

H α Line Profil study of the Be binary star ζ Tauri

Ladies and gentlemen,
with my talk I would like to introduce long-term measurements of certain parameters of the H α line profile of zeta Tauri. Some of these parameters have been combined with certain studies of the professional astronomy which underlines the sense and the meaning of collaboration of amateurs with the professionals.

Fig. 1

ζ Tau, is one of the brighter Be stars in the northern sky, with a visual brightness of 2.7 - 3.2 mag, and is now a well-known and frequently observed object, with observations of the H α emission line, dating back many decades.

The star shows significant variability, in its brightness, in its spectrum, and in its color on several timescales. In addition, ζ Tau is also known as a spectroscopic binary star, with an orbital period of 133 days.

Fig. 2

The H α line profile normally, shows the two emission components separated, by a so-called central absorption core.

In ζ Tau both peak strengths, do not vary at the same time, so that the ratio of the height of the violet, to the height of the red component, the V to R ratio, changes cyclically from V higher than R, to V lower than R, and back.

Fig. 3 (Animation)

Caused by a radial perturbation, the gas atoms move on eccentric orbits, creating an one-armed density wave in the common periastron, keeping this global pattern stable. In ζ Tau now, this density wave preceedes around the central star, within a period of about 1500 days.

On of the consequences of this precession of the density waves is the cyclically changing of the V to R ratio, showing in the Fig. below.

Fig. 4

This Figure shows our V/R monitoring of the H α emission since 1991 to now. In general, periodic variations of the V/R ratio of ζ Tau, represents local density differences in the precessing Be star disk.

This monitoring shows a significant decrease in amplitude and period.

The observed, large V/R differences in the disk until 2010 became afterwards with time, more and more balanced, a process which is observable until now.

Both time sections, the strong V/R variability from April 1991 to January 2010 and from that time until now, did allow a period analysis, which leads in the first case to a dominant period of 1410 days (shown in the phase plot bottom left) and for the time section after January 2010 until now to a period of 133 days (shown in the phase plot bottom right).

This observed strong change of the V/R ratio in amplitude and period leads of course to the question of the physical causes.

Even if we know that the one-armed density wave of the disk is responsible for the 1410 day precession period, even we know that the 133 day period is caused by the orbital period of the companion, there is at present no plausible mechanism, which would be able to explain these sudden significant changes in amplitude and period.

Fig. 5

Occasionally the central absorption may become weaker or even disappear, so that the emission peaks may take on a rather complicated structure, and be split into sub-peaks, or appears as a triple peak structure.

Such a behaviour shows this overview from 2003 to 2015, an investigation of Tycner & Sigut, presented in August 2015 at an assembly of the IAU.

Although the reasons for the formation of these profile structures are not yet fully understood, today it is generally assumed that they appears only in the transformation phases from V lower than R to V higher than R, but not vice versa.

Fig. 6

Since ζ Tau is a binary star system, due to the tidal effect of the companion the inclination of the disc, and thus also its axis of rotation, is modulated.

(Animation)

This can manifest in a nodding motion, or by a wobbling movement of the disk axis, as the investigations by Gail Schaefer in 2010 shows in this illustration.

Fig. 7

If P_p is the precession period, and P_b the orbital period, then a "nodding period" may be given in this formular, developed by Schaefer in 2010.

$$P_n = \frac{1}{2} \frac{P_p P_b}{P_p - P_b},$$

With the known precession period P_p of 1430 days, and the orbital period P_b of 133 days, the "nodding period" is 73.3 days.

This hypothesis is supported by the fact, that in a joint study, performed by Thomas Rivinius from ESO and me from September 2000 to March 2007, a period of approx. 70 days could be detected, in the Helium absorption line at 6678 Angströms.

Fig. 8

Now, while the $H\alpha$ emission line captures the disk as a whole, the area covered by the central absorption line, reflects the structure and dynamics of the disk in the observers line of sight.

The possibility of diagnosis, opened up by this line, should not be neglected, since the variable absorption depth reflects the structure and dynamics of the disc in the direction of the observer.

The literature assumes, and here I want to mention again the publication of Schaefer, that the central absorption line is caused by different angles of the disk plane, relative to the line of sight of the observer, as a result of the disk precession around the primary star.

It is also known, described by Katz et al. in 1982, by Larwood et al. in 1996, and by Lubow & Ogilvie in 2001, that the precession of the disk due to gravitational effects, depends on its radius and its

mass.

Fig. 9

Our monitoring of the depth of the central absorption line for more than 7 years, here to see in the plot above, allows now the study of its variability of the time behavior.

On the basis of more than 220 high-resolution spectra of the ARAS spectroscopy group, this obvious cyclic variability has been evaluated in the sense of a periodic analysis.

In contrast to Escolano and co-workers in 2015, who found only marginal central absorption intensity variations of this shell line, in our studies the central absorption included the range in units of the relative intensity of the normalized continuum from 0.28 to 1.9.

This raises of course the question, which mechanisms are responsible for such a periodic behavior.

The periodic tilt of the disk, as a result of the precession of its rotational axis, could manifest as nodding, and thus affect the central absorption variability. This was just shown in the previous overview of Schaefer.

The period analysis, of our time series data, resulted in two period sections: a section with a period of 445 days and a section with a period of 171 days. The corresponding phase diagrams of both periods are shown in this Figure below.

According the equation of Schaefer et al. for calculation of the nodding period, and according the assumption of a constant binary period of 133 days during the investigation period presented here, one can assume that a mass change of the disk and hence a change of the precession period was responsible for the section of the 171 d period.

Fig. 10

In the following we have now tried to find out, if and how the disk mass affects the precession period.

The upper plot shows the long-term monitoring of the H α -equivalent width, as collaboration of amateurs with the professional astronomy since 1975.

It shows within the framed observation period the different levels of the equivalent width, with its historical minimum at March 2013 in window 2.

The lower plot shows the disk mass versus time from studies by Tycner & Sigut's interferometric measurements published in 2015.

The almost identical observation period of Tycner / Sigut's investigation to our EW-long-term monitoring shows in window 2, that the minimum of the disk mass coincides very well with the historical minimum of equivalent width.

By coincidence, the window 2 with the historical EW-minimum from March 2013 to April 2015 (24566043 - 2457120) in the upper EW-plot, matched in time very well with our monitoring of the central absorption.

So that we can match the found central absorption period of 445 days directly to the historical minimum of the disk mass.

The higher disk mass area in Tycner & Sigut's investigation corresponds on the other hand to the precession period of approximately 1430 days, found by Schaefer et al.

If we consider the nodding movement or the disk tilt as the cause of the CA variability, then the precession period of 445 days would at least be applicable for the disk mass in the time window examined here.

Since it is known that precession is among others a function of the mass, future investigations could clarify to what extent the precession period of the disc rotation axis found here, with meanwhile slowly increasing EW or disk mass, will likewise change to correspondingly higher periods.

This would be expected anyway. Corresponding investigations will be continued during the next few years.

Thank you.