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MAPPING OF SURFACE ACTIVITY ON THE W UMA-TYPE SYSTEM VW CEPHEI

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ABSTRACT

Multifilter photometry of the W UMa-type contact binary VW Cep (P = 6.67 hr; G5V + K0V) in 1986/87 revealed large asymmetries in the light curves believed to be caused by large, cool starspot regions on the surface of the larger star. In April 1987 we observed VW Cep with IUE to study the chromospheres and transition regions of the components. During one complete orbital cycle 3 SWP and 4 LWP low dispersion spectra were obtained including and then excluding the suspected active region. For the first time, phase dependent TR line emission strengths were found, most notably C IV, which was 50% stronger when the spot region was most visible. These results could be important because VW Cep represents an extreme case for studying stellar dynamo theory and observations can play a crucial role in the understanding of magnetic fields and activity cycles in rapidly rotating solar-like stars.

Keywords: Cool Stars, W UMa Binaries, Starspots, Chromospheric Activity, Stellar Dynamos

1. INTRODUCTION

Observations of W UMa-type binaries with the IUE have shown that these stars are rich sources of ultraviolet emission. They generally have large surface fluxes of high temperature lines such as C II, C IV, NV, and S IV as well as moderate temperature (10^4 K) chromospheric emission lines of Mg II, Lyα, C I, O I, and Si II. In analogy with the chromospherically active RS CVn stars, these line emissions are thought to arise from dynamo generated magnetic fields since these stars possess tidally enforced rapid rotation and deep convective zones, at least for the shorter period systems. However, because of their strong tidal interactions, components of W UMa systems should not possess significant differential rotation (both radial as well as latitudinal) which is believed to be an important component of stellar dynamo theory (Refs. 1, 2).

The light curves of most of the shorter period W UMa systems, of G to K spectral type, display markedly asymmetric light curves. Modeling of light curves using cool spotted regions can account for these asymmetries (Ref. 3). The presence of starspots on these stars is not unexpected because of their very short orbital and rotational periods. However, the W UMa-type stars are not as active as simple extrapolations of trends for detached binaries (the RS CVn stars) would indicate (Ref. 4). This could indicate a saturation of the dynamo mechanism in these stars.

2. PHOTOMETRY OF VW CEPHEI

VW Cep (HD 197433) is one of the brightest ($V_{max} \simeq +7.8$ mag), best observed short period W UMa-type binaries. It consists of ~ G5V and ~ K0V components in contact with their Roche limiting surfaces. Photoelectric photometry has been carried out on this star since 1948. Since 1978, VW Cep has been monitored photoelectrically at Villanova University Observatory. These light curves were combined with others obtained over the same time interval and found to change systematically with time. During 1979-81 asymmetries are evident in the light curves with the brightness of maximum I (at 0.25P) and maximum II (at 0.75P) as well as minimum I (at 0.0P) and minimum II (at 0.50P) changing up to 0.07 mag (in yellow) with a characteristic period of ~ 155 $\pm$ 5 days. The light curves obtained during 1982-84 appear to be disturbed the least amount. Beginning in 1985, and continuing through 1987, the light curves are asymmetric with max I being ~ 0.06 mag brighter than max II. The long term behavior of the system is illustrated in Fig. 1 in which the differences between the brightness of the maxima at 0.25P and 0.75P for a given light curve are plotted against time in the sense [mag(max II) - mag(max I)]. This gives a rough measure of the asymmetry present in the light curves. A value of 0.0 for this quantity corresponds to a time when the two maxima of the light curve are equal while a negative number would indicate that max II is brighter than max I. As shown in the figure, the ~ 155 day periodicity of the light curve asymmetry found during 1978-81 was not present during 1985-87. In the lower portion Fig. 1, the mean light levels from the light curves are plotted. The mean light level was determined by averaging the system's brightness at phases 0.0P, 0.25P, 0.50P, and 0.75P. As shown, the mean light level of VW Cep varies by ~ 0.06 mag with time. VW Cep was faintest during 1979/80 and 1986/87 and brightest during 1982-84. The asymmetries appear to be greatest when the system is the least luminous.

The apparent correlation between the mean brightness of the system and the size of the light curve asymmetries indicates that starspots are probably responsible for this behavior. Using the starspot model developed by Bradstreet (Ref. 3), we were able to reproduce the observed light curves with extended starspot regions on the surface of the larger, cooler star of the system. We were able to make a preliminary fit to the asymmetric light curve obtained during April 1987 shown in Fig. 2. The area of the two spots at this time was ~ 6% of the total surface area of the larger star, with a temperature of 450° ± 150 K cooler than the surrounding photosphere.

The ~ 155 day cyclic behavior observed during 1978-81 appears to arise from a small difference between the rotational period of the starspot region and the orbital period of the binary. The 155 day period is apparently the beat period between the orbital period and the rotational period of the photospheric region where the spots were located at this time. The migration of the spotted region around the surface of the cooler star produces the varying light levels of the maxima and minima of the light curve. At times, when the spots are small, such as in 1982-84, the asymmetries are smallest and the mean brightness of the system is greatest, and vice-versa as in 1979/80 and in 1986/87. A spot cycle of ~ 7-8 years appears in which the spots reach their maximum areal extent during 1979/80 and 1986/87. This apparent spot cycle produces the long-term variation in the mean light level of the binary as shown in Fig. 1.

3. IUE OBSERVATIONS OF VW CEPHEI

During 1986/87, the light curves of VW Cep were very asymmetric and the mean light level was about 0.10 mag fainter than observed during 1982-84. Because of this high level of surface activity we were granted, in April 1987, one US1 discretionary shift to study the nature and location of the phenomena affecting the light curves. During one complete orbital cycle, 3 SWP and 4 LWP low dispersion spectra were obtained. The location of the spotted region was inferred from ground-based photometry. The SWP exposures were centered on the orbital phases 0.84P, 0.13P, and 0.60P. These phases were chosen in an attempt to include and then exclude the suspected active region. The LWP exposures were centered on phases 0.90P, 0.25P, 0.45P, and 0.75P. Fig. 3 shows a polar view of VW Cep illustrating the exposure intervals of the IUE spectra. The integrated emission line fluxes of C II (λ1335) and C IV (λ1550) are given below the SWP image numbers (in units of ergs cm^{-2} s^{-1} x 10^{-13}). The Mg II line fluxes are given below the LWP image numbers in the same units. The locations of the starspot regions obtained from modeling the light curve are also shown in the figure. Fig. 4 shows the SWP spectra of VW Cep obtained on 05 April 1987. The strongest emission features are identified in the figure. The top spectrum (SWP 30713) was taken when the starspots were most visible and displays the strongest emission features. The other two spectra were obtained when the spotted regions were only partially visible. For the first time, phase dependent variations in the TR line emissions were discovered, most notably C IV, which was 50% stronger when the spot regions were most visible. From the LWP observations there appears to be a 20% variation in the level of Mg II emission, but this occurred during secondary eclipse and, thus, may be due to the occultation of a localized emitting region in the chromosphere. Fig. 5 shows the possible phase dependent variations of the C IV and Mg II line emissions, plotted together with the ground-based light curve obtained during April 1987. As depicted in the figure, the phases of maximum spot visibility

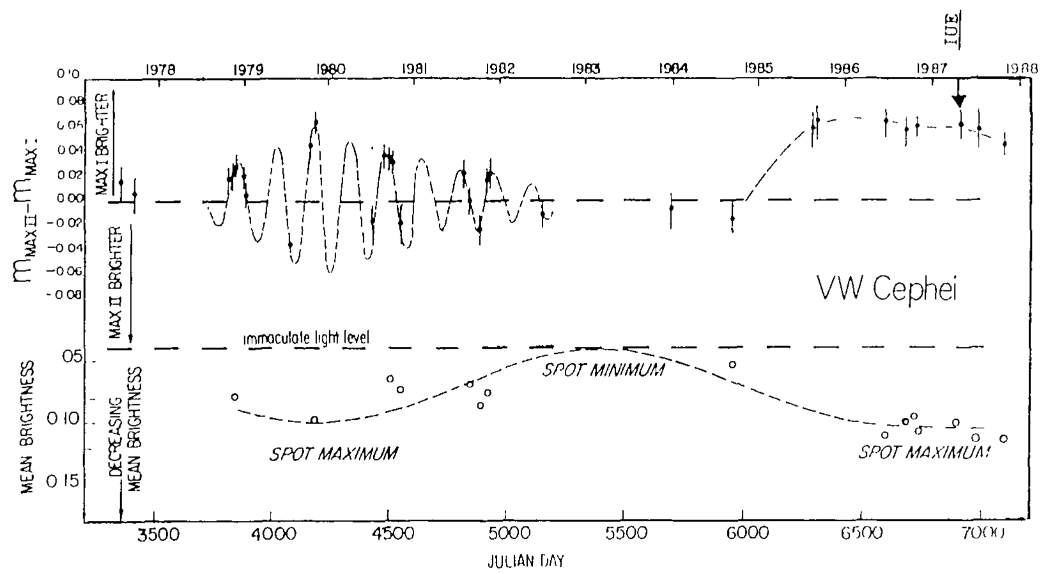

Figure 1. The long term photometric behaviour of VW Cep is shown above. The upper portion represents the changing levels of maximum light in the sense mag(Max II) - mag(Max I) where Max II and Max I are 0.75P and 0.25P, respectively. The lower panel shows the mean light level of the system over time.

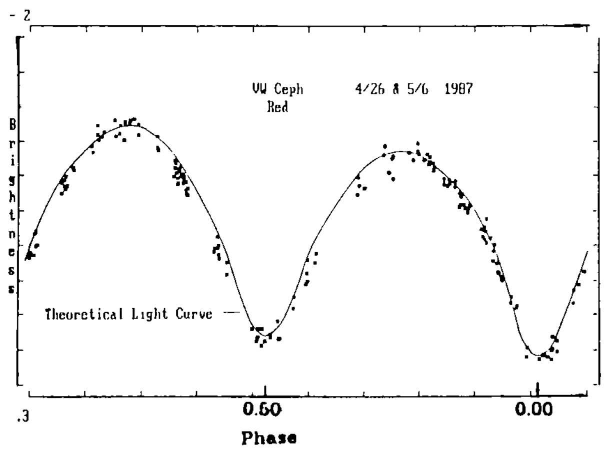

Figure 2. Red (λ6600) light curve obtained in April 1987 at Villanova. The solid curve represents the theoretical light curve with starspots. The starspots are 450° ± 150° K cooler than the surrounding photosphere and occupy an area ~ 6% that of the larger star.

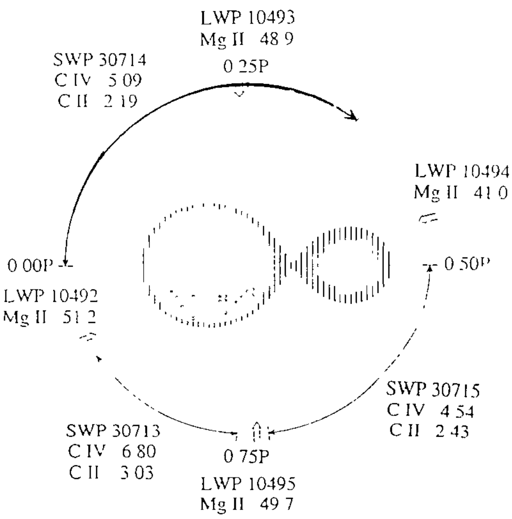

Figure 3. Polar view of VW Cep illustrating the exposure intervals of the SWP spectra. The phase at which the LWP spectra were taken is also shown. Below the SWP image numbers is the line flux (in ergs cm^{-2} s^{-1}) x 10^{-13} of C II and C IV. The Mg II line fluxes are given below the LWP image numbers.

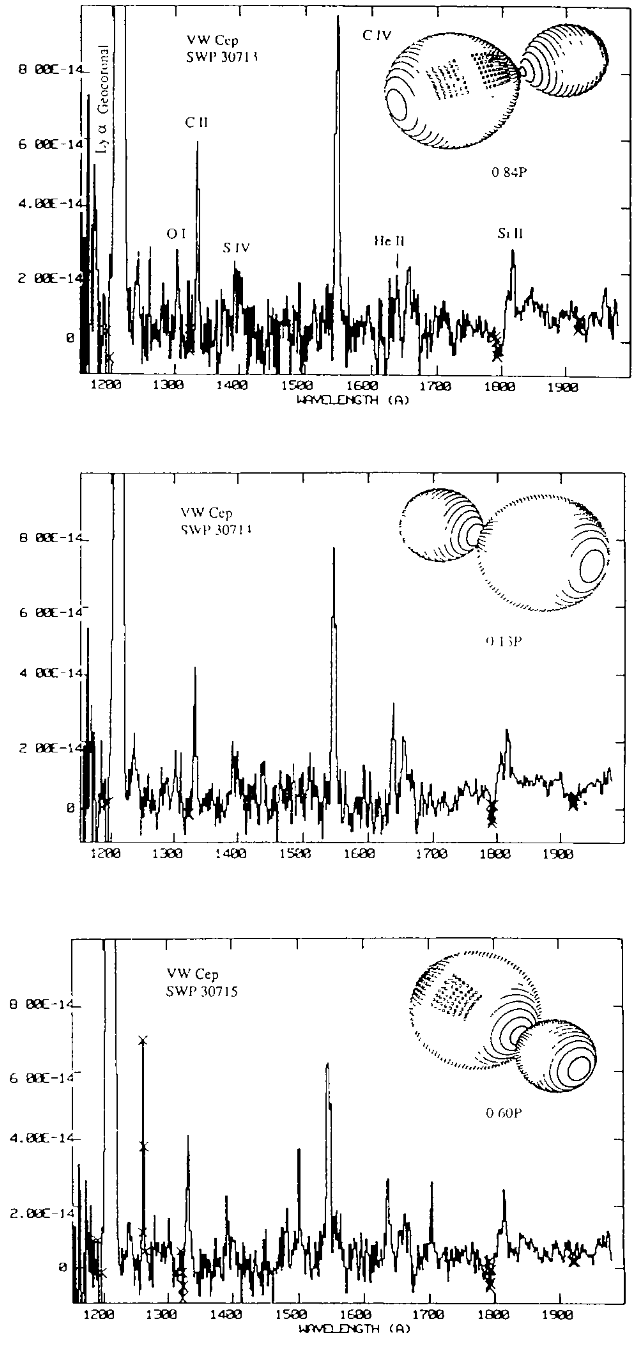

Figure 4. SWP spectra of VW Cep obtained 05 April 1987. The top spectrum (SWP 30713) was centered on 0.84P when the starspots were most visible. The middle spectrum (SWP 30714) was centered at 0.13P, and the bottom spectrum (SWP 30715) was centered at 0.60P. The insets in the upper righthand corners show representations of VW Cep at the appropriate phase of mid-exposure.

roughly coincide with the maximum C IV emission. However, the small number of spectra and their phase distribution are insufficient to determine unambiguously the association of the UV line emissions with the stellar regions defined by the starspots. We plan more observations of VW Cep with IUE during 1988 to test our results.

4. CONCLUSIONS

VW Cep seems to possess all of the common indications of enhanced solar activity that are expected from dynamo generated magnetic fields. The presence of starspots and a possible starspot cycle are inferred from the ground-based photometry. As this study shows there are strong chromospheric and transition region emissions which are indicators of enhanced stellar activity. Moreover, there appears to be a correlation between the visibility of the starspots and the strength of the transition region emissions in the sense expected if the spot forming regions and the transition region sites were physically related. However, the phase dependence of the transition region line emissions and the possible variation of Mg II emission needs to be confirmed with more observations.

The rapid rotation ($V_{rot} \simeq 150$ km s^{-1}) of VW Cep and deep convective layers of its components are in general accord with the high levels of surface activity inferred from the ultraviolet and ground-based observations. However, due to the strong tidal interactions between the two components, the other assumed necessary ingredient to most stellar dynamo theories - that of differential rotation - should be missing or at least substantially reduced in contact systems like VW Cep. Nonetheless, VW Cep and other W UMa-type binaries display levels of implied chromospheric and transition region activity that are among the greatest of solar-like stars. Perhaps extrapolations of the solar activity paradigm to these complex binaries are naive, missing some important mechanism which creates and sustains such large and long-lived active regions. During 1988 we have been granted time on the IUE satellite to secure more detailed ultraviolet observations of VW Cep and these observations should answer some of these questions (or possibly raise new ones) concerning the study of stellar activity and dynamo theory at extreme rotational velocities.

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5. REFERENCES

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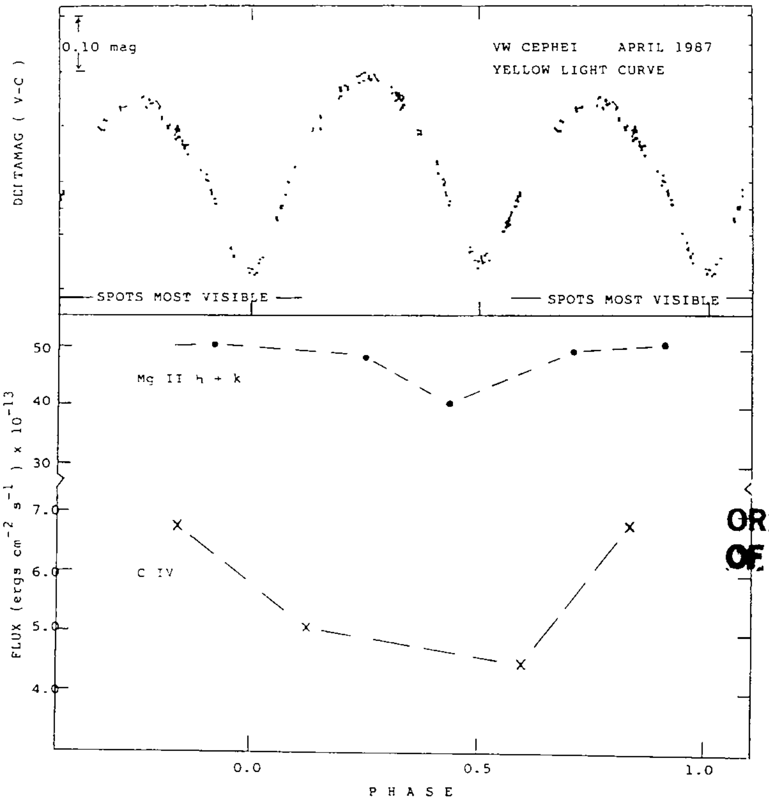

Figure 5. The yellow light curve of VW Cep obtained during April 1987 is shown in the top panel. The phases most affected by the starspots are indicated. The Mg II and C IV line fluxes are plotted versus phase in the lower panel.