NON-RADIAL PULSATIONS IN THE EXTREME HELIUM STAR HD 160641

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ABSTRACT. Simultaneous radial velocity and photometric observations are reported for the variable extreme helium star HD 160641. Pulsation in the l = 4 mode could explain the observed variations; the corresponding Wesselink radius would be 8 ± 2 $R_\odot$. The consequent luminosity of log $(L/L_\odot)$ = 4.8 ± 0.2 would be consistent with Schönberner's evolutionary model for a 1 $M_\odot$ extreme helium star.

1. INTRODUCTION

Landolt (1975) and Walker & Kilkenny (1980) suggest a period in the range $0^d.6$ - $0^d.7$ for the extreme helium star HD 160641. HD 160641 is therefore a candidate for radial velocity monitoring to establish whether or not it pulsates. Hill et al. (1981) and Lynas-Gray et al. (1984) have determined a pulsation mass for the radially pulsating extreme helium star BD +13°3224, but it has a surface gravity (log g = 3.7 ± 0.2) and composition (n(H)/(n(He)+n(H)) = 0.01 by numbers) inconsistent with other extreme helium stars found on Schönberner's (1977) evolutionary track. Aller (1954) determined carbon and helium abundances in HD 160641 roughly consistent with those found for HD 124448 (Schönberner & Wolf 1974), BD -9°4395 (Kaufmann & Schönberner 1977), HD 168476 (Walker & Schönberner 1981) and BD +10°2179 (Heber 1983), which are found to lie on Schönberner's evolutionary track. HD 160641 might also lie on Schönberner's evolutionary track, a fine analysis has not yet proved feasible because of the difficulty in computing non-LTE model atmospheres composed primarily of helium and carbon (Husfeld et al. 1984).

This paper presents simultaneous radial velocity and photometric observations of HD 160641. A mass of 1 $M_\odot$ seems consistent with l = 4 mode pulsation and Schönberner's (1977) evolution scheme. A

K. Hunger et al. (eds.), Hydrogen Deficient Stars and Related Objects, 87–93.

more detailed account of this work will be given by Kilkenny & Lynas-Gray (1986) and Lynas-Gray et al. (1986).

2. OBSERVATIONS

Photoelectric observations were made in 1979 June and 1982 June with a "People's Photometer" attached to the Cassegrain focus of the 0.5-m telescope at the South African Astronomical Observatory (SAAO). Strömgren filters were used, the standard stars being selected from Crawford & Barnes (1970) and Grønbech et al. (1976). HD 160641 and Landolt's (1975) comparison star (BD −17°4880) were observed with six 20-s integrations (star) and one 20-s integration (sky); 10^5 counts per observation were thereby obtained, corresponding to a theoretical photometric accuracy of $0^m.003$. Figure 1 shows the photometric variation observed on a few nights in 1982; no single period is identifiable over this 9-day interval.

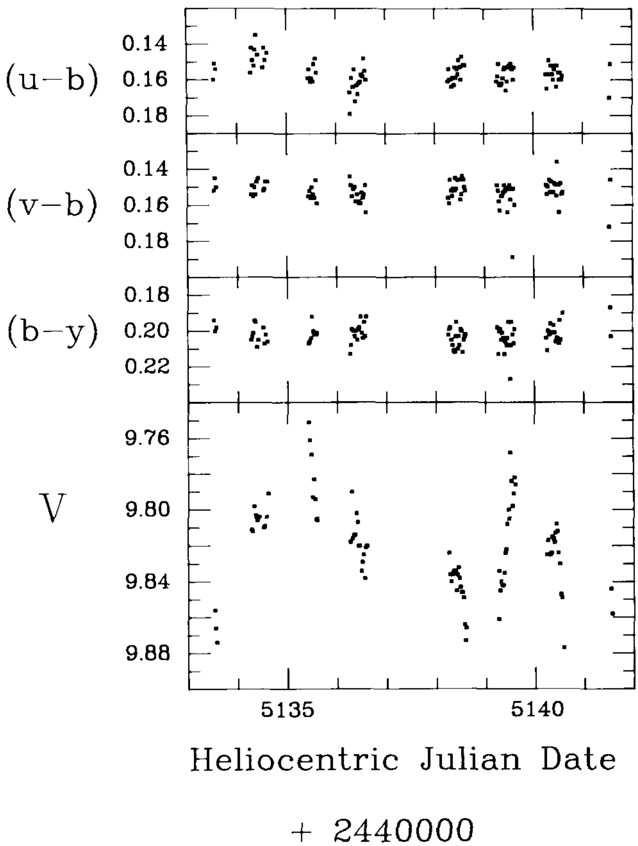

Figure 1. 1982 Strömgren four-colour photometry of HD 160641.

https://doi.org/10.1017/S0252921100090643 Published online by Cambridge University Press

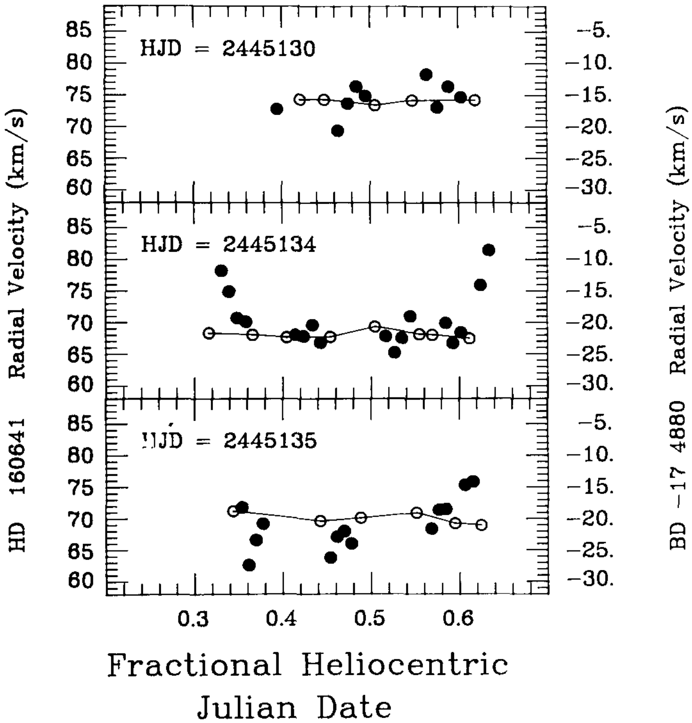

Figure 2. Radial velocities of HD 160641 (filled circles) compared with BD −17°4880 (connected open circles).

Spectra were obtained with the Image Tube Spectrograph, and Reticon Photon Counting System, attached to the Cassegrain focus of the SAAO 1.9-m telescope. A dispersion of 30Å/mm was used, with an integration time of 1000-s. Simultaneity with 0.5-m photometry was achieved on the nights of 1982 June $9^{th}/10^{th}$, $13^{th}/14^{th}$ and $14^{th}/15^{th}$. As a check on instrumental stability, BD −17°4880 was also observed at frequent intervals. Radial velocities are determined with the cross-correlation method of Tonry & Davis (1979). BD −17°4880 has a constant radial velocity (−19 ± 7 km/sec) within errors of the template velocity (Figure 2); the comparatively large standard deviation is due to the paucity of lines available for velocity measurement. HD 160641 velocity variations seen in Figure 2 are therefore considered to be real.

Low resolution ultraviolet spectra of HD 160641 were obtained with the International Ultraviolet Explorer (IUE) Satellite on 1979 July $14^{th}/15^{th}$ and 1983 May 14^{th}. All other available IUE low resolution images for HD 160641 were retrieved from the data bank. Geometric and photometric corrections are applied, as necessary, with standard procedures described by Boggess et al. (1978) and absolute fluxes

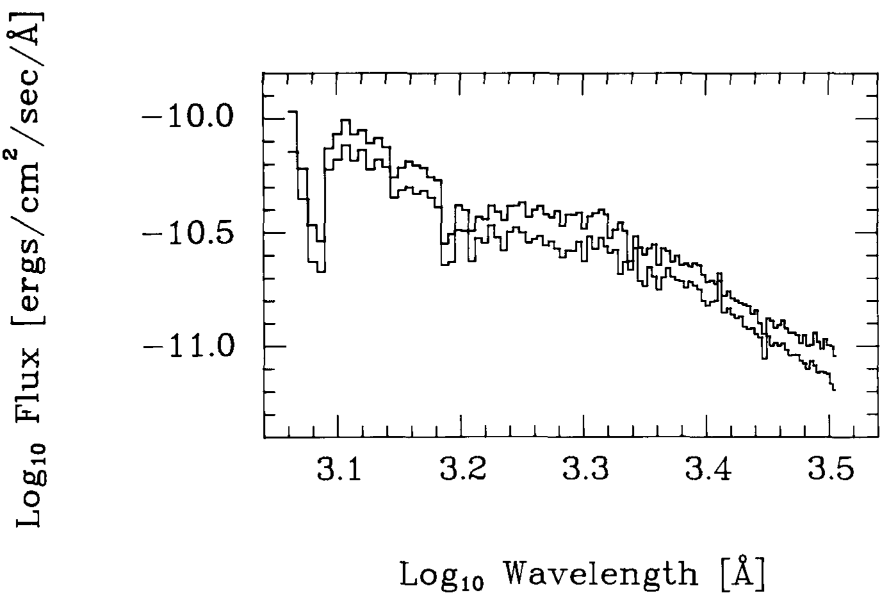

Figure 3. Maximum (SWP 5801 + LWR 5051: thick line) and minimum (SWP 19982 + LWR 15942: thin line) ultraviolet fluxes observed for HD 160641, de-reddened with E(B-V) = 0.40 and presented in 20Å bins.

extracted using IUEDR (Giddings 1983). Adopting E(B-V) = 0.40 (Drilling et al. 1984) and using Seaton's (1979) formula, all ultraviolet spectra are de-reddened and compared with each other; the maximum difference is illustrated in Figure 3.

3. FREQUENCY ANALYSIS

Photometric data from the two seasons (1979 and 1982) are interpreted using Skillen's (1985) power spectrum analysis code. The optimum set of frequencies, with corresponding amplitudes and phases, deemed to be present in the data, are listed in Table I. Figure 4 shows the comparison between observations and the fitted light curve for the 1982 season.

4. *DISCUSSION*

From optical photometry (Figure 1) and ultraviolet spectrophotometry (Figure 3) there appears to be no observable colour change associated with the magnitude variations. Jeffery et al. (1985) have found a similar phenomenon in BD -9°4395. The absence of colour variations, particularly in the ultraviolet, indicates that a constant effective temperature prevails during the pulsation; this precludes the possibility of radial pulsation being responsible for the light

https://doi.org/10.1017/S0252921100090643 Published online by Cambridge University Press

Table I

Optimum Frequencies Derived for HD 160641

Data	Frequency (cycles/day)	Amplitude (magnitudes)	Phase (cycles)
1979	0.89278	0.046	0.3595
	0.49741	0.049	0.3799
	1.41691	0.040	0.8475
	2.64278	0.018	0.4590
1982	1.41540	0.029	0.6632
	0.89446	0.021	0.3591
	0.58110	0.018	0.5849
	2.95494	0.009	0.1241

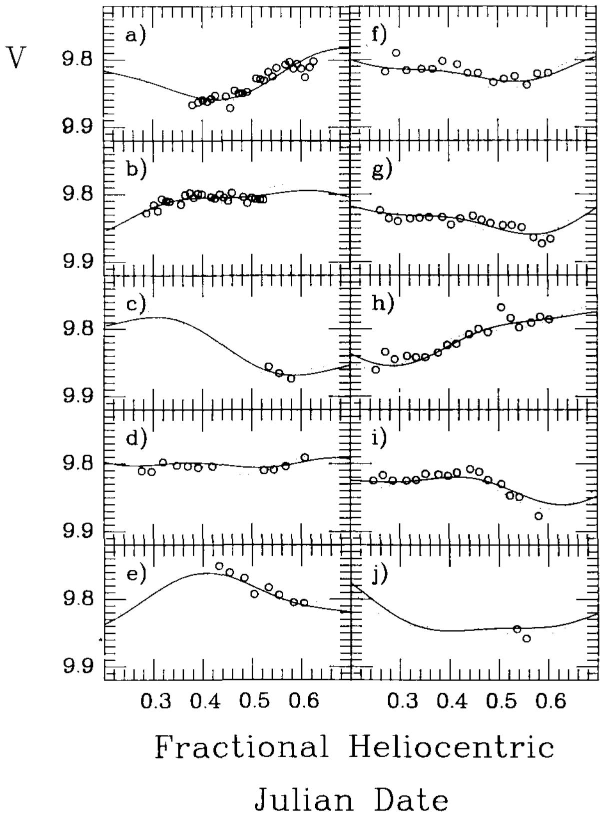

Figure 4. 1982 June Johnson V-magnitude observations (derived from Strömgren y) compared with the Fourier series representation for the following heliocentric Julian dates a) 2445129, b) 2445130, c) 2445133, d) 2445134, e) 2445135, f) 2445136, g) 2445138, h) 2445139, i) 2445140 and j) 2445141.

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variations. It also seems implausible that the irregular light curve could have originated from a binary system. Light variations in HD 160641 are considered to arise entirely from geometrical distortions of the projected stellar disk. HD 160641 would therefore seem to be a non-radial pulsator with the mode l being even and non-zero; odd values of l are precluded because they occur when the light variation is entirely due to surface brightness changes (Balona & Stobie 1979).

The Wesselink radius of HD 160641 is derived following Balona & Stobie (1979), adopting Buta & Smith's (1979) expression for the dimensionless frequency (ω_o) defined as $\omega_o^2 = \omega^2 R^3/GM$, from simultaneous photometry and radial velocities obtained on 1982 June 13th/14th. In addition to being even, l cannot be 2 since a negative radius would result. For l = 4 or 6 the respective radii are 8 ± 2 $R_\odot$ and 69 ± 14 $R_\odot$; the latter is improbable because of the implied luminosity.

HD 160641 appears, therefore, to be a non-radial pulsator oscillating with mode l = 4 and having R = 8 ± 2 $R_\odot$. With the effective temperature and angular radius obtained by Drilling et al. (1984), the corresponding luminosity and distance are log $L/L_\odot$ = 4.8 ± 0.2 and 3.3 ± 0.6 kpc. Errors larger than those quoted may be present because of the assumption of Eddington limb-darkening. Evolutionary tracks computed by Schönberner (1977) show a 1 $M_\odot$ extreme helium star to have log $L/L_\odot$ = 4.6. The luminosity derived in this paper is therefore consistent with Schönberner's model.

Assuming a mass of 1 $M_\odot$ for HD 160641, the fundamental pulsation frequency for the l = 4 mode is 0.65 cycles/day. Frequency resolutions of 0.2 cycles/day (1979) and 0.08 cycles/day (1982) are present in reported observations. Consequently, the lowest observed frequencies of 0.497 cycles/day (1979) and 0.581 cycles/day (1982) are entirely consistent with fundamental l = 4 mode pulsation. Lower frequencies could be present in the data, but remain undetected because of the limited duration of observing runs. Accordingly, it is not possible to ascertain as to whether or not the higher frequencies are overtones or the result of rotation splitting.

https://doi.org/10.1017/S0252921100090643 Published online by Cambridge University Press

Acknowledgements

We are indebted to Dr. P.W. Hill for suggesting that radial velocities be obtained simultaneously with the photometric data in 1982. Telescope time and travel grants were awarded by the United Kingdom Science and Engineering Research Council (SERC) and the South African Council for Scientific and Industrial Research. Presentation of this paper at the 87th Colloquium of the International Astronomical Union (IAU) was made possible by travel grants received from the IAU and University College London. The work was carried out during the tenure of SERC research assistantships held by two of us (IS and CSJ). AELG is supported by the SERC Collaborative Computational Project No. 7.

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