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The line variability of high-resolution spectra of TW Hya

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Abstract. We present the analysis of 42 spectra of the Classical T Tauri star TW Hya observed with the FEROS echelle spectrograph over one and a half year. The star exhibits strong emission lines that show a variety and variability in profile shapes. The system apparently shows periodic variations in line and veiling intensities. We see evidence of a variation in the mass accretion rate over a 1 year period and magnetospheric accretion models with moderate mass accretion rates (10^{-9} up to 10^{-8} $M_{\odot}yr^{-1}$) fit well our observed NaD lines.

TW Hya presents typical spectral characteristics of the low mass accretion rate stars in Taurus, despite its older age, indicating that active accretion disks can survive up to 10 Myr without changing much.

1. Introduction

Classical T Tauri stars (CTTSs) are young, almost solar-mass stars that exhibit a wide range of permitted and sometimes also forbidden emission lines, together with an excess continuum emission that ranges from the infrared to the ultraviolet. Their spectral energy distribution is consistent with the presence of a circumstellar disk that appears to play a major role in the regulation of the mass flows in and around the star–disk system. A strong wind component is also thought to be present and cause the blueshifted absorption features commonly seen in the Balmer lines.

Recently several groups of young stars located in regions without any molecular clouds have been discovered in the solar neighborhood. Initially thought to be isolated young stars these associations, such as the TW Hya Association (TWA), are now believed to have already dispersed their parent clouds and may represent the evolution of star formation regions like Taurus. Up to now only 2 out of 21 possible members of the TWA have shown evidence of accretion: TW Hya and Hen 3-600A (Muzerolle et al. 2000). At ~50pc and an age of ~10Myr (compared to ~1Myr of the CTTSs in Taurus), TW Hya is ideal for the study of the accretion process evolution.

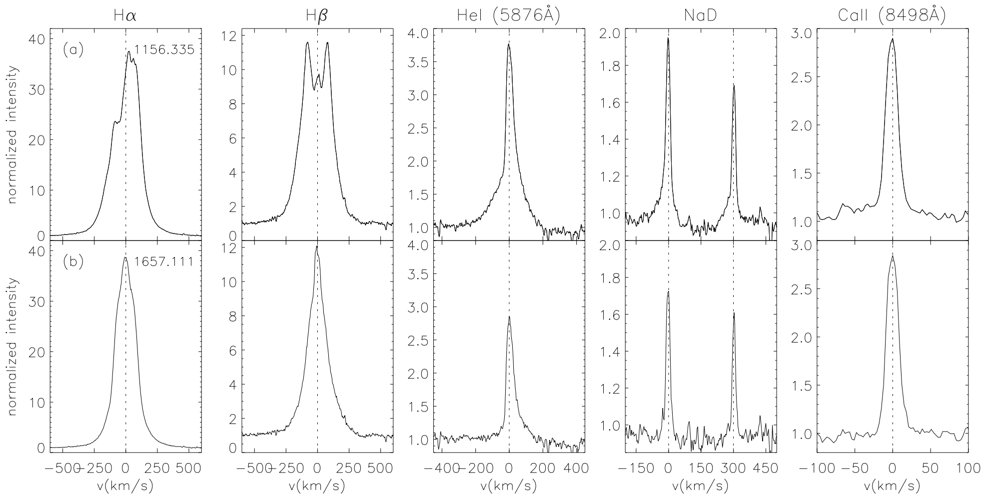

Figure 1. Sample of residual line profiles. The vertical dotted lines are the spectral line's center at the stellar rest frame. The numbers on the left are Julian Days (JD-2450000.5).

2. Observations and veiling

We present the analysis of a sample of 42 high-resolution spectra of the CTTS TW Hya. The observations, which span over one and a half year, were carried out at La Silla using the 1.52m ESO telescope with the FEROS spectrograph. The mean resolution of the spectrograph is $\lambda/\Delta\lambda \approx 48000$ and the spectral coverage ranges from 3500 Å to 9200 Å.

The reduction was performed on line by the FEROS routines which include flatfielding, background subtraction, removal of cosmic rays, wavelength calibration and barycentric correction. Radial velocity corrections are applied and all the data shown are in the stellar rest frame. The spectra are not flux calibrated, so each spectrum has been continuum normalized. We determined the rotational and radial velocity by cross-correlating the photospheric lines of TW Hya with those of a template star of the same spectral type (K7) and obtained $v \sin i = 5 \pm 2$ km s^{-1} and $v_{\rm rad} = 12.5 \pm 0.5$ km s^{-1}.

The veiling was determined as a function of wavelength using a program that compares a list of photospheric lines of TW Hya with a template star through a least-square method. The template is a standard K7 star that has been rotationally broadened to the TW Hya $v \sin i$. In the Hα region, veiling values range from 0.12 to 0.84 with a mean error of 0.1.

3. Survey of line profiles

A sample of the various residual line profiles discussed in the following sections is shown in Fig. 1. To obtain the residual profiles we subtract from the TW Hya spectra the rotationally broadened and veiled K7 template star used in the veiling measurements.

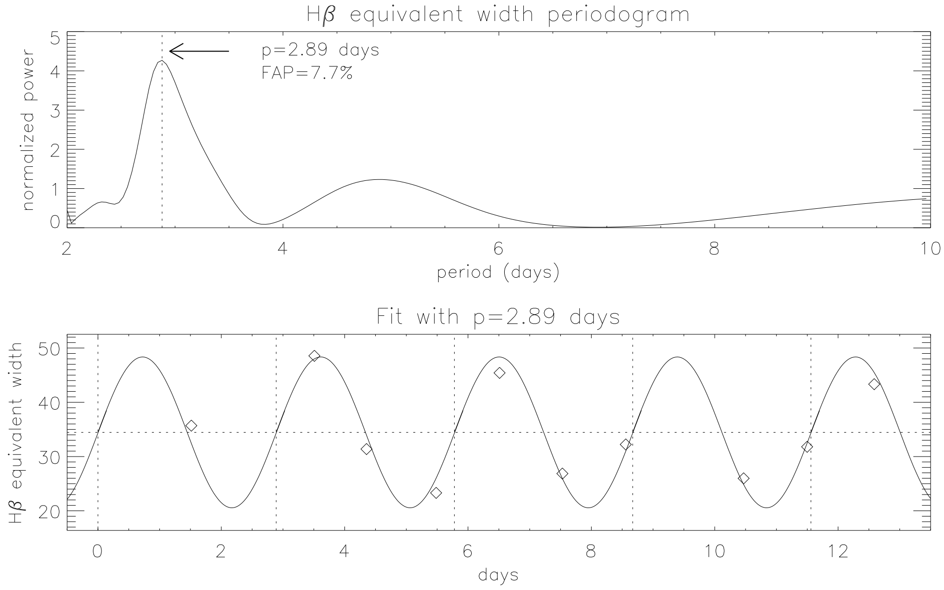

Figure 2. Hβ equivalent width period search with the February 2000 data. Top: periodogram results. Bottom: the diamonds are the measured Hβ equivalent widths and the curve is a sine fit to the data with the 2.89 day period. The horizontal line corresponds to the mean equivalent width and the vertical lines are plotted every 2.89 days.

The Hα line presents P Cygni profiles in most of the observations, where we can easily distinguish a blueshifted absorption (Fig. 1*a*). Sometimes it also shows a rather centered emission where the blue absorption at low velocities, if present, is much less intense, and a blue absorption at higher velocities can be seen (Fig. 1*b*). The Hβ line shows a blueshifted absorption less intense than Hα, what is expected if the absorption originates in a wind, due to the differences in optical depth between the two lines. Hβ also presents a redshifted absorption at low velocities. This redshifted component is not so clear in Hα. The He I line shows narrow (NC) and broad (BC) components and the BC is clearly redshifted. The Ca II and the NaD lines only present a narrow component.

4. Periodicities and inclination

Many attempts have been made in the literature to determine the rotation period of TW Hya. Rucinski (1988) did not find a significant period from his 1986 light variation data but reported a possible 2 day period from earlier data, while Herbst & Koret (1988) obtained p=1.28 day, also photometrically. Mekkaden (1998) obtained a 2.2 day period from the TW Hya light curve and he claims that $i > 20^\circ$ if the variations are due to the rotation of a hot spot. Mekkaden (1998) points out that sudden brightenings probably due to short-lived hot spots can occur at any photometric phase and could possibly mask the periodicities.

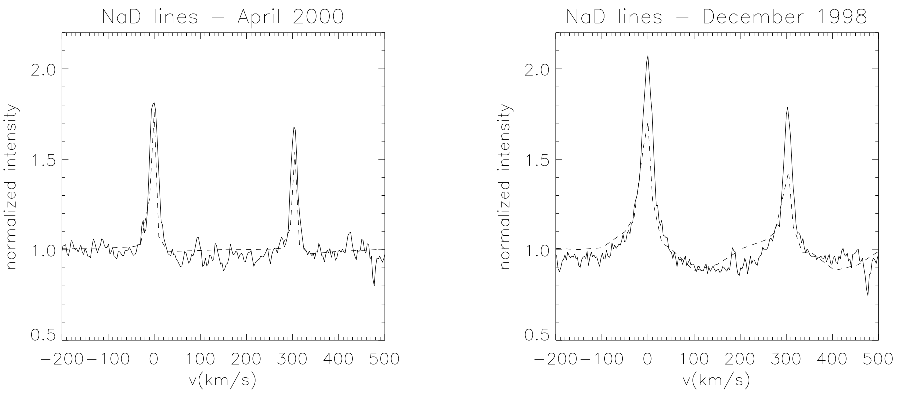

Figure 3. Observed (solid) and theoretical (dashed) profiles with T_{max} = 12000 K, *left* : $\dot{M} = 10^{-9}M_{\odot}yr^{-1}$, $R_{mag} = 5.8 - 6R_{\odot}$ and *right* : $\dot{M} = 10^{-8}M_{\odot}yr^{-1}$, $R_{mag} = 5.2 - 6R_{\odot}$ (Muzerolle et al. 2001).

We performed a periodogram analysis of the veiling and line intensity variations using the Scargle (1982) periodogram estimator as modified by Horne & Baliunas (1986). We used our data set of February 2000 where we have 10 spectra taken in 12 almost consecutive nights. Due to the ∼1 day step between the observations we can only consider periods longer than 2 days as reliable detections. With the veiling results we find a period at 3.75 ± 0.45 days. But the veiling values are small and the errors are comparatively high and consequently the power peak has a high false alarm probability (FAP) of being created by chance. The emission line intensities present a periodicity at 2.9 ± 0.3 days, marginally different within the errors from the one found with the veiling. The errors that could affect this result would be due to the continuum normalization process and tend to be very small. In Fig. 2 we show the period search result with the equivalent width measurements of Hβ that confirms the 2.89 day value obtained with the line intensities. This period has a FAP of being created by chance of less than 10%. If the system is seen at low inclinations, we would always see the star at approximately the same configuration and the periodicities we detected would require a magnetospheric model with a very inclined magnetic axis with respect to the rotation axis.

Imaging results showed a nearly circular disk structure around TW Hya in the IR (Krist et al. 2000) and mm (Wilner et al. 2000) and suggest the system is viewed close to face-on ($i \sim 0°$). Its low $v \sin i$ and no visual extinction give support to that idea. Using our measured periods (3-4 days) and $R\star = 1R_{\odot}$, we obtain $i = 13°$ to $22°$, which is still consistent with the other observations.

5. Mass-accretion rate variations

Our data is not flux calibrated and we cannot directly calculate mass-accretion rates from it, but we can investigate its variations by comparing our observed line profiles with theoretical ones. We decided to compare the NaD lines with the predicted magnetospheric accretion profiles. These emission lines should only be due to accretion and they do not display any wind signature in TW Hya. In Fig. 3 we show the comparison of the theoretical line profiles of Muzerolle, Hartmann, & Calvet (2001) with 2 typical profiles from December 98 and April 2000 and we notice that the model's fit is good. These models point to a significant variation in the mass accretion rate over 1 year. Emission lines from December 98 and April 2000 are shown in Fig. 1 *a* and *b* respectively. In the former not only accretion was enhanced (more emission in the Hα and Hβ wings) but also the outflow was stronger, since we see a substantial wind absorption in the Hα blue wing. Recently Beristain, Edwards, & Kwan (2001) showed that high mass accretion rate CTTSs tend to exhibit a blue emission excess in the He I BC when compared to low mass accretion ones. In TW Hya the He I profiles of Fig. 1 present a strong decrease in the broad component blue emission which indicates, following Beristain et al. (2001), that the mass-accretion rate decreased from one observation to the other in agreement with the above results.

6. Conclusions

TW Hya exhibits spectral characteristics very similar to any low-mass accretion rate CTTS in Taurus. It displays the expected line variabilities and line equivalent widths and veiling values in the ranges of those measured in stars like AA Tau (K7), DN Tau (M0) and DS Tau (K5) (Alencar & Basri 2000). We found periodicities in its spectral features at 2.9 and 3.8 days that, if due to stellar rotation, point to low system inclinations ($18^\circ \pm 6^\circ$) but hardly to a totally face-on geometry. The mass accretion rate seems to vary substantially over a 1 year period. All this indicates that active accretion disks can survive up to 10 Myr without changing much, which is rather surprising.

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