The *XMM-Newton* view of TW Hya

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We present the X-ray spectrum of TW Hya observed at high spectral resolution with the Reflection Grating Spectrometer onboard the *XMM-Newton* satellite. We determine line fluxes for individual emission lines in the high resolution spectrum, and find that the predominant emission is from neon and oxygen, with comparatively weak iron lines. No emission from magnesium and silicon is detected. Comparison to a *Chandra* HETGS observation carried out about one year before shows that TW Hya exhibits moderate, irregular variability. Unlike all other high-resolution X-ray spectra of late-type stars obtained so far the flux ratio between the forbidden f and the intercombination i line of helium-like ions is very low ($R := f/i < 1$) indicating high densities. For TW Hya we find $n_{\rm e} > 10^{12}\,{\rm cm}^{-3}$, while the density in typical stellar coronae is about two orders of magnitude lower. Together with the lack of Mg and Si emission this provides strong evidence that its X-ray emission is produced in a disk-fed accretion column (depleted of grain-forming elements) rather than by magnetic activity.

1. Introduction

At a distance of $\sim$ 60 pc TW Hya is one of the nearest classical T Tauri stars (cTTS), i.e. a late-type pre-main sequence star in the phase of disk accretion. X-ray emission from pre-main sequence stars is commonly explained by analogy to the Sun and solar-like stars as resulting from magnetic activity. However, it is unclear whether this holds for the youngest stars with dense circumstellar environments. In these latter ones X-ray emission could also arise in the accretion column where the magnetically funneled flow hits the surface of the star.

A precise assessment of the physical conditions in the X-ray emitting region has become possible with the new generation of dispersive X-ray instruments. TW Hya is the only cTTS observed with both *XMM-Newton* and *Chandra* so far. In this poster paper we present a 30 ksec long *XMM-Newton* observation obtained in July 2001. About a year before TW Hya had been targeted by *Chandra* ([3]). As we show here the high-resolution X-ray spectrum obtained with both satellites strongly contrasts to that of more evolved late-type stars.

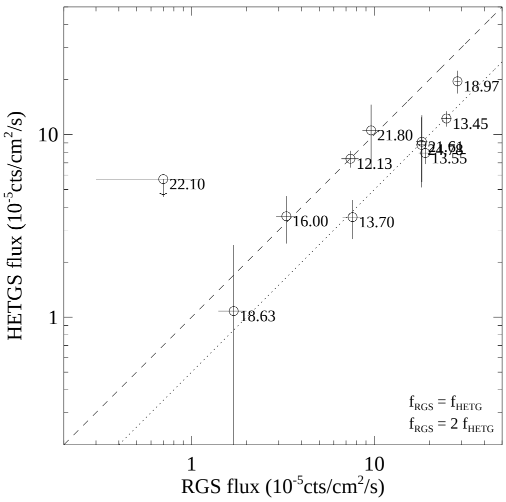

Figure 1. Comparison of photon fluxes for individual emission lines in the X-ray spectrum of TW Hya measured with the *XMM-Newton* RGS and the *Chandra* HETGS-MEG.

2. The High-resolution X-ray Spectrum of TW Hya

The RGS spectrum of TW Hya shows several remarkable features (see Fig. 2; next page). The most obvious one is the strength of neon emission lines (near $12-14$ Å) as compared to the relatively weak emission at $15-17$ Å where most late-type stars show strong lines corresponding to iron L shell transitions. Magnesium and silicon seem to be completely absent from the RGS spectrum, which could in part be due to the low effective area of the RGS in the respective wave-

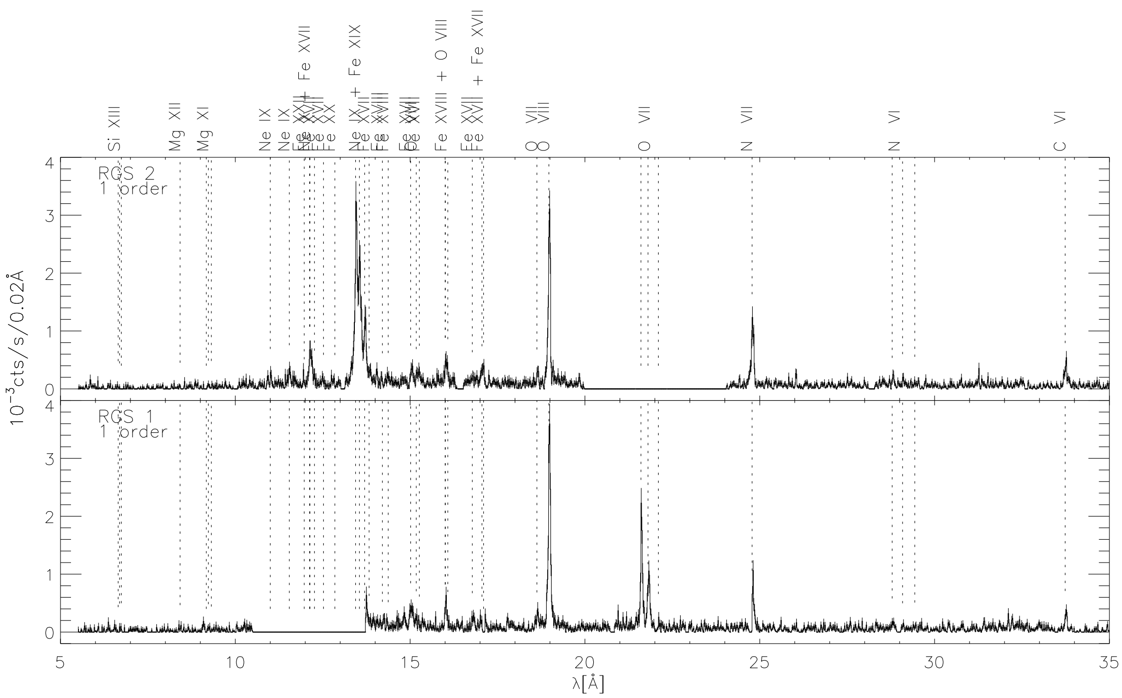

Figure 2. First order *XMM-Newton* RGS count rate spectrum of TW Hya; exposure time is 29 ksec. Horizontal lines mark gaps due to the failure of individual CCDs.

length range. A curious lack of emission at the position of the Mg XI triplet has also been observed by [3].

We have measured photon fluxes for the bright emission lines in the RGS spectrum, and compare the result to the *Chandra* HETGS measurement (see Fig. 1). Most fluxes agree within a factor of two with each other, with a tendency towards higher fluxes in the RGS, i.e. the spectral variability of TW Hya is quite modest. The observed variations could be due to long- or short-term variability. During the *Chandra* observation a flare-like outburst dominated the second half of the observing time. The increase in intensity was about a factor two in this event. During the *XMM-Newton* observation TW Hya was variable but without the clear signature of a flare. From the time-averaged HETGS spectrum [3] derived an X-ray flux of $3.7\,10^{-12}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ for the $0.45 - 6.0$ keV band. Integrating the EPIC pn spectrum in the same energy band we arrive at a slightly lower value of $f_{\mathrm{x,EPIC}} = (2.2 \pm 0.2)\,10^{-12}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. Our result is also compatible with an ASCA observation of TW Hya (presented by [2]).

3. Helium-like Ions

Line flux ratios formed from the individual components of the triplets of He-like ions are important diagnostic tools for the X-ray emitting plasma. Fig. 3 shows a zoom into the RGS spectrum of TW Hya around the He-like triplets of neon and oxygen. The Ne IX triplet is only partly resolved and known to form a blend with a number of iron lines. However, in view of the fact that all other Fe lines are very weak, it seems safe to assume that the contamination of the Ne IX triplet is negligible. In contrast to the *Chandra* result by [3] who gave a very high upper limit for the flux of the intercombination line of the oxygen triplet (see also Fig. 1) this line is clearly detected with the RGS, although very weak. We modeled both triplets with the CORA line fitting application ([7]) using three Lorentzian line profiles added on a constant to take account of the local background. The values for the photon fluxes of the resonance r, intercombination i, and forbidden f line are listed in Table 1.

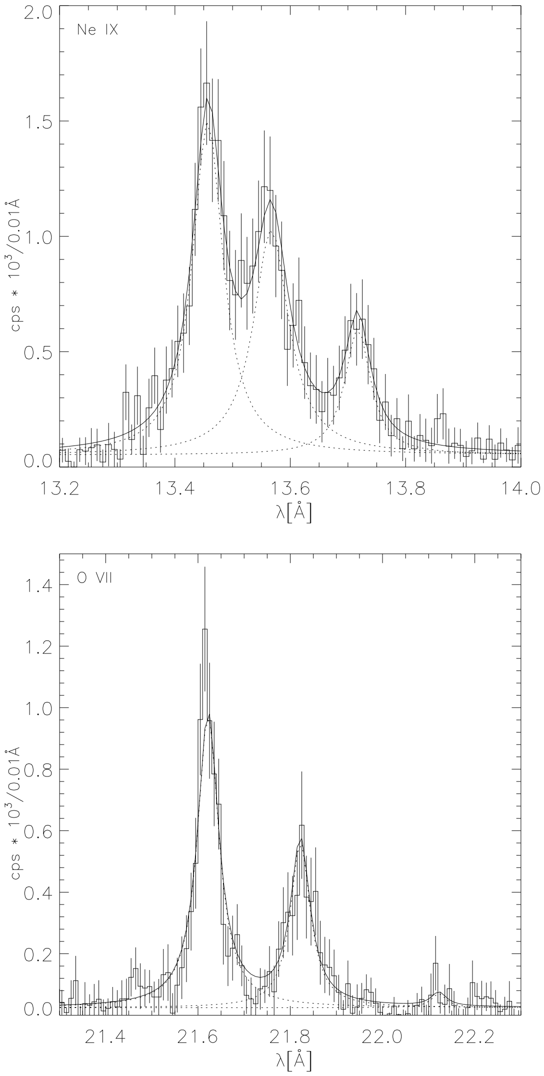

Figure 3. Triplet of helium-like neon and oxygen measured on TW Hya with the RGS: data and best fit model.

4. Temperature and Density of the X-ray Emitting Region

Calculations for a collision dominated plasma relate flux ratios between the He-like triplet lines directly to electron temperature T_e and density n_e in the emitting region ([10]). In particular, $G := (f+i)/r$ is temperature sensitive, and $R := f/i$ is density sensitive. The line strengths (and consequently the line ratios) can be altered in the presence of UV radiation. Therefore, only stars with similar UV flux can directly be compared in a grid of T_e versus n_e.

Table 1
Photon flux for the He-like triplet transitions of oxygen and neon measured in units of 10^{-5} phot/s/cm^2.

	r	i	f
O VII	18.2 ± 1.3	9.6 ± 1.0	0.7 ± 0.4
Ne XI	24.8 ± 1.6	19.0 ± 1.5	7.6 ± 0.9

The UV continuum of TW Hya is comparatively weak ([1]). In Fig. 4 we confront the G and R ratios of the pre-main sequence star TW Hya to a number of late-type main-sequence stars, for which the UV field is negligible (data from [8]; [12]). All main-sequence stars gather near the low-density limit where only an upper limit to n_e can be derived. TW Hya stands out as the only object with very high coronal density: $n_e \sim 6\,10^{12}\,\mathrm{cm}^{-3}$, i.e. about two orders of magnitude higher than for normal stellar coronae.

5. Temperature-Activity Relation

The flux ratio between the $Ly\alpha$ line of the H-like ion and the resonance line of the He-like triplet of the same element can be used as a measure for the coronal temperature. We compared TW Hya to a number of active late-type stars on the main-sequence. Using the stellar parameters of TW Hya we derive an X-ray surface flux of $F_x = 9.6\,10^6\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ in the $0.1 - 2.4$ keV *ROSAT* band. Fig. 5 shows that the temperature of TW Hya as measured by Ne X / Ne IX is lower than that of most active stars. Its high X-ray flux – typical for a pre-main sequence star – places TW Hya above the correlation defined by the more evolved stars.

6. Summary

We have shown that the high-resolution X-ray spectrum of TW Hya strongly contrasts to all stellar coronae observed thus far with *XMM-Newton* and/or *Chandra*. Its most outstanding character-

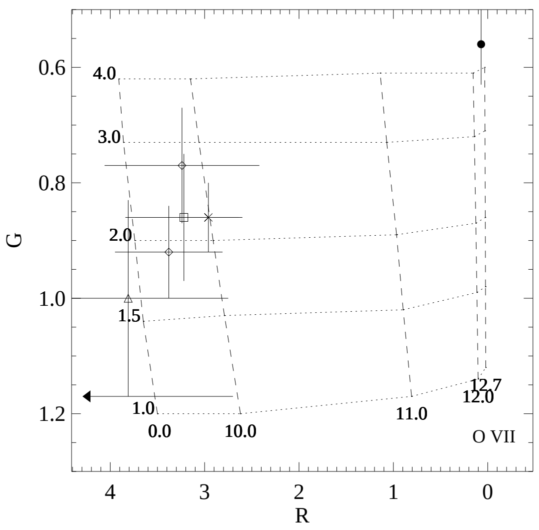

Figure 4. G- versus R- ratio and model grid of electron temperature (dotted lines) and density (dashed lines) for a coronal plasma in collisional ionization equilibrium and negligible UV radiation field. The model calculations are from [10]. Data: *filled circle* - TW Hya, *diamonds* - YY Gem (RGS and LETGS measurement), *square* - AD Leo, *x-point* - ϵ Eri, *triangle* - α CenA, *arrow* for upper limit of α CenB.

istics are peculiar elemental abundances (strong neon and oxygen, but weak iron lines, and only marginal silicon and magnesium), high density ($> 10^{12}\,\mathrm{cm}^{-3}$), and high X-ray flux. All these features indicate a fundamental difference in the emission process as compared to other late-type stars. TW Hya so far is the only pre-main sequence star in the phase of disk accretion observed at high resolution in X-rays. Therefore, it seems natural to attribute its X-ray emission to an accretion column. To date it remains unclear whether the X-ray properties of TW Hya are typical for this phase of stellar evolution. Further high-resolution X-ray observations of pre-main sequence stars in different stages of disk evolution are required to establish or refute the solar-stellar analogy for the youngest stars.

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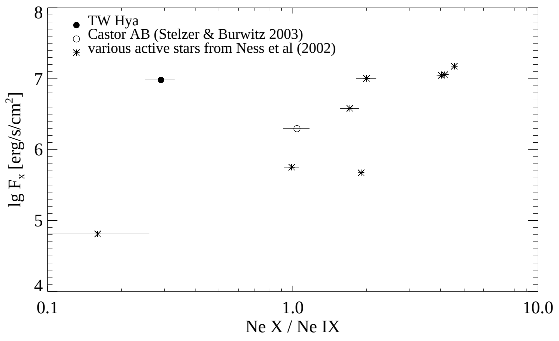

Figure 5. Relation between X-ray surface flux and $Ly\alpha/r$ flux ratio of neon for TW Hya and a sample of active main-sequence and RS CVn stars.

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