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Long-term study of the starspot activity on the eclipsing short-period RS Canum Venaticorum binary UV Piscium

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Abstract. We present optical photometry of the short-period eclipsing RS CVn system, UV Piscium for the years 1966-1984. For each light curve, we model the distortion waves in order to study the behaviour of starspots in this system. After removing the spot effects from the light curves, we model the cleaned data to obtain system parameters. We also note changes in the luminosity of the primary star that are not explained by the spot variation.

1. Introduction

UV Piscium (UV Psc) is a member of the short period group of RS CVn stars defined by Hall (1976) (BD 6°197; G2, P=0.861d). It is a doubled lined spectroscopic binary with spectral types G8V and K3V. As part of our on-going study of RS CVn systems, we have analysed the available photometry of UV Psc from 1966-1984.

2. Data

Photoelectric photometry of this system was made by Carr (1969), Oliver (1974), Sadik (1979), Vivekananda Rao (1981), Zeilik (1981, 1982) and Busso et al. (1986). All the observations made so far indicated that this system is very active showing signatures of asymmetry in their light curves like several other RS CVn systems. Spectroscopic observations of this system were made by Popper (1997) who could obtain reliable radial velocity curves from which the masses and radii of the system were found. Spangler et al. (1977) had detected radio emission from UV Psc - the first star of this period ranged to be a radio binary. Agrawal et al. (1980) have detected soft X-rays from UV Psc. The origin of the X-ray emission was attributed to the coronal region. To our knowledge, no far-ultraviolet and infrared observations exist for this system in the liternature. UVPsc is classified as a member of the Chromospherically Active Binary Stars (CABS) by Strassmeier et al. (1988, 1993).

3. Light curve analysis and discussion

All the studies made sofar on UV Psc suggested it to be a detached system. All the available light curves in the literature showed enhanced asymmetries which are attributed to starspots

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located on the surface of one or both components. In the Wilson-Devinney (1971) (W-D) method, separate mode exists for analysing detached systems and also has the provision for incorporating spots on them. Hence, in order to determine the spot characteristics the first step is to obtain clean light curves (ones obtained after the removal of the effect of the wave from the observations) in various passbands (UBV) and solve them for the various physical parameters. For obtaining the clean light curves we have used the UBV observations of Vivekananda Rao and Sarma (1981). The procedure adopted for obtaining them is described in the paper of Vivekananda Rao & Sarma (1983).

3.1 Clean solution

Treating the wave removed light curves as the observed ones, the light curves are normalised to unit intensity at maximum by adding appropriate values of magnitudes for the various passbands. For initiating the W-D programme, we used the values of a few of the required parameters given by Vivekananda Rao & Sarma (1984) and Popper (1997) as initial parameters. We treated the following parameters as fixed: the temperature, $T_{e,h}$ (5520 K) of the hot component; the mass-ratio, q (0.78) of the system; the ratio of the surface rotation rates to synchronous rotation rates as unity, F_h and F_c; the limb darkening coefficients, x_h and x_c; the albedos A_h and A_c; and the gravity darkening coefficients G_h and G_c of the hotter and cooler components, respectively. All the previous investigators on UV Psc have classified this system as a detached binary and hence mode 2 is used for the analysis. According to the principles of the W-D method, we adjusted the following parameters: the inclination, i; the relative monochromatic luminosity of the hot component L_h; the temperature of the cool component $T_{e,c}$ and the third light l_3. Sufficient number of runs of the DC programme is made until the sum of the residuals, i.e. $\Sigma W(O-C)^2$ showed a minimum and the corrections to the parameters became smaller than their probable errors. In order to check the internal consistency of the results (Popper 1984), separate solutions, for each of the U, B and V light curves, are made. The results indicate that the individual solutions are consistent and that a combined solution for U, B and V is adequate to derive the system parameters.

Using the derived luminosities, the magnitude and colour of the comparison star [V = 9.12, B = 9.92 and U = 10.18] and the corresponding differential magnitudes for unit luminosity at the quadrature [V = +0.495, B = –0.258 and U = 0.011], we derived the colours (B-V) and (U-B) of the primary, hot component to be 0.73 and 0.20 and the secondary, cooler component to be 1.10 and 0.60. These colours correspond to spectral types of G8 for the primary and K3 for the secondary.

The distance of this binary from parallax study (Popper 1998) is found to be about 60pc and hence it is assumed that there is no space reddening. The derived colours for the hotter component corresponds to an average temperature of 5520 ± 100 K (Allen 1976, Popper 1980), Schmidt-Kaler 1982). Hence, as stated above, a combined solution for U, B and V colours with $T_{e,h}$ = 5520 and q = 0.78 as fixed parameters is made. The average parameters derived from the individual solutions are used as preliminary elements for the combined solution. The theoretical curves obtained from the final elements are found to fit the observations quite satisfactorily.

3.2 Spotted solution

Vivekananda Rao & Sarma (1983) have found that the hotter component is responsible for the distortion wave in UV Psc. In order to obtain the spot parameters on this system and study their evolution, we tried to obtain a better fit by introducing cool spots on the surface of the hotter (primary) component to explain the light curve asymmetries. The spot region is centered in the full range of latitudes (0° to 90°), while the other spot parameters namely longitude (measured counter-clockwise on the secondary as defined in the Wilson-Devinney programme). Angular size and temperature factor are first selected by trial and error to reproduce the light curve perturbations by using the parameters found in the clean solution in the LC (light curve) programme of the Wilson & Devinney. The latitude is the most difficult spot parameter to fit with photometric modelling. It is also to be noted that UV Psc has an inclination very close to 90° and hence there is a north-south latitude ambiguity. Only positive latitudes are adopted, but the spots could be in either hemisphere. Busso et al. (1985) put forth a model based on the solar analogy in which spot areas are formed at a certain latitude of the stellar surface then migrate towards the equator: when they pass through the corotational latitude the apparent direction of the wave motion gets reversed. Using the above mentioned hypothesis, Busso et al. (1986) have derived the initial latitude, θ_i, where the spots are formed to be around 24° and the co-rotational latitude, θ_c, to be about 12° for UV Psc. These values of θ_i and θ_c are extracted from the differential rotation and on the latitude shear of the starspots from the photoelectric light curves of UV Psc spread over several years of observations.

The spot parameters are later subjected to a DC programme. These data are used for deriving the spotted solution of the light curve. The mass-ratio and temperature of the hotter (primary) component is fixed at the value found in the unspotted solutions. The other parameters namely, i, T_c, Ω_h, and L_h are varied. The differential corrections are calculated until the adjustments became smaller than their probable errors. This procedure is adopted for the light curves observed by Carr (1969 observed during 1966), Oliver (1974 observed during 1969), Sadik (1979 observed during 1977), Vivekananda Rao & Sarma (1981 observed during the seasons 1976-77, 1977-78 and 1978-79), Zeilik et al. (1981, 1982, observed during the seasons 1980 & 1981) and Busso et al. (1986 observed during 1984). However in this starspot modelling, the R light curves of Zeilik et al. (1981, 1982) and the UBRI light curves of Busso et al. (1986) could not be done. Our derived values of the spot latitudes obtained by modelling the light curves are in general agreement with the ones found by Busso et al. (1986). The fit of the spotted solutions to the observations are found to be satisfactory except for a large scatter which we attributed to the pulsations in the hotter component. Figure 1 shows the fit of the spotted solution in the V passband to the 1978-79 observations of Vivekananda Rao and Sarma (1981). From our spotted solution it is found that the spots tend to occur in two Active Longitude Belts (ALB) roughly at quadrature, 90° and 270°. Another noticeable feature is that they show a trend in the latitude region between 10° to 25° for both the ALB's. Similar spot locations in longitude at quadratures and at low latitude are also found in several contact

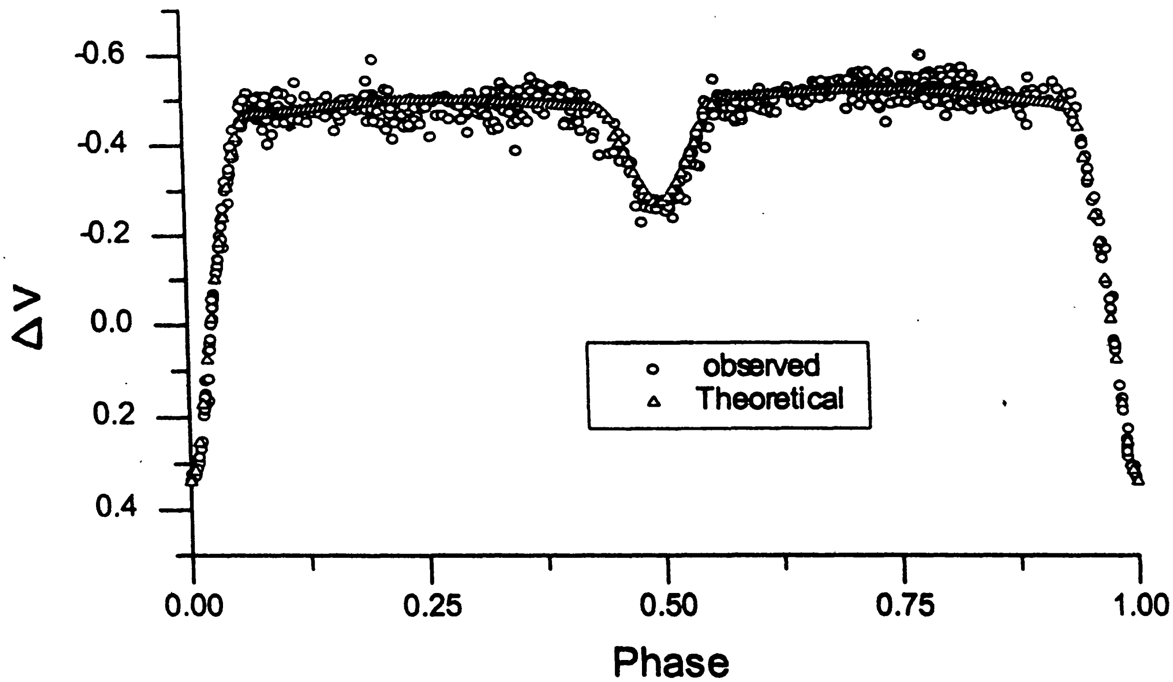

Figure 1. UV Psc : Light curve observed by Vivekananda Rao and Sarma (1981) during the year 1978-79 in V passband. Circles (o) indicate observations and triangles (Δ) theoretical values obtained from spotted solution.

binaries (Vivekananda Rao et al. 1999; Niarchos et al. 1992, 1994, 1998). What would be causing the spots to confine at these two ALB's and at low latitudes ? We have no explanation for this effect. Maybe this is a phase in a longer cycle. From the available light curves analysis, we could not find any latitudinal spot cycle as the period of the observations is limited to about 1.5 decades. To arrive at any conclusion on this, systematic long term observations are needed to find latitudinal spot cycles in this star. Similarly, spot lifetimes could not be determined from the above analysis because the light curves available are too intermittent. However, the relative stability in the light curves indicates that the spots on UV Psc are typically stable for long time scales. By contrast, other members of the short peroid RS CVn group showed frequent changes in the spot behaviour over short time scales of a month or so (Zeilik et al. 1994; Heckert & Zeilik 1991; Hempelmann et al. 1997). There are apparently differences in the short term stability of spots in the short period RS CVn group. To try to understand why UV Psc seems to have more stable spots and some other stars in this group have rapidly changing spots, we examined various properties of these systems looking for correlations. The only trend we found was that the systems whose spots change rapidly tend to have higher X-ray fluxes as compiled by Strassmeier et al. (1993). UV Psc along with WY Cnc and BH Vir belong to the class of chromospherically active binaries which have weak X-ray emission. The X-ray indicate a high level of coronal activity. Both the high coronal activity level and the rapid spot changes are driven by a high level of magnetic activity. Perhaps these stars go through long term cycles.

During the active phase of the cycle, spots change quickly, and during the quiescent phase, the spots are more stable. UV Psc would then be in a quiescent phase like WY Cnc (Heckert et al. 1998) while other group members are in an active phase. If this idea is correct, the relative number of stars in each phase suggests that the active phase would be longer than the quiescent phase.

Conclusions

UV Psc has secular variations in the mean brightness out of the eclipse and during the primary eclipse that are not explained by spot models and indicate luminosity changes in the primary star. The spots on UV Psc are relatively stable for long periods compared to other short period RS CVn systems. The spots are confined to two Active Longitudinal Belts (ALB's) of near 90° and 270°. The spots near 90° are found to be in the latitude range 18° - 25° while the spots near 270° to be in the range 10° - 15°. The stability of the spots in these two regions could be due to low X-ray fluxes compared to the ones which show rapid spot changes. No altitude drifts in the spot regions have been noticed.

Unfortunately, for most of the period UV Psc was observed sporadically and hence it is difficult to draw any definite conclusions about the nature of the starspot cycle.

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