Discovery of the neutron star nature of SLX 1737−282

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Abstract. SLX 1737−282 is a persistent moderately bright X-ray source 1'2 from the Galactic center. X-ray observations with the Wide Field Cameras on BeppoSAX have for the first time revealed the true nature of SLX 1737−282: a 15-min long thermonuclear flash was detected exposing the source as a neutron star in a binary system. The flash was Eddington-limited constraining the distance to between 5 and 8 kpc. We analyze BeppoSAX, ROSAT, and RXTE data on SLX 1737−282. The persistent 0.5–200 keV luminosity is close to or less than 1\% of the Eddington limit which implies a rarely-seen circumstance for thermonuclear flash activity.

Key words. accretion, accretion disks – binaries: close – X-rays: stars: individual (SLX 1737−282, 2E 1737.5-2817, 1RXS J174043.1-281806, RX J1740.7-2818, AX J1740.7-2818)

1. Introduction

SLX 1737−282 was discovered with the Spacelab-2/X-Ray Telescope (SL2-XRT) which flew from 29 July to 6 August 1985 (Skinner et al. 1987). SL2-XRT targeted the Galactic center a number of times for a total of 7 hrs. SLX 1737−282 was detected with an average flux of 7.7×10\(^{-11}\) erg cm\(^{-2}\)s\(^{-1}\) in 3 to 30 keV. No timing or spectral features were noticed. Skinner et al. also went back to data from the Einstein galactic plane survey (Hertz & Grindlay 1983) and found that SLX 1737−282 was clearly present. The Einstein source was later given the name of 2E 1737.5-2817 and provided a 1'-accurate position.

Sakano et al. (2002) reported on all ASCA-GIS observations of a 5°×5° field centered on the galactic center. The position of SLX 1737−282 (also designated AX J1740.7-2818) was covered on 3 occasions in 1996, 1998, and 1999 with a total exposure time of 61.5 ksec and was detected every time with 0.7–10 keV fluxes between 4.8 and 6.5×10\(^{-11}\) erg cm\(^{-2}\)s\(^{-1}\). The spectrum is consistent with a constant absorbed power law with a photon index $\Gamma$ of 2.17±0.07 and $N_H = (2.0 \pm 0.1) \times 10^{22}$ cm\(^{-2}\). The flux varied up to 100\% on time scales of 10\(^3\) to 10\(^4\) s.

Because of being so close to the Galactic center, SLX 1737−282 was serendipitously targeted in a number of X-ray wide-field monitoring programs such as those carried out with Kvant/COMIS-TTM (In ’t Zand 1992, Emelyanov et al. 2000) and Granat/ART-P (Pavlinsky et al. 1994). The source was never detected in these programs. The upper limits are consistent with the ASCA and SL2-XRT detections.

Despite that a neutron star hypothesis was suggested by the spectrum, variability and flux, definite evidence was lacking; an AGN hypothesis could not be ruled out (e.g., Sakano et al. 2002). This has now changed. We present in this paper the first detection of an X-ray burst from SLX 1737−282 which settles the nature of SLX 1737−282. In addition we discuss ROSAT and RXTE data.

2. BeppoSAX-WFC observations

The Wide Field Cameras (WFCs; Jager et al. 1997) on the BeppoSAX satellite (Boella et al. 1997a) carry out a monitoring program in 2 to 28 keV of the galactic center since mid 1996. SLX 1737−282 is well inside the 40°×40° field of view and, through the 5° angular resolution, well-resolved from nearby sources. The monitoring program till early 2002 totalled a net exposure of ≈70 days. SLX 1737−282 was never detected in individual observations above an upper limit of roughly 2×10\(^{-10}\) erg cm\(^{-2}\)s\(^{-1}\) (2-10 keV) except for a single 15 min period on 27 March 2000 when a flare was detected from a location consistent with the Einstein position of SLX 1737−282 (see Fig. 6). Figure 6 (top panel) shows the time history of the intensity. The
The event is characterized by a fast rise – within one second – and a factor-of-3.5 decay in the following 880 sec (or an e-folding decay time of 600 s). At that point a data gap starts which lasts 1122 s after which SLX 1737−282 is not detected anymore. Thus, the flare is shorter than 2000 s.

We modeled the spectrum of the flare successfully with pure black body radiation, see Fig. 2. This, and the softening of the spectrum during the decay unambiguously identify this flare as a so-called type-I X-ray burst originating from a thermonuclear flash on the surface of a neutron star. The bolometric fluence of the burst before the data gap is $3 \times 10^{-5}$ erg cm$^{-2}$.

The burst lasts fairly long, with a 2-min long radius expansion phase at the start and a 6.5 min period after that when the flux and temperature retain their maximum values. The radius expansion during the burst suggests that the flux reaches near-Eddington values. This allows a rough estimate of the distance. For an Eddington limit between 2 and $4 \times 10^{38}$ erg s$^{-1}$ (Kuulkers et al., in prep.), the peak flux of $(6.0 \pm 0.5) \times 10^{-8}$ erg cm$^{-2}$s$^{-1}$ yields a distance between 5 and 8 kpc.

3. BeppoSAX-NFI observations

A follow-up observation of the burst was carried out with the BeppoSAX Narrow Field Instruments (NFI) half a year later, from 14 October 2000 01:44 UT to 15 October 2000 10:25 UT. Three NFI were turned on: the low-energy concentrator spectrometer LECS (0.1–4 keV; Parmar et al. 1997), the medium-energy concentrator spectrometer MECS (1.8–10.5 keV; Boella et al. 1997b), and the Phoswich Detector System PDS (Frontera et al. 1997).

The PDS is a collimating instrument with a hexagonal field of view of diameter 1°3 to 1°5; the LECS and MECS are imaging devices with field of views of 40′ and 30′ diameter respectively and few arcmin resolution. The exposure times were 14.0 ksec (LECS), 48.0 ksec (MECS) and 22.2 ksec (PDS).

SLX 1737−282 was clearly detected in the LECS and MECS data. Figure 3 shows the light curve as derived from the MECS data. The source exhibits variability with a maximum to minimum ratio of 10 to 1 on typical time scales of a few minutes. The power spectrum shows red noise (i.e., a power-law function with an index of $-1.17 \pm 0.04$) that becomes indistinguishable from Poisson noise beyond 1 Hz. There are no narrow features. The fractional rms is 40 ± 1% between 0.001 and 1 Hz.

A spectrum was generated by combining all LECS, MECS and PDS data. The power spectrum shows red noise (i.e., a power-law function with an index of $-1.17 \pm 0.04$) that becomes indistinguishable from Poisson noise beyond 1 Hz. There are no narrow features. The fractional rms is 40 ± 1% between 0.001 and 1 Hz.
4. ROSAT-PSPC observations

ROSAT carried out a number of pointings on 29 February and 1 March 1992 which cover SLX 1737–282. All of these were with the Position-Sensitive Proportional Counter (PSPC) in 0.5 to 2.4 keV. We analyzed these data because they represent the X-ray data with the highest angular resolution and enable a check on source confusion. In the two observations where SLX 1737–282 is almost on axis (obs ids rp400199 and rp400200), we identify two sources close to SLX 1737–282: 1RXS J174043.1–281806 (=RX J1740.7–2818) and 2RX J174104.3–281504. Only the former is consistent with the Einstein position of SLX 1737–282, see Fig. 3, and we identify it with SLX 1737–282. The other is close to Tycho-2 star 6839–218, whose colors are compatible with a G star at about 150 pc. The detected X-ray flux is compatible with such a counterpart. Using this object to determine the bore sight, and combining both ROSAT observations, we obtain a position for 1RXS J174043.1–281806 of \( \alpha_{2000.0} = 17^h 40^m 43.00^s \), \( \delta_{2000.0} = -28^\circ 18' 11''/9 \) or \( \ell = 359^\circ 9731 \), \( b = +1^\circ 2481 \). The positional accur
Table 1. History of X-ray flux from SLX 1737−282

| Data set  | Time  | Band | Flux in 0.5–10 keV |
|----------|-------|------|-------------------|
| SL2-XRT  | Jul 85 | 3–30 | 7.7 ± 13 ± 3 |
| ROSAT-PSPC | Feb 92 | 0.5–2.4 | 0.72 ± 10 ± 1 |
| ASCA-GIS | Sep 96 | 0.7–10 | 5.7 ± 13 ± 3 |
| ASCA-GIS | Sep 98 | 0.7–10 | 6.5 ± 14 ± 3 |
| ASCA-GIS | Mar 99 | 0.7–10 | 4.8 ± 11 ± 2 |
| BSAX-NFI | Oct 00 | 0.5–10 | 6.3 ± 14 ± 3 |

Footnotes:

1. Bandpass in which flux originally was measured; 2. Original flux measurement in 10^{-11} erg cm^{-2}s^{-1}; 3. Flux in 0.5–10 keV band, as extrapolated by assuming power law with photon index Γ = 2.15 and N_H = 1.9 × 10^{22} cm^{-2}. The errors are propagated errors in Γ of 0.1 and in N_H of 0.1 × 10^{22} cm^{-2}.

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6. Discussion

The detection of the type-I burst from SLX 1737−282 unequivocally identifies the origin as a neutron star. By analogy with other type-I X-ray bursters, it is almost certain that this neutron star is in a low-mass X-ray binary (LMXB) with a solar mass companion. According to a count based on the LMXB catalog by Liu et al. (2001) which was updated with recent discoveries, SLX 1737−282 is the 69th X-ray burster (c.f., In ’t Zand 2001). Among a LMXB population of about 150, this means that at least about half of all LMXBs contain neutron stars. Identifying the companion star in the optical may prove difficult, because of its proximity to the galactic center and the high reddening (A_V ≈ 11) implied by the value of N_H.

Whenever the average 0.5–10 keV flux of SLX 1737−282 is measured with sufficient accuracy (see Table 1) it is in a narrow range of 1.0 to 1.4 × 10^{-10} erg cm^{-2}s^{-1}. The NFI observation shows that this may extrapolate to as much as 2.3 × 10^{-10} erg cm^{-2}s^{-1} in 0.5–200 keV. The RXTE data show that during several hundred brief monitoring observations in 3 years the source never shows signs of strong brightening. Given the distance, the 0.5–200 keV flux translates to a luminosity of 5 × 10^{35} to 1.8 × 10^{36} erg s^{-1}, suggesting a bolometric luminosity that is less than or similar to 1% of the Eddington limit (as is also suggested by a direct comparison between the peak flux of the Eddington-limited burst and the persistent flux).

If one ignores ‘superbursts’ (e.g., Kuulkers et al. 2002a), the burst duration and fluence are among the largest (c.f., Tawara et al. 1984, Lewin et al. 1984, Van Paradijs et al. 1990, Swank et al. 1997, Kaptein et al. 2000, Kuulkers et al. 2002b). The amount of radiated energy, if isotropic, is between 1.0 and 2.2 × 10^{41} erg. If the energy released per gram of accreted material is between 1.6 and 6 × 10^{18} erg, this is equivalent to 2 × 10^{22} to 1.4 × 10^{23} g of accreted material. Given the persistent luminosity of perhaps a few times 10^{36} erg s^{-1}, the mass accretion rate may be 5 to 10 × 10^{15} g s^{-1} (or 1 to 2 × 10^{-10} M⊙ yr^{-1}). This implies a waiting time between bursts between 20 and 320 days, consistent with the detection of just a single burst.

The long duration combined with the low persistent flux suggests that the burst is caused by a thermonuclear flash in a hydrogen-rich environment in a mass accretion regime of M < 2 × 10^{-10} M⊙ yr^{-1} (Fujimoto et al. 1981).

There is a slight similarity to sources like 2S 0918-549 (e.g., Jonker et al. 2001) and 4U 1850-087 (e.g., Kitamoto et al. 1992). These are also rare bursters and moderately bright sources that, foremost, show broad emission features at about 0.7 keV attributable to an overabundance of Ne which would be consistent with a hydrogen-depleted donor in an ultracompact orbit (Juett et al. 2001). Our data are not constraining with regards to the 0.7 keV feature due to the high value of N_H, but the hydrogen-rich environment inferred from the burst duration suggests that the similarity is superficial. In this respect we note that the burst in SLX 1737−282 is an order of magnitude longer than in 2S 0918-549 and 4U 1850-087.

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