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INTERMEDIATE BAND LIGHT CURVES FOR FIVE SOUTHERN HD STARS

Introduction:

In the course of obtaining intermediate band photoelectric light curves for 16 southern Wolf-Rayet stars during a run in Feb/March 1975, seven of the 26 comparison stars used were found to be low amplitude variable stars. A search of the literature at the end of 1975 revealed that only one of these seven stars was previously known to be variable (HD 93206=Var.No.6797 in Carina). Two of the seven stars have been discussed elsewhere (HD 58360 = ηCMa: Moffat, 1977; HD 114911 = ηMus: Moffat and Seggewiss, 1977). This communication presents the photometric results for the remaining five stars (listed in Table 1) along with their respective comparison stars. These comparison stars are of constant magnitude within the attained observational accuracy, as verified by intercomparison of magnitudes obtained during the same nights.

The Observations

Measurements were obtained, normally one per night, over an interval of 37 days. A diaphragm of diameter 18" was normally used in the one channel dry-ice cooled photometer attached to the 61 cm Bochum telescope located on La Silla, Chile. The filters used are listed in Table 2: they were chosen to isolate certain features (emission line or continuum) in the spectra of Wolf-Rayet stars. Integration times ranged from 30 to 60 sec per filter depending on the magnitude. The air mass was always <1.5 but normally $\lesssim 1.2$ for all observations. The internal r.m.s. deviation of one observation was normally $\pm 0^{m}.003$ increasing to $\pm 0^{m}.006$

for the fainter stars. The r.m.s. scatter after systematic correction for the light curve was usually $\pm 0^m.007$ for one data point, which comprises the difference in magnitude or colour between 2 stars. This value increased to $\pm 0^m.015$ for the faintest magnitudes. UBV photometry (one observation for each star) obtained with the same telescope is also listed in Table 1. These data are subject to variability but still give a good indication and check on the spectral type. A journal of magnitudes (in F3 or F4) is given in Table 3 for 4 of the 5 variable stars; data for HD 96829 are excluded from the Table because no period was found for this low amplitude variable. Using all the magnitude information in turn, periods were searched for the remaining 4 periodic variables using the method of Lafler and Kinman (1965). The light curves resulting from the most likely periods so obtained are plotted for these 4 stars along with HD 96829 in Figs. 1-5. In Table 4 is presented a résumé of some parameters for each of the 5 variable stars.

Brief Description of Individual Stars

(1) HD 86441

This star was always measured with a near, faint, visual companion in a diaphragm of diameter 28". Being 5 magnitudes fainter than HD 86441, the companion is not likely to be responsible for the magnitude variation. The best period is P = 5.73 days; the light curve with period 2P also shows 2 minima but has other bumps making it unnecessarily complicated. Other alias periods shorter than that corresponding to the Nyquist frequency (~ 0.5 day^{-1}) produce even less plausible looking light curves. It appears that HD 86441 is an eclipsing binary with distortion, implying that the radii of the stars may be larger than that estimated for normal dwarfs in Table 4.

(2) HD 93206

At the time of observation, the author was unaware of the eclipsing nature of this star as noted by Walker & Marino (1972) who derived a period of 6.000 ± .007 days from 51 observations spread over 10 months. The present data (34 observations spread over 37 nights) yield the best median period of 5.98 days which is so close to an integral number of days, that the light curve

is rather ill determined. However, since colour variations appear to be negligible we can combine the previous V data with the present F3 data. On this basis we were able to sketch in the light curve with some confidence in Fig.2. All data together yield an improved period of 5.986 ± .001 days. The only other possible period, 6.011 days, although compatible with the previous observations, appears to be inferior for the present observations.

(3) HD 96829

Only a slow variation of $\Delta m \sim 0^{m}.02$ over 36 days has been observed for this star with no indication of a period.

(4) HD 115599

Any other periods besides 0.6755 days (e.g. its aliases) produce more complex, implausible light curves. With amplitude increasing from $0^{m}.07$ in the red (F3) to $0^{m}.14$ in the blue (F1), this star appears to be a pulsating variable, probably of the short period Cepheid type or, if population II, of the RR Lyrae type.

(5) HD 152235

Both this star and its comparison star HD 152003 are likely members of the O type cluster in Scorpius NGC 6231 or of its surrounding association Sco OB1. Neither of them is mentioned in the work on spectroscopic orbits of luminous stars in NGC 6231 by Hill et al. (1974). The best period given here ($2^{d}.63$) is only marginally better than the period 6.20 or 6.85 days which also yield simple, single-minimum light curves. It is also not possible to exclude periods of double these lengths, having 2 minima per cycle. The period $2^{d}.63$ is close to the critical period for contact (cf. Table 4), assuming both stars to be moderate supergiants. The relatively large residual scatter in the light curve may be a consequence of this.

Final Remarks

From the 36 originally chosen comparison stars, all the 7 variable stars detected have small amplitudes - less than $\sim 0^{m}.1$, which is small enough to have escaped previous discovery by photographic techniques. This high yield of variables in interesting in itself since the 26 stars were chosen without bias. Four

of the seven variables appear to show low-inclination eclipses (or ellipsoidal variations) in the light curves. Since most binaries will have inclined orbital planes which are non conducive to yielding eclipses, this lends support to the commonly accepted hypothesis that a large fraction of all stars are binaries.

Acknowledgements

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Table 1: Stars observed

HD		Sp.(HD)	V	B-V	U-B	Sp.(UBV)
86441**	variable	B9	7.49	-0.02	-0.55	B4(V),B8(Ib)
86199	comparison	B9	6.76	-0.14	-0.48	B6(V)
93206	variable	B0 Ib:*	6.32	0.14	-0.83	0B
93222	comparison	07*	8.10	0.05	-0,90	0B
96829	variable	B3III*	7.32	0.24	-0.66	B1(III)
96970	comparison	A0	8.20	0.19	0.18	A
115599	variable	A2	9.00	0.21	-0.18	B7 (V)
115496	comparison	G5	8.61	0.66	0.15	G
152235	variable	B0.5 Ia*	6.34	0.54	-0.48	0B
152003	comparison	B0 I*	7.05	0.39	-0.63	0B

*Sp from LSS catalogue (Stephenson and Sanduleak, 1971).

**observed with a near faint companion star (V=12.55,B-V=0.46, U-B=0.33).

Table 2: Filters

Designation	<λ>	Half-width	mean terr. extinction coeff.
F1	3635 Å	70 Å	0.485 mag/air mass
F2	4680	130	0.183
F3	5170	190	0.139
F4	5640	110	0.115

Table 3: Magnitudes [m(var) - m(comp)] and times of four variable stars

(1) HD 86441		(2) HD 93206		(3) HD 115599		(4) HD 152235	
J.D.	m(F4)	J.D.	m(F3)	J.D.	m(F3)	J.D.	m(F3)
-2 442 400		-2 442 400		-2 442 400		-2 442 400	
47.6906	0.737	47.8087	-1.817	48.7842	0.305	48.8680	-0.617
48.6072	0.755	48.6955	-1.616	49.8589	0.263	52.8451	-0.647
49.6708	0.753	49.7560	-1.821	53.8254	0.259	53.8662	-0.637
51.6420	0.839	51.7198	-1.668	54.8536	0.332	54.8805	-0.637
52.6807	0.782	52.7250	-1.834	55.8355	0.260	55.8845	-0.667
53.6559	0.749	53.7069	-1.820	56.8256	0.326	56.8855	-0.623
54.6859	0.776	54.7713	-1.605	57.8514	0.274	57.8796	-0.684
55.7063	0.751	55.7755	-1.838	58.8324	0.335	58.8592	-0.710
57.7380	0.837	56.7589	-1.848	59.8556	0.289	59.8819	-0.656
58.7275	0.735	57.7805	-1.657	60.8345	0.346	60.8872	-0.637
59.7537	0.771	58.7669	-1.826	62.8594	0.330	61.8852	-0.642
60.7244	0.773	59.7931	-1.811	63.7785	0.318	62.8909	-0.674
61.7166	0.767	60.7655	-1.621	66.8004	0.284	63.8775	-0.636
62.6245	0.834	61.7327	-1.820	68.8753	0.332	64.8882	-0.637
63.5962	0.824	62.6676	-1.837	70.8584	0.300	65.8792	-0.682
64.5827	0.739	63.6442	-1.656	71.8456	0.313	66.8920	-0.645
65.5577	0.767	64.6271	-1.837	79.8127	0.321	67.8944	-0.638
66.5998	0.778	65.6346	-1.827	84.8034	0.295	68.8947	-0.667
67.7167	0.794	66.7306	-1.638			69.8758	-0.614
68.7558	0.841	67.7629	-1.837			70.8993	-0.664
69.7490	0.781	68.7984	-1.851			71.8840	-0.658
70.6335	0.741	69.7645	-1.683			72.8986	-0.651
71.5521	0.776	70.7654	-1.840			73.8947	-0.642
72.6254	0.764	71.5971	-1.827			74.8965	-0.597
73.5948	0.780	72.6416	-1.613			75.8927	-0.577
74.6367	0.831	73.6116	-1.806			78.8912	-0.668
75.6747	0.777	74.6768	-1.850			83.9057	-0.647
77.5864	0.843	75.6886	-1.657				
78.6825	0.729	77.6558	-1.830				
80.7531	0.811	78.6982	-1.619				
81.6655	0.746	80.7690	-1.836				
82.6576	0.782	81.7655	-1.680				
83.6703	0.790	82.7046	-1.845				
84.6526	0.755	84.6981	-1.617				

Table 4: Parameters of the Variable Stars

HD	Periods Searched	R_1+R_2	m_1+m_2	P_{min}*	P*	J.D.-2 442 400 T_o*	Depth prim.	Depth sec.	Type
86441	$0^d.8$-25^d	$7R_\odot$	$10M_\odot$	$0^d.7$	$5^d.73\pm 0^d.04$	68.79±0.05	$0^m.10$	$0^m.05$	eclipsing
93206	1.8-15	30	60	2.4	5.98±(0.10)	72.64±0.10	0.09	0.07	eclipsing
96829	-	-	-	-	-	-	$\Delta m \simeq 0^m.02$ in 36^d ?		
115599	0.4-15	5	6	0.5	0.6755±0.0005	60.84±0.03	$0^m.07$	-	Cepheid?
152235	0.4-20	30	60	2.4	2.63±0.05	69.86±0.10	$0^m.05$	-	eclipsing?

* P_{min}= minimum period of a binary with estimated sum of radii (R_1+R_2) and masses (m_1+m_2) using Kepler's third law.

P = most likely period based on the present data

T_o= epoch of primary minimum (phase zero).

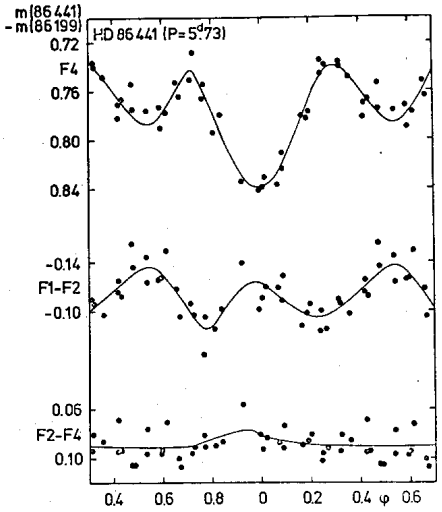

Fig. 1 Light curve of HD 86441

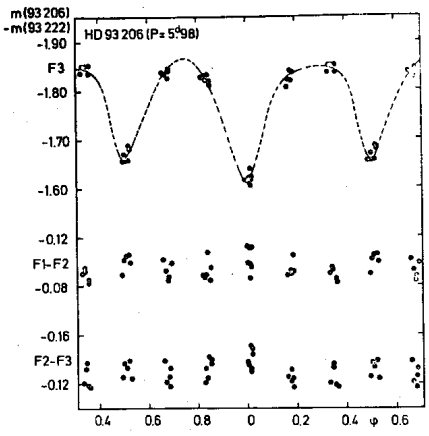

Fig. 2 Light curve of HD 93206

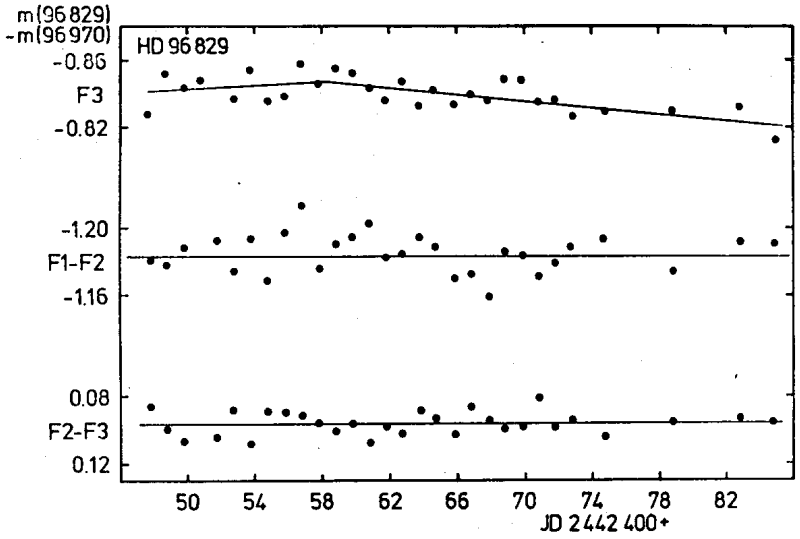

Fig. 3 Light curve of HD 96829

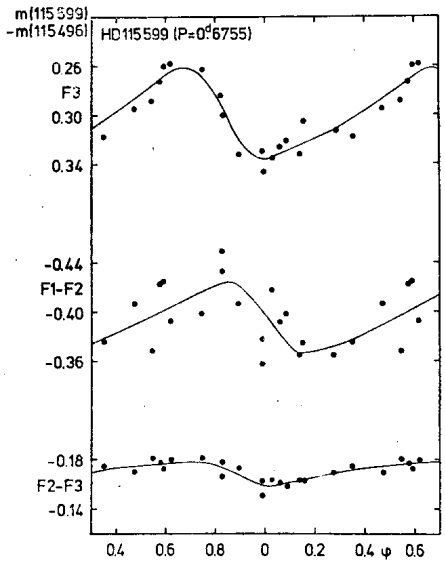

Fig. 4 Light curve of HD 115599

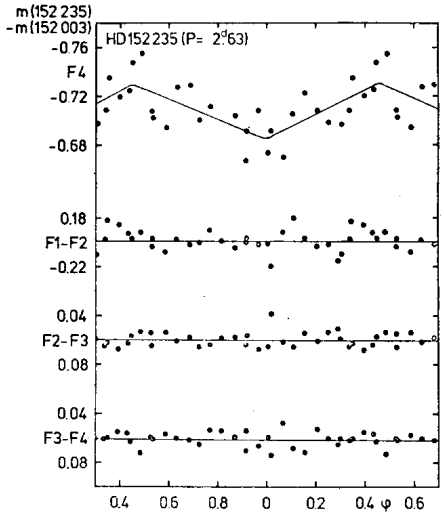

Fig. 5 Light curve of HD 152235

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