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[S0002-7537(99)03001-2]

This report covers the period from 9/97-9/98.

## 1. PERSONNEL

During the report period, 9/97 - 9/98, the staff included Assistant Professor Carol W. Ambruster, Instructor Larry DeWarf, Assistant Professor Edward L. Fitzpatrick, Professor Edward F. Guinan, Associate Professor Frank P. Maloney, Professor George P. McCook (Chairman), and Professor Edward M. Sion. Post-Doctoral Fellow Dr. Fu Hua Cheng worked with Dr. Sion. Dr. Rex Saffer was Research Assistant Professor. Research Associate Dr. Ulysses J. Sofia accepted a position at Whitman College (WA) as of August 1998. Ignasi Ribas of the University of Barcelona was visiting Research Associate on a pre-doctoral grant; Richard Watson served as a research assistant. Dr. Elizabeth R. Jewell served as Department Assistant.

Tara Anselowitz, Daniel Bambeck, Paul DiTuro, Jonathan Hagsis, Karen Matthews, Steven Margheim, Rahul Mittal, Michele Sauer, Richard Slevinsky, and David Stys served as research assistants.

## 2. INSTRUMENTATION

### 2.1 Automated Photoelectric Telescopes

The Fairborn Observatory, home of the Four College APT (FCAPT), is located in the Patagonia Mountains of AZ (Lat: +31 23 12; Long:// -110 41 41). This 0.8-m automated photoelectric telescope is operated by the Four College Consortium (FCC) consisting of The College of Charleston, The Citadel, University of Nevada-Las Vegas, and Villanova University. The FCAPT is supported by NSF grant AST95-28506. The 0.8M APT is equipped with *UBVRI* wide-band filters as well as *uvby*,  $H\beta$  and  $H\alpha$  narrow- and wide-band interference filters.

### 2.2 Internet Access

The Astronomy & Astrophysics WorldWideWeb (WWW) address is: <http://www.phy.vill.edu/astro>. Our email address is: [astronom@ast.vill.edu](mailto:astronom@ast.vill.edu). Experimental laboratory work for non-science majors can be found at: <http://astro4.ast.vill.edu>. This project is supported by the Pew Charitable Trusts.

## 3. CURRENT RESEARCH

### 3.1 Stellar Astronomy

E.L. Fitzpatrick and D. Massa (Raytheon STX) have completed the initial investigation in a multiyear program whose goals are: 1) to test quantitatively the level of agreement between the theoretical stellar energy distributions predicted by the current generation of line-blanketed model atmospheres (the ATLAS9 models from R.L. Kurucz) and the observed UV/optical energy distributions of the main se-

quence B stars; 2) to determine how precisely and accurately the stellar properties (effective temperature, surface gravity, metallicity, and microturbulence velocity) can be determined from analyses of the stellar continua; and 3) to study the physical properties of the Galactic B stars, concentrating on their evolutionary states and evidence for spatial abundance variations in the Milky Way. In this initial investigation, it is demonstrated that the ATLAS9 models can reproduce the observed UV/optical continua of unreddened main sequence B stars to a level consistent with the uncertainties in currently available spectrophotometric data. Further, it is shown that both the model atmosphere parameters *and* the shape of the UV/optical interstellar extinction curve can be extracted from analysis of UV/optical spectra of reddened stars. This is possible because the spectral "signature" of interstellar extinction is very different from the "signatures" of temperature, surface gravity, metallicity, or microturbulence. These results are being prepared for submission to the *ApJSuppl* (Fitzpatrick & Massa 1999, "Determining the Physical Properties of the B Stars I. Methodology.")

A. Ulmer (Princeton U.) and Fitzpatrick have studied the temperature dependence of the maximum luminosity attainable by a stable star, under the assumption that radiation pressure in the stellar photosphere is the dominant physical effect. For stars in the Large Magellanic Cloud, it was found that temperature dependence of this theoretical limiting luminosity corresponds closely to that defined observationally by the most luminous supergiants, but that the theoretical limit is actually a full magnitude brighter than observed. The observed limit is consistent with theoretical models in which the maximum value of the ratio of the radiation force outwards to the gravitational force inwards,  $Y_{\max} \approx 0.9$ , i.e., the photospheres of stars at the observed luminosity limit are bound. As massive stars evolve, they move to higher, and therefore less stable values of  $Y_{\max}$ , so mass loss, either sporadic or continuous, may halt their natural evolution as they approach the  $Y_{\max} \approx 0.9$  limit. See Ulmer & Fitzpatrick 1998.

### 3.2 Instrument Calibration

D. Massa (Raytheon STX) and Fitzpatrick have examined the newly reprocessed low-dispersion data archives ("NEWSIPS" data) of the International Ultraviolet Explorer Satellite and found that, while the new processing system represents a significant improvement over the original system, the data still contain serious systematic effects which compromise their utility for certain applications. It is shown that the low-resolution data contain systematic effects of 10-15% due to residual temporal and thermal dependencies. In addition, the NEWSIPS flux calibration is shown to be inconsistent by nearly 10%. New algorithms have been developed to correct the systematics to the 3% level – a factor of 5 improvement. In addition, a transformation between the corrected *IUE* data

and the Hubble Space Telescope absolute calibration system is derived, placing the data from both telescopes onto a single system. Finally, it is shown that the remaining 3% systematics in the corrected IUE data are traceable to problems with the NEWSIPS intensity transfer function (ITF). A paper describing these results is being prepared for submission to the *ApJSuppl* (Massa & Fitzpatrick, "A Recalibration of IUE NEWSIPS Low-Dispersion Data,").

### 3.3 Interstellar Medium

Fitzpatrick delivered an invited review talk at an international symposium held in Seville, Spain (November 1998) celebrating the contributions to astronomy made by data obtained with the International Ultraviolet Explorer satellite (IUE). The talk reviewed the particular impact of IUE ultraviolet data on the study of interstellar extinction, i.e., the absorption and scattering of light by interstellar dust grains. While some of the important initial characterizations of interstellar extinction predated the launch of the IUE, data from IUE are nevertheless largely responsible for most of the quantitative statements made today about UV extinction. The talk highlighted IUE's observations of spatial variations in the wavelength dependence of extinction. This review was published in the conference proceedings (see below, Fitzpatrick 1998).

Fitzpatrick completed a study of UV/optical extinction by interstellar dust grains that addresses the issue of how best to correct astronomical data for the wavelength-dependent effects of Galactic interstellar extinction. Several strategies for dereddening are evaluated along with estimates of the uncertainties inherent in each method. In addition, a new derivation of the wavelength dependence of an average Galactic extinction curve from the IR through the UV is presented, along with a new estimate of how this extinction law varies with the parameter  $R \equiv E(\lambda - V)/E(B - V)$ . These curves represent the true monochromatic wavelength dependence of extinction and, as such, are suitable for dereddening IR-UV spectrophotometric data of any resolution, and can be used to derive extinction relations for any photometry system. The results of this study will be published in the January 1999 issue of the *PASP* (Fitzpatrick 1999).

U. Sofia, Fitzpatrick, and D. Meyer (Northwestern U.) reanalyzed the GHRS dataset presented in a recent paper by Snow *et al.*, which contains the interstellar intersystem C II] 2325Å line through a translucent cloud toward the star HD 24534 (X Persei). In contrast to the results of Snow *et al.*, it is shown that the C II] feature is clearly detected at the  $3 - \sigma$  confidence level and corresponds to a  $C^+$  column density of  $2.7 \pm 0.8 \times 10^{17} \text{ cm}^{-2}$ . This result, combined with the  $C^0$  column density along the line, implies  $C/H = 106 \pm 38 \times 10^{-6}$  in the interstellar gas toward this star. This gas-phase carbon-to-hydrogen ratio suggests that slightly more carbon depletion onto dust grains may be occurring in translucent as compared to diffuse clouds. The average diffuse-cloud C/H, however, is within the  $1 - \sigma$  uncertainty of the measurement toward HD 24534. It cannot, therefore, be ruled out that the two cloud types have comparable gas-phase C/H, and thus comparable depletions of carbon. A

paper describing these results appeared in the *ApJ(Let)* (Sofia, Fitzpatrick, & Meyer 1998).

E. B. Jenkins (Princeton U.), T. M. Tripp (Princeton U.), and Fitzpatrick examined high resolution UV spectra toward the star HD72089 obtained by the STIS spectrometer aboard the Hubble Space Telescope. The spectrum of this star, which is located behind the Vela supernova remnant, shows a complex array of high and low velocity interstellar absorption features arising from shocked clouds. A spectrum of this star was recorded over the wavelength range 1196.4 to 1397.2 Å at a resolving power  $\lambda/\Delta\lambda = 110000$  and a signal-to-noise ratio of 32 by STIS. Seven narrow components of C I were identified and their relative populations in excited fine-structure levels were measured. Broader features at heliocentric velocities ranging from -70 to +130 km/s are seen in C II, N I, O I, Si II, S II and Ni II. In the high-velocity components, the unusually low abundances of N I and O I, relative to S II and Si II, suggest that these elements may be preferentially ionized to higher stages by radiation from hot gas immediately behind the shock fronts. A paper describing these results appeared in *ApJL* (Jenkins, Tripp, Fitzpatrick *et al.* 1998).

### 3.4 The Sun in Time Project: Coordinated Studies of G0V-G5V Solar Analogs of Different Ages

Guinan, McCook, DeWarf, and M. Güdel (ETHZ) continue this successful multi-frequency program studying the evolution of magnetic activity of the Sun with time. Photometry of about 20 single, nearby G0-5 V stars has been ongoing with the 0.8m FCAPT since 1992 (and before that time with telescopes located at Villanova). Subsets of this sample have been observed from the X-ray region (with ASCA, ROSAT, and AXAF in 1999), in the EUV (with EUVE), in the FUV (with FUSE in 1999), in the UV-NUV (IUE, HST), and at the radio wavelengths (with the VLA).

Following its contraction to the ZAMS, our study expects the Sun to have been rotating more than 10x faster than the present Sun which rotates at 2km/s (or  $P_{rot} = 25.4$  days). The spin-down of the Sun is due to magnetic braking in which the magnetized solar wind interacts with the ISM and a loss of angular momentum occurs. The young Sun's more rapid rotation and, consequently, its stronger magnetic dynamo results in more vigorous magnetic activity from the photosphere, chromosphere transition region, and corona. The stronger magnetic dynamo activity results in greatly enhanced coronal X-ray and transition-region and chromospheric EUV-NUV emissions up to hundreds of times more intense than the present Sun. The enhanced high energy and UV emissions of the young Sun could have played an important role in the evolution of planetary atmospheres, and possibly also in the origin and evolution of life on Earth.

Some of the stars being studied are: HD 129333 (Pleiades Moving Group; age = 70 Myr),  $\chi^1$  Ori,  $\pi^1$  UMa (UMA Moving Group; age = 300Myr), HD1835, HD134319 (Hyades; age = 600Myr),  $\kappa^1$  Cet (P-age; age = 800 Myr);  $\beta$  Com (P-age; isochrones; age = 1.7Gyr), 15 Sge (isochrones; age = 2.0Gyr), 51 Peg (isochrones; age = 7.5Gyr), and 16 Cyg A&B (isochrones; age = 9.5 Gyr). In addition, observations are being made of the solar twin 18 Sco (isochrones;

4.7 Gyr). 18 Sco is the closest match to the present Sun. Additional solar twin candidates are being observed to provide more examples of mid-life solar-type stars.

All of these stars (and several additional ones) are being observed to monitor starspot activity. Light variations due to starspots have been discovered on all of the dG stars younger than 2 Gyr. Rotation periods and the percentage of the star's surface covered with starspots (as well as spot temperatures) can be directly determined from the *UBVRI* or *uvby* APT photometry. For example, the youngest star in this sample, HD 129333 (=EK Dra), can serve as a proxy for the ZAMS Sun. APT observations show it to have low amplitude (5-9%) light variations with a rotation period of  $P_{rot} = 2.5 - 2.8d$ . Analysis of the photometry indicates that the star is covered with a variable amount of starspots covering about 7-15% of the star's surface. (even at starspot maximum, today's Sun has < 0.2% of its surface covered with sunspots.) The observed long-term brightness changes of HD129333 are best explained by the presence of a 7-8 yr starspot cycle. The apparent variations in the star's photometric period most likely arises from the effects of differential rotation as the major starspot concentrations change latitude over an activity cycle. Joint APT-ASCA/ROSAT satellite and radio studies of HD 129333 have been conducted over the last 3 years. Also, HD129333, HD1835, and  $\beta$  Com are approved targets for FUSE and XMM during 1999/2000 and photometry with FCAPT will be critically important in linking magnetic activity in the photosphere (the starspots) to magnetic structures in the star's transition region (via FUSE) and corona (with ROSAT, XMM, and AXAF with one target). Moreover, Guinan and Güdel have submitted an HST proposal to observe several of the above targets with HST.

Guinan and McCook continue the long-term FCAPT observations of the stars already on the "Sun in Time" program to identify and define magnetic activity cycles which have average durations of about 10 yrs. Many of the stars have been observed since 1990 so that most of the activity cycle is already covered. Also, intensive photometry of several of the more active stars will be made to study differential rotation.

### 3.5 In Search of the True Solar Twin

Guinan, DeWarf, student Paul DiTuro (Villanova U.), M. Güdel (PSI, ETHZ), and I. Ribas (U. de Barcelona) continued the "Sun in Time" program by searching for a solar twin close in age to the Sun ( $\pm 1$  Gyr) in addition to having similar physical properties such as spectral type, color,  $T_{eff}$ ,  $M_v$ . When possible, the optically selected solar twin candidates are compared to the energy distributions and emission fluxes of the present Sun in the X-ray, EUV, FUV, and NUV wavelength regions. The X-ray - UV emissions from the Sun arise chiefly from magnetic-dynamo activity. The magnetic activity and related coronal X-ray and chromospheric emissions vary as functions of the star's rotation period, and thus age. Thus, a star's age can be estimated from its levels of magnetic activity by using age-activity relations.

At the present time, the star best matching the Sun in  $M_v$ ,  $T_{eff}$ , age, and chemical abundance  $[M/H]$  is 18 Sco (see Porto de Mello & Da Silva 1997, ApJ, 482, L89). Analysis of

age-magnetic activity indicators such as  $L_x$ , CaII H+K and Mg II h+k indicate levels of magnetic activity closely matched to the Sun. These proxies of age (chiefly MgII emission) indicate that 18 Sco is rotating within a few days of the Sun's 25.5 day rotation period. Isochronal fits to the observed  $M_v$  and  $T_{eff}$  of 18 Sco were carried out and indicate an age of  $4.7 \pm 0.8$  Gyr with an inferred mass closely matched to the Sun of  $M = 1.0 \pm 0.03 M_{\odot}$ . Other leading solar twin candidates, 16 Cyg A and B and HD 44592 (HR 2290) turn out to be much older than the Sun while yet another solar twin candidate, HD1835 is much younger (age = 600Myr).

This research is supported by NSF/RUI Grant AST93-15365 and NASA Grant NAG5-2160 which we gratefully acknowledge.

### 3.6 Searches for Planets &/or Brown Dwarfs in Edge-on Eclipsing Binaries with Low Mass Components: CM Draconis and YY Gem

Guinan, McCook, D. Bradstreet (Eastern C.), I. Ribas (U. de Barcelona) and students continue work on the CM Dra system. Since the surprising discovery of a probable planetary transit (light loss = 0.080 mag at I-band) in the CM Dra eclipsing system in June 1996 (Guinan *et al.* 1996, IAUC 6423), intensive photometric monitoring of this dM4 +dM4 eclipsing binary has been conducted with the FCAPT and Bradstreet Observatory (at Eastern C.). CM Dra is an ideal system to search for substellar bodies, chiefly because the orbital plane of the binary is viewed almost exactly edge-on ( $i = 89.8$  deg). Moreover, its component dM stars are small, with well determined radii and masses from the analyses of its light and RV curves (e.g.,  $R_{1,2} \approx 0.24R_{\odot}$ ). A giant planet or brown dwarf orbiting the binary in its orbital plane (a dynamically stable and likely location), would transit across the disks of the stars, producing a decrease in brightness, proportional to the relative areas of the planet to the stars. Additional photometry of CM Dra is being obtained from the Czech Republic by Marek Wolf.

The photometry of the June 1996 event was obtained over a 3.5 hr interval, but this was not long enough to cover the entire transit eclipse. From an analysis of the portion of the transit covered, it is estimated that the entire event may have lasted for 7-8 hrs. From the depth of the transit eclipse and a knowledge of the radii of the stars, the radius of the eclipsing body was estimated to be about  $R_p = 0.94R_{jupiter}$ . Because of the incomplete coverage of the transit, its orbital period is not well constrained. This period is estimated to be about  $2.1 \pm 0.6$  yrs. (see Guinan *et al.* 1997).

Guinan and McCook, collaborators and students are currently observing CM Dra to search for confirming evidence of the presence of substellar bodies. In addition to searching for another transit event, they propose to search for evidence of orbiting bodies from the classical *light-time* effect. The gravitational influence of a third body would produce small periodic variations in the arrival times of the eclipses of the binary. This arises from the motion of the eclipsing binary around the common barycenter of the binary system and its companion(s). When the binary system is on the near-side of the barycenter (i.e., closer to the Earth), the light-travel time

is shortened and the eclipses appear to occur early. The motion of the binary around the barycenter produces sinusoidal variations (assuming  $e=0.0$ ) in the arrival times of the eclipses that are proportional to the mass and distance of each orbiting body.

CM Dra has very sharp, deep eclipses that permit the light-time effect to be precisely measured from photometry. During the last year, over 25 eclipse timings of CM Dra have been obtained, chiefly by Bradstreet and Eastern C. students. The average precision of determining mid-eclipse timing from a well covered light minimum for CM Dra is about  $\pm 5$  sec. As reported at the June 1998 AAS meeting (Guinan *et al.* 1998), from the light-time effect there is evidence of *at least* one substellar body orbiting CM Dra. The analysis of the arrival times of stellar eclipses indicates a light-time amplitude of  $7.4 \pm 1.8$  sec with period of  $P = 39.6 \pm 0.7$  days. If confirmed by more eclipse timings, the body producing this light-time variation would have a mass of about  $M_p \approx 42 \pm 8 M_{jup}$  and thus be a brown dwarf. There also appears to be a possible long-term variation in the eclipse timings with a time-scale of several hundred days indicating a more distant object with a mass (about 8-14  $M_j$ ). This object, if confirmed, would most likely be a giant planet rather than a brown dwarf. Interestingly, a preliminary analysis of the light-time effect indicates that the orbital phasing of these possible objects are not consistent with the body that produced the transit event.

Additional observations are needed before anything definite can be said, but it may be that the CM Dra system contains several substellar bodies. Existence of these possible bodies needs to be confirmed. Photometry of CM Dra over the next 2-3 years should be sufficient to confirm or deny these tantalizing, but yet preliminary, results.

Guinan, Mc Cook and Bradstreet have added another low mass eclipsing binary, YY Gem (dM0 + dM0;  $i = 89$ deg), to this program. YY Gem is well suited for planet/brown dwarf searches by searching for transits and from a study of the light-time effect.

### 3.7 UBVRi and uvby Photometry of Young Stellar Objects

UBVRi/uvby photoelectric photometry of several bright Young Stellar Objects (YSOs) are being made with the 0.8m APT by Guinan, DeWarf, and McCook. Nightly photoelectric photometry of several interesting (but sparsely observed) T Tauri variables was obtained. The chief scientific motivations were to find the rotation periods and investigate possible activity cycles of these stars by searching for the starspot-induced light variations. Also, the short-term and long-term variations of the properties of the accretion disks were investigated. Several objects were selected for study. The stars under study are the classical T Tauri stars SU Aur (G2 IIIe), AB Aur (B9 pec), V470 Tau (K2 Ve), HD 283447 (K2 IV), GW Ori (K3 IVe), and the FU Ori variable V1331 Cyg. Noteworthy in the current program is the photometric behavior of SU Aur.

Long-term uvby photometric monitoring of SU Aur with FCAPT has revealed the presence of large *eclipse-like* drops in light with durations of 30-40 days. Several of these dim-

ming events have been observed so far. These dimming events show a very strong wavelength dependence with the average decrease in brightness at  $u$ (350nm) and  $y$ (550nm) of about 0.8mag and 0.4mag, respectively. The preliminary results have been discussed by DeWarf *et al.* 1998. As discussed, these eclipse-like, dimming events could be caused by concentrations (blobs) of matter located in the outer regions of the accretion disk. These blobs may temporarily obscure the star and inner (hotter) regions of the accretion disk. Observations of SU Aur obtained during 97/98 indicate a possible periodicity in the occurrence of the sharp dimming events. This needs to be more thoroughly investigated.

Hipparcos parallaxes are available for most of the stars on the current observing program. As in the case of AB Aur and SU Aur, this allows absolute magnitudes to be determined and evolutionary ages to be estimated by fitting the observations with stellar evolution codes for PMS stars. For example, SU Aur and AB Aur are at same distance (in the Taurus-Aurigae star forming complex) and have a common space motions and a common age of about 4 Myrs.

### 3.8 Stellar Evolution in Real Time: Photometry of Sakurai's Object (V4334 Sgr)

Guinan, DeWarf, and Villanova students DiTuro, Mittal, and Margheim worked on Sakurai's Object. Pre-discovery observations show that Sakurai's Object (SO) had been a 21<sup>st</sup> mag central star of a faint planetary nebula(PN), which during late 1994 or early 1995 began to rapidly brighten. In Feb. 1996, Y. Sakurai discovered the object as an 11<sup>th</sup> magnitude star. The star was first thought to be a slow nova but, later, with more information it was identified as a final helium flash object (see Duerbeck & Benetti, 1996, ApJ 468, L111). The recent brightening occurs when the star descends the white dwarf cooling track and undergoes a final thermal pulse when the helium shell ignites causing it to expand rapidly to high luminosity and become a *born again* PN. This phase of stellar evolution is extremely short, lasting decades to centuries and would be rarely observed (Iben *et al.* 1983, ApJ 264,605).

UBVRi photometry of SO has been conducted with the APT in Arizona since Spring 1997. The APT photometry was combined with photometry made from other sites and light curves were formed. During 1996, the star steadily increased brightness rising from  $V = +11.4$  to  $+10.9$  mag. During 1997, the star remained bright varying between 11.0 and 10.8 mag while at this time showing low amplitude (0.05 -0.10 mag in V) semi-periodic light variations. However, in early 1998 SO dropped to  $V \approx +12.6$  mag. It then underwent slow oscillations in brightness – varying between  $+11.7$  and  $+12.8$  mag up to mid-1998. During September 1998, its brightness plummeted to below 15<sup>th</sup> mag. These dimming events were accompanied by increases in reddening and thus probably occurred as dust formed in the star's cooling outer atmosphere. The photometric behavior of Sakurai's Object appears to be similar to that of another final flash candidate V605 Aql whose outburst and subsequent fading occurred during 1919-1923 (see Clayton & Marco, 1997, AJ, 114, 267).

This research is supported by NSF/RUI grants AST93-15365 and AST95-28506.

### 3.9 Eclipsing Binaries in the Magellanic Clouds

Guinan, Fitzpatrick, Maloney, DeWarf, P. Maurone (Villanova), and D. Bradstreet (Eastern C.), Ignasi Ribas (U. de Barcelona), Alvaro Giménez (LAEFF, Spain), John Pritchard and William Tobin (U. of Canterbury, NZ) continue their investigations of eclipsing binaries in the Magellanic clouds. These systems provide important laboratories for studying stellar structure, evolution, and mass loss for stars with reduced metallicity. They have obtained IUE/SWP (1150-2000 Å) spectra of a dozen hot O/B eclipsing systems in the LMC and SMC that have well determined light and radial velocity curves, and during 1996/7 HST/FOS and GHRS spectra were obtained for ten of these systems. The chief purpose of the UV spectrophotometry is to determine temperatures for the stars in these systems. Since these hot stars radiate most of their energy in the UV, the character of the UV continuum and the presence of highly ionized elements are sensitive measures of stellar temperatures. The UV data have been combined with the *UBV* (or *uvby*) photometry and fit with the most recent version (ATLAS9) of Kurucz model atmospheres at metal abundances appropriate for the LMC or SMC.

Current analysis of optical light curves and HST/GHRS radial velocity curves has provided the mass and radii of the LMC system harvard Variable 2274 (HV2274;  $< V_{max} > \approx 14.2$ : B1+2 IV-III+B1-2 IV-III;  $P = 5.73$ d). analysis of HST/FOS UV/optical spectrophotometry provided the temperatures of the components and the interstellar extinction to the system. Combined, these results yielded a direction to the binary system. After correcting for the location of HV2274 with respect to the center of the LMC, they have found  $d_{LMC} = 46.7 \pm 1.6$ kpc, or  $(V_o - M_v)_{LMC} = 18.30 \pm 0.07$  mag. This result is immune to the metallicity-induced zero-point uncertainties that have plagued other techniques. Two more systems, HV 2226 and HV 2241 are currently being studied.

This project is beginning to lead to the first Mass-Luminosity relationship, using directly measured masses and luminosities, for stars outside the Milky Way, and extends the parameter space in stellar interior models to chemical compositions different from the Milky Way. Though the above result is very precise, it does not by itself resolve the LMC distance issue. Unanticipated external systematic effects, such as a peculiar location of the star within the LMC could compromise the derived distance. Such effects can only be addressed through the analysis of more systems, preferably with a variety of locations within the LMC and covering a range of stellar properties. The ultimate precision of the LMC distance will best be evaluated by the range of results derived from such analyses. These initial results, however, demonstrate the power of eclipsing binaries to address fundamental astrophysical issues, such as the derivation of basic stellar properties, and cosmologically important issues, such as the distance to the LMC, by serving as first class *standard* candles. This research is supported by NASA grants NAG5-2160 and NSF grant AST-9315365.

### 3.10 Near Infrared TiO and V-band Photometry of Pulsating Red Giants and Supergiants

Guinan and Wasatonic continue to carry out near-IR photometry of bright red giants and supergiants. The stars being studied are the pulsating red giant giants Mira, R Leo, and V CVn and the supergiants  $\alpha$  Ori (Betelgeuse),  $\alpha$  Sco (Antares),  $\alpha$  Her, and CE Tau. The observations are being made using the Wing 3-filter near-IR system (see Wing 1992; JAAVSO,21,42). The near-IR filters are a subset of the 8-color photometric system developed by Dr. Robert Wing of OSU for studying cool stars.

The Wing 3-filter system consists of a near-IR intermediate-band filter (A) centered on the TiO gamma(0,0) bandhead at 719nm and two additional filters (B,C) centered on continuum regions (free of strong lines) at 754nm and 1024nm, respectively. These observations are complemented with V-band measures. Reddening-free TiO-indices, near-IR color indices (B-C), and near-IR magnitudes (C) are formed from the observations. The TiO 719nm band strength increases as function of increasing spectral type for K- and M-type stars, making it an excellent indicator of stellar temperature. The TiO-index and (B-C)-index have been calibrated with stellar temperatures through the extensive observations of standard stars.

For K- and M-type stars the C(1024)-mag closely approximates the behavior of the apparent bolometric magnitude ( $m_{bol}$ ). This permits the C(1024)-mag to be transformed to apparent bolometric magnitude ( $m_{bol}$ ). Calibration of the C(1024)-mag with  $m_{bol}$  has been made by the observations of standard stars with well determined bolometric magnitudes. The absolute bolometric magnitudes ( $M_{bol}$ ) and luminosities ( $L/L_{\odot}$ ) can be calculated from  $m_{bol}$  using Hipparcos parallaxes.

Thus, Wing photometry of a pulsating star on a particular night provides simultaneous measures of its luminosity (or relative changes in luminosity if no parallax is available) and  $T_{eff}$ . This means that the instantaneous radius of the star can also be calculated from the relation  $R/R_{\odot} = [(L/L_{\odot})/(T/T_{\odot})^4]^{1/2}$  on each night on which Wing photometry is obtained.

Photometry of the Mira variables Mira and R Leo with Wing photometry show the expected  $T_{eff}$ ,  $L/L_{\odot}$ , and  $R/R_{\odot}$  variations over their respective pulsational phases. However, the observations of V CVn show a possible shock front occurring during the descending branch of its light curve that causes dissociation of TiO molecules but without accompanying changes in temperature (see Wasatonic & Guinan 1998; IBVS No 4579 for more details).

Wing photometry of the red supergiants shows some possible surprises. For example, for CE Tau and  $\alpha$  Ori the semi-regular light variations that occur over time scales of several months indicate luminosity variations that are driven chiefly by temperature changes, but have no accompanying variations in the stellar radii. The apparent lack of radius variations indicates that these short-term light variations do not arise from fundamental radial pulsations but rather from non-radial modes or from the growth and decay of supergranulations on the supergiants' surfaces. On the otherhand, long-term light variations of these stars (time scales of a few to

several years) arise from correlated variations in radius and temperature that appear to be driven by pulsations.

This research is supported by NSF grants AST-9315365 to Villanova University and AST-9528506 to the Four College Consortium.

### 3.11 Villanova Catalogue of Spectroscopically Identified White Dwarfs

McCook and Sion completed their catalog of 2237 white dwarfs which have been identified spectroscopically and presented, complete through 1998 April. Their compilation is the fourth edition of the Villanova *Catalog of Spectroscopically Identified White Dwarfs*. For each degenerate star, the following data entries with references are provided: (1) a catalog coordinate designation or WD number, in order of right ascension; (2) the right ascension and declination for epoch 1950.0; (3) the spectral type based upon the new system; (4) a catalog symbol denoting binary membership; (5) a list of most names known to exist for a given star; (6) proper motion and position angle; (7) broad-band *UBV* photometry, *V*, *B-V*, *U-B*; (8) multichannel spectrophotometry, *V(MC)*, *g-r*; (9) Strömgen narrow-band photometry *y*, *b-y*, *u-b*; (10) an absolute visual magnitude based upon the best available color-magnitude calibration or trigonometric parallax; (11) the observed radial velocity uncorrected for gravitational redshift or solar motion; and (12) the trigonometric parallax with mean error when available. A Notes section for unusual or peculiar stars and a coded Reference Key alphabetized by the first author's last name are presented, as well as an expanded table cross-referencing all names to catalog WD number. The catalog will appear in *Astrophysical Journal Supplement*.

### 3.12 Pre-Cataclysmic Binaries & Wind/Flare Accretion

Sion, Saffer, H. Bond (STScI), K. Schaefer (Towson State), and F. Cheng (Villanova) used *HST*'s Goddard High-Resolution Spectrograph to detect a photospheric metallic absorption line, Si III  $\lambda$ 1206, in the spectrum of the magnetic white dwarf component of the Hyades pre-cataclysmic binary V471 Tauri. The Si III feature is modulated on the soft X-ray/EUV/optical 9.25-min rotational period of the white dwarf, and is strongest at the time of soft X-ray/EUV minimum and optical maximum. A model in which the soft X-ray/EUV magnetic pole is dark due to metallic and helium absorption, and bright in the optical due to flux redistribution, is strongly supported. They derived a Si abundance of  $0.10^{+0.03}_{-0.07}$  times solar in the accretion cap. Assuming equilibrium between mass accretion onto, and diffusion of Si out of the photosphere, they find the white dwarf to be accreting from its dK companion's wind at only  $3.8 \times 10^{-18} M_{\odot} \text{ yr}^{-1}$ , some five orders of magnitude lower than the Bondi-Hoyle fluid rate. This strongly suggests operation of a magnetic-centrifugal propeller mechanism which rejects most of the material that attempts to accrete. They tentatively detect Zeeman splitting of the Si III line, implying a polar field strength of  $\sim 350$  kG. V471 Tau is destined, in the distant future, to become a DQ Her-type cataclysmic binary.

### 3.13 White Dwarfs in Cataclysmic Binaries

In direct response to a need for a theoretical framework for white dwarf accretion physics, Sion and Sparks (LANL) have begun constructing a large grid of 1D quasi-static and 1D hydrodynamic models (with shear mixing, accretion luminosity and compression) of white dwarfs undergoing time-variable accretion with different values of the white dwarf mass, accretion rate, initial  $T_{eff}$  value and different outburst intervals and quiescent (accretion switched off or at a very low level) to simulate dwarf nova outburst-quiescence cycles. It is essential to understand accretion physics in the simpler 1D case first; earlier 1D simulations by Sion (1995) and Sparks *et al.* (1993) yielded promising agreement with the observations of U Gem and WZ Sge. Once they complete the 1D grid, they will calculate a 2D hydrodynamic evolution sequence for the parameters of the best fitting 1D simulation to the observations, in order to explore the 2D effects and compare them to our 1D results. For this project they will use the newly developed fully implicit 2D hydrodynamic code produced by M. Huang, W. Sparks and E. Sion. This code is not restricted in timestep length by the Courant Condition and hence will be used to construct several sequences of evolutionary models. However, as a comparison with our 2D code results (and as a fallback in case of convergence difficulties), the group has the full collaborative use of the 2D explicit code of Patrick Godon (STScI).

The fundamental goal is to construct a global picture of how long term and short term accretion affect CV evolution, white dwarf cooling and cataclysmic/explosive behavior which goes hand in hand with the theoretical accretion studies. In parallel with the theoretical simulations, they will develop a global picture of the evolution of CVs by greatly enlarging the sample of CV degenerates with known  $T_{eff}$ . They are using their suite of synthetic spectral codes at Villanova to re-analyze, with solar composition models and multi-component fitting, earlier, generally cruder determinations or estimates of white dwarf surface parameters and analyze much more multi-wavelength spectroscopic data for many other systems, encompassing other CV subtypes as well as dwarf novae, over a broad range of accretion rates, orbital periods, outburst/ quiescence durations, and ranges of high state intervals in nova-likes.

In parallel with the quasi-static and hydrodynamic simulations, they have assembled the most updated and complete sample of CV white dwarf parameters including the  $T_{eff}$  values for 38 systems tabulated by Warner (1995), and the IUE archival estimates of Hassall and La Dous (1996) using single white dwarf spectra as templates to estimate white dwarf flux contributions/temperatures. A collaboration with C. La Dous on the IUE sample has been initiated. The  $T_{eff}$  values for individual systems will be assessed as to accuracy and where possible, new multi-component (white dwarf, optically thick (thin) accretion disk models during outburst (quiescence), disk curtain absorption, boundary layer) synthetic spectral fitting will be carried out to improve the values. A paper on TT Ari using both new optical spectra from ESO in collaboration with Boris Gansicke (Gottingen) and IUE archival spectra of its extended low state is close to

submission. They are carrying out similar analyses for many other systems with exposed white dwarfs.

During the past year, Sion, Szkody (U.WA), Cheng and Sparks (LANL) reported the following new observational insights and breakthroughs on CV white dwarfs:

(1) The first determination of stellar rotation rates for accreting white dwarfs in cataclysmic variables, revealing an amazing range from 100 km/s to 1200 km/s, which raises profound questions about the angular momentum transfer during tangential accretion (Sion *et al.* 1994, ApJL, 430, 653; Sion *et al.* 1995, ApJL, L31; Cheng *et al.*, 1997a, ApJL, 484, L149);

(2) The first detection of a rapidly spinning (3300 km/s) accretion belt on the surface of a white dwarf in a CV which points the way to a solution for the missing boundary layer mystery by ameliorating its low boundary layer luminosity and implying shear mixing with the resulting implied gradients of differential velocity, both inward and with latitude on the stellar surface, stimulating a critical need for further accretion belt detections (Sion *et al.* 1996, ApJL, 471, L41; Cheng *et al.*, AJ, 1997b);

(3) The first detection of, and chemical abundances for, proton capture nuclear reactions and their resulting synthesized heavy elements as well as a past CNO thermonuclear runaway on a white dwarf in a prototype dwarf nova, thus establishing the first spectroscopically determined evolutionary link between dwarf novae and classical novae and providing a veritable laboratory for nuclear physics where proton capture cross sections and reaction rates are poorly known and based upon only quantum mechanical calculations (Sion *et al.* 1997b, ApJL, 480, L17);

(4) The first HST determined cooling timescales for the accretion-heated atmospheres/ envelopes of white dwarfs in dwarf novae following normal outbursts and longer super-outbursts and their detailed comparison with quasi-static and hydrodynamic accretion simulations, including accretional heating mechanisms due to compressional heating, downward BL irradiation and shear mixing (Sparks *et al.* 1993, Sion *et al.* 1994, ApJ, 424, 649; Sion *et al.* 1994, ApJL, 430, L53; Sion *et al.* 1996, ApJL, 471, L41; Cheng *et al.* AJ, 1997b).

(5) The first gravitational redshift masses for white dwarfs in cataclysmic variables (Sion *et al.* 1994, ApJL, 430, L53; Sion *et al.* 1997, ApJL, 480, L17).

### 3.14 IUE Archival Studies of Isolated & Binary White Dwarfs

Sion and astronomy majors Tara Anselowitz, Karen Mathews, David Stys, Richard Slevinsky and visitor Rick Wasatonic carried out several investigations on the formation and evolution of isolated white dwarfs and the effects of accretion on white dwarfs in binaries.

Tara Anselowitz, Karen Mathews and Wasatonic have compiled basic data for different spectroscopic subgroups of white dwarfs with multi-wavelength (EUV, Far UV, Optical and IR) observations. Their focus has been on the origin and evolutionary status of the magnetic white dwarfs, the carbon molecular band DQ white dwarfs and the cool helium-rich DZ white dwarfs, three groups with uncertain formation

channel(s). Using the multiwavelength space and ground-based data, effective temperatures, absolute magnitudes and space velocities have been generated and compared with other white dwarf spectroscopic types such as the H-rich DA stars and the helium-rich DB stars. The first paper to be submitted from this work concerns the magnetic degenerates. The kinematical data, statistical data, cooling ages and rotation rates from variable polarization point to a mixed origin for the magnetic degenerates: some are the evolutionary descendants of the Ap and Bp stars on the main sequence, others are the progeny of low mass progenitors, while still others appear to be the progeny of now extinct AM Herculis magnetic cataclysmic variables in which mass transfer has ceased due to the cannibalization of the secondary donor star over billions of years as active cataclysmics. Papers are in preparation for the other subgroups under study, the DZ, DQ and DB stars.

David Stys and Richard Slevinsky have discovered a rare DAOZ white dwarf named EC1148-2, a hot (40,000K) white dwarf having an atmosphere of both H and He, rarity in itself. Normally either H or He is seen but not both. However, this object is one of only three DAO stars known to have photospheric metals. Gravitational diffusion (at  $\log g = 8$ ) allows only the lightest element to be seen at the surface. Their paper proposes explanations for the hybrid composition and is based upon our synthetic spectral analysis of the far UV IUE archival spectra of what was thought to be a garden-variety hot DA star.

Richard Slevinsky, David Stys and Karen Mathews worked on the analysis of Hubble Space Telescope archival spectra and IUE archival spectra of white dwarfs in both magnetic and non-magnetic cataclysmic variables. They have completed an analysis of the 20 archival far UV spectra of the white dwarf in the 81 minute orbital period cataclysmic WZ Sagittae. These far UV spectra were obtained weeks to years after the 1978 December outburst of WZ Sge. The team has determined the cooling of the accretion-heated white dwarf and the temporal evolution of chemical abundances of its accreted atmosphere. A paper is soon to be submitted to the Astronomical Journal. Studies of the archival spectra for other CVs in the IUE and Hubble archive are still in progress.

Research on white dwarfs and cataclysmic variables at Villanova during the report period was supported by NSF/RUI grant AST90-16283 and its cost supplements, NASA LTSA grant NAG3726, by several HST Guest Observer grants, by an HST Archival grant and by summer undergraduate research assistantships provided by the NASA/Delaware Space Grant Consortium.

### 3.15 UV Flares from a ZAMS K Dwarf

Ambruster, Villanova students S. Margheim and K. Mathews, and T. Ayres (CASA, U. Colo.) analyzed 11 years of IUE observations of the Pleiades-age K2 dwarf HD 82558 (LQ Hya). The data totalled 50 SWP-Lo, LWP-Lo, and LWP-Hi spectra taken between 1982 and 1993. The SWP-Lo images were reduced by Ayres using his state-of-the-art automated reduction routine (T.R. Ayres, 1993, PASP 105, 538); the LWP spectra were reduced using standard IUE

software. Two large flares were present in the data (on 1988 Oct30 and 1993 Dec17), both of which displayed factor 5-10 flux increases in the transition region C IV (1550 Å) line flux. The second flare (1993 Dec17) was also present as a factor 3 increase in the chromospheric Mg II (2800 Å) line flux. Of greatest interest was the fact that both flares showed strong continuum emission in their respective SWP-Lo spectra that could be fit by 17000 K and 13500 K black body models, respectively: thus, both flares could have been detected at optical wavelengths as well. It is worth noting that very few stellar flares in the IUE archives affect what little continuum is present in K and M stars: this young, rapidly rotating ( $P=1.601$  d) K dwarf therefore appears to produce exceptionally energetic flares. Both flares occurred near the minimum of an apparent 6.2 yr activity cycle discovered by L. Jetsu (1993, *A&A* 276,345), and essentially on opposite sides of the star (phases 0.1 and 0.6 using Jetsu's ephemeris). Modulation is apparent in the Mg II light curve, which may also reflect the optically-derived 6.2 yr activity cycle; further analysis is in preparation, and a paper is in preparation.

### 3.16 Archaeoastronomy

Ambruster and A.B. Hull (Corning OCA) continued work on an early Navajo archaeoastronomy rock art site in Chaco Canyon National Culture Historical Park, New Mexico. Over the Vernal Equinox in March 1998 they visited the site, along with David M. Brugge, an ethnoarchaeologist and expert on the Navajo habitation of Chaco Canyon. As suggested by calculations, the sun on the day of Vernal Equinox rose exactly at the base of one of the few cliffs on the eastern horizon visible to an observer standing in front of the elaborately carved Shabikeshchee Sun Shield petroglyph; the next morning the sun rose approximately its own diameter further north, rather than at the base of the cliff. Brugge discovered a deeply carved arc at the corner of the large boulder that may mark the sunrise viewing point used by the Navajo; he also identified several other glyphs that further emphasize the ceremonial importance of the site. Whether the Navajo actually recognized or valued true astronomical Equinox is unclear: they made use of a naturally placed, large (approximately 10 feet high) boulder to view the base of a cliff on the horizon that happened to be due East of the boulder. There is evidence that the prehistoric Anasazi culture of the region (with whose descendants, the Pueblos, the Navajo had considerable contact) marked the Equinox as the midpoint in time between the two solstices; this would have occurred two days later than the true Vernal Equinox. In fact, the Sun does rise at the base of the same horizon cliff exactly two days later when viewed from another early Navajo sacred rock art panel on a narrow ledge just below the mesa top almost directly above the Shabikeshchee Sun Shield. Again, the surface that the Navajo carved was placed there by Nature, not oriented by Man. Both these Equinox sunrises may reflect early Pueblo influence, since present-day Navajo do not commemorate solstices and equinoxes. Or it could reflect the fact that East is particularly important to the Navajo, and the day on which the sun rises due East might then also be im-

portant. Pueblo influence may also be present for the summer and winter Solstice sunrises confirmed earlier. A new paper is in preparation.

### 3.17 Pulsating Hot Subdwarf Stars

In collaboration with M. Billeres, G. Fontaine, P. Brassard, S. Charpinet, P. Bergeron (University of Montreal), J. Liebert (Steward Observatory), and G. Vauclair (Observatoire Midi-Pyrenees), Saffer participated in the discovery of multiperiodic luminosity variations in the hot B subdwarf KPD 2109+4401. At least five periodicities were seen in the light curve, from 182.5 to 198.4 s. The largest oscillation has an amplitude  $\sim 8.6$  mmag in white light and a period 196.3 s. A model atmosphere analysis of the time-averaged optical spectrum of KPD 2109+4401 indicates that this star has  $T_{eff} = 31,200$  K and  $\log g = 5.84$ . A comparison with pulsation periods computed from stellar models having similar atmospheric parameters implies that the observed brightness variations must be identified with low-order radial and non-radial (p and f) pulsation modes. The overall similarity of periods and derived stellar parameters shows that KPD 2109+4401 is a genuine member of the EC 14026 class, the most recent family of pulsators uncovered in the field of asteroseismology. However, KPD 2109+4401 is slightly but significantly cooler than the previously known members of this class, thus widening significantly the empirical instability strip. Interestingly, theory predicts that a cooler EC 14026 pulsator (of a given surface gravity) should show larger excited periods, and this is indeed what KPD 2109+4401 shows, with periods reaching values as large as 198 s, not seen previously in other pulsators of the class. The survey which discovered the star continues, to search for additional EC 14026 pulsators.

### 3.18 Early-Type Stars at High Galactic Latitude

In collaboration with F.P. Keenan, N.C. Hambly, P.L. Dufton (Queen's University Belfast), and J. Liebert (University of Arizona), Saffer analyzed optical spectroscopy of a large sample of B-type stellar candidates. Of a total of 298 objects, the largest sample of its kind to date, 205 were drawn from the Palomar Green Survey of high Galactic latitude ultraviolet-excess stellar objects and comprise a complete magnitude-limited sample. Effective temperatures, surface gravities, and helium abundances for the hot subdwarf (high-gravity) component of the sample were derived from a detailed line profile analysis of the hydrogen and helium absorption lines in intermediate-resolution (3-5 Å FWHM) optical spectra. A separate analysis of the lower gravity component was made using a newly calculated grid of synthetic spectra. Additional estimates of the effective temperatures were made from wide- and intermediate-band photometry taken from the literature. Two follow-up programs continue: (1) Detailed abundance analyses of high-resolution echelle spectra of the lower gravity component of the survey using modern model atmosphere and synthetic spectrum techniques will differentiate between massive Population I main-sequence B stars and low-mass, lower luminosity Population II blue horizontal branch stars and post-asymptotic giant

branch stars. (2) The derived atmospheric parameters for the higher gravity component, the field extended horizontal branch stars, will be combined with radial velocity measurements to determine their spatial and kinematic distributions, which will distinguish between competing evolutionary scenarios for this hot, evolved stellar population.

### 3.19 The Double Degenerate Progenitors of Type Ia Supernovae

In collaboration with M. Livio (Space Telescope Science Institute) and L.R. Yungelson (Institute of Astronomy of the Russian Academy of Sciences), Saffer analyzed radial velocity observations of a large sample of apparently single white dwarfs (WDs), obtained in a long-term effort to discover close double-degenerate (DD) pairs, which might comprise viable Type Ia supernova (SN Ia) progenitors. The WD sample was augmented with a previously observed sample of apparently single subdwarf B (sdB) stars, which are believed to evolve directly to the WD cooling sequence after the cessation of core helium burning. The sample yielded 18 new radial velocity variables, including five confirmed sdB + WD short-period pairs. The observations are in general agreement with the predictions of the theory of binary star evolution. A numerical method was used to evaluate the detection efficiency of the survey and estimate the number of binary systems not detected because of the effects of varying orbital inclination, orbital phase at the epoch of the first observation, and the actual temporal sampling of each object in the sample. Follow-up observations are in progress to solve for the orbital parameters of the candidate velocity variables.

### 3.20 PG 1002+506: A Be Star Apparently at $z > +10$ Kiloparsecs

In collaboration with F.A. Ringwald (Pennsylvania State University) W.R.J. Rolleston (Queen's University Belfast), and J.R. Thorstensen, Saffer participated in the discovery that PG 1002+506 is a Be star, one of three found so far by the Palomar-Green survey. Its spectrum is classified as a B5Ve, with  $T_{eff} = 14,900$  K,  $\log g = 4.2$ , and  $v \sin i = 340$  kms. At  $b = +51^\circ$ , its height above the Galactic plane would therefore be  $z = +10.8$  kpc, putting this apparently young, rapidly rotating star well into the Galactic halo. Its heliocentric radial velocity is found to be  $-2$  kms, consistent with either having been formed in the Galactic disk and subsequently ejected or having been formed in the halo.

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