

Villanova University
Department of Astronomy & Astrophysics
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This report covers the period from October 2002 to September 2003.

1. PERSONNEL

During the report period, 10/02-9/03, 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), Professor Edward M. Sion, and Research Associate Richard Wasatonic. Dr. Elizabeth R. Jewell served as Department Assistant.

Students Laura Marie Barge, Eric Barron, Jessica Castora, James J. Davis, Joseph Drescher, Michael Dulude, Scott Engle, Ryan Hamilton, Kelly Kolb, Michael Lesniak, Joleen Miller, Rebecca Percy, Abington H.S. (PA) student A. Pouch, Adric Riedel, FIT student L. Seward, Jeffrey C. Tracey, Joel Urban and Lisa Winter served as research assistants.

2. INSTRUMENTATION

2.1 Automated Photoelectric Telescopes

The Fairborn Observatory, home of the Four College APT (FCAPT) is located in the Patagonia Mountains of AZ (Lat: +31 23 12; Long: -110 41 41). This 0.8m automated photoelectric telescope is operated by the Four College Consortium (FC) consisting of the College of Charleston, The Citadel, University of Nevada-Las Vegas, and Villanova University. The FCAPT is supported by NSF grants AST95-28506 and AST-0071260.

After testing during May 2003, the Robotically Controlled Telescope (RCT) 1.3 m telescope on Kitt Peak is now in limited operation conducting CCD photometry (*UBVRI*). The Research Consortium includes Villanova, Western Kentucky, South Carolina State, Francis Merion and the Planetary Science Institute.

3. RESEARCH

3.1 Interstellar Medium

Fitzpatrick delivered an invited review talk at the *Astrophysics of Dust 2003* Symposium held in May 2003 at Estes Park, Colorado. The talk, entitled "Interstellar Extinction in the Milky Way Galaxy," reviewed the current state of our characterization of the wavelength dependence of absorption and scattering (i.e., "extinction") by interstellar dust grains. The ability of dust grains to transmit, redirect, and transmute electromagnetic radiation as it travels through interstellar space has a great impact on the physical processes occurring in interstellar space and on the resultant physical conditions there. Understanding the ambient radiation field in space requires a detailed knowledge of the extinction properties of

the dust. In addition, the wavelength dependence of extinction provides important diagnostic information about the physical properties of the dust grains themselves, and often serves as a first test for possible grain models. Finally, and perhaps most far-reaching, interstellar extinction profoundly limits our ability to study the universe. It is certainly fair to say that many more astronomers care about extinction, than care about the dust grains that produce it! The primary goal of the talk was to review the evidence supporting the idea that Galactic extinction in the UV through IR region can be considered a 1-parameter family characterized by their value of $R_V \equiv A_V/E(B-V)$. Based on analysis of new (i.e., *2MASS*) and old (i.e., *IUE*) data for ~ 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. It is likely 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. A paper based on this talk will appear in the *Astrophysics of Dust 2003* conference proceedings, to be published in 2004.

Fitzpatrick and Derck Massa (SGT, Inc.) presented a poster paper at the *Astrophysics of Dust 2003* Symposium, entitled "Extinction Without Standards and UV Extinction Curves for Stars with Small Color Excesses." The poster illustrated a new technique for deriving the wavelength dependence of interstellar extinction, utilizing stellar atmosphere models rather than unreddened "standard stars," the classical pair method technique. The benefits to this technique are numerous, including: 1) the elimination of the subjective process of determining the pair method standard; 2) a large reduction in mismatch error in the resultant extinction curves; 3) the ability to determine reliable extinction curves for lower $E(B-V)$ sightlines than possible previously; and 4) the ability to determine reliable UV extinction curves for later type stars (i.e., as cool as late-B) than previously possible. The poster described the new analysis and provided examples of its application. Particularly important was the demonstration that the new technique greatly reduces the scatter among the extinction curves derived from lightly reddened, late-B stars in the young galactic cluster IC 4665. This result verified that the technique does indeed provide dramatic improvements over classical methods of analysis. Fitzpatrick and Massa are preparing a reanalysis of the entire UV extinction database, based on the new analysis.

3.2 B Stars in the Milky Way

Fitzpatrick and D. Massa (Emergent IT) successfully proposed a Cycle 4 Observing Program with the *Far-Ultraviolet Spectroscopic Explorer (FUSE)* satellite, entitled “Temperature Variations in Slowly Pulsating B Stars”. As a class, these stars are seen to exhibit low-amplitude, multi-periodic photometric variability on time scales of 0.5 - 2.0 days. They also display low-amplitude radial velocity variations (i.e., a few $\times 10$ km/sec). The variability has been shown to result from non-radial g-modes excited by the κ -mechanism, due to the presence of a relative maximum in the metal opacity below the atmosphere. These stars are prime candidates for astroseismology studies since the g-modes penetrate deeply into the stellar interior. Far-UV spectra (912 - 1180 Å) will be obtained for several candidate stars to determine their level of flux variability in the very temperature-sensitive FUV spectral domain. The most extreme variable will be chosen for detailed monitoring, to determine whether surface temperature variations contribute to the photometric variability. Robust measures of temperature variability throughout a pulsation cycle would provide a strong constraint on theoretical models which seek to explain the pulsation process.

3.3 Magnetic Activity of Dwarf G, K, & M Stars

As part of the “Sun in Time” Program, Guinan, DeWarf, Güdel (PSI), and Ribas have been carrying out multi-wavelength (X-ray to near-IR) observations of solar-type (G0 V-G5 V) stars with different ages. These stars serve as proxies for the Sun (and other solar type stars) and cover ages that include most of the Sun’s main sequence life time. This program addresses a variety of topics that include: the study of short and long term magnetic evolution; the physics and energy transfer mechanisms of the chromosphere, transition region, and corona; and the evolution of the XUV spectral irradiance of the Sun and of the high energy radiation on paleo-planetary environments and atmospheres. As part of this program, excellent correlations were found among age, rotation period, and magnetically generated coronal X-ray and EUV emissions, Transition Region and Chromospheric FUV-NUV emissions. For example, for this narrow spectral range of solar type stars, the coronal X-ray emission of young main sequence early G stars are ~ 100 – 1000 times stronger than stars near the Sun’s age of 4.6 Gyr.

This program recently has been expanded to include samples of nearby dK and dM stars. As part of the initial program, undergraduate students Joseph Drescher, Kelly Kolb, Joleen Miller, Laurie Barge and Ryan Hamilton have compiled the properties of new candidates. The stars selected for study have well determined parallaxes, colors, spectral types and also have measures of age (=rotation) sensitive measures such as Lx, Ca II HK, Mg II hk emission fluxes. As was done in the “Sun in Time” program, most younger stars selected are members of clusters or moving groups. The ages of the some of the older, less active stars are estimated using isochronal fits. The ages of some of the dM stars were estimated from kinematical considerations or associations with nearby hotter stars. The initial results of this program and

relations between magnetic activity indicators (such Lx or Ca II) and age (rotation) have been presented at the May 2003 AAS Meeting in Nashville. Tight relations for the late G and K stars were found as long as the physical properties of the stars (colors, T_{eff} , or spectral types) are kept very narrow. The implications of this program for identifying late type stars that might be suitable for life were also presented.

3.4 Erosion of Mercury’s Mantle by the Young Sun

The planet Mercury is often referred to as the “Iron” Planet. This is because its iron core is large compared to other terrestrial planets and extends more than half way out to its surface. One of several theories for this anomaly is that strong, dense, strong winds and very high X-ray-FUV irradiances of the young Sun (during the first 500 Myr of its life) eroded (swept) away its early atmosphere and much of its outer mantle. Even today (with a much weaker Sun), 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 of isotope anomalies in planetary atmospheres and meteorites indicate that our early Sun underwent a highly active phase after its origin, including continuous flare events where the particle and radiation environment 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 radiation flux. Recently Guinan and Ribas (Univ. of Barcelona) have been working with Helmut Lammer and the Astrobiology group at Graz (Austria) on this problem. Guinan and Ribas have provided them with preliminary irradiance (X-ray/FUV) values determined from the “Sun in Time” program. Also, they have estimated the winds of the young Sun from the work of Brian Wood (CASA). Initial calculations indicate that energetic flares and large CME events (combined with the steady enhanced winds and strong high energy solar emission) could be sufficient to explain the present large iron core of Mercury.

This research is partially supported by NASA, FUSE and HST grants.

3.5 Near-Infrared and TiO-band Photometry

Rick Wasatonic and Guinan with M. Mirtorabi (Iran) are carrying out a pilot program of Wing near-IR, TiO-band, and V-band photometry of the RS Canum Venaticorum type, chromospherically active, G8 IV-III star $|\lambda$ Andromedae. The primary aim is to investigate a possible relationship between variation of the ~ 54 day rotationally starspot modulated visual light curve and TiO absorption strength. The TiO ($\gamma, 0, 0$) absorption band strength at $\lambda = 719$ nm is very sensitive to temperature for cool stars and manifests itself in cooler starspot regions ($T < 4000$ K). TiO photometry has an advantage over conventional photometry in that it provides unambiguous measures of the fractional cool starspot coverage. In addition, as the stars rotate, the variation in the TiO index yields information about the longitudinal distribution of the starspots. Importantly, combining the TiO

photometry with the V-band and near-IR light curves allows the discrimination of white light faculae (=hot spot) and cool starspot contributions. Initial results of this study indicate that the observed V-band and near-IR continua light variations found for λ And primarily arise from bright spot (plage) features rather than dark starspots as is usually assumed. This is in contrast to current theories that the visual light variation is solely due to dark spots. Models using both bright and dark spot features have been developed and are being used to fit the light and TiO-index curves. The models account for cool/hot spot characteristics such as projected filling factor and temperature. The long-term variation of the V-band observations and TiO index have been investigated to search for any activity cycles. The results of this study are published in the *Astronomical Journal* (2003) Vol. 125, 3265-3273.

Wing near-IR and TiO photometry of additional stars are being carried out by Wasatonic. These stars include the RS CVn variable stars κ^1 Ceti, IM Peg and continued observations of λ And, the Mira variables: R Leo and Mira, and the pulsating red supergiants: Betelgeuse, α Her, TV Gem, and XX Per.

3.6 Young Stellar Objects: SU Aurigae

DeWarf and Guinan, with former undergraduate astronomy student J. Sepinsky (currently a graduate student at Northwestern University), continue their study of the nearby Pre-Main Sequence (PMS) star SU Aurigae. PMS stars are known to have a large circumstellar accretion disks. Our photometry of SU Aur with robotic telescopes shows that its brightness varies on time scales of days, months, and years, and the star often displays dramatic ‘‘dips’’ ($\Delta V \leq 0.80$ mag) that last for several days. These sudden drops in light are not accompanied by spectral changes (*i.e.*, line blocking effects), which implies obscuration of the star by dusty concentrations. Because SU Aur is viewed at high inclination (nearly ‘‘edge-on’’), the source of these obscurations is most likely 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.

They hope to expand the program to obtain FUV spectra with *FUSE*. These spectra, if approved for observations in 2004, will 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 our understanding of the complex inflow, accretion, and outflow dynamics that occur during this stage of evolution and possibly provide insights into the nature of the ‘‘eclipse-like’’ events.

In addition to observing SU Aur, differential photometry of its proper motion companion, AB Aur, is conducted at the same time. AB Aur is observed less frequently per night and shows only small light variations (± 0.07 in u and ± 0.03 in y).

This research is supported by NSF/RUI Grant AST-00-71260.

3.7 T Tauri Stars: GW Orionis

DeWarf and Guinan, with former undergraduate astronomy student J. Sepinsky (NW Univ.) and A. Pouch (Abington H. S.) continue their intensive long-term photometric monitoring of the Young Stellar Object (YSO) GW Orionis (HD 244138; K3 - G5 (?) Ve; $\langle V \rangle = +9.92$ mag; $\langle B - V \rangle = +0.97$). They have obtained over 10 years of *UBV* observations carried out with the 0.8m Four College Automatic Photoelectric Telescope (FCAPT). GW Ori is possibly a single-lined spectroscopic binary ($P_{\text{orb}} = 242$ days), in which the physical properties of the secondary component remain unknown. There is an observed systemic change in the radial velocity measurements with an ~ 1000 day period that is attributed to either a third component, or possibly an asymmetric global gravitational instability (one-armed spiral density mode) in the circumstellar disk. After applying moderate reddening corrections, GW Orionis can be satisfactorily placed on the pre-main sequence evolutionary tracks, yielding a mass of about $2.5 M_{\odot}$ and an age of approximately 3 Myrs.

Their photometric data from 1992 to 1997 show variability over an ~ 1100 day cycle that may be correlated with the spectroscopic measurements. This variability is seen in each filter and in the photometric indices ($(U-B)$ and $(B-V)$). This suggests that this modulation might be stellar in origin, as opposed to the result of some dynamical mechanism, possibly indicative of variable accretion from the circumstellar environment, magnetic activity cycles, and/or perturbations in the circumstellar disk(s). They also find some evidence for the 242 day binary periodicity in their *U*-filter data, but find no accompanying variability in either the *B*- or *V*-band data.

Additionally, 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 modeled by a simple two-component (stellar atmosphere + blackbody) energy distribution. They find that the observed stellar component has a temperature of order 6200 K and the mean temperature for the circumstellar component(s) is about 1700 K.

3.8 TiO Photometry of Naked T Tauri Stars: V410 Tau

Guinan, McCook, and DeWarf, with Villanova senior M. Lesniak, began a study of the weak emission-line T Tauri (WTT) star, V410 Tauri (HD 283518; K4 V-IV; $\langle V \rangle = +10.6$ mag; $\langle B - V \rangle = +1.3$). This star has very large (nearly) periodic light variations ($\Delta V \approx 0.4$ mag) and with a period of $P \sim 1.87$ days. Modeling of the light curves and Doppler imaging techniques indicate the light variations primarily arise from the rotational modulation by large dark starspot regions, distributed unevenly over its surface. Bright (warm) regions also appear to be present. The rapid rotation of the star ($P = 1.87$ d; $v \sin i = 70$ km/s), coupled with its expected deep convective zone (\sim K4 V-IV spectral type), insure a vigorous magnetic dynamo that results in the observed large starspot coverage and related strong coronal X-ray and chromospheric emissions.

A *TiO*-index was formed from the photometry. This *TiO*-index, when calibrated with *Wing* standard stars, yielded a measure of the strength of the *TiO* absorption band at 719 nm relative to a continuum region at 754 nm. *TiO* absorption is very sensitive to T_{eff} for cool stars and is also present in cooler sunspot and starspot regions. *TiO* photometry, coupled with *VRI* photometry, was used to determine the properties of the surface features on V410 Tau. *TiO* photometry provides unambiguous measures of the fractional cool starspot coverage. Importantly, combining the *TiO* with the *VRI* photometry allows the discrimination of white-light faculae (=hot spots) and cool (*TiO* absorption) starspots. During 2003, there was a good correlation between the light variations and *TiO*-index in the sense that the *TiO* absorption is strongest when the star is faintest. They recently presented new *TiO* narrow, and *VRI* wide-band, photometry of V410 Tau, carried out with the recently refurbished photoelectric photometer attached to the 0.8 m FCAPT, at the 202nd meeting of the *American Astronomical Society* in Nashville, TN. This research is supported by NSF/RUI Grant AST-00 71260.

3.9 The Sun in Time: Magnetic Activity

Sergio Messina (Catania Obs) and Guinan and McCook continued their study of the magnetic activity in a selected sample of young solar analogues. The sample includes five single G0-G5V stars with ages between = 130 Myr and 700 Myr: EK Dra, pi 1 UMa, HN Peg, k1 Cet and BE Cet. The Pleiades-age (=130 Myr) K0V star DX Leo was also included in the study. Our analysis is based on high precision photometric observations carried out as part of The Sun in Time project carried out with the Four College 0.8 m robotic telescope and is a multi-wavelength study of stars with solar-like global properties, but with different ages and thus at different stages of evolution. Previous analyses of the photometry shows the presence of starspot cycles and their correlation with the global stellar properties. This year they investigated the surface differential rotation (SDR). The periodogram analysis of the photometric data time series has allowed the determination of the rotational periods and to derive the following results: i) all the selected stars show variations of the rotational period. Such variations are definitely periodic and in phase with the starspot cycle for BE Cet and DX Leo. These variations are likely periodic and in phase also for pi-1 UMa, EK Dra and HN Peg, but still need confirmation. By analogy with the solar butterfly diagram, the rotational period variations are interpretable in terms of surface differential rotation, that is, they are attributable to the existence of active latitude belts migrating during the activity cycle on a differentially rotating star; ii) BE Cet, pi 1 UMa and EK Dra show a solar-like pattern of SDR, that is the rotational period steadily decreases along the activity cycle, jumping back to higher values at the beginning of the next cycle; on the contrary, DX Leo, k1 Cet and HN Peg show an antisolar pattern; iii) the amplitude of the rotational period variations shows a power law dependence on the rotational period similar to that found in previous studies. Contrary to theoretical predictions, the cycle length is not correlated to the Dynamo number, it is indeed positively

correlated to the SDR amplitude. More precisely, stars tend to concentrate along three different branches with the cycle length increasing with increasing Delta Omega/Omega. Moreover, they found that the SDR amplitude changes from cycle to cycle, which is reminiscent of a wave of excess rotation propagating in latitude; iii) the apparently different solar and antisolar behaviors are probably due to different inclinations of the stellar rotation axis under which the star is seen. The long-term photometry of the young single star LQ Hya, although not included in the initial project, is also used in the present analysis to enlarge the investigated sample. It was found that LQ Hya has three different starspot cycles and an antisolar pattern of SDR.

3.10 The Sun in Time: Identification of the ‘Solar Twin’

Guinan, DeWarf, and McCook, with Villanova junior R. Hamilton and FIT student L. Seward, along with I. Ribas (Univ. de Barcelona) and M. Güdel (PSI, Switzerland) continue their ongoing investigation of the coronal (X-ray; *Einstein/ROSAT*), transition region (FUV; *IUE/FUSE*), and chromospheric (FUV-UV; *IUE*) emissions of single solar-type stars. By considering only main-sequence stars in a restricted range of spectral types ranging from F8 V to G8 V and stars with measured rotation periods, they have focused on the role of rotation in determining activity levels. The selection of solar-like stars significantly limits the range of variation of stellar properties. 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 an adequate 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.

An important component of this “Sun in Time” project focuses on the identification of a star whose properties are most like the Sun—the much coveted *solar twin*. Comparison of the XUV emission fluxes of the present Sun with solar twin candidates has revealed that in addition to properties used to historically define a solar twin (spectral type, color, T_{eff} , M_V , [Fe/H], etc.); age is also crucial. Because these emissions arise primarily from the magnetic-dynamo, they vary as a function of rotation period, which is related to the stellar age. They have developed correlations between X-ray (corona), FUV (transition region), and UV (chromosphere) emissions and rotation period relations obeyed by the entire group and those of the solar twin candidates. They have also introduced a Mg II $h+k$ (2800 Å) “index” that corrects for varying continuum levels and instrumental sensitivities present in the *IUE/LWP* spectra. From all the available data, the closest match to our Sun in all of its properties (including age), is 18 Sco. The preliminary results of this study are being presented at the 203rd meeting of the *American Astronomical Society* in Atlanta, GA.

This research is supported by grants from NSF/RUI (AST00-71260), NASA/*FUSE* (NAG5-12125), and the Delaware Space Grant College Consortium through the Un-

dergraduate Summer Research Assistance program (NTG5-40024).

3.11 LMC Eclipsing Binaries: Cosmic Distance Scale

Maloney, student L. M. Barge, I. Ribas (U. de Barcelona), 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.

Fitzpatrick, I. Ribas (U. of Barcelona), Guinan, Maloney, and A. Claret (Instituto de Astrofísica de Andalucía) published a paper in the April 20, 2003 issue of the *Astrophysical Journal* describing a detailed analysis of the eclipsing binary system HV5936 in the Large Magellanic Cloud. As in the previous studies of LMC eclipsing binaries, 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 was 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 11.6 M_{ffl} and 4.7 M_{ffl} , respectively. The initial masses of the two stars were approximately 7.5 M_{ffl} and 13 M_{ffl} , 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.

Financial support from the NASA - Delaware Valley Space Grant Consortium, and from the National Science Foundation through HST grant GO-06683 is gratefully acknowledged. We are grateful for the skilled assistance of the CTIO staff during our January 2000 observing run.

3.12 Apsidal Motion Studies: DI Her

Maloney, Guinan, and student L. M. Barge are re-analyzing 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 $2.34^\circ/100$ y., whereas the theoretically predicted classical contribution (due to tidal and rotational deformation of the component stars) is $1.93^\circ/100$ y. The interesting fact is that the observed apsidal motion, determined from timings of the stars' mutual eclipses, is anomalously low: $\sim 1^\circ/100$ y., well below the combined theoretical expectation of $.27^\circ/100$ y. 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, we are computing a new determination of the apsidal motion for DI Her. With R. A. Mardling (Monash), we are also computing models utilizing a new formalism for studying three-body interactions in the DI Her system.

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

3.13 Polaris

Villanova astronomy students, Scott Engle (Villanova), James Davis (now SDSU) and Jeffrey Tracey (now Catholic Univ.) with Guinan continued to carry out photoelectric photometry of Polaris during 2002 and 2003. These observations were used to study light variations and period changes of this nearby, low-amplitude, pulsating classical Cepheid. Previous studies have found a steady decline of Polaris' light and radial velocity amplitudes since the early twentieth century. An analysis of the times of maximum light (or corresponding times derived from radial velocity data) show that Polaris is undergoing an increase in pulsation period of $dP/dt = +3.2$ sec/yr. Our photometry, when combined with previous results, shows that the light amplitude change of Polaris appears to be holding steady from 1994 until early 2002 with a light amplitude of $\text{Amp}(V) = 0.028 \pm 0.002$ mag. But photometry secured recently during Fall 2003 indicates a possible increase in the light amplitude to $\text{Amp}(V) = 0.035 \pm 0.00$ mag. In addition an analysis of all of the photometric and spectroscopic timings shows that the period continues to increase at the rate of $+3.51$ sec/yr (using a cubic least squares fit to the data). These observations (together with interferometric diameter measures and Hipparcos parallaxes) support the overtone nature of Polaris' pulsations. The transition from a moderate to a low amplitude pulsator is delineated in the literature (e.g., see Evans *et al.*). This work is a

continuation of the previous work done by K.W. Kamper and J.D. Fernie, whose invaluable study of the radial velocity/light amplitude relationship of Polaris serves as the basis for this continuing monitoring of Polaris after the minimum in the light amplitude occurred during the mid-1990s.

The increase in Polaris's pulsation period, however, continues unabated. In addition to the long term secular period increase, a detailed analysis of the times of light maximum possibly shows a small cyclic (sinusoidal) oscillation of the apparent period on time scales of several decades. A formal least squares analysis of the residuals yields a period of $P' \sim 53.6 \pm 1.4$ years. The semi-amplitude of this variation is $\delta(O - C) = 0.314 \pm 0.033$ days. This amplitude is too large to be produced by the light travel time effect from a massive companion. Possible explanations for this are small cyclic variations in the star's pulsation that could be produced by small cyclic changes in its average radius. These radius changes could arise from cycles of magnetic activity of the order of 54 yrs. Also these oscillations could arise from interactions of the fundamental and overtone + pulsation modes. The preliminary results of this study were presented at the January 2003 Meeting of the AAS (Seattle, WA.) and a detailed paper is being prepared for publication.

3.14 Loss of Water from Mars

Working with Helmut Lammer, H.I.M. Lichtenegger, C. Kolb, R. Abart, and S.J. Bauer, Guinan and Ribas investigated the loss of water on Mars over the last 3.5 Gyr. The evolution of the Martian atmosphere with regard to its H₂O inventory is influenced by thermal loss processes of H, H₂, nonthermal atmospheric loss processes of H⁺, H₂⁺, O, O⁺, CO₂, and O₂⁺ into space, as well as by chemical weathering of the surface soil. The evolution of thermal and nonthermal escape processes depend on the history of the intensity of the solar XUV radiation and the solar wind density. Actual data from the observations of solar proxies with different ages from the *Sun in Time* program were used to reconstruct the Sun's radiation and particle environment from the present to 3.5 Gyr ago. The correlation between mass loss and X-ray surface flux of solar proxies follows a power law relationship, which indicates a solar wind density up to 1000 times higher at the beginning of the Sun's main sequence lifetime. For the study of various atmospheric escape processes a gas dynamic test particle model was used to estimate the pick-up ion loss rates. In these calculations they also considered pick-up ion sputtering, as well as dissociative recombination. The loss of H₂O from Mars over the last 3.5 Gyr was estimated to be equivalent to a global Martian H₂O ocean with a depth of about 12 m, which is smaller than the values reported by previous studies. If ion momentum transport, a process studied in detail by Mars Express is significant on Mars, the water loss may be enhanced by a factor of about 2. In this investigation they found that the sum of thermal and nonthermal atmospheric loss rates of H and all nonthermal escape processes of O to space are not compatible with a ratio of 2:1, and is currently close to about 20:1. Escape to space cannot therefore be the only sink for oxygen on Mars. These results suggest that the missing oxygen (needed for the validation of the 2:1 ratio between H and O) can be ex-

plained by the incorporation into the Martian surface by chemical weathering processes since the onset of intense oxidation about 2 Gyr ago. Based on the evolution of the atmosphere-surface-interaction on Mars, an overall global surface sink of about $2 \times 10^{+42}$ oxygen particles in the regolith can be expected. Because of the intense oxidation of inorganic matter, this process may have led to the formation of considerable amounts of sulfates and ferric oxides on Mars. To model this effect several factors were considered: (1) the amount of incorporated oxygen, (2) the inorganic composition of the Martian soil and (3) meteoritic gardening. Lammer *et al.* show that the oxygen incorporation has also implications for the oxidant extinction depth, which is an important parameter to determine required sampling depths on Mars aimed at finding putative organic material. The oxidant extinction depth is expected to lie in a range between 2 and 5 m for global mean values. This results of this research have been recently published in *Icarus*, 165 (2003).

3.15 CCD Photometry of Variable Stars

Using the recently refurbished 1.3 m Robotically Controlled Telescope (RCT) located at KPNO, Mc Cook and Guinan initiated a pilot program of carrying out high precision VRI CCD photometry. Test observations have been carried out during the Spring 2003 and the RCT is expected to achieve near-full operation during late 2003 or early 2004. This photometric program focuses on the study of variable stars in clusters. Selected astrophysically important eclipsing binaries, pulsating variables, blue stragglers, and chromospherically active variable stars will be studied. Also, searches of new variable stars will be made from the expected large samples of cluster stars. For example, photometry is planned of the several W UMa eclipsing binaries and blue straggler stars in the old open cluster NGC 188. Photometry also will be carried out of the young open cluster NGC 7790. This cluster is unique because it has three confirmed classical cepheid members: CE Cas A ($V \sim +10.9$ mag; F8 Ib; $P = 4.446$ d), CE Cep B ($V \sim +11.0$ mag; F9 Ib; 5.128 d), and CF Cas ($V \sim +11.1$ mag; F8 Ib; 4.875 d). NGC 7790 also contains the 10th mag eccentric B0+B0 eclipsing binary QX Cas. The observations of QX Cas are being conducted to determine the accurate distance to this star and thus to the cluster and its cepheid members. When complete these observations, combined with spectroscopy, will permit a reliable calibration of the "zero-point" of the galactic cepheid Period-Luminosity Law. Another possible project is the search of light variations of PMS stars and chromospherically active stars (from star spot rotational modulations) in young clusters such as the α Perseus Cluster, h & χ Per, M34, and the Pleiades.

Refurbishment of the RCT has been made possible by NASA grant NAG 58762. The RCT Consortium includes: Western Kentucky Univ., S. Carolina State Univ., Francis Marion Univ., Villanova Univ., and the Planetary Science Institute (PSI).

3.16 FUSE Observation of Solar Analogs

Guinan, Ribas and Graham Harper (CASA) completed the study of *Far Ultraviolet Spectroscopic Explorer (FUSE)* observations of six solar analogs. These are single main-sequence G0-G5 stars selected as proxies for the Sun at several stages of its main-sequence lifetime from ~ 130 Myr 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: from $\sim 10^4$ K for the H I Lyman series to $\sim 6 \times 10^6$ K for the coronal Fe XVIII and $\lambda 975$ line. Using the flux ratio C III $\lambda 1176$ & $\lambda 977$ as diagnostics, they investigated the dependence of the electron pressure of the transition region as a function of the rotation period, age, and magnetic activity. The results from these solar proxies indicate that the electron pressure of the stellar $\sim 10^5$ K plasma decreases by a factor of ~ 70 between the young fast-rotating ($P_{\text{rot}} = 2.7$ days) magnetically active star and the old, slow-rotating ($P_{\text{rot}} \sim 35$ days) inactive star. They also studied the variations in the total surface flux for specific emission features that trace the hot gas in the stellar chromosphere (C II), transition region (C III, O VI), and corona (Fe XVIII). The observations indicate that the average surface fluxes of the analyzed emission features strongly decrease with increasing stellar age and longer rotation period. The emission flux evolution with age or rotation period is well fitted by power laws, which become steeper from cooler chromospheric ($\sim 10^4$ K) to hotter coronal ($\sim 10^7$ K) plasma. The relationship for the integrated (920-1180 Å) *FUSE* flux indicates that the solar far-ultraviolet (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. Our analysis suggests that the strong FUV emissions of the young Sun may have played a crucial role in the developing planetary system, in particular, through the photoionization, photochemical evolution, and possible erosion of the planetary atmospheres. Some examples of the effects of the early Sun's enhanced FUV irradiance on the atmospheres of Earth and Mars are also discussed. The results are now published in the *Astrophysical Journal* (2003), Volume 594, 561-572.

Based on observations made with the NASA-CNES-CSA Far Ultraviolet Spectroscopic Explorer. *FUSE* is operated for NASA by the Johns Hopkins University under NASA contract NAS5-32985.

3.17 Archaeoastronomy

Ambruster, E.R. Jewell (Villanova), and T. Hull (NASA Jet Propulsion Lab) continued their mapping project in Chaco Canyon National Historical Culture Park, NM during a two-week research trip in June 2003. The core site contains several rock art covered boulders and 1 prehistoric Anasazi shrine that denote observing places for equinox, summer solstice, and winter solstice sunrises. Only these boulders 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: the sun rises in a notch formed by the leading edge of that boulder and a distant cliff 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), 2 traditional drilled constellations for November and 2 traditional drilled constellations for December. The importance of this site is that, in anthropological literature, the Navajo are not known to have marked solstices or equinoxes for the last 100 years. Thus, this could be evidence for an early group of Pueblo-influenced Navajo in Chaco Canyon, which had an extensive historical Navajo occupation extending to the 1940's. (It is well established that the Pueblos, and their Anasazi ancestors marked, and continue to mark, solstices and equinoxes and that they exerted considerable cultural influence on the Navajo, who may only have been in the Southwest 500 years.) The summer solstice and equinox boulders observe the sun rising at the base of one of the few cliffs (features) on a relatively featureless horizon on the appropriate day.

The project goal is to map the surrounding 1-2 km in order to establish the cultural context of the core site, and identify any other sky-associated rock art or structures and their cultural context for comparison. In June, 2003, 28 sites were mapped with a GPS unit in UTM coordinates. These, combined with 17 sites mapped on October 2002, result in 45 sites mapped and documented over the last year. Of these, 28 are rock art sites, 12 are structures (6 Navajo, 4 Anasazi, 1 rock shelter, and 1 historic Anglo sheep camp), 3 are sherd scatters, and 2 are metates on boulders. During June 2003, four new rock art sites with archaeoastronomical potential at summer solstice sunrise/sunset were observed and documented; at least two are convincing, one Anasazi and one joint Anasazi and Navajo. Several more sites have been identified as having winter solstice sunrise potential and will be observed and analyzed in a future trip.

3.18 Dwarf Novae

Sion, Godon and collaborators continued work on White Dwarfs and Dwarf novae with data from HST and FUSE. Due to a family emergency, his 2003 report will be included in the next annual report.

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