The weak-line T Tauri star V410 Tau. A multisite observing campaign

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Introduction

V410 Tau is a young star, still at its formation stage, which has been called *the Sun at one million years* (Herbst 1989). Young, solar type stars show very often variability, due to one or different mechanisms, and they are named after one of the first discovered stars of this type, T Tau (T Tauri stars, Joy 1945).

Being one of the brightest stars of its class, V410 Tau has been monitored photometrically for more than 30 years. Already in the early 80's, it was discovered that the variability of its brightness is periodic (Rydgren & Vrba 1983) and the variations were attributed to cold spots located on the surface of the star. The nature of these spots has been assumed to be similar to that of the solar spots, which are related to the interaction of the magnetic field, the differential rotation and the convective transport of radiation in the outer layers of the star. The same mechanism is also responsible for several phenomena, which are grouped together under the name of magnetic activity. These phenomena include, e.g., chromospheric and coronal emission, and flares.

Up to now, most of the observational efforts had focused on the variability due to the cold spots and detailed optical broad band light curves have been obtained yearly, which show slow and smooth changes in the light curve profile. The changes were most notorious in the mid-80's, when the two most important active regions merged (Herbst 1989). Since then, a modulation of the amplitude is observed with a time scale of years, the maximum amplitude reaching values of 0.6 mag, one of the largest among spotted stars.

Other activity related phenomena (chromospheric, coronal, and flare activity) had been studied only partially and their relation to the variability due to surface spots remained unclear. High resolution spectroscopy carried out along 6 nights with the Coudé spectrograph of the 2.2m telescope of Calar Alto allowed Fernández & Miranda (1998) to study the relation between the chromospheric H_α emission and the cold spots. As one step further in this direction in 2001 we organized an international multisite campaign, which involved 6 telescopes located at 5 different observatories (the 2.2m telescope of Calar Alto among them),

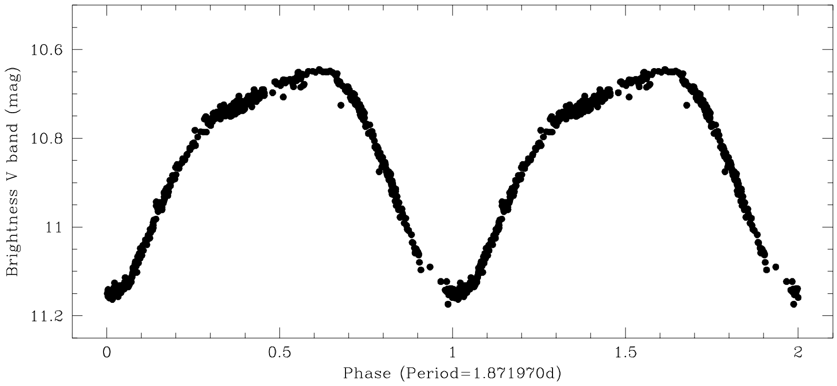

Figure 1: Phase folded V band light curve of all the observations carried out along our November 2001 monitoring campaign, after removing all the flares.

plus the X-ray satellite Chandra. Dedicated photometric as well as intermediate- and high-resolution spectroscopic observations in the optical were planned for a time interval of 10 days, simultaneous to three exposures with the Chandra X-ray satellite.

In this letter we will focus on the results of the observations carried out at Calar Alto. A complete study of the relation between emission in various energy bands and the optical rotation cycle, and the long-term photometry has been reported by Stelzer et al. (2003), while in a subsequent paper (Fernández et al., submitted) we have concentrated on the numerous flares found during our campaign. A detailed light curve has been obtained (see Fig. 1) and it will be used as a reference for the discussion of the results.

Observations

High-resolution spectroscopic observations were performed using the Fiber Optics Cassegrain Echelle Spectrograph (FOCES) and a 2048x2048 pixel SITe CCD attached to the 2.2m telescope at the Calar Alto Observatory (Almería, Spain). The spectra include some seventy orders, covering a range from 4200 Å to 7000 Å, with a nominal resolving power of $\lambda/\Delta\lambda \approx$ 30 000. Technical details regarding FOCES can be found in Pfeiffer (1998).

The spectra have been reduced and extracted using the standard IRAF reduction procedures (bias subtraction, flat-field division and optimal extraction of the spectra). Wavelength calibration was done using spectra of a Th-Ar lamp. Finally, for each order we normalized the extracted spectra by means of a polynomial fit to the observed continuum.

Analysis and discussion

The high resolution spectra show that on the entire quiescent spectrum of V410 Tau only the H_α line appears in emission and presents clear variations in the intensity and shape of the profile. In order to study the variations of this line, we got the residual line by subtracting the spectrum of a template star (rotationally broadened to a $v \sin i$ of 74 km s^{-1}) from that of V410 Tau. This way can remove all photospheric lines that appear in the spectral range observed.

As shown in previous works, there are two variable emission components in this line

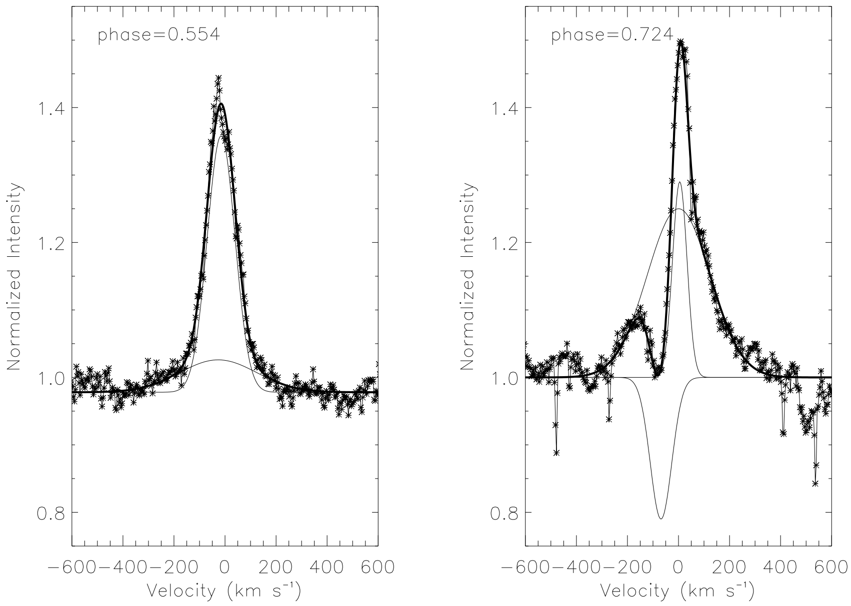

Figure 2: Residual H_α line profile decomposition. The thin lines show the individual components and the thick line represents the final fit.

(e.g. Petrov et al. 1994; Hatzes 1995; Fernández & Miranda 1998). Our observations show this pattern too, although more prominently in the residual profile where the two components are readily visible: a narrow emission peak close to the stellar rest velocity and a broad, less intense component producing extending wings (up to $\pm$ 300 km s^{-1}). Superimposed on those two components is a blueshifted absorption feature that appears at some phases. The variability of the residual H_α line shape seems to be related to the observation phase. On phases corresponding to the maximum brightness of the star, the residual H_α profile is symmetrical. As the stellar brightness decreases, however, the broad component appears more intense and the blueshifted absorption develops, forming a P Cygni profile which suggests the presence of a stellar wind.

In order to better characterize the general behaviour of the kinematic components, we have decomposed the H_α line into the two abovementioned emission components by fitting a double Gaussian. When a clear absorption appeared, a third Gaussian in absorption was added. The fitting process is optimized by minimizing the χ^2 statistic. Figure 2 shows the result of this procedure for two phases. The small number of spectra and the poor phase coverage do not allow a detailed analysis of the fit parameters. We are, however, convinced that, for the spectra obtained at phases greater than 0.7, a third component in absorption is needed to improve the fit. This could explain the lack of strong variations in the residual H_α equivalent widths between the high and low stellar brightness stages.

A chromospheric origin has been suggested for the narrow peak; its velocity comes from the projected rotational velocity of the star at the position of the emitting regions. In the case of the broad component, the velocities involved reach more than 400 km/s and cannot be due the stellar rotation ($v$sin$i$ of 74 $\pm$ 3 km/s, Stelzer et al. 2003). We also consider it quite improbable that it is due to the circumstellar gas environment, as it has been suggested (Petrov et al. 1994), because V410 Tau shows very little infrared excess, and it has been attributed to one, maybe two, close companions at sub-arcsecond separation (Ghez et al. 1993; Ghez et al. 1997). Due to the strong evidence against the presence of detectable remnant from a circumstellar disk (Beckwith et al. 1990), we consider it more likely that the platform or extended wings are due to microflaring. This explanation has been provided by Montes et al. (1998) for the broad H_α component of chromospherically active binary systems and weak-line T Tauri stars, and is supported by its similarity to the broad components found in the chromospheric Mg II h & k lines, as well as in several active star transition region lines.

For the strongest H_α broad component detected (ϕ=0.724), we have estimated, using its equivalent width and the R band brightness at that instant, that the energy emitted in this component is $8 \cdot 10^{29}$ erg/s. This is about one order of magnitude below the smallest brightness variation that we were able to detect photometrically (0.016 mag in the U band, which corresponds to $3.9 \cdot 10^{30}$ erg/s). Thus, it seems reasonable to think that the broad H_α emission comes from numerous weak flares that we are not able to detect photometrically. Robinson, Carpenter & Percival (1999) reported microflaring activity on the dMe star YZ CMi. They detected up to 54 flare events ranging in integrated flux from $2.0 \cdot 10^{28}$ to $3.0 \cdot 10^{30}$ erg in the ultraviolet (2400Å) during a 150-minute monitoring with the *Hubble Space Telescope*. Since the time exposures for our high resolution spectra range from 45 to 60 minutes, such a microflaring activity could explain the broad H_α component observed on V410 Tau. Furthermore, if microflare events are important in the heating of stellar coronae, the higher X-ray luminosity of V410 Tau ($7.36 \cdot 10^{30}$ erg/s, Costa et al. 2000) compared to YZ CMi, L_x=$3.0 \cdot 10^{28}$ erg/s, would support a stronger microflaring activity on V410 Tau than on YZ CMi.

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