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AN X-RAY FLARE FROM A B9+POST–T TAURI STAR SYSTEM IN THE FIELD OF THE SEYFERT GALAXY III ZW 2

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ABSTRACT

We report the serendipitous discovery by *EXOSAT* of a flaring X-ray source in the field of the Seyfert type I galaxy III Zw 2. In contrast to an earlier report that attributed the variability observed by the medium energy experiment to III Zw 2, we show that the variability was entirely due to the serendipitous source. We identify this source with the visual binary HD 560 (B9V+G5Ve) and we argue that virtually all of the observed X-ray flux from the binary, including the flare, came from its late-type component. These X-ray observations bring support to the optical classification of HD 560 B as a post–T Tauri star.

Subject headings: stars: coronae — stars: late-type — stars: pre-main-sequence — X-rays: sources

I. INTRODUCTION

The Low Energy Imaging Telescopes and CMA detectors on the *EXOSAT* satellite (Taylor *et al.* 1981) have proved to be very good instruments for detecting serendipitous sources in the soft X-ray energy band 0.05–2.0 keV (Giommi, Tagliaferri, and Angelini 1988). In particular, the relatively long ($\geq 10^4$ s) and uninterrupted *EXOSAT* observations allow the variability of these new X-ray sources to be studied on time scales ranging from seconds to several hours.

In this *Letter* we present the serendipitous detection of X-ray emission from the visual binary HD 560, consisting of a B-type primary and a late-type secondary. This system was seen in the field of the Seyfert type I galaxy III Zw 2, which was observed four times by *EXOSAT*. During one of these observations (1985 November 30), the serendipitous source was observed to flare in both the low energy (LE) and medium energy (ME) experiments. Pounds and Turner (1987) have attributed the flare observed in the ME to the Seyfert galaxy. We show here that the observed variability was in fact entirely due to the serendipitous source. We also argue that virtually all of the X-ray flux from the binary came from its late-type component (HD 560B) and that this component is likely to be a post–T Tauri star, as recently suggested by Lindroos (1986) on the basis of optical evidence.

II. OBSERVATIONS

In order to perform broad-band spectral analysis, different filters could be rotated in front of the CMA. During three out of the four observations of III Zw 2 the Thin Lexan (3 Lex) and the Aluminium/Parylene (Al/P) filters were used. In the other observation, the Thick Lexan (4 Lex) filter was used instead of Al/P. On all occasions, a second source was detected $\sim 12'$ from III Zw 2. It had a constant count rate, except on day 1985 November 30 when a flare was seen in the 3 Lex filter light curve (Fig. 1). The flare started at $\sim$03:48 UT with the flux increasing more than a factor of 3 in $\sim$40 minutes. The decay was exponential-like, but $\sim$50 minutes after the peak there was a hump in the light curve. Unfortunately, at this time the filter was changed to Al/P and it is not possible to follow the late flare decay. After 07:10 UT, when the 3 Lex filter was back in use, the flux was found to be at the same level as before the flare. No variability was detected in the Al/P observation, which had a much lower signal to noise ratio.

The source was also included at $\sim$85% efficiency in the collimator response of the ME experiment; a large area proportional counter sensitive in the 1–15 keV energy band, with a FWHM of the field of view of 45′ (Turner, Smith, and Zimmermann 1981). The ME light curve on 1985 November 30 is shown in Figure 1. It is dominated by the flux from III Zw 2 and is constant except for a period starting at $\sim$03:55 UT and ending at $\sim$05:35 UT when a strong flare is seen, similar in shape to the one detected simultaneously in the LE light curve of the serendipitous source. The ME flare appears to start some minutes later than the LE event; however, this delay is probably due to the high background count rate of III Zw 2. The rise of the flare in the ME is somewhat faster than in the soft energy band and the flare peaks a few minutes earlier. A hump during the decay phase is seen, which occurs some minutes before than in the LE (Fig. 1). A cross correlation analysis shows that the delay between the flux in the two experiments (LE delayed with respect to ME) was 6.0 ± 1.1 minutes (90% confidence). We note that an earlier peak in hard X-rays than in soft X-rays is usually observed in solar and stellar flares and can be easily understood as due to rapid heating and subsequent cooling of the hot flare plasma.

An analysis of the same *EXOSAT* observation has been reported by Pounds and Turner (1987), who ascribed the flare seen in the ME to III Zw 2. However, the lack of variability in the Seyfert LE light curve (Fig. 1) and the similarity between the ME event and the LE flare in the serendipitous source, leads us to conclude that the flare was not produced by the Seyfert galaxy but was entirely due to the serendipitous source.

III. IDENTIFICATION OF THE SERENDIPITOUS SOURCE

The X-ray position of the serendipitous CMA source is $\alpha_{1950} = 00^h07^m28^s.7$, $\delta_{1950} = +10°51'57'' \pm 10''$. Only two

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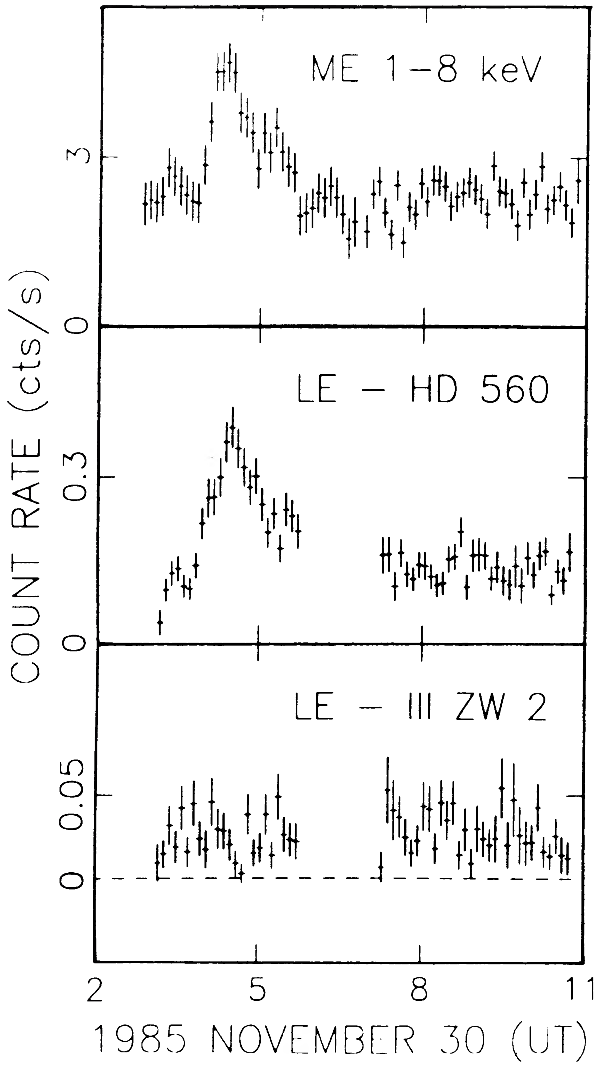

FIG. 1.—*EXOSAT* observation of the field of III Zw 2 on 1985 November 30. From top to bottom: (*a*) ME light curve for the field containing both the Seyfert galaxy and the serendipitous source; (*b*) LE light curve of the serendipitous source; (*c*) LE light curve of III Zw 2. All light curves have been background subtracted.

cataloged objects are included in this error circle: the stars HD 560A and HD 560B. They are classified as B9V ($m_v = 5.53$) and G5 Ve ($m_v = 10.37$), respectively, and constitute a physical double system with a separation of 7".7 (Gahm, Ahlin, and Lindroos 1983).

The CMA detector was sensitive to UV radiation and the filters had different UV transparencies (e.g., Chiappetti and Giommi 1985). It is difficult to separate any quiescent X-ray flux due to HD 560 from the UV induced count rate due to the bright B star HD 560A. However, the fact that the flare was a true X-ray flare is confirmed both by the simultaneous occurrence of the ME flare and by the shape of the "sum signal" distribution of the CMA photons, which changed from one typical of an UV source, before and after the flare, to one typical of an X-ray source *during* the flare (see Fig. 2). The expected flux due to UV radiation from the B9 star in the two Lexan filters (see Chiappetti and Giommi 1985), is similar to the quiescent flux seen. On the other hand, the UV contribution in the Al/P filter is expected to be less than 1×10^{-4} counts s^{-1}, i.e., much less than actually observed; therefore, the flux observed in this filter in the two observations when the serendipitous source was not flaring can be attributed to the quiescent X-ray emission of HD 560.

HD 560 was also serendipitously detected on two occasions by the IPC experiment on *Einstein* satellite. The observed IPC count rates were 5.5×10^{-2} and 4.4×10^{-2} counts s^{-1}, respectively (Maccacaro, Garilli, and Mereghetti 1987), which correspond to a luminosity of $\sim 8 \times 10^{29}$ ergs s^{-1}, obtained using a conversion factor of 2×10^{-11} ergs cm^{-2} count^{-1} (Vaiana *et al.* 1981) and a distance for this system of 81 parsec (Lindroos 1986).

In order to estimate the X-ray luminosity in the band 0.05–2.0 keV for the source detected by *EXOSAT* in the Al/P filter, we assume an optically thin line + continuum thermal model as computed by Mewe, Gronenschild, and van den Oord (1985). For typical coronal temperatures, ranging from 0.3 to 1.0 keV, the X-ray luminosity is between 2.2 and 2.5×10^{30} ergs s^{-1}, a factor of 3 larger than that deduced from the IPC observations. Such a difference is commonly encountered in observations of stellar coronal sources: as shown by Pallavicini *et al.* (1988), this systematic difference between *EXOSAT* and IPC fluxes can be explained by a multitemperature structure of the source, the higher *EXOSAT* flux being produced by low-temperature plasma (≤ 2 keV) to which the IPC is not sensitive. We conclude that the two quiescent Al/P and the two IPC detections are consistent with each other and that they likely represent the quiescent flux of HD 560 B (see § V).

IV. SPECTRAL ANALYSIS OF THE FLARE

We have obtained the ME flare spectrum of HD 560 by subtracting a pre- and postflare Seyfert + background spectrum. The flare spectrum has been integrated from 03:50 UT to 05:30 UT. In the spectral fitting we have used the model of Mewe, Gronenschild, and van den Oord (1985). The best-fit temperature is $3.9^{-0.9}_{+1.5}$ keV (errors have 90% confidence, $\chi^2_{min} = 20$ for 23 d.o.f.), the corresponding emission measure is 1.8×10^{54} cm^{-3}. For the fit we fixed the interstellar column density (N_H) at 1.8×10^{19} cm^{-2}, the value expected for a uniform interstellar density of 0.07 cm^{-3} (Paresce 1984). The count rate in the LE 3 Lex band predicted from the best-fit spectrum of the ME data is lower by $\sim 10\%$ than that observed. This small difference may be due either to the presence of a second lower temperature component in the flaring plasma (with an emission measure ~ 0.1 of the high-temperature component) or to a substantially lower value of the N_H. An essentially equivalent fit of the LE and ME data together can be in fact obtained with a temperature of 4.1 keV and an N_H of 3.9×10^{18} cm^{-2}. The total flare energy between 0.05 and 10 keV is 1.9×10^{35} ergs.

V. DISCUSSION

We have reported the discovery by *EXOSAT* of a flaring X-ray source in the field of the Seyfert galaxy III Zw 2 and we have identified the flaring source with the visual binary HD 560 which contains a B9 V primary and a G5 Ve secondary. The *EXOSAT* and *Einstein* observations do not have the angular resolution to discriminate between the two stars. The special interest of this observation is that the late-type star HD 560B has been suggested to be a post–T Tauri star (PTTS; Lindroos 1986), i.e., a star still contracting toward the main-sequence and intermediate between classical T Tauri stars and zero-age, main-sequence (ZAMS) stars.

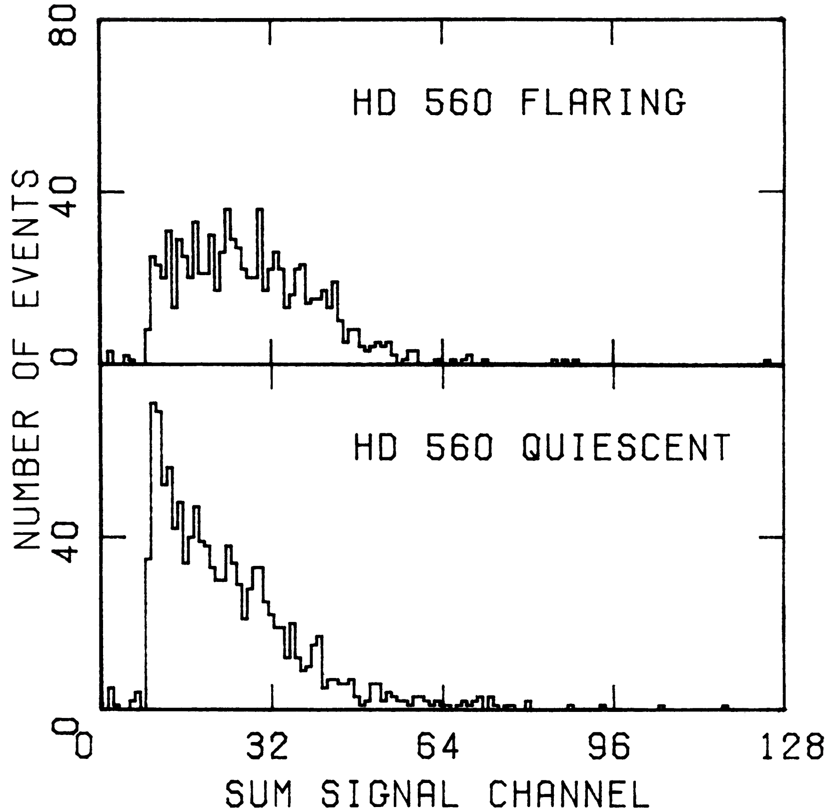

FIG. 2.—Sum signal distribution for the LE observation of the serendipitous source. The sum signal is the summed output from the four readout contacts on the resistive disk of the CMA and can be used to discriminate between UV and X-ray photons. Lower distribution refers to the quiescent phase, and it is typical of an UV source. Upper distribution refers to the flare phase, and it is typical of an X-ray source.

The extensive stellar surveys carried out with the *Einstein Observatory* (Rosner, Golub, and Vaiana 1985; Schmitt 1988) have shown that B8-A5 stars as a class are not X-ray emitters at levels greater than $\sim 10^{27}$ ergs s^{-1}, except for a few Ap stars with strong magnetic fields (Cash and Snow 1982). Early reports of the contrary (Golub *et al.* 1981) have been demonstrated to be due either to UV contamination in the HRI detector or to the contribution of late-type companions to the IPC flux (Schmitt *et al.* 1985). Recently, Caillault and Zoonematkermani (1987) and Walter *et al.* (1988) have detected X-ray emision from a few late-B stars in regions of star formation. Whether or not the X-ray emission in these cases can be properly attributed to the hot stars or to possible hidden late-type companions remains to be determined. In contrast to the other few detections of B9 stars, in this case we observe a young late-type companion star to be present.

Pre-main-sequence (PMS) stars are known to flare (Feigelson and DeCampli 1981; Montmerle *et al.* 1983; Collier Cameron *et al.* 1988), and to have X-ray luminosity in the range 10^{30}–10^{31} ergs s^{-1} (Mundt *et al.* 1983; Walter 1986). We are not aware of any report of an X-ray flare from an early-type (O-B) star. During the *EXOSAT* mission many bright serendipitous B stars were detected as UV sources in the 3 Lex filter (Giommi, Tagliaferri, and Angelini 1988) and, apart from the case discussed in this paper, no X-ray flares have been detected despite an average exposure $\geq 10^4$ s. For these reasons we identify the flaring and probably the quiescent X-ray source with the late-type star. Our identification relies heavily on the assumption that main-sequence stars in the range B8-A5 are not strong X-ray emitters, if at all.

The X-ray observations bring further support to the identification of HD 560B as a PMS star and shed light on the X-ray properties of PTTS. PTTS were first proposed as a class of PMS objects by Herbig (1978), who noticed that the T Tauri phase occupies only a small fraction ($\sim$5%–10%) of the contraction time of a 1 $M_{\odot}$ star toward the main sequence. As a consequence, many more PTTS should exist than classical T Tauri stars. Unfortunately it is quite difficult to detect PTTS and, so far, only a handful of bona fide PTTS have been identified (see reviews by Herbig 1978 and Haro 1983).

Gahm, Ahlin, and Lindroos (1983) proposed a different approach to find PTTS. They suggested a search for visual double systems composed of primaries of spectral type O and B and of late-type secondaries of ~ 1 $M_{\odot}$. Since the contraction time of such secondaries is longer than, or at least a large fraction of, the entire time spent on the main sequence by early-type stars, the secondaries must still be contracting or have just reached the ZAMS. Lindroos (1986) was able to identify ~ 80 visual binaries of this type and showed that the secondaries were located on or slightly above the ZAMS on the radiative part of the evolutionary tracks of contracting stars with masses between 0.2 and 2 $M_{\odot}$. More than 50% of them exhibit spectroscopic features (Ca II H, K, and Hα emission and strong Lithium absorption) typical of T Tauri stars although not as conspicuous as in classical T Tauri stars. Both facts suggest that these stars, or at least most of them, may have an evolutionary status older than that of classical T Tauri stars and are appropriately described as "post–T Tauri." HD 560B is one of the secondaries in the list of Lindroos (1986).

The spectroscopic observations of Gahm, Ahlin, and Lindroos (1983) have shown that HD 560B has Hα and the H and K lines of Ca II in emission as well as having an exceptionally strong Lithium line at 6707 Å. Hα in emission is extremely rare in G5 V stars (as HD 560B has been classified) and the presence of a strong Li line is further evidence that the star must be quite young. Lindroos (1985), from *uvbyβ* photometry of the primary, dates HD 560B to less than 50×10^6 yr, an age comparable to or shorter than the contraction time of a 1 $M_\odot$ star to the ZAMS.

Are the observed X-ray properties consistent with the identification of HD 560B as a post–T Tauri star? The quiescent X-ray luminosity we derive for HD 560B is comparable to that of the PTTS candidates observed by *Einstein* (Mundt *et al.* 1983; Walter 1986). It is also comparable to the quiescent X-ray luminosity of another *EXOSAT* source (HD 36705 = AB Dor) for which some evidence has recently been produced (although not conclusive as yet) that it might be a pre–main-sequence object, possibly a PTTS (Rucinski 1982, 1985; Vilhu, Gustafsson, and Edvardsson 1987). The strong Li line and the high level of activity strongly suggest that it may be indeed a PTTS contracting toward the main sequence along a radiative track. The X-ray luminosity of all these sources is $\sim 10^{30}$ ergs s^{-1}, i.e., much higher (by a factor 10–1000) than typical X-ray luminosities of late-type main-sequence stars and subgiants (see Rosner, Golub, and Vaiana 1985), except for the special case of close binaries of the RS CVn type.

AB Dor was observed as a flaring source by both *Einstein* (Pakull 1981) and *EXOSAT* (Collier Cameron *et al.* 1988). The *EXOSAT* observations show that AB Dor had a quiescent X-ray luminosity of 2×10^{30} ergs s^{-1} and a flare peak luminosity of 6.7×10^{30} ergs s^{-1}. Both values are comparable to the quiescent and flaring X-ray luminosities derived by us for HD 560B. We also note that the total energy released in X-rays by the flare on HD 560B was $\sim 10^{35}$ ergs, which is larger (by at least a factor of 10) than the highest total energies typically released by flares of main-sequence stars (Pallavicini 1988). This energy is comparable to the total X-ray energy released by large flares on RS CVn and Algol-type binaries (see White *et al.* 1986) and is indicative of an extreme level of activity.

To conclude the X-ray emission from HD 560 is more likely attributed to the G5 Ve star not its B9 companion. The high quiescent X-ray luminosity, the flaring behavior and the large energy released in the flare, all indicate that this is a star with a very active corona and has X-ray characteristics typical of PMS stars. This is consistent with the results of optical studies which have identified it as a member of the elusive class of post–T Tauri stars. Since these stars are difficult to detect by optical methods, X-ray observations may prove to be the best way to identify them.

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