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Photometric study of HD 224085

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Summary. B and V photometry of HD 224085 obtained on 21 nights between 1979 November and 1980 February is presented. The amplitudes of light variation observed are ~ 0.15 mag in both B and V. The photometric period is found to be $P_{\text{phot}} = 6.7026 \pm 0.0034$ day. A new orbital solution obtained from the available radial velocity data shows that the orbital period is 6.724464 day. The radius of the visible primary estimated from the Barnes–Evans surface brightness relation is ~ $1.9 R_\odot$, indicating a position above the main sequence.

1 Introduction

HD 224085 (II Peg = BD + 27° 4642) is a single lined late-type spectroscopic binary with strong Ca II H and K and Hα emissions which exhibits most of the characteristics of both the dwarf BY Draconis variables and the giant RS Canum Venaticorum systems. The light variability was first noted by Eggen (1968). Chugainov (1976a) overlooked the known duplicity of the system and derived the photometric period to be 6.75 day, on the basis of light curves obtained during two observing seasons. From the flare activity and the time-scales of the change in the highly asymmetric but continuous light curves he concluded HD 224085 to be a BY Draconis variable. He attributed the photometric behaviour to the presence of starspots which rotationally modulate the observed flux. The mean spectral type K0 V (Breakiron & Upgren 1979) of the visible primary is earlier than that of any other BY Draconis variable (Bopp & Espenak 1977). Two years later Rucinski (1977) re-observed the star photometrically and found that the average light level had dropped by ~ 0.10–0.15 mag. He suggested that the photometric period is closer to the known spectroscopic period than to the value given by Chugainov (1976a). Recently Hartmann, Londono & Phillips (1979) have found that HD 224085 was essentially constant in mean light over the interval 1900–1940. Large changes both in the short-period variability and mean light level began to occur around 1945.

Interest in HD 224085 increased when Spangler, Owen & Hulse (1977) in a radio survey of close binaries discovered that it is a radio variable with the longest time-scale of variation among the known radio binaries. The observed absolute radio luminosity is comparable to that of the well known RS CVn systems such as AR Lac, SZ Psc and HR 1099 (Owen & Gibson 1978). Also X-ray emission comparable in intensity to that of the RS CVn systems UX Ari, RS CVn, AR Lac and HR 1099 has been detected from HD 224085 in the *HEAO 1* A-2 low energy X-ray sky survey (Walter *et al.* 1980). The most intriguing feature about this star is the presence of the λ6707 Å line of neutral lithium (Chugainov 1976b; Rucinski 1977) indicating a pre-main-sequence evolutionary status whereas the giant RS CVn systems are believed to be in their post-main-sequence phase (Popper & Ulrich 1977).

We started a photometric programme on late-type emission stars in order to study their photometric behaviour and chromospheric activity. In this paper we present the results of the photoelectric observations of HD 224085 in *B* and *V* made at Kavalur and an analysis of all available information, both spectroscopic and photometric.

2 Observations

During the period from 1979 November 30 to 1980 February 1, HD 224085 was observed on 21 nights through standard *B* and *V* filters with the 34-cm Cassegrain reflector. HD 223094 and HD 224895 (spectral types K2 and K0 respectively) were observed along with the variable as comparison stars. All observations were made differentially with respect to HD 223094 and transformed to the *UBV* system.

The average magnitudes and colours of the comparison stars determined by us are given in Table 1. The *V* and $B-V$ values of HD 223094 are in good agreement with those given by Nicolet (1978). The results for the variable star are summarized in Table 2. Each value is a mean of three or four independent measurements. The probable errors of the differential magnitude and colour of the variable star are ± 0.008 and ± 0.009 mag respectively. With an error of ± 0.013 mag in *V* of the comparison star, the total uncertainty of a *V* value given in Table 2 is ± 0.015 mag. Similarly the total uncertainty of a $B-V$ value given in Table 2 is ± 0.011 mag with an error of ± 0.006 mag in the $B-V$ value of the comparison star.

Table 1. Magnitudes and colours of comparison stars.

Star	V	$B-V$
HD 223094	6.957 ± 0.013	1.621 ± 0.006
HD 224895	6.844 ± 0.011	1.197 ± 0.004

Table 2. *V* and $B-V$ values of HD 224085.

JD	V	$B-V$	JD	V	$B-V$
2440000.+			2440000.+		
4208.161	7.548	1.009	4243.088	7.562	1.043
4209.154	7.571	1.005	4245.093	7.461	1.016
4228.118	7.531	1.040	4246.096	7.624	–
4229.135	7.530	1.013	4255.088	7.575	1.052
4231.120	7.427	1.025	4258.097	7.474	1.039
4235.087	7.549	1.002	4262.099	7.572	1.039
4236.101	7.573	1.027	4266.099	7.538	1.064
4237.097	7.529	1.047	4267.103	7.586	1.046
4238.103	7.476	1.021	4269.104	7.582	1.055
4240.127	7.594	1.073	4271.109	7.462	1.039
4241.106	7.566	1.038	–	–	–

3 Discussion

3.1 ORBITAL ELEMENTS

The orbital elements of HD 224085 were first determined by Sanford (1921). Halliday (1952) re-investigated the orbital parameters after adding a few more observations to those of Sanford. Radial velocity measurements of Chugainov (1977) show a systematic shift of about $0.15P$ with respect to the elements of Halliday; and this prompted us to re-examine the orbital solution. We subjected the same observations which Halliday had used to a fresh orbital solution and the results obtained are presented in Table 3. The two determinations give exactly the same γ, κ and e and ω is within the uncertainty quoted by Halliday. The two periods differ by about 0.0003 day and the accumulated effect of this could generate the $0.15p$ shift found by Chugainov. We combined the radial velocities listed by Rucinski (1977) and Chugainov with the above mentioned observations and derived the final orbital elements which are also listed in Table 3. The two determinations agree very closely. Sterne's (1941) method for orbits of small eccentricity was used for the least squares solution. Since the eccentricity and its probable error are comparable, a circular orbit was assumed following Lucy & Sweeney (1971).

3.2 PHOTOMETRIC RESULTS

The Julian days of observation given in Table 2 are converted to orbital phases using the ephemeris:

$$\text{Phase} = \text{JD}\,2443030.396 + 6^{\text{d}}.724464\text{E},$$

where the initial epoch corresponds to the conjunction with the visible primary in front. The final elements of the circular orbit were used for calculating the initial epoch. The V and $B-V$ observations are plotted in Fig. 1 against the orbital phases. We find that the light curve has changed significantly both in nature and mean brightness since the observation of Rucinski towards the end of 1976. The highly asymmetric light curve has a nearly flat minimum over more than half the orbital period. The maximum, which is more clearly defined, occurs at $\sim 0.60P$. Amplitudes of variation are about 0.15 mag in both B and V. Incidently, the light curve strongly resembles that obtained by Chugainov during the spring of 1974, (*cf.* Fig. 1 of Rucinski (1977) for the light curves in 1974 and 1976).

The available photometry of HD 224085 shows that the mean brightness has secularly decreased since Chugainov obtained the first light curve. Because of the asymmetry exhibited by the light curves we have used the definition

$$\bar{m}_{\text{V}} = \int_0^P m_{\text{V}}(\phi)\, d\phi$$

to represent the mean brightness. Values of $\bar{m}_{\text{V}}$ derived from the present and other available photoelectric photometry are given in Table 4 along with the mean Julian Day of observation. A similar trend in the mean light level seems to have occurred around 1945 (Hartmann *et al.* 1979).

The observations of Chugainov, Rucinski and the present study indicate that the light curves have better defined maxima than the minima. An unbiased estimate of ϕ_{max}, the phase corresponding to the maximum of the light curve, was obtained by fitting a general second degree equation to the light curve near the maximum. Table 4 gives the values of ϕ_{max} estimated by us and is plotted in Fig. 2 against the mean Julian Day of observation. It

Table 3. Spectroscopic orbital elements of HD 224085.

Orbital elements	Halliday (1952)	Present analysis	
		Redetermination	Final
P	6.724183 ± 0.000034 day	6.724485 ± 0.000038 day	6.724464 ± 0.000024 day
e	0.032 ± 0.026	0.032 ± 0.027	= 0.0 (assumed)
ω	$324^\circ.8 \pm 45^\circ.3$	301° ± 8°	–
κ	$37.3 \pm 1.0\,\mathrm{km\,s^{-1}}$	$37.3 \pm 1.1\,\mathrm{km\,s^{-1}}$	$37.4 \pm 1.0\,\mathrm{km\,s^{-1}}$
γ	$-18.1 \pm 0.7\,\mathrm{km\,s^{-1}}$	$-18.0 \pm 0.7\,\mathrm{km\,s^{-1}}$	$-18.3 \pm 0.7\,\mathrm{km\,s^{-1}}$
T_0	JD 2422220.3553 ± 0.0318	JD 2422219.854 ± 0.032	JD 2443032.078 ± 0.062
T	JD 2422219.6986	JD 2422218.748 ± 0.158	–
$a \sin i$	3.4484×10^6 km	3.4478×10^6 km	3.4634×10^6 km
$f(m)$	$0.0361_\odot$	$0.0361_\odot$	$0.0366_\odot$

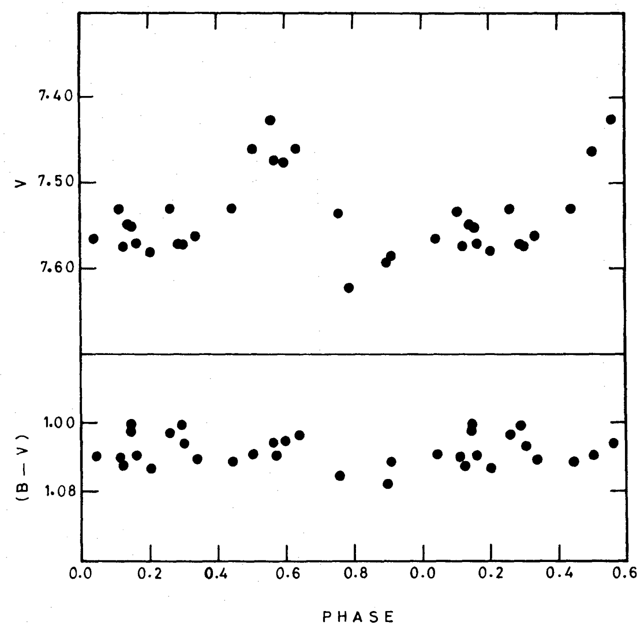

Figure 1. V and $B-V$ light curves of HD 224085.

is clear from the figure that the light curve maximum is migrating linearly towards decreasing orbital phase. A least squares fit to the times of maximum gives $P_{\mathrm{phot}} = 6.7026 \pm 0.0034$ day. This implies a rotation faster than that demanded by synchronism. It is possible that synchronism exists in the system and the migration of the light maximum is caused by the migration of the 'area of activity' on the surface of the star.

The observations listed in Table 2 span nearly 10 orbital periods. The scatter seen in Fig. 1 is slightly larger than that expected from the observational uncertainty. This may be due to the intrinsic variation in brightness associated with the redistribution of the surface brightness inhomogeneity on time-scales of the order of a couple of orbital periods. More frequent and systematic photometric observations are needed to understand the nature of the light variability of HD 224085.

3.3 RADIUS OF THE PRIMARY

The radius of HD224085 can be estimated from the Barnes–Evans relation in conjunction with the known parallax. In the region of interest (Barnes, Evans & Moffett 1978)

$$F_V = 3.841 - 0.321\,(V-R). \tag{1}$$

Further, Lacy (1977) has shown that

$$\log(R/R_\odot) = 7.4724 - 0.2\,V - 2\,F_V + \log d. \tag{2}$$

Table 4. Mean brightness and $\phi_{\max}$ of HD 224085.

JD	V (mean)	$\phi_{\max}$
2440000.+		
2060	7.362 mag	0.86 P
2307	7.325 mag	0.77 P
3082	7.476 mag	0.38 P
4240	7.536 mag	−0.41 P

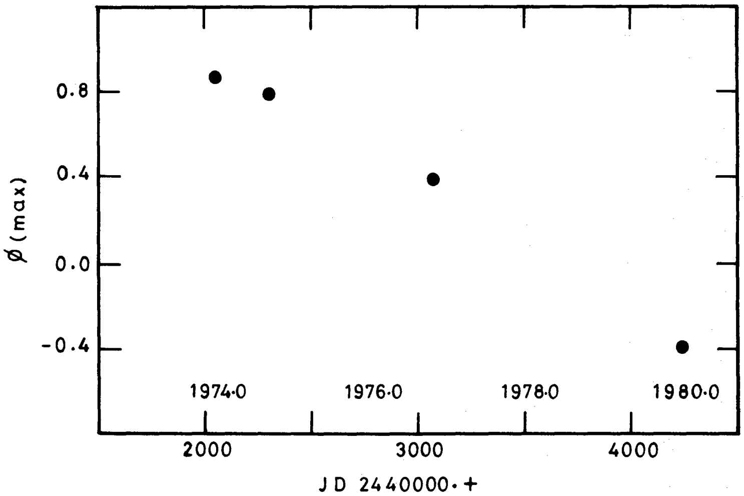

Figure 2. Phase of light maximum plotted against Julian Day of observation.

Since to our knowledge ($V-R$) colour index of HD 224085 is not available in the literature, we used the scanner observations of Taylor (1970) to estimate it. The counts given therein were integrated in the corresponding wavelength bands to get ($v-r$) index in the natural system. This in turn was tied to the Johnson system through a linear transformation by deriving similar ($v-r$) for 10 other stars. The ($V-R$) indices of these standards were taken from Johnson, MacArthur & Mitchell (1966).

With $V = 7.4$ mag, $(V-R) = 0.89$ mag, and from the Allegheny parallax (weight = 28) $\pi = 0.039$ arcsec, we arrive at a radius of the primary $R \sim 1.9 R_\odot$, indicating a position above the main sequence.

The mean ($B-V$) obtained by us and Chugainov are in good agreement whereas the mean brightnesses differ by about 0.20 mag, confirming the earlier observation of Taylor (1970) that the colour of HD 224085 does not vary with brightness. This suggests that the contribution to ($V-R$) from the invisible companion is almost negligible unless both the components have the same colour index. However, since the observed mass function $f(m) = 0.036 M_\odot$, this is unlikely. The companion is probably a low luminosity dwarf. Interstellar reddening in ($V-R$) should be negligible because of the small distance of HD 224085. Therefore, if we assume that the Barnes–Evans relation holds good in the case of HD 224085, which is apparently the case, the only source of error in the radius quoted above is the uncertainty in the parallax used.

4 Conclusions

Photometry of HD 224085 during 1979 November 30–1980 February 1 shows that the amplitudes of the light variation are ~ 0.15 mag, in both B and V. The light maximum occurs at ~ 0.60P. The asymmetric light curve indicates a highly non-uniform brightness distribution on the surface of the visible primary. The mean brightness of the system continued to decrease secularly since Chugainov obtained the first light curve in 1974. From the linear migration of the maxima of the light curves, the photometric period is derived as $P_{\text{phot}} = 6.7026 \pm 0.0034$ day. This is shorter than the binary orbital period. Fresh orbital solution obtained from the radial velocity data available in the literature shows that the period given by Halliday should be increased by ~ 0.0003 day to account for all the radial velocity observations. It is found that Barnes–Evans relation together with the published parallax leads to a radius of ~ $1.9 R_\odot$ indicating a position above the main sequence. The large lithium abundance log N(Li) = 1.5, derived by Chugainov (1976b) is close to that of a K0 V star in Pleiades (Zappala 1972). The mass loss of about $10^{-8} - 10^{-6} M_\odot \mathrm{yr}^{-1}$ quoted by Chugainov (1977) is comparable to the mass loss rate found for T Tau type stars by Kuhi (1964). HD 224085 is probably very young. More detailed photometric and high dispersion spectroscopic studies are needed to explain all the peculiarities of HD 224085 in a consistent manner.

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References

Barnes, T. G., Evans, D. S. & Moffett, T. J., 1978. *Mon. Not. R. astr. Soc.*, **183**, 285.
Bopp, B. W. & Espenak, F., 1977. *Astr. J.*, **82**, 916.
Breakiron, L. A. & Upgren, A. R., 1979. *Astrophys. J. Suppl.*, **41**, 709.
Chugainov, P. F., 1976a. *Bull. Crim. Astrophys. Obs.*, **54**, 89 (Russian).
Chugainov, P. F., 1976b. *Bull. Crim. Astrophys. Obs.*, **55**, 85 (Russian).
Chugainov, P. F., 1977. *Bull. Crim. Astrophys. Obs.*, **57**, 22 (English).
Eggen, O. J., 1968. *R. Obs. Bull. No. 137.*
Halliday, I., 1952. *J. R. astr. Soc. Can.*, **46**, 103.
Hartmann, L., Londono, C. & Phillips, M. J., 1979. *Astrophys. J.*, **229**, 183.
Johnson, H. L., MacArthur, J. W. and Mitchell, R. I., 1966. *Astrophys. J.*, **152**, 465.
Kuhi, L. V., 1964. *Astrophys. J.*, **140**, 1409.
Lacy, C. H., 1977. *Astrophys. J. Suppl.*, **34**, 479.
Lucy, L. B. & Sweeney, M. A., 1971. *Astr. J.*, **76**, 544.
Nicolet, B., 1978. *Astr. Astrophys. Suppl. Ser.*, **34**, 1.
Owen, F. N. & Gibson, D. M., 1978. *Astr. J.*, **83**, 1488.
Popper, D. M. & Ulrich, R. K., 1977. *Astrophys. J.*, **212**, L131.
Rucinski, S. M., 1977. *Publs astr. Soc. Pacif.*, **89**, 280.
Sanford, R. F., 1921. *Astrophys. J.*, **53**, 201.
Sterne, T., 1941. *Proc. natn. Acad. Sci.*, **27**, 175.
Spangler, S. R., Owen, F. N. & Hulse, R. A., 1977. *Astr. J.*, **82**, 169.
Taylor, B. J., 1970. *Astrophys. J. Suppl.*, **22**, 177.
Walter, F. M., Cash, W., Charles, P. A. & Bowyer, C. S., 1980. *Astrophys. J.*, **236**, 212.
Zappala, R. R., 1972. *Astrophys. J.*, **172**, 57.