LONG TERM STUDIES OF Z SOURCES
WITH HEXTE/RXTE

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ABSTRACT

We have analyzed the long pointed observations of the Z sources in the Rossi X-Ray Timing Explorer (RXTE) public archive to study the high energy emission in those sources. Our analysis is concentrated on the High Energy X–Ray Timing Experiment (HEXTE) waveband, since we are primarily interested in studying the hard X–ray (i.e., \( E > 20 \text{ keV} \)) production in those sources. We give here the preliminary results of this ongoing study.

We have found no hard X–ray tails (besides Sco X-1) in our database from any of the Z sources, i.e., GX 349+2 (< \(7.9 \times 10^{-5}\) photons cm\(^{-2}\) s\(^{-1}\), 3\(\sigma\), 50–150 keV), Cyg X-2 (< \(8.4 \times 10^{-5}\) photons cm\(^{-2}\) s\(^{-1}\), 3\(\sigma\), 50–150 keV), GX 17+2 (< \(4.2 \times 10^{-5}\) photons cm\(^{-2}\) s\(^{-1}\), 3\(\sigma\), 50–150 keV), GX 5–1 (< \(2.1 \times 10^{-5}\) photons cm\(^{-2}\) s\(^{-1}\), 3\(\sigma\), 50–150 keV), and GX 340+0 (< \(6.0 \times 10^{-5}\) photons cm\(^{-2}\) s\(^{-1}\) 3\(\sigma\), 50–150 keV). From the point of view of HEXTE/RXTE observations shown here, the production of hard X–ray tails in Z sources is a process triggered when special conditions are fulfilled. One of these conditions, as derived from our analysis, is a threshold of \(\sim 4 \times 10^{36} \text{ erg s}^{-1}\) for the luminosity of the source’s thermal component.

INTRODUCTION

The class of Z sources comprises 6 Galactic LMXBs (i.e., Sco X-1, Cyg X-2, GX 349+2, GX 5–1, GX 17+2 and GX 340+0) which are accreting mass via Roche lobe overflow. The inclusion of Cir X-1 in this list remains questionable (see, e.g., Iaria et al., 2002), and recently LMC X-2 was discovered as the first Z source outside our Galaxy (Smale, Homan and Kuulkers, 2003). Another feature of these sources is that the inferred neutron star magnetic field strength is intermediate (\(B \sim 10^9\) G) between the range for the atoll sources (\(\sim 10^8\)) and accreting pulsars (\(\gtrsim 10^{12}\)). Also, all of the Z sources besides Sco X-1, Cyg X-2, and of course the recently found LMC X-2 are near or in the Galactic plane. They are called Z sources due to the track that they display in a color–color diagram (see, e.g., van der Klis, 1996). The movement along the Z occurs in a continuous fashion, in the sense that a source must spend some time in the normal branch (NB) if it is moving from the horizontal branch (HB) to the flaring branch (FB), i.e., a jump from the HB to the FB (or vice-versa) has never been observed. It is believed that the movement in the Z is due to variations in the mass accretion rate (\(\dot{M}\), see, e.g., van der Klis, 1996), which increases in the sequence HB→NB→FB.

The literature shows some examples of the detection of hard X–ray tails (HXT) in Z sources. In this article we will present our definition of a HXT. For Sco X-1 such detections were reported first by Strickman and Barret (2000), and then confirmed and deeply studied by us (D’Amico et al., 2001a, 2001b). A preliminary report of a HXT detection in Cyg X-2 was presented by Frontera et al. (1998). Analyzing BeppoSAX data, Di Salvo et al. (2000) reported the detection of a HXT in GX 17+2, and also in GX 349+2 (Di Salvo et al., 2001). We present the preliminary results of an ongoing study that uses Rossi X-Ray Timing Explorer (RXTE)/High Energy X-Ray Timing Experiment (HEXTE) data in searching for HXT in Z sources. In the next sections we present our selected database and data analysis, and then our results are discussed. It is interesting to highlight that we found no HXT in the HEXTE selected database (apart from Sco X-1; see D’Amico et al., 2001a, 2001b). We will present our interpretations about this result.
INSTRUMENTATION AND DATA ANALYSIS

We used data from HEXTE (Rothschild et al., 1998) to search for hard X–ray emission of the Z sources in the ∼20–220 keV interval and data from the Proportional Counter Array (PCA, Jahoda et al., 1996) to determine the position of the source in the Z diagram (although such positions are not shown here in this article). We have chosen, from the public RXTE database those subsets of data in which ∼ 2000 s of HEXTE total on–source time was available, in order to achieve better sensitivity. The number of selected observations for each source is shown in Table 1.

As we said in the previous section, almost all of the Z sources are near or in the Galactic Plane. The background in this particular region of the sky is known to vary as a function of the latitude (i.e., up to ∼ 20 keV, see Valinia and Marshall, 1998) up to γ–ray energies (see, e.g., Boggs et al., 2000). We took advantage of the HEXTE design to carefully manage this problem by measuring the background at the same latitude of the source’s location, a feature that is possible only because HEXTE has two clusters that measure the background in 4 different sky regions (dubbed plus and minus regions). Source confusion is another issue, again carefully studied for each particular source. When a source was present in one of the two background sampled regions, their presence was easily identified and the other region was used as the source’s background estimate.

We analyzed our data using the FTOOLS and XSPEC. Since we are most interested in the HEXTE data, data from PCA was modeled (in the spectral analysis) using available literature models for each source. In order to construct an uniform database for all the 6 Z sources, HEXTE data was modeled with a sum of two parts: a soft part (up to ∼ 40 keV in most of the cases) which was modeled as a simple thermal bremsstrahlung, and a hard part which was modeled as a power law model. We refer the reader to D’Amico et al. (2001a, 2001b) for a more detailed description of the data analysis, since we use the same procedure applied in Sco X-1 for the remaining Z sources.

RESULTS

As defined in our previous studies (see, e.g., D’Amico et al., 2001b) we developed two criteria to determine the presence of a HXT in a particular spectrum: 1) a signal to noise ratio (SNR) ≥ 5 in the 75-220 keV range, and 2) a F-Test null significance for the addition of the hard component at a level of 10<sup>−7</sup> or less (we caution the reader however, that F-test can, in certain conditions, drive to wrong conclusions: see, e.g., Protasov et al., 2002). We claim that we detected a HXT only when both of these criteria are fulfilled.

We found no HXT in any of the observations of the Z sources, but Sco X-1. In Table 1 a compilation of our results is presented. In order to estimate luminosities, the distances to the sources must be known. Distances to Sco X-1 and Cyg X-2 were already given in literature (Bradshaw, Fomalont and Geldzahler, 1999; Orosz and Kuulkers, 1999, respectively). The distance to the remaining sources was adopted as being 7.9 ± 0.3 kpc, the distance to the Galactic Center (GC: McNamara et al., 2000) since that distance has been generally used as an estimate for the distance to all Z sources (see, e.g., Bandyopadhyay et al., 1999).

The thermal component was easily detected by HEXTE up to 50 keV. Nevertheless, the detection level was always below 3σ in the 50-75 keV band (except for one case for GX 340+0) for all the Zs but Sco X-1 and GX 5–1. The GX 5–1 source is strongly contaminated by the presence of the nearby source GRS 1758–258, discovered by the GRANAT satellite (Sunyaev et al., 1991) and highly studied with RXTE (Smith, Heindl and Swank, 2002). At this point of our study we can firmly say that we did not observe a HXT in GX 5–1, but we can say nothing yet about the flux of GX 5–1 in the 50-75 keV band.

DISCUSSION

From Table 1, and comparing the observations of the remaining sources with Sco X-1, it seems to be that our HEXT observations were sensitive enough to detect HXT. In comparison with the BeppoSAX results reported for HXT detections in Cyg X-2 (Frontera et al., 1998), GX 17+2 (Di Salvo et al., 2000), and GX 349+2 (Di Salvo et al., 2001), our results can be interpreted in terms of variability in the appearance of a HXT in the source’s spectrum, as we observed in Sco X-1 on a 4 hour time-scale (D’Amico et al., 2001b).

All the sources were observed in all the branches, but GX 349+2 (from which the HB was never observed up to date). It’s also interesting to note that the Sco X-1 results (D’Amico et al., 2001b) found no correlation between the observation of a HXT and the position of the source in the Z, contrary to the BeppoSAX results for GX 17+2 and...
Table 1. HEXTE Results: Fluxes and Luminosities

| Source Name | Number of observations | Flux$^a$ | L$_{20-80}$$^b$ | L$_{20-50}$$^c$ |
|-------------|------------------------|---------|-----------------|-----------------|
| Sco X-1     | 28                     | $<2.0\times10^{-3}$ | 6.7$^e$        | 4.5–9.0$^f$    |
| GX 349+2    | 10                     | $<7.9$   | $<6.8$      | $<3.10$        |
| Cyg X-2     | 13                     | $<8.4$   | $<5.0$      | $<2.10$        |
| GX 17+2     | 11                     | $<4.2$   | $<8.8$      | $<2.01$        |
| GX 5–1      | 12                     | $<2.1$   | $<16.1$     | $<2.97$        |
| GX 340+0    | 13                     | $<6.0$   | $<13.4$     | $<2.08$        |

NOTE: bremsstrahlung + power law model used

$^a$ 3σ upper limit power law flux in the 50-150 keV range, in units of $10^{-5}$ photons cm$^{-2}$ s$^{-1}$ (otherwise noted)

$^b$ 3σ power law luminosity in the 20-80 keV range, with power law index frozen at 2 (otherwise noted), in $10^{35}$ erg s$^{-1}$

$^c$ Luminosity of the thermal component in the 20-50 keV range, in $10^{36}$ erg s$^{-1}$

$^d$ averaged in the HXT detections of Sco X-1: see D’Amico et al. (2001b)

$^e$ measured in Sco X-1: see D’Amico et al. (2001b)

$^f$ when a HXT is detected in Sco X-1: see D’Amico et al. (2001b)

GX 349+2 (Di Salvo et al., 2000 and 2001, respectively).

As we pointed out in previous studies (D’Amico et al., 2001b, 2001c), the chance of observing a HXT in Sco X-1 is higher when the thermal component (20-50 keV) of the spectrum is brighter. As we can see in Table 1, our measured level for the thermal luminosities of the Z sources (besides Sco X-1) is always below a level of $\sim 4 \times 10^{36}$ erg s$^{-1}$.

While comparable values were not given by the BeppoSAX results for Cyg X-2, GX 17+2, and GX 349+2 (nor by the CGRO results for Sco X-1: see Strickman and Barret, 2000), it is possible to extrapolate BeppoSAX results for GX 349+2 in order to estimate the luminosity of the thermal component. We estimate that the 20-50 keV luminosity GX 349+2 luminosity measured by BeppoSAX was greater than $\sim 5 \times 10^{36}$ erg s$^{-1}$. It thus appear from the point of view of the HEXTE observations shown here, that the production of HXT in Z sources is a process triggered when special conditions are fulfilled. Our observations show that one of this special conditions is the brightness of the thermal component, being the HXT production triggered when this luminosity is above the threshold of $\sim 4 \times 10^{36}$ erg s$^{-1}$.

We still want to emphasize the case of Sco X-1 as a peculiar Z source. Scorpius X-1 remains the only Z where a HXT was detected more than once, and also by two different satellites.

CONCLUSIONS

As we have shown here, our HEXTE results on Z sources show no evidence for the presence of HXT in several long pointed observations. We took advantage of the HEXTE design to constrain the contamination of the source’s spectrum due to the variations of the background with latitude in the Galactic ridge region, and also carefully studied background and/or source contaminations by nearby sources, as is the case for GX 5–1 which is contaminated by the presence of GRS 1758–258. We have shown that our observations were sensitive enough to detect the presence of the HXT, in comparing with our observations of HXT in Sco X-1 and with other reported HXT detections by BeppoSAX. Our interpretation for this is in terms of variability of the sources. Such variations were observed in Sco X-1 on a 4 hour time-scale. From the point of view of HEXTE observations shown here, and also from the BeppoSAX HXT detection in GX 349+2 the production of a HXT in a Z source is a process triggered when, at least, among other possible conditions, the brightness of the thermal component is above a level of $\sim 4 \times 10^{36}$ erg s$^{-1}$.

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