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THE MAGNETIC FIELD AND LIGHT VARIATIONS OF HD 32633*

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ABSTRACT

Concurrent *UBV* photometric and Zeeman spectroscopic observations of HD 32633 are used to show that the period and the ranges of the light and magnetic variations have remained approximately constant over an interval of 8 years The coincidence of magnetic minimum and light maximum reported by Rakos is confirmed, and the possibility of a short-period variation in the radial velocity is noted.

I. INTRODUCTION AND OBSERVATIONS

Babcock (1958*a*, *b*) called attention to the strong reversing magnetic field of HD 32633 and suggested a provisional magnetic period of $4^{\mathrm{d}}.0$. Rakos (1962) found that a period of $6^{\mathrm{d}}.4351$ satisfactorily represented his photoelectric observations of 1960–1961, those of Jarzebowski (1960) made in 1959, and Babcock's seven published observations of the magnetic field made in 1956 and 1957.

Eighteen Zeeman spectrograms (dispersion 8.2 Å/mm) of HD 32633 were obtained with the coudé spectrograph of the 120-inch telescope from October, 1964, to January, 1967, in order to verify the magnetic periodicity and to define the magnetic variation more accurately. The first seven spectrograms, obtained with the 0.9-mm analyzer (for details see Preston and Pyper 1965) from October, 1964, to March, 1965, were rather narrow. They were followed by eleven spectrograms obtained with a 2.0-mm analyzer that produces Zeeman spectrograms with a total widening of 0.67 mm at the focus of the 40-inch camera employed in this study. Effective magnetic fields, as defined by Babcock, were derived from measures of thirty to forty lines of Ti II, Cr II, and Fe II made with a Grant spectrocomparator. The results are given in Table 1 together with the Julian dates and phases derived from the ephemeris given below. The average probable errors for spectrograms obtained with the 0.9- and 2.0-mm analyzers are ±340 and ±190 gauss, respectively.

Photoelectric observations of HD 32633 were obtained on seventeen nights between December 26, 1966, and March 8, 1967, with the 24-inch reflector of the Lick Observatory. On most of the nights a 1P21 photomultiplier was used with a set of standard *UBV* filters, but on a few nights an experimental photomultiplier with an S20 photocathode was used with the following filters: for the ultraviolet 3 mm of Corning 9863 plus a liquid chamber filled with a $CuSO_4$ solution; for the blue 2 mm of BG12 plus 2 mm of GG13 plus 2 mm of BG18; for the visual 2 mm of GG14 plus 2 mm of BG18. No appreciable differences between results obtained from these two filter-cell combinations was found.

The star BD+38°942 was used as a primary comparison star. Beginning February 6, 1967, BD+34°948 was used as a secondary comparison. Values of V, $B - V$, and $U - B$ for these stars derived from observations of *UBV* standards on several nights are given below:

Comparison Star	V	$B-V$	$U-B$
BD+34°942	8 427±0 002	+0 323±0 003	+0 081±0 005
BD+34°948	7 702±0 002	+0 413±0 002	−0 031±0 006

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Instrumental magnitude differences, variable *minus* comparison, were converted to the UBV system by use of monthly mean transformation coefficients. Final magnitudes and colors were obtained by adding differences to the appropriate values for the comparison star and forming averages when two comparison stars were observed. The results are given in Table 2. The internal accuracy of the observations can be estimated from the average differences between the two comparison stars when both were observed, namely, ± 0.003 in V and ± 0.004 in $B - V$ and $U - B$.

TABLE 1

EFFECTIVE MAGNETIC FIELDS AND RADIAL VELOCITIES OF HD 32633

Plate ECZ	Analyzer (mm)	J D ⊙ 2430000+	Phase ($P=6^{d}431$)	H_e (gauss)	V_{rad} (km/sec)	Phase ($P=0^{d}073502$)
3718 .	0 9	8691 080	0 23	+3500	−18 2	0 15
3759.	0 9	8694 906	83	−3100	17 2	.21
3869.	0 9	8723 856	33	+3000	16 0	07
3923. .	0 9	8773 694	08	−4200	16 0	.12
3971 .	0 9	8778 711	.86	−3800	18 4	38
4100..	0 9	8835 637	71	−1300	15.8	86
4153 ..	0 9	8841 628	64	0	18 7	37
4660 .	2 0	9047 888	71	−1700	16 8	56
4661 ...	2 0	9047.946	72	−2300	17 8	35
5376..	2 0	9453 876	84	−4600	17 7	07
5391 ..	2 0	9454 898	00	−5700	14 7	97
5400 .	2 0	9455 842	15	+ 400	17 9	.82
5403 .	2 0	9456 031	18	+1600	17 9	.39
5408 .	2 0	9456 719	29	+2600	17 3	75
5418...	2 0	9459 786	.76	−2800	18 2	.47
5431.	2 0	9480 844	04	−4800	14 7	.97
5465..	2 0	9491 763	73	−2500	20 2	52
5475 .	2 0	9492 799	0 90	−4600	−18 4	0 62

TABLE 2

PHOTOMETRIC DATA FOR HD 32633

J D ⊙ 2439000+	Phase ($P=6^{d}431$)	n*	U	$U-B$	$B-V$
486 878 .	0 975	4	6 564	−0 421	−0 044
487 793	117	5	6 573	436	044
488 702	259	1	6 598	.415	.044
490 858	.594	2	6.604	428	047
491 636	715	2	6.613	411	041
492 867	906	1	6 565	436	048
496 824	522	4	6 619	412	042
497 719	661	1	6 602	425	053
498 721	817	4	6 597	418	.057
499 719	972	3	6 570	.432	048
527 785	336	2	6 605	410	052
531 738	951	2	6 562	434	058
535 654	560	1	6 613	405	052
536 741	729	2	6 603	414	.055
542 698	655	1	6 612	419	037
543 656	804	1	6 582	430	044
558 758	0 152	2	6 576	−0 425	−0 054

* n = number of sets of observations, variable star and comparison star

II. DISCUSSION

The present photometry yields a time of maximum light at J.D. 2439499.9. If this time is combined with times of maximum derived by Rakos (1962) from his own observations and those of Jarzebowski (1960), there result the periods given in the last column of Table 3. The present Zeeman observations also yield a time of positive magnetic crossover at J.D. 2439455.8. If this time is combined with a time of positive crossover in 1956 estimated from Babcock's (1958*a*) data, a period of $6\overset{d}{.}4305$ is obtained. On the basis of these results we adopt a period of $6\overset{d}{.}431$ and the ephemeris

$$\text{J.D.}_{\odot} \text{ (light max., magnetic min.)} = 2439499.9 + 6.431E \,. \qquad (1)$$

From the residuals given in the last column of Table 3 it is clear that a more accurate period cannot be derived from the data because the uncertainties in the individual times of maxima ($\pm 0\overset{P}{.}05$) are all of the same order of size as the largest residuals.

The photometric and magnetic-field data in Tables 1 and 2, phased together by means of equation (1), are shown in Figure 1. Filled circles represent Lick data. The small symbols denote observations which deserve lower weight because they were made with

TABLE 3

TIMES OF MAXIMA, PERIODS, AND RESIDUALS FOR HD 32633

Observations by	Max Light at J D ⊙ 2430000+	Period (Days)	O−C (Eq [1]) Days	Phase
Jarzebowski in 1959	6573 6	6 4314	−0 20	−0 03
Jarzebowski in 1960	6959 9	6 4304	+0 24	+0 04
Rakos in 1960–1961	7307 2	6 4302	+0 27	+0 04
This study in 1966–1967	9499 9	. .	0 00	0 00

the 0.9-mm analyzer (see discussion above). Open circles denote Babcock's observations of 1956 and 1957. Curves drawn through the data points are all freehand smoothed representations. A number of comments follow from inspection of Figure 1. First, the U, $U - B$, and $B - V$ (not shown) observations indicate that the U, B, and V variations are all in phase and that the light amplitude decreases with increasing wavelength. Second, there is little indication of the pronounced asymmetry in the light variation reported by Rakos. Thus, a secular variation in the form of the light-curve is possible, and it is also possible that an associated change in the magnetic curve might account for the deviations of Babcock's magnetic fields from the 1964–1967 mean magnetic curve. In this regard it should be mentioned that a possible scale factor between the Babcock and Lick fields has been reported earlier (Preston and Pyper 1965) and that differences in derived magnetic fields of 20–30 per cent can result from the choice of lines used to measure the Zeeman effect. The disentanglement of all these possibilities is beyond the scope of this study. Third, the asymmetry in the magnetic-field variation reported by Rakos appears to be due partly to the use of an incorrect period for the variation and partly to the small number of observations available to him. Unfortunately, because of the gap in our magnetic data between phases 0.35 and 0.65 we similarly cannot distinguish between possibilities such as those indicated by the dashed curves in Figure 1, but an asymmetry as pronounced as that shown by Rakos seems unlikely. Fourth, the time overlap in the present series of photometric and Zeeman observations assures us that the coincidence of magnetic minimum and light maximum is real. Thus HD 32633 definitely

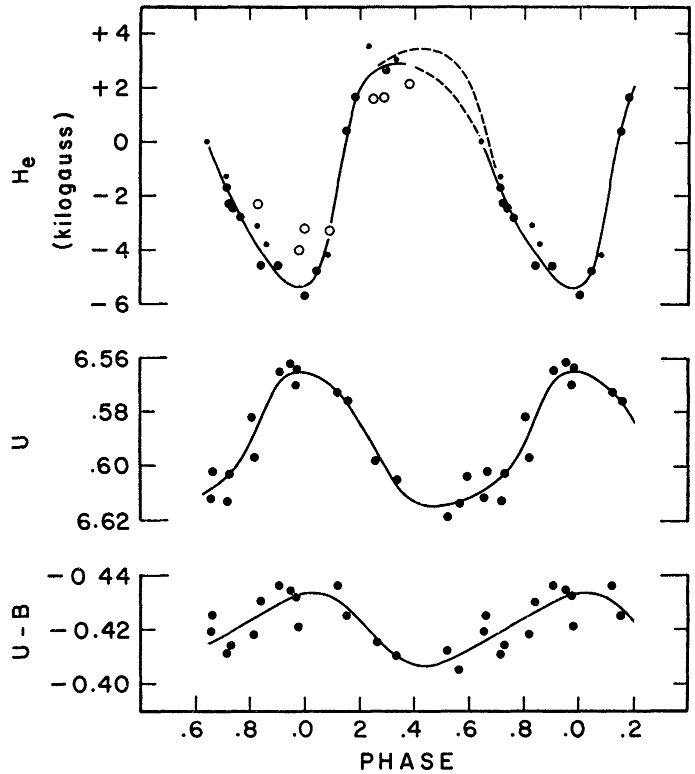

FIG. 1.—The magnetic field, U, and $U - B$ variations of HD 32633. Filled circles denote Lick Observatory data obtained in 1966–1967. Small and large symbols for the magnetic-field data denote observations made with 0.9- and 2.0-mm analyzers, respectively, as described in the text. The open circles denote observation made by Babcock in 1956–1967. The dashed sections of the mean magnetic curve indicate the uncertainty in the shape of the curve due to lack of observations. Note the coincidence of magnetic minimum and light maximum.

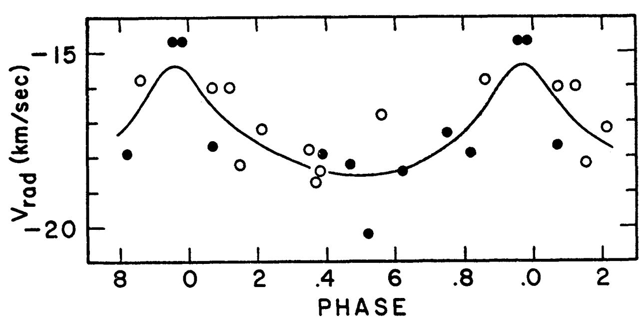

FIG. 2.—A possible short-period velocity-variation of HD 32633. Phases were calculated from equation (2) in the text. Open and filled circles denote observations made in 1964–1965 and 1966–1967, respectively.

belongs to the set of periodic magnetic variables that possess this curious property (see reports by Gollnow 1965 and Jarzebowski 1965).

Finally, Rakos (1963) has reported that HD 32633 possesses a rapid light variation with a period of 1^h46^m ($= 0\overset{d}{.}07361$). The radial velocities given in Table 1 also show some evidence of a small velocity variation in this period. Comparison of the 1964–1965 and 1966–1967 observations suggest a slightly shorter period $0\overset{d}{.}073502$. Phases computed from the ephemeris

$$\text{J.D.}_\odot\ (\text{velocity maximum}) = 2439454.900 + 0\overset{d}{.}073502 \cdot n \qquad (2)$$

are given in the last column of Table 1. The resulting mean velocity variation, shown in Figure 2, has a range of only 3 km/sec. Confirmation of this result by means of a series of observations distributed over one or more cycles would be desirable.

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