High energy in T Tauri stars: The future is bright

V. M. Costa[1] and M. T. V. T. Lago [2]
Centro de Astrofisica da Universidade do Porto, Rua das Estrelas P-4150 Porto, Portugal

L. Norci and E. J. A. Meurs
Dunsink Observatory, Castleknock, Dublin 15, Ireland

ABSTRACT

One striking question about young low-mass stars is the origin of their extreme activity. Some related phenomena, such as X-ray emission, flares and strong chromospheric emission are present in T Tauri stars, being equally responsible for some of the observed peculiar characteristics of this class of stars.

We will review the impact of the ultraviolet and X-ray observations on the understanding of the temperature structure in the surroundings of T Tauri stars. The UV observations unveiling the presence of plasmas at temperatures characteristic of "transition regions" have prompted the study of higher energies and subsequent findings of emission from plasmas at temperatures up to several 10^7 K. The thermal nature of the X-ray emission is well established. However, the corresponding modeling has often been limited by the poor spectral resolution of the available instruments. The very high sensitivity and spectral resolving power of XMM will certainly be crucial in this field providing further insight in the dominant mechanisms working at this early stage of stellar evolution.

1. Introduction

T Tauri stars (TTS) are young ($\leq 10^7$ years), low mass stars (< 3 $M_\odot$) still contracting towards the main sequence. Most of them show absorption spectra of late K, early M type. Compared to other stars of similar spectral type they show a significant IR and UV excess.

It is challenging to try to understand the complex properties of these analogues to the very young Sun. The IUE satellite data provided evidence for the presence of emitting regions with temperatures up to several 10^5 K, strongly enhanced relatively to the Sun (e.g. Lago et al. 1984). This amazing result for these cool low mass stars prompted their observation with the *Einstein Observatory.* Surprisingly enough many compact sources associated to TTS were revealed (Walter & Kuhi 1981). The higher sensitivity and spatial resolution of the ROSAT satellite led

---

[1] also Departamento de Matemática, ISEP, Portugal

[2] also Departamento de Matemática Aplicada, FCUP, Portugal

to the further discovery of hundreds of new X-ray emitting TTS (e.g. Neuhäuser et al. 1995). Furthermore, ASCA shows that hard X-ray emission is also a characteristic of TTS (Koyama 1992) as well as the occurrence of large X-ray flares.

Some authors have interpreted the X-ray emission in terms of loop structures, as observed in the Sun (e.g. Giampapa et al. 1996). In spite of all limitations the one- or two-component (hereafter, 1T and 2T) plasma models are still the standard analysis of the stellar X-ray spectra. However, the significance of these analyses is limited by the spectral resolution of the available instruments. Therefore the very high spectral resolving power of XMM will certainly be crucial and provide further insight in the dominant mechanisms at work at this early stage of stellar evolution.

2. X-ray spectral analysis

We have analysed data retrieved from the ROSAT Public Archive for 22 TTS also observed with the IUE. We have analysed these spectra with the standard 1T and 2T models which describe the emission from a hot, optically thin plasma in collisional equilibrium (Raymond & Smith 1977). Assuming, as a first approximation, a spectrum with $kT = 1$ keV we find X-ray luminosities, L_X, in the range 3×10^{28} - 7×10^{30} erg s^{-1}.

Table 1: Results for the spectral fitting of the ROSAT data using a two temperature component model.

Object	Date of Obs.	Total Counts	N_H ($10^{20} cm^2$)	kT_1 (keV)	kT_2 (keV)	χ^2_{red}
TW Hya	12 Dec 91	2116	4.44	0.150±0.005	$0.85 \pm^{0.03}_{0.04}$	0.95
V410 Tau	4 Mar 91	870	3.55	$0.25\pm^{0.02}_{0.02}$	$1.40\pm^{0.21}_{0.08}$	0.68
V410 Tau	20 Aug 91	5471	3.55	0.21±0.02	1.50±0.09	2.35
CS Cha	4 Mar 91	638	15.70	$0.24\pm^{0.16}_{0.02}$	1.61±0.76	1.76

A detailed spectral analysis has been performed for three further stars: TW Hya, V410 Tau and CS Cha (Costa et al. 1998). A first analysis of V410 Tau and CS Cha was published by Strom & Strom (1994) and Preibisch (1997), respectively. We have tried and failed to fit the spectra with a 1T model. However, the 2T model clearly fits the spectra. The best fitting parameters are given in Table 1 and Fig.1 displays one of the fits, for illustration. We found no evidence for non-photospheric abundances and therefore we have assumed cosmic abundances. Throughout the analysis we have used the interstellar absorption given by Morrison & McCammon (1983).

3. The TTS UV continuum

The observed continuum of TTS in the UV is well fitted by two components: a black body at the star's T_{eff} and an optically thin hydrogenic free-free plus free-bound emission component (Lago et al. 1984). After correction for a "mean" interstellar extinction, the temperature for the hydrogenic component is generally in the range 1.4 to 5×10^4 K. In the case of some stars a third component is necessary to achieve a good fit. This extra component is well fitted by hot black body emission covering only a small fraction of the area of the star (Fig. 2). This extra component may result from accretion or flaring activity, which are phenomena known to occur in some TTS.

In Figure 3 we plot the ratio of stellar to solar fluxes for TW Hya, CS Cha and V410 Tau as a function of the peak temperature. This plot allows a direct comparison between the stellar and the solar UV emission line fluxes and X-ray continuum flux over that range of temperatures. The plot suggests that the energy output for some TTS peaks at temperatures characteristic of the solar transition region while for others the emission keeps rising up to coronal temperatures. In any case the emission line fluxes at the various temperatures, from the chromosphere through the transition region up to the corona, are always well above the solar values by one to four orders of magnitude.

4. Conclusions

The 22 stars in our sample show X-ray luminosities in the range 3×10^{28} - 7×10^{30} $\mathrm{erg\,s^{-1}}$. The X-ray spectral analysis for TW Hya, V410 Tau and CS Cha is consistent with emission from a two-temperature (10^6 K and 10^7 K) hot, optically thin plasma in collisional equilibrium.

The UV continuum can in general be explained by the sum of a hydrogenic component, with a temperature in the range 1.4 to 5×10^4 K, the stellar black body continuum and, in some cases, a non-stellar black body emission at higher temperature yet covering only a small fraction of the stellar surface. Flaring activity and/or accretion may be the explanation for such cases. Furthermore, the excess emission observed in the UV, relatively to the Sun, seems a feature extending into the X-ray band. This might result from different exciting mechanisms operating in these stars. Namely, enhanced solar-like magnetic activity, variable magnetically driven winds or accretion, are alternative explanations proposed by different authors. However, the picture is still far from clear and the identification of the mechanism(s) operating in any given star remains controversial.

The connection from the UV to the X-ray band is a valuable diagnostic tool for the study of the conditions and mechanisms responsible for the peculiar characteristics of TTS. The observations with XMM hold a clear promise to improve our understanding of the high energy associated phenomena observed in this class of stars.

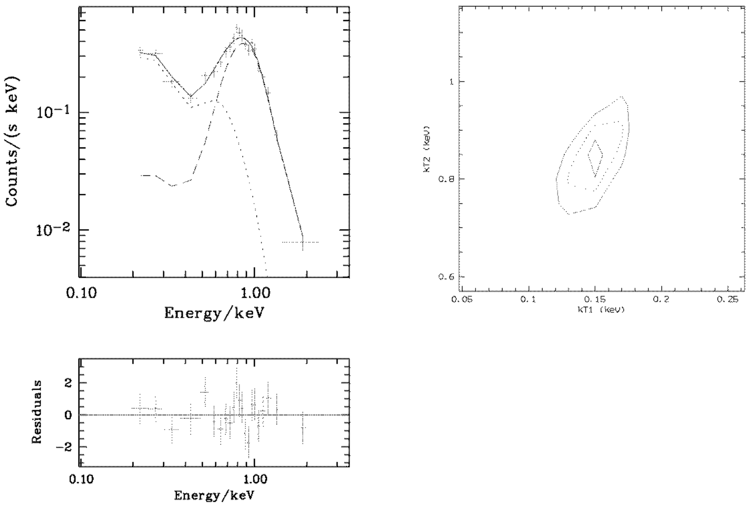

Fig. 1.— ROSAT spectrum of TW Hya where the fit corresponds to a two-component model. The residuals and a χ^2 grid (68.5%, 90%, 95.5% confidence contours) are also shown.

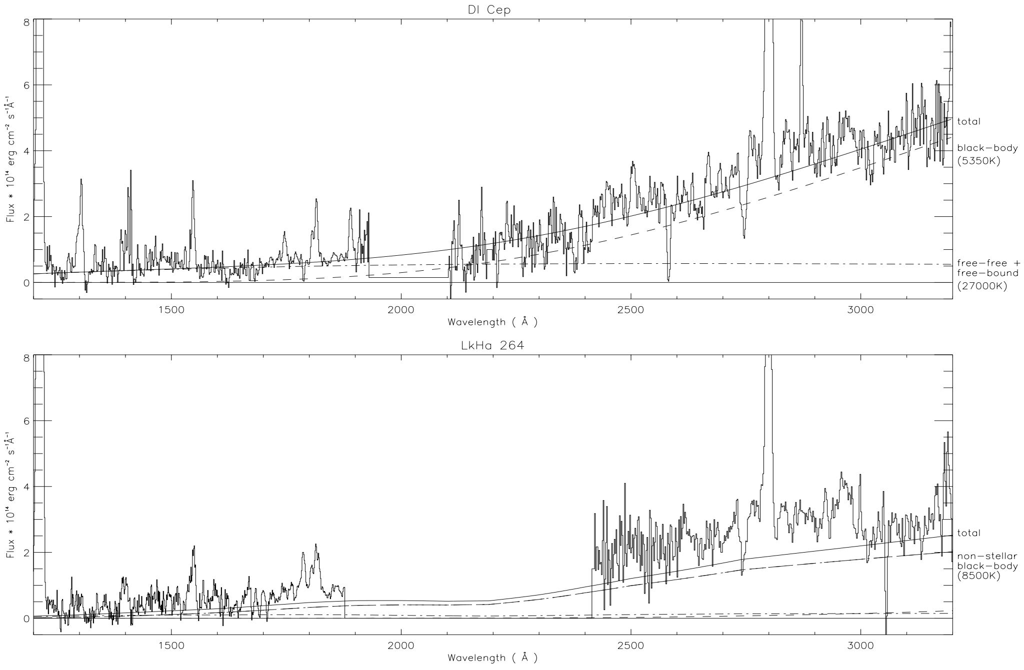

Fig. 2.— The continuum fitting for the stars DI Cep and LkHα 264. For DI Cep it is the sum of hydrogenic free-free plus free-bound emission at 2.7×10^4 K and emission from a 5350 K black body. For LkHα 264, besides the hydrogenic component at 3×10^4 K and the stellar black body at 4300 K, the fitting requires a third component, well identified with the emission from a black body at 8500 K covering only 5% of the stellar surface.

REFERENCES

Costa, V.M., Lago M.T.V.T., Norci L., Meurs E.J.A. 1998 (in preparation)

Gahm, F.G., Fredga, K., Liseau, R., Dravins, D. 1979, A&A, 73, L4

Giampapa, M.S., Rosner, R., Kashyap, V., Fleming, T.A., Scmitt, J.H.M.M. 1996, ApJ, 463, 707

Koyama, K., Asaoka, I., Kuriama, T., Tawara, Y. 1992, PASJ, 44, L255

Lago, M.T.V.T., Penston, M.V., Johnstone, R. 1984, in: Proceedings of Fourth European IUE Conference, Rome, p.233

Montmerle, T., Feigelson, E., Bouvier, J., André, P. 1993, Protostars and Planets III, University of Arizona Press, p.689

Morrison, R., Mc Cammon, D. 1983, ApJ, 270, 119

Neuhäuser R., Sterzik M. F., Schmitt J. H. M. M., Wichmann R., Krautter J. 1995, A&A, 297, 391

Preibisch T. 1997, A&A, 320, 525

Raymond J. C., Smith B. W. 1977, ApJS, 35, 419

Strom K. M., Strom S. 1994, ApJ, 424, 237

Walter F. M., Kuhi L. V. 1981, ApJ, 250, 254

This preprint was prepared with the AAS LaTeX macros v4.0.

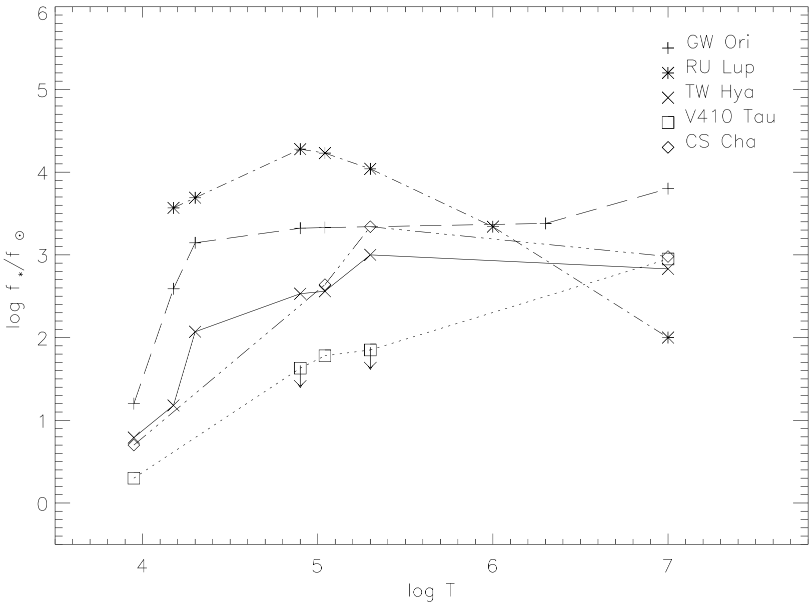

Fig. 3.— The plot displays the ratio of stellar to solar fluxes as a function of temperature. The values for the TTS GW Ori and RU Lupi are included for comparison and were adapted from Lago et al. (1984). The X-ray flux for V410 Tau is an average of two ROSAT observations. The behaviour of $f_\star/f_\odot$ with T is quite different for the four TTS included in the plot. The distribution of material with temperature is in these stars different from the Sun.