

# Long-term Radial Velocity Monitoring of the HeI 6678 Line of $\zeta$ Tauri

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**Abstract** The binary star  $\zeta$  Tau, one of the brightest Be stars in the northern sky, shows cyclic behavior in the radial velocity (RV) variations on several distinct time scales. The star shows cyclic behavior in the radial velocity of, among others, the HeI 6678 absorption line. With an investigation period of approximately 15 years (December 2000 to February 2016) we have been able to compare three time intervals: quasi-quasi-period = 1503 d in Stefl *et al.* (2007) for 1993–2005, quasi-period = 1325 d in Ruzdjak *et al.* (2009) for 2001–2008, and quasi-period = 1190 d this paper for 2008–2016. The last quasi-period (1190 d ( $\pm 35$ )) points out that the quasi-period found for RV data since 2003 has constantly decreased.

## 1. Introduction

The binary star  $\zeta$  Tauri, 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-day orbital quasi-period established by Harmanec (1984). Its orbital RV variations are superimposed on the cyclic long-term and short-term ones.  $\zeta$  Tau also shows cyclic behavior in the radial velocity of, among others, the HeI 6678 absorption line. As far we know the first long-term investigation (time quasi-period 1993–2005) of the RV of the HeI 6678 absorption line was performed by Stefl *et al.* (2007). The result of that monitoring until circa 2007 led to a long-term quasi-quasi-period of 1503 days.

## 2. Observations

The spectra presented here for the RV measurements of the HeI 6678 line were taken at different locations with a 20-cm Newtonian and a 40-cm Schmid-Cassegrain telescope. Spectrographs with spectral resolving power of 10,000 to 20,000 were used. The signal to noise ratio of these spectra was of the order of magnitude  $S/N = 200\text{--}300$ . The spectra have been reduced with standard procedures (instrument response, normalization, wavelength calibration) by using the program VSPEC (Desnoux 2016). 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.

## 3. Long-term changes

With our much longer investigation quasi-period of approximately 15 years (December 2000 to February 2016) we have been able to compare the 1503-day quasi-period of Stefl *et al.* (2007) with our results. Such a long investigation quasi-period was possible because we were able to combine radial velocity data from Ruzdjak *et al.* (2009) with our data of the Astronomical Ring for Access to Spectroscopy (ARAS) group (2016). This long-term monitoring is shown in Figure 1. In order to recognize the separate cyclic behavior of the Ruzdjak *et al.*

data and the ARAS data, the corresponding separate phase plots are shown in Figures 2 and 3. The overlay of both quasi-periods is shown in Figure 4. For this analysis the program AVE (AVE Software 1999) was used.

Altogether three time intervals are now for a comparative investigation available: 1) the 1503-day quasi-period in Stefl *et al.* (2007) 1993–2005; 2) the 1325-day quasi-period in Ruzdjak *et al.* (2009) 2001–2008; and 3) the 1190-day quasi-period this paper 2008–2016.

The comparison of Figures 2, 3, and 4 points out that the quasi-period found for RV data since 2003 has constantly decreased, as well as the amplitude of the RV variations. Even more

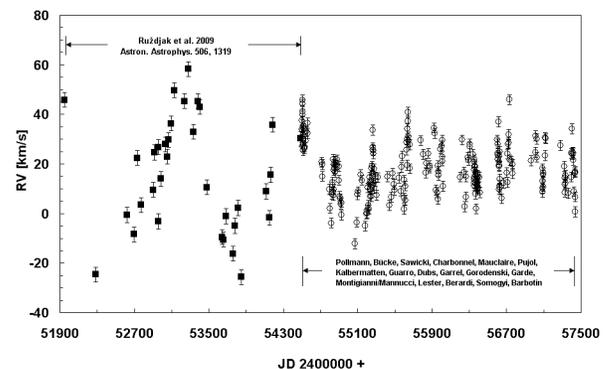


Figure 1. RV Long-term monitoring of the HeI6678 line from December 2000 to February 2016.

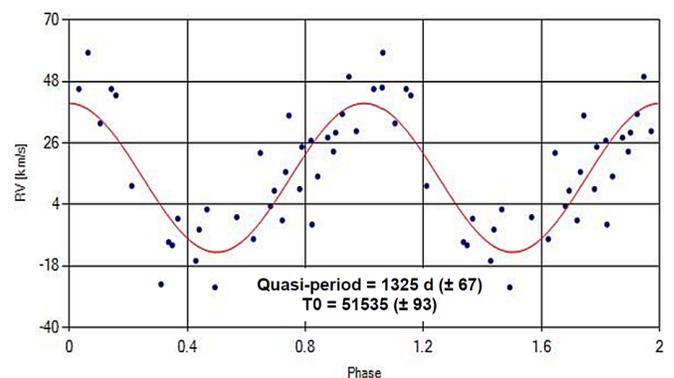


Figure 2. RV variation (quasi-quasi-period = 1325 d ( $\pm 67$ )) of Ruzdjak *et al.* (2009) data in Figure 1.

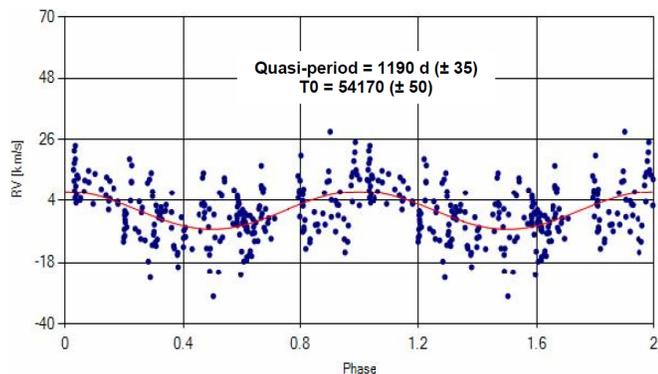


Figure 3. RV variation (quasi-quasi-period = 1190 d ( $\pm 35$ )) of ARAS (2016) data in Figure 1.

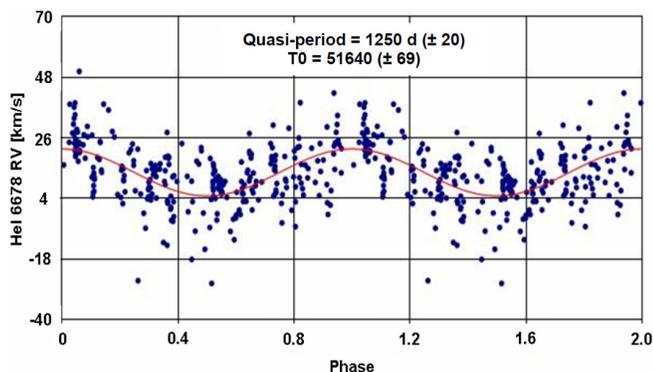


Figure 4. RV variation (quasi-quasi-period = 1250 d ( $\pm 20$ )) of the ARAS (2016) and Ruzdjak *et al.* (2009) data in Figure 1.

complicated behavior of the RV variation of H-alpha and or HeI profiles is documented in Ruzdjak *et al.* (2009; their Figure 2).

#### 4. Orbital variations

One of the most interesting studies of the RV variations in the spectrum of  $\zeta$  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 ( $\pm 0.9$ ) obtained with different analysis programs (Pollmann *et al.* 2012) are very close to those of Ruzdjak *et al.* (2009) for the most important parameters.

#### 5. Discussion

The attempts to detect long-term cyclic RV variations of the HeI 6678 absorption line in the spectrum of  $\zeta$  Tau—Steffl *et al.* (2007) quasi-period = 1503 d; Ruzdjak *et al.* (2009) quasi-period = 1325 d ( $\pm 67$ ); this paper, quasi-period = 1190 d ( $\pm 35$ )—point out that the quasi-period found for RV data since 2003 has constantly decreased, as documented in Ruzdjak *et al.* 2009 (their Figure 2). In addition, it is necessary to take into account the overlaid medium-term orbital RV period of 133 days (Harmanec 1984; Ruzdjak *et al.* 2009; Pollmann *et al.* 2012).

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