Spectral Variability of the T Tauri Star T Chamaeleontis

Università "Federico II", Napoli
Dipartimento Scienze Fisiche

E. Schisano, E. Covino, J.M. Alcalá, E. Guenther, M. Esposito

University of Naples "Federico II" – Italy   INAF-Capodimonte Astronomical Observatory - Italy   Thueringer Landessternwarte Tautenburg, Germany

OA Capodimonte, Napoli

1. T Tauri Stars

T Tauri stars (TTSs) are young optically visible objects that, spanning from classical (cTTSs) to weak TTSs (wTTSs), represent the final stages of accretion from a circumstellar disk and disk-clearing processes leading to the formation of low-mass main sequence stars and their eventually associated planetary systems.

The two classes reflect different physical processes active in young solar-type stars, chromospheric activity and disk accretion, and are connected by an evolution scenario.

Detailed studies of properties of young stellar systems and associated disks provide observational costraints to star and planet formation, which must also explain the unexpected properties of recently discovered planetary systems.

Here we report some of the results of the study carried on the star T Cha (Schisano et al. in prep.) based, mainly, on 50 high-resolution spectra acquired with FEROS@ESO 1.5m and 2.2m telescopes during seven years (1999-2006).

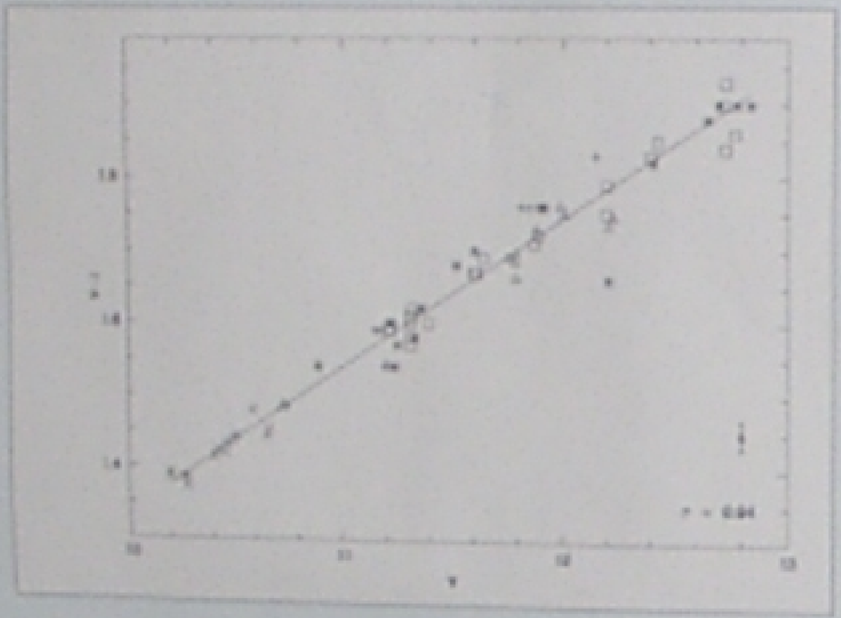

Fig. 1 Correlation between V-I color and V magnitude. This relationship is mantained over different years as illustrated in figure (different symbols refer to data acquired in different years from 1989 to 1994). A similar behaviour is present also in U-B, B-V and V-R color.

2. T Chamaeleontis

T Cha is a G8V star spatially associated to the cloud G.300.2-16.9, in the Chamaleon star formation region, that, based on the strength of the LiI line at 6708 Å and the presence of Hα emission, is recognized as a young star and classified as TTS (Alcalá et al. 1993).

The star shows high irregular variability (ΔV up to 3 mag) and **a color-magnitude correlation, in the sense that the star is redder when fainter** (Fig.1). A similar behaviour is also observed in other stars like RY Lupi and AA Tauri (Gahm et al. 1993; Bouvier et al. 2003). A value of $E(B-V) = 0.45$ is observed even when the star is brighter.

2MASS, IRAS, ISO and Spitzer data indicate **near and far infrared excess emission compatible with presence of circumstellar dust.**

3. The Spectrum

In the spectrum there are some of the emission line typical of TTS, Balmer H lines, CaII K and H (3933 and 3969 Å), CaII IRT (8498, 8542 and 8662 Å) and the forbidden lines of the [OI] (6300 and 6363 Å). **All spectra do not show sign of "veiling"** (i.e. a continuum emission overimposed on photospheric spectrum). The equivalent width (EW) of LiI 6708 Å of 360±30 mÅ correspond to interstellar abundance.

The most striking feature is the **variability of forbidden [OI] and of Hydrogen Balmer lines, in particular Hα which changes drammatically from a pure emission to absorption** (see Fig.2 and 3).

From few data avaliable in literature (Covino et al 1994) the **photometric and spectroscopic variability appears to be correlatated: when the star is fainter Hα is more in emission.**

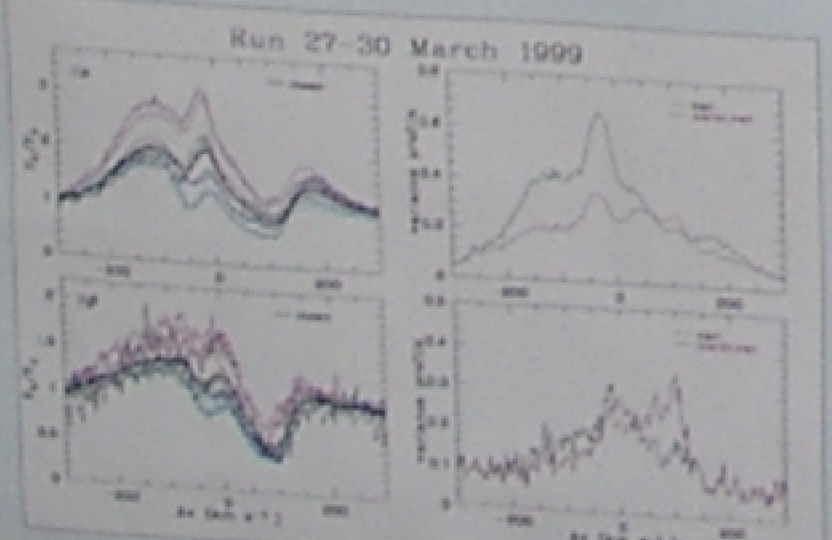

Fig. 2 Variability of profile of line Hα (upper left) and Hβ (lower left). In bold line is reported the mean profile, while different color refers to different nights. The respectively variance (black) and the normalized variance (red) (i.e. the variance divided by the mean profile) are shown on right. During this period profiles hold the same form, differently from other period in which they change in shape and type (see also Fig. 3).

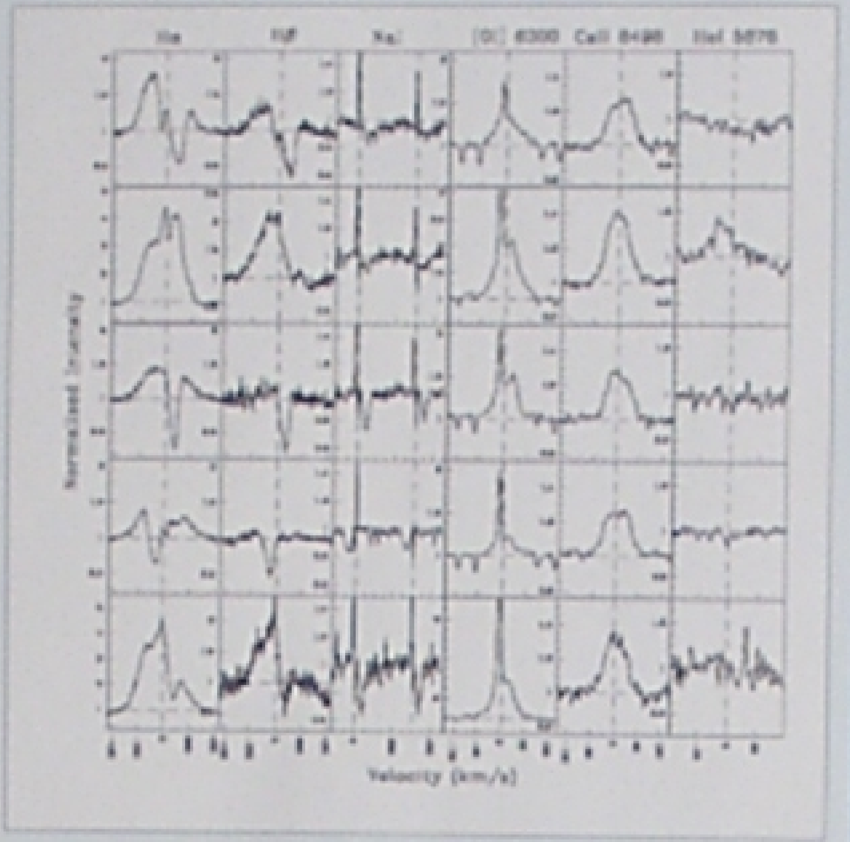

Fig. 3 Line profiles after subtraction of a template spectrum of the same spectral type artificially broadened to the rotation velocity of T Cha. Each row corresponds to a different date, showing the extreme variability in intensity and in shape of the Hα and Hβ lines. The CaII IRT lines are also variable but do not appear correlated with Hα. The narrow component of the [OI] line is the terrestrial sky emission. The Na I doublet shows the presence of blue and red-shifted absorptions linked to the ones in the Balmer lines.

4. Emission lines survey:

Because the origin of emission lines is not photospherical, we have removed all the spectral contribution from the underlying photosphere. We shifted all spectra to the stellar rest frame and then subtracted a template spectrum artificially broadened for vsini = 37 km/s, measured independently on different spectra. Examples of residual line profiles are shown in Fig 3. The spectra refer to different period of observation.

Some of the results are:

1) **The spectral type of the star does not change from one spectrum to the other.**

2) Hα and Hβ show very similar profiles. Blue and red-shifted absorptions appear in both lines at nearly the same velocity. **The equivalent widths of the two Balmer lines are also correlated.**

3) Broad (almost 100 km/s) **symmetric forbidden lines whose equivalent widths correlate with that of Hα.** Forbidden emission lines, connected with stellar wind or jets, originate far from the star, and their symmetry indicate that we are observing the whole velocity field around the star, consistent with **a high inclination angle**.

4) The emission core of CaII IRT is symmetric and shows enhancements on a few spectra when also the He I 5876 Å line becomes detectable. **No correlation is found with Balmer emission lines, sign that the Hα variability has not a chromospheric origin.**

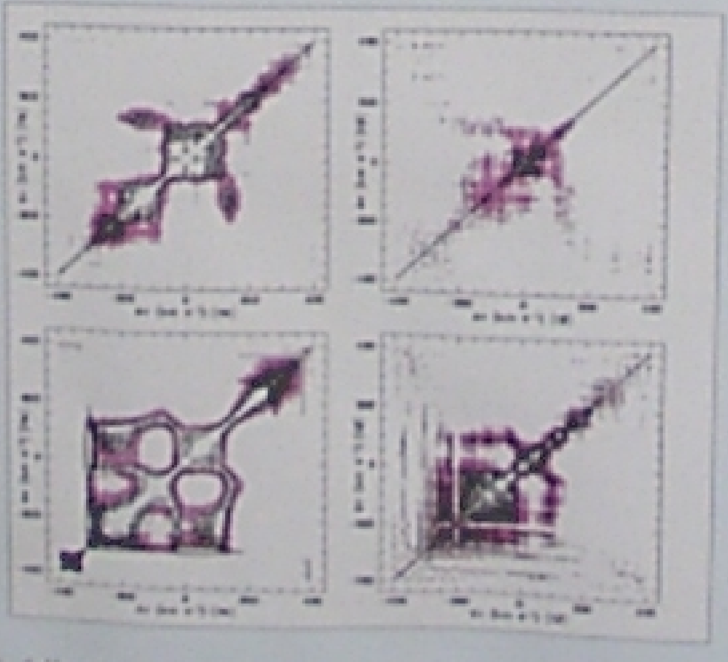

Fig. 4 Hα vs Hα correlation matrix, calculated with spectra acquired in two different periods (upper and lower left panels). The same for Hβ vs. Hβ (on right). Upper correlation matrix refers to the spectra of Fig.1.

5. Short time-scale variability - Correlation Matrix

We computed also the correlation matrix (CM) of Hα and Hβ with themselves. The CM expresses the linear correlation coefficient between the time variation of each velocity bin in the line profiles with that of all the other bins in the same or other lines (Johns and Basri 1995; Alencar and Batalha 2002). Due to the wide time separation between spectra we choose to analyse separately groups acquired on short time scale.

The squarrish form from about -250 to +150 km/s (excluding well defined regions, corresponding to the absorptions, that do not correlate with the rest of the profile) means that, in both runs, **the process causing the emission variation is simultaneously affecting the entire line.**

6. Spectral Energy Distribution (SED):

We built the SED of T Cha and fit it with theoretical models with the aim of extrapolating disk and circumstellar enviroment parameters. The two different models used are:

- Flared Passive Disk with an internal "rim" in hydrostatic equilibrium at truncation radius (dust evaporation radius) that shadows part of the disk outer regions (Dullemond et al. 2001).
- Active Disk with the presence of an outer envelope (Robitaille et al. 2007).

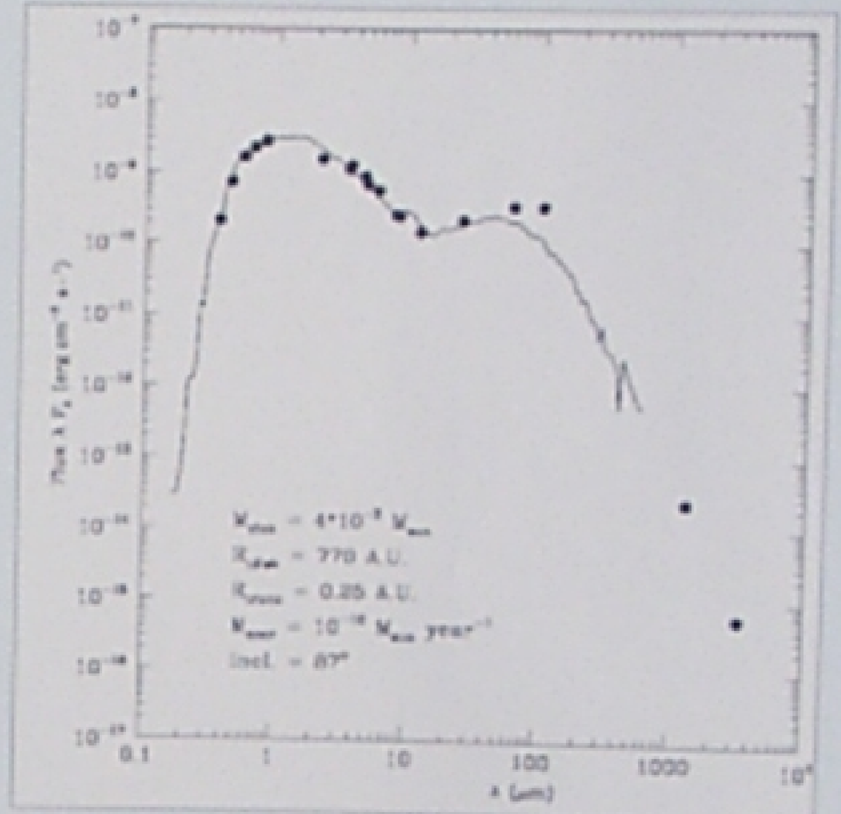

Fig. 5 Spectral Energy distribution of T Cha. The continuos line represents the Robitaille's model best fitting the observations. The data points in the optical are the maximum fluxes observed, that in our scheme correspond to the star photosphere. The main model parameters are indicated.

Main features observed in the SED are:

- Optical data well reproduced by a G8V star with $L = 2.2\ L_{\odot}$ and $M = 1.5\ M_{\odot}$ (tracks of Palla and Stahler 1999) and age ~ 3 Myr, with $A_V = 1.24$.
- Near-IR excess, $(K-L) \sim 1$, due to inner regions of the disk. SED drops between 2 and 10μm with a slope -1.75.
- SED rises at about 12μm with a peak at ~ 80 μm.
- In the mm-range SED slope is ~-4. For an optically thin disk, where $\lambda F_\lambda \propto \lambda^{-3-\beta}$, this implies $\beta \sim 1$, i.e. larger dust grains in the circumstellar environment.

A well fitted reprocessing model gives a more massive disk ($M_{disk} \approx 0.03\ M_{\odot}$), with radius $R_{disk} \approx 250$ AU and inner radius $R_{wall} \approx 0.24$ AU.

7. T Cha a possible unresolved binary?

Spectra analysis with cross-correlation function (CCF) shows variability in radial velocity. Fig.6 left shows **how the CCFs changes in shape and peak position, even on daily time-scale.** The right panel shows that the line-width variation is real: rms <Δ vsini.

Possible interpretations, neither confirmed nor excluded from available data, are photospheric spots or an unresolved spectroscopic companion.

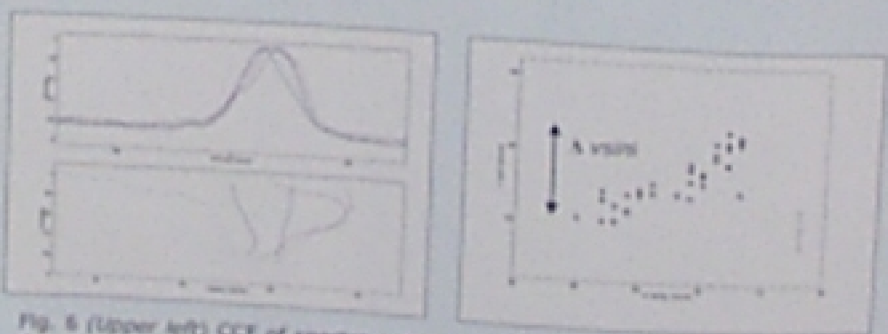

Fig. 6 (Upper left) CCF of spectra acquired on different nights separated by 1 day, and (lower left) corresponding CCF bisectors. (Right panel) on the x-axis calibrated parameter measuring the CCF width, and on y-axis another parameter linked to width of lines measured directly on spectra. [illegible]

8. Conclusions and future developments

T Cha presents a complex scenario in which all main features of young stellar objects merge together. The photometric behavior might be explained in terms **of variable circumstellar extinction, with orbiting clumps screening the photosphere,** allowing the emission lines (formed far from the star) to stick out with respect to the stellar continuum. The system is seen close to edge-on and the source of extinction lies in the disk (Bertout 2000).

VLTI should allow to spatially resolve the disk and to probe its inhomogeneous structure, with the aim to establish if the disk is dynamically evolving at present time.

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