ISSN 1845–8319

RECENT OBSERVATIONS OF ζ TAU

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Abstract. We report a recent decrease of the Hα emission strength in a bright Be shell star ζ Tau. The decrease of emission is caused presumably by depletion of the material in the circumstellar disc which resulted in disappearance of pronounced long term radial velocity and V/R variations. The period analysis of the equivalent width data gives the period of 132 days for the Hα equivalent width and about 70 days for the He I 6678 Å line.

Key words: ζ Tau

1. Introduction

We present the recent spectroscopic and photometric observations of the frequently observed Be shell star ζ Tau (HD 37202, 123 Tau, HR 1910). It is one of the brightest Be stars in the northern sky (V=$2^{\rm m}\!\!.7$-$3^{\rm m}\!\!.2$ var.), exhibiting spectral, brightness and colour variations on several distinct time scales. ζ Tau is also a spectroscopic binary with an orbital period of 133 days, and its orbital radial-velocity (RV) variations are superimposed on the cyclic long-term ones. ζ Tau also exhibits the long-term V/R and emission-line strength changes. The star was the subject of a large number of studies which are summarized in Ruždjak *et al.* (2009). Most recently ζ Tau was studied using optical interferometers which are capable of resolving the envelope surrounding the star (see e.g., Schaefer *et al.*, 2010; Kraus *et al.*, 2012).

2. Data and Reduction

In this work we combined the new observations with the ones previously published in Ruždjak *et al.* (2009). Majority of the new spectra were obtained using the 40-cm Cassegrain telescope of the "Vereinigung der Sternfreunde Köln" with a 2400 grooves/mm grating spectrograph attached.

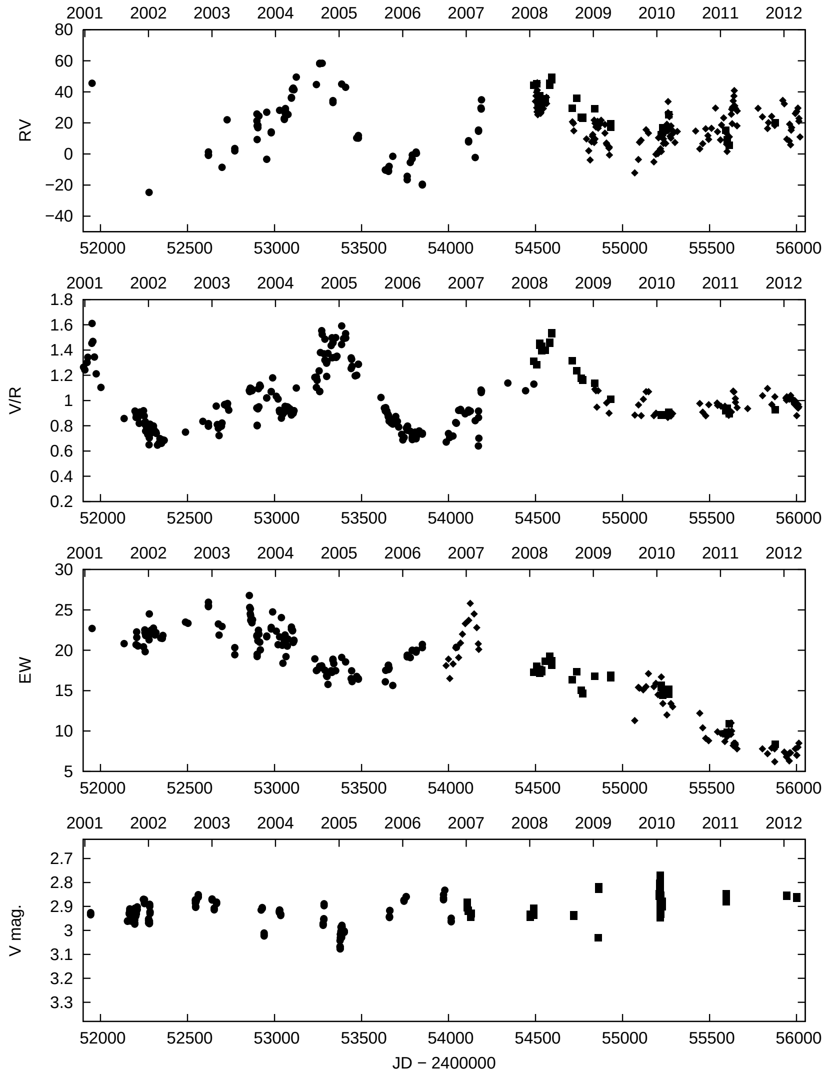

Figure 1: Long term RV, V/R, emission and brightness changes during this century. Different symbols denote: circles - data from Ruždjak *et al.* (2009), squares - Ondřejov spectra and Hvar photometry and diamonds - Pollmann spectra.

The reciprocal linear dispersion of the spectra was 13.3 Å/mm at Hα and R≈14000. The spectra were reduced using MaximDL software[1] and mea-

[1] http://www.cyanogen.com

sured by using the MK32 stellar spectral synthesis program[2]. The spectra covered the red part of the spectrum containing Hα and He I 6678 Å lines. In addition we used 35 spectra obtained with the Ondřejov 2-m telescope. Those spectra were reduced using IRAF and measured using SPEFO (Horn *et al.*, 1996; Škoda, 1996). Majority of radial velocities are measured using mirrored profile fit. Additionally, Gaussian fit was used in some of the spectra.

Photometric observations were obtained with the Hvar Observatory 65-cm telescope and were reduced to the standard UBV system using HEC22 code (Harmanec and Horn, 1998)

3. Results and Discussion

Changes of RV, V/R ratio, Hα emission equivalent width, brightness and $U-B$ and $B-V$ colours of ζ Tau in the first decade of the 21^{st} century are shown in Figures 1 and 2. It can be seen that the strong decrease of Hα equivalent width was accompanied by mild brightness increase and disappearance of pronounced long term RV and V/R variations. Both $U-B$ and $B-V$ colours became bluer during the emission decrease, and the star moved toward an earlier spectral type on the $(U-B)-(B-V)$ colour-colour diagram. This all is consistent with the decrease of the radius and density of the circumstellar disc from which the emission originates. The change of brightness, if present, is small. This might be caused by the balance between the increase of brightness caused by the improved visibility of the star and the decrease of brightness of the disc itself.

A similar decrease of emission strength was observed during the 1980-ies (Mon *et al.*, 1992; Ballereau *et al.*, 1992; Guo, 1994). The quiet stage without presence of pronounced long term variations lasted for about 10 years after which the disc was replenished with new material. During the time intervals when no pronounced long term variations are present, it should be easier to detect variations on other timescales. Therefore we performed period analysis of the V/R and equivalent width data from last three seasons. This was performed using the Period04 software (Lenz and Breger, 2005). While no convincing period was found analysing the V/R data, a period of 132 days was found for changes of Hα equivalent width and a period of about 70 days for He I 6678 equivalent width data. The phase plots of individual

[2]http://www1.appstate.edu/dept/physics/spectrum/spectrum.html

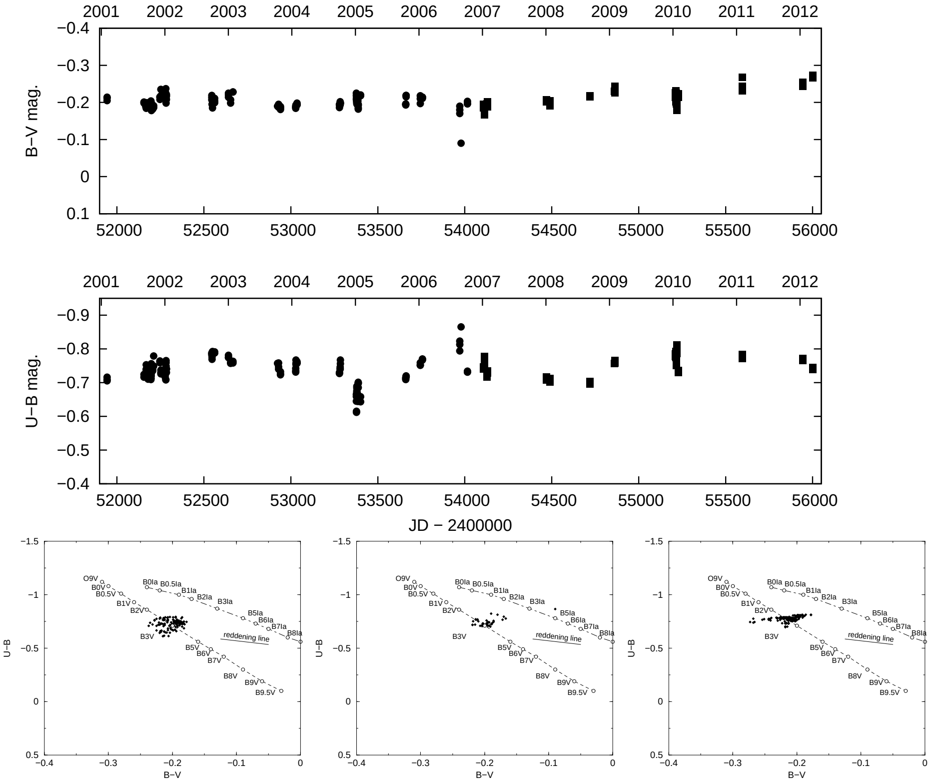

Figure 2: Long term colour changes of ζ Tau together with $(U-B)-(B-V)$ colour diagrams. The colour-colour diagrams are constructed for the time intervals 2451943–2453402, 2453660–2454491 and 2454719–2456003, from left to right.

Hα equivalent width measurements are shown in Figure 3. The longer term variations (C) were modelled as a sum of five sine waves.

The period of 132 days found for changes of the Hα equivalent width agrees well with the orbital period of the binary system. The decrease of emission happens in the vicinity of the orbital phase 0.5. The decrease could not be seen in the latest data. This might be due to depletion of the disc or because latest data are measured on low resolution spectra and the larger errors are making the effect invisible. According to the ephemeris given in Ruždjak *et al.* (2009), at this phase the line connecting the stars is perpendicular to the line of sight, so the observed decrease of emission can be explained by material located near the Lagrangian point L4. Alternatively,

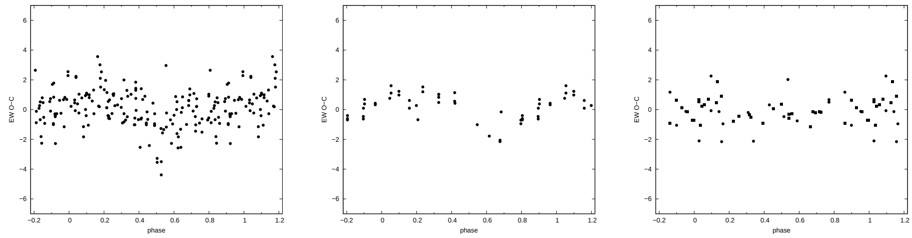

Figure 3: Phase plots for individual Hα equivalent width observations. From left to right: data for electronic spectra from Ruždjak *et al.* (2009) (JD 249049–2453850), Ondřejov spectra (JD 2454490–2455878) and Pollmann spectra (JD 2455091–2456013) are shown. Right panel: data recorded before JD 2455495 are represented by circles and data after JD 2455546 are represented by squares. The ephemeris T=HJD 2447025.6 + (132$^{\mathrm{d}}$.987 $\times$ E was used.

the observed effect can be explained by interplay of density enhancement precession and disc tilt changes.

Since ζ Tau is a binary, any tilt of the disc will be modulated by tidal force of companion. This can manifest itself as nodding (Schaefer *et al.*, 2010). If P_{prec} and P_{orbit} are precession and orbital periods, then the nodding period is given by:

$$P = \frac{P_{prec} \cdot P_{orbit}}{2(P_{prec} - P_{orbit})} \tag{1}$$

In the case of the precession period of 1428 days and orbital period of 133 days, the nodding period is 73.3 days. This hypothesis is corroborated by the fact that the ~70 day period is observed in absorption lines (He I 6678 is an absorption line and the V/R ratio is strongly modulated by additional absorption cores when complex profiles are present) which originate in outer parts of the disc, i.e, the parts of the disc that are more affected by tidal force.

4. Conclusion

During the last three observing seasons the equivalent width of the Hα emission of the Be shell star ζ Tau decreased significantly that lead to disappearance of pronounced long term radial velocity and V/R variations. The emission decrease was accompanied by a mild brightness increase and blueing of $U - B$ and $B - V$ colours. This is consistent with the depletion of the circumstellar disc. If the depletion of the disc continues, it is possible that ζ Tau will lose its line emission completely. On the other hand, new material might be supplied to the disc and emission strength will increase.

The period analysis of the observed variations of the Hα and He I 6678 lines gives the periods of 132 and 70 days, respectively. These periods are possibly caused by eclipses of the emitting part of the disc by some material near the Lagrangian point L4 (132 day period) and nodding as a consequence of tidally modulated precession of the disc tilt (70 day period).

Acknowledgements

We wish to thank P. Hadrava, P. Harmanec, D. Korčakova, P. Koubský, P. Škoda, M. Šlechta and M. Wolf for obtaining and providing the Ondřejov spectra and the referee for helpful comments and suggestions.

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