XMM-NEWTON OBSERVATIONS OF X-RAY LUMINOUS G-TYPE STELLAR CORONAE

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We present results obtained from the analysis of *XMM-Newton* spectra of the Hertzsprung-gap giant 31 Com and of the pre-main-sequence star HD 283572, two G-type stars in very different evolutionary phases, but having similar high X-ray luminosities. We discuss methodological issues related to the data analysis, as well as the results on the inferred properties of the stellar coronae.

1. Scientific Issue

There is a growing observational evidence that the coronae of very active stars cannot be described simply as a scaled-up version of the solar corona [1–3]: the shape of the plasma emission measure distribution vs. temperature in these stars is substantially different from the solar one [4], suggesting the *continuous* presence of hotter and denser plasma in coronal magnetic loop structures, possibly undergoing frequent flaring events.

Our investigation aims at testing whether the coronal characteristics are related only to the X-ray emission level, or whether they may depend on other parameters such as the stellar evolutionary stage. To this aim, we have selected two X-ray active stars having very similar spectral types and X-ray luminosities (Table 1), one of them (HD 283572) being a Weak T Tauri Star in Taurus, and the other (31 Com) an evolved Hertzsprung gap giant. Details on the *XMM-Newton* observations are reported in Table 2.

2. Methodological Issues

The following methodological issues have been addressed in this work: (a) Is it possible to co-add the RGS1 and RGS2 spectra, so to improve the data quality and hence the analysis results ? (b) Is it possible to measure individual line fluxes, in spite of problems related to line blends and large wings in the line profiles, so to be able to perform a detailed reconstruction of the emission measure (EM) distribution vs. temperature ? (c) Is it possible to obtain a consistent multi-temperature model description of *both* the RGS and EPIC spectra, over the whole wavelength range ?

3. Data Analysis

Data reduction was performed with SAS V5.3.3. Good Time Intervals were selected with time screening criteria based on the X-ray light curve of the background.

For the analysis of the RGS spectra (Fig. 1) we employed the Package for Interactive Analysis of Line Emission (PINTofALE [5]), and in part also the MIT/CXC Interactive Spectral Interpretation System (ISIS), using different approaches. Line identification and EM analysis were based on the Astrophysical Plasma Emission Database (APED/ATOMDB V1.2), adopted also for the spectral fitting of the EPIC data using XSPEC.

3.1. RGS Spectra

We have identified about 50 lines in the spectrum of HD 283572, and about 80 lines in the spectrum of 31 Com, but only half of them were eventually used for the EM analysis (following [6]). Both spectra show lines from Fe XVII–XXIV ions, and lines from He-like and H-like O and Ne ions. Only in the 31 Com spectrum we were also able to measure line fluxes from C VI, Mg XI–XII, Si XIII, and Ni XIX–XX.

For the measurement of individual line fluxes we have adopted and compared two approaches,

Table 1
Stellar properties

Star	Spectral Type	$M/M_\odot$	$R/R_\odot$	Age [yr]	D [pc]	N_H cm^{-2}	L_x (0.3–8 keV) erg s^{-1}
HD 283572	G2	2	2.7	3×10^6	128	10^{21}	9×10^{30}
31 Com	G0 III	3	8.0	6×10^8	94	10^{18}	7×10^{30}

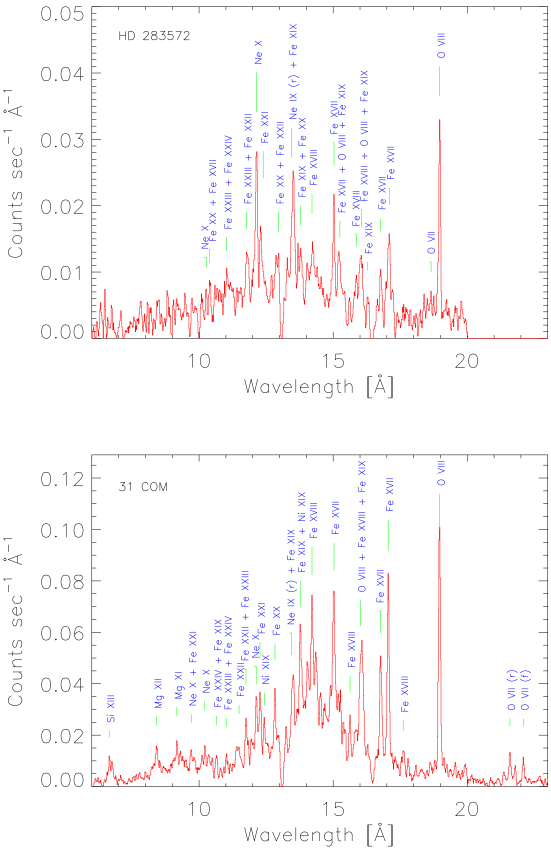

Figure 1. RGS2 spectrum of HD 283572 and co-added RGS spectrum of 31 Com, with identifications of the most prominent emission lines.

using the spectrum of 31 Com as a test case: (a) selected lines have been fitted with ISIS, using a delta-function model convolved with the actual Line Spread Function (LSF) of the RGS1 and RGS2, considered separately; (b) the same lines have been measured in the rebinned and co-added RGS spectrum using a Lorentzian line profile, with a wavelength-dependent width fixed at the value which provides the best matching with the actual LSF. In both cases, the continuum emission was estimated from a 3-temperature fit of the EPIC spectrum. Comparison of the two sets of measurements (Fig. 2) shows agreement within the statistical uncertainties. We have eventually adopted the second method to measure all the other line fluxes.

3.2. EPIC Spectra

Source and background EPIC spectra were extracted from the central *pn* and MOS CCDs. A pile-up effect occurred only in the case of the *pn* observation of 31 Com, and we have adopted an annular (7.5″–50″) source region to avoid it. The background-subtracted *pn* spectra of both sources clearly show emission down to the Fe XXV 1.85 Å line. Instead, the MOS spectra start to be background-dominated shortward of ~ 2.5 Å.

A three-component isothermal model – with free abundances for O, Ne, Mg, Si, Fe, S and Ni – multiplied by a *fixed* ISM absorption component, provides a sufficiently good description of each EPIC spectrum, although not always statistically acceptable. Moreover, the *pn* and MOS best-fit models differ significantly as for some of the abundance values, and – at least in the case of 31 Com – for the temperature of the coolest component (Table 3).

4. Results

The results obtained separately from the RGS, *pn*, and MOS spectra are shown in Table 3 and in Fig. 3; in Fig. 4 and 5 models and data are compared (for 31 Com only).

In the case of 31 Com, the best overall quality of the fits is provided by the RGS EM model and by the *pn* 3-T model. The main problems with the MOS 3-T model are the underprediction of the O VII–VIII, C VI and Ni XIX line fluxes. On the other hand, the *pn* 3-T model overpredicts the O VII and Fe XVII–XVIII lines, and the EM model shows an emission excess in the region 12–13 Å.

5. Conclusions

Line flux measurements can be derived from co-added RGS spectra using a Lorentzian line

Table 2
Log of the *XMM-Newton* observations

Name	Obs Date	RGS1	RGS2	MOS1	MOS2	*pn*	MOS & *pn*
		$T_{\rm exp}$ [ks]		$T_{\rm exp}$ [ks]		$T_{\rm exp}$ [ks]	Mode/Filter
HD 283572	Sep 2000	**0**	47.4	38.4	38.3	41.1	FF Medium
31 Com	Jan 2001	39.6	38.5	37.9	37.9	32.2	LW&FF Thick

Table 3
Best-fit models. Discrepant values are indicated in bold face.

	31 Com			HD 283572		
Parameter	RGS	*pn*	MOS	RGS	*pn*	MOS
$\log T_{1,2,3}$ K	6.5 – 7.2	**6.4**, 6.9, 7.3	**6.8**, 7.0, 7.2	6.5 – 7.4	6.6, 7.0, 7.4	6.7, 7.0, 7.4
$\log EM_{1,2,3}$ cm^{-3}	EM(T)[a]	52.6,53.1,53.0	52.5,53.4,53.2	EM(T)[a]	53.5,53.5,53.7	53.1,53.3,53.8
C/Fe	$0.3^{+0.2}_{-0.1}$	= 0.3	= 0.3	—	= 1.3	$1.3^{+0.6}_{-0.5}$
O/Fe	$\mathbf{0.5}^{+0.1}_{-0.1}$	$0.38^{+0.02}_{-0.03}$	$0.30^{+0.05}_{-0.05}$	$0.6^{+0.4}_{-0.2}$	$0.63^{+.04}_{-.04}$	$0.86^{+.08}_{-.08}$
Ne/Fe	$0.8^{+0.1}_{-0.2}$	$\mathbf{1.5}^{+0.1}_{-0.1}$	$0.8^{+0.1}_{-0.1}$	$1.2^{+0.2}_{-0.3}$	$1.2^{+0.1}_{-0.1}$	$\mathbf{2.0}^{+0.1}_{-0.1}$
Mg/Fe	$1.0^{+0.4}_{-0.3}$	$1.3^{+0.1}_{-0.1}$	$1.1^{+0.1}_{-0.1}$	—	$0.9^{+0.1}_{-0.1}$	$0.9^{+0.1}_{-0.1}$
Si/Fe	$0.9^{+0.9}_{-0.3}$	$0.8^{+0.1}_{-0.1}$	$0.8^{+0.1}_{-0.1}$	—	$0.7^{+0.1}_{-0.1}$	$0.6^{+0.1}_{-0.1}$
S/Fe	—	$0.4^{+0.1}_{-0.1}$	$\mathbf{0.7}^{+0.1}_{-0.1}$	—	$0.7^{+0.2}_{-0.2}$	$0.4^{+0.2}_{-0.2}$
Ni/Fe	$3.5^{+2.1}_{-0.7}$	$2.6^{+0.3}_{-0.2}$	$\mathbf{1.9}^{+0.1}_{-0.2}$	$1.2^{+1.0}_{-0.6}$	$\mathbf{4.1}^{+0.3}_{-0.3}$	$0.7^{+0.4}_{-0.4}$
Fe	~ 1.4	$\mathbf{1.54}^{+.02}_{-.02}$	$\mathbf{0.80}^{+.01}_{-.01}$	~ 0.7	$\mathbf{0.37}^{+.01}_{-.01}$	$\mathbf{0.49}^{+.01}_{-.01}$
χ^2_r/dof	1.2/280	1.1/367	1.5/317	0.8/98	1.1/688	1.0/411

[a] EM distribution (Fig. 4)

profile, provided the continuum level is independently estimated from EPIC spectra. There is still some disagreement between independent descriptions of the coronal plasma temperature structure, as derived from detailed emission measure analysis or from multi-T fitting of the EPIC spectra. Our results suggest that the coronae of stars with similar X-ray luminosity share the same shape of the EM distribution, from $T \sim 3 \times 10^6$ K up to the peak at 10^7 K, but they may show significant differences in the amount of plasma at higher temperatures.

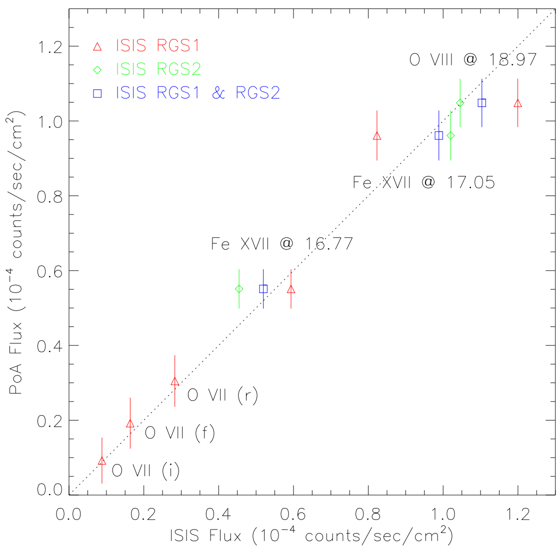

Figure 2. Comparison of (ISIS) fluxes from the RGS1 and RGS2 spectra of 31 Com, taking into account the LSF, and (PoA) fluxes measured in the co-added RGS spectrum, using a Lorentzian line profile.

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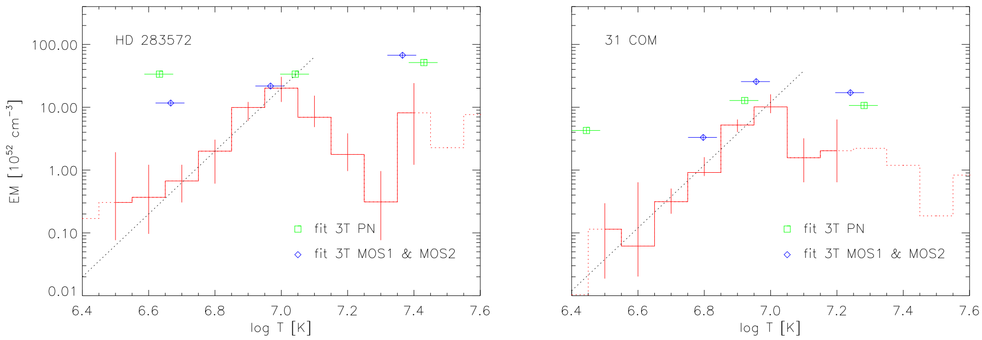

Figure 3. RGS-based EM distributions (solid lines), and EPIC best-fit 3-T model solutions (green squares and blue diamonds) for HD 283572 (left panel) and 31 Com (right panel). The dotted lines represent the same power-law $EM(T) \propto T^5$, for ease of comparison.

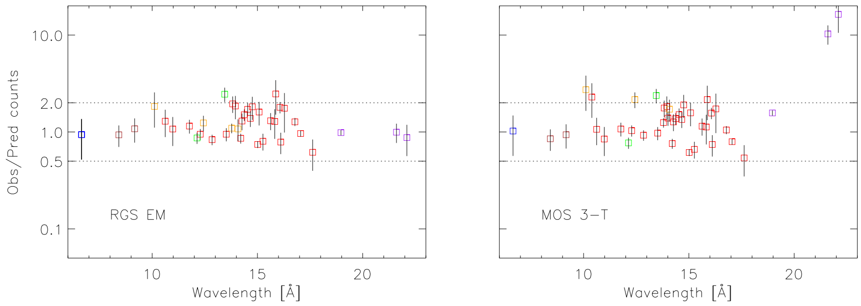

Figure 4. Comparison between observed and predicted fluxes for 31 Com, based on the RGS EM distribution (left), and on the MOS best-fit 3-T model (right).

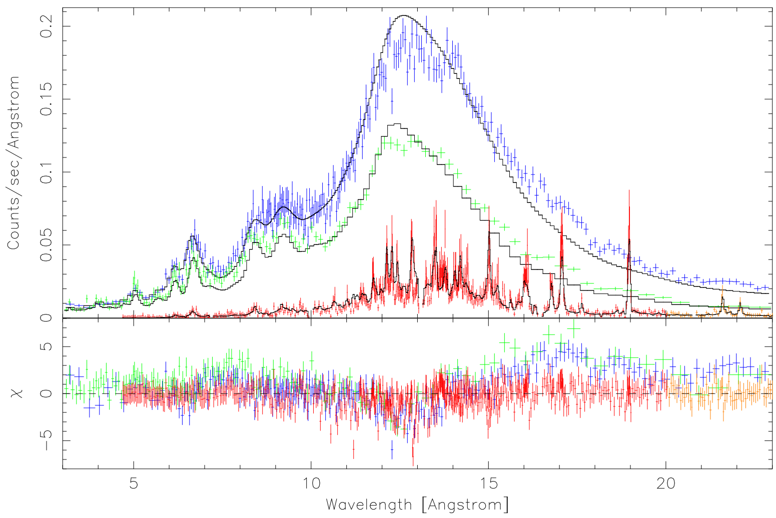

Figure 5. EPIC *pn* (upper, blue) and MOS2 (mid, green) spectra, compared with the EM model spectrum (solid histogram, black) based on the RGS (lower, red/orange) data for 31 Com.