THE EFFECTIVE TEMPERATURE DISTRIBUTION FUNCTION OF CATACLYSMIC VARIABLE WHITE DWARFS

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ABSTRACT. With the recent detection of direct white dwarf photospheric radiation from certain cataclysmic variables in quiescent (low accretion) states, important implications and clues about the nature and long-term evolution of cataclysmic variables can emerge from an analysis of their physical properties. Detection of the underlying white dwarfs has led to a preliminary empirical CV white dwarf temperature distribution function and, in a few cases, the first detailed look at a freshly accreted white dwarf photosphere. The effective temperatures of CV white dwarfs plotted versus orbital period for each type of CV appears to reveal a tendency for the cooler white dwarf primaries to reside in the shorter period systems. Possible implications are briefly discussed.

I. INTRODUCTION

Until very recently, direct observations of white dwarfs in cataclysmic and novalike short-period binaries had been restricted to systems without accretion disks, such as AM Her binaries where the white-dwarf magnetic field disrupts a disk, or the V471 Tauri precataclysmic binaries in which there can be no accretion by Roche-Lobe overflow. However, within the past two years a number of authors (e.g. Panek and Holm 1984; Mateo and Szkody 1984; Shafter et al. 1985) have reported the direct detection of the underlying white-dwarf photosphere either during a dwarf nova minimum (Panek and Holm 1984) or during the exceptionally "low" state of a novalike variable (Shafter et al. 1985). The evidence from IUE, and optical continua and absorption lines as well as indirect inferences based on colors, eclipse geometry, and emission line fluxes were summarized by Patterson and Raymond (1985). A number of additional effective temperatures have been added by Smak (1984), Wood (1986), and Szkody et al. (1986).

The most reliable of these temperature determinations of cataclysmic variable (CV) white dwarfs are for those systems in which the white dwarf dominates the ultraviolet energy distribution. In those cases, standard high-gravity, model-atmosphere analyses are possible, yielding temperatures and gravities from

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Lyman-α profile fits and the slope of the UV continuum. In a few cases the white dwarf optical spectrum is revealed (cf. Shafter et al. 1985) thus allowing direct comparison with model atmosphere line profiles. For example, Balmer wings and He II 4686 were detected in TT Arietis during a very low state, yielding log g = 8, a He/H ratio near solar and spectral classification DAOI (*Shafter et al.* 1985; Liebert 1984).

The effective temperatures determined thus far, if viewed together, lie in the range $10^{4.1} \leq T_{eff} \leq 10^{4.7}$ with a median temperature of 25,000K. If these temperatures represent that of the underlying photospheres, they are considerably hotter and more luminous than field white dwarfs where the median effective temperature of a single DA white dwarf is 12,000K (see Sion 1984).

2. Physical Interpretations of CV White Dwarf Effective Temperatures

The observed distribution of effective temperatures and the higher median temperatures of CV white dwarfs relative to that of single "field" white dwarfs begs *for a precise physical interpretation*, but is very complicated. Patterson and Raymond (1985) invoke an interpretation of these objects as being white-dwarf "pseudo-photospheres" due to the reprocessing in the optical of boundary layer hard -rays, locally heating the white dwarf outer layers. Shafter et al. (1985) address the possibility that the high effective *temperature of a CV white dwarf is simply maintained by re-radiated accretion* energy at the white dwarf surface. If they are correct, the effective temperature of a CV white dwarf would depend upon the mass, M_{WD} and the accretion rate, $\dot{M}$. Using the theoretical framework provided by long-term accretion studies in the quasi-static approximation, Sion (1985) argues that the *observed surface temperatures and luminosities of white dwarfs in low-*cataclysmic variables are entirely consistent with those expected for white dwarfs accreting at rates 10^{-9} to 10^{-11} $M_{\odot}$ yr^{-1} over time intervals of the same order as the estimated recurrence times of classical novae. This interpretation is supported by observational constraints on the length of classical nova recurrence times and by the lower limit imposed on the effective temperatures of white dwarfs in cataclysmic variables, by the long-term rate at which gravitational potential energy is liberated by a white dwarf in response to accretion. These intrinsic effective temperatures and luminosities appropriate to thermonuclear outburst cycles depend on $M_{WD}, \dot{M}$, the envelope mass, and the white dwarf core temperature. Knowing the depth of accretion heating in the outer layers of the white dwarf would provide a critical test of which interpretation is correct.

Szkody, Kiplinger and Sion (1986) have recently obtained intense IUE spectral coverage of U Gem in quiescence over a span of 2 to 103 days following outburst. Like Panek and Holm (1984) their data reveal Lyman α profiles and stellar continua which agree nicely with $T_{e} \sim$ 30,000K, log g = 8 *model atmosphere fits*. Furthermore, their SWP images *reveal a rich metal* absorption line spectrum, which like Panek and Holm, they attribute to the white dwarf photosphere.

If these features do originate in the white-dwarf photosphere they would represent our first detailed look at a freshly accreted stellar surface. Analysis *of these features in light of diffusion/accretion is now in progress* (Szkody et al. 1986). But these spectra of U Gem may provide additional very significant insight; strong evidence that the white dwarf cooled from 40,000K just after the outburst to 30,000K far into quiescence.

This cooling measurement implies a short thermal time which constrains the amount of envelope mass having undergone heating as a result of the outburst, to be small. Their evidence, together with earlier detections of white-dwarf cooling following dwarf-nova outbursts by Smak (1984) and Wu and Panck (1982), would tend to suggest that the surface temperatures of white dwarfs in cataclysmic variables cannot be simply maintained by instantaneously re-radiated accretion energy at the surface. The interpretation that these temperatures characterize a pseudo-photosphere due to the reprocessing, in the optical, of boundary layer hard X-ray heating (e.g. Patterson and Raymond 1985) is difficult to support in view of these cooling observations. Nonetheless further investigations as to the extent of accretion heating in the white-dwarf envelope are crucial.

3. Discussion of CV White Dwarf T_{eff} Versus Orbital Period

The effective temperatures of CV white dwarfs, are plotted versus orbital period with each type of CV labeled, as displayed in Figure 1. The temperature values are taken either from Smak's (1984) analysis of emission-line fluxes in low M

TABLE 1

Reference List for Effective Temperatures of CV White Dwarfs

CV Name	References	Adopted T_{eff} (°K)
VV Pup	Liebert and Stockman (1984)	9,000
AH Her	Smak (1984)	40,000
EM Cyg	Smak (1984)	40,000
HT Cas	Patterson (1981), Smak (1984)	12,000
Z Cha	Patterson and Raymond (1984), Bailey (1979), Rayne and Whelan (1981), Wood (1986).	15,000
OY Car	Bailey and Ward (1981), Smak (1984) Wood (1986)	15,000
U Gem	Holm and Panek (1984), Smak (1984), Szkody et al. (1986)	30,000
SS Cyg	Fabbiano et al. (1981), Smak (1984)	40,000
MV Lyr	Robinson et al. (1981), Schneider (1981), Szkody and Downes (1982).	50,000
AM Her	Schmidt et al. (1981), Patterson and Price (1981), Szkody et al. (1982).	50,000
TT Ari	Shafter et al. (1984)	75,000
VW Hyi	Hassall et al. (1983), Smak (1984) Mateo and Szkody (1984).	18,000
WZ Sge	Krzeminski and Smak (1971), Gilliland (1983), Smak (1985).	15,000
SW UMa	Shafter (1983)	15,000
T Leo	Shafter and Szkody (1984)	25,000
V436	Gilliland (1982)	15,000
UU Aql	Thorstensen et al. (1985)	25,000
YY Dra	Patterson et al. (1985)	25,000
CW 1103	Szkody et al. (1985)	11,000
SS Aur	Smak (1984)	31,600
YZ Cnc	Smak (1984)	25,100

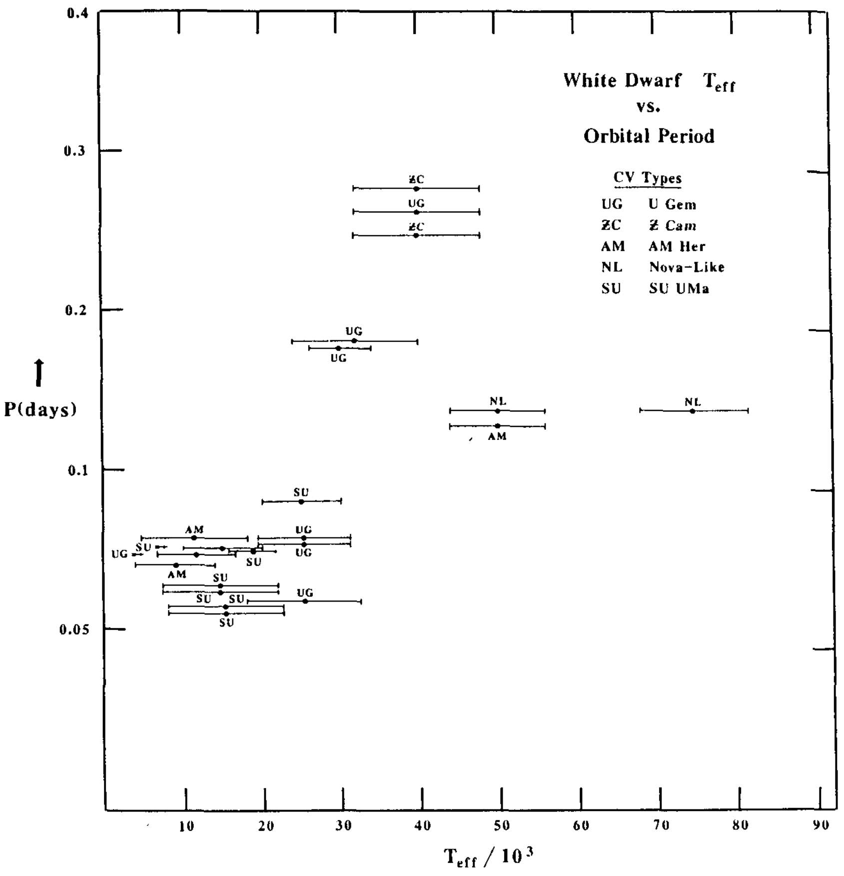

Figure 1. The effective temperatures of the underlying white dwarfs in cataclysmic variables of various types are plotted versus orbital period. Uncertainties in the individual temperatures were estimated as indicated by the horizontal lines. See text for details.

systems, or white dwarf model-atmosphere fits by Wood (1986), or from the tabulation in Patterson and Raymond (1985). Original references to the data used in the temperature analyses are listed in Table 1 where the individual values of T_{eff} adopted for use in Figure 1 are tabulated. The effective temperatures obtained by Smak (1984) from emission line CVs may be uncertain by a factor 2 (Smak 1986). Despite the large uncertainties in the individual values (20%-50%), there appears to be a clear tendency for cooler white-dwarf primaries to reside in the shorter-period systems like the SU Ursae Majoris CVs or AM Herculis CVs. Such a correlation would not be unexpected if the orbital period of a CV binary is correlated with its long-term accretion rate (cf. Patterson 1984). If, however, the accreting white dwarfs in CVs cool as single white dwarfs during long-term evolution (cf. Sion 1985; Prialnik 1986), one would expect white dwarf cooling to proceed concurrently with angular momentum loss and thus the coolest white dwarf primaries to appear in the shortest period systems. A more detailed discussion of the implication of figure 1 is now in preparation.

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REFERENCES

Bailey, J. A. 1979, M.N.R.A.S., 187, 645.

Cordova,F. and Mason, K. O. 1983, in Accretion Driven Stellar X-Ray Sources, ed. W. H. G. Lewin, and E. P. J. van den Heuvel (Cambridge: Cambridge University Press).

Fabbiano, G. et al. 1981, Ap.J., 243, 911.

Gilliland,R. 1983, in I.A.U. Colloquium 72, 'Cataclysmic Variables and *Related Objects', ed. M. Livio and G. Shaviv (Dordrecht: Reidel).*

Hassall, B. J. M. et al. 1981, M.N.R.A.S., 197, 275.

Krzeminski, W. and Smak, J. 1971, Acta Astr., 21, 133.

Liebert, J. and Stockman,H. 1984, in Cataclysmic Variables and Low Mass X-Ray Binaries, ed. D. Q. Lamb and J. Patterson (Dordrecht: Reidel).

Mateo, M. and Szkody, P. 1984, A. J., 89, 863.

Panek, R. and Holm, A. V. 1984, Ap. J., 277, 700.

Patterson, J. 1984, Ap. J. Suppl., 52, 84.

Patterson, J. 1981, Ap. J. Suppl., 45, 517.

Patterson J., and Price, C. 1981, Pub. A.S.P., 93, 71.

Patterson, J. and Raymond, J. 1985, Ap. J., 292, 535.

Prialnik, D. 1986, Ap.J., in press.

Rayne, M. and Whelan, J. 1981, M.N.R.A.S., 196, 73.

Robinson, E. L. 1976, Ann. Rev. Astr. Ap., 14, 119.

Schmidt, G. D., Stockman, H. S., and Margon,B. 1981, Ap.J. (Letters), 243, L157.

Shafter, A. and Szkody, P. 1984, Ap. J., 276, 305.

Shafter, A. 1983, Ph.D. Thesis, University of California at Los Angeles.

Shafter, A., Szkody, P., Liebert, J., Penning, W. R., Bond, H. E., and Grauer, A. D. 1985, Ap.J., 290, 707.

Sion, E. M. 1984, Ap. J., 282, 612.

Sion, E. M. 1985, Ap. J., 297, 597.

Smak, J. 1984, Acta Astr., 34, 317.

Smak, J. 1986, private communication.

Szkody, P., Raymond, J., and Capps,R. W. 1982, Ap.J., 257, 686.

Szkody, P., Kiplinger, A., and Sion, E. M. 1986, in preparation.

Thorstensen, J., Sandford, A., and Patterson, J. 1985, in preparation.

Wood, J. 1986, Ph.D. Thesis, Cambridge University, United Kingdom.

Wu, C. C., and Panek, R. J. 1982, Ap. J., 262, 244.