ULTRAVIOLET EMISSION LINES OF T TAURI STARS

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ABSTRACT

We present a study of the UV emission lines fluxes of the T Tauri stars (TTS). We have used for this purpose the *final IUE sample of TTS* which includes 33 TTS with good spectra in whole IUE range. We have derived the lines fluxes and compared them with the X-rays fluxes measured by the EINSTEIN satellite. Flux-flux diagrams are shown confirming that the X-rays flux of the TTSs is significantly lower than the expected if their atmospheres were similar to those of late-type main sequence stars. We have also found a weak correlation between the MgII and CIV lines fluxes suggesting that there is connection between the mechanism for line formation.

Key words: T Tauri stars; stars: late-type; X-rays: stars; ultraviolet: stars ;

1. INTRODUCTION

The T Tauri stars (TTS) are low-mass, pre-main-sequence stars. The UV spectrum of the TTS is dominated by strong emission lines; the strongest lines are those of MgII in the 2000-3000Å range and those of CIV, CII and OI in the 1200-2000 Å range. It is well known that the UV lines fluxes of the TTS are significantly higher than the observed in late-type main sequence stars; the surface fluxes of the TTS are $\sim 10^6$-10^7 erg.cm^{-2}.s^{-1}. In 1980 Imhoff & Giampapa showed that the UV lines surface fluxes for RW Aur were 100-300 times greater than those of the Sun. However, as the emission line ratios were similar to the solar values Imhoff & Giampapa (1980) concluded that the UV emission lines of RW Aur were formed in physical conditions similar to those in the solar chromosphere and transition region. In 1992 Lemmens et al. retook the problem using for this purpose the UV spectra of 11 TTS. They showed that TTS as a whole deviate (although only slightly) from active stars in the flux-flux relations. In this work we make use of the IUE Final Archive data to get insight into this problem. The IUE Final Archive provides the UV spectra of *33* TTS, in the full 1200-3200 Å IUE range The characteristics of the IUE sample are described in Sect. 2, and a summary of the IUE and Einstein data on these stars is provided in Sect. 3. Flux-flux and flux-ratios diagrams are analyzed in Sect. 4 and 5 respectively. Finally, we summarize in Sect. 6 our major findings.

2. THE SAMPLE

The sample of TTS observed in the low dispersion mode with the IUE satellite has been studied in detail by Gómez de Castro & Franqueira (1997; hereafter GF)). A detailed description of the spacecraft configuration can be found in Gonzalez-Riestra et al (1995) and references therein. The subset of TTS observed in the short wavelength range (1200-2000 Å) consist of 33 stars . Basic parameters for these stars are provided in Table 1.

3. THE DATA

3.1. The UV data

We have studied the UV spectrum of the TTS observed with the IUE which have good quality spectra in the whole IUE range. Each line-by-line image has been cleaned from bright spots and cosmic rays hits after visual inspection of the spectrum. The mean UV spectrum of the sources has been calculated as a mean of all the unsaturated spectra. A detailed list with image numbers, dates of observations and other useful parameters can be found in GF.

We have selected for this work the lines of OI(UV1), CII(UV1), SiIV(UV1), CIV(UV1), HeII(1640Å) and MgII(UV1). The line fluxes have been measured by gaussian fitting to the line profiles in the mean spectrum [1]. The fluxes have been corrected using the extinctions (A_V) provided in the fifth column. A standard ISM extinction law has been applied for the correction. There are significant discrepancies in the A_V values found in the literature depending on the work (and technique) considered. For instance Beckwith et al (1990) assign A_V = 2.7 mag to RY Tau while Strom et al (1989) assign A_V = 0.55 mag to the same source. We have decided to use the Beckwith et al (1990) values for the Taurus sources since

[1] Note that these fluxes are average fluxes of all the observations carried out by the IUE for each star. It is well known that the line fluxes may vary by a factor of ~ 2

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they obtain A_V from a fitting of the energy distribution between V and J to a reddened star. In any case, the references from which the A_V values have been taken are indicated in Table 1.

3.2. X-rays data

The X-rays fluxes for the T Tauri stars have been calculated from the EINSTEIN satellite data. We have followed the same procedure as Damiani et al (1995) but we have recalculated the X-rays fluxes with the extinctions provided in Table 1. We have assumed a common temperature of 0.86 KeV (10^7K) to all sources. The coefficients to convert the Einstein counts into fluxes have been obtained assuming that the underlying spectrum is a coronal- like thermal spectrum (Raymond-Smith spectrum).

Table 1. General properties of the IUE sample of TTS

hbc	Star	Sp.T.	$\log T_{eff}$ (K)	A_V	L_{bol} ($L_\odot$)
10	WY Ari	K5			
32	BP Tau	K7	3.602	1.37 [1]	1.21
33	DE Tau	M1	3.566	1.62 [1]	1.21
34	RY Tau	K1	3.708	2.7 [1]	7.5
380	HD 283572	G5	3.760	0.3 [2]	6.31
35	T Tau	K1	3.708	2.1 [1]	14
36	DF Tau	M0,1	3.587	1.96 [1]	2.97
37	DG Tau	M?	3.590	1.6 [1]	1.7
43	UX Tau	K2	3.695	1.8 [1]	2.7
45	DK Tau	K7	3.602	2.01 [1]	1.94
56	GI Tau	K7	3.602	2.52 [1]	1.66
58	DL Tau	?	3.590	1.53 [1]	0.77
74	DR Tau	?	3.590	1.6 [1]	2.5
77	GM Aur	K7	3.602	0.5 [1]	0.7
79	SU Aur	G2	3.761	1.45 [1]	14.4
80	RW Aur	K1	3.707	0.65 [3]	5.49
85	GW Ori	G5	3.760	0.8 [4]	26
435	AB Dor	K0,2	3.720	0.00 [5]	1.21
482	BN Ori	F2,3e			
568	TW Hya	K7	3.609	0.4 [6]	
569	CS Cha	K4		0.85[7]	2.7
575	VW Cha	K5		2.39 [7]	4.2
247	CV Cha	G8			8.0
250	GK Lup	K7-M0	3.591	0.95 [8]	1.55
251	RU Lup	K7-M0	3.591	1.28 [8]	2.14
252	RY Lup	K4	3.662	0.65 [8]	1.26
253	EX Lup	M0	3.580		0.39
264	SR 9	K5,7		0.5 [9]	3.55
271	AK Sco	F5e			
656	AS 216	K2			
662	V4046 Sgr	K5,6	3.616	0.16 [10]	
664	FK Ser	K5	3.638	0.7 [11]	2.13
315	DI Cep	G8	3.746	0.24 [12]	

Notes to Table: Extinctions:(1) Beckwith et al 1990; (2) Walter et al 1987; (3) Damiani et al 1995; (4) Cohen and Kuhi 1979; (5) Rucinski et al., 95; (6) Extinction computed from E(B-V)< 0.1 Rucinski et al., 1983, taking R=4;(7)Gauvin & Strom, 1992; (8)Hughes et al., 1994; (9) Bouvier 1990 ;(10) Hutchinson, 1990; (11) Simon et al., 1985; (12) Gómez de Castro et al., 1996.

4. Flux-Flux diagrams

We have studied the location of the TTS in flux-flux diagrams in order to compare them with late-type main-sequence and giants stars. We have used as standars those included in the RIASS Coronathon Sample (RCS) (Ayres et al.,95).

We have plotted the relations between a coronal indicator (X-Rays flux) against chromospheric (MgII) and transition region (CIV) indicators. We have divided the emission line fluxes by the bolometric fluxes of each star. These quantities are represented by R_{line}. The bolometric flux has been obtained from the bolometric stellar luminosity (the contribution of the disk has been substracted out). The distances to the targets are given in Table 2(in parsecs). The X-rays fluxes of the standard stars (as measured from the Einstein satellite) have been taken from Schmitt et al., 90.

Table 2. Distances for the IUE sample of TTS

Name	Distance(pc)
Taurus	140
Orion	460
Lupus	150
Chamaleon	140
Ophiuco	160
AB Dor	27
TW Hya	40
V4042 Sgr	42
FK Ser	220
DI Cep	300

The most relevant flux-flux diagrams, e.g. those corresponding to coronal, transition region and chromospheric indicators are shown in Figures 1,2 and 3.

In Fig.1 , we represent the X-ray flux versus the CIV flux. The average CIV flux of the TTS is 2 orders of magnitude larger than the observed in late-type stars, however the X-rays flux is only 1 magnitude larger. This indicates a deficiency in X-rays (or an excess in CIV) in the TTS atmospheres with respect to late-type stars. The clear-cut correlation between X-rays and CIV fluxes observed in dwarfs stars does not extend to the TTS; a broad range of CIV fluxes are observed for similar X-rays fluxes in the TTS.

In Figure 2 we observe a similar trend. The TTS show an X-rays defficiency (or a MgII excess) when compared with late-type stars . In this case, there is a weak correlation between MgII and X-rays fluxes with *a negative slope* , just the opposite to the observed in late-type stars; the MgII lines are stronger in stars with weaker X-rays emission.

Finally, in Fig. 3 we represent the CIV vs. the MgII fluxes. Notice that these lines fluxes are correlated both in the TTS and and in late-type stars. However the slopes of the best fitting (least squares) lines are different; again the TTS show a MgII enhacement. We provide in Table 3 the best fits to power laws of the flux-flux relations for TTS, late-type dwarfs and giants.

These diagnostic diagrams show that the UV and the X-rays fluxes of the TTS cannot be explained altogether in the framework of an active star and that other physical processes ought to be taken into account. In particular, we think that there is a non-negligible contribution of the wind to the MgII line flux.

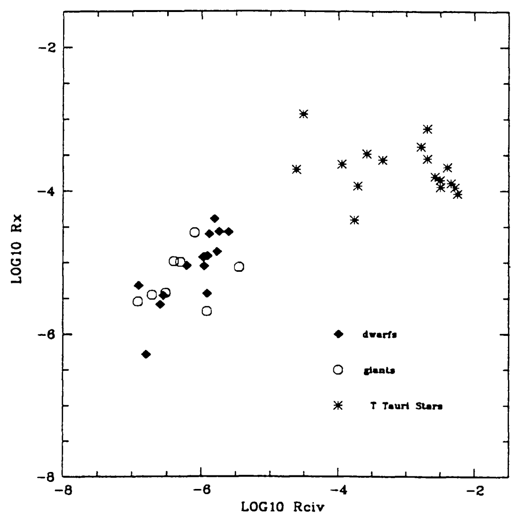

Figure 1. Flux-Flux diagram: X-rays vs. CIV

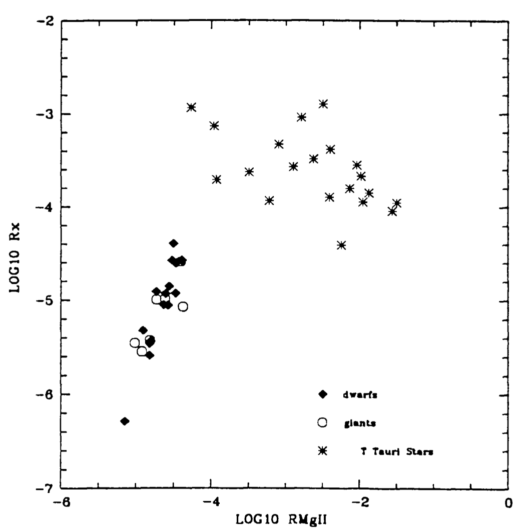

Figure 2. Flux-Flux diagram: X-rays vs. MgII

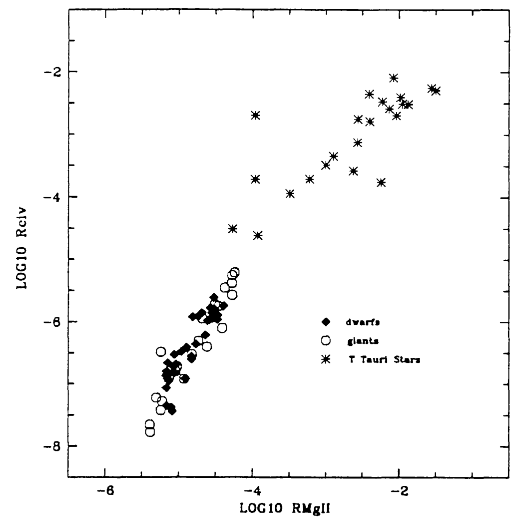

Figure 3. Flux-Flux diagram:CIV vs. MgII

5. Flux-ratio diagrams

We have also plotted some flux-ratio diagrams which may provide further insight in the excitation mechanism of the UV lines in the TTS.

In Fig.4 we have compared the CIV emission with the X-Rays/HeII ratio. The HeII line can be excited by recombination after the photoionization by X-rays photons. The TTS clearly show an inverse correlation which is not observed in the RCS sample. The emission in the CIV line decreases steeply with the X-rays/HeII ratio, as approaching the location of the MS stars.

The CIV to CII ratio versus the X-rays is shown in Fig.5. An enhacement of the CIV/CII ratio is observed in the TTS when compared with late-type stars.

6. CONCLUSIONS

The strong UV emission lines fluxes cannot be explained within the context of standard atmospheric models for late-type stars since the X-rays fluxes are far too low. We have found a weak correlation between the "chromospheric" MgII and the "transition region" CIV lines, suggesting a connection between the mechanism of line formation; however the slope of the correlation is different than the observed in late-type stars. This may be caused, in part, by the contribution of the wind to the Mg II line.

The presence of an accretion disk around the central star could explain the IR and UV escess as coming from the boundary layer (Basri & Bertout, 89), but the high temperature required to enhance the CIV, SiIV lines emission to the fluxes observed in the TTS cannot be reproduced by these models. The X-rays excess of the TTS with respect to late type

Table 3. Power-law slopes

log(Flux)-log(Flux) relation	TTS	Dwarfs	Giants
X-rays vs. CIV	-	0.98 ± 0.20	-
X-rays vs. MgII	-0.26 ± 0.09	2.23 ± 0.25	1.15 ± 0.35
CIV vs. MgII	0.72 ± 0.12	1.80 ± 0.15	1.86 ± 0.14

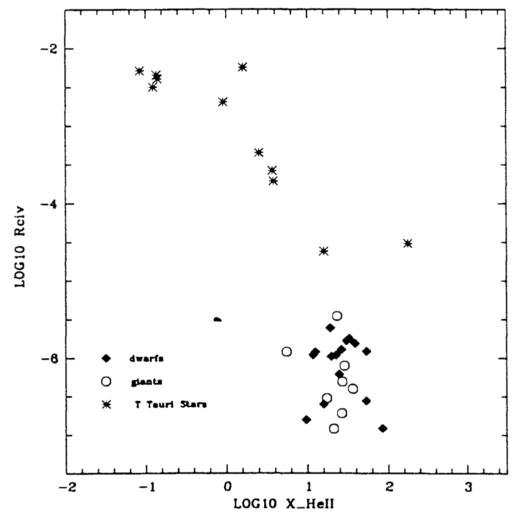

Figure 4. Flux-ratio diagram: CIV vs. X-rays/HeII

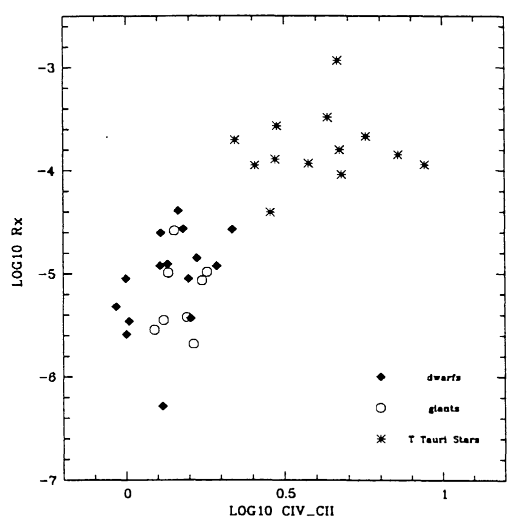

Figure 5. Flux-ratio diagram: X-rays vs. CIV/CII

stars could be responsible of the photoionization of some of these species, as Fig. 5 suggests. However, the source of the X-rays emission is still uncertain; strong X-rays emission could be produced either in coronal-like loops by dissipation of magnetic energy or by the release of gravitational energy in accretion shocks.

Finally, we want to stress that obtaining highly accurate Av values is instrumental for this type of studies. In fact, the uncertainties in Av could be responsible of the high scatter observed in the diagrams, and especially in those relating UV tracers with the X-rays emission.

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