Coronae and accretion shocks in T Tauri stars

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ABSTRACT

The ratio between the X-rays and the He II(1640 Å) line luminosity (L_x/L_{HeII} ratio) is considered as a "coronal proxy" for cool stars since the line is partly formed by recombination following photoionization by coronal extreme UV radiation (Hartmann et al 1979). In this work, this ratio is examined for the whole sample of TTSs observed with the IUE satellite. It is shown that the TTSs with strong signs of accretion and outflow display an unusually low L_x/L_{HeII} ratio. We suggest that the difference between the X-rays deficient TTSs and the main sequence-like stars is caused by a fundamental difference in the dominant heating mechanisms: shocks (accoustic waves) for the former and magnetic heating (Alfvén waves) for the later. Theoretical predictions for the X-rays spectrum from accretion shocks in TTSs are presented.

1. Introduction

The X-rays luminosity of the T Tauri stars (TTSs) accounts for $\sim 10^{-3}$ of the stellar bolometric luminosity (see e.g. Feigelson & DeCampli 1981) and is larger by a factor of 10^3 to 10^6 than the X-rays luminosities of main sequence stars with similar spectral types. In the current context for low mass stars formation and pre main sequence evolution there are two main physical processes which could contribute to this high X-rays luminosity namely, enhanced magnetic activity associated with the hydromagnetic stellar dynamo and accretion shocks. Accretion shocks are produced by the release of gravitational energy from the infalling material as it shocks with the stellar surface. T Tauri stars (TTSs) are accreting material from their surrounding disk and it is now widely assumed that the disk does not reach the stellar surface and that henceforth, the matter falls onto the star at *nearly* free-fall speed. The kinetic energy is then released in shocks at the point of impact. X-rays radiation is expected to be generated in the hot (T$\sim 10^6$ K) postshock region.

In this work we examine the characteristics of the X-rays emission from the TTSs using the L_x/L_{HeII} "coronal proxy". We suggest that the X-rays emission from stars with small L_x/L_{HeII} ratio may be generated in accretion shocks. Then we present theoretical models for the postshock spectrum and briefly sketch how the spectrum is expected to vary with infalling gas density and velocity. The X-rays spectrum of the TTSs ought however, to depend on the density and geometrical distribution of the infalling gas. The role that X-rays/FUV monitorings may play to constrain the geometry is briefly outlined at the end of this contribution.

1.1. The L_x/L_{HeII} "coronal proxy"

The far UV HeII$_{1640}$ (Bα) line has been proven to be a coronal proxy in late-type stars (see e.g. Ayres et al 1995). The line is formed partly by recombination following photoionization by coronal extreme UV radiation (Hartmann et al 1979). It is expected within this context that the He II line luminosity is significantly smaller (a factor of 1/30 -1/50) than the X-rays luminosity. The He II line is also observed in the spectrum of the TTS although in this case the excitation mechanisms are more unclear. A detailed study for the case of T Tau was carried out by Brown et al (1984). They showed that recombination after photoionization by the coronal X-rays flux is two orders of magnitude smaller in T Tau than the expected if the late-type stars scaling is applied. However, if the He II line is excited by the photoionizing radiation produced in the postshock region of the accretion shocks the absorption of the X-rays photons would be much more efficient.

We have measured He II emission from all the TTSs observed with the IUE and compared it with their X-rays luminosities computed from the EINSTEIN counts in the 0.1-3.5 KeV band. Most of the sources have X-rays luminosities comparable to or smaller than the total luminosity radiated in the He II line. The L_x/L_{HeII} is ≥ 10 only for the fastest rotators in the IUE sample: AB Dor (P=0.5 days), and HD 283572 (P=1.55 days) and it is however, ≤ 0.1 for stars like DF Tau, RY Tau or BP Tau with longer periods and strong indications of outflow (strong forbidden line emission) and accretion (presence of hot spots on the surface and large infrared excesses). The correlation between the rotation period and the L_x/L_{HeII} ratio (see Fig. 1) suggests that the X-rays deficient stars are distinguished from the "normal" main sequence-like stars by a fundamental difference in the heating mechanisms: accretion shocks (accoustic waves) for the former and magnetic heating (Alfvén waves) for the later. This X-rays defficiency is indeed, reminiscent of the reported for early F-dwarfs and the Hertzsprung gap giants (Simon & Drake, 1989, Ayres et al 1995).

2. High density (N∼ 10^{11} to 10^{13} cm^{-3}) shocks in T Tauri stars (TTSs)

Recently, numerical calculations of the structure and spectrum of plane-parallel 1-D stationary accretion shock waves from midly magnetized (H $\sim 0.01 - 1$ G), dense (N∼ 10^{11} to 10^{13} cm^{-3}) blobs of gas falling at superalfvénic speeds onto the stellar surface have been carried out (Lamzin, 1998). X-rays radiation is generated in the hot (T∼ 10^6 K) postshock region. The predicted spectrum of the postshock gas is shown in Fig. 2 for various shock conditions in the 300 eV - 2 KeV region. As expected the postshock spectrum becomes harder (hotter) as the velocity increases; this is noticed both in the lines and in the overall continuum energy distribution. In particular, the flux of the Fe XVII lines at 0.74, 0.89 and 1.02 KeVs formed in transitions from the 2p^6 1S level rises significantly with the shock velocity. The total accretion luminosity released in the postshock region within the 0.35-2.0 KeV band increases by a factor of $\sim$ 2.5 when the velocity rises from 350 to 400 km/s for a fiducial density of the infalling gas of $\log N = 12.5$.

The postshock spectrum depends only mildly on the density of the infalling matter. Note however, that the observed output spectrum of an accretion shock will depend strongly on this parameter as well as on the relative orientation of the shocked area with the line of sight (the distribution of the X-rays absorbing preshock matter). The computation of these effects requires 2D accretion shock models as well as a good knowledge of the spatial distribution of the shocked area on the stellar surface. In fact, the 1-D models predict that the only geometry-independent (optically thin) indicators are some semiforbidden lines as those of C III], O III] in the far UV range (Lamzin & Gómez de Castro, 1998).

3. Monitorings and geometry: the BP Tau case

Important hints on the spatial distribution and geometry of the infalling material can be derived from monitorings lasting a few rotation periods. In fact, some TTSs have periodic photometric variability which is best modelled by *hot spots* on the stellar surface. BP Tau is one of the few classical T Tauri Stars (TTSs) for which the presence of a hot spot in the surface has been reported without ambiguity. The variations of the UV spectrum of BP Tau from the 5th to the 19th of January of 1992, when the star was monitored with the IUE during 2 rotational periods, were studied by Gómez de Castro & Franqueira (1997). They showed that the lines susceptible to be directly pumped by the radiation generated in the recombination of ionized gas, as those of O I and He II, have periodic-like light curves which follow the UV (Balmer) continuuum, however the lines which are only collisionally excited as those of C IV, Si II and Mg II do not follow a periodic-like trend. This behaviour can be interpreted within the accretion shock models if a fraction of the X-rays radiation escapes from the postshock region allowing for a photoionization (and further recombination) of the surrounding gas. The UV (Balmer) continuuum and the O I and He II lines are direct outputs of the recombination process. However, the C IV, Si II and Mg II lines are collisionally excited not only in the shock region but also in the active (and flaring magnetosphere) and therefore their light curves may be blurred by these irregular processes. Should this interpretation of the UV light curves be correct, the X-rays emission from BP Tau should be variable and follow a periodic-like light curve.

BP Tau was monitored for 5 days with ROSAT by Gullbring et al (1996). They detected some rapid variations which they associated with magnetic activity but also some variations in dayly basis were reported by them. We have extracted from the ROSAT Archive these observations and plotted the variation of the count rates (dayly averages) in the A, C and D bands. The star is only marginally detected in soft X-rays (A-band); however there is a measurable flux at energies ~ 1 KeV which is variable. There is some qualitative agreement between the UV continuum and the X-rays light curves (compare Fig. 3 with Gómez de Castro & Franqueira 1997) but a joint FUV-X-rays monitoring campaign needs to be carried out to confirm it since both sets of observations were carried out ~ 1 year appart and the X-rays monitoring did not even track 1 complete rotation period.

The X-rays energy distribution of BP Tau at maximum (Sept. 14, 1993) is also displayed in Fig. 3; notice that the maximum of energy is around 1 KeV. At the bottom left corner of the figure we have represented the postshock spectrum of an accretion shock assuming an extinction of 1 mag (the BP Tau extinction). Notice that there is a good qualitative agreement between the model and the observations although the model spectrum has not been convolved with the ROSAT PSF (this is deferred for a later work).

REFERENCES

Ayres, T.R. et al 1995, ApJS, 96, 223.

Brown, A., Ferraz, M.C. de M., Jordan, C., 1984, MNRAS,207,831.

Hartmann, L., Davis, R., Dupree, A.K. et al, 1979,ApJ,233,L69.

Feigelson, E.D., DeCampli, W.M., 1981, ApJ, 243, L89.

Gómez de Castro, A.I., Franqueira, M., 1997, ApJ, 482, 465.

Gullbring, E., Barwig, H., Schmitt, J.H.M.M., 1996, AA, 307, 791.

Lamzin, S.A., 1998, Astronomy Reports, 42, 157.

Lamzin, S.A., Gómez de Castro, A.I., 1998, Astron. Lett., Nov. issue.

Simon, T., Drake, S.A., 1989, ApJ, 346, 303.

Simon, T., Vrba, F.J., Herbst, W., 1990,AJ,100,1957

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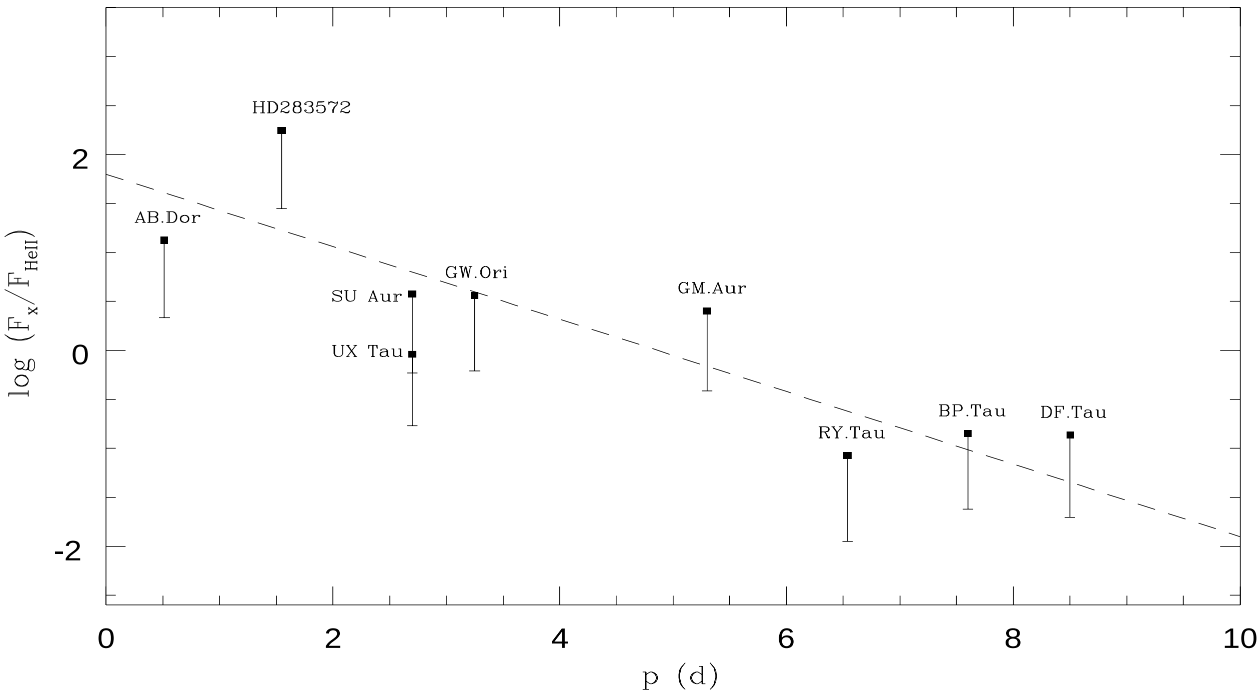

Fig. 1.— The L_x/L_{HeII} "coronal proxy" vs. the rotation period for the TTSs observed with the IUE and detected by EINSTEIN; the squares mark the actual location of the stars. The L_x/L_{HeII} ratio is sensitive to the extinction which is not accurately known for many TTSs. The effect of an increment of Av=1mag. is illustrated by an error bar.

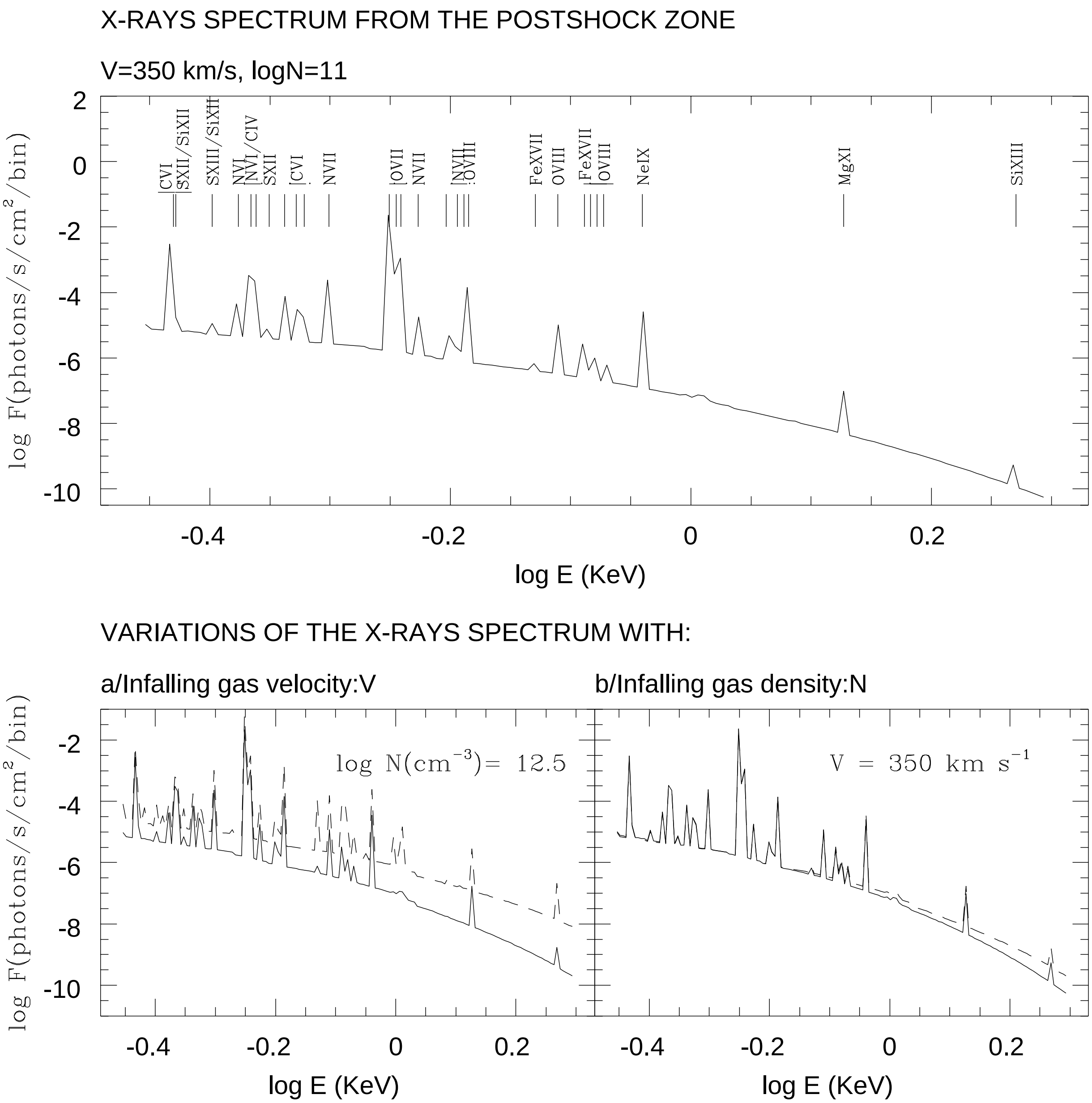

Fig. 2.— The postshock spectrum from accretion shocks. *Top:* Predicted spectrum for $\log N = 11$ and V= 350 km/s; the major features are identified. *Bottom: a)* Variation of the postshock spectrum with the shock velocity: V=350 km/s (continuous line), V=400 km/s (dashed line). *b)* Variation of the postshock spectrum with the density of the infalling gas: $\log N$=11 (continuous line), $\log N$=12 (dashed line). The output spectrum is given in photons/s/cm^2/bin; the energy bins have been selected so the dispersion is the same (D = E/δE = 86) in the 0.35-2.0 keV band.

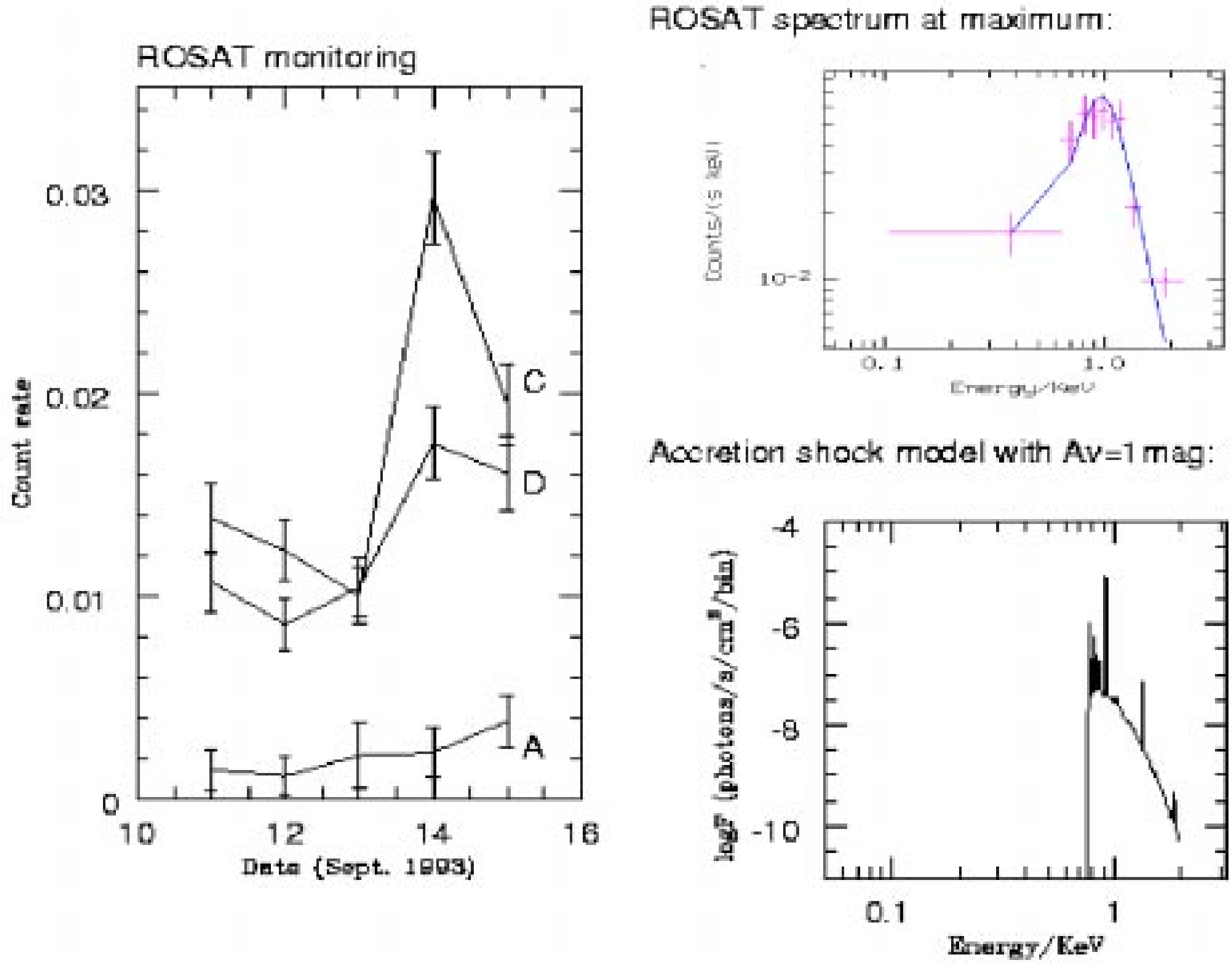

Fig. 3.— *Left:* X-rays light curves of BP Tau in the A, C and D bands. *Right top:* The X-rays spectrum of BP Tau measured with the ROSAT satellite at maximum X-rays brightness (14/September/1993). *Right bottom:* The X-rays spectrum from the postshock zone of an accretion shock (logN=12.5, V=350km/s) extincted Av=1 mag.