THE PHYSICAL STATUS OF VW CEPHEI

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Abstract. The decreasing period of VW Cep, interpreted on conservative case mass transfer, implies mass flow from primary to secondary. The TRO theory then predicts semi-detached status. The system b-v color is the same at the two minima, to within observational error. This is in marginal disagreement with a hot secondary. It also implies close thermal contact, in disagreement with the postulated semi-detached status.

Unanimous agreement is lacking among research workers concerning the evolutionary status of W UMa stars and the interpretation of their light curves. The evolutionary status protagonists include the supporters of thermal relaxation oscillations (TRO) in one group, led by Lucy (1976), Flannery (1976), and Robertson and Eggleton (1977). The other group supports a thermal equilibrium model, made possible by an entropy discontinuity at the inner contact surface. This group is led by Shu, Lubow, and Anderson (1976).

In the study of W UMa light curves, the usual interpretation of the W-subclass (Binnendijk, 1970) systems has required a secondary (less massive) component whose photosphere is hotter than that of the primary. This accounts for the observed association of primary minimum with the eclipse of the less massive component. Rucinski (1974) used the hot secondary model in his study of W UMa light curves, as have several other investigators. The W-subclass systems were a problem for the Lucy (1973) light curve study, which otherwise was successful in representing the A-subclass systems. The Lucy common convective envelope model asserts a gravity brightening coefficient of 0.08 for convective envelopes, and incorporates a Rucinski (1969) bolometric albedo factor of 0.5.

The most extensively developed light curve synthesis program is that of Wilson and Devinney (1971). Wilson and Devinney (1973) were able to fit the W-type light curve of RX Com successfully, but required a value of gravity brightening much larger than the Lucy coefficient.

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Wilson and Biermann (1976) have made a detailed light curve synthesis study of the W-subclass system TX Cnc. They found that if the temperature at the pole of the primary is taken as a free parameter, allowing a temperature discontinuity between components, in disagreement with the Lucy common convective envelope model, a fair fit could be obtained with a hot secondary and a bolometric albedo that agrees with the Rucinski value 0.5. If no temperature discontinuity between components is allowed, the solution produced a hot primary, with a bolometric albedo of 1.0. However, the gravity brightening coefficient in both solutions is much larger than the Lucy value, reaching eleven times larger in the second one. Significant residuals remain near secondary minimum in both solutions.

Anderson and Shu (1977) have developed a new theory of W UMa light curves which differs from the model used by Lucy, Wilson, and others in several important respects. The Anderson-Shu (hereafter called AS) theory obtains a gravity brightening coefficient of 0.0. This theory also asserts the existence of a "reflection effect" in which the local temperature rises as the amount of unobscured sky decreases, an effect not present in the Lucy or Wilson models. A notable feature of the AS theory is its ability to produce W-subclass light curves without requiring a hot secondary.

Thus, the theoretical interpretation of W-subclass light curves remains obscure. It would be most desirable if observational means could be found, reasonably model-independent, which could directly test whether the secondary has a higher temperature than the primary or not. We return to this point later.

VW Cep is a W-subclass system which has been studied extensively. Reliable times of minima are available spanning 55 years. Photometric results of a two-year international campaign have been summarized by Kwee (1966). More recently it has been shown to be a triple system (Hershey, 1975), with a third component moving in a relative orbit of substantial eccentricity, but far enough away to be a negligible tidal or thermal influence on the eclipsing system. Light of the third component does contaminate the binary light curve, and motion of the binary about the common center of mass with the third component modulates the observed times of minima. The system has gained special interest recently. Dupree (1978) has found high excitation far ultraviolet lines in IUE spectra, and Cruddace (1978) reports that a low flux level soft X-ray source has a position error box which includes VW Cep. Observations of the system began with the MSU automated photometer in the fall of 1978. A discussion of the entire light curve will appear elsewhere. This paper considers times of minima and system color.

The times included in the period study by Hershey (1975), IBVS times published since Hershey's paper, and minima obtained at MSU have been combined in a new period study. The period has been decreasing monotonically for the 55-year interval during which reliable observations have been reported. Available light curve solutions for VW Cep (Lucy, 1973; Rucinski, 1974) agree on shallow contact, a common property of W-subclass systems. It is unlikely the system is losing mass at L_2. The period variation then implies conservative case mass transfer from primary to secondary.

The most detailed study of TRO effects is in the paper by Robertson and Eggleton (1977). During close thermal contact mass is transferred from secondary to primary at a rate $\sim 10^{-8} M_\odot$/yr. During the semi-detached phase, mass flows from primary to secondary at a rate $\sim 10^{-7} M_\odot$/yr. The rate of period variation for VW Cep and the component masses obtained by Hershey lead to a mass transfer from primary to secondary of $2 \times 10^{-7} M_\odot$/yr. The implied semi-detached status is consistent with the Lucy (1973) solution for the surface potential, compared with the potential of inner critical surface. It is of interest that hydrodynamic mass flow could deliver enough energy to the secondary to account for its entire luminosity. This is an alternative to the Whelan (1972) mechanism of energy transfer in the superadiabatic region as a means to produce a hot secondary. It then is an attractive speculation to attribute the observed high energy phenomena to the impacting stream.

Earlier mention was made of the need for model-independent means to measure the component temperatures. The B-V color of a thermal stellar source has a close and well-calibrated correlation with color temperature. The color at elongation phases has a different interpretation in different theories, and so is model-dependent. At conjunction the "neck" region is hidden if the orbital inclination is high. At maximum phase of transit eclipse the visible annulus of the eclipsed star experiences relatively small irradiation from the eclipsing star, so different assumptions concerning the bolometric albedo should have a small effect. The silhouette of each star is much closer to a circle than at elongation. The difference between limb darkening in V and B is much smaller than their individual center-limb variation. Thus, B-V color data at conjunctions should be interpretable on the basis of uniform temperature circles, in a relatively model-independent manner.

Table 1 compares the b-v data at the two conjunctions. Four sets of data are from Kwee mean light curves. The last two lines are from MSU observations, uncorrected and corrected for contamination by the third component. To within observational accuracy ($\pm$ 0.01 mag.), the difference in color between the two minima is zero. This implies the secondary is not hotter than the primary, and that the components are in very close thermal contact. On an approximation modelling the stars as uniform temperature circles, but attributing the difference in depths of primary and secondary minima to a hot secondary, the color difference should be about 0.01 mag.

TABLE 1

(b-v) (comp. star) - (b-v) (VW Cep)

Source	Phase 0.0	Phase 0.5	Diff.
Kwee I	0.207	0.201	+0.006
Kwee II	0.201	0.194	0.007
Kwee III	0.196	0.191	+0.005
Kwee IV	0.203	0.210	-0.007
Linnell (U)	0.192	0.192	0.000
Linnell (C)	0.160	0.162	+0.002

This result is in disagreement with the semi-detached status imputed from the period variation. It seems unlikely that the close temperature equality would result from thermalization of hydrodynamic flow. Robertson and Eggleton (1977) calculate an appreciable difference in component surface temperatures during the semi-detached stage of TRO oscillations. This difference would be easily detected.

These results suggest that the TRO model for close thermal contact may need further elaboration, possibly along the lines of Webbink's (1977) model which includes substantial circulation currents.

Further details concerning these results will appear elsewhere.

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COMMENTS FOLLOWING LINNELL

Leung: If there is enough time in my talk, I will show some slides on VW Cep. It is suggested that VW Cep may be a semidetached system from the photometric solution.

Webbink: In the model of energy exchange I published, some temperature excess of the secondary envelope was required, assuming it were convective, to close the circulation and establish good thermal contact. I don't think there is then necessarily any inconsistency in having equal surface temperatures and mass flow from primary to secondary (as indicated by the period derivative), both of which could be symptomatic of poor thermal contact in such a late-type W UMa system.

Linnell: I'm glad to know that!