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MASS AND PRECESSION OF THE DISK IN ζ Tau

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1 Introduction

ζ Tauri (HD 37202, HR 1910) is a well known classical Be binary star with a gaseous circumstellar disk. Observations of the Hα emission line of that star reach back many decades. Since ζ Tau is a binary, any tilt of the disk will be modulated by the tidal force of the companion. This can manifest itself as nodding. During the observing period from approximately JD 2455500 to JD 2457500 the equivalent width of the Hα emission of ζ Tau decreased significantly what led to a depletion of the circumstellar disk. The depletion of the circumstellar disk led to a significant decrease of the equivalent width of the Hα emission of ζ Tau (Ruzdjak et al. 2009). The disk matter reached its minimum at JD 2456359, but afterwards new material was supplied into the disk, and the emission strength increased. The study presented here investigates how the minimum of the disk mass affects the precession period. In addition to monitoring the Hα equivalent width of ζ Tau, studying the time behavior of the central absorption (CA) core of that emission profile is also of interest. The depth of CA is defined as the difference between the local continuum level (equal to unity) and the minimum value at the line minimum intensity (Fig. 1). While the Hα emission line samples the disk as a whole, the region probed by the shell lines (CA) is restricted to the line of sight. The diagnostics they provide should not be neglected, as their properties (absorption depth) reflect the structure and dynamics of the disk in the observers direction (Escolano et al. 2015).

In the literature it is assumed (Schaefer et al. 2010) that the CA is caused by a different angle of the disk plane related to the observer's line of sight, as a consequence of the disk precession around the primary star. It is also known that the precession of the disk depends on its size (radius) and its mass due to gravitational effects (Katz et al. 1982, Larwood et al. 1996, Lubow & Ogilvie 2001).

2 Observation and Results

The Hα spectra were obtained with 0.2 m to 0.4 m telescopes with a long-slit (in most cases) and echelle spectrographs with resolutions of R = 10000–20000. All spectra included the 6400–6700 Å region, with a S/N of $\sim$ 100 for the continuum near 6600 Å. The

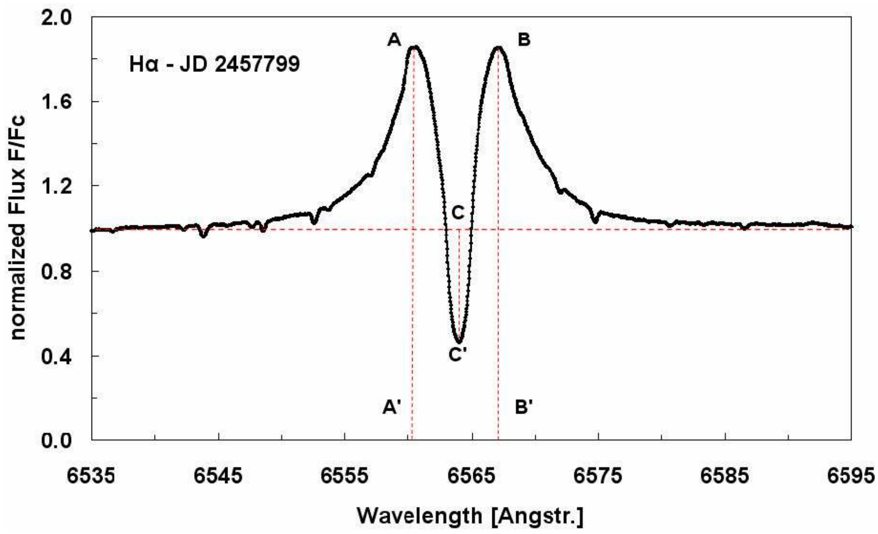

Figure 1. Measured quantities illustrated on a Hα line profile: (AA) and (BB) emission peaks, depth of the central absorption (CC). The horizontal line marks the normalized continuum.

spectra have been reduced with standard professional procedures (instrumental response, normalisation, wavelength calibration) by using of the program VSpec and the spectral classification software package MK32. The EWs reported here included the entire Hα emission profile (including both red and blue components) from 6540 to 6590 Å. Figure 2 shows the long-term monitoring of the Hα equivalent width (EW) as a result of collaboration between amateurs (mostly members of the ARAS spectroscopy group) astronomers. Figure 2 represents the time interval which includes the EW historical minimum on JD 2456359.

The higher disk mass (top-left-frame) in Fig. 3 corresponds to a precession period of (approximately) 1430 days (Schaefer et al. 2010).

3 PDM analysis and discussion

The bottom-right red frame in Fig. 3 also shows that within the time window highlighted in Fig. 2 the disk mass minimum coincides with the EW minimum. High-resolution spectra of ζ Tau were taken during the time window from JD 2455640 (March 2011) to JD 2457799 (February 2017) in collaboration with the ARAS group. This time window contains the time interval where the mass of the disc of ζ Tau reached its lowest value within the whole time this star has been observed. From those spectra the depth of the CA within the Hα emission profile was measured and the resulting time series is shown in Fig. 4.

In other words, the CA investigation presented here was performed within a time window when the disk mass of ζ Tau was the lowest for the entire time of the star studies. Therefore a logical question is: How does the disk mass minimum depend on the precession period during that time section?

Figure 4 shows the Hα CA time series (the time window shown in red in Figs. 2 & 3) of the normalized high-resolution spectra from JD 2455640 to JD 2457799. Phase

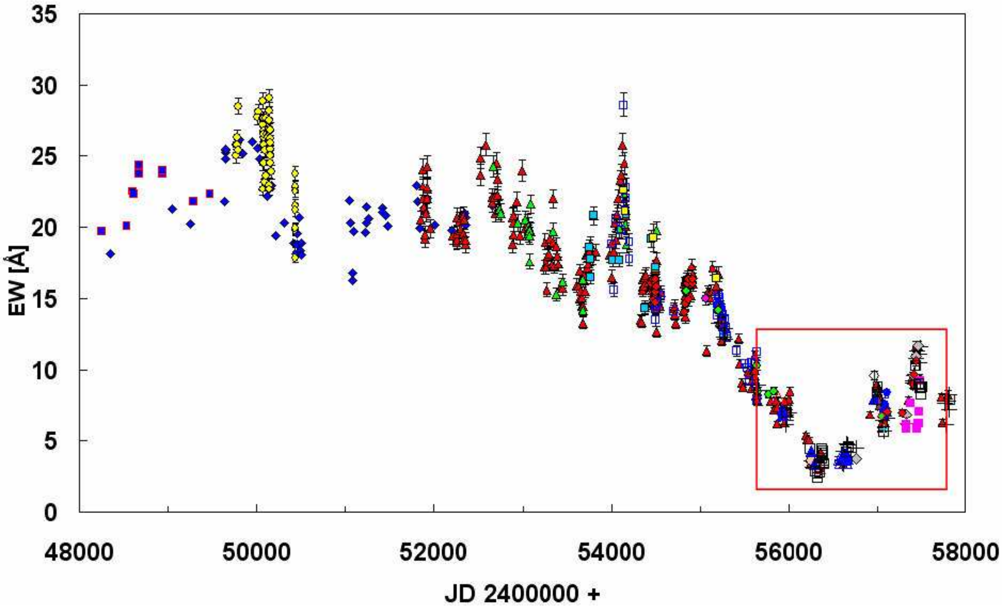

Figure 2. Long-term monitoring of the Hα equivalent width (EW). The red frame represents the time window of the historical EW minimum at JD 2456359. The time of the minimum around JD 2456300 corresponds to ~JD 2456650 in time scale of Fig. 3.

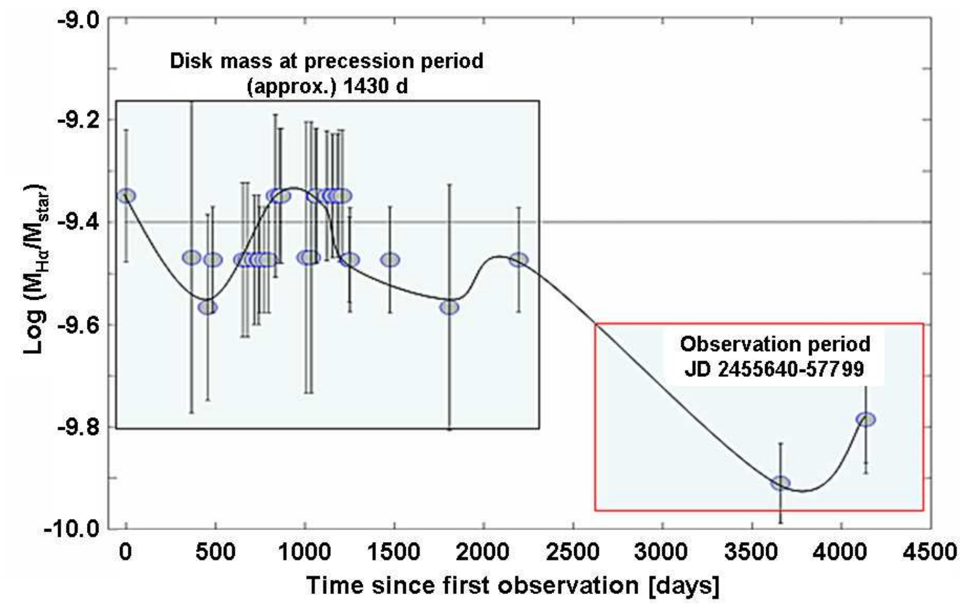

Figure 3. Disk mass versus time since the first observation, taken from Tycner & Sigut, 2015. The zero-time corresponds to JD 2452977 (2003/12/03). The red frame corresponds to the same time window highlighted in Fig. 2.

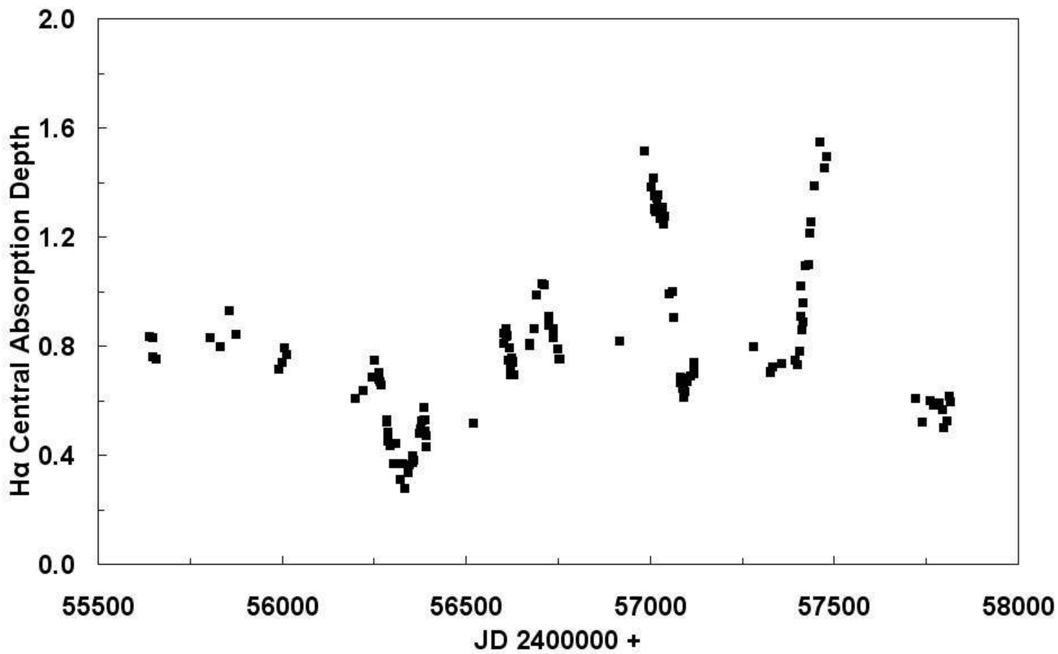

Figure 4. The CA in Hα of ζ Tau is a function of time from JD 2455640 to JD 2457799 (red frame in Figs. 2 & 3).

dispersion minimization (PDM) analysis on the time series was performed with the use of the program AVE (Barbera 1998), and produced the phase plot of Fig. 5 with the discriminant factor plotted in Fig. 6.

In contrast to Escolano et al. (2015), who found only marginal CA variations of the shell lines between approximately JD 2449000 and JD 2455000, the CA, as measured in this work, covered a considerable range of F/F_c from 0.28 to 1.55. The PDM analysis led to a CA period of 442 ± 5 d. But the question is, what are the mechanisms responsible for that periodic behavior? The periodic tilt of the disc as an effect of the precession could be manifested as a nodding, and could subsequently affect the variability in CA. Also, it is well known that the precession is, among other factors, a function of mass. Nevertheless it remains unclear whether the Hα CA period of ζ Tau found herewith can be understood as a consequence of changed precession period and changed disk mass, as shown in the plot from Tycner & Sigut (2015) in Fig. 2. But if we attribute the CA variability to a nodding caused by disk tilting, then this is the precession period. This investigation will continue during the coming years.

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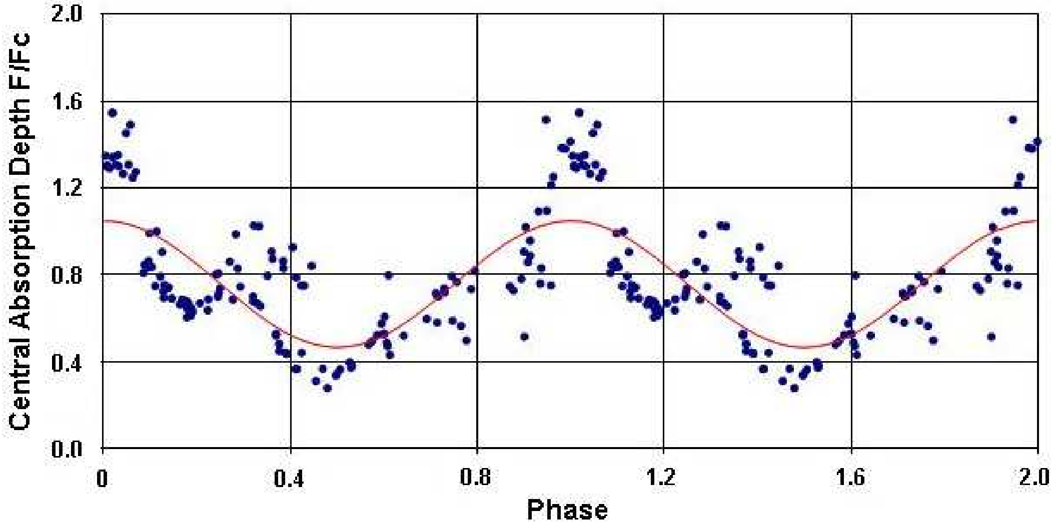

Figure 5. Phase plot of the PDM analysis in Fig. 6; period = 442 d (±5), Epoch = JD 2455571 (±16).

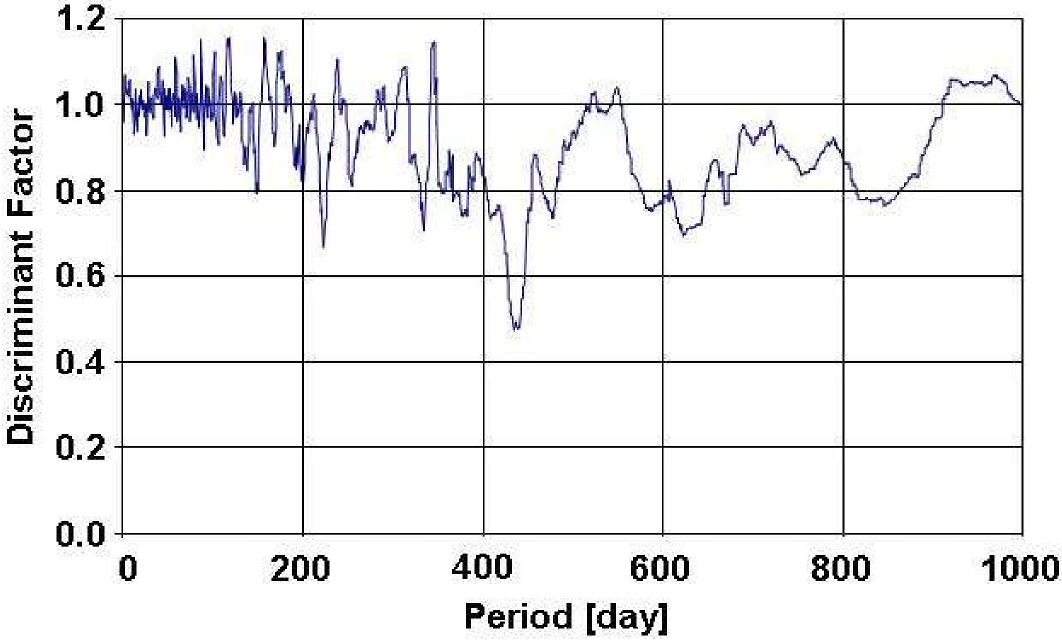

Figure 6. PDM analysis of the time series in Fig. 4.

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