A *Beppo-SAX* Observation of HD 9770: a Newly Discovered Short-Period Eclipsing Binary System

G. Tagliaferri\textsuperscript{1}, S. Covino\textsuperscript{1}, G. Cutispoto\textsuperscript{2}, and R. Pallavicini\textsuperscript{3}

Abstract:

We present the results of a *Beppo-SAX* observation of the short-period eclipsing binary star HD 9770. The *Beppo-SAX* data confirm that this is a very active coronal source, with strong flare activity. The 0.1–10 keV light curve is modulated by the star rotation with the eclipse detected at all energies. However, there seem to be an hint of a different behaviour with energy in the eclipse. The coronal metal abundances determined with *Beppo-SAX* are subsolar ($\sim 0.2$), in line with the results found for many other active stars.

1. Introduction

HD 9770 is a very interesting nearby (20 pc), short period ($\sim 0.47$ day) eclipsing binary system (K4/5 V + K5 V) belonging to the BY Dra type of variable stars. It shows two almost identical primary and secondary eclipses that last for about 70 minutes each (Cutispoto et al. 1997). HD 9770 was clearly detected during both the all-sky EUV surveys obtained with the WFC on board the *ROSAT* satellite (Pounds et al. 1993, Pye et al. 1995) and with the *EUV* satellite (Malina et al. 1994), as well as in the *ROSAT* all-sky survey X-ray with an average PSPC count rate of $\sim 3.5$ cts s\textsuperscript{-1}. The star was observed over more than 2 days with an additional single scan obtained after a gap of about 160 days. HD 9770 turns out to be a strong and clearly variable X-ray source, with a mean X-ray luminosity of $L_x = 1.6 \times 10^{30}$ erg sec\textsuperscript{-1} (Cutispoto et al. 1997).

Disentangling the temperature and spatial structure is fundamental in order to construct models of stellar coronal features and to understand the heating mechanism. The three-dimensional spatial distribution of the X-ray emitting corona on other stars is not known, but can be mapped by observing through an eclipse either by a binary companion, or by the rotation of the underlying star. So far X-ray monitoring of eclipsing binary systems has been extensively carried out for the active RS CVn and Algol type of binaries (e.g., White et al. 1986; Ottmann 1994; Singh et al. 1995). The most studied object is the RS CVn binary system AR Lac, for which it has been reported both the detection of the eclipse modulation and also the lack of it as a function of the energy (Walter et al. 1983; Swank & White 1980; White et al. 1990; Ottmann et al. 1993; White et al. 1994).

\textsuperscript{1}Brera Astronomical Observatory, Via Bianchi 46, I–22055 Merate, Italy
\textsuperscript{2}Catania Astrophysical Observatory, V.le A.Doria 6, I–95125 Catania, Italy
\textsuperscript{3}Palermo Astronomical Observatory, Pza del Parlamento 1, I–90134 Palermo, Italy
Thanks to the very short period of this active eclipsing binary system, we monitored $\sim 3.5$ contiguous orbital cycles with the Beppo-SAX satellite. Although Beppo-SAX has a lower energy resolution, typical of proportional counters, with respect to the ASCA CCD detectors, its extended spectral range, from 0.1 to 10 keV for coronal sources, is well suited to study the overall temperature and emission measure plasma distributions of active stars, and to study the rotational modulation of their X-ray emission over such an extended energy range.

Here we present the preliminary analysis of the Beppo-SAX data of HD 9770, discussing both the X–ray spectrum and the X–ray light curve of this source.

2. The Data

The Beppo-SAX satellite carries onboard various X-ray detectors covering a very large energy band from 0.1 to 300 keV (Boella et al. 1997a). However, for the study of typical coronal sources only the Low Energy Concentrator Spectrometer (LECS, Parmar et al. 1997) and Medium Energy Concentrator Spectrometers (MECS, Boella et al. 1997b) detectors are suitable. The LECS has a wide energy range, 0.1–10 keV, and good spectral resolution, comparable to CCD detectors at low energies where it fills the gap between EUVE and ASCA. On the contrary the three MECS detectors cover only the 1.7–10 keV energy range, however they have an effective area about three times larger than the LECS one, thus allowing to study the Fe K complex at $\sim 6.7$ keV more effectively.

Beppo-SAX observed HD 9770 on December 7–9, 1996 lasting for about 45 hours, resulting in 40 ks and 83 ks of observing time in the LECS and MECS detectors respectively. The difference is due to LECS being operated only when the spacecraft was in the Earth shadow. The data analysis was based on the linearized, cleaned event files obtained from the Beppo-SAX SDC on-line archive (Giommi & Fiore 1997). Light curves and spectra were accumulated for each pointing using the SAXSELECT tool, using 8.5 and 4 arcmin extraction radii for the LECS and MECS, respectively, that provide more than 90% of the fluxes. The LECS and MECS background is low, but not uniformly distributed across the detectors, on the other hand it is rather stable. For this reason, it is better to evaluate the background from blank fields, rather than in annuli around the source region. Thus, after having checked that the background was stable during the three observations, we used the background files accumulated from blank fields available from the SDC public ftp site.

The light curve analysis was performed using the XRONOS 4.02 package, while the spectral analysis was performed with the XSPEC 9.01 package, using the response matrices released by the SDC in early 1997. For spectral analysis, the LECS data have been considered only in the range 0.1–4 keV, due to still unsolved calibration problems at higher energies. The LECS and MECS spectra have been jointly fit after allowing for a rescaling factor of $\sim 30\%$ for the LECS data to account for uncertainties in the intercalibration of the instruments.
Figure 1. *SAX LECS* (top panel) and *3MECS* (bottom panel) light curves for HD 9770; the time bin is 300 s.
3. Results

In Figure 1 we plot the total LECS and MECS light curve of HD 9770. A strong flare is clearly detected at the beginning of the observations, while a second weaker flare is detected about 18 hours after the observation started.

Besides the flare events, the light curves are clearly variable. Moreover there seems to be some rotational modulation. This is better shown in Figure 2 where we plot the LECS 0.1–1 keV and MECS 2-10 keV folded light curves. We used the ephemeris HJD = 2449311.3731 + 0.476533E (Cutispoto et al. 1997), with the two eclipses centered at phase 0 and 0.5. Although the folded light curves around phase 0.1 are dominated by the flare, it is clear that both LCs have a minimum at phase 0.5 in correspondence to the second eclipse. In first approximation both LCs seem to behave in the same way, i.e., there is no difference in the flux modulation as a function of energy (below and above 1 keV). However, also the hardness ratio seems to be modulated, this would imply that the soft and hard light curve are not modulated in the same way. Clearly this result is only preliminary and a more detailed analysis is necessary.

For the spectral analysis, we used the optically thin plasma models by Raymond & Smith (1977) and Mewe et al. (1996a), also known as “mekal”, as implemented inside XSPEC. The interstellar absorption $N_H$ was also included in the fit. We first let the $N_H$ free to vary in the fit procedure and the best–fit value was of the order of $3 \times 10^{19}$ cm$^{-2}$. This value is quite high for a star whose distance should be about 20 pc (Cutispoto et al. 1997), for instance if we apply the relation $N_H \sim 0.07$ cm$^{-3}$ from Paresce (1984) with the above distance we get $N_H \sim 4.3 \times 10^{18}$ cm$^{-2}$. In order to minimize the number of free parameters and also the influence that the $N_H$ could have on the metallicity values (a high $N_H$ would be compensated by a low metallicity value), we fixed the value $N_H = 5 \times 10^{18}$ cm$^{-2}$.

<table>
<thead>
<tr>
<th></th>
<th>$kT_1$ keV</th>
<th>norm$_1 \times 10^{-2}$</th>
<th>$kT_2$ keV</th>
<th>norm$_2 \times 10^{-3}$</th>
<th>$Z$</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.88$\pm$0.08, 0.09</td>
<td>1.02</td>
<td>2.83$\pm$0.94, 0.04</td>
<td>5.63</td>
<td>0.23$\pm$0.09, 0.04</td>
<td>1.20</td>
</tr>
<tr>
<td>Flare</td>
<td>0.98$\pm$∞, 0.34</td>
<td>1.52</td>
<td>4.40$\pm$∞, 0.18</td>
<td>3.82</td>
<td>0.46$\pm$0.04, 0.34</td>
<td>1.28</td>
</tr>
<tr>
<td>No Flare</td>
<td>0.83$\pm$0.11, 0.10</td>
<td>0.94</td>
<td>2.09$\pm$0.88, 0.39</td>
<td>5.37</td>
<td>0.22$\pm$0.10, 0.06</td>
<td>1.01</td>
</tr>
</tbody>
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Table 1. 2–temperature MK family model best fit parameters. Spectra are analyzed considering a) the whole data set, b) only the flare data and c) the whole observation but the flare activity time window. The energy bins are 110 for each dataset.

In Figure 3 we report the LECS+3MECS spectra of the whole observation, the spectra accumulated only during the flare and the spectra accumulated outside the flare. In all cases it is impossible to fit a single temperature model. Good fit to the data can only be obtained with a 2–$T$ model with the metal abundance value free to vary (in solar proportion). The best-fit models shown in Figure 3 refer to the 2–$T$ mekal model, the best-fit parameters together with the errors (90% confidence) are reported in Table 1. Similar values are obtained
Figure 2. SAX 3MECS (top panel), LECS (middle panel), and 3MECS/LECS folded light curves for HD 9770.
with the Raymond & Smith model. As it can be noted HD 9770 is characterized by a quite hot plasma, with the Fe K complex at \( \sim 6.7 \) keV clearly detected in the MECS spectrum, in particular during the flare. As expected during the flare the X-ray emission is dominated by hotter plasma with a temperature of more than \( 4 \) keV.

The metal abundance value is significantly lower than the solar one, confirming the previous results found in particular with *ASCA* (White et al. 1994, White 1996; Singh et al. 1995, 1996; Tagliaferri et al. 1997, Ortolani et al. 1997, Mewe et al. 1996b, 1997), but also with other satellites (Tsuru et al. 1989; Stern et al. 1992, 1995; Ottmann & Schmitt 1996; Schmitt et al. 1996; Mewe et al. 1996b, 1997). Similar results have recently been obtained for another *BeppoSAX* observation of the star VY Ari (Favata et al. 1997b). VY Ari is an active non-eclipsing SB1 binary with the visible star classified as K3-4/V–VI (Bopp et al. 1989), a source very similar to HD 9770. Thus, it is by now clear that the coronal metal abundances found in most of the very active stars are sub-solar. This does not immediately imply that these values are in contradiction with the photospheric values found for these stars. Indeed the low–metal abundances found for the coronal plasma of CF Tuc (Schmitt et al. 1996), \( \lambda \) And (Ortolani et al. 1997) and the first results from *Beppo-SAX* for Capella (Favata et al. 1997a), do not seem to be in contradiction with the photospheric values. However, the low metal abundance values found for the PMS AB Dor (Mewe et al. 1996b) and the very young star HD 35850 (Tagliaferri et al. 1997) are in contradiction with their photospheric values. In the case of HD 9770 we do not know what is its photospheric value, yet. We already obtained high resolution spectra in the optical band and will soon be able to determine its photospheric metal abundances (from a preliminary analysis they do not seem to differ from the solar ones).

Finally note that the metal abundance value seems to increase during the flare from 0.2 to 0.4 the solar value, a behaviour similar to the one seen for a strong flare event detected in Algol with *ROSAT* (Ottmann & Schmitt 1996).

4. Conclusions

- The *Beppo-SAX* observation of HD 9770 confirmed that this is a very active coronal source, with the detection of a strong hard flare.

- The 0.1–10 keV light curve is modulated by the star rotation with the eclipse detected at all energies. However, there seem to be a hint of a different behaviour with energy in the eclipse.

- The coronal metal abundances determined with *Beppo-SAX* are subsolar (\( \sim 0.2 \)), in line with the results found for many other active stars. It is still an open question if these values are in contradiction with the photospheric values found for these stars or not.
Figure 3. SAX LECS+3MECS spectra of HD 9770. Spectra were collected for the whole observation (bottom panel), outside the flare (middle panel) and only during the flare (top panel).
References

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Mewe, R., Kaastra, J.S., & Liedahl, D.A. 1996a, Legacy: The Journal of the HEASARC, 6, 17