THE RADIAL VELOCITY CURVE OF V652 HER (BD+13°3224)

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ABSTRACT. New radial velocity data for the pulsating extreme helium star V652 Her (BD+13°3224) have been obtained with a time resolution of 100 s. High frequency structure in the radial velocity curve is detected, and a comparison with previous data suggests that the detailed shape of the velocity curve is variable. The data imply that the effective surface gravity must increase by a factor of 4 at minimum radius.

1. INTRODUCTION

The hot extreme helium star V652 Her (=BD+13°3224) has both higher surface gravity for its temperature and higher hydrogen abundance, n_H=10^{-2} (Hill et al. 1981; Paper I) than the true extreme helium stars. Likewise it is too hydrogen-deficient to be regarded as an intermediate helium star (Hunger 1975). The discovery of radial pulsations with a period of 0.108 day by Landolt (1975), confirmed spectroscopically in Paper I, enabled a mass of $0.7^{+0.4}_{-0.3}M_{\odot}$ to be derived (Lynas-Gray et al. 1984; Paper II). The location of V652 Her in the HR diagram and the discovery that its period is decreasing on a secular time-scale (Kilkenny & Lynas-Gray 1982, 1984) are consistent with the hypothesis that the star is contracting rapidly onto the helium main-sequence (Jeffery 1984). It is not known to be a binary, and yet appears to have lost its hydrogen-rich envelope either before or simultaneous with the ignition of core-helium burning.

The radial velocity curve of V652 Her is characterised by a slow rise to maximum radial velocity followed by a rapid transition to minimum velocity (Paper I). Previous studies have found some evidence for additional structure in the velocity curve (Paper II), but the data suffer from poor time resolution at minimum radius and from comparatively large standard errors (±5 km/s). The short period makes V652 Her an ideal target from which to obtain radial velocities with good S/N and complete phase coverage for detailed comparison with theoretical pulsation models when these become available. A fine

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analysis to determine the surface gravity and elemental abundances of V652 Her is in progress (Jeffery et al. 1986). This is essential to improve the mass determination and understand its evolutionary history and pulsational properties.

2. OBSERVATIONS

New spectroscopic data have been obtained with the RGO Cassegrain spectrograph on the Anglo-Australian Telescope (AAT) in 1982 and 1984. Full details will be published elsewhere (Jeffery & Hill 1986). Over 300 individual heliocentric radial velocities determined by the cross-correlation technique of Kilkenny et al. (1981) are shown in Figs. 1 and 2 with phases derived from the cubic ephemeris of Kilkenny & Lynas-Gray (1984). Increasingly high precision and time resolution have enabled us to examine closely the detailed behaviour of the radial velocity curve.

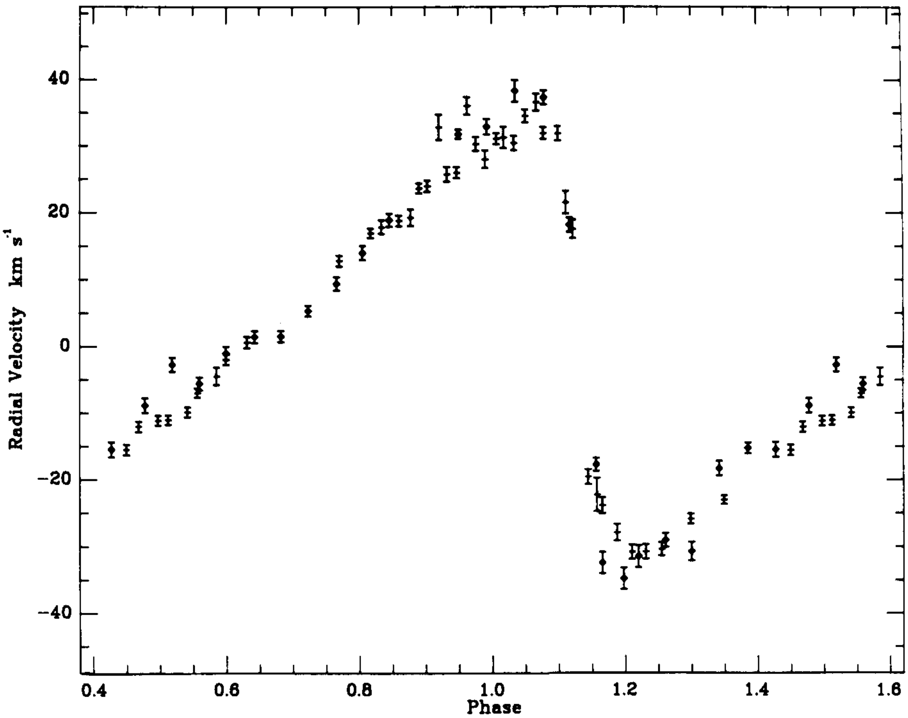

Figure 1. The radial velocity curve of V652 Her obtained with the AAT in 1982. Exposures were for 300 s at 10 Å/mm with the IPCS on July 2 (horizontal bars) and for 200 s at 26 Å/mm with a CCD on July 3 (diamonds).

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Two features of the 1982 radial velocity curves are noteworthy. In the IPCS data, the scatter of the data is greater at phase 0.95 (just before radial velocity maximum) than during the rest of the cycle. At phase 0.2 the approach to minimum velocity is much shallower in the IPCS data than in the CCD data. These data raise particular questions which we attempt to answer in the following analysis; namely: 1) Are small amplitude high frequency oscillations superimposed on the radial velocity curve, particularly around radial velocity maximum? 2) Does the shape of the radial velocity curve vary, e.g. from cycle to cycle? 3) What is the acceleration at minimum radius?

The general shape of the radial velocity curve of V652 Her comprises a rapid acceleration phase covering 0.1 cycles at minimum radius followed by a relaxation phase covering 0.8 cycles. Previous analyses suffered from a paucity of observations in the rapid acceleration phase. Moreover, exposure times were long compared to this phase of the pulsation cycle. The 1982 data go some way toward ameliorating this situation, but only with the 1984 data was continuous coverage of the radial velocity curve achieved with good time resolution.

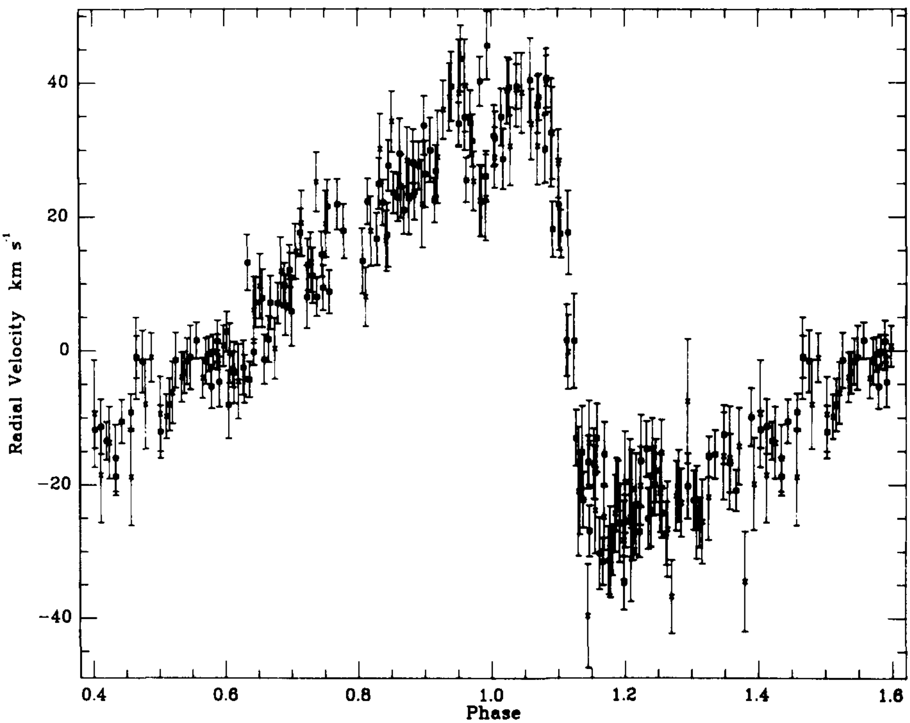

Figure 2. The radial velocity curve of V652 Her obtained with the AAT in 1984 on April 15 (solid squares) and April 17 (crosses) from 100 s exposures at 10 Å/mm using the IPCS.

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In this paper the data are represented by models defined by passing a Gaussian filter through the observed values. Although noise is reduced at the expense of time resolution, the latter can be optimised to the noise level in the data by selecting an appropriate value for the FWHM of the filter. The combined radial velocity data from both 1984 runs were used to obtain a model which satisfied a χ^2 test at the 95% confidence level. The standard deviation of the adopted Gaussian smoothing function was 0.02 cycles. All the data obtained prior to 1984 (including that from Papers I and II) were combined to produce a similar model. There is a small difference between the mean velocities of the two models, 1.3 km/s (pre-1984) and 3.5 km/s (1984), but this is within the absolute error obtained from measurements of radial velocity standards made with the same instrumental configurations. It is best removed by transforming the heliocentric velocities to the stellar rest frame (Parsons 1972). The resulting surface velocity curves (Fig. 3) will be those referred to in the rest of this paper.

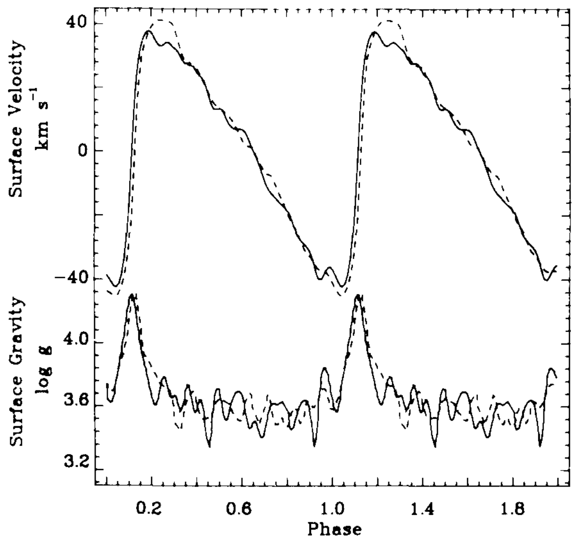

Figure 3. The transformed stellar surface velocity curves and 'effective' surface gravity derived from the two smoothed radial velocity models (1979-82: broken line, 1984: solid line).

3. DISCUSSION

The two surface velocity curves obtained in section 2 provide some useful information about the pulsation of V652 Her. The smoothed 1984 velocity curve (Fig. 3, solid line) shows a dip just 0.1 cycles before minimum velocity, with amplitude 6 km/s. The χ^2 test also implies that the small amplitude oscillations on the falling part of the velocity curve are physically significant, but these features do not seem to persist over many cycles. In the 1979-82 data (Fig. 3, broken line) these features are not so pronounced.

Minimum velocity occurs at the same phase in both models. The small displacement between the curves is accounted for by a new ephemeris (Lynas-Gray & Kilkenny 1986) including the period of these observations. The phase discrepancy at maximum velocity ($\sim$0.1 cycles) cannot be attributed to the adopted ephemeris and the amplitudes of the velocity curves differ by 9 km/s, implying that there are real long-term variations in the shape of the velocity curve.

In Paper II a mean radius, $1.98R_{\odot}$, was obtained and a mass of $0.7M_{\odot}$ derived from the best available spectroscopic value for the surface gravity, log g=3.7. The absolute radius variation around the cycle is derived from the integrated velocity curve and this mean radius, but with an amplitude of <0.1 mean stellar radii this alone has little effect on the surface gravity of the star as given by $g=GM/R^2$. However the effective gravity experienced by a particle in the stellar atmosphere also includes the acceleration due to pulsation. Differentiating the velocity curve and combining this with the small gravity changes due to radius variations yields an 'effective' surface gravity as a function of phase (Fig. 3). A startling feature of this 'effective' gravity curve is the amplitude of the peak at minimum radius which represents an increase in the surface gravity by a factor of at least 4 during a short part of each pulsation cycle.

The magnitude of the accelerative forces in V652 Her raises the question of whether a shock wave develops in the atmosphere at minimum radius. This question can be resolved by comparing the time for a pressure wave to propagate through the photosphere, t_p, given by the ratio of the pressure scale height to the photospheric sound speed, with the actual time taken for the photosphere to respond to the accelerative forces of the pulsation, given simply by the time between minimum and maximum velocity, t_a=1400 s. Making the simplifying assumptions of small radiation pressure, ionisation roughly uniform throughout the photosphere, and mean molecular weight 2, with T=23500 K (Paper II), then t_p=150 s. Since $t_a \gg t_p$, a shock wave is unlikely to be produced by the pulsation. This conclusion is supported by the apparent absence of other spectroscopic phenomena normally associated with the presence of atmospheric shock waves such as emission-lines and absorption-line splitting (e.g., Willson 1975).

Models of pulsation in luminous helium stars have only been calculated for the cooler R Coronae Borealis (R CrB) variables (Wood 1976, Saio & Wheeler 1985). With lower temperatures and surface gravities (Schönberner 1975, Cottrell & Lambert 1982) than those of V652 Her, pulsation in the comparitively tenuous envelopes of the R CrB variables may only be compared with that in V652 Her via the period mean density relation (Jeffery 1984). One non-linear pulsation model (Saio & Wheeler 1985, model 8) for a $0.7M_{\odot}$ R CrB star with T_{eff}=7000 K and $L=1.5\times10^4L_{\odot}$ gives a period of 0.15 day for a star with similar surface properties to V652 Her (T_{eff}=23500 K, $L=1.1\times10^3L_{\odot}$, Paper II) and an internal structure homologous with that of the R CrB stars.

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Although the agreement with the observed period (0.11 day) is reasonable, the comparison is of limited value because the homology condition is almost certainly violated by stars with such different temperatures. Indeed, the shock waves present in the R CrB models appear to be absent in V652 Her. Linear and non-linear studies of pulsation in *hot* helium stars are urgently needed in order to understand the pulsation in V652 Her. The detailed features of the radial velocity curve presented in this paper provide sensitive tests which models should endeavour to satisfy.

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DISCUSSION

SCHÖNBERNER: What is the range of the variations in effective gravity?

HILL: 3.6 to about 4.2; 3.7 would be roughly what we had before. This of course is only the variation, we do not have the absolute limit at that.

LYNAS-GRAY: Is the old radial velocity curve the one published by Lynas-Gray et al. (1984)?

HILL: No. The "old" curve includes the 1979 and 1980 velocities from Lynas-Gray et al. (1984) along with additional velocities obtained in 1982.

LIEBERT: Can you put useful limits on a binary companion at a separation close enough to affect the period change determination?

HILL: Yes, we looked at the mean velocities to see if there is anything obvious that could be due to a close binary. There seems to be no evidence for large changes in the systemic velocity which could be due to a binary.

JEFFERY: I think we can put an upper limit of $\pm$ 1 kms^{-1} to the velocity variations.