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CzeV615 – A NEW ECLIPSING BINARY

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The field of an RR Lyrae star, AT Serpentis (discovered by Hoffmeister, 1935), was observed at a private observatory in Brno during 7 nights in June and July 2014. The determination of maxima timings of the pulsating star was the main aim of the observations. One of stars in the field, CzeV615[1](Ser) = BD+09 3111 = USNO-A2.0 0975-08030166 (RA=$15^{\mathrm{h}}53^{\mathrm{m}}23\overset{\mathrm{s}}{.}634$, DEC=$+08^{\circ}47'22\overset{''}{.}32$), was identified as a new variable object from our CCD measurements. Light changes of about 0.1 mag in V-band were detected.

A small Malokuk telescope was used. The telescope comprises an ATIK 16IC CCD camera (659×494 pix, Sony ICX 424AL chip), a Sonnar $f/4$ 135 mm photographic camera lens, and an EQ-1 Table Top mount. The field of view of the telescope is about $2.1^{\circ}\times1.6^{\circ}$, and the angular resolution is $11.3''$/pix. The CCD camera is equipped with a *green* filter with a transmission similar to the Johnson V-band (see Fig. 1).

All CCD frames were calibrated in the standard way including dark and flat corrections. Groups of 5 consecutive frames were combined into a single image with a time resolution of about 150 s to achieve a better signal-to-noise ratio. An exposure time of 30 s was used for each frame. These procedures, as well as differential aperture photometry, were performed using C-Munipack[2] (Motl 2009) based on Daophot (Stetson 1987). HD 142799 and BD+08 3106 were used as comparison and check star, respectively. The list of observations is given in Table 1.

Own photometric data[3] are insufficient to determine the type of variability and for period estimation. Nevertheless, an eclipse explanation is proposed based on the detected dip in brightness. Fortunately, data for CzeV615 were found in the archives of the following projects: ASAS-3 (Pojmanski 2002, V band), NSVS (Woźniak et al. 2004, unfiltered measurements) and WISE (Wright et al. 2010, 4 infrared bands).

We verified transmission of our filter to be able to compare our measurements with data from sky-surveys. For this reason, transmission measurements were made with an Avantes AVS-S2000 spectrometer (wavelength range: 190–856 nm, resolution: 0.37–0.27 nm px^{-1}). The sensitivity of our ATIK 16IC CCD camera and the relative transmission function

[1]star included in Czech catalogue of discovered variable stars (Brát 2006), http://var2.astro.cz/czev.php
[2]http://c-munipack.sourceforge.net/
[3]available on-line at the IBVS website (`6124-t1.txt`)

Table 1: List of observations. N is the number of combined images.

Night	Start UTC	Exp. [s]	N
9 June 2014	23:46	30	29
15 June 2014	20:19	30	89
18 June 2014	20:18	30	46
19 June 2014	22:10	30	16
20 June 2014	22:00	30	67
24 June 2014	20:10	30	37
18 July 2014	20:56	30	10

of our filter were compared with that of the V-filters of the Johnson & Morgan (1953) UBV photometric system, the Johnson (1965) $UBVRI$ system and the Bessell (1990) $UBVRI$ system. Data for the individual filters were taken from the ADPS[4] (Moro & Munari 2000). The shape of the transmission function of our filter is evidently different than the transmission functions of the standard V-filters (Fig. 1). We also detected a red leak in wavelengths longer than 750 nm, which contributes about 20 % to the total signal (relative spectral response of our CCD is less than 40 % in this area). Nevertheless, these differences are negligible for our purpose. Our data are comparable with ASAS-3 measurements (similar photometric bands).

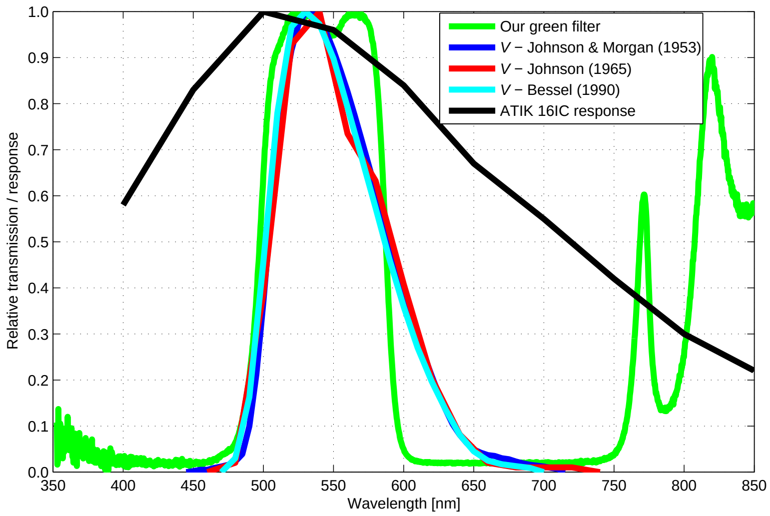

Figure 1. Relative transmission in the range of 350–850 nm for our *green* filter (own measurement) and for the standard photometric filters from the Asiago database together with the relative spectral response of the used ATIK 16IC CCD camera.

Using PERIOD04 (Lenz & Breger 2005), the period was found to be about 0.7435 d based on data from ASAS-3 and NSVS (Fig. 2). The data set from the WISE project was omitted from period analysis and fitting of the light variations, because it contains only a small number of measurements (28 points in $W1$, $W2$ bands, 12 points in $W3$, $W4$). In addition, the shape of the infrared light curve could be very different from that in the optical band.

[4]Asiago Database on Photometric Systems, http://ulisse.pd.astro.it/Astro/ADPS/

The shape of variations with this period evidently corresponds to eclipsing binary behaviour, but no significant depression of a secondary minimum is visible in the phase diagram. We tested two possible scenarios: a semi-detached system with two different components (different radius, surface temperature, brightness) and orbital period close to 0.75 day; a detached binary system with similar components causing similar depths of eclipses and a period of double the value (about 1.5 day). Period analysis could not assist in selecting the correct solution, because the double-period value is not visible in the frequency spectra from PERIOD04 (Fig. 2). This is generally a problem for eclipsing binaries with similar eclipses – only half the value of the period is present in the frequency spectrum from PERIOD04. The other methods, e.g. Renson or a similar method implemented in PERANSO software[5] (Vanmunster 2011), show both values of the period in the spectrum to be of nearly the same strength (Fig. 3).

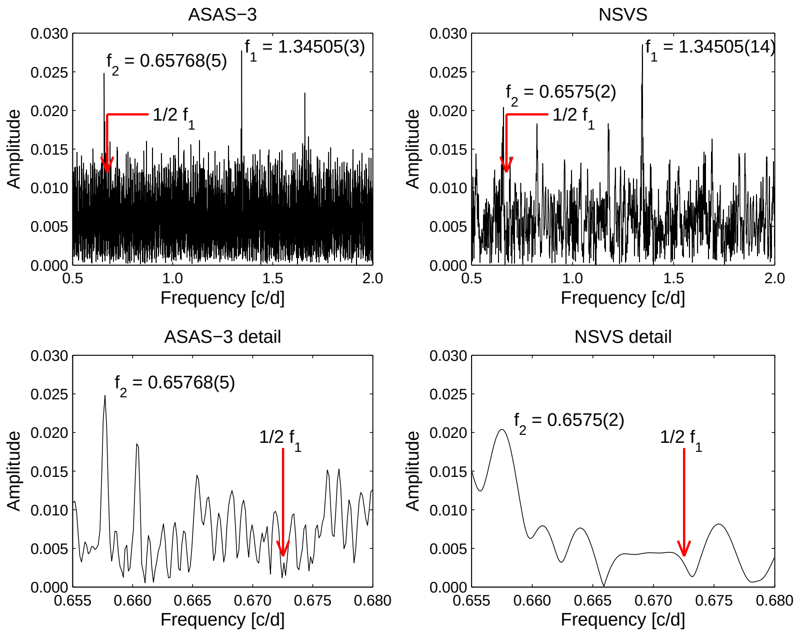

Figure 2. Frequency spectra from ASAS-3 and NSVS data (PERIOD04) contain the strongest frequency $f_1 = 1.34505\,\mathrm{c\,d^{-1}}$ which corresponds to the period 0.7435 d (figures on the top). The half value of the frequency $1/2\,f_1 = 0.67253\,\mathrm{c\,d^{-1}}$(double period 1.487 d) has a very low amplitude and it is at the bottom of the frequency spectra in the noise (clear visible in the detail of the figures at the bottom). The frequency marked as f_2 suggests a very blurred phase light curve.

We decided to give priority to the latter explanation ($P \sim 1.5\,\mathrm{d}$) due to the following reasons. The primary and secondary eclipses have slightly different depths from our model for a 1.5 d period (more below). We did not detect a secondary minimum for the period of 0.75 d. The last indication is given by proximity effects which are visible in the phase light curve. A typical light curve influenced by proximity effects has two maxima close to phases 0.25 and 0.75 and minima close to phases 0.0 and 0.5. The maximum brightness for our 0.75-day period is at phase 0.5, which is contrary to the mentioned statement and

[5] `http://www.peranso.com/`

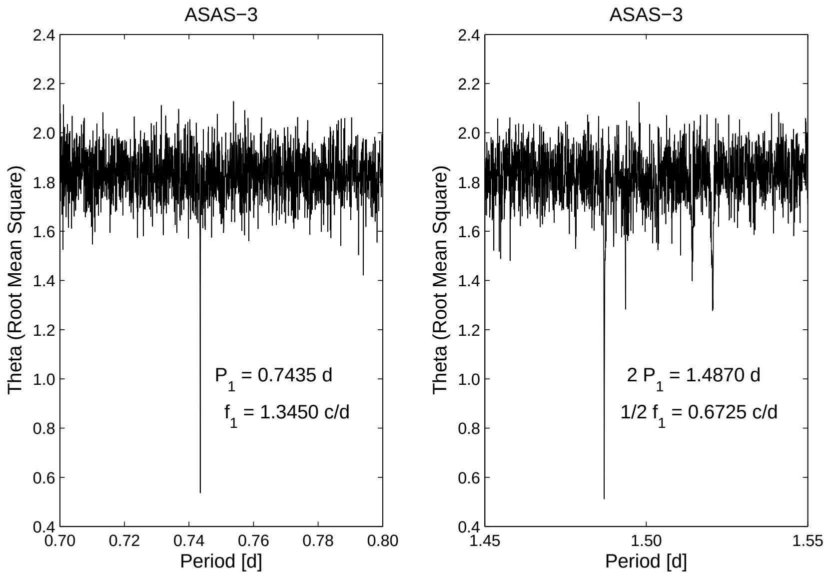

Figure 3. Frequency (period) spectrum for ASAS-3 data obtained from the Peranso software and the Renson method contains both periods with nearly identical strengths (minimum value of dispersion).

supports the correctness of the double-period preference. Nevertheless, it is necessary to verify our preliminary results using more accurate photometry or spectroscopy.

The observed light variations were fitted using a non-linear least-squares method based on the work of Mikulášek, Zejda & Janík (2012), Mikulášek & Zejda (2013), Chrastina, Mikulášek & Zejda (2014). The function $m(t)$ for describing an eclipsing binary light curve was chosen in the form

$$m(t) = m_{0\,i} + a_1\,\exp\left[\frac{-\varphi_1^2(t)}{2\,\sigma^2}\right] + a_2\,\exp\left[\frac{-\varphi_2^2(t)}{2\,\sigma^2}\right] + a_3\,\cos[4\,\pi\,\vartheta(t)], \tag{1}$$

where $m_{0\,i}$ is the zero point for the i-th dataset and $a_{1,2}$ are the amplitudes of the primary and secondary eclipses, respectively. Eclipses are represented by a Gaussian function including constant σ to control their widths. Parameter a_3 is the amplitude of correction for small changes in brightness outside of the eclipses (proximity effects). Finally, the phase function $\vartheta(t)$ and the phases of the primary or secondary eclipses $\varphi_{1,2}(t)$ can be written as

$$\vartheta(t) = \frac{t - E_0}{P},\;\; \varphi_1(t) = \vartheta(t) - \mathrm{round}[\vartheta(t)],\;\; \varphi_2(t) = \left[\vartheta(t) - \frac{1}{2}\right] - \mathrm{round}\left[\vartheta(t) - \frac{1}{2}\right], \tag{2}$$

where the time t is in heliocentric Julian date, E_0 is the zero epoch and P is the period in days. The input parameter σ was quasi-randomly generated. The model with the lowest χ^2 (for the data without evident outliers) was selected as the best solution (Fig. 4). The uncertainties of parameters were subsequently determined using the bootstrap method.

Brightness variation was determined from our model in the range of 10.008(2)–10.121(5) mag in the V-band (ASAS-3) and 10.306(2)–10.419(5) mag (NSVS, close to the R-band). The semi-amplitude a_3 of brightness changes outside of the eclipses was found to be 0.006^{+2}_{-2}. The time of minimum light (mid-eclipse) can be expressed in the form

$$T_{\min} = 2453144.9028^{+11}_{-14} + 1.4869803^{+14}_{-15}\,\mathrm{d}\cdot E. \tag{3}$$

Nevertheless, primary and secondary minima have similar amplitudes of $a_1 = 0.100^{+6}_{-5}$ mag, $a_2 = 0.091^{+6}_{-5}$ mag. Due to the low accuracy of measurements, it is difficult to differentiate between primary and secondary minima. Similar depths of minima from ASAS-3 and NSVS measurements for the period 1.4869803 d indicate that CzeV615 is a detached binary system with both components of similar surface temperature and spectral type. It could be an advantage for future spectroscopic analysis, because the spectral lines of both components could be easily detected in the spectrum. The duration of both eclipses is about 3.5 h ($\sigma = 0.0211^{+11}_{-11}$). Eclipses are also detectable in the infrared region. Four measured values from WISE ($W1$, $W2$) obtained in phases close to mid-eclipse, are about 0.1 mag fainter than outside the eclipses.

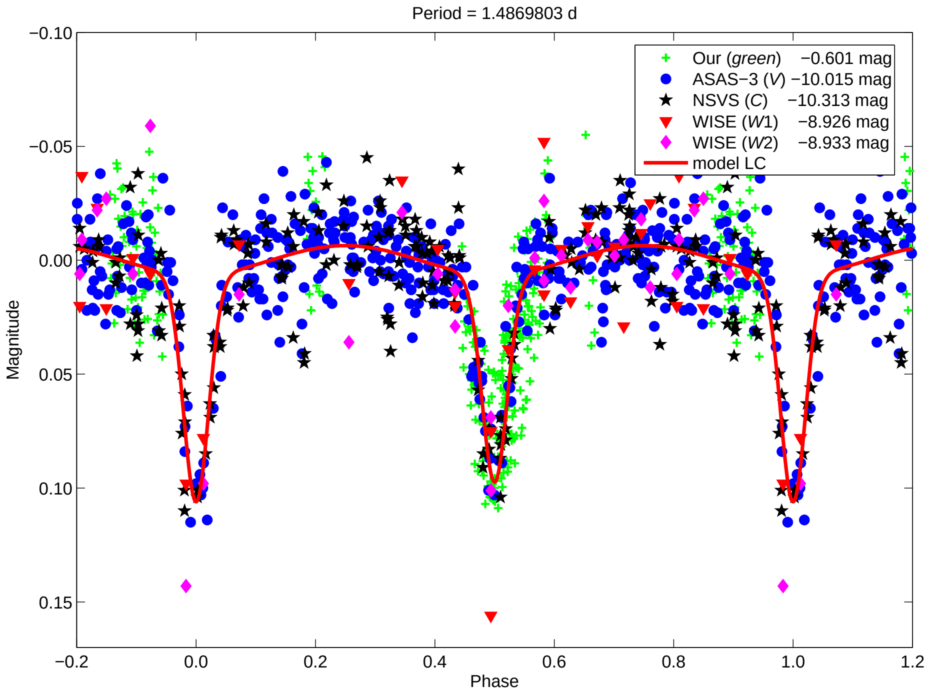

Figure 4. Own measurements together with data from ASAS-3, NSVS and WISE database and our model of the light curve phased according to eq. (3).

Data from WISE can also be useful for possible elimination of the half value for the orbital period (0.7434902 d). The phase curve constructed with this period does not contain a secondary minimum in optical photometry (ASAS-3, NSVS). This can be explained as a semi-detached system where secondary eclipses are not visible in the optical band, but they are detectable in infrared wavelengths (components with very different surface temperatures). WISE photometry also does not show a depression in phases outside of the primary minimum. Unfortunately, the number of WISE measurements is not high and values have low accuracy.

Literature, found in the VizieR database (Ochsenbein, Bauer & Marcout 2000), does not contain much information about the object CzeV615. Its spectral type is probably F0 (Heckmann 1975), colour $B - V = 0.319(83)$ mag (ESA 1997) and effective temperature about 7000 K, e.g. Wright et al. (2003) give 7200 K, Ammons et al. (2006) give 6698 K or 6564 K. The distance of CzeV615 is very uncertain. Measurements from the Hipparcos satellite have very large uncertainty (parallax 27.00(32.09) mas, ESA 1997) resulting in a distance of 37(44) pc. These values are completely different from the values of Pickles & Depagne (2010), who give the distance as 347 pc and the spectral type as F5IV. Additional photometric and spectroscopic observations are therefore needed.

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References:

Ammons, S. M., Robinson, S. E., Strader, J., et al., 2006, *ApJ*, **638**, 1004
Bessell, M. S., 1990, *PASP*, **102**, 1181
Brát, L., 2006, *OEJV*, **23**, 55
Chrastina, M., Mikulášek, Z. & Zejda, M., 2014, *CoSka*, **43**, 422
ESA 1997, The Hipparcos and Tycho Catalogs, ESA SP–1200
Heckmann, O., 1975, Hamburg-Bergedorf: Hamburger Sternwarte, edited by Dieckvoss, W.
Hoffmeister, C., 1935, *Astron. Nachr.*, **255**, 401
Johnson, H. L. & Morgan, W. W., 1953, *ApJ*, **117**, 313
Johnson, H. L., 1965, *ApJ*, **141**, 923
Lenz, P. & Breger, M., 2005, *Comm. Asteroseismology*, **146**, 53
Mikulášek, Z., Zejda, M. & Janík, J., 2012, *IAUS*, **282**, 391
Mikulášek, Z. & Zejda, M., 2013, Úvod do studia proměnných hvězd, Masarykova univerzita, muni PRESS, Brno
Moro, D. & Munari, U., 2000, *A&AS*, **147**, 361
Motl, D., 2009, C-Munipack, `http://c-munipack.sourceforge.net/`
Ochsenbein, F., Bauer, P., & Marcout, J. 2000, *A&AS*, **143**, 23
Pickles, A. & Depagne, É., 2010, *PASP*, **122**, 1437
Pojmanski, G., 2002, *Acta Astronomica*, **52**, 397
Stetson, P. B., 1987, *PASP*, **99**, 191
Vanmunster, T., 2011, Peranso, `http://www.peranso.com/`
Woźniak, P. R., Vestrand, W. T., Akerlof, C. W., et al., 2004, *AJ*, **127**, 2436
Wright, C. O., Egan, M. P., Kraemer, K. E. & Price, S. D., 2003, *AJ*, **125**, 359
Wright, E. L., Eisenhardt, P. R. M., Mainzer, A. K., et al., 2010, *AJ*, **140**, 1868