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LONG-TERM RADIAL VELOCITY MONITORING OF THE HeI 6678 LINE OF ζ TAURI

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Introduction

The binary star ζ Tau, one of the brightest Be stars in the northern sky, shows cyclic behaviour in the radial velocity (RV) variations on several distinct time scales. It is also a spectroscopic binary with a 133 d orbital period established by Harmanec (1984). Its orbital RV variations are superimposed on the cyclic long-term and short-term ones. ζ Tau also shows cyclic behaviour in the radial velocity of the HeI 6678 Å absorption line. As far as we know the first long-term investigation (time period 1993–2005) of the RV of the HeI 6678 absorption line has been performed by Stefl et al. (2007). That monitoring until about 2007 led to the estimation of a long-term period of 1503 d.

Observations

The spectra for the RV measurements of the HeI 6678 line presented here were taken with 20 cm Newtonian- and 40 cm Schmidt-Cassegrain telescopes. Spectrographs with spectral resolving power of 10000 to 20000 were used. The signal to noise ratio of these spectra was of the order of magnitude $S/N = 200 - 300$. The spectra have been reduced with standard procedures (instrument response, normalisation, wavelength calibration) by use of the program VSPEC[1]. The evaluation of the heliocentric RV was performed by the profile mirror method. This method measures the Doppler shift of spectra by correlation of the spectral line with their mirroring around the laboratory wavelength, and is particularly suitable for the evaluation of asymmetrical lines within exactly specified profile ranges.

Long-term changes

We will compare the 1503 d period of Stefl et al. (2007) with our results covering approximately 15 years (December 2000 to February 2016). Such a long investigation interval was possible because we combine radial velocity data from Ruzdjak et al. (2009) with our data of the ARAS group[2]. This long-term monitoring is shown in Fig. 1. In order to

[1] `http://www.astrosurf.com/vdesnoux`
[2] `http://www.astrosurf.com/aras/`

recognize the separate cyclic behaviour of the Ruzdjak et al. (2009) data and the ARAS data, the corresponding separate phase plots are shown in Figs. 2 and 3. The overlay of both periods is shown in Fig. 4. For this analysis the program AVE[3] was used.

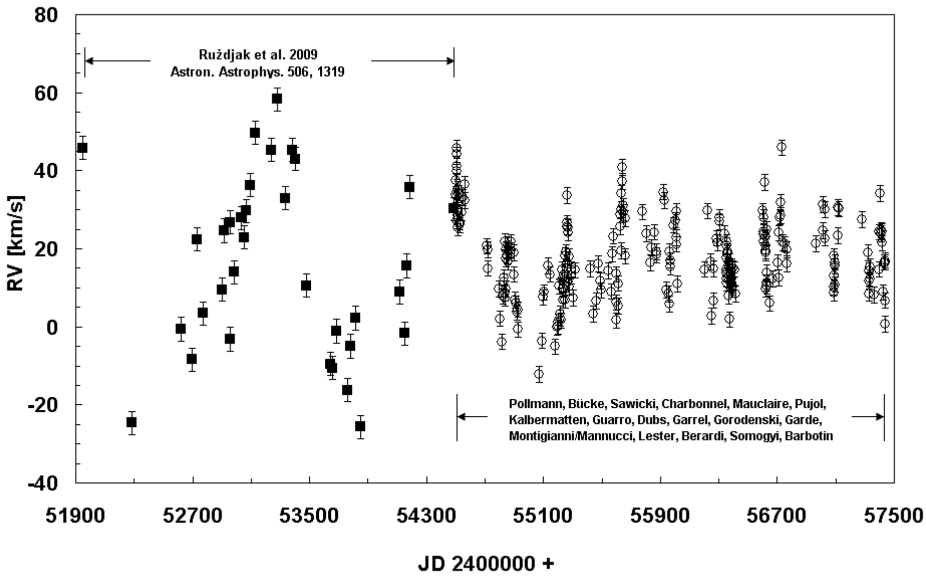

Figure 1. RV Long-term monitoring of the HeI 6678 line from December 2000 to February 2016.

The RV comparison of these three time intervals, P = 1503 d for 1993–2005 (Stefl et al. 2007), P = 1325 d for 2001–2008 (Ruzdjak et al. 2009), and P = 1190 d for 2008–2016 (this paper), points out that the long-term RV period has constantly decreased at least since 1993 .

Orbital variations

One of the most interesting studies of the RV variations in the spectrum of ζ Tau is the paper by Ruzdjak et al. (2009). We were fortunate to start a long-term observing campaign of the HeI 6678 line at the time when the investigations of the researchers of the mentioned paper ended, approximately at JD 2454500. Our findings on the HeI 6678 RV orbital variability of 132.2 d ($\pm$ 0.8) and 131.3 d ($\pm$ 0.9) received with different analysis programs (Pollmann et al. 2012) are very close to those of Ruzdjak et al. (2009) for the most important parameters.

Short-term variations

The HeI 6678 absorption line of ζ Tau consists of a strong central shell absorption, which is overlaid by a rotation-broadened photospheric component with a projected rotation velocity $v \sin i = 320$ km/s. The profile of this absorption line shows weak but sharp features which cross periodically through the entire line profile. These features are observed as small absorption “bumps”, generally moving through the line profile from blue to red.

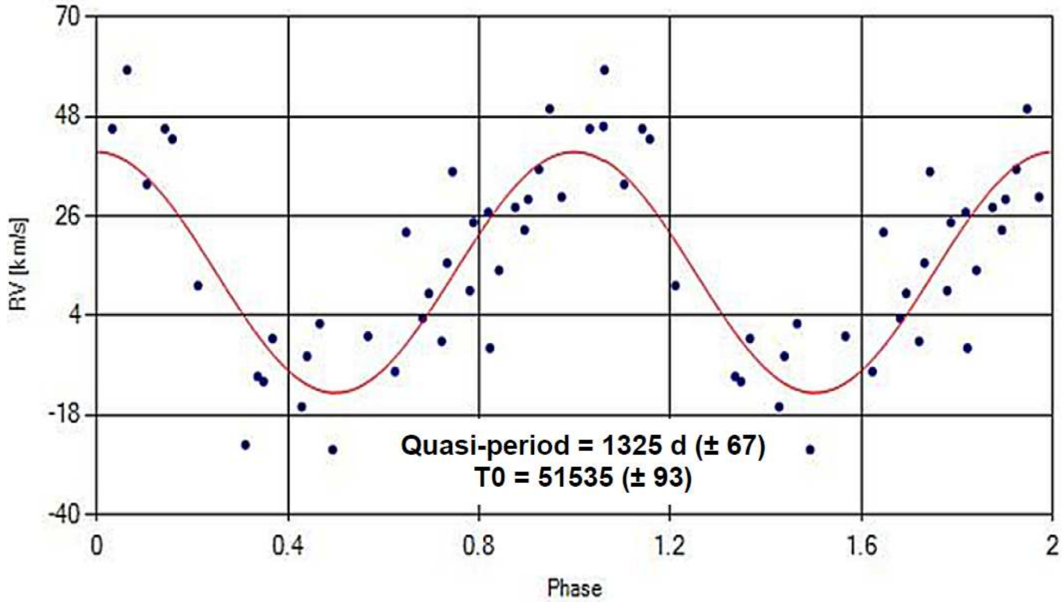

Figure 2. RV variation (period = 1325 d (± 67), starting from T_0 = JD 2451535) of Ruzdjak et al. (2009) data in Fig. 1.

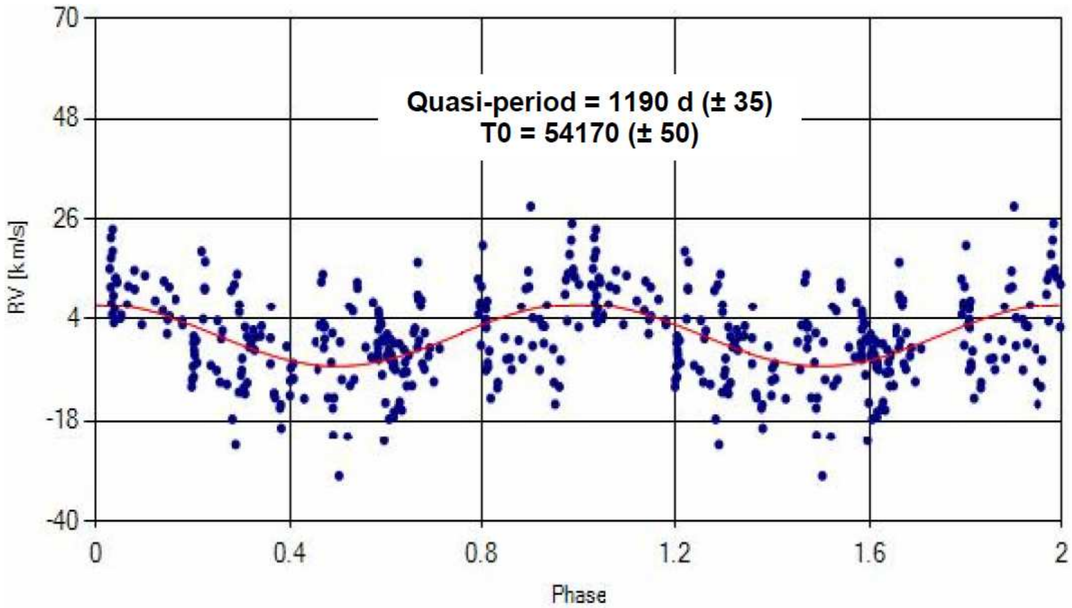

Figure 3. RV variation (period = 1190 d (± 35), starting from T_0 = JD 2454170) of ARAS data in Fig. 1.

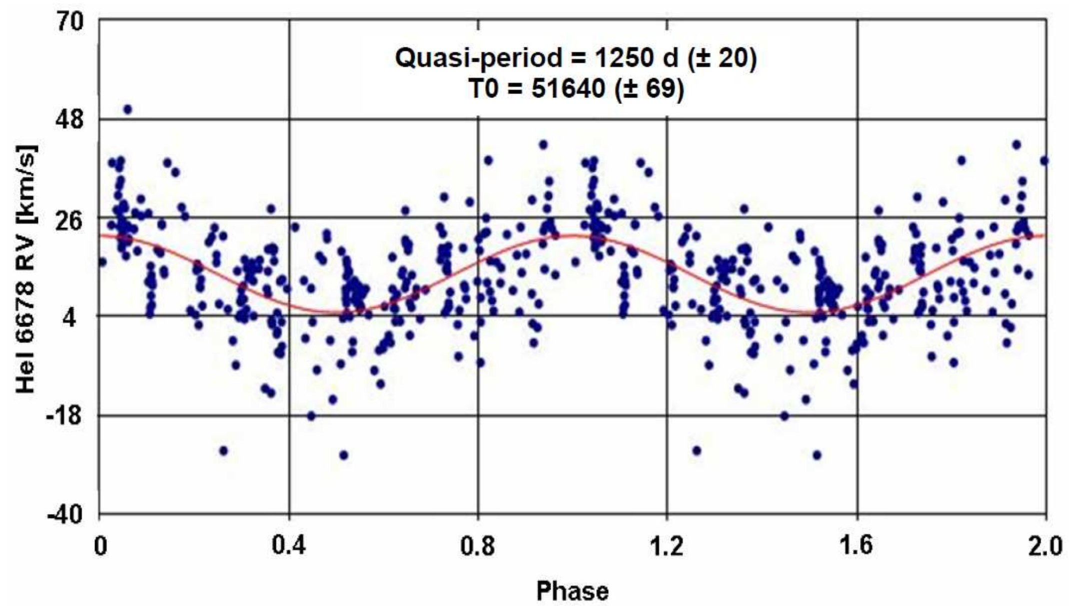

Figure 4. RV variation (period = 1250 d (± 20), starting from T_0 = JD 2451640) of the ARAS & Ruzdjak et al. (2009) data in Fig. 1.

Such a profile could be the result of stellar rotation and dark or bright regions (star spots) on the surface of the star (Yang et al. 1990; Balona 1991, 1995), or by circumstellar material orbiting the primary component (Vogt & Penrod 1983; Harmanec 1989). Local density enhancement in certain regions between the circumstellar gas disk and the star could be another possible cause of this phenomenon.

Short-term RV measurements of the HeI 6678 line have been performed by the author with a LHIRES III spectrograph (R=17000) at the C14 telescope of the Vereinigung Sternfreunde Köln (Germany) on three nights: 2012/11/16, 2013/01/11 and 2013/01/12. We took ten individual spectra with exposure times between 300–350 s. The signal to noise ratio of the sum spectrum was in general > 1000.

The results of these RV measurements are shown in Figs. 5a-b and 6a-b. Figure 5a (top) shows the RV short-term behaviour of the HeI 6678 line during the nights 2012/11/16, 2013/01/11 and 2013/01/12. Figure 5b (middle) shows the result of a period analysis of the RVs, i.e. 0.499 days. Figure 6a (top) shows the RV short-term behaviour of the HeI 6678 line on two nights: 2013/12/02 and 2013/12/03. Figure 6b (middle) shows the result of a period analysis of the RVs, i.e. 0.469 days period, and Fig. 6c (bottom) shows the corresponding phase plot.

The spectrograph used for these measurements was firmly mounted on the telescope and moved with it. In order to take into account possible effects of flexture, the author measured the RV of the Hα line in the spectrum of Aldebaran (α Tau, dec = +16°) on a similar hour angle. The results are shown in Fig. 7.

The spectra were likewise evaluated with the mirror method. As can be seen, there is a small RV trend with increasing hour angle, in the order of 1km/s, a magnitude (smaller than the RV variation) which is negligibly small compared with the RV variability in ζ Tau. The error bar indicates the reproducibility accuracy of repeated evaluations (3 times).

[3] `http://astrogea.org/soft/ave/aveint.htm`

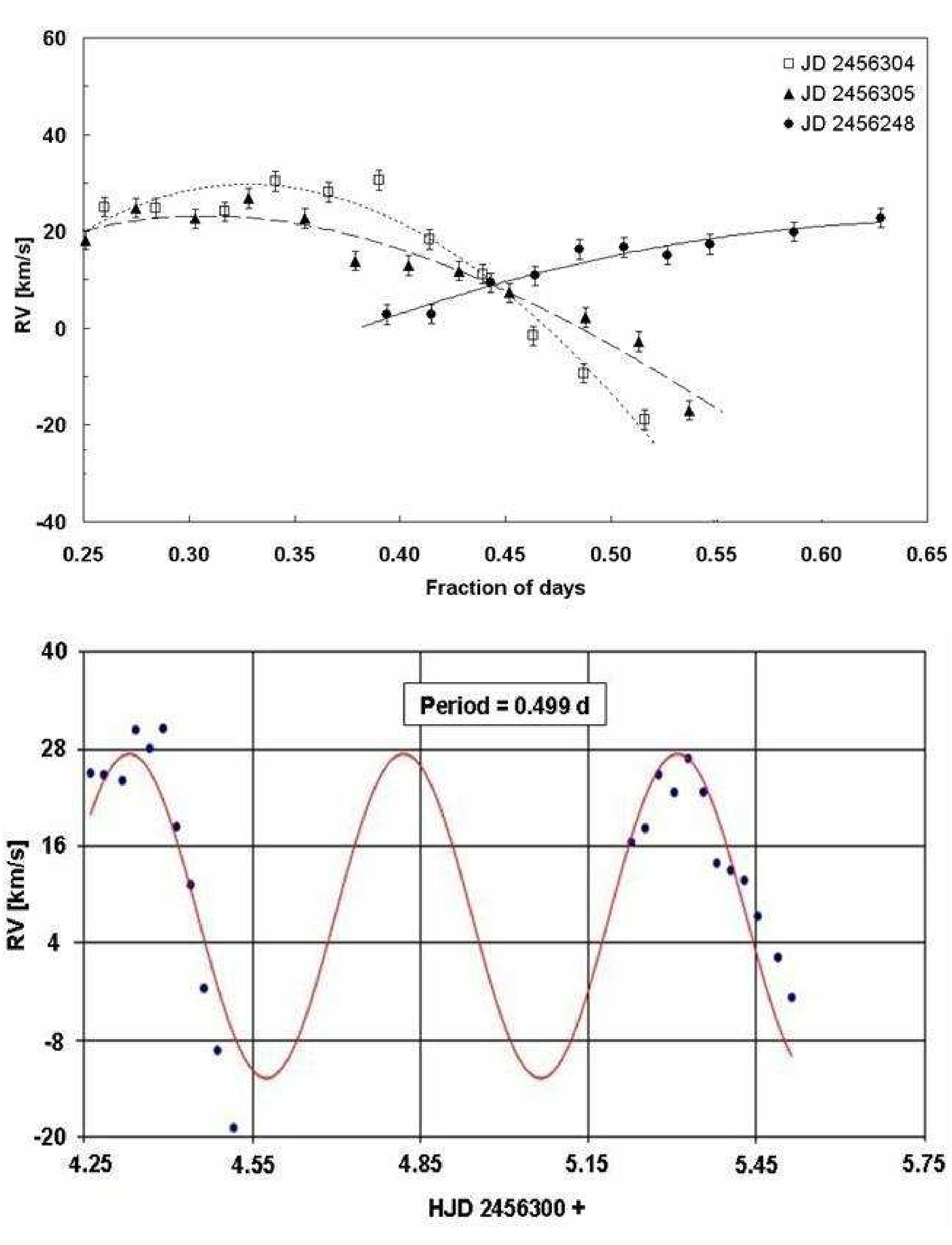

Figure 5. Short-term RV observations of the HeI 6678 line on three nights: 2012/11/16, 2013/01/11 and 2013/01/12.

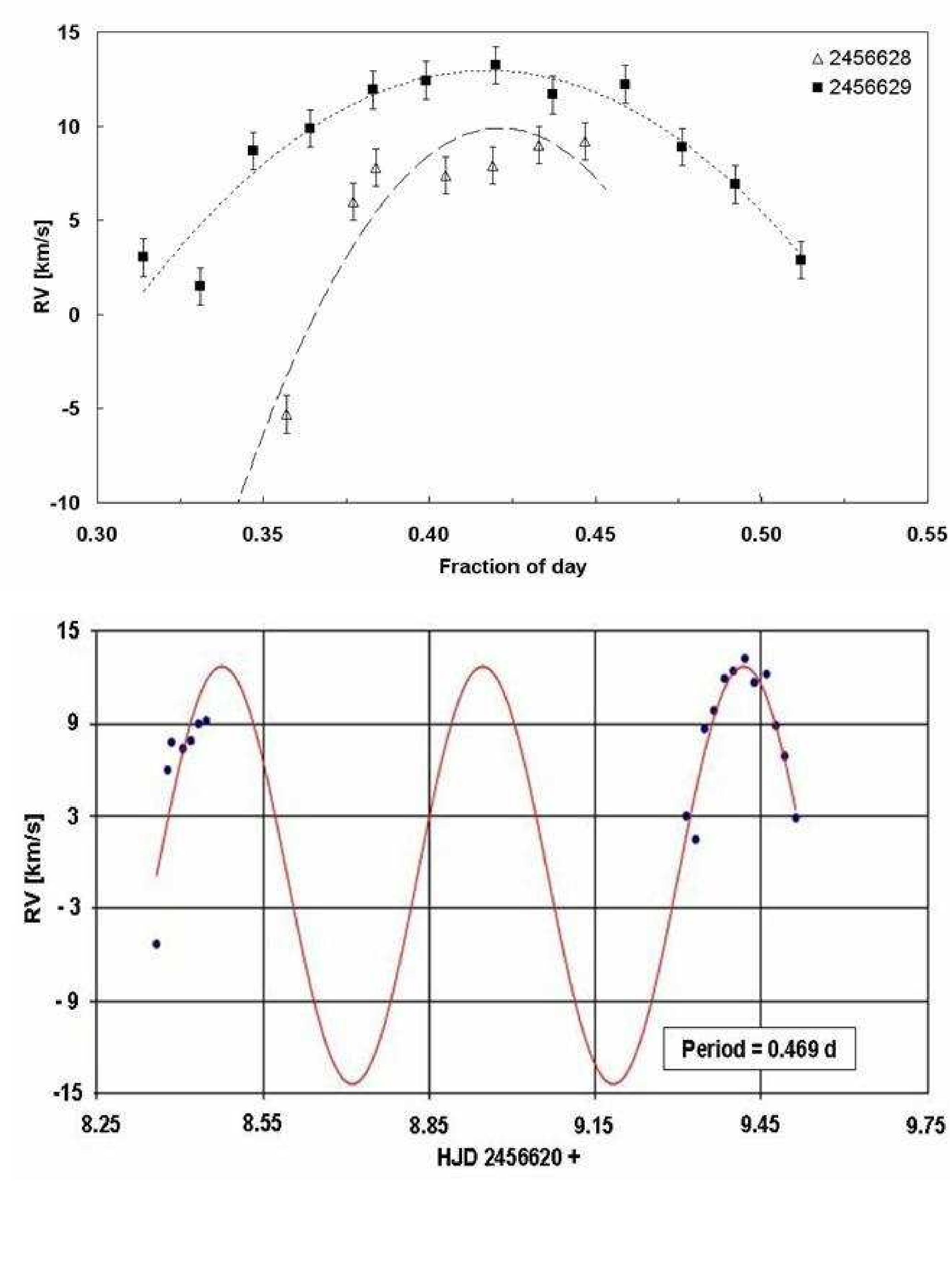

Figure 6. Short-term RV observations of the HeI 6678 line on two nights: 2013/12/02 and 2013/12/03.

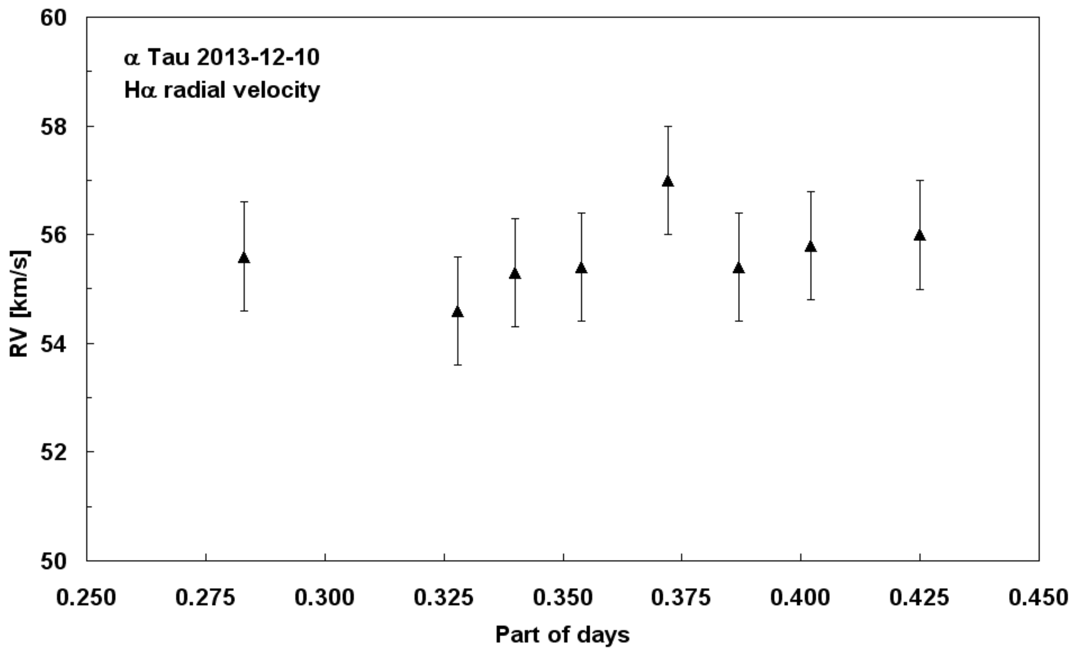

Figure 7. Check measurements of the RV stability at α Tau for comparable hour angles of ζ Tau.

Discussion

Attempts to detect long-term cyclic RV variations of the HeI 6678 absorption line in the spectrum of ζ Tau (Stefl et al. (2007) found quasi-period = 1503 d; Ruzdjak et al. (2009) found quasi-period = 1325 d ($\pm$ 67); we found quasi-period = 1190 d ($\pm$ 35)) points out that the long-term RV period at least since 1993 has constantly decreased. We also confirmed the overlaid medium-term RV period of 133 d corresponding to the orbital period of the binary already established in the past by Harmanec (1984), Ruzdjak et al. (2009), Pollmann, Mauclaire & Bücke (2012). Finally, we also distinguished short-term RV variations. All, long-, medium- and short-term variations have to be taken into account for a complete study of the variability of ζ Tau.

Whether the short-term cyclic variations we found are connected with the assumed combination of stellar rotation and dark or bright ranges (spots) on the surface, or with orbital circumstellar material around the primary star (as mentioned above) remains unclear. We cannot conclude on the nature of these variations from a study of just one line, therefore we intend to extend this study in the future.

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