X-ray emission from PTT stars

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Abstract

We present preliminary results on the first XMM-Newton observation dedicated to Post-T-Tauri stars. We observed the visual binary nicknamed 'Horace' (2RE J0241-53). The two stars are active X-ray emitters, and are members of an association of Post-T-Tauri stars. The XMM observations have been complemented with ground-based optical spectroscopy and photometry. Many flares have been observed. The average X-ray spectrum shows similarities to that of Classical T-Tauri stars, with high-temperature emission non-existent, and strong neon and oxygen H- and He-like emission.

Key words:
Post-T-Tauri stars, X-ray emission, Spectroscopy

Introduction

In the recent years, XMM-Newton and Chandra observations have shown that a great number of stars have strong X-ray emission. Only a few X-ray observations of young stars have been obtained. Classical T-Tauri (CTT) stars have been observed a few times, and since there is evidence for the presence of disks around these stars, it is likely that their X-ray emission is due to accretion (as proposed by Kastner et al. 2002 for TW Hya, one of the best-known classical T-Tauri stars).

Post-T-Tauri (PTT) are young, pre-main sequence stars that have strong X-ray emission, as shown by the XUV all-sky survey of the ROSAT and EUVE satellites. PTT stars do not have accretion disks, but are normally rapid rotators, and it is therefore possible that their X-ray emission is similar to that of the solar corona with a stronger dynamo effect. In reality we are only now starting to study in some detail the X-ray emission from these stars. Indeed as far as we are aware, the study described here is the first XMM-Newton observation dedicated to the investigation of PTT stars. The only other spectroscopic observation of a PTT star (PZ Tel) in the X-rays was recently presented by Argiroffi et al. (2004).

One of the most striking results from XMM-Newton and Chandra observations of active stars are their (apparent) peculiar chemical abundances. Stellar coronal abundances have important implications for our understanding of the stellar atmospheres, and yet are poorly known. In the solar case, coronal abundances appear to be correlated with the first ionization potential (FIP) of the various elements. The abundances of elements with low FIP ($<$ 10 eV, e.g. Fe) appear enhanced (in respect to the photospheric values) compared to those of the high FIP ($>$ 10 eV, e.g. Ne) elements. There are, however, variations depending on the solar feature observed, and possibly on its evolution. On the contrary, active stars appear to have a strong anti-FIP effect, i.e. elements such as iron are strongly depleted, compared to the solar photospheric values. Furthermore, this anti-FIP effect appears to be more pronounced in more active stars and related to the stellar age (see e.g. Guedel 2002).

Chemical abundance variations are important to study because they must be associated with the physical processes that occur in the chromosphere. Ultimately, they could reflect on the origin of the heating mechanisms of the coronal plasma. Laming (2004) suggested that the FIP and anti-FIP effect are associated with the upward-propagating chromospheric waves impinging on the coronal structures.

In terms of broad characteristics, CTT stars such as TW Hya show a strong (factor of 5) anti-FIP effect, but do not show any emission from hot multi-million degrees plasma. The only other PTT star that was observed, PZ Tel, showed instead the presence of hot (temperatures above 10^7 K) plasma, and a smaller (factor of 3) anti-FIP effect. It is therefore interesting to see first if similar characteristics can be found in other PTT stars.

1 The target

2RE J0241-53 (EUVE J0241-530) is a bright XUV visual binary, discovered by the ROSAT and EUVE all-sky surveys. We nickname the stars ‘Horace’. The stars were studied by Jeffries et al. (1996), who used high-resolution ROSAT observations to show that both stars are soft X-ray emitters, with the weaker component contributing to about 1/4 the total emission. The system is composed of two dK7e and dM3e young and fast rotating (v sin i=12, 70 km/s) stars, with an angular separation of 22". Since the two stars are almost aligned along the N-S direction, we will refer to them as the northern and southern component. Both stars have strong chromospheric emission (large H_α and Ca H+K equivalent width EW), and are very active. Recurrent flares in both components have been reported (including large flares, cf. Ball and Bromage 1995). The southern star is Li-rich. ROSAT observations indicated that the southern star was 3 times brighter than the northern one in the XUV. Jeffries et al. suggested that the system could represent a pair of PTT stars. The PTT classification was later confirmed by Torres et al. (2000) on kinematic grounds. Torres et al. identified the binary as belonging to the nearby Horologium association of young stars, with an age of $\sim$ 30 Myr.

2 Observations

XMM-Newton is equipped with a suite of EPIC (PN and MOS) X-ray CCD cameras and two reflection grating spectrometers (RGS 1,2). XMM-Newton also has an optical telescope (OM) which allows broad-band photometry in the UV. We designed the observation to operate EPIC in the small window mode and the OM in fast mode (1s time resolution) with two small windows centred on the two stars. The instruments performed extremely well, in particular the OM. To separate the spectra of the two sources, the observation needed to be performed at specific roll angles. XMM successfully observed the stars for 38ks between 21:30 and 8:20 UT on 9-10 Feb 2004. In order to complement the XMM observations, we coordinated simultaneous optical observations. In theory the OM should provide continuous support of the X-ray observations, so ground-based photometry should not be necessary. In reality this is not the case, because filter selection on the OM has some limitations, and because during ground station handovers the OM is switched off, causing data gaps.

The scientific importance of having spectral information on the lower atmospheric layers such as the chromosphere, in particular for flare stars, is self-evident. However, organising simultaneous ground-based observations is particularly difficult, given the fact that normally XMM observations are scheduled only a few weeks in advance. We were fortunate to obtain one week of photometric and spectral observations at the South African Astronomical Observatory (SAAO) around the the time of the XMM observation. Spectra were obtained using the SAAO 1.9-m grating spectrograph with 1 Å resolution in the wavelength range 3700 – 4360 Å on 6 consecutive nights. UBV aperture photometry was carried out for 3 consecutive nights with the 0.5-m telescope. On the night of the XMM observation, SAAO covered the period 18:32 UT - 00:04 UT.

We were also able to obtain CCD B- and U-band photometry with the 0.9m and low-resolution (17.2 Å FWHM) spectroscopy on the 1.5m telescope at Cerro Tololo Interamerican Observatory (CTIO, Chile) covering part of the XMM observation, during 01:17–04:40 UT. Other photometric observations were obtained at the Pico dos Dias Observatory (Brasil) during 23:00-00:30 UT, courtesy of Carlos Alberto and Germano Quast. CASLEO (Argentina) also planned photometry (courtesy of Federico Gonzalez), but the weather was cloudy.

3 Results

Fig. 3 (left) shows a sample SAAO spectrum of the northern star. Strong chromospheric emission is present. The southern star presents a similar spectrum. The striking feature was the high variability of these lines even at the 90s time resolution of the observations, and during quiescence in the X-ray emission/ U-band. Equivalent widths were measured for the Hδ and Ca II K lines. The values for the Northern star on the XMM night are shown in Fig. 1.

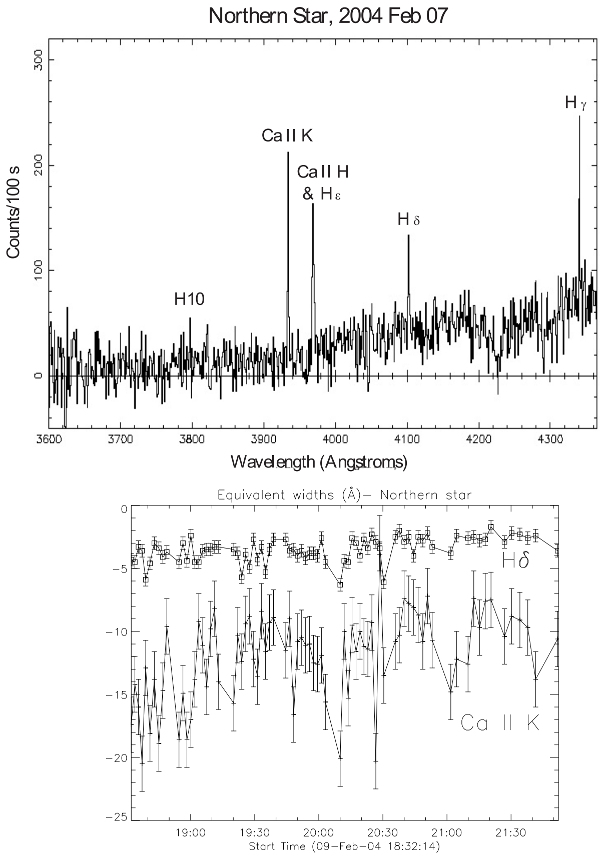

Fig. 1. SAAO spectrum of the northern star (above) and equivalent widths during the XMM observation (below).

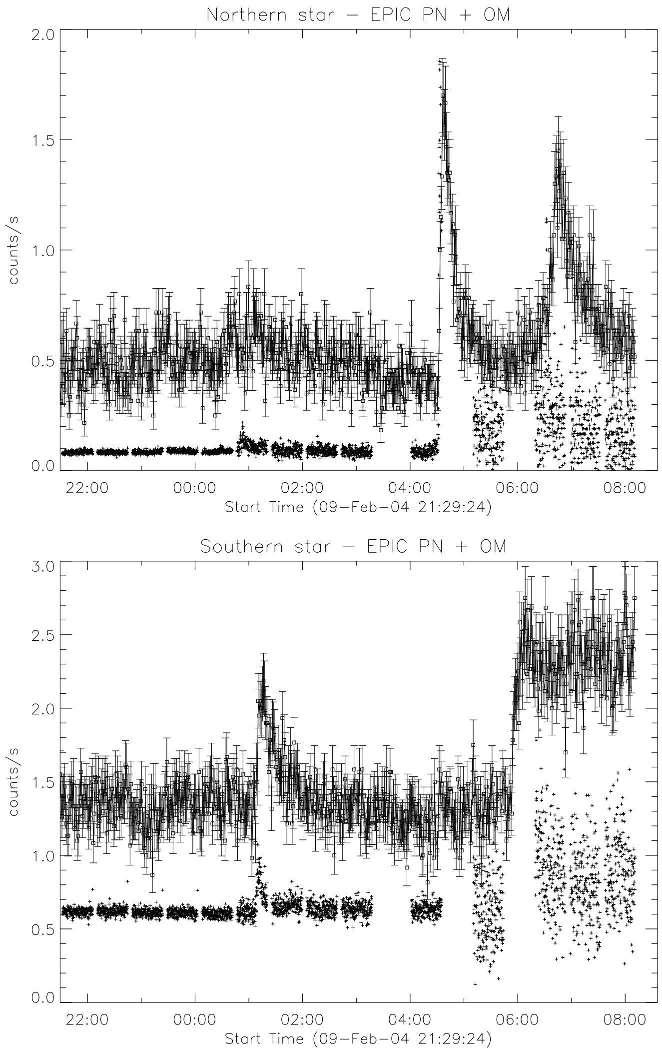

Fig. 2. X-ray (EPIC PN) and UV (OM) light curves of the XMM observation. The upper points show the EPIC count rates for the two stars in the entire 0.2–12 keV energy band. The lower points show the normalised OM count rates in the various filters.

We performed relative aperture photometry on the XMM/OM fast-mode windows and on the CTIO B,U images. The background regions were stationary and with low count rates, compared to the source regions. We performed the standard pipeline processing of the XMM X-ray data and constructed energy-resolved light-curves of both sources. Fig. 2 gives an overview of the X-ray and U light curves of the two stars. Both stars are confirmed to be active, with strong variability and flares. The northern star had two large X-ray flares toward the end of the observations. The first flare was not observed by the OM, and only partly by CTIO. The second flare was observed by the OM but with low signal-to-noise. The southern star was in an unusually quiescent state for most of the observation, with X-ray count rates only 2.6 times higher than those of the north component. A flare occurred at 01:10 UT, and the

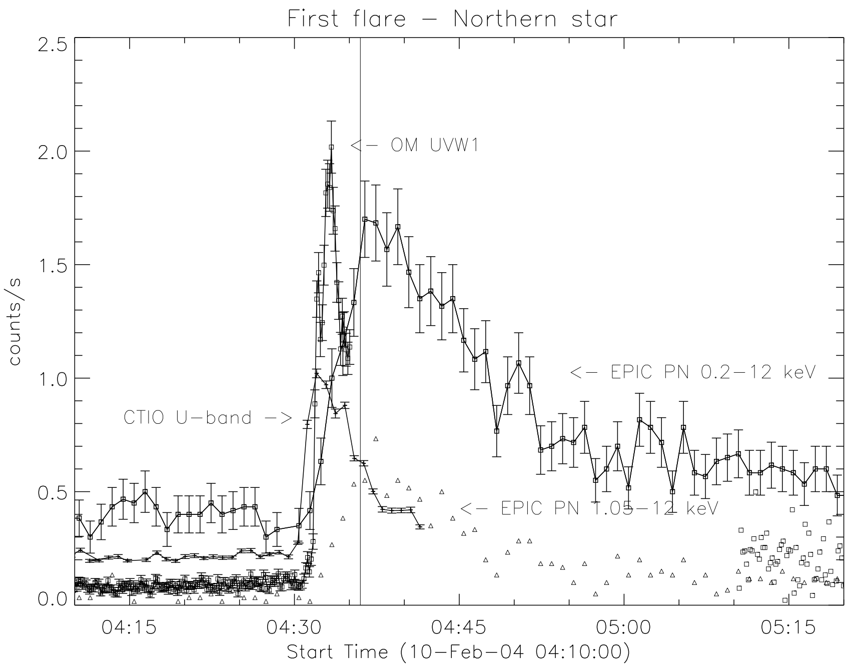

Fig. 3. Light curves for the first large flare on the Northern star. See text for details.

X-ray count rates had a sudden increase toward the end of the observation. This increase occurred over a period of 5-10m, and the star reached a steady state that lasted at least until the end of the observation, i.e. at least 2 hours. This increase in the X-ray emission in the southern component is still under investigation.

The observed flares showed the usual characteristics, i.e. a short-duration increase in the optical U-band, followed by a slower but longer-lasting increase in the X-rays (Neupert effect). The U-band emission is mainly dominated by bremsstrahlung of non-thermal electrons probably directly related to the creation of a large number of energetic particles at the beginning of the energy release. Beams of fast particles would impinge on the chromosphere and induce chromospheric evaporation of plasma filling the atmosphere in the form of post-flare X-ray loops or arcades of loops. Fig. 3 shows the EPIC count rates in two energy bands, both of which peak approximately where the vertical line is located. Superimposed on the graph, we have the corresponding CTIO U-band and XMM/OM UVW1 count rates (normalised). The light curves in the U and UVW1 bands clearly peak a few minutes before the X-rays.

Fig. 4 shows the average RGS 2 first order spectrum of Horace. The strongest lines are the oxygen and neon H- and He-like lines, with very little Fe XVII emission. For comparison, the Chandra spectra of PZ Tel (with twice the exposure time – 74 ks) and of TW Hya (48 ks) are also shown. The Chandra spectra are the un-calibrated total counts in one of the first-order channels, and have been obtained from the Chandra archive. PZ Tel shows strong 'hot'

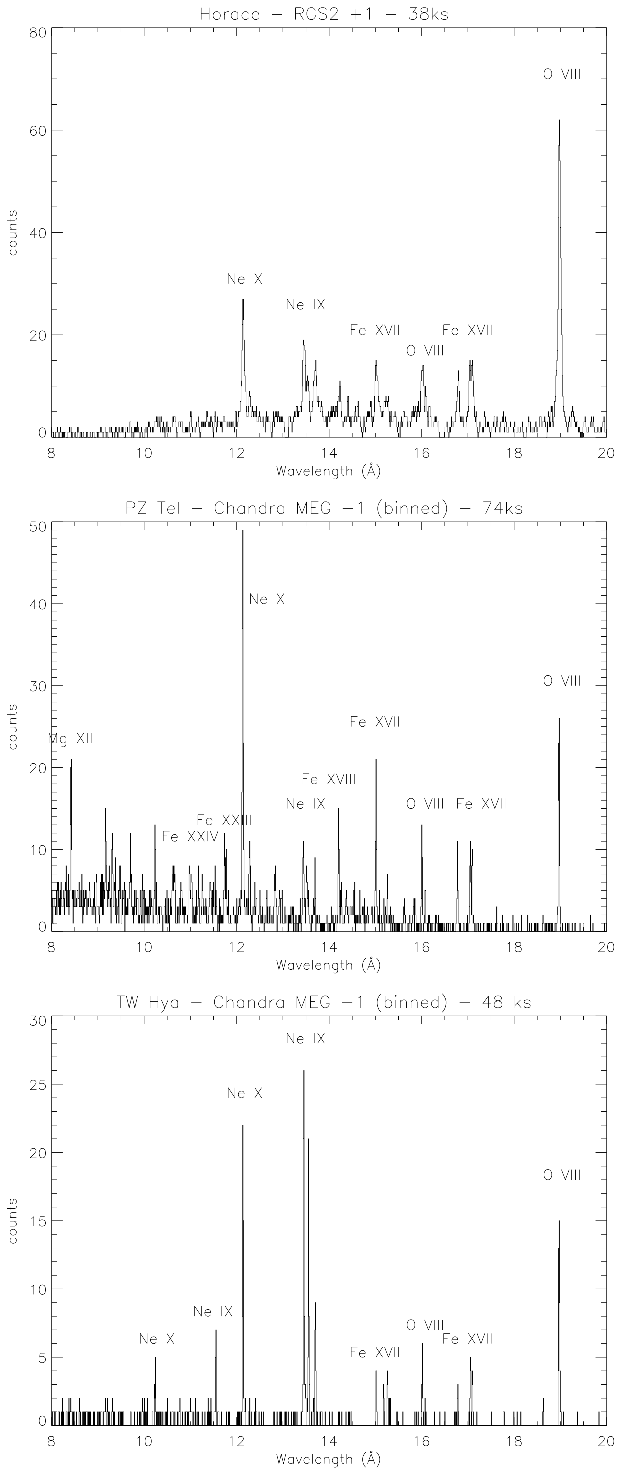

Fig. 4. X-ray spectra of Horace (XMM-Newton, 38 ks), PZ Tel (Chandra, 74 ks) and TW Hya (Chandra, 48 ks). The Chandra spectra are first-order counts for the total duration of each observation, rebinned to improve the signal.

emission from Fe XXIII and Fe XXIV $n = 3 \rightarrow n = 2$ transitions, and much stronger H-like (e.g. Ne X) compared to He-like (Ne IX) emission. Compared to other young stars and PZ Tel, Horace has no 'hot' emission and its total spectrum has more similarities to that one of the CTT star TW Hya. Horace also appears to have a very strong anti-FIP effect, with iron strongly depleted.

Fig. 5 shows the emissivities of some of the prominent lines in the spectra of these young stars, calculated assuming the ionization equilibrium of Arnaud and Rothenflug (1985) and the CHIANTI atomic data (Young et al., 2003). If ionization equilibrium holds, then the Fe XVII and Ne IX lines should be emitted by the same plasma (at the same temperature), and their intensity ratio would be directly proportional to the element abundance ratio. The relative intensity of the Fe XVII vs. the Ne IX lines can therefore be used as an approximate proxy of the FIP effect. Note that in the Sun and in the case of young stars such as AB Dor the Fe XVII lines are much more prominent, compared to the Ne IX lines.

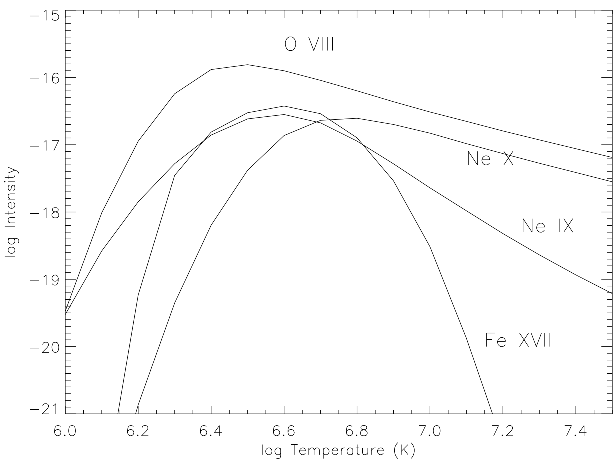

Fig. 5. Emissivities (intensities per unit emission measure) of a few of the prominent lines in the Horace spectrum, calculated assuming ionization equilibrium.

4 Discussion and conclusions

X-ray spectral observations of PTT are difficult to obtain and require long exposure times. However, a single spectrum is worth thousands of images or broad-band observations. Indeed the Horace X-ray spectrum is largely different from what we could predict on the basis of the broad-band ROSAT and EUVE measurements, which were in a different spectral region. The Horace spectrum shows a distinctive difference compared to the only other known spectrum of a PTT star, PZ Tel. In particular the absence of any 'hot' emission, despite the presence of multiple flares, is striking. Therefore, until more observations of

PTT stars are available, we cannot assume that neither PZ Tel nor Horace's characteristics can be assumed to be 'typical' for PTT stars. Horace's spectra show characteristics more similar to those of the CTT star TW Hya.

Much of our understanding on PTT stars could be improved with simultaneous multi-wavelength observations, but unfortunatley these are difficult to obtain. A detailed study of the Horace X-ray emission will require an in-depth analysis of the flaring and more quiescent periods. Also, a knowledge of stellar characteristics such as rotation and photospheric abundances of the stars. A few comments can however be made. The FIP effect could in principle be used as an additional diagnostic to help us understand the basic physical processes that occur in the stellar atmospheres. In reality there are however various effects that complicate the analysis and interpretation of stellar coronal abundances. For example, there are large uncertainties associated to the methods and the various assumptions (e.g. ionization equilibrium) used (see, e.g., Del Zanna et al. 2002, Del Zanna et al. 2001). Also, coronal abundances are rarely compared to the photospheric abundances of the same star. In turn, measurements of photospheric abundances of active stars are scarce, show large scatter, and are difficult (sometimes impossible) to obtain to within a reasonable accuracy, in particular for the fast rotators, which are common in young stars.

Compared to the solar photospheric abundances, the CTT star TW Hya showed an iron depletion by a factor of 5, while the PTT star PZ Tel was found to have an iron abundance 0.3 times the solar photospheric one. PZ Tel is a member of the Tucana association, a local ($\simeq$45 pc) group of young ($\simeq$20-30 Myr) stars, while Horace is a member of the Horologium association. The Tucana and Horologium associations have similar characteristics. Recently, Rojas and Gregorio-Hetem (2005) provided measurements of photospheric abundances for 9 members of the former and 3 members of the latter association. A large scatter of values can be found, with variations up to factors of 3. These measurements stress the need to directly compare abundances of the same star. However, on average the photospheric abundances are not too different from the solar ones, hence the anti-FIP effect is presumably real, despite all the cautionary remarks that can be made.

Further X-ray observations of active stars with different ages are crucial for a better understanding of any correlation between age and X-ray emission, and to identify the mechanisms that produce the X-ray emission in the first place.

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