THE LIGHT CURVE OF THE PULSATING EXTREME HELIUM STAR BD +13°3224: FURTHER EVIDENCE OF A DECLINE IN THE PERIOD DECREASE RATE

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ABSTRACT. Further optical and infrared (J-filter) observations are presented for the extreme helium star BD +13°3224. No infrared excess, which could have been attributed to a cool companion, is found. Very recent times of maximum light confirm the ephemeris cubic term already proposed. Current models for the evolution of BD +13°3224, while approximately accounting for the period decrease rate ($\dot{P}$), do not explain the decreasing $\dot{P}$ indicated by the cubic term.

1. INTRODUCTION

The hydrogen-deficient hot star BD +13°3224 (V652 Her, FB 168) was discovered to be a short-period variable by Landolt (1975), who derived a period of 0.107995 ± 0.000004 days from the observation of 10 maxima distributed over more than 200 cycles. Radial velocity measurements and spectral analyses by Hill et al. (1981) and Lynas-Gray et al. (1984), show BD +13°3224 to be a radial pulsator with mean values of $\log L/L_\odot = 3.03 \pm 0.12$, $R/R_\odot = 1.98 \pm 0.21$, $T_{eff} = 23450 \pm 1320$°K, $\log g = 3.7 \pm 0.2$, $M/M_\odot = 0.7^{+0.4}_{-0.3}$ and a hydrogen abundance (by numbers) of $n(H)/(n(H)+n(He)) \simeq 0.01$.

2. EPHEMERIS

Kilkenny & Lynas-Gray (1982, hereafter KLG1) discovered the pulsation period of BD +13°3224 to be decreasing at a rate of about 46×10^{-10} days/cycle. The $\dot{P}$ is consistent with evolution towards higher effective temperatures and smaller radii, as suggested by Schönberner's (1977) models for a post-giant helium star evolving towards a DB white dwarf. Schönberner's models are not applicable to BD +13°3224, which has non-zero hydrogen abundance, but Kilkenny

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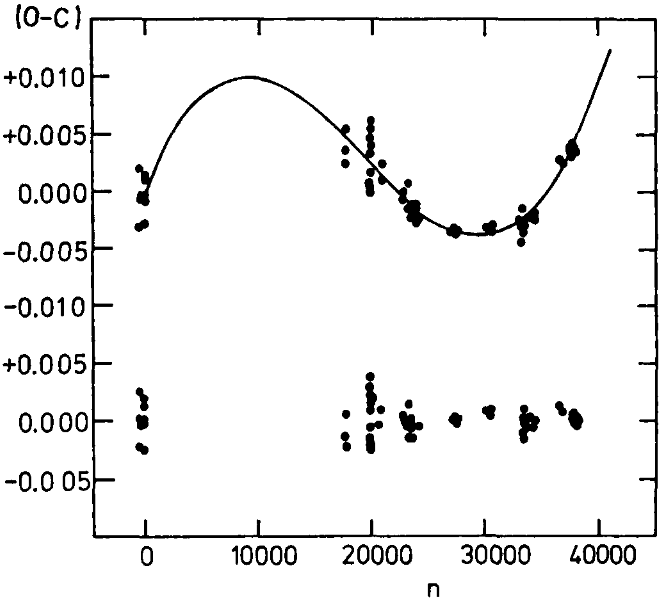

Figure 1. Observed minus calculated residuals for 62 maxima of BD +13°3224. The lower diagram is for the cubic ephemeris given in Section 2; the upper diagram is for the best-fit quadratic with the same 'n' values as the cubic. The solid line is the difference (cubic minus quadratic) between the two solutions.

(1982) discovered the R Coronae Borealis variable RY Sgr to have a $\dot{P}$ entirely consistent with Schonberner's models.

Subsequently, Kilkenny & Lynas-Gray (1984, hereafter KLG2) noted that the KLG1 ephemeris needed revision to fit observations of maxima during 1982-83. In particular, it was suggested that a quadratic ephemeris (ie. constant $\dot{P}$) was insufficient and that a cubic ($\dot{P}$ decreasing) equation was a better representation of the observations. A binary hypothesis was also proposed by KLG2. As Jeffery (1984) is able to explain the quadratic (but not the cubic) term in the KLG2 ephemeris with evolution sequences for horizontal branch stars having very low envelope hydrogen abundance (X < 0.01 by numbers), we obtained a further 18 timings of maxima of BD +13°3224 in 1984 and 1985. Using the KLG2 ephemeris to determine cycle numbers (n) for new maxima, and adopting KLG2 nomenclature where

$$T_{max} = T_o + nP_o + n^2k_1 + n^3k_2$$

we find from 62 maxima, including 10 from Landolt (1975):

T_o = 2442216.80405 ± 0.00032 day
P_o = 0.10799295 ± 0.00000014 day
k_1 = (−44.711 ± 0.095) x 10^{-10} day
k_2 = (+3.23 ± 0.16) x 10^{-15} day

The standard deviations are considerably improved over KLG2, although the ephemeris parameters are essentially unchanged. A simple quadratic fit is much less satisfactory (see Fig. 1).

It is interesting to note that if the cubic term is correct and if it is a result of evolutionary effects, then BD +13°3224 must be in a phase of very rapid evolution because the k_2 term will dominate the k_1 term in about 7 x 10^5 cycles (≃ 200 years). At this stage, the period will start increasing again, presumably as a result of the star reversing its direction of evolution. That BD +13°3224 is in a rapid phase of evolution is supported by the fact that it appears to be unique insofar as its hydrogen abundance (≃ 1%) is between the extreme and intermediate helium stars (with $n(H)/(n(H)+n(He)) < 10^{-3}$ and > 0.06 respectively).

Again, if the cubic term is the correct interpretation, the cubic and quadratic solutions, which presently differ in predicted T_{max} by less than $0^{d}.01$ (0.1 cycles) will within about 4 years differ by one complete cycle and within 12 years the difference will be about a day (≃ 10 cycles). Hence the risk of aliasing will increase rapidly with time and so it is important to monitor BD +13°3224 more frequently in future if we wish redetermine ephemeris parameters and thus provide constraints for the evolutionary models.

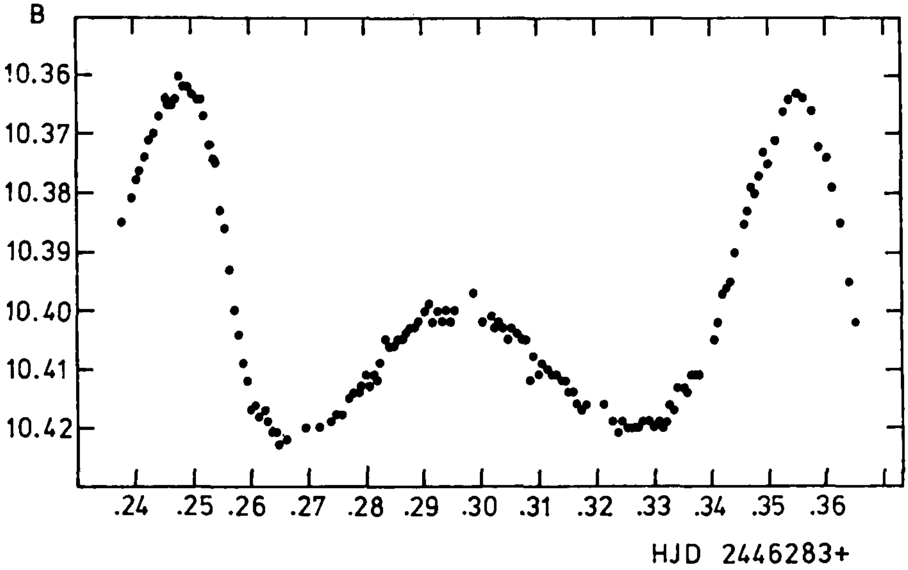

Figure 2. B-Light Curve obtained on 1985 August 5th/6th.

3. THE B-LIGHT CURVE

Previous observations (Kilkenny 1983) have suggested that small amplitude variations ($< 0\overset{m}{.}01$) might be superimposed on the mean light curve of BD +13°3224. In our latest observations (1985 August) obtained with facilities used by KLG2, we made an almost continuous series of 60-s integrations over 3 hours using a Johnson B-filter. Only occasionally was the sky or comparison star (HD 151862, HR 6246) measured. The resultant light curve, the best we have, is shown in Fig. 2 and it can be seen that there is no evidence for any superimposed fluctuations larger than about $0\overset{m}{.}002$.

4. THE J-LIGHT CURVE

Johnson J-filter photometry of BD +13°3224 was obtained in 1985 July/August using the Mk II Infrared Photometer, see Glass (1984) for a brief description, attached to the 0.75-m telescope of the South African Astronomical Observatory (SAAO). The observing procedure was similar to that adopted for optical photometry, HD 151862 being used as a comparison star. Integration times were fixed at 10-s with repeat integrations being used as necessary to reach a precision of $\Delta J \simeq \pm 0\overset{m}{.}05$ for each observation of BD +13°3224. Comparison star observations are presented in Table I, where 'N' is the number of observations in a night.

After differential correction, J-filter observations of BD +13°3224 are presented in Fig. 3. Phases are computed using the ephemeris presented in this paper. It can be seen that there is little evidence of any variation. The solid line in Fig. 3 is the result of convolving J-filter observations with a Gaussian having FWHM = 0.07 cycles, the mean time taken to obtain an observation. From 166 observations, we obtain a mean value of $J = 10.963 \pm 0.039$ (sd).

Lynas-Gray et al. (1984) adopt a static plane parallel model atmosphere having $T_{eff} = 25000$°K, $\log g = 3.5$ and $n(H)/(n(H)+n(He)) = 0.01$ as representing the atmosphere of BD +13°3224 at a reference phase of $\phi = 0.856$; the corresponding angular radius and interstellar reddening were found to be $(2.97 \pm 0.10) \times 10^{-11}$ radians and $E(B-V) = 0.07$ respectively. The predicted model atmosphere physical flux at the stellar surface is 1.682×10^{7} ergs/cm^{2}/sec/Å at 1.25μ; applying Howarth's (1983) galactic extinction law (for optical and infrared spectral regions) and Wamstecker's (1981) calibration for J-filter photometry, this leads to a prediction of $J = 10.89 \pm 0.07$ for BD +13°3224. It is therefore clear that BD +13°3224 has no infrared excess larger than $\Delta J \simeq 0\overset{m}{.}05$.

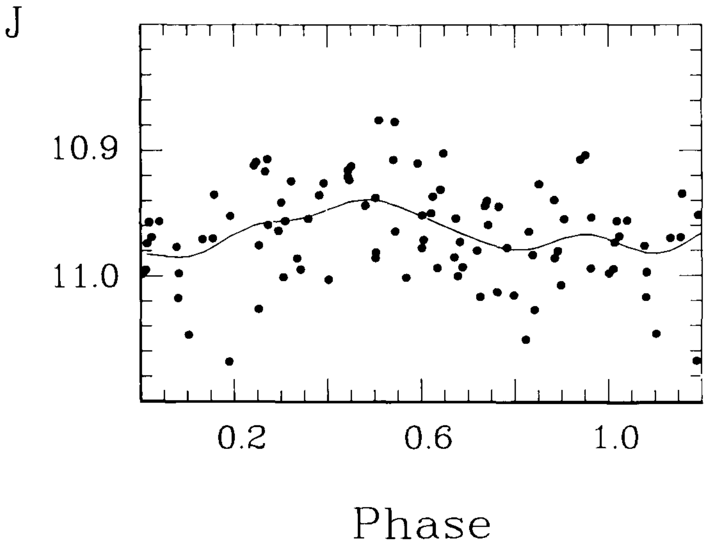

Figure 3. Phased J-Filter observations of BD +13°3224 (see text).

Table I

J-Filter Photometry of Comparison Star HD 151862

HJD	Mean J	N
2446278	5.825 ± 0.009	6
2446279	5.864 ± 0.009	5
2446281	5.863 ± 0.018	6
2446282	5.837 ± 0.006	7
2446283	5.799 ± 0.023	7
2446288	5.869 ± 0.004	7
Mean	5.853 ± 0.023	

5. CONCLUDING REMARKS

From temperature and radius curves derived by Lynas-Gray et al. (1984), and by analogy with the Johnson-V and Strömgren-u light curves given by KLG1, the J-light curve would be expected to have a more pronounced secondary maximum than the V curve. Higher precision infrared photometry is clearly needed to establish the JHKL light curves for comparison with predictions made using a series of plane-parallel static model atmospheres by Lynas-Gray et al. (1984), and as a further search for an infrared excess which might indicate the presence of a cool companion needed to explain departures from the quadratic ephemeris. Times of maximum optical light will continue to be obtained on a regular basis, with the view to continued monitoring of the evolution.

Acknowledgements

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DISCUSSION

HILL: Calculations based on black body energy distributions show that at wavelengths longer than about 10 microns the flux from BD+13°3224 will be in the Rayleigh-Jeans region and simply proportional to temperature. Magnitude changes arising from temperature and radius changes are about the same. As temperature and radius vary in antiphase these magnitude changes will tend to cancel each other out so that nowhere in the spectrum will the radius variation dominate the light curve. Towards shorter wavelengths the temperature effect gradually begins to dominate, but any infrared photomerty would need to be very precise to measure details of the light curve.

LYNAS-GRAY: Yes, at 12 microns, I think the situation is considerably improved over B.

HILL: Around J it might be fairly flat.

LYNAS-GRAY: This is right. But further and better observations are needed.