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Photometric study of two β Cephei pulsators in eclipsing systems

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We present results of a photometric study of the young southern open cluster Stock 14. This cluster is known to contain two eclipsing systems with presumed β Cephei components, HD 101794 and HD 101838. We confirm variability due to pulsations and eclipses in both targets and announce the discovery of other variable stars in the observed field.

1 Introduction

Pulsating components of eclipsing binary systems play an important role in asteroseismology. This is because a combination of photometric and spectroscopic solutions allows determination of masses and radii of both components. These parameters can be subsequently used in seismic study. By putting tighter constraints on fundamental stellar parameters, greater accuracy of the asteroseismic model can be achieved.

Photometric variability of HD 101794 was discovered by the Hipparcos satellite. The star was at first identified as a γ Cassiopeiae-type variable and was assigned the name V916 Cen. Its spectral type was classified as B1.5 V (Feast et al. 1961), B0/1 ne (Houk & Cowley 1975), B1 IVne (Garrison, Hiltner & Schild 1977) and B0.5 IVne (FitzGerald & Miller 1983). Emission was confirmed by measurements of β index (Moffat & Vogt 1975; Klare & Neckel 1977; Johannson 1981; Kaltcheva 2003) and Hα photometry (McSwain & Gies 2005). The eclipsing nature of HD 101794 was revealed by Pojmański (2000), who determined its orbital period $P_{\rm orb}$ = 1.4632 d from the I-filter All Sky Automated Survey phase 2 (ASAS-2) photometry. Since both eclipses are similar in depth, the system could be a double-lined (SB2) spectroscopic binary. Analysis of the ASAS-3 (Pojmański 2002) V-filter photometry by Pigulski & Pojmański (2008) led to the discovery of two pulsation modes: f_1 = 4.45494 d^{-1}, typical for a β Cephei star, and f_2 = 1.83952 d^{-1}, attributed to λ Eridani-type variability by the authors. It is not clear if both modes originate in the same component.

HD 101838 is also an early B-type star, classified as B1 III (Feast et al. 1961), B0.5/1 III (Houk & Cowley 1975), B1 II-III (Garrison et al. 1977) and B0 III (FitzGerald & Miller 1983). It was discovered to be variable by Pigulski & Pojmański (2008). The star exhibits a single pulsation mode with frequency f_1 = 3.12764 d^{-1}, which is quite low for a β Cephei variable. The orbital period probably amounts to 5.41167 d, but from the photometry alone one may not exclude the possibility that the true orbital period is twice as long. If the shorter period is assumed, the eclipsing light curve does not exhibit a secondary minimum. If the period is longer, both eclipses are similar in depth. The latter case would be more favourable, as the system would probably be an SB2 binary. Additional observations, preferably spectroscopic, are needed to resolve this ambiguity.

It is worth noting that both HD 101794 and HD 101838 might be members of Stock 14, a sparsely populated young open cluster in Centaurus. According to the WEBDA[1] database, the mean $E(B-V)$ colour excess for cluster stars amounts to 0.23 mag, the distance of the cluster is about 2.1 kpc and it is 11×10^6 years old. Arguments in favour of the membership of HD 101794 and HD 101838 can be found in papers by Moffat & Vogt (1975), FitzGerald & Miller (1983) and Peterson & FitzGerald (1988). The membership criteria used in those papers are either based on photometry (position in colour-magnitude and colour-colour diagrams, the agreement of individual reddenings), or on the concordance of spectral types of individual stars.

Due to the known poor spatial resolution of the ASAS observations, amounting to about 15 arcseconds per pixel, it is higly desirable to carry out follow-up photometry in order to minimize the possibility of contamination by nearby stars. The aim of this paper is to verify that the variability of HD 101794 and HD 101838 is both eclipsing and pulsating in nature, and also to provide a status report on the ongoing photometric study of the Stock 14 field.

2 Observations, calibration and reduction

Follow-up observations were carried out between 7 March and 13 May 2007 (19 nights in total). We used the 40-inch

[1] Web version of the BDA (Base de Données des Amas ouverts) database, http://www.univie.ac.at/webda

Cassegrain telescope at Siding Spring Observatory, Australia. The detector was the Wide Field Imager (WFI), an eight CCD (2048 × 4096 pixels each) mosaic with 52 × 52 arcmin^2 field of view. The entire target cluster is located in a single WFI chip #3. For this reason, only results from that particular CCD are presented here. A set of standard UBV Johnson filters was used, with respectively 881, 1085, and 1125 frames taken through each filter. Since target stars are bright, typical exposure times were short: starting from 10 s in V up to 50 s in U. In total, we identified 7011 stars in our V-filter reference frame.

The frames were calibrated using a standard procedure, which included correcting signal values in each CCD pixel for the known nonlinearities[2]. Stellar magnitudes were calculated using the Daophot software package (Stetson 1987). Atmospheric effects were accounted for by means of differential photometry using 15 comparison stars, distributed evenly in the frame. The mean instrumental magnitude of each star was calculated as an average value from its σ-clipped time-series. In eclipsing binaries, only points outside of eclipses were considered in this computation. Judging by the errors in mean instrumental magnitudes and by the appearance of colour-magnitude and colour-colour diagrams we conclude that a subset of 2401 stars has reasonably good photometry in both V and B filters. Only 943 stars have decent photometry in all filters. We have not obtained any photometry of star V810 Cen. This supergiant is the brightest star in the field and was severely overexposed in all frames. Photometric standards were not observed during our observing run. However, we have been able to transform our instrumental magnitudes to the standard system using data from the paper by Peterson & FitzGerald (1988).

3 Analysis and results

The time series of HD 101794 and HD 101838 were analysed in the following way. First, they were folded with orbital periods provided by Pigulski & Pojmański (2008), i.e., 1.46323 d and 5.41167 d, respectively. Visual inspection of the resulting light curves revealed the eclipses in both targets. Significant scatter of data points was also present. That was to be expected, taking into account the existence of pulsations. In order to proceed with the analysis we had to remove the contribution of eclipses. The orbital frequency with the appropriate number of harmonics was fitted to the original data. Finally, a discrete Fourier transform of the residuals was calculated. This step revealed the presence of pulsations.

The most prominent maximum visible in the frequency spectrum of HD 101794 corresponds to $f_1 = 4.4482$ d^{-1} (Fig. 1), which is in good agreement with f_1 of Pigulski & Pojmański (2008). The second frequency we detect, $f_2' = 1.8760$ d^{-1} is a 25-day alias of f_2 from aforementioned paper (our photometry consisted of three runs separated roughly by 25–30 d). We do not detect any additional frequencies in the residuals.

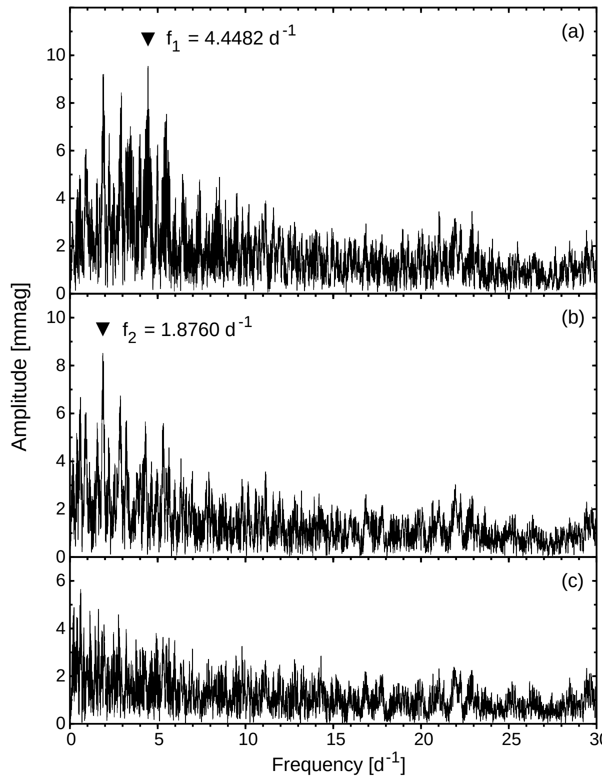

Fig. 1 Frequency spectrum of the V-filter photometric data of HD 101794: (a) after subtraction of the eclipsing light curve; (b) prewhitened with f_1; (c) prewhitened with f_1 and f_2.

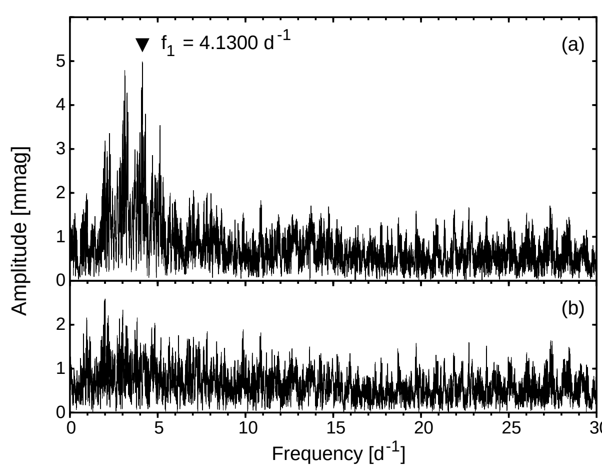

Fig. 2 Frequency spectrum of the V-filter photometric data HD 101838: (a) after subtraction of the eclipsing light curve; (b) prewhitened with f_1.

The frequency spectrum of HD 101838 (Fig. 2) features two nearly equal maxima. The one at $f = 3.1299$ d^{-1} corresponds to the frequency already known from the ASAS-3 data, the other is its daily alias. The amplitude of the lat-

[2] Tinney, C.G.: 2002, http://www.aao.gov.au/wfi/wfi_pfu.html

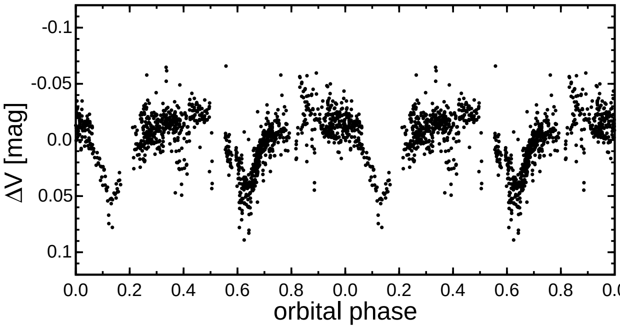

Fig. 3 Eclipsing differential V-filter light curve of HD 101794. The orbital period is 1.46323 d.

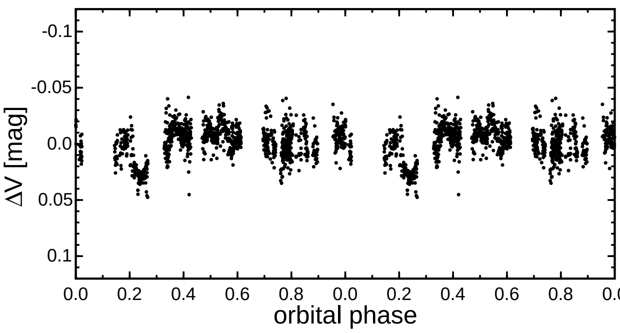

Fig. 4 Eclipsing differential V-filter light curve of HD 101838. The orbital period is 5.41167 d. A shallow primary eclipse is seen around the orbital phase of 0.25.

ter is slightly larger than the former. With no means to decide which maximum corresponds to the real frequency, we assumed that $f_1 = 4.1300$ d^{-1} is the true one. After prewhitening the spectrum with this frequency, no significant maxima can be seen.

Having removed the contribution of pulsations from our original time series, we folded them with their respective ASAS-3 orbital periods. Resulting eclipsing light curves of HD 101794 and HD 101838 are shown in Fig. 3 and Fig. 4, respectively. There is no doubt that the targets indeed are eclipsing binary systems. While HD 101794 shows two eclipses of similar depth, only a shallow primary eclipse is seen in HD 101838.

An interesting by-product of this work is the discovery of seven new variable stars in the field of the Stock 14 open cluster. They include a multiperiodic β Cephei star, a multiperiodic SPB star and a δ Scuti variable with at least two excited modes. Since only frames from one CCD chip of the WFI have been analysed so far, the variability search is not complete. Because of this, we refrain from disclosing detailed information about discovered variable stars in this paper. The full results of the variability search in the field of Stock 14 will be published elsewhere.

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