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Research Note

An X-ray flare from the Lindroos binary system HD 560

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Abstract. We report on a large X-ray flare from the Lindroos binary system HD 560 during a pointed *ROSAT* PSPC observation. HD 560 is composed of a B9 and a G5 type star. The late-type companions in bound Lindroos binaries are Post T Tauri star (PTTS) candidates, i.e. pre-main sequence stars on their final approach to the main sequence. Strong (magnetic) activity is, therefore, expected for the G star, in contrast to the late-B type component for which no mechanism of X-ray production is known. The system is unresolved in the *ROSAT* image.

During outburst the count rate has changed by at least a factor of 2, and presumably more (the maximum was not observed). The peak luminosity measured is $\sim 10^{31}$ erg/s, comparable to the largest values derived for flares on pre-main sequence T Tauri stars. A two-temperature model for thermal emission from a hot, optically thin plasma shows an increase of the higher temperature as a result of coronal heating during the flare. The lower temperatures do not change during outburst.

Key words: X-rays: stars – stars: binaries: general – stars: individual: HD 560 – stars: late-type – stars: activity

1. Introduction

T Tauri stars (TTS) are young, late-type stars contracting to the main sequence (MS). In their evolution pre-main sequence stars pass through a phase before reaching the MS, defined as Post T Tauri stars (PTTS). Herbig (1978) first defined PTTS as young stars more evolved than Classical T Tauri stars (CTTS) but still contracting to the MS.

PTTS are difficult to detect because they do not show extreme properties which make them easy to identify: unlike CTTS, they do not show IR or UV excesses and the Hα line is no longer seen in emission. Therefore, their identification relies on the presence of the Li I (6708Å) absorption line and the Ca II chromospheric lines in their spectra as well as on their X-ray emission.

Murphy (1969) was the first to propose that PTTS could be found in binary systems composed of early-type primaries and late-type secondaries, given that the MS lifetime of high-mass stars is comparable to the contraction timescale of late-type stars to the MS. Gahm et al. (1983) and Lindroos (1985) carried out photometric and spectroscopic observations of 253 binary systems and Lindroos (1986) was able to isolate a sample of 78 visual binary systems with likely PTTS secondaries.

The X-ray emission from these PTTS candidates as observed by *ROSAT* has been studied by Schmitt et al. (1993) and Huélamo et al. (2000). The derived X-ray luminosities for most of the late-type stars range between $\lg L_{\rm x} = 28 - 31\,[{\rm erg/s}]$. These values are comparable to those reported for TTS (Neuhäuser et al. 1995), showing that PTTS although somewhat more evolved are still strong X-ray emitters.

PMS late-type stars are also known to emit X-ray flares (see e.g. Feigelson & DeCampli 1981; Montmerle et al. 1983; Stelzer et al. 2000). Therefore, we have studied the X-ray lightcurves of all Lindroos PTTS candidates observed by the *ROSAT* satellite (see Huélamo et al. 2000 for further details) in order to search for X-ray variability due to activity episodes.

As a result of our study of the *ROSAT* PSPC and HRI lightcurves of the Lindroos systems, we have detected a large flare from HD 560, a binary system composed of a B9 and a G5 star. A previous flaring episode from HD 560 observed with *EXOSAT* was reported by Tagliaferri et al. (1988). The *EXOSAT* Medium Energy experiment provided no spatial resolution, however. Therefore, it was unclear whether to ascribe the event to HD 560 or to the nearby Seyfert type I galaxy, QSO 0007+107, located at $\alpha = 00^{\rm h}10^{\rm m}31.01^{\rm s}$ and $\delta = 10^\circ 58' 29.5''$. While Pounds & Turner (1987) attributed the flare to the galaxy, Tagliaferri et al. (1988) argued in favor of HD 560. The observation of another flare with the *ROSAT* PSPC whose spatial resolution is sufficient to identify the flaring source with HD 560, supports the arguments put forth by Tagliaferri et al. (1988). In this paper we provide an analysis of the *ROSAT* data of HD 560, and discuss the flare event.

2. The *ROSAT* data

The X-ray telescope and the instrumentation onboard the *ROSAT* satellite are described in detail by Trümper (1982), Pfeffermann et al. (1987) and David et al. (1996). The data presented

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Table 1. PSPC pointed observations of HD 560. See text for a description of the columns.

ROR number	X-ray position α_{2000} [h m s]	X-ray position δ_{2000} [° ′ ″]	Δ [″]	Offaxis [′]	Counts	Expo [sec]	HR1	HR2	ML
700503p	00 10 02.48	11 08 41.2	5.6/6.8	12.32	1993.2±45.3	8238.3	-0.04±0.02	0.05±0.03	7713.6
701092p	00 10 02.47	11 08 40.4	6.1/6.0	12.31	4258.3±65.7	8121.8	-0.08±0.02	0.12±0.02	18859.8

in this work were obtained with the Position Sensitive Proportional Counter (PSPC) in pointed mode.

The spectral resolution of the PSPC (43% at 0.93 keV) allows spectral analysis in three energy bands:

— Soft: 0.1 to 0.4 keV
— Hard 1: 0.5 to 0.9 keV
— Hard 2: 0.9 to 2.0 keV

We can obtain spectral information of our sources studying the X-ray hardness ratios (HR) defined as follows:

$$HR1 = \frac{(H1 + H2 - S)}{(H1 + H2 + S)} \quad \text{and} \quad HR2 = \frac{(H2 - H1)}{(H2 + H1)} \qquad (1)$$

where $H1$ and $H2$ are the counts observed in the Hard 1 and Hard 2 bands, and S are the counts observed in the Soft band. Hence, HR values can range from -1 to $+1$.

3. The X-ray emission from HD 560

HD 560 was observed twice by the PSPC. The details of these two observations are summarized in Table 1, where the *ROSAT* observation request number (ROR) is provided. Columns $2-4$ show the position of the X-ray detection, its displacement with respect to the B9 and G5 components of HD 560, respectively, and the distance of the X-ray source to the center of the detector. The latter number is important, given that the spatial resolution of the PSPC is off-axis dependent. The count rates, exposure times, and HR's are given in Columns $5-8$. An estimation of the probability of the detection according to the maximum likelihood (ML) algorithm implemented in EXSAS (Extended Scientific Software Analysis System, Zimmermann et al. 1995) is given in the last column. Note that $ML = 5$ corresponds to a 2.7 σ signal over the background.

The spatial resolution of the PSPC ($\sim 25''$ at $1\,\mathrm{keV}$ at the center of the detector) does not allow to resolve the binary system ($7.7''$ separation). Therefore, in both observations there is a single X-ray detection located at ∼6″ from the binary system (see Table 1).

4. The X-ray flare on HD 560

During the *ROSAT* PSPC observation ROR 701092p the binary system HD 560 showed a large flare. The complete lightcurve is shown in Fig. 1. Next to the large outburst (around JD 2448814.4) an increase of the count rate is observed from the 2nd and 3rd data interval in Fig. 1. Since the count rate just before the eruption of the flare is about the same as that of the

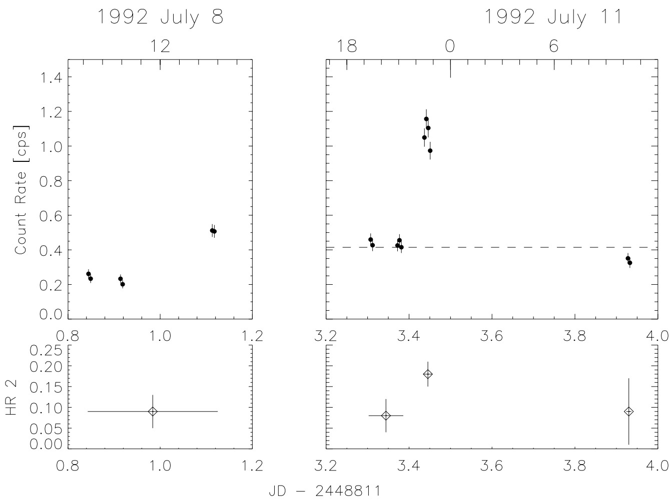

Fig. 1. ROR 701092: PSPC lightcurve and $HR2$ of the unresolved HD 560 binary. Plotted are only fully exposed 400 s bins. The mean pre-flare count rate (dashed line) was determined only from the 4th and 5th data intervals because the quiescent level seems to be variable during the first part of the observation. For the estimation of the pre-flare level we have also made use of partially exposed time bins, which are not displayed in the figure. $HR2$ increases during the flare as a result of coronal heating.

3rd data interval, we suppose that between the 3rd and 5th data interval we see the quiescent emission. However, due to poor data sampling it is unknown for how long the emission indeed remained stable at this level. The strong variability besides the large flare might also reflect rotational modulation as a result of a spot on the surface of one of the companions in the binary, or it could be some kind of orbital effect.

With a binary separation of $7.7''$ the system is not resolved in both PSPC observations. Late-B type stars are not expected to produce X-rays because they lack both convective envelope (necessary for solar-type dynamo activity) and strong stellar winds (providing hot, shocked gas). However, in earlier studies (Schmitt et al. 1993; Huélamo et al. 2000) X-rays were observed from both stars in those Lindroos pairs that were resolved by the *ROSAT* HRI. While the typical $\lg{(L_\mathrm{x}/L_\mathrm{bol})}$ ratio for late-type stars is -3, early-type stars are characterized by $\lg{(L_\mathrm{x}/L_\mathrm{bol})} \sim -7$. Huélamo et al. (2000) found that late-B type stars show intermediate $L_\mathrm{x}/L_\mathrm{bol}$ values, but the hardness ratio is similar to that of late-type stars, suggesting unresolved companions. In the case of HD 560 we derive $\lg{(L_\mathrm{x,qui}/L_\mathrm{bol})} = -4.81$ using the bolometric luminosity of the primary. Therefore it is likely that the late-type component is the X-ray source, and, although

Table 2. Best fit parameters for the PSPC spectra of HD 560 during quiescence and during the flare. The column density of a photo-absorption term was held fixed at $N_{\rm H} = 5.5\,10^{19}\,{\rm cm}^{-2}$ in all cases. In the 1-T model the abundance was left free. A good fit was obtained with 2-T models without varying the abundances. The uncertainties represent the 90 % confidence level.

Model	T_1 $[10^7\,{\rm K}]$	EM_1 $[10^{53}\,{\rm cm}^{-3}]$	Abundance	T_2 $[10^7\,{\rm K}]$	EM_2 $[10^{53}\,{\rm cm}^{-3}]$	Abundance	$\chi^2_{\rm red}$ (dof)
Flare							
1-T	1.30 ± 0.28	12.8 ± 1.1	0.17 ± 0.07	—	—	—	1.05 (50)
2-T	0.16 ± 0.03	1.0 ± 0.3	$= 1.0$	1.47 ± 0.20	5.2 ± 1.1	$= 1.0$	1.21 (49)
Quiescence							
1-T	1.01 ± 0.10	4.8 ± 0.3	0.08 ± 0.03	—	—	—	0.78 (64)
2-T	0.19 ± 0.03	0.5 ± 0.1	$= 1.0$	1.23 ± 0.08	1.2 ± 0.2	$= 1.0$	0.93 (63)

we cannot exclude the opposite case, we assume that the flare occurred on the G5 dwarf star.

We have used the count-to-energy conversion factor of $1.1\,10^{11}\,{\rm cts\,cm^2/erg}$ (Neuhäuser et al. 1995) to compute the X-ray luminosity. For the *Hipparcos* distance of 100 ± 9 pc the maximum count rate observed corresponds to a luminosity of $L_{\rm x,max} = 1.3\;10^{31}\,{\rm erg/s}$. The luminosity derived for the quiescent count rate is $L_{\rm x,qui} = 4.5\;10^{30}\,{\rm erg/s}$. We note, that an estimate of the possible contribution from the early-type primary to the quiescent emission is impossible. Therefore, for the evaluation of the flare luminosity, $L_f = L_{\rm max} - L_{\rm qui}$, we have studied two different cases: (a) all X-rays (during quiescence and during the flare) come from the late-type component, and (b) both stars in the binary system contribute the same level to the quiescent emission, but the additional emission during the flare is only due to the late-type star. For these two cases we have found the following values for the flare luminosity:

(a) $L_f = 8.1 \times 10^{30}\,{\rm erg/s}$
(b) $L_f = 1.0 \times 10^{31}\,{\rm erg/s}$

No data is available for both rise and decay phase of the flare event. We chose 400 s for the binsize of the lightcurve displayed in Fig. 1. This is the best choice for the bin time given the satellite orbit wobble, and in order to achieve good S/N in each bin and high time resolution. Furthermore, we find that choosing finer time resolution does not improve our knowledge about the temporal development of the intensity. Due to the incomplete data sampling during the flare we can give only upper limits for both rise and decay timescales: $\tau_{\rm rise} < 1.2\,{\rm h}$ and $\tau_{\rm decay} < 11.3\,{\rm h}$.

The time evolution of the PSPC hardness ratio $HR\,2$ is displayed in the lower panel of Fig. 1. $HR\,2$ seems to increase during the flare. However, the data are not conclusive in this respect due to low statistics. To verify whether the source really hardened during the flare event, we have extracted X-ray spectra for two time intervals representing the non-flaring state (pre- and post- flare data) and the flare (data interval #6). Spectral models for thermal emission from a hot, optically thin plasma (RS-model; Raymond & Smith 1977) plus a photo-absorption term are used to describe the spectra of both states.

We obtain good fits for two-temperature (2-T) RS models with abundances fixed to the solar value. One-temperature (1-T) models with solar abundance do not lead to acceptable fits ($\chi^2_{\rm red} > 1.6$ for both flare and quiescent data). The F-test reveals that the significance of the improvement of the fit when the second temperature component is introduced is higher than 0.99. Only if the abundance is allowed to vary during the fitting process the quality of the fit is comparable to that of the 2-T models with fixed abundance. In all cases the column density $N_{\rm H}$ was held fixed at $5.5\;10^{19}\,{\rm cm}^{-2}$ (Berghöfer et al. 1996). In Table 2 the best fit parameters from the 1-T model with free abundance are compared to the result of the 2-T model with fixed abundance for both quiescent and flare spectra. In the 1-T model only a marginal temperature increase during the flare is observed despite the increase in spectral hardness (see Fig. 1). The contour plot for the two temperatures of the 2-T model is shown in Fig. 2. While the uncertainties make flare and quiescent state undistinguishable concerning kT of the cooler component, the higher of the two temperatures is clearly representing the plasma heated during the flare.

5. Results and conclusions

We have presented a large X-ray flare from the Lindroos binary system HD 560 observed with the *ROSAT* PSPC. Earlier observations of a flare by *EXOSAT* had been reported, but left the identification with HD 560 ambiguous due to the lack of spatial resolution of the Medium Energy experiment.

The maximum X-ray luminosity during the *ROSAT* flare corresponds to $\sim 10^{31}$ erg/s, a value typical for young late-type stars. We have computed the bolometric luminosity for the G and the B star in HD 560 from the V magnitudes (Lindroos 1985) and the bolometric correction listed by Schmidt-Kaler (1982). Using the observed quiescent emission we derive the ratio of X-ray to bolometric luminosity $\lg{(L_{\rm x,qui}/L_{\rm bol})}$ for primary and secondary: $(\lg{(L_{\rm x,qui}/L_{\rm bol})})_{\rm prim} = -4.81$ and $(\lg{(L_{\rm x,qui}/L_{\rm bol})})_{\rm sec} = -2.76$. The latter value agrees well with the 'canonical' value of -3 for late-type stars, while the value for the primary is neither typical for late-type nor for early-type stars. Therefore, supposedly, the flare has erupted on the G5 component of the system. However, the binary is unresolved, and it can not be ruled out that the flare originated on the B9 star. Whether or not late-B type stars emit X-rays is an unsolved problem.

We have analysed X-ray spectra for both the quiescent and the flare phase, and find acceptable fits for both phases with a

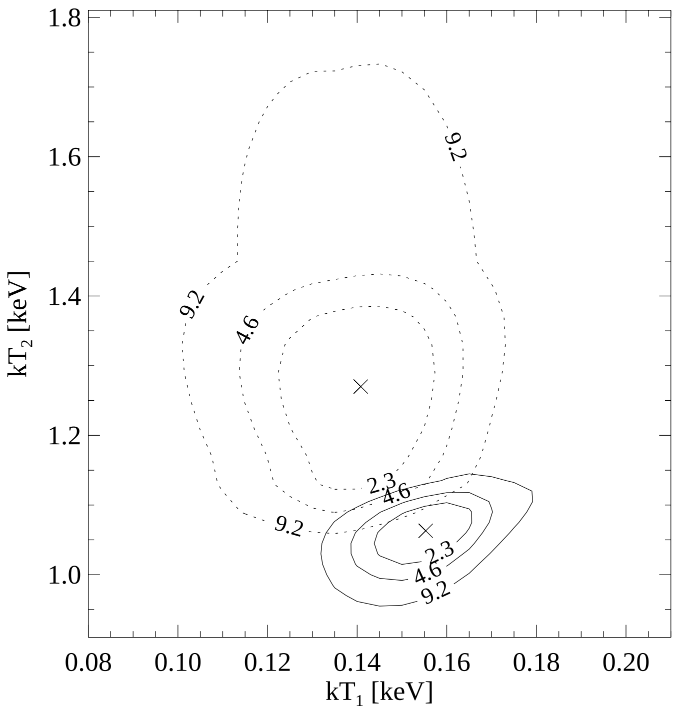

Fig. 2. Contour plot comparing the quiescent and the flare state with respect to the two temperatures of the 2-T RS-model from Table 2. Three contours are drawn corresponding to $\Delta\chi^2 = 2.3$, 6.41, and 9.21. Solid lines for quiescence, dashed lines for the flare. Heating during the flare is expressed in an increase of the temperature in the hotter component. The cooler component remains little affected by the outburst.

two-temperature Raymond-Smith model. During the flare the higher temperature showed an increase with respect to the quiescent stage, while the lower temperature remained unaffected. A one-temperature model with free abundance provides fits of comparable quality. However, the rather similar temperature derived for the flare and the quiescent state with the one-temperature model is difficult to reconcile with coronal heating expected during flare outburst.

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