

AN ANALYSIS OF THE SLOW LIGHT VARIABILITY OF BY DRACONIS

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ABSTRACT

An attempt is made to interpret consistently the photometric observations of BY Dra obtained over the last 20 years, using new results from Byurakan and McDonald Observatories. These observations, like previous ones in the literature, can be represented as blocks of sinusoidal variations with abrupt changes of mean level, amplitude, period, and phase. These changes can be interpreted as due to the disappearance of spots and appearance of new ones at different locations. The spots occur on the brighter component of this binary star in high latitudes, even including the extreme polar region. A natural explanation for the two-day phase shift found by Krzeminski is found. The absence of any close correlation of period and latitude suggests quasi-solid-body rotation. The star originally had a dark spot which has now been replaced by a series of bright areas.

Subject headings: stars: individual — stars: emission-line — stars: late-type

I. INTRODUCTION

Much effort has been expended on the interpretation of periodic, usually small-amplitude, slow light variations in red dwarf emission-line stars, all of which are believed to flare. These have been attributed to inhomogeneities of surface brightness (starspots) which produce the variations as the result of axial rotation of the stars (Kron 1952; Krzeminski and Kraft 1967; Krzeminski 1969; Torres and Ferraz Mello 1973; Evans 1971; Chugainov 1971; Bopp and Evans 1973; Vogt 1975). Photometric amplitudes are usually in the range of a few hundredths of a magnitude, occasionally as large as a few tenths of a magnitude, and periods in the range from rather less than a day up to about five days.

Although the basic explanation of these phenomena now seems to be generally accepted, various areas of debate over details remain. It seems difficult in many cases to arrive at a unique solution and, in particular, to decide whether spots are dark (favored by the very small observed range in color) or whether they can sometimes be bright (Vogt 1975). In the last case there has been dispute over the cause of possible bright spots, which cannot be attributed to line emission from the star surface (Fix and Spangler 1976).

In the present paper we do not address ourselves to the general problem of starspot analysis but to the special case of BY Draconis, where a variety of circumstances seems to provide an opportunity to draw some firm conclusions. The analysis may seem somewhat simplistic and is deliberately kept so, on the one hand to avoid the charge of overinterpretation of data, and on the other, because there seems to have

developed a tendency for mathematical refinements to obscure the essential physics of these situations. As we shall see, the data may not be ideally suited to this style of discussion, but in consequence future efforts may be better directed, while on the other hand one ought to be able to make profitable deductions from even a discontinuous run of 20 years of photometry on this star. In our discussion we are careful to enumerate the assumptions made and hope to justify the claim that these have the balance of probability on their side.

BY Draconis is a binary star for which an orbit has been derived (Bopp and Evans 1973) giving an orbital period near 5.98 days and an eccentricity of 0.487. The ratio of luminosities of primary to secondary is about 3:2, and plausible arguments from the mass function suggest that the inclination is near 30° . Since $i = 90^\circ$ corresponds to an equatorial view, then provided that the axis of rotation is somewhere near perpendicular to the orbital plane, it may be assumed that one sees a rather large circumpolar area and only a relatively small equatorial area. Any surface inhomogeneity in the polar area will always be in view. An inhomogeneity in the equatorial area will disappear completely during part of each rotation period. The polar area will extend from latitude $\phi = i$ to $\phi = 90^\circ$, and the equatorial zone from $\phi = -i$ to $\phi = +i$. The circumpolar zone will occupy a fraction $\cos^3 i$ of the visible disk, which for $i = 30^\circ$ is 65%. The true area of the circumpolar zone is 50% of the curved surface of the hemisphere. In the case of BY Dra the rotation period (i.e., the photometric modulation period) is not equal to the orbital period and, being near 3.84 days, is not commensurable with it.

If the "spot" modulation has an amplitude of only a few hundredths of a magnitude, we assume that there

is only one small spotted area on the surface of one component. This assumption cannot be justified mathematically since clearly we can paint any star surface with some regular checkerboard pattern so as to make it vary photometrically in any arbitrary sub-multiple of the rotation period. Physically, however, the assumption is the most economical one, especially since no secondary period, neither a harmonic nor an unrelated period, has been detected in the data. In particular, since in a highly eccentric system such as this, it would seem very unlikely that the two components should rotate synchronously, we believe we are so far dealing always with spot phenomena on only one of them.

We also assume that in general when no variations are observed, the star is immaculate. The exception to this would occur if a spot were located at the pole of rotation so that it always presented essentially the same aspect to the observers. We shall not completely exclude this possibility but count on being able to distinguish it on continuity grounds.

II. OBSERVATIONAL DATA

Previous photometric observations of BY Dra have been summarized by Vogt (1975). New differential photometric observations were obtained in 1974 and 1975 by V. S. Oskanyan at the Byurakan Astrophysical Observatory in Soviet Armenia (with additional observations by K. Olah, Konkoly Observatory, Hungary, and by A. Melkonian and A. Oskanyan, students of the University of Erevan), and by R. McMillan at McDonald Observatory using 40 cm and 76 cm telescopes, respectively. A standard Johnson B filter and an antimony-caesium cathode photomultiplier were used at Byurakan, while at McDonald Johnson B and V filters were used with various photomultiplier tubes. Comparison stars used and adopted magnitudes and colors from Vogt (1975) are SAO 31077 = C1 ($V = 7.508 \pm 0.005$, $B - V = 1.285 \pm 0.005$) and SAO 31070 = C2 ($V = 7.893 \pm 0.005$, $B - V = 1.259 \pm 0.005$). These stars lie within half a degree of, and are of comparable magnitude and color to, BY Dra.

At Byurakan Observatory the differential observations (see Table 1) were made at half-hour intervals throughout the night as part of a larger program primarily concerned with monitoring for flares. The observations consisted of 30 second integrations in B in the sequence C1-BY-C2. One such sequence and sky measurement was taken on the hour and half-hour, the nightly mean being assigned to midnight (local zone time). At McDonald Observatory the differential observations (see Table 2) were obtained from about 10 cycles C1-BY-C2 over a period of about 70 minutes. The uncertainties in B and V are of the order of a few thousandths of a magnitude. The data obtained at the two observatories do not overlap in time, but at one point are separated by only a week, and there they fit in a very satisfactory manner as remarked below.

The photometric amplitudes and colors derived from the observations and those of previous investigators are shown in Figure 1 (after Vogt 1975, with

TABLE 1
OBSERVATIONS MADE AT BYURAKAN OBSERVATORY

JD - 2,440,000	B	JD - 2,440,000	B
2181.33.....	9.334	2600.33.....	9.331
2192.33.....	9.309	2601.33.....	9.331
2193.33.....	9.325	2602.33.....	9.280
2208.33.....	9.310	2603.33.....	9.341
2209.33.....	9.293	2604.33.....	9.341
2210.33.....	9.294	2605.33.....	9.326
2213.33.....	9.293	2606.33.....	9.317
2216.33.....	9.298	2607.33.....	9.322
2217.33.....	9.276	2608.33.....	9.341
2218.33.....	9.313	2609.33.....	9.309
2237.33.....	9.206	2623.33.....	9.335
2238.33.....	9.296	2625.33.....	9.288
2240.33.....	9.274	2626.33.....	9.302
2242.33.....	9.281	2627.33.....	9.308
2243.33.....	9.243	2628.33.....	9.295
2244.33.....	9.312	2629.33.....	9.281
2245.33.....	9.316	2630.33.....	9.312
2247.33.....	9.284	2631.33.....	9.314
2248.33.....	9.321	2632.33.....	9.282
2250.33.....	9.272	2633.33.....	9.283
2251.33.....	9.286	2634.33.....	9.307
2252.33.....	9.321	2635.33.....	9.314
2253.33.....	9.306	2636.33.....	9.286
2254.33.....	9.280	2637.33.....	9.288
2255.53.....	9.295	2638.33.....	9.306
2269.33.....	9.272	2639.33.....	9.314
2270.33.....	9.274	2640.33.....	9.342
2272.33.....	9.323	2641.33.....	9.296
2273.33.....	9.252	2642.33.....	9.278
2274.33.....	9.289	2643.33.....	9.279
2275.33.....	9.323	2648.33.....	9.339
2276.33.....	9.308	2649.33.....	9.298
2278.33.....	9.295	2650.33.....	9.274
2279.33.....	9.291	2651.33.....	9.294
2281.33.....	9.271	2652.33.....	9.318
2299.33.....	9.331	2653.33.....	9.295
2300.33.....	9.269	2654.33.....	9.268
2310.33.....	9.372	2656.33.....	9.292
2311.33.....	9.306	2657.33.....	9.330
2312.33.....	9.280	2662.33.....	9.303
2313.33.....	9.300	2664.33.....	9.345
2314.33.....	9.352	2665.33.....	9.317
2315.33.....	9.301	2667.33.....	9.352
2599.33.....	9.338	2668.33.....	9.323

TABLE 2
OBSERVATIONS MADE AT McDONALD OBSERVATORY

JD - 2,440,000	B	$B - V$	ΔB_{2-1}	$\Delta(B - V)_{1-2}$
2322.60.....	9.303	1.227	0.360	0.027
2323.60.....	9.263	1.225	0.367	0.024
2329.66.....	9.345	1.228	0.357	0.021
2336.60.....	9.330	1.221	0.358	0.019
2337.61.....	9.329	1.222	0.359	0.018
2338.62.....	9.276	1.217	0.354	0.021
2339.59.....	9.279	1.214	0.355	0.022
2363.61.....	9.334	1.214	0.369	0.015
2364.60.....	9.321	1.215	0.363	0.016
2366.60.....	9.288	1.203	0.363	0.019
2367.59.....	9.324	1.212	0.356	0.019
2370.61.....	9.307	1.213	0.373	0.012
2371.59.....	9.325	1.216	0.361	0.015
2373.58.....	9.277	1.212	0.362	0.014
Mean.....			0.361	0.019
Standard deviation			0.006	0.004

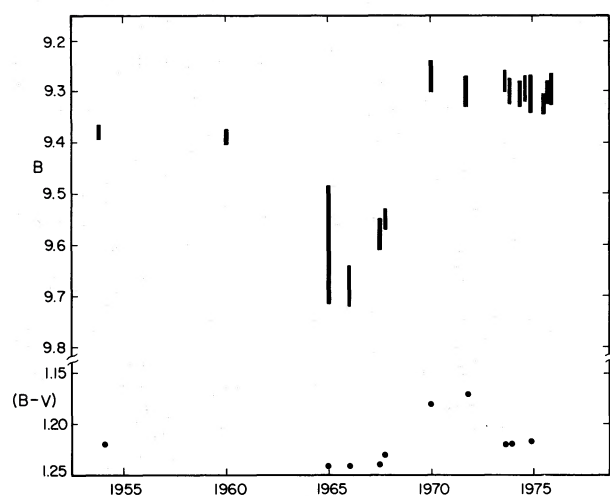


FIG. 1.—Ranges of B and mean values of $B - V$ for BY Draconis during the last 20 years.

additions). Recent behavior does not differ significantly from that of the last several years. A detailed examination of the magnitude data, however, reveals several surprising features (see Fig. 2): (1) It is not possible to fit a single waveform to the entire recent data set—i.e., the period, amplitude, and mean level vary within the set; (2) the changes can occur suddenly,

as best illustrated by data around JD 2,442,640; (3) there can be long intervals of at least several months during which the amplitude, period, and phase are quite constant, as best illustrated by the data from JD 2,442,299 to 2,442,375.

When it was found that no single waveform could fit the full data set, the data were divided into a number of smaller intervals such that the data within those intervals appeared to be homogeneous. Sine waves of the form

$$f(\text{JD}) = K \sin \left(2\pi \frac{(\text{JD} - 2440000)}{P} + \psi \right) + \bar{B},$$

where the symbolism for mean value, amplitude, period, and phase is obvious, were then fitted to each of the small blocks of data using an iterative least-squares fitting method, and were found to represent all the data very closely. Strictly speaking, the sine wave fits should be to luminosities, not magnitudes, but with only slight exceptions the ranges are small enough to make this difference unimportant. If the fitting parameters of two adjacent blocks did not differ significantly these were combined and a new fit made. In this way the sine waves shown in Figure 2 were determined for which the fitted parameters are given in Table 3. In the two adjacent blocks where the observations made at Byurakan Observatory and McDonald Observatory join, it was found that the sine waves joined smoothly, and they were therefore

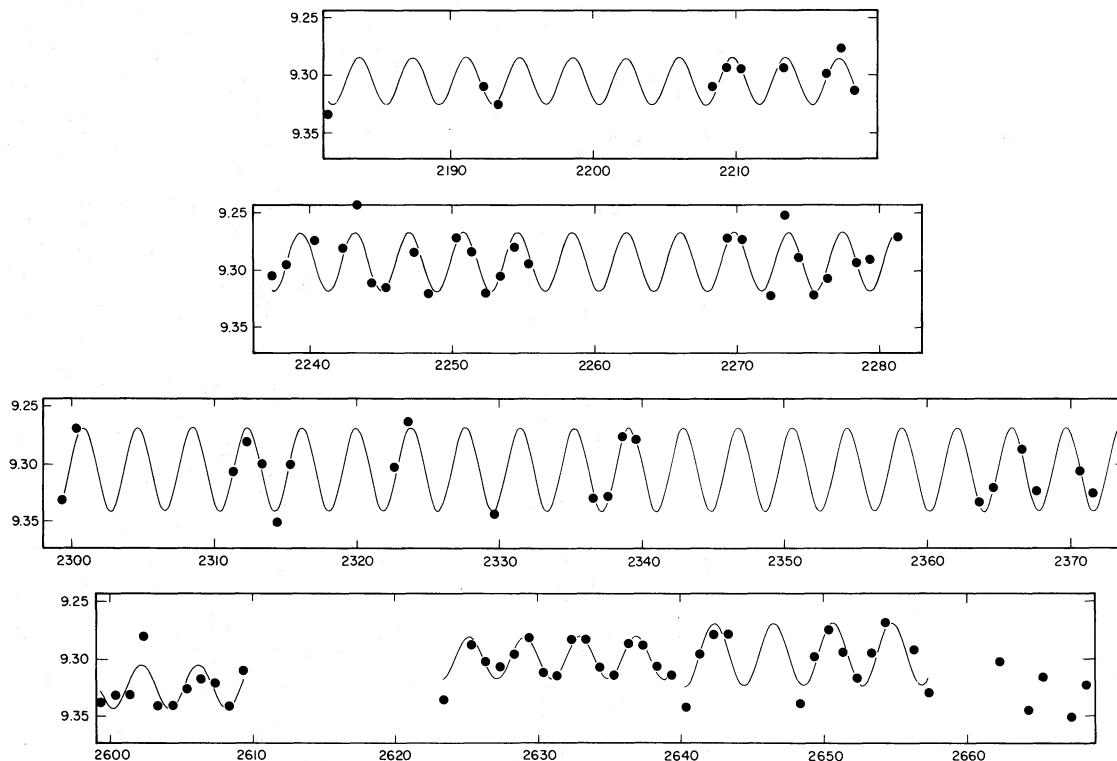


FIG. 2.—Sinusoidal waveforms fitted to blocks of recent photometric observations of BY Draconis. Ordinates B magnitudes, abscissae $\text{JD} - 2,440,000$.

TABLE 3
FITTING PARAMETERS OF SINE WAVES

Dates (JD - 2,440,000)	Mean Magnitude ($\bar{B}$)	Amplitude (K) (mag)	Period (P) (days)	Phase (ψ) (degrees)	Phase Shift of Adjacent Sets
2181-2218.....	9.305 ± 0.003	0.021 ± 0.002	3.739 ± 0.008	250	$+46^\circ \pm 5^\circ$
2237-2281.....	9.293 ± 0.002	0.026 ± 0.001	3.806 ± 0.005	110	-47 ± 5
2299-2373.....	9.305 ± 0.002	0.037 ± 0.002	3.829 ± 0.003	288	
2599-2609.....	9.324 ± 0.003	0.019 ± 0.002	3.982 ± 0.04	104	$+65 \pm 5$
2623-2639.....	9.299 ± 0.002	0.019 ± 0.002	3.909 ± 0.02	37	-130 ± 5
2640-2657.....	9.296 ± 0.003	0.028 ± 0.002	4.140 ± 0.02	217	

combined into one block with one fitted wave. The fitted periods are shown in Figure 3. Phase shifts between adjacent fitted curves are given in Table 3.

Vogt (1975) found an amplitude in $B - V$ of 0.014 mag accompanied by only a small variation in B , and used this to rule out the possibility of a dark spot during the time of his observations (1973-1974). The data of Table 2 (shown in Fig. 4) indicate an amplitude of about 0.012 mag in $B - V$ during the autumn of 1974. The accuracy of this photometry is such that this can be taken as indicating a real, small variation.

The fact that all the amplitudes are small is interpreted to mean that we are always dealing with a single spotted area of small extent. The fact that the observations are representable by sine waves, so that each block would give a light curve of sinusoidal form against phase without flat portions, is interpreted to mean that the spot never disappears altogether and must therefore be in the polar and not the equatorial part of the stellar surface.

III. MATHEMATICAL FORMULATION

Let the radius of a single star be a , the limb darkening formula be $p + q \cos \theta$, where $p + q = 1$, and the radiation parameter I per unit area; consider a small spot of true area A , perfectly black, at latitude $\phi > i$. At position P_1 (Fig. 5) the spot will subtract light $IA \sin(\phi + i) [p + q \sin(\phi + i)]$ and at P_2 $IA \sin(\phi + i) [p + q \sin(\phi - i)]$. The range of

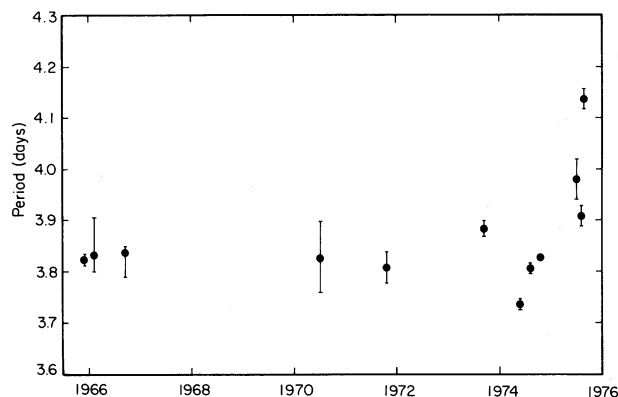


FIG. 3.—Adopted periods for successive data blocks in Fig. 2.

variation will then be $R = IA(2p \cos \phi \sin i + q \sin 2\phi \sin 2i)$ and the mean loss $\Delta L = IA(p \sin \phi \times \cos i + q/2 - q/2 \cos 2\phi \cos 2i)$.

The range as a fraction of the total light of the immaculate star is

$$\frac{R}{L_0} = \frac{A}{2\pi a^2} \left(\frac{2p \cos \phi \sin i + q \sin 2\phi \sin 2i}{p/2 + q/3} \right), \quad (1)$$

where we write $\alpha = A/2\pi a^2$ and α is the proportion of the hemispherical surface occupied by the spot. If the spot is not perfectly black the calibration can be expressed in the same phraseology. Thus

$$\frac{R}{L_0} = \alpha \left[\frac{2p \cos \phi \sin i + q \sin 2\phi \sin 2i}{p/2 + q/3} \right]. \quad (2)$$

The ratio of the range to the depression is

$$\frac{R}{\Delta L} = (2p \cos \phi \sin i + q \sin 2\phi \sin 2i) / \left(p \sin \phi \cos i + \frac{q}{2} - \frac{q}{2} \cos 2\phi \cos 2i \right), \quad (3)$$

which is a function of the latitude and limb darkening.

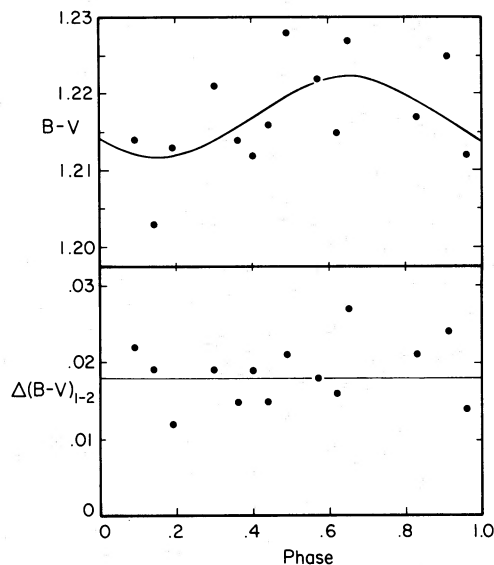


FIG. 4.—McMillan's color observations of BY Draconis (Table 2).

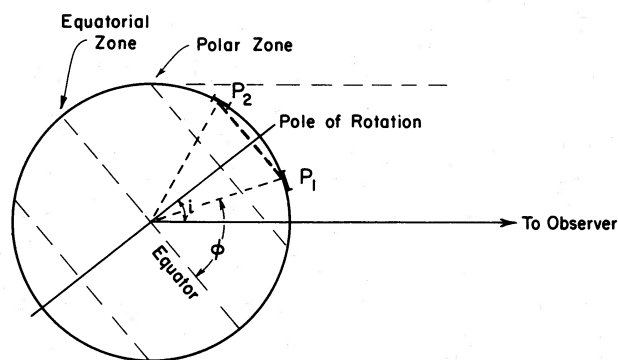


FIG. 5.—Geometry of BY Draconis

Values are readily calculable and are illustrated in Figure 6.

The same formulation can be used if the spot is bright, and, whereas in the dark case, α represents the proportionate area subtracted, in the bright case it will represent the proportion of the area added. ΔL will then be the mean elevation of light level. It is not certain that the limb darkening coefficients for a bright spot would be identical with those for a dark spot on the same star. Note that, if a spot at a given position changes from dark to bright, the spot modulation photometric curve will change in phase by half a period. This would also occur if a spot migrated on the star surface through the rotation pole or near it.

We shall use equation (3) in the analysis of the BY Dra observations. Before doing so we must take account (a) of the duplicity of BY Dra, and (b) of the fact that the data are expressed in magnitudes. Let the luminosities of the components be L_1 and L_2 and the maximum and minimum light defects during the modulation be Δ and Δ' . We also write $g(m) = 10^{-0.4m}$.

Then in suitable units $L_1 + L_2 - \Delta = g(m)$, where m is the light minimum magnitude, and

$$L_1 + L_2 - \Delta' = g(m'),$$

where m' is the light maximum magnitude. The range R is given by

$$R = \Delta - \Delta' = g(m') - g(m).$$

Also, the immaculate composite star with combined magnitude m_0 is given by

$$L_1 + L_2 = g(m_0),$$

so that $\Delta = g(m_0) - g(m)$:

$$\Delta' = g(m_0) - g(m'),$$

and the mean depression is $\frac{1}{2}(\Delta + \Delta') = \frac{1}{2}[2g(m_0) - g(m) - g(m')]$. Hence

$$\begin{aligned} \frac{R}{\Delta L} &= \frac{2[g(m') - g(m)]}{2g(m_0) - g(m) - g(m')} \\ &= \frac{2(10^{0.4\Delta m} - 1)}{(10^{0.4\Delta m_0} - 1)(10^{0.4\Delta m} + 1)}, \end{aligned} \quad (4)$$

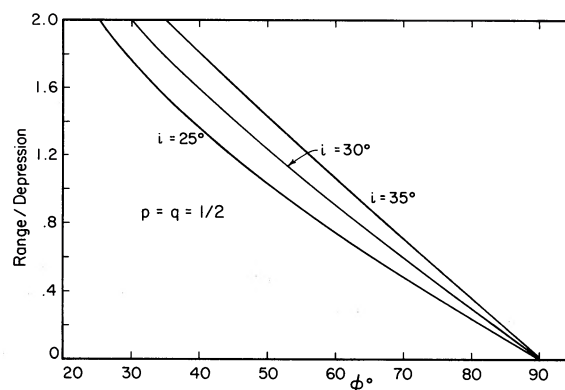


FIG. 6.—Ratio of range to depression versus latitude for spots on BY Draconis computed from eq. (3).

where Δm is the range in magnitudes and Δm_0 the mean luminosity depression expressed in magnitudes. This is equated to the expression given in equation (3). It depends only on observed quantities and does not require a knowledge of the ratio L_2/L_1 . Given the constants p and q , the latitude of the spot may be determined directly from the observations.

To find the area parameter α of the spot assumed to be on component 1, we have, if $L_2/L_1 = k$,

$$L_1 \left(1 + \frac{L_2}{L_1} \right) = g(m_0),$$

and hence

$$\alpha = [1 - g(\Delta m_0)]/F(p, q, \phi, i, k),$$

where $F(p, q, \phi, i, k) = (p \sin \phi \cos i + q/2 - q/2 \times \cos 2\phi \cos 2i)/(1 + k)(p/2 + q/3)$. Because it is small in most cases, we can describe the mean depression either in terms of mean luminosity or mean magnitude, and even in the most extreme case of line 3 in Table 4 the resulting changes are at most unity in the least significant figure.

IV. INTERPRETATION

In interpreting the observations in terms of this model, one problem concerns the value of m_0 (i.e., of the immaculate star in B) to be adopted. We need to establish a level at which no variation occurred, and at first sight the earliest observations in 1954 and 1960 (Masani, Broglia, and Pestarino 1955; Chugainov 1961), where the variation in B is stated to be less than 0.03 magnitudes, would seem to provide this. This would make m_0 near 9.38 and would imply that in all cases where the star was brighter than this and showed variations, α would be negative and the spot would be bright. In view of the phraseology describing only an upper limit to the range in B for the early observations, and considering the ranges found in later photometry, it is doubtful whether this choice is correct, but it is interesting that values of $B - V$ for levels above this choice are mostly relatively small, which would be consistent with a brighter, hotter spot. The lesson is,

TABLE 4
SPOT PARAMETERS FOR VARIOUS ASSUMED VALUES OF m_0

YEAR/DATE	$\bar{B}$	Δm	$m_0 = 9.25$				$m_0 = 9.30$				$m_0 = 9.35$				REMARKS
			Δm_0	$R/\Delta L$	ϕ (deg)	α (%)	Δm_0	$R/\Delta L$	ϕ (deg)	α (%)	Δm_0	$R/\Delta L$	ϕ (deg)	α (%)	
1954.....	9.38	< 0.03	0.13	< 0.22	> 83	< 15	0.08	< +0.36	> 78	< 9	+0.03	< +0.99	> 57	< +4	Masani <i>et al.</i> 1955
1960.....	9.39	< 0.03	0.14	< 0.20	> 83	< 16	0.09	< +0.32	> 80	< 10	+0.04	< +0.74	> 65	< +5	Chugainov 1961
1965.....	9.60	0.23	0.35	0.56	71	38	0.30	+0.66	68	34	+0.25	0.82	63	+30	Chugainov 1966
1966.....	9.68	0.08	0.43	0.15	85	43	0.38	+0.18	84	38	+0.33	0.21	83	+34	Krzeminski 1969
1967.5.....	9.58	0.06	0.33	0.16	85	34	0.28	+0.19	84	30	+0.23	0.23	83	+25	Krzeminski 1969
1967.7.....	9.55	0.04	0.30	0.12	86	31	0.25	+0.14	85	27	+0.20	0.18	84	+22	
1970.....	9.27	0.06	0.02	2.97	...	...	-0.03	-2.03	...	...	-0.08	-0.78	64	-11	Chugainov 1971
1971.8.....	9.30	0.06	0.05	1.17	52	8	0.00	...	...	...	-0.05	-1.23	50	-8	Chugainov 1973
1973-1974...	9.28	0.048	0.03	1.58	40	6	-0.02	-2.42	...	...	-0.07	-0.71	66	-10	Vogt 1975
2181-2218...	9.305	0.042	0.055	0.74	65	7	0.055	+8.38	...	...	-0.045	-0.95	59	-7	
2237-2281...	9.293	0.052	0.043	1.19	45	7	-0.007	-7.45	...	...	-0.057	-0.94	59	-8	
2299-2373...	9.305	0.074	0.055	1.31	48	9	0.005	+14.8	...	...	-0.045	-1.68	38	-9	This study
2599-2609...	9.324	0.038	0.074	0.50	73	9	0.024	+1.57	40	4	-0.026	-1.48	43	-5	
2623-2639...	9.299	0.038	0.049	0.76	64	6	-0.001	-38.0	...	...	-0.051	-0.76	64	-7	
2640-2657...	9.296	0.056	0.046	1.19	45	8	-0.004	-14.0	...	...	-0.054	-1.06	57	-8	

of course, that to exploit these arguments we need very precise photometry. We resort to the customary device when faced with such a dilemma and see what happens when we choose a range of values of m_0 , say $m_0 = 9.35, 9.30, 9.25$. We can get a reasonable feel for the numbers by considering the case $p = \frac{1}{2}, q = \frac{1}{2}$. The results for B photometry are tabulated in Table 4. The results are rather surprising and include the following:

1. Values of m_0 near 9.30 are excluded because they result in values of $R/\Delta L > 2$ for almost all observations after 1970.

2. Values of m_0 near 9.25 result in only dark spots, while values of m_0 near 9.35 result in dark spots before 1970 and bright spots after this date. Either of these values of m_0 is nearly equally acceptable on the basis of the B magnitude alone, but the fact that the $B - V$ color became bluer at just the time when the $m_0 = 9.35$ model indicates that bright spots appeared strongly suggests that this value of m_0 should be adopted. This idea is in accordance with Vogt's (1975) conclusion that his data could not be explained on the basis of a thermal dark spot model.

3. Spots occur in much higher latitudes than on the Sun, and there is no well-marked correlation of rotation period with latitude. Lest it be thought that the Sun ought to be a model for the behavior of this kind of star, we may remind ourselves that the astronomical object with the most permanent spot known does not have a rotation scheme identical with that of the Sun and that its circumpolar areas exhibit solid-body rotation.

4. The spots migrate both in latitude and longitude and exhibit a continuity of behavior lasting from some tens of days up to several months. Quite rapid changes in photometric behavior can occur (we have already remarked the abrupt change at JD 2,442,640) which may possibly be best explained by the disappearance of one spot and the appearance of another in the same active area. The longitude extent of such an active area is indicated by the figures in the last column of Table 3 and are consistent with prevalent ideas concerning the size of active areas on spotted flare stars.

5. It will be seen from Table 4 that the spot area parameter α for the observations of 1965 through 1967 are large, in fact so large that for 1966 with $m_0 = 9.35$ most of the polar area must be a single dark spot, and our simplified analysis must probably become inadequate.

However, it seems clear that the 1965, 1966 phenomena refer to the same active area, with the range in the second case being much less than the first. We are also encouraged in our choice of $m_0 = 9.35$ rather than 9.25. This follows since, if we are to achieve the observed depression to a mean B of 9.60 or 9.68 and all this is on the brightest component star with even approximately the light ratio assumed for the components of the binary, we would have for $m_0 = 9.25$ to black out the whole star rather than merely the major part of the polar area. We could obviously, to account for Krzeminski's 1966 and the 1975.5 observations, compute in detail the effect of a large spot, necessarily near the pole because of the small modulation range coupled with a large depression and a sinusoidal light curve. However, the results would depend critically on the shape adopted for the spot; e.g., perfect symmetry produces no modulation whatever. This remark enables us to understand the phase shift of 2^d01 found by Krzeminski between two of his series of observations.

We have a plausible scenario in which a large dark spot at intermediate latitude appeared (Chugainov 1966) and then spread poleward until it occupied most of the polar area, the modulation being produced by its asymmetries. A change in shape, conceivably a bulge at one longitude being replaced by an almost opposite bulge (note the rough coincidence of 2^d01 with $P/2$) produced the phase jump.

Between 1967.7 and 1970 the polar dark spot disappeared, the total luminosity of the star increased, and the $B - V$ decreased, and since then a number of relatively small bright areas have appeared in one or more active areas at relatively low latitudes.

It may be thought that this scenario presses the observations too far, and perhaps this charge can be sustained. What should, however, be clear—and this is the intended message of this paper—is that at least in certain circumstances there is hope that long and careful series of photometric observations of spotted flare stars could provide a sound basis for the production of a scenario of spot development.

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