Time-resolved spectral analysis of the pulsating helium star V652 Her

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V652 Her

V652 Her is an early-type extreme helium star which pulsates with a period of 0.108 days. Its surface composition and location in the HR diagram have posed a considerable challenge to the theory of stellar evolution. However, its regular pulsation, a decreasing pulsation period and unusual surface composition have allowed stringent tests of various evolution models. The most successful model (Saio & Jeffery 2000) involves the merger of two helium white dwarfs which, after expanding to become a yellow giant, contracts towards the helium main sequence (where sdB stars are found). The most poorly determined property of V652 Her is its mass, a consequence of the difficulty of measuring surface gravity. The most crucial measurement, however, is that of radius, which may be measured using Baade's method. In this poster we summarise (bulleted highlights) the analysis of new observations (Jeffery et al. 2001) aimed at refining the radius and mass measurements of V652 Her.

Observations

A series of 59 moderate-resolution high signal-to-noise spectra of the pulsating helium star V652 Her covering 1.06 pulsation cycles were obtained with the William Herschel Telescope in 1998 July. These have been supplemented by archival ultraviolet and visual spectrophotometry and used to make a time-dependent study of the properties of V652 Her throughout the pulsation cycle.

Analysis

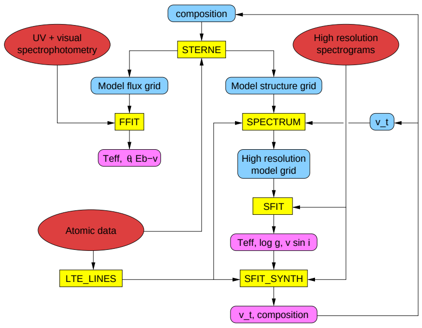
composition
UV + visual spectrophotometry
STERNE
High resolution spectrograms
Model flux grid
Model structure grid
FFIT
SPECTRUM
v_t
Teff, θ, Eb−v
High resolution model grid
SFIT
Atomic data
Teff, log g, v sin i
LTE_LINES
SFIT_SYNTH
v_t, composition

Figure 1. Block diagram illustrating the procedures (boxes), inputs (ellipses) and outputs (oval boxes) used in the analysis of high-resolution optical spectra and broad-band spectrophotometry of V652 Her.

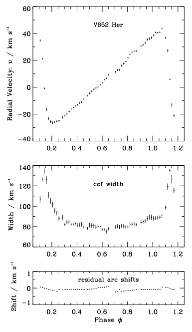

Figure 2. Radial velocity curve (top) with ccf widths (middle) and the residual arc shifts (bottom). Note the small velocity errors and the ccf broadening at minimum radius.

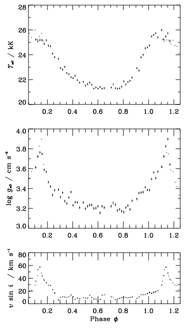

Figure 3. The run of $T_{\rm eff}$, $\log g_{\rm eff}$ and $v\sin i$ as a function of phase as derived from the high-resolution spectra. The values of $v\sin i$ represent the formal solution from the free-parameter fit.

Analysis of the new data features the following:

- new software for the automatic measurement of effective temperature, surface gravity and projected rotation velocities from moderate-resolution spectra,
- the most precise radial velocity curve for V652 Her measured so far,
- self-consistent high-precision measurements of effective temperature and surface gravity around the pulsation cycle,

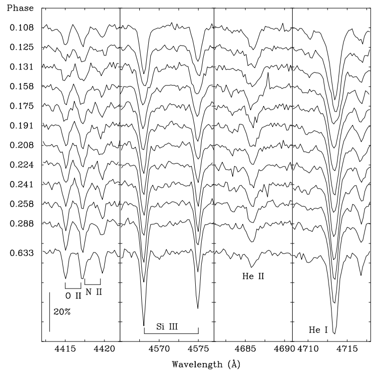

Figure 4. A sequence of line profiles for Si III, He I, He II and other ions demonstrates line broadening around minimum radius. Pulsation phase is shown on the left. A single spectrum obtained around maximum radius ($\phi = 0.633$) is shown for comparison. Rapid acceleration around minimum radius is visible as a change from a red to a blue shift. The core of He I λ4713 Å broadens around phase 0.13.

- a demonstration of excessive line-broadening at minimum radius and evidence for a pulsation-driven shock front,
- a new method for the direct measurement of the radius of a pulsating star using radial velocity and surface gravity measurements alone,

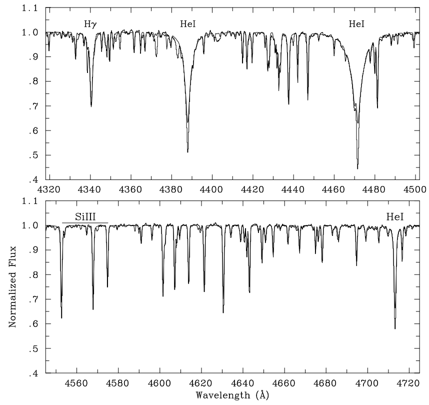

Figure 5. Sections of the average normalized spectrum of near maximum radius (histogram) together with the automatically computed best-fit synthetic spectrum (smooth curve: $T_{\rm eff} = 22\,000\,K$, $\log g_{\rm eff} = 3.25$(cgs), $v_{\rm t} = 9\,km\,s^{-1}$, $v\sin i = 7\,km\,s^{-1}$).

- new software for the automatic measurement of chemical abundances and microturbulent velocity,
- updated chemical abundances for V652 Her compared with previous work (Jeffery et al. 1999),
- a reanalysis of the total flux variations (cf. Lynas-Gray et al. 1984) in good agreement with previous work,
- an independent verification of the interstellar reddening using Lyman α from IUE high-resolution spectra and spectrum synthesis.

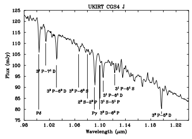

Figure 6. UKIRT CGS4 J-band spectrum of V652 Her showing He I (labelled by transition) and hydrogen Paschen lines (P_γ, δ).

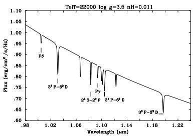

Figure 7. LTE model spectrum for V652 Her matching the UKIRT J-band spectrum.

- the first infrared spectrum of an extreme helium star, showing He I λ10830 Å to be unexpectedly weak and hydrogen Paschen lines to be unexpectedly strong relative to other He I lines.

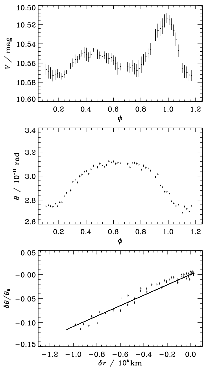

Figure 8. Derivation of radius from visual photometry (Kilkenny & Lynas-Gray 1982: top panel). The angular radius θ is estimated by fitting model flux distributions corresponding to the spectroscopic $T_{\rm eff}$ to the visual photometry (centre). The radius may be deduced from the gradient of $\delta\theta/\theta_0$ with δr (bottom panel).

- revised measurements of the stellar mass and radius from a number of different diagnostics (surface gravity, visual magnitude, bolometric flux).

The mass of V652 Her

Masses measured without reference to the ultraviolet fluxes turn out to be unphysically low ($\sim 0.25{\rm M}_\odot$). The best estimate for the dimensions of V652 Her averaged over the pulsation cycle is given by:

- $\langle T_{\rm eff}\rangle = 22\,930 \pm 10{\rm K}$
- $\langle \log g\rangle = 3.46 \pm 0.05$ (ionization equilibrium),
- $\langle T_{\rm eff}\rangle = 20\,950 \pm 70{\rm K}$ (total flux method),
- $\langle R\rangle = 2.31 \pm 0.02{\rm R}_\odot$,
- $\langle L\rangle = 919 \pm 14{\rm L}_\odot$,
- $M = 0.59 \pm 0.18{\rm M}_\odot$ and
- $d = 1.70 \pm 0.02{\rm kpc}$.

Two significant problems were encountered. The line-blanketed hydrogen-deficient model atmospheres used yield effective temperatures from the optical spectrum (ionization equilibrium) and visual and UV photometry (bolometric flux) that are inconsistent. Secondly, the IUE spectra are poorly distributed in phase and have low signal-to-noise. These problems may introduce systematic errors of up to $0.1{\rm M}_\odot$. New models and new ultraviolet observations are required.

References

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