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Hα OBSERVATIONS OF ζ TAURI

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Be stars are well known to be variable on virtually all timescales, reaching from minutes to dozens of years. For the study of the latter, long term data collections as homogeneous as possible are necessary.

The professional astronomer, however, is often hampered in the study of intermediate- to long-term time scale processes as in Be stars. The reasons are the observational practices usually employed at professional observatories, which typically are not suited for observing a bright object with execution times of a few minutes only about every other week for several seasons; as well as the funding timescales, making it hard to start the collection of a long-term database that does not promise a significant number of publications within the first few years.

On the other hand, the interpretation of time-limited observations with professional resources, such as interferometers, polarimeter, or high-resolution spectrographs, in almost all cases can profit from the knowledge of the disc state in the course of the long-term evolution.

The problems in long-term data acquisition for the professional astronomer, however, open a promising field for the dedicated amateur. Amateur spectrographs at relatively small telescopes of about 20 cm diameter, equipped with CCD-detectors meanwhile reach resolution powers well above 10 000 and and are sensitive enough to reach many of the brighter Be stars. This work describes a database worth of more than five years of observation of the Be star ζ Tau.

ζ Tau is a well known frequently observed object. Observations of the Hα emission line reach back many decades. This work amends those series by the results of Hα-observations taken between late 2000 and early 2006, i.e. six full observing seasons. All observations were made with a 20 cm Schmidt-Cassegrain telescope. From Nov. 2000 to Apr. 2003, a slitless prism-spectrograph with a dispersion of 43 Å/mm was used ($R \approx 8000$), from Sep. 2003 to Apr. 2006 a slitless grating one with a dispersion of 27 Å/mm and $R \approx 14\,000$.

The spectra were normalized by hand-selecting a number of continuum points through out the spectrum from 6500 to 6700 Å and then applying a spline fit through those points. The wavelength calibration was derived using telluric features in the region of Hα, reaching an accuracy of about 0.1Å on those features when compared to wavelengths derived with high resolution instruments (telluric wavelengths measured with UVES were kindly provided by R. Hanuschik, priv. comm.).

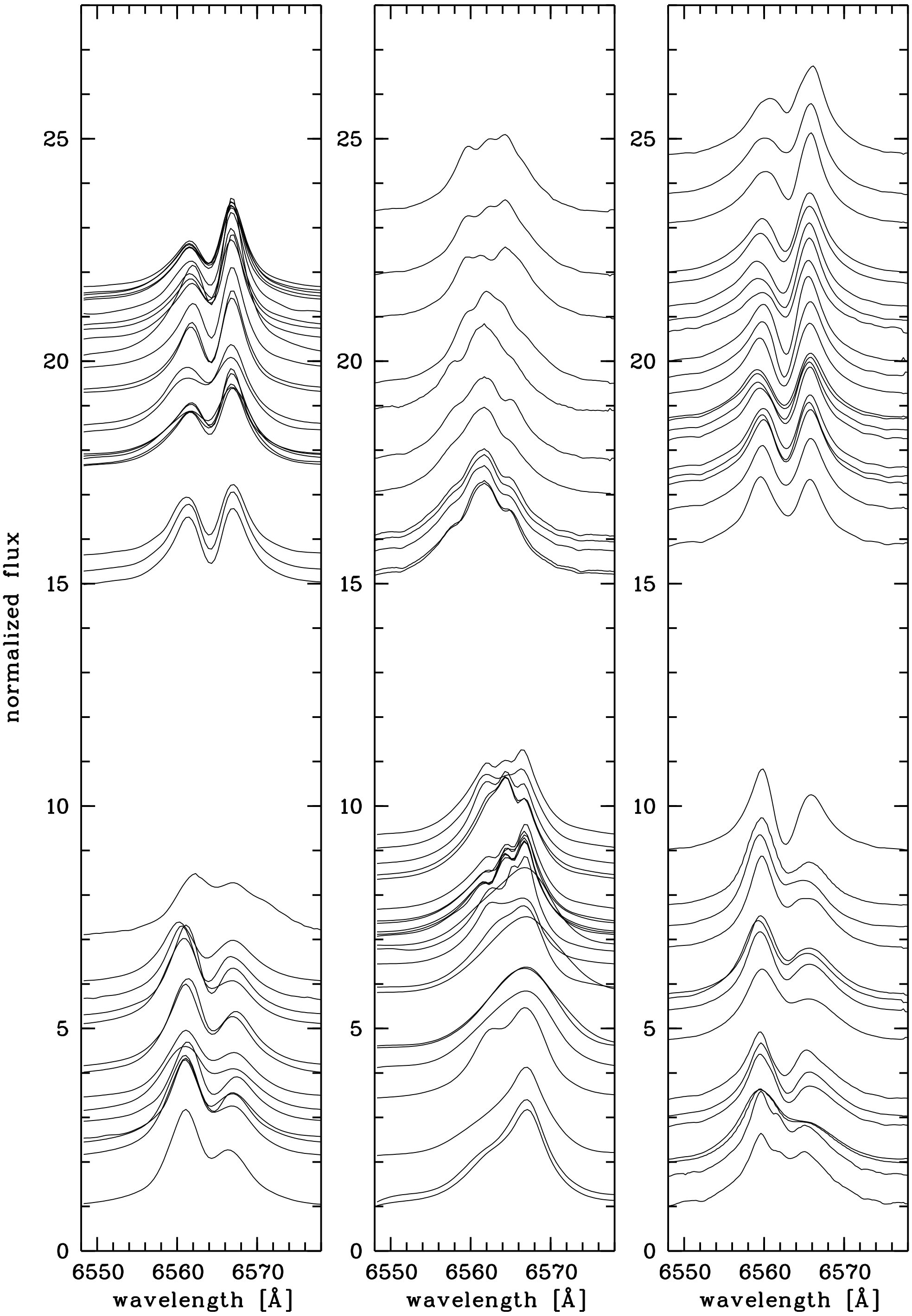

Figure 1. All Hα profiles measure from late 2000 to early 2006. The vertical offset of the profiles is proportional to time and corresponds to 25 days per continuum unit. The lowermost spectra date from Nov. 1, 2000 (left), Sep. 9, 2002 (middle) and Aug. 23, 2004 (right), respectively.

The Hα spectra obtained by EP will be published electronically together with this communication in the form of ASCII tables. (The files are available through the IBVS website as `5813-t1.txt` and `5813-t2.txt`.) The first column of each table is holding the wavelength, while the first row notes the Julian date (minus 2 400 000) at mid exposure.

Equivalent width. In the normalized and calibrated spectra, the Hα equivalent width was measured by integrating the normalized spectrum in the range from 6520 to 6600 Å. Comparison of the data presented here with quasi-simultaneous spectra taken by Rivinius et al. (2006) confirm the scientific reliability of the present data, both in terms of profile shape (see Fig. 1 vs. Rivinius et al.) and equivalent width (see Figs. 2 and 3).

In theory, the measured equivalent width should be independent from dispersion. In practice, this is typically not the case, however: spectra with lower resolution, i.e. the ones with 43Å/mm, differ systematically from higher resolution data. In our observations, this can be seen from the available quasi-simultaneous observations with professional instruments. We attempt no correction of this effect, but rather point out its existence in order not to over-interpret the data.

In general, the accuracy of amateur instruments for measuring equivalent widths currently is hardly better than about 5 %.

To check the accuracy obtained, both for the equivalent width and the peak height ratio of the emission, a series of observations of standard stars was obtained in three nights, 8h worth of observations in total. For both quantities, the RMS-error of the individual measurements in a single night was below 3 %. No correction for the contamination due to telluric vapour lines to the total EW was attempted, as the effect is, with about 1 %, well below the measuring accuracy.

Fig. 2 shows the measurements of this work combined with various published values from about 1975 to 2006 to illustrate the longest variation time scale present in ζ Tau, while Fig. 3 shows a closeup centered on the data derived in this study. The EW currently is on a slow, but steady decline, similar to the one seen before 1990.

Peak height ratio. The Hα-profile normally shows two emission peaks separated by a central absorption core. In ζ Tau, both peaks strengths vary in anti-phase respective to each other, so that the ratio of their violet to red heights, called V/R-ratio, cyclically changes from $V > R$ to $V < R$ and back. At times, however, the clear central absorption may weaken or even disappear, and the emission peaks then may have complicated appearance, split into sub-peaks and often called triple-peak profile. The origin of such triple-peak profiles is unclear. They generally appear at transitions from $V < R$ to $V > R$, but not vice versa. In the observations reported here such triple-peak structures are seen from Dec. 2003 to Sept. 2004. The temporal evolution of the Hα profile between 2000 and 2006 is shown in Fig. 1.

V/R-ratio have been measured in the spectra in which both peaks are apparent, and subjected to a formal period analysis using the time series tools introduced by Kaufer et al. (1996). Note that the following uncertainties are 1σ-errors. The first iteration reveals a V/R cycle time of 1471±15 d, i.e. about 4.0 years (Fig. 4, left). While this is shorter than the 5 to 7 years in the list by Okazaki (1997) derived from 1960 to 1993, it is consistent with the 4.25 years cycle time given by Rivinius et al. (2006) for 1991 to 2003. Given that only a little more than one cycle is covered the main purpose of this exercise is to pre-whiten the data for the analysis of shorter variations.

The second iteration on the residuals, i.e. after removing the sine wave fit derived in the first step, reveals a 69.3±0.2 d cycle (Fig. 4, right). This cycle is clearly present during

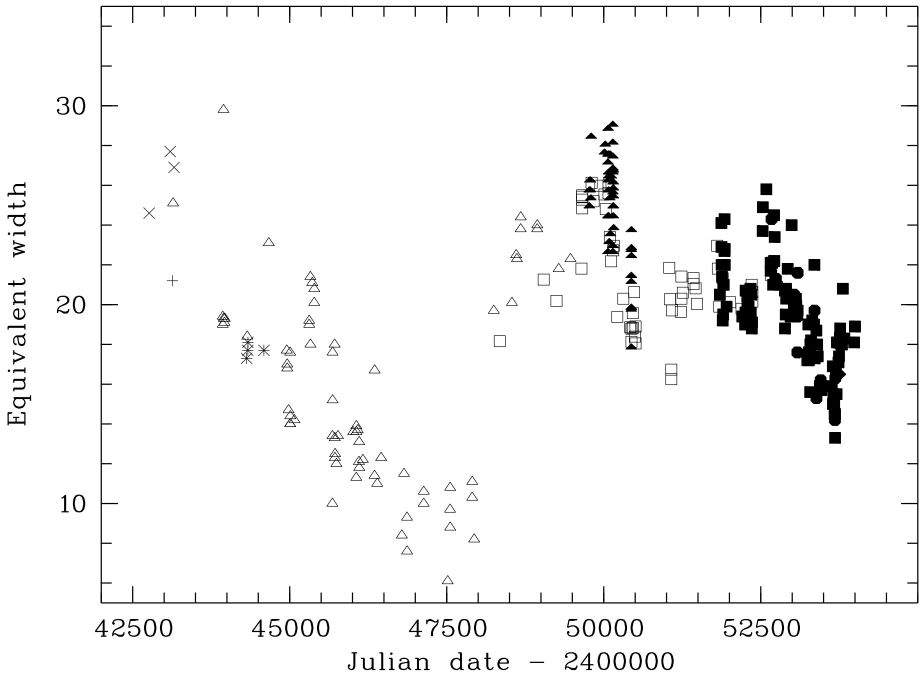

Figure 2. Hα equivalent widths of ζ Tau since 1975. Data taken from the literature are plotted as open symbols: HEROS group (Rivinius et al., 2006, squares), Guo et al., 1995 (triangles), Fontaine et al., 1982 (plus), Slettebak & Reynolds, 1978 (crosses), Andrillat & Fehrenbach, 1982 (asterisks); data taken by various amateur observers as filled ones: Pollmann prism (filled triangle), Pollmann grating (filled square), Stober (filled circles), and Schanne (filled diamonds).

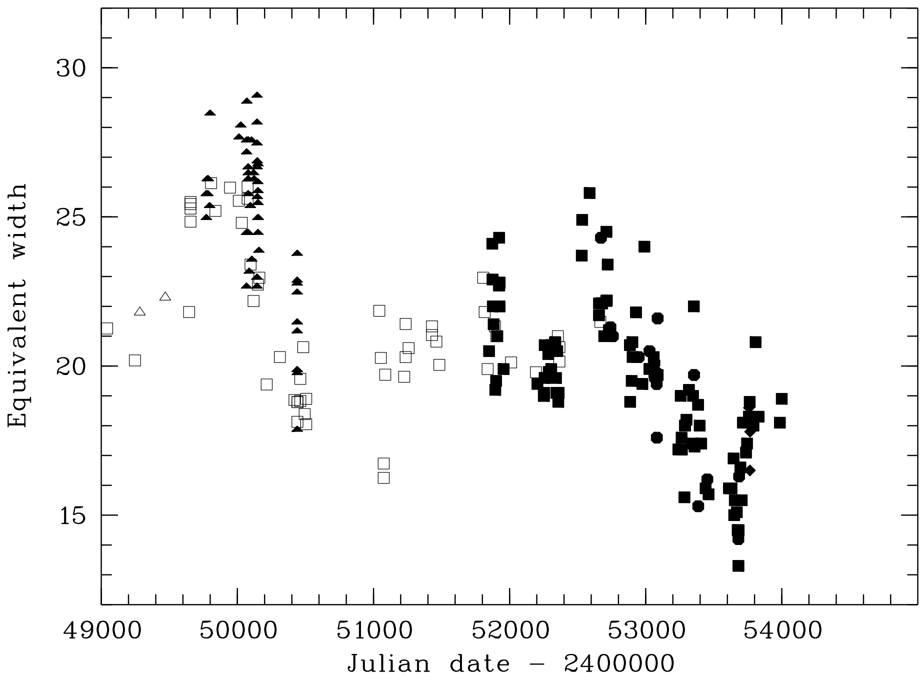

Figure 3. Enlargement of Fig. 2 (see there for symbols and data sources), showing the data presented in this work in greater detail, also for comparison between values taken with professional and amateur equipment.

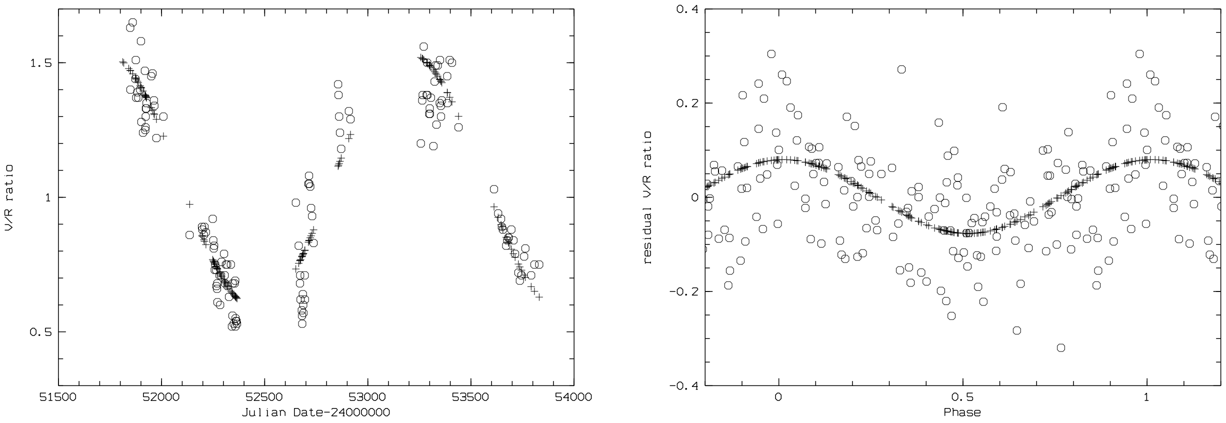

Figure 4. Hα V/R-ratio. Left: The measured values vs. Julian date (open symbols) and the sine wave with $\mathcal{P} = 1471$ d (plus signs). Right: The residuals of the left panel, folded with $\mathcal{P} = 69.3$ d and the respective sine fit. Shown are 1.4 cycles for clarification, i.e. 40 % of the points are redundant.

the central part of the dataset, but it is not of constant amplitude. The variance seen in the right panel of Fig. 4 is well above the measuring uncertainty. In fact, looking at individual seasons, the 69.3 d cycle is not seen before JD=2 452 100, hardly visible until 53000, but then becoming very strong, and finally weakening again after JD=2 453 500.

The ephemeris of the residual V/R maximum is

$$2\,452\,996 + 69.3 \times E$$

The cycle time of 69.3 days is about half of the orbital period of the system of 132.97 d (Harmanec, 1984), but a precise 1:2 ratio is well outside a 3σ uncertainty. As a check, sorting the data with the orbital period rather shows the properties of a scatter diagram than a meaningful phase curve.

Phase locking of the V/R ratio has been observed in a number of binaries. However, while Harmanec et al. (2002) attribute this to the property of the Roche lobe, e.g. for the case of 59 Cyg, Štefl et al. (2007, also Okazaki, priv. comm.) found in hydrodynamical simulations that a true phase lock will not happen for a density wave, usually thought to cause V/R variations. Rather, they attribute precise locks, as in 59 Cyg, to radiative effects (Maintz et al., 2005) which is not likely in ζ Tau, however. Instead of an exact tidal lock, the Štefl et al. mention that in eccentric binaries tidally induced disturbances may develop with a period slightly longer than the orbital one, and we may note that at least the double-wave period would qualify under this statement.

This small difference may also offer an explanation for the strongly variable amplitude: The orbital period, supposedly causing a tidal disturbance and the V/R variation cycle length as observed, would give rise to a long-term beating period in the excitation mechanism of about 9 years.

Discussion and Outlook. The data presented in this work extend the ζ Tau spectra shown by Rivinius et al., (2006, their Fig. A.4 in Appendix A). While their data cover the years 1991 to 2003, the data here cover 2000 to 2006, with the observations ongoing.

Long-term spectroscopic monitoring by dedicated amateurs can deliver important data for the professional community. For instance, one easily recognizes state of the V/R cycle due to the one-armed density wave, as well as maxima in equivalent width at 50150 and 52600, that do not coincide with the V/R cycle.

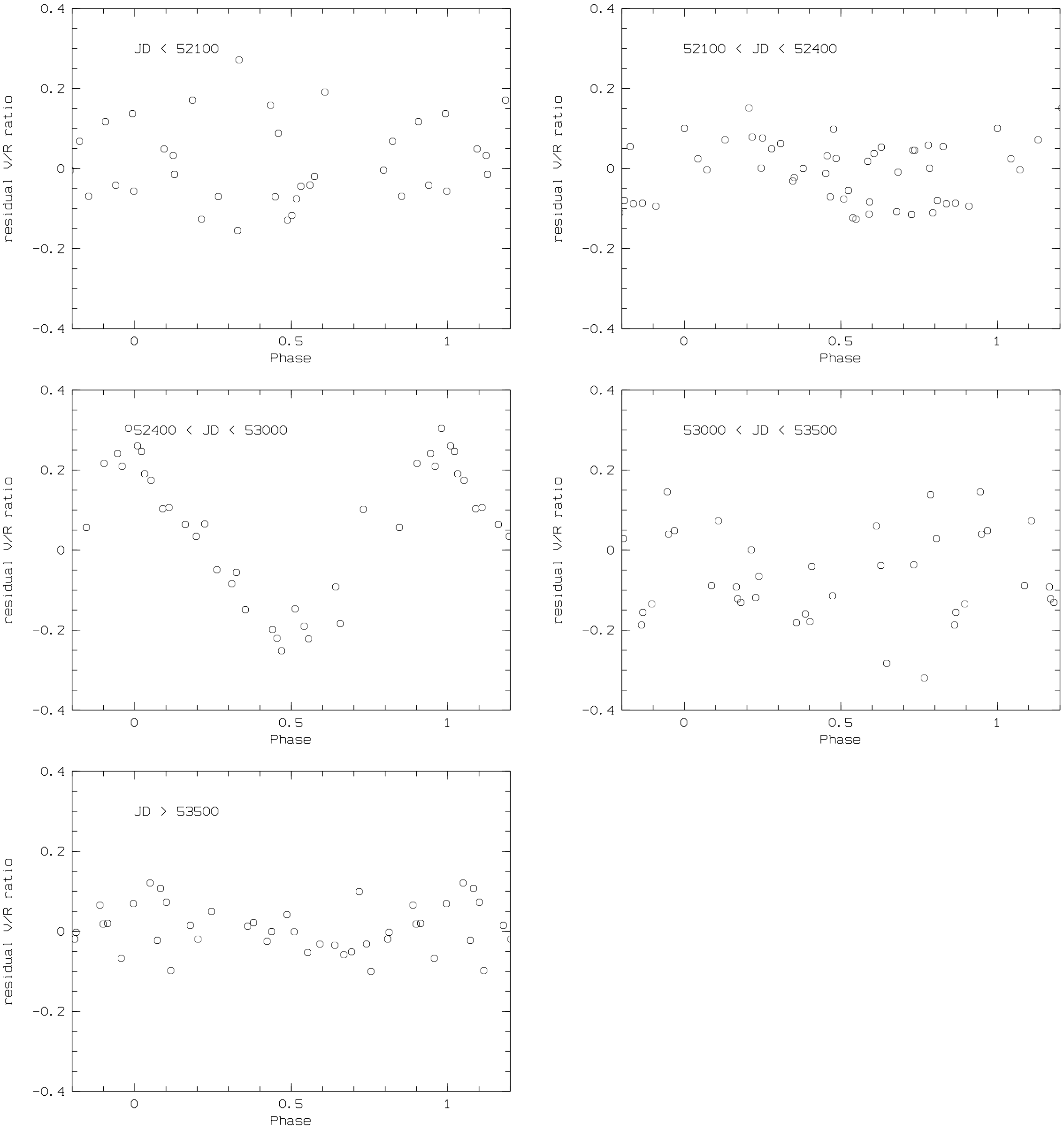

Figure 5. Strength of 69.3 d V/R-ratio cycles in individual data subsets.

The 69.3 d cycle in spectroscopy is another example of a phenomenon almost inaccessible to professional astronomers due to the observational timescales required, which on the other hand poses no problem to the dedicated amateur observer.

In the first few spectra of the 2006/2007 observing season, a sharp rise in equivalent width from about 18 to 26 Å is seen. At the same time, as the V/R ratio changes from $V < R$ to $V > R$ again, the emission has developed a triple-peak profile, entering a new cycle in its V/R variations.

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