early solar system when primitive life had just established a foothold on Earth and when Mars may have been warm, wet, and suitable for life. From the available data, we computed the XUV spectral irradiances. These can be used to model the radiation effects of the younger Sun's stronger x-ray (~10× present) and FUV (2−3× present) radiation on paleoplanetary atmospheres. The large XUV solar fluxes may have had major effects on the younger planets' ionospheres and resulting mass loss. The stronger FUV fluxes may have been influential in photochemical reactions that could affect life. They are researching the effects of star's strong XUV emission on its brown dwarf companion, and the importance of the refined age determination of 15 Sge. Using their Age-Rotation-Activity relations will help pin down the age of its brown dwarf companion, and allow comparisons to current brown dwarf models.

3.10 Evolution of the Solar Magnetic Activity over Time and Effects on Planetary Atmospheres

I. Ribas (IEEC, Spain), along with Guinan, M. Güdel (PSI, Switzerland), and M. Audard (Columbia Un.) have recently completed a study that has yielded new results within the broader ''Sun in Time'' program. This is a multiwavelength program (x-rays to the UV) that employs a sample of solar analogs with ages covering ~0.1−7 Gyr to serve as proxies of the Sun at different stages of its evolution. The chief science goals are to study the solar magnetic dynamo and to determine the radiative and magnetic properties of the Sun during its evolution across the main sequence. The recent study has focused on the latter goal, which has the ultimate purpose of providing the spectral irradiance evolution of solar-type stars to be used in the study and modeling of planetary atmospheres. The results from the ''Sun in Time'' program suggest that the coronal x-ray–EUV emissions of the young main-sequence Sun were ~100−1000 times stronger than those of the present Sun. Similarly, the transition region and chromospheric FUV–UV emissions of the young Sun are expected to be 20–60 and 10–20 times stronger, respectively, than at present. When considering the integrated high-energy emission from 1 to 1200 Å, the resulting relationship indicates that the solar high-energy flux was about 2.5 times the present value 2.5 Gyr ago and about 6 times the present value about 3.5 Gyr ago (when life supposedly arose on Earth). The strong radiation emissions inferred should have had major influences on the thermal structure, photochemistry, and photoionization of planetary atmospheres and also played an important role in the development of primitive life in the Solar System. The application of the ''Sun in Time'' results on exoplanets and on early Solar System planets is being carried out in collaboration with F. Selsis (CAB, Spain) and H. Lammer (IWF-OAW, Austria). The topics under study include: Thermal escape on exoplanets, the Martian water inventory, the erosion of Mercury's surface, and the paleo-climate of the Earth.

3.11 Magnetic Activity and High Energy Irradiances of dK and dM Stars - Impacts on Extrasolar Planetary Environments & Life

Guinan and DeWarf, with I. Ribas (IEEC, Spain), M. Cuntz (University of Texas), G. Harper (University of Colorado), and students S. Engle, R. Hamilton, E. Voyer, S. Lakatos, & A. Riedel are working on extending and expanding their ongoing ''Sun in Time'' program on x-ray (*XMM*), EUV (*EUVE*), and FUV (*FUSE*) irradiances (and effects on planetary atmospheres) and solar/stellar dynamo physics of solar-type (G0-5 V) stars to cooler, more numerous dK and dM stars with deep convective zones. These studies are motivated by the upcoming exoplanetary search missions (e.g. *Kepler*, *SIM*, and *Darwin/TPF*) that will search for earth-like planets in the habitable zones of nearby G-K-M stars. They have isolated a complete sample of dK stars, which covers ages from ~100 Myr ($P_{\rm rot}$ = 1.8 d) to 7–8 Gyr ($P_{\rm rot}$ = 45 d), and correspondingly large differences in magnetic activity. Similarly, their sample of dM stars contains wide ranges of ages (~12 Myr-13 Gyr) and rotation rates ($0.5d <$ P_{rot} $<$190d).

Of particular interest is the determination of x-ray - FUV emission flux evolution with age for these dK and dM stars. This is because of the critical roles that these high energy emissions play on the photochemical and photoionization evolution (and possible erosion) of planetary atmospheres and ionospheres of extrasolar planets that may be hosted by these stars. These observations would also have a major impact on the possible origin and evolution of extraterrestrial life on such planets.

3.12 Polaris

Villanova graduate S. Engle and Guinan continue to carry out photoelectric photometry of Polaris (α UMi A; ~+2.0 mag; F7Ib; P = 3.97d). These observations were used to determine the light amplitude change of this nearby, bright classical Cepheid. Previous studies have found a steady decline of Polaris' light amplitude since the early twentieth century. Their work is a continuation of the work done by Kamper and Fernie (1998, ApJ, 116, 936), whose invaluable study of the radial velocity/light amplitude relationship of Polaris serves as the basis for this continuied monitoring of the star after the cessation of its amplitude decrease. Its light variation has decreased from ~0.15 mag (visual) in the 1900s to a minimum value of 0.020 mag during the mid-1990s. However, their 2002-04 photometry indicates its light (V) amplitude is again increasing and is 0.038 mag during 2004.

In addition, Polaris is undergoing an increase in pulsation period of dP/dt = +3.2 s/yr. Along with the long term secular period increase, a detailed analysis of the times of light maximum shows cyclic oscillations in the apparent period on time scales of 11-12 years. They also report on yet another remarkable characteristic of Polaris. Their analysis of all available 20th century photometry indicates that the mean brightness of Polaris has increased from about V ≈ +2.12 mag in the 1900s to the current high value of = +1.95 mag. Motivated by this apparent luminosity increase, they have carefully investigated its brightness, starting with Ptolemy (Almagest 137 AD; m = +3 mag), and have examined all available historical sources. They have reconstructed its apparent visual magnitude by comparing its given magnitude at each epoch with a grid of nearby bright stars. The sources of historical data include Ptolemy, Al- Sufi, Ulegh Beg, Tycho Brahe, Herschel, and many 19th century measurements. Overall, when all of the data are combined and weighted, there is strong evidence that Polaris has increased in brightness by more than 1 mag over the last two millennia.

3.13 Spectroscopy on a Shoestring: Worthwhile Science for Undergraduates

Guinan and McCook, with Wasatonic and students R. Hamilton & S. Engle, are proceeding with an ongoing pilot program utilizing a commercially available SBIG Self-Guided Spectrograph (SGS) and a relatively small Celestron 14'' on-campus telescope. Low resolution spectroscopy (2.4Å) is being carried out at red wavelengths (6400-7600Å). They chose this wavelength range to take advantage of the high quantum efficiency of the detector and because of the presence of important spectral features such as Hα and Titanium Oxide (TiO). They are testing the scientific viability of the spectroscopic system by initially observing a sample of Be stars as well as bright pulsating red giants, supergiants, and Cepheids.

Be stars are noteworthy because they have strong and often variable Hα (6563Å) emission. They have photometric observations of the Pleiades star Pleione (BU Tau), ω Ori, and X Per (HD 24534). This allows them to compare Hα emission changes on both short time scales as well as long ones, particularly for both ω Ori and Pleione. For Pleione, dramatic night to night changes were seen in both the strength and profile of the Hα emission feature. Photometric observations of ω Ori have been carried out at Villanova since 1982 to the present. Having simultaneous spectroscopy and photometry is allowing insights into the nature of its variability.

Spectroscopy of pulsating red giants/supergiants as well as Cepheids are of interest. Some representative stars include Mira, α Ori, and TV Gem, as well as the Cepheids δ Ceph, Polaris, and SV Vul. These stars undergo spectral changes as they pulsate. For the M stars in particular, the TiO bands are sensitive to temperature changes in the star. Complementary V and Wing near-IR TiO band photometry are also being carried out for the cooler stars.

3.14 Archaeoastronomy

Ambruster, E.R. Jewell (Villanova), and T. Hull (NASA Jet Propulsion Lab) continued their archaeoastronomy project in Chaco Canyon National Historical Culture Park, NM with two research trips: December 18-20, 2003 and June 15-24, 2004. The initial site studied (SJ 1655) is located on the south side of Chaco Canyon near the eastern end of National Park Service land; it contains several rock art covered boulders and 1 prehistoric Anasazi shrine that denote observing places for equinox, summer solstice, and winter solstice sunrises. Only those boulders with dramatic views of solar events contain significant rock art, either Anasazi or early (18th c.) Navajo; other boulders nearby are not inscribed. The winter solstice sunrise boulder is particularly important for cultural studies: the sun rises in a notch formed by the leading edge of that boulder and a distant cliff (North Defining Cliff or NDC) on the horizon, and rises up the slanted edge of the boulder over the next 2 hours. Among the glyphs on the boulder (all are Gobernador-phase 18th c Navajo) are

2 sun shields, 2 Yei (holy people), and 2 sets of traditional drilled constellations for November and December. In anthropological literature, the Navajo are not known to have marked solstices or equinoxes during the past 100 years. Thus, this could be evidence for an early group of Pueblo-influenced Navajo in Chaco Canyon. The project goal is to establish the cultural context for this solstice and equinox site with an archaeological survey of the surrounding 1-2 km; the survey should also identify any other sky-associated rock art or structures and their cultural context.

On the December 2003 trip, measurements suggested, and observations on 19Dec03 confirmed that, as seen from the high ledge on the North Defining Cliff (our site number AHJ 340) the winter solstice sun rises precisely at the base of a cliff approximately a km further southeast along the north side of Chaco Canyon. This winter solstice event is stunningly similar to the winter solstice sunrise seen from Rock B at the original study site. The viewing position was just in front of a small stone circle (which could be either Anasazi or Navajo); there is an Anasazi spiral (ca. 1100 AD) about 40 feet to the west visible from the canyon floor. It will require a permit from the Navajo Nation, on whose property this newly identified WSSR cliff is located, to discover whether the observational 'chain' continues further down the valley. We will be applying for this permit. The area around the NDC also contains another credible winter solstice sunrise site, AHJ343, which was also confirmed on 19Dec03. AHJ343 is a ca. 8-foot high boulder with extensive rock art, including spirals, on both its northern and eastern sides, as well as spirals on the broad corner between them. Viewed from AHJ343, the winter solstice sun rises in a v-shaped notch formed by the split slabs of rock art site AHJ342 about 20 meters to the southeast. Also on 19Dec03, we observed winter solstice sunset (WSSS) from AHJ 351. Here a concentric circle marks the place to stand: the sun sets near prominent rock forms on the horizon, but not in any interesting way. We conclude that there is no WSSS effect at this site. Finally, three new site components were mapped and documented; a total of about 50 new sites and components not found in the National Park Service site forms have been located by our project.

During the June 2004 trip, Ambruster and Jewell completed standard site forms for several sites discovered earlier in the program. They also explored, with Dr. Hugh Rogers and his son, an early Navajo painted panel up on a ledge three rincons east of the core solstice-equinox site and a densely incised Navajo panel nearby, as well as early rock art sites in the ancestral Navajo homeland, the Dinetah, some 50 miles north of Chaco Canyon. Finally, we completed documentation of the 6-hour long changing light and shadow patterns on the 3.8 meter high boulder AHJ251 at summer solstice: this northwest facing panel, containing two Anasazi spirals covered with black lichen, only receives direct sunlight right around the summer solstice. Various shadow daggers penetrate both spirals and at other times are tangent to their boundaries throughout a 6 hour period.

3.15 Accreting White Dwarfs in Binaries

Sion, P. Godon (Villanova), P. Szkody (U.WA), Long (STScI) and Froning (CASA) analyzed a 904-1183 Å spectrum of the dwarf nova VW Hydri taken with the *Far Ultraviolet Spectroscopic Explorer* during quiescence, eleven days after a normal outburst, when the underlying white dwarf accreter is clearly exposed in the far ultraviolet. However, model fitting show that a uniform temperature white dwarf does not reproduce the overall spectrum, especially at the shortest wavelengths. A better approximation to the spectrum is obtained with a model consisting of a white dwarf and a rapidly rotating ''accretion belt.'' The white dwarf component accounts for 83% of the total flux, has a temperature of 23,000K, a $v\sin i=400$ km s^{-1}, and a low carbon abundance. The best-fit accretion belt component accounts for 17% of the total flux, has a temperature of about 48,000−50,000K, and a rotation rate $V_{rot}\sin i$ around 3,000 −4,000 km s^{-1}. The requirement of two components in the modeling of the spectrum of VW Hyi in quiescence helps to resolve some of the differences in interpretation of ultraviolet spectra of VW Hyi in quiescence. However, the physical existence of a second component (and its exact nature) in VW Hyi itself is still relatively uncertain, given the lack of better models for spectra of the inner disk in a quiescent dwarf nova.

Sion, F. Cheng (U.Shanghai), Gänsicke (U.Warwick) and Szkody analyzed an HST STIS data of VW Hyi that we acquired ∼14 days after a superoutburst. At the time of their observation the system appears to be going into outburst with the longest wavelengths increasing in flux by a factor of 5 while the shortest wavelengths increase by only a factor of 2. Using the distance of 65 pc, a system inclination angle of 60 degrees and a white dwarf mass of 0.86 $M_{\odot}$, they carried out model fits involving a white dwarf by itself, an optically accretion disk by itself, a composite model using an optically thick accretion disk and a white dwarf, a two-temperature white dwarf model with a cooler more slowly rotating photosphere and a hotter, rapidly rotating accretion belt and a composite model involving a white dwarf and a rapidly rotating cooler disk ring heated up to a ''low'' temperature of ∼13−14,000K. This component of temperature stays fairly constant throughout the HST observations while the area of the disk ring increases by a factor of 12. They see evidence of a delay in the UV emission consistent with the outburst beginning outside of a disk truncation radius.

Sion, Villanova students L. Winter and J. Urban, B. Gänsicke, G.Tovmassian and S. Zharikov (U.Mexico), and M. Orio (Torino) explored the origin of FUSE and HST STIS far UV spectra of the dwarf nova, EY Cyg, during its quiescence using *combined* high gravity photosphere and accretion disk models as well as model accretion belts. The best-fitting single temperature white dwarf model to the FUSE plus HST STIS spectrum of EY Cygni has $T_{eff}=24{,}000$K, $\log g=9.0$, with an Si abundance of 0.1 x solar and C abundance of 0.2 x solar but the distance is only 301 pc. The best-fitting composite model consists of white dwarf with $T_{eff}=22{,}000$K, $\log g=9$, plus an accretion belt with $T_{belt}=36{,}000$K covering 27% of the white dwarf surface with $V_{belt}\sin i=2000$ km/s. The accretion belt contributes 63% of the FUV light and the cooler white dwarf latitudes contribute 37%. This fit yields a distance of 351 pc which is within 100 pc of their adopted distance of 450 pc. EY Cyg has very weak C IV emission and very strong N V emission, which is atypical of the majority of dwarf novae in quiescence. They also conducted a morphological study of the surroundings of EY Cyg using direct imaging in narrow nebular filters from ground-based telescopes. They report the possible detection of nebular material associated with EY Cygni. 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 or as a descendant of a precursor binary that survived thermal timescale mass transfer. The scenario involving pollution of the secondary by past novae may be supported by the possible presence of a nova remnant-like nebula around EY Cyg.

Sion, Villanova student J. Urban, F. Cheng, and P. Szkody have analyzed the Far Ultraviolet Spectrocopic Explorer (FUSE) spectra of two U Gem-Type dwarf novae, SS Aur and RU Peg, observed 28 days and 60 days (respectively) after their last outburst. In both systems the FUSE spectra (905 − 1182 Å) reveal evidence of the underlying accreting white dwarf exposed in the far UV. Their grid of theoretical models yielded best-fitting single temperature photosphere models to the FUSE spectra with T_{eff}=33,000K for SS Aur and T_{eff}=53,000K for RU Peg. For SS Aur, a white dwarf of 27,000K plus a 48,000K accretion belt yields the best agreement with the FUSE spectrum and parallax distance. This work provides two more dwarf nova systems with known white dwarf temperatures above the period gap where few are known. The absence of C III (1175 Å) absorption in SS Aur and the elevation of N above solar suggests the possibility that SS Aur represents an additional accreting white dwarf where the surface C/N ratio derives from CNO processing. For RU Peg, the modeling uncertainties prevent any reliable conclusions about the surface abundances and rotational velocity.

Villanova student R. Hamilton and Sion used newly determined parallaxes for dwarf novae to derive outburst accretion rates for VY Aqr, RU Peg and T Leo and for T Leo during quiescence. The two short-period dwarf novae, VY Aqr and T Leo, show good agreement with optically thick steady-state accretion disks in outburst, whereas RU Peg shows a significant departure from a steady-state disk (see below). They have determined that the white dwarf in T Leo has T_{eff} = 16,000 ± 1000 K, a value consistent with long term compressional heating when gravitational wave emission drives mass transfer. The white dwarf in T Leo has a temperature in the same narrow range as other WZ Sge-like dwarf novae. They derived accretion rates for 3 dwarf novae in outburst, and have provided the first temperature determination of the white dwarf in T Leo derived from the analysis of its quiescent *IUE* spectrum. For the best accretion disk fits to the outburst spectra of VY Aquari and T Leo, a steady-state optically thick accretion disk represents the observed FUV energy distribution very well with no significant deviations. For RU Peg in outburst, however, there is a large deviation from the observation longward of 1600 Å . This implies an additional radiating component (secondary star or hot spot?) or that the temperature distribution, T(r), in the disk differs from the steady-state T(r).

The temperature of the white dwarf in T Leo is consistent with the predicted range of temperature expected from long term compressional heating at a rate of mass transfer driven by gravitational wave emission as shown by Sion *et al.* (2003) and Townsley and Bildsten (2002). The effective temperature of the T Leo white dwarf agrees with the white dwarf effective temperatures in dwarf novae with similar orbital periods. Recently, Vrielmann *et al.* (2004) provided evidence from T Leo's XMM-Newton X-ray light curve that it might contain a magnetic white dwarf and hence be the first superoutbursting intermediate polar (IP). They found a 414s signal which could be due to the rotation of the white dwarf. However, it is also possible this signal could be an ordinary QPO. If T Leo is an IP, their temperature for the white dwarf is one of only three.

3.16 White Dwarfs in Symbiotic Variables

Villanova students K.Kolb, J. Miller, Sion, and J. Mikolajewska (Warsaw) applied grids of NLTE high gravity model atmospheres and optically thick accretion disk models for the first time to archival IUE and FUSE spectra of the S-type symbiotic variable EG And taken at superior spectroscopic conjunction when Rayleigh scattering should be minimal and the hot component is viewed in front of the red giant. For EG And's widely accepted, published hot component mass, orbital inclination and distance from the Hipparcos parallax, they find that hot, high gravity, NLTE photosphere model fits to the IUE spectra yield distances from the best-fitting models which agree with the Hipparcos parallax distance but at temperatures substantially lower than the modified Zanstra temperatures. NLTE fits to an archival FUSE spectrum taken at the same orbital phase as the IUE spectra yield the same temperature as the IUE temperature (50,000K). However, for the same hot component mass, inclination and parallax-derived distance, accretion disk models at moderately high inclinations, $\sim 60-75°$ with accretion rates $\dot{M} = 1 \times 10^{-8}$ to $1 \times 10^{-9} M_{\odot}/yr$ for white dwarf masses $M_{wd} = 0.4 M_{\odot}$ yield distances grossly smaller than the distance from the Hipparcos parallax. Therefore, they rule out an accretion disk as the dominant source of the FUV flux. Their findings support a hot bare white dwarf as the dominant source of FUV flux.

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