Chemical Composition and Geometry Diagnostics in High Resolution X-ray Spectra of T Tauri stars

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ABSTRACT

Chandra archival spectra of the weak-lined T Tauri Stars HDE 283572 and DoAr 21, and the classical T~Tauri SU Aur have been analysed in order to investigate diagnostics of chemical composition and hot plasma geometry during flaring and quiescent states. Temperature-insensitive line ratios have been used to estimate the coronal abundance ratios Ne/O, Mg/Si, Si/S and Ca/Ar. Limits have been placed on plasma densities using transitions of He-like Mg. We also place limits on the strength of cold Fe fluorescence induced by X-ray irradiation of circumstellar disks. We discuss the results in the context of chemical fractionation, coronal structure and disk geometry in pre-main sequence stars.

T TAURI STARS:

T Tauri stars are young late-type objects with an age of a few Myr contracting toward the ZAMS phase. They are classified, based on Hα emission, in two groups: classical T Tauri stars (cTTs) and weak-lined T Tauri stars (wTTs). cTTs are still accreting material from their circumstellar disk shown by the observed infrared excess. The wTTs are PMS stars, between the accreting phase of a cTTs and the disk-free phase of a ZAMS stars, which show no accretion. One characteristic of the T Tauri stars is that they are prodigious sources of X-ray emission, although the reasons still largely unknown (Feigelson et al. 2003, ApJ, 584, 911). One of the debated questions is whether and how the X-ray emission of accreting cTTs and non-accreting wTTs differs.

THE TARGETS:

Our sample contains two wTTs (HDE 283572 and Doar 21) and one cTTs (SU Aur). Two large flares were observed Doar 21 and SU Aur. Stellar parameters, light curves and spectra of the targets are shown below.

HDE 283572, member of the Taurus-Auriga star-forming region, is X-ray coronal source at the upper end of the observed X-ray luminosities in single young active stars. It is a probable predecessor of an A-type MS star.

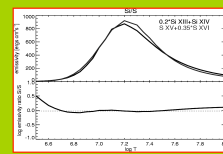
SU Aur, also member of the Taurus-Auriga star-forming region, has a rather low disc mass (~7.9e-6 $M_\odot$) compare with typical cTTs. Its accretion rate is ~ 10^{-8} $M_\odot yr^{-1}$.

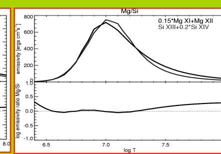
Doar 21, member of the Ophiucus star-forming cloud, shows strong and high rate flares. Neither Hα emission nor strong IR excess have been reported.

TEMPERATURE-INSENSITIVE ABUNDANCE RATIO DIAGNOSTICS:

These are ratios formed by combining two sets of lines of two different elements, constructed such that the combined emissivity curves of each set have essentially the same temperature dependence (see Figs.) The resulting ratio of measured line fluxes then yields directly the ratio of the abundances of the relevant elements, independent from the atmospheric temperature structure (Drake & Testa 2005, Nature, 436, 525).

Heavy absorption affects the long wavelength elements (e.g.; Ne, O, Fe). The O/Ne values for SU Aur and HDE 283572, specially for later, suggest the ongoing coagulation of grains into much larger bodies depleting the accreting gas into grain-forming elements (Drake et al. 2005, ApJL, 627, 149). The Ar/Ca, S/Ar, Si/S and Mg/Si show opposite behavior during the flares on Doar 21 and SU Aur.





Abundance Ratios using Temperature-Insensitive Diagnostics.

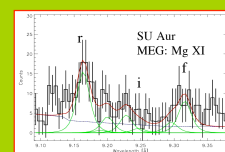
Abundance Ratio	Doar 21 Flare	Doar 21 Quiet	SU Aur Flare	SU Aur Quiet	HDE283572 Quiet
$[Ar/Ca]_\odot$	-0.36± 0.32	0.02± 0.42	-0.14± 0.21	···	···
$[S/Ar]_\odot$	0.26± 0.18	0.13± 0.19	0.22± 0.22	0.50± 0.69	···
$[O/Ne]_\odot$	···	···	0.13± 0.50	···	0.15± 0.19
$[Ne/Mg]_\odot$	···	···	0.63± 0.10	···	0.72± 0.09
$[Mg/Si]_\odot$	0.09± 0.06	-0.32± 0.08	-0.05± 0.08	0.24± 0.08	0.00± 0.08
$[Mg/Fe]_\odot$	···	···	0.30± 0.22	0.53± 0.22	0.10± 0.15
$[Si/S]_\odot$	0.21± 0.12	-0.04± 0.10	0.26± 0.17	0.34± 0.28	···

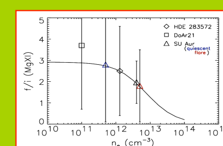
Top panels: Emissivities and their ratios for lines comprising the temperature-insensitive indices for the abundance ratios Si/S (left) and Mg/Si (right). Bottom: Abundances ratios using the temperature-insensitive diagnostics.

ELECTRON DENSITY DIAGNOSTICS:

The electron density is, along with the electron temperature, one of the crucial parameter that determines heating, cooling, and geometric properties of a stellar coronae. Electron density, the missing parameter linking emitting volumes and EM, is fundamental for calculating the sizes of X-ray emitting regions. We use the density sensitive He-like triplets *f/i* line ratios to diagnose the plasma electron density.

The MgXI triplet provides the most reliable constraints on density due to the heavy absorption affecting the OVII and NeIX triplets. Line blending effects taking into account (Testa et al. 2004, ApJ, 617, 508). SU Aur is characterized by high density (~5 10^{12} cm^{-3}) during the flare, while densities are significantly lower (<10^{12} cm^{-3}) in quiescence. Doar 21 shows low density regime. HDE 283572 shows, based on both NeIX and MgXI, values that are compatible with high a density regime (a few 10^{12} cm^{-3}) however the measurements are poorly constrained.





f/i line ratios, and corresponding densities, from MEG measured fluxes.

Source		Mg XI f/i	Mg XI $\log n_e$	Ne IX f/i	Ne IX $\log n_e$
HDE 283572		2.5 ± 2.1	12.1 [< 13.3]	2.8 ± 2.5	12.3 [< 13]
DoAr21		3.7 ± 3	< 13		
SU Aur -	flare	1.8 ± 1.7	12.7 [< 14]		
	quiescent	2.8 ± 2.7	< 14		
	whole obs.	1.97 ± 1.	12.6 [12 – 13]		

Top left: Mg XI He-like triplet spectral region. MEG spectrum of SU Aur. The best-fitting model with the blending components is superimposed to the spectrum. Top right: Comparison of theoretical and derived values for the density sensitive f/i ratios of the Mg XI He-like triplet. Bottom: Plasma densities derived from the R ratio of the He-like triplets of Mg and Ne.

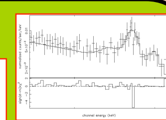
THE Fe Kα FLUORESCENCE LINE:

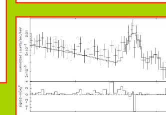
Photospheric fluorescence lines are caused by inner shell photoionization of the 'cold' atoms by incident coronal X-rays. They act like the corona viewed in a mirror: the further away the mirror from the coronal source, the lower the 'reflected' flux. Therefore they provide a direct spectroscopic observational constraints on the average coronal scale height.

We have deteted the Fe Kα line (~6.4 keV) in SU Aur. Its equivalent width, 101 Å, suggest that a geometry is required in which the photoionizing X-ray suffer a localized absorption much larger that in the line of sight (Tsujimoto et al. 2005, ApJS, 160, 503). A emission feature, at 6.32 keV, possibly reminiscent of fluorescence emission by Fe ions is observed in Doar 21. No emission at that energy is observed in HDE 283572.

Best Fit parameters of zero order spectrum.

	HDE 283572	SU Aur	Doar 21
Z	0.90	0.70	0.28
kT_1 [keV]	0.76	1.07	1.10
kT_2 [keV]	2.35	7.07	5.73
log L_x [erg/s]	31.2	30.5	31.2
log N_H [cm_{-2}]	20.69	21.34	21.99
FeK(λ) [Å]	···	6.42±0.06	6.32±0.16
EW(FeK) [Å]	···	101	42



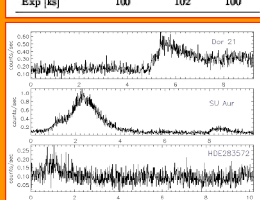


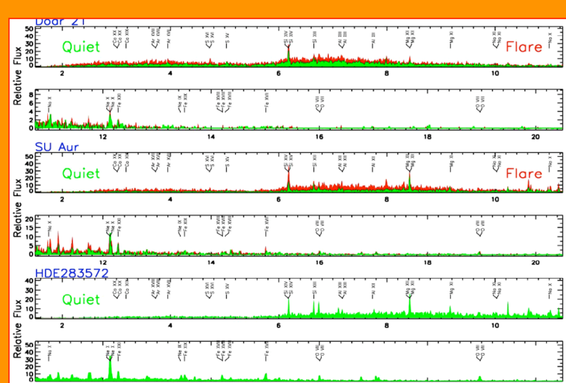
Top left: Best fit parameters of the zeroth order spectra of HDE 283572, SU Aur and Doar 21 are shown. The parameters for the Fe K line fits are also shown.. Right: Zoom-in of the zeroth order spectrum of SU Aur around the Fe K (6.4 keV) and Fe XXV (6.7 keV) features. An additional line component is needed to fit the flux excess observed at 6.4 keV. A model with (top) and without (bottom) the emission line is shown.

SPECTRA AND LIGHT CURVE:

Stellar Parameters and HETGS Observations.

	HDE 283572	SU Aur	Doar 21
SpTy	G5 IV	G2 III	K1V
Class	wTTs	cTTs	wTTs
Age [Myr]	3	4	1
K [mag]	6.53	5.86	6.13
vsini [km/s]	78	80	···
EW(Hα) [Å]	1.6	3.5	0.8
d [pc]	140	152	170
ObsID	3756	3755	3761
Exp [ks]	100	102	100





Top left: Summary of stellar parameters for HDE 283572, SU Aur and Doar 21. Bottom left: *Chandra* X-ray light curves binned at 100s intervals. Doar 21 and SU Aur show a single large flare while HDE 283572 was relatively quiescent. Right: *Chandra* X-ray HETG-ACIS-S (MEG) spectra. The strongest lines over the observed wavelength range are identified. Red and green spectra are shown for the flare and quiescent phases respectively.

CONCLUSIONS:

The O/Ne values for SU Aur and HDE 283572, specially for later, suggest the ongoing coagulation of grains into much larger bodies depleting the accreting gas into grain-forming elements

Doar 21 and SU Aur in quiescent state show low electron density. HDE 283572 and SU Aur in flare state show high electron density.

The Fe Kα line (~6.4 keV) is observed in SU Aur. A geometry might be needed to account for the localized absorption.