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EVOLUTION OF STARSPOT REGIONS IN DM UMa

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Abstract. B and V photometry of DM UMa obtained between January, 1980 and June, 1984 is presented. Analysis yields a mean photometric period $7^{\mathrm{d}}.478 \pm 0^{\mathrm{d}}.010$, compared to the known orbital period of $7^{\mathrm{d}}.492 \pm 0^{\mathrm{d}}.009$. Light curves obtained during any two seasons do not agree in any of the following: shape, amplitude, phases of the light maxima and minima, mean light level, or brightness at the light maxima and minima. From the change in $B - V$ over the photometric period, we conclude that the hemisphere visible during the light minimum is cooler than that seen during light maximum. The mean color $B - V = 1^{\mathrm{m}}.065 \pm 0^{\mathrm{m}}.002$ is consistent with K1 III or K2 IV. Phases of light minima lie on two well-separated groups with different slopes; the corresponding periods are $7^{\mathrm{d}}.471 \pm 0^{\mathrm{d}}.002$ and $7^{\mathrm{d}}.481 \pm 0^{\mathrm{d}}.001$, indicating that both migrate linearly towards decreasing orbital phase. In terms of the starspot model this indicates that two respective centers of activity were situated at different longitudes and latitudes on a differentially rotating star. From circumstantial evidence we infer that the dark region seen from 1979 onwards disintegrated sometime between the 1982 and 1983 observing seasons, leaving behind an area of relatively high surface brightness. We can put a lower limit of about four years on the lifetime of a center of activity.

1. Introduction

DM UMa (= BD + 61° 1211 = SAO 015 338) has been the object of several observational studies since it was proposed as the prime candidate for the X-ray source 2A 1052 + 606, as a result of an accurate location from the HEAO I Scanning Modulation Collimator Experiment (Liller, 1978; Schwartz *et al.*, 1979; Charles *et al.*, 1979). Now it is recognized as one of the most active members of the RS CVn group of binaries

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described by Hall (1976). DM UMa is a single-lined spectroscopic binary with a period of 7.5 days and, like other members of its class, displays strong and variable Ca II H and K emission (Crampton *et al.*, 1979; Charles *et al.*, 1979). Photometry in 1979 by Kimble *et al.* (1981) showed it to be variable with approximately the same 7.5-day period and with an amplitude quite large for variables of this type. They interpreted their light curve in terms of a starspot model. The spectral type of the only visible component is K0–K1 and the luminosity class is III–IV (Kimble *et al.*, 1981). Both hard and soft X-ray flares from DM UMa have been detected (Schwartz *et al.*, 1979; Walter *et al.*, 1980). This is one of the four RS CVn systems so far known that show Hα as a pure emission feature above the continuum consistently at all times, the other three being V711 Tau, UX Ari, and II Peg (Bopp, 1982).

RS CVn systems have attracted much attention since their identification as a class of coronal X-ray sources (Walter *et al.*, 1980). Before that, however, they had been interesting because of their strong chromospheric activity (Simon and Linsky, 1980), their very strong flare-like radio activity (Spangler *et al.*, 1977; Feldman *et al.*, 1978), and their very peculiar photometric behavior. The general picture emerging as a result of extensive investigation of several RS CVn binaries in recent years is that the unusual (in comparison with single stars of similar spectral type) characteristics of these systems observed in wavelength regions from radio to X-ray can be understood in terms of enhanced activity analogous to that seen in our Sun. Further, it has been deduced that the most crucial factor responsible for this enhanced activity is rapid rotation forced by the orbital synchronization (Bopp and Fekel, 1977; Linsky, 1980; Charles, 1982).

Here we are interested in the peculiar photometric behavior. The most prominent and striking photometric characteristic in virtually all of these binaries is the 'wave' seen in their light curves. This wave often changes in shape, mean light level, and amplitude. In several well observed systems it is found that changes can occur over a time-scale as short as a few orbital cycles. In order to evolve a comprehensive model which would accomodate all the various time-scales involved, the nature of the variations and the various time-scales involved should be known in sufficient detail; this calls for more frequent and systematic observation of these active binaries.

In this paper we present the results of B and V photometry of DM UMa obtained at several observatories during the last five years, 1980 through 1984. An analysis of the data thus collected and that available in the literature will be made in terms of the starspot model.

2. Observations

Photometry of DM UMa was begun at Kavalur Observatory in early 1980 as part of an observational program on RS CVn systems and related objects. At other observatories it was included in the regular photometric program from 1981 onwards. Table I lists the names of the various institutions involved and the apertures of the telescopes employed.

Altogether, between January 1980 and June 1984, observations of DM UMa were

TABLE I

The observatories involved

Observatory	Location	Aperture (cm)	Probable errors	
			ΔV	$\Delta(B-V)$
Kavalur	India	34	$0.^{\mathrm{m}}012$	$0.^{\mathrm{m}}016$
Dyer	Tennessee	60	0.005	0.009
Kitt Peak	Arizona	40	0.003	–
Cloudcroft	New Mexico	120	0.003	–
Stelzer	Illinois	35	0.009	–
Louth	Washington	28	0.003	–
Braeside	Arizona	40	0.005	0.008
Lines	Arizona	50	0.006	0.006

obtained on 121 nights in *V* of the *UBV* system. On many occasions the variable was observed in *B* also. All measurements except those at Kavalur were made differentially with respect to the comparison star BD + 60°1301 (= SAO 015365). At Kavalur, where observation of DM UMa had begun first, before the coordinated efforts at the other observatories were known, the measurements were made differentially with respect to BD + 61°1210. On all nights when the variable was observed at Kavalur, BD + 60°1297 was observed also, as a check of the constancy of the comparison star. The difference between the two thus obtained during the three observing runs are given in Table II, in the sense BD + 61°1210 minus BD + 60°1297.

TABLE II

Comparison star minus check star differences

Year	ΔV	$\Delta(B-V)$
1980	$0.^{\mathrm{m}}638 \pm 0.^{\mathrm{m}}003$	$0.^{\mathrm{m}}103 \pm 0.^{\mathrm{m}}003$
1981	0.643 ± 0.003	0.116 ± 0.003
1982	0.639 ± 0.004	0.101 ± 0.010

The differential magnitudes and colors of DM UMa, in the sense DM UMa minus BD + 61°1210 (for Kavalur) and DM UMa minus BD + 61°1301 (for the other observatories), are listed in Table III. Each value given in Table III is a mean of three or four independent observations obtained on one night, each corrected for differential atmospheric extinction and transformed differentially to the *UBV* system. The internal probable errors of the means are given in Table I.

3. Photometric Period and Light Curves

By employing the period-finding technique outlined by Raveendran *et al.* (1982) we tried to derive the photometric period. Since observations obtained at different epochs indicated large differences in the nature of the light variation from season to season, as

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TABLE III

Differential magnitudes and colors of DM UMa

J.D. (Hel.) 2 440 000 +	ΔV	$\Delta(B - V)$
Kavalur		
4268.5010	+ 0.079	–
4269.4541	+ 0.019	–
4270.4282	– 0.029	–
4271.4017	– 0.041	–
4273.3788	+ 0.134	–
4273.4288	+ 0.131	–
4273.4746	+ 0.131	+ 0.619
4274.4746	+ 0.142	+ 0.674
4275.4663	+ 0.075	+ 0.639
4276.4735	+ 0.007	+ 0.641
4278.4550	– 0.054	+ 0.611
4279.4876	– 0.005	+ 0.603
4280.3920	+ 0.070	–
4280.4323	+ 0.092	–
4280.4732	+ 0.100	–
4282.4044	+ 0.086	+ 0.618
4282.4419	+ 0.061	–
4290.4008	+ 0.095	+ 0.624
4290.4303	+ 0.070	+ 0.638
4291.4149	+ 0.013	+ 0.623
4292.4075	– 0.052	+ 0.632
4293.4082	– 0.092	+ 0.577
4294.4015	– 0.028	+ 0.603
4295.4023	+ 0.039	+ 0.647
4296.3993	+ 0.148	–
4297.3984	+ 0.076	+ 0.630
4320.2698	+ 0.087	+ 0.636
4321.3733	+ 0.021	+ 0.606
4322.3374	– 0.019	+ 0.614
4323.3225	– 0.028	+ 0.607
4325.1899	+ 0.032	+ 0.609
4326.3145	+ 0.126	+ 0.661
4642.4557	– 0.030	+ 0.590
4643.3121	+ 0.012	+ 0.632
4647.3654	+ 0.126	+ 0.633
4659.3515	– 0.004	+ 0.612
4661.3481	+ 0.096	+ 0.620
4662.4054	+ 0.110	+ 0.622
4663.3983	– 0.001	+ 0.604
4664.3437	– 0.056	+ 0.616
4665.3131	– 0.022	+ 0.631
4667.3133	– 0.019	+ 0.622
4670.3115	+ 0.065	+ 0.611
4671.3154	– 0.060	+ 0.601
4672.2603	– 0.059	+ 0.603
4673.3129	– 0.002	+ 0.613
4984.4137	– 0.051	+ 0.601
4985.4071	– 0.026	+ 0.589
4986.3968	– 0.031	+ 0.614
4987.4092	– 0.050	+ 0.603
4989.3808	– 0.048	–
Dyer		
4650.8175	+ 0.462	– 0.119
4660.8003	+ 0.488	– 0.133
4675.7311	+ 0.475	– 0.145
4677.7783	+ 0.502	–
4678.6636	+ 0.415	–
4680.6427	+ 0.445	–
4682.7227	+ 0.429	–
Kitt Peak		
4713.6856	+ 0.549	–
4714.7376	+ 0.564	–
4716.6663	+ 0.392	–
4717.8087	+ 0.443	–
4718.6669	+ 0.447	–
4719.6697	+ 0.443	–
4722.8164	+ 0.484	–
4723.6907	+ 0.401	–
4727.6911	+ 0.465	–
Cloudcroft		
4956.9877	+ 0.444	–
4959.9338	+ 0.453	–
4961.9470	+ 0.408	–
4962.9510	+ 0.398	–
4966.9212	+ 0.420	–
4967.9302	+ 0.482	–
4973.9225	+ 0.382	–
4984.9239	+ 0.382	–
4993.8963	+ 0.459	–
4994.8631	+ 0.401	–
4997.9051	+ 0.482	–
5003.8463	+ 0.383	–
5021.7909	+ 0.418	–
5023.7450	+ 0.450	–
5045.6826	+ 0.429	–
5051.7666	+ 0.391	–
5052.7475	+ 0.402	–
5106.6895	+ 0.439	–

Table III (continued)

J.D. (Hel.) 2440000+	ΔV	$\Delta(B-V)$	J.D. (Hel.) 2440000+	ΔV	$\Delta(B-V)$
5115.6616	+0.361	–	5815.6750	+0.613	−0.121
5116.6397	+0.411	–	5820.6569	+0.488	−0.162
5118.6625	+0.383	–	5826.6801	+0.457	−0.135
5119.6393	+0.383	–	5827.6596	+0.470	−0.154
5120.6858	+0.465	–	5828.6698	+0.496	−0.162
5121.6670	+0.451	–	5830.6611	+0.614	−0.127
5128.6447	+0.479	–	5832.6717	+0.573	−0.136
5130.6462	+0.367	–	5840.6789	+0.508	−0.148
5136.6387	+0.466	–	5844.6750	+0.553	−0.132
			5846.6869	+0.663	−0.124
Braeside			5847.6688	+0.579	−0.137
			5848.6736	+0.476	−0.138
5457.8032	+0.507	−0.163	5854.6753	+0.630	−0.127
5458.7442	+0.429	−0.156	5859.6757	+0.568	−0.129
5464.7435	+0.505	−0.142	5861.6814	+0.651	−0.132
5465.7881	+0.492	−0.164	5862.6813	+0.571	−0.159
5467.7162	+0.295	−0.159	5864.6870	+0.474	−0.169
5470.7392	+0.427	−0.157			
			Stelzer		
Lines					
			5060.6968	+0.395	–
5804.7496	+0.429	−0.164			
5805.6829	+0.474	–	Louth		
5806.6976	+0.517	−0.143			
5807.6841	+0.571	−0.131	5346.0488	+0.427	–
5813.6590	+0.499	−0.143	5430.6978	+0.305	–
5814.6672	+0.551	−0.131	5789.6927	+0.419	–

is the case with virtually all RS CVn binaries which exhibit waves in their light curves, we analyzed the data obtained during each season separately. The result yielded a mean photometric period of $7\overset{\mathrm{d}}{.}478 \pm 0\overset{\mathrm{d}}{.}010$, in good agreement with the orbital period of $7\overset{\mathrm{d}}{.}492 \pm 0\overset{\mathrm{d}}{.}009$ derived spectroscopically by Crampton *et al.* (1979).

For analysis of the photometry the Julian date of observation was converted to orbital phase with the ephemeris

$$\text{J.D. (Hel.)} = 2443881.4 + 7\overset{\mathrm{d}}{.}492E\,, \tag{1}$$

where the initial epoch corresponds to a time of maximum positive radial velocity and the period is the orbital period mentioned above. The differential magnitudes ΔV given in Table III are plotted versus orbital phase in Figures 2 through 6. Figure 1 is a similar plot of the 1979 observations of Kimble *et al.* (1981), who had used BD + 60° 1301 as a comparison star also.

The observing runs at Kavalur during 1981 and 1982 overlap with those at Dyer and Cloudcroft, respectively. The well-defined portions of the light curve obtained during overlapping intervals were used to derive the magnitude difference between the two

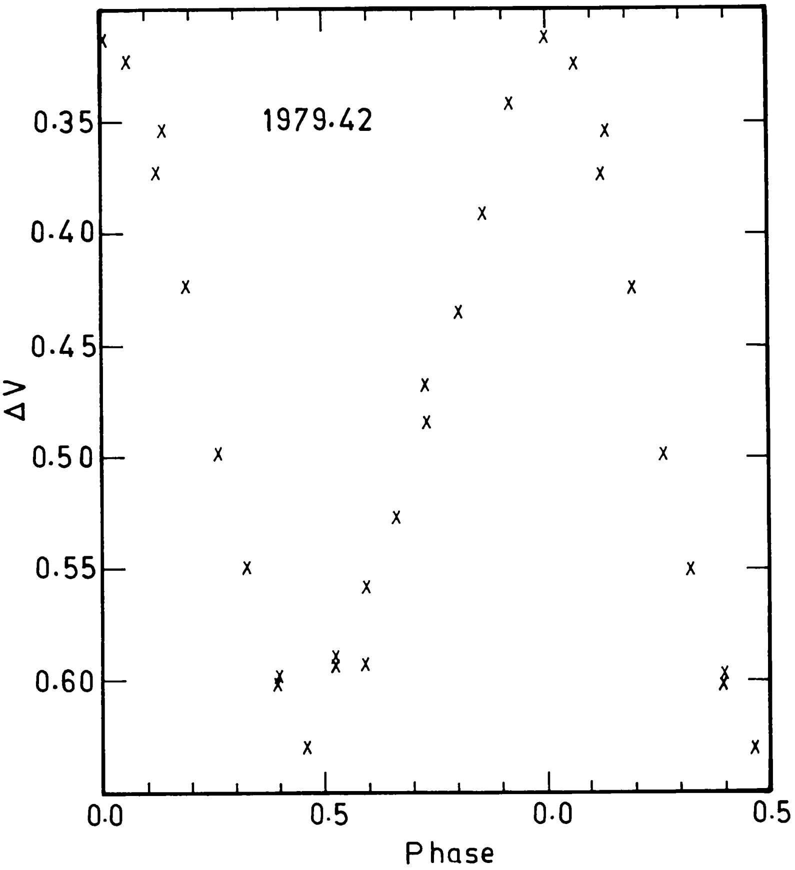

Fig. 1. The 1979.42 light curve of Kimble *et al.* (1981).

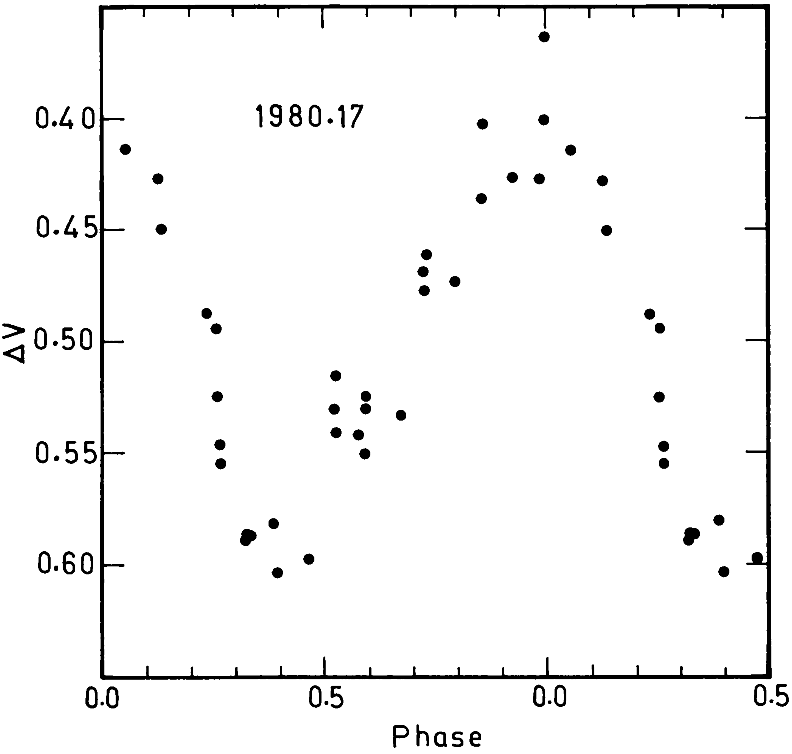

Fig. 2. The 1980.17 light curve determined at Kavalur.

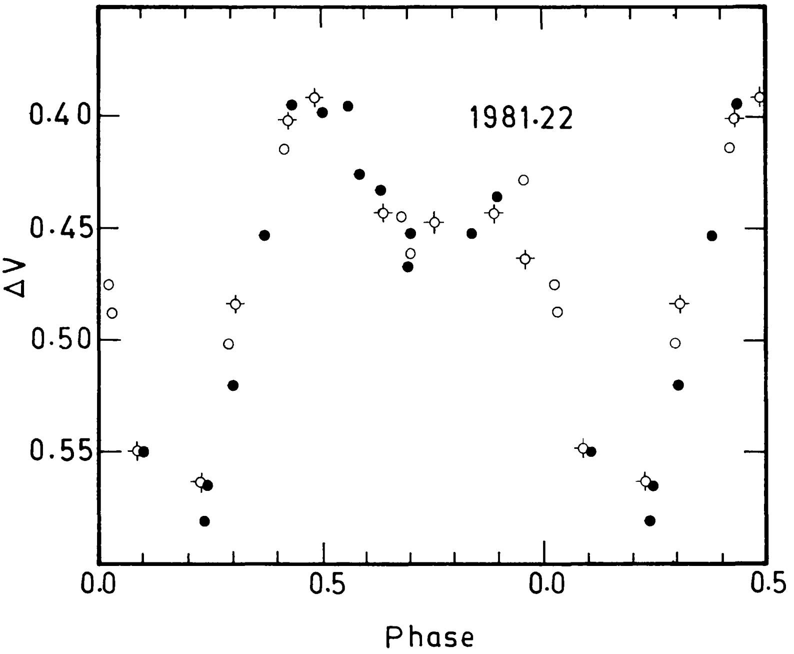

Fig. 3. The 1981.22 light curve determined at Kavalur (filled circles), Dyer (open circles), and Kitt Peak (open circles inside plus mark).

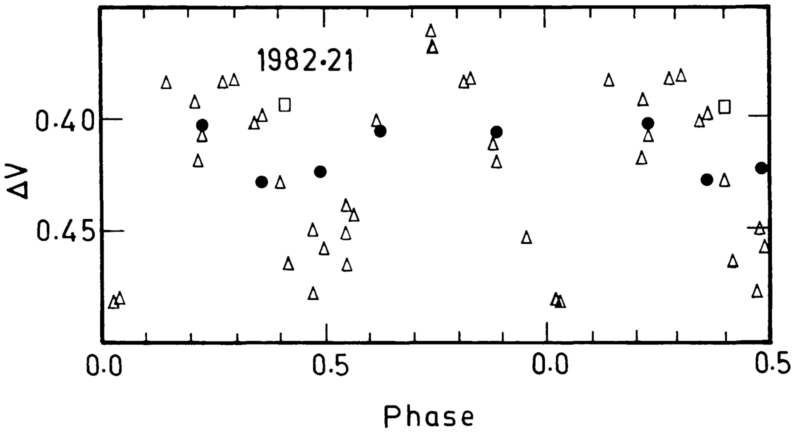

Fig. 4. The 1982.21 light curve determined at Kavalur (filled circles), Cloudcroft (open triangles), and Stelzer (open square).

different comparison stars. The resulting difference ($\Delta V = 0^{m}.455 \pm 0^{m}.004$ in the sense BD + 61°1210 minus BD + 60°1301) was added to the Kavalur ΔV means before plotting.

The mean epochs of observation are inserted in Figures 1 through 6 to give a clear overall view of the drastic changes the light curve of DM UMa has undergone during the six years since its variability was discovered in 1979. It is evident that no two light curves agree with each other in any of the following characteristics: shape, amplitude, mean light level, and brightness or phase of light maxima or minima. Several parameters which characterize these six light curves are listed in Table IV: the mean epoch, the

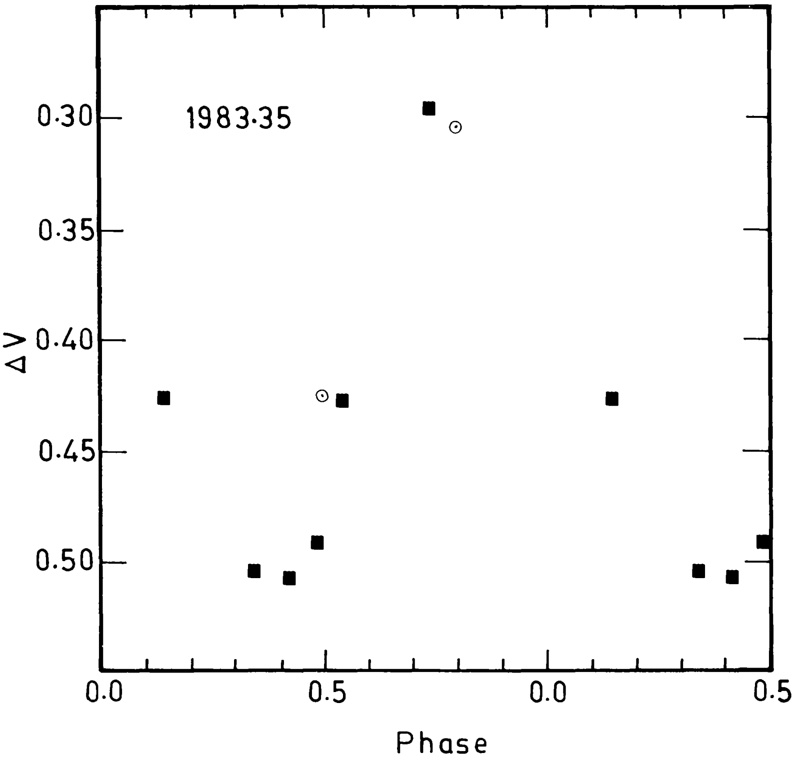

Fig. 5. The 1983.35 light curve determined at Braeside (filled squares) and Louth (encircled points).

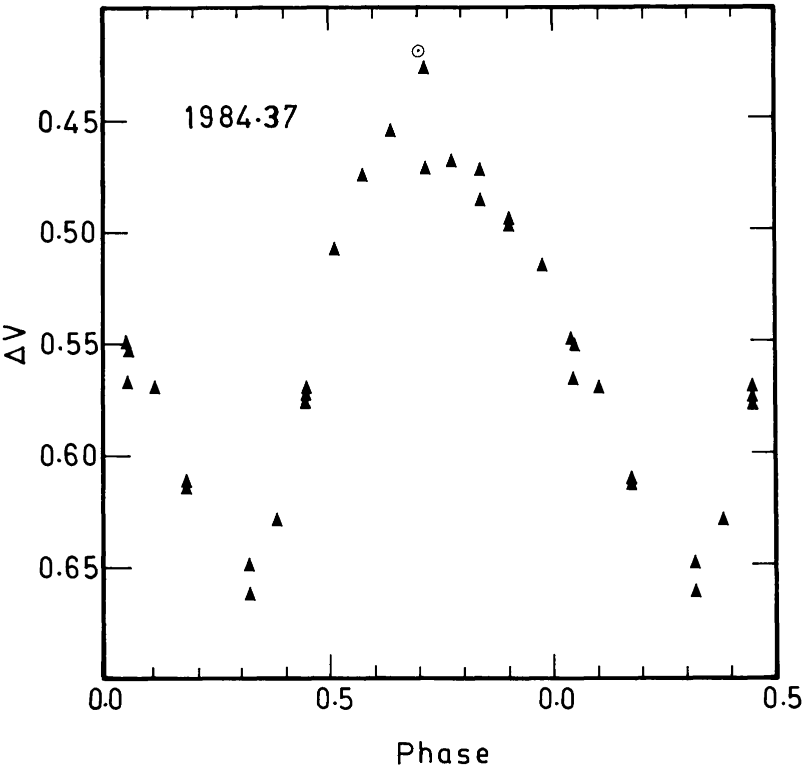

Fig. 6. The 1984.37 light curve determined at Lines (filled triangles) and Louth (encircled point).

TABLE IV

Parameters characterizing the six light curves

Epoch	Mean J.D. 2440000+	Phase maximum	Phase minimum	ΔV maximum	ΔV minimum	Maximum amplitude
1979.42	4030	$0^{\mathrm{p}}.01$	$0^{\mathrm{p}}.47$	$0^{\mathrm{m}}.310$	$0^{\mathrm{m}}.630$	$0^{\mathrm{m}}.320$
1980.17	4297	0.96	0.39	0.400	0.600	0.200
1981.22	4685	0.49	0.20	0.395	0.580	0.185
		0.93	0.70	0.435	0.455	
1982.21	5047	0.28	0.03	0.385	0.480	0.115
		0.75	0.49	0.470	0.365	
1983.35	5464	0.78	0.39	0.300	0.505	0.205
1984.37	5835	0.72	0.32	0.425	0.655	0.230

phases of maximum and minimum light (two values given if the light curve is double-humped), the values of ΔV at maximum and minimum light, and the maximum amplitude (from the highest maximum to the lowest minimum).

4. Background for Light Curve Analysis

According to the simple canonical model proposed by Hall (1972), one of the hemispheres of the active star in the binary system is predominantly covered by spots, analogous to sunspots, which rotationally modulate the observed flux and thus give rise to the photometric wave. The fractional area which the spots are expected to cover in order to account for the considerable optical variation is indeed far greater than is seen on the Sun even during sunspot maximum.

In the case of RS CVn, Eaton and Hall (1979) have shown convincingly that the large asymmetry in the light curve at the time of secondary eclipse can be reproduced only on the assumption of the existence of large surface inhomogeneities on the active component being eclipsed. Spectroscopy of V711 Tau by Ramsey and Nations (1980) and spectrophotometry of II Peg by Vogt (1981) has established that, at the phase of the minimum of the wave, a region cooler than the surrounding photosphere is seen. This makes it clear that the starspot-sunspot connection is on the right track.

It is in the context of this picture that we discuss our photometry of DM UMa.

5. Color Variation

The mean color index of DM UMa, determined at Kavalur, was $B - V =$ $= 1^{\mathrm{m}}.065 \pm 0^{\mathrm{m}}.002$. If we assume negligible interstellar reddening, this implies a spectral type of K1 III or K2 IV, consistent with the K0-1 III–IV classification of Kimble *et al.* (1981).

To determine how $B - V$ might vary in DM UMa, we have plotted $\Delta(B - V)$ on the ordinate versus ΔV on the abscissa. This is done separately in Figure 7 (Kavalur) and Figure 8 (other observatories) because of the different comparison stars used. It is evident from Figures 7 and 8 that a change in the V magnitude is followed by a change in $B - V$ color in the sense that the star becomes redder as it becomes fainter. This confirms what Kimble *et al.* (1981) had found.

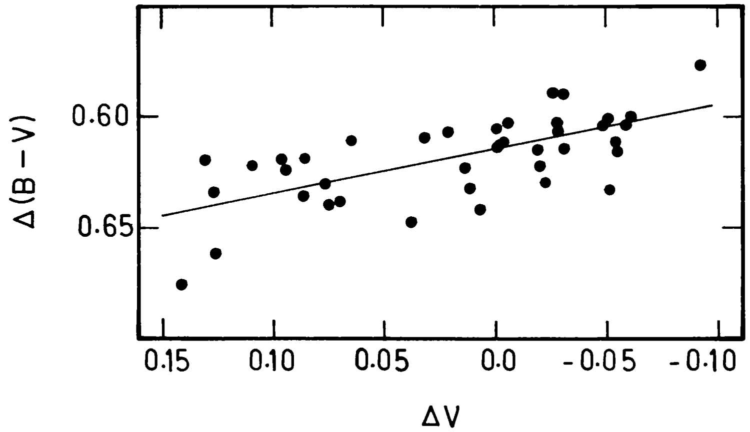

Fig. 7. $\Delta(B - V)$ versus ΔV obtained at Kavalur.

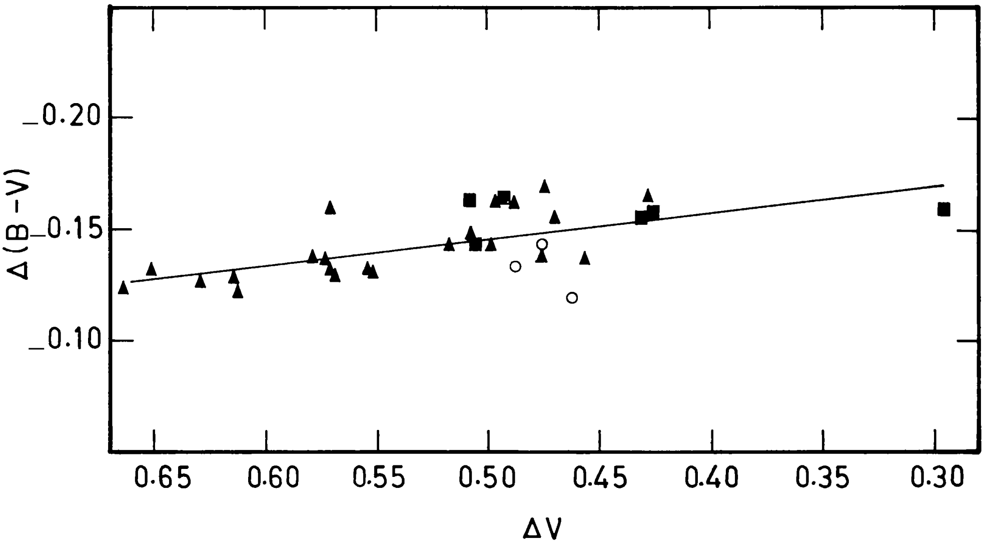

Fig. 8. $\Delta(B - V)$ versus ΔV obtained at Dyer (open circles), Lines (filled triangles), and Braeside (filled squares).

From consideration of the mass function (Crampton *et al.*, 1979) and the comparatively large amplitude of the photometric wave (which puts a lower limit on the orbital inclination) Kimble *et al.* (1981) have suggested that the unseen companion is probably a K5 dwarf. The increased fractional contribution to the $B - V$ color from the dK5 secondary, as the K0–1 IV–III primary becomes fainter, will be negligible. We conclude, therefore, that the hemisphere of the primary component of DM UMa seen at the time of light minimum is cooler than that seen at the time of light maximum.

The straight lines drawn in Figures 7 and 8 represent the assumed linear relationship found by the method of least squares. The corresponding slopes are 0.197 ± 0.025 and 0.116 ± 0.019. The observations of Kimble *et al.* (1981) indicate a change of about $0\overset{m}{.}05$ in $B - V$ for a change of $0\overset{m}{.}32$ in V, corresponding to a slope of 0.156, which is midway between the two values we found. We note that these three slopes apply to data obtained at three different epochs, but is difficult to be sure whether or not the differences are real.

6. The Phase of Light Minimum

In almost all well observed RS CVn-systems, the photometric wave has been found to drift slowly with respect to the orbital phase. Hall (1972) has pointed out that the enforced synchronization need not completely suppress the natural tendency for the active (convective) component to rotate differentially. His model assumes the existence of an intermediate latitude which does rotate synchronously with the orbital period. Active (spotted) regions present at other latitudes thus would make the photometric wave appear to migrate with respect to the orbital phase as a result of the star's differential rotation.

In Figure 9 we have plotted the phase of the light minima, estimated from the Figures 1 through 6 and tabulated in Table IV, versus the mean Julian date of observation. As is evident from Figures 1 through 6, the light curve at times shows two minima, indicating the simultaneous presence of two active regions separated in stellar longitude. It is

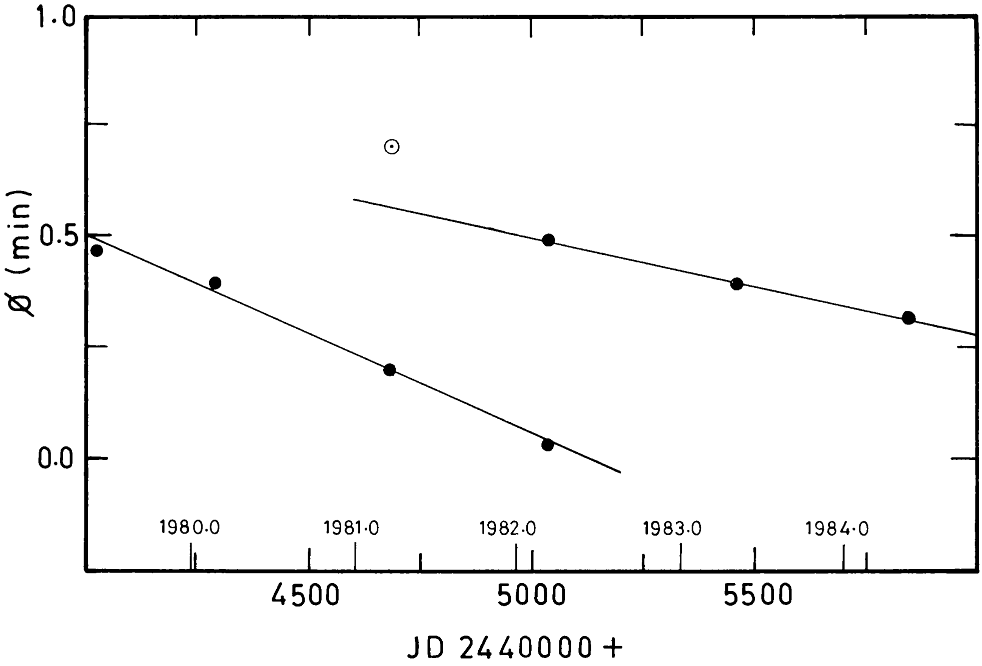

Fig. 9. Phase of light minimum versus mean Julian date.

interesting to see that the phases of these light minima fall on two distinct lines with different slopes, indicating different migration rates. This implies that the two regions refer to two different latitudes and, due to the differential rotation of the active star, lead to the two different migration rates observed. Let us call these two active regions *A* (bottom line) and *B* (top line).

The corresponding rotation periods, obtained by least squares solutions, are $7\overset{\mathrm{d}}{.}471 \pm 0\overset{\mathrm{d}}{.}002$ for region *A* and $7\overset{\mathrm{d}}{.}481 \pm 0\overset{\mathrm{d}}{.}001$ for region *B*. If the orbital period is assumed to be exactly $7\overset{\mathrm{d}}{.}492$, then the corresponding migration periods would be seven years for region *A* and fourteen years for region *B*. The encircled point in Figure 9 was not included in the solution because of the comparatively large uncertainty involved in its estimation; but, even if we include this point in the solution, the difference in the migration rates derived turns out to be larger than the error in its determination.

The phases of light maximum do not show the same migration curves exhibited by the phases of light minimum. We are assuming here that only the light minima, determined by the dark starspot regions, can be used as tracers of the stellar rotation.

An extrapolation of the bottom line in Figure 9 falls very near $0\overset{\mathrm{P}}{.}78$ in 1983.35, which corresponds to the brightest *maximum* ever shown by DM UMa. Moreover, the brightness at the minima produced by region *A* had become monotonically brighter ever since 1979.42, from $\Delta V = 0\overset{\mathrm{m}}{.}630$ to $0\overset{\mathrm{m}}{.}480$. These two facts suggest that active region *A* disintegrated sometime between 1982.21 and 1983.35, and that the disintegration was gradual rather than abrupt.

7. Understanding the Light Maxima

One of the basic parameters involved in quantitative spot modelling is the brightness of the unspotted photosphere (Eaton and Hall, 1979; Bopp and Noah, 1980; Dorren and Guinan, 1982; and La Fauci and Rodono, 1982). This is very difficult to assign, in DM UMa as well as in other spotted variables. In DM UMa we note that maximum brightness has varied from as bright as $\Delta V = 0\overset{\mathrm{m}}{.}30$ to as faint as $\Delta V = 0\overset{\mathrm{m}}{.}47$. There are three logically different ways to explain the fainter maxima. (1) Spots cover more than 180° in stellar longitude. (2) Some spots were present in the polar region and, hence, since the orbital inclination differs from 90°, were visible throughout the entire rotation cycle. (c) The brightness of the unspotted photosphere is not the same from year to year. Let us discuss the implications of these three possible explanations.

During 1981.22 and 1982.21 the maxima were faint but the double-humped shape of the light curves in those two years makes it easy to hypothesize two dark regions separated widely in longitude as the explanation. During 1980.17 and 1984.37 the maxima were also faint but the light curve was single-humped in those years, indicating the existence of a single dark region or two regions not much separated in longitude. If the spotted area extended more than 180° in longitude, we would expect flatter minima than were actually observed. Such is the difficulty with explanation (1).

The single-humped light curves in 1980.17 and 1984.37 could be caused by one spotted region at relatively low latitudes and the diminished brightness at maximum could be caused by another spotted region at higher latitudes. Crampton *et al.* (1979) had placed a lower limit of ~45° on the orbital inclination, so the always-visible polar region could contain a dark area up to 45° in radius. Such a dark region probably could have diminished the brightness at maximum by as much as $0\overset{m}{.}100$ (in 1980.17) or $0\overset{m}{.}125$ (in 1984.37). Solar-type differential rotation, however, implies *slower* rotation at higher latitudes. We see that both regions A and B rotates *faster* than synchronously, implying they are nearer to the equator than the synchronous latitude. Such is the difficulty with explanation (2).

Hartmann and Rosner (1979) have pointed out that the large fractional area of the star covered by the comparatively cooler spotted regions implies significant changes in the bolometric luminosity of the star and under such circumstances there is no reason to assume a constant photosphere until the missing flux is shown not to be significantly redistributed from the spots to the surrounding photosphere. Thus, it is not certain that we can safely assume the unspotted photosphere remains constant in brightness. It is perhaps significant that, immediately following what we believe was the disintegration of spotted region A, the maximum was brighter than ever observed before, $\Delta V = 0\overset{m}{.}30$. It is well known in the case of our Sun that sometimes a sunspot group disintegrated leaving behind bright plages. Something similar may have happened in DM UMa. The other comparably bright maximum, $\Delta V = 0\overset{m}{.}310$ in 1979.42, might have coincided with the expected phase of another dark region which disintegrated and left bright plages in its wake but unfortunately there is no photometry prior to 1979 to test this conjecture. Oskanyan *et al.* (1977) and Vogt (1981) have shown that changes in the light curves of BY Dra can be accounted for on the assumption that the cool dark spots that were present dissolved leaving bright plage-like remnants. Recently, however, Poe and Eaton (1985) have shown that, if spot modeling is done with the correct limb-darkening coefficients, the observed light and color changes in BY Dra can be accounted for entirely with cool regions; i.e., without having to hypothesize hot spots.

8. Integrated Light Loss

In the literature we often find the wave amplitude used as an indicator of the activity level (Hall, 1972; Blanco *et al.*, 1982; Catalano, 1982). But the wave amplitude depends only on the inhomogeneity in the surface brightness distribution. In the case of our Sun we know that during maximum activity the fractional area covered by spots is also a maximum. Hence, we feel that the fractional loss of light integrated over the photometric cycle, which should be a measure of the fractional stellar area covered by spots, would be a better index of activity level from the photometric point of view. Taking $\Delta V = 0\overset{m}{.}30$ as a reference level, we have calculated the relative loss of light by integrating over the photometric cycle. The results are plotted in Figure 10. These values would represent the actual fractional light loss if our reference magnitude truly represented the brightness of an unspotted hemisphere; the distinction, however, would be merely a vertical shift of points in Figure 10. It is perhaps significant that the relative fractional light loss was least during 1982 and 1983, when the light curve was undergoing its most drastic changes.

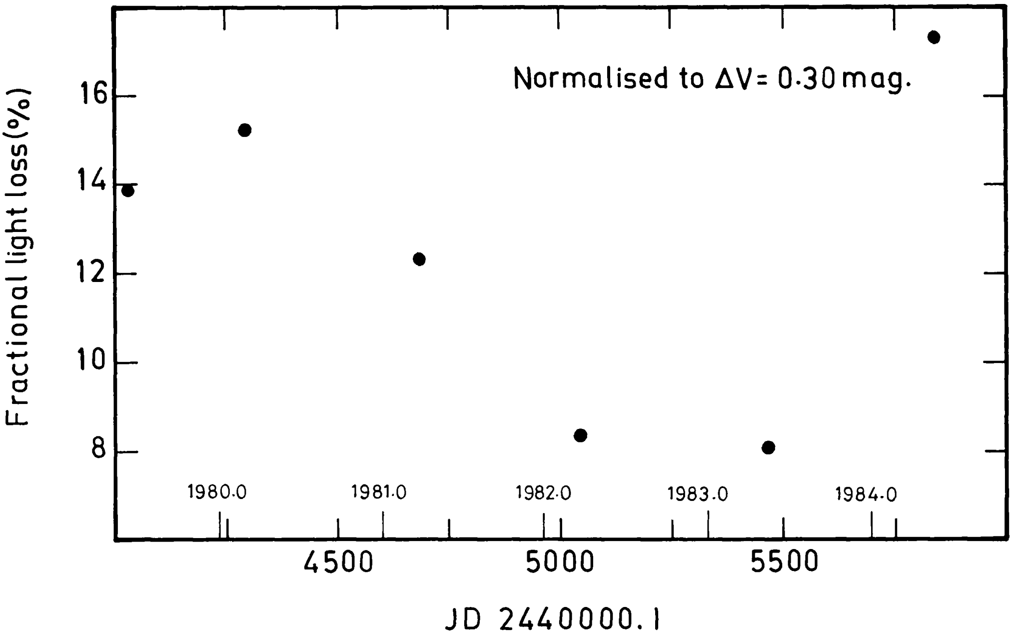

Fig. 10. Relative fractional light loss versus Julian date.

9. Active Region Lifetimes

Light curves in many RS CVn systems have been observed to change after just a few orbital cycles. From this we know changes must be occurring within the dark regions on time-scales at least this short. Such changes might involve one or several of the following: the numbers of spots, the distribution of spots within a region, the shape of a region, or the temperature of the spots. Despite these relatively rapid changes, the average lifetime of a center of activity must be much longer. This follows because, in several well-observed RS CVn systems, one could trace the migration of the phase of the light minimum over several seasons without apparent discontinuity, despite marked changes in the brightness at light minimum. In the case of DM UMa the minimum first observed in 1979 (which we identify with region *A*) could be traced until 1982. Since observations prior to 1979 do not exist in the literature, we can put only a lower limit of ~ 4 yr on the lifetime of this center of activity. A second minimum first appeared in 1982 (which we identify with region *B*). As of 1984 it was still in existence, so we can put a lower limit of ~ 4 yr on its lifetime also.

The migration of the phase of light minimum observed in many an RS CVn system is often approximated by a smooth curve and the continuous change thus seen in the migration rate is ascribed to latitude drift of the same active region (Hall, 1981; Blanco *et al.*, 1982; Catalano, 1982). Such an interpretation often leads to quite long lifetimes, namely, decades. Recently, however, Raveendran *et al.* (1985) have shown that the migration curve can be approximated instead by line segments each with a different slope and that a change in the nature of the light curve invariably follows a change in the slope of the wave migration. This they interpret in terms of the difference in latitude and longitude between the different centers of activity. In such an interpretation the average lifetime of a center of activity turns out to be much shorter and is of the order of the minimum lifetimes we see in DM UMa.

10. Concluding Remarks

Since DM UMa has been observed photometrically for at least two or three months each year since its variability was discovered in 1979, it would be good to continue photometry and see how the light curve and the activity centers continue to evolve. For example, we can ask how long region *B* continues to live and we can look for the birth of a new active region.

It is generally accepted now that the unusual properties exhibited by the RS CVn systems can be understood in terms of enhanced solar-type activity. Nevertheless, a real understanding of the physics involved is far in the future. Even a phenomenological description of the behavior of the large spotted regions is difficult. The main problem is that several free parameters are involved in attempts to use quantitative spot modelling to account for the photometric behavior, and ignorance of those free parameters renders the quantitative results ambiguous. More systematic and frequent observation, including spectroscopy as well as photometry and including wavelengths longer and shorter than *B* or *V*, will help to provide useful observational constraints.

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