Using high resolution spectroscopy to measure Cepheid pulsation

Kevin Gurney *k.gurney@shef.ac.uk*

1. Introduction

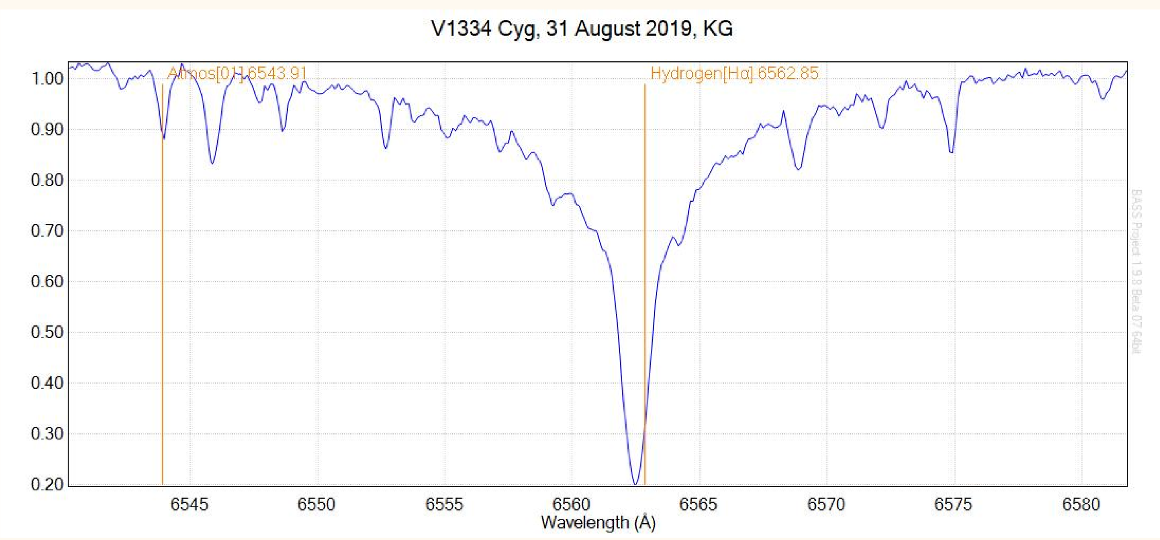
Using a high resolution spectrograph like the Lhires III (Shelyak Instruments) it is possible, in principle, to measure radial velocities of the order of 1km/s [1]. Thus, within these bounds, it should be feasible to measure radial velocities associated with Cepheid pulsation. However, extracting this component of the Doppler shift from a multiple system in which orbital components play a role is challenging; it requires information on the orbital ephemeris which, in turn, may require substantial observational and modelling effort. Fortunately, such information is availaible in a recent paper by Gallenne et al. [2] for the target described here – V1334 Cygni. Here, I show how measurements of the wavelength of the Hα line of V1334 can be used, in conjunction with this published model, to determine a putative pulsation profile of this Cepheid variable, and validate it against AAVSO-derived photometry.

2. Data preparation

Spectra were taken of the Cepheid variable V1334 Cygni, around the Hα line, over five nights between 26th August 2019 and 6th September 2019. The observations were made with a Lhires III spectrograph and C11 OTA. The Hα minimum was consistently blue shifted and varied from night to night.

The figure below shows part of one such spectra. The atmospheric water absorption line is very close to its nominal position at 6543.91Å, whereas Hα is clearly blue-shifted.

Spectra were aligned to the water absorption, and corrected for heliocentric velocity. The Hα minima were still all blue shifted by an equivalent velocity of between -7.4km/s and -17.2 km/s (all greater than the nominal stellar radial speed of -1.8km/s). These velocities are inconsistent with a simple interpretation in terms of a Cepheid-like, pulsation. However, a recent model of V1334 Cyg is able to give insight as to why this might be so.



Part of spectrum of V1334 Cyg from 31 August 2019, showing atmospheric , and stellar Hα absorption lines.

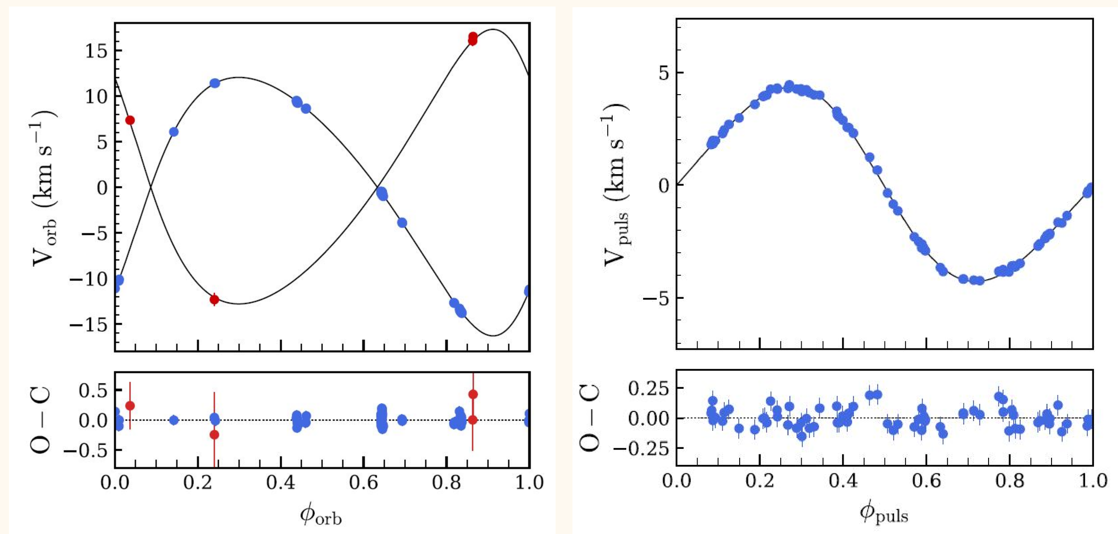
Full details of data collection and processing are available in [3]

3. A model of V1334 Cygni

V1334 is a triple system. The Cepheid itself has a very close (but faint) companion, and this pair has a wider companion (just about separable visually).

The paper by Gallenne et al. [2] focuses on the wide pairing, and the visible spectrum is dominated by the Cepheid itself [4]. This allows us to interpret the spectra I observed as plausibly derived from the main Cepheid component.

Importantly, Gallenne et al provide a model of the radial velocity of the Cepheid, split into components due to the orbital motion and pulsation. The results of the model and fit to data are shown in the figure below.



Left: model of orbital motion for wide binary components of V1334 Cyg from [2]. Blue and red data dots identify models for primary and secondary components respectively. Right: model of pulsation radial velocity of primary component.

The period of the orbit is around 5.4 years and so any contribution from this to my data will be almost constant. The period of pulsation is around 3.3 days and so may figure in any variation I saw, as observations were taken over an 11 day period.

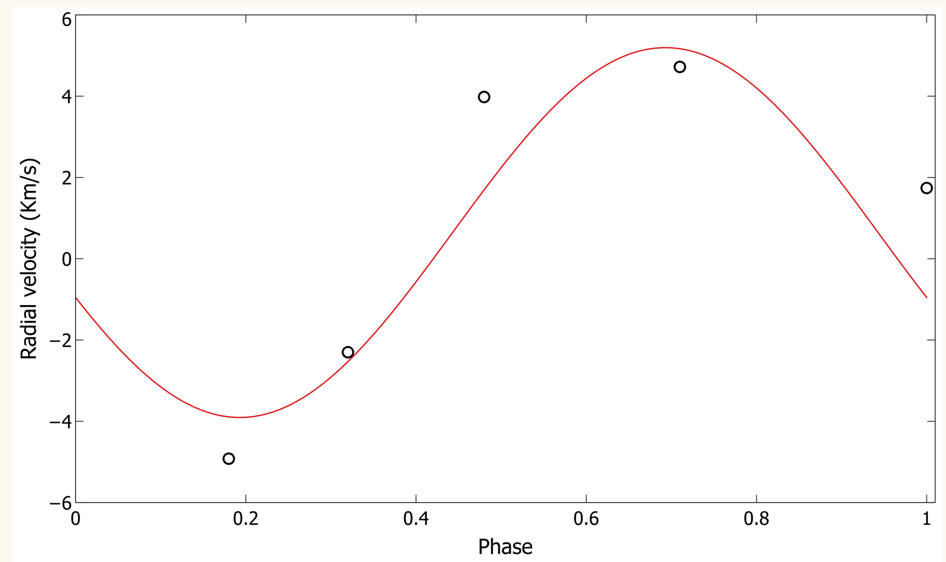
4. Using the model

Orbital component of radial velocity

The orbital solution for radial velocity against phase in the model of Gallenne et al., is analytic but is given implicitly, and would require (a non-trivial) numerical solution. I therefore fitted a polynomial to the primary component curve. Then, using the orbital ephemeris of Gallenne et al., I mapped my observation times to an orbital phase and read off radial velocities from the polynomial. The values are (as expected) approximately the same and close to 12Km/s.

Pulsation component of radial velocity

Subtracting the orbital component of radial velocity from the Doppler shift in my data, gives a residual observed velocity V_{res} which might be due to pulsation of V1334 Cyg. I converted my observations times to a phase using the pulsation ephemeris of Gallenne et al. and fitted a single sinusoid to the data pairs of phase and V_{res}. The results are shown the figure below

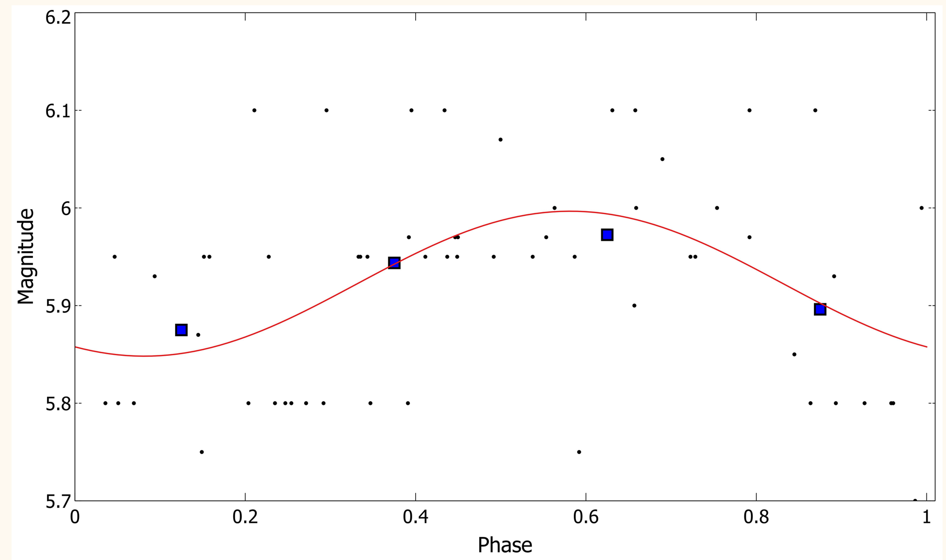


Fitting a sinusoid to the residual Doppler shifts V_{res}. Open circles are these data expressed as a function of pulsation phase. The red line is the best fitted sinusoid

Fortunately, my five observations are scattered fairly evenly across phase values which highlights any pattern in the results. There is clear indication of a sinusoidal trend, and the amplitude is similar to that shown in the pulsation model of Gallenne et al. (right hand side of figure in panel 2). Further, my sinusoidal fit makes the prediction that the phase offset (shift of $V = 0$ from zero phase) is 0.56. It is possible to test this against photometric data which should show a similar sinusoidal pattern.

5. Comparison with photometry

Photometry data for V1334 Cyg (visual - observer SSHA) was available from the AAVSO database. A similar procedure to that used for the Doppler shifts was used to convert times to phase and fit a sinusoid with parameters of amplitude and phase offset. The results are shown in the figure below. To help overcome effects of noise, the data were binned into four equal periods. Interestingly, the phase offset here is 0.67 which is reasonably close to the prediction from the Doppler shift analysis (0.56).



Fitting a sinusoid to the photometric data for V1334 Cyg. Black dots are the raw data, filled squares are the data binned over four equal periods, and the red line is the best sinusoidal fit.

6. Summary

The Doppler shifts observed in my spectra appear to be consistent with the decomposition into orbital and pulsation components described in Gallenne et al 2018 [2]. The shifts corresponding to the pulsation velocities (range ±5km/s) are of the order of 0.1Å which is smaller than the nominal resolution of the equipment (≈ 15000). However, the latter refers to line distinguishability, and velocitiy discriminations may be significantly smaller [1]. More data may sharpen up the outcomes suggested here, but I provisionally conclude that observation of Cepheid pulsation is within the domain of amateur equipment.

References

[1] R. Leadbeater, *Pushing the limits using commercial spectrographs*, AAVSO, BAA Joint Meeting, Warwick, (2018)

[2] Gallenne et al., *A Geometrical 1% Distance to the Short-period Binary Cepheid V1334 Cygni*, Astrophys. J., 2018

[3] K.N. Gurney *A model-based interpretation of Hα dynamics in spectra of V1334 Cyg*, BAV Magazine Spectroscopy, No. 7, June 2020.

[4] V. V. Kovtyukh et al., *Mode identification of three low-amplitude classical Cepheids: V1334 Cyg, V440 Per and V636 Cas.*, Mon. Notices Roy. Astro. Soc., 2012.