Letter to the Editor

Discovery of type-I X-ray bursts from GRS 1741.9–2853

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Abstract. For the first time X-ray bursts have been detected from a sky position consistent with the one of GRS 1741.9−2853, a *GRANAT* transient source located only $\sim 10'$ from the Galactic Centre. A total of 3 bursts have been observed by the Wide Field Cameras telescopes on board *BeppoSAX* during a monitoring observation of the Sgr A region in August-September 1996. The characteristics of the events are consistent with type-I bursts, thus identifying the source as a likely low-mass X-ray binary containing a neutron star. Evidence of photospheric radius expansion due to super-Eddington luminosity is present in one of the observed bursts, thus leading to an estimate of the source distance (~ 8 kpc).

Key words: stars: binaries: general – stars: novae, cataclysmic variables – stars: individual: GRS 1741.9−2853 – X-rays: bursts – X-rays: stars

1. Introduction

GRS 1741.9−2853 was discovered during the first observations of the Galactic Centre region performed by the *GRANAT* satellite in Spring 1990. The source was detected by the low-energy (4–30 keV) imaging telescope ART-P in the March 24–April 8 observations and was tentatively associated (Mandrou 1990) to the soft *EINSTEIN* source 1E 1741.7−2850 (Watson et al. 1981). Further analysis of the same data (Sunyaev 1990, Sunyaev et al. 1991, Pavlinsky et al. 1994) refined the source position, obtaining $\alpha = 17^{\mathrm{h}}41^{\mathrm{m}}50^{\mathrm{s}}$, $\delta = -28°52'54''$ (B1950, error radius $45''$, 90% confidence). The possible association with 1E 1741.7−2850 and also with the nearby *GINGA* transient GS 1741.2−2859/1741.6−289 (Mitsuda et al. 1990) was ruled out. The average 4–20 keV intensity of GRS 1741.9−2853 was 9.6 ± 0.7 mCrab, corresponding to $(1.6 \pm 0.1) \times 10^{36}$ erg s^{-1} at 8.5 kpc, and the source spectrum could be fitted by a thermal bremsstrahlung with a temperature of ~ 8 keV. During the same *GRANAT* observations, GRS 1741.9−2853 was detected

above the 3.5σ detection level of the soft Gamma-ray telescope SIGMA in the 40–100 keV band (Churazov et al. 1993, Vargas et al. 1997). On the other hand, both ART-P and SIGMA did not detect the source ~ 4 months later during the Fall 1990 observation campaign, suggesting GRS 1741.9−2853 is transient in nature. A 3σ upper limit of 1.2 mCrab was obtained by ART-P in the 4–20 keV band (Pavlinsky et al. 1994), thus implying a drop in the source intensity of at least a factor of 7. Moreover, *GRANAT* failed to detect GRS 1741.9−2853 in all the subsequent campaigns on the Galactic Centre (Spring 1991, Fall 1991, Spring 1992, e.g. Churazov et al. 1993, Pavlinsky et al. 1994, Vargas et al. 1997). The source was not observed in detailed mappings of the Galactic Centre region by soft X-ray instruments like *EINSTEIN* (0.5–4.5 keV, 3σ upper limit of ~ 0.7 mCrab, see Watson et al. 1981), *SPACELAB-2* (3–30 keV, < 0.8 mCrab, Skinner et al. 1987), and by *ROSAT* (0.8–2.5 keV, < 0.1 mCrab, Predehl & Trümper 1994), thus confirming its transient nature. More recently, no detections of GRS 1741.9−2853 were reported by *RXTE*-ASM in the 2–10 keV energy band since February 1996.

In the next section we briefly introduce the Wide Field Cameras telescopes and report on the observations of GRS 1741.9−2853. Time resolved spectroscopy of the burst data is presented in Sect. 3, while the impact of our results on the knowledge of the source are discussed in Sect. 4. In particular, we propose GRS 1741.9−2853 as a transient low-mass X-ray binary harbouring a neutron star and we give an estimate of the source distance.

2. Observations

One of the main scientific objectives of the Wide Field Cameras (WFC) on board the *BeppoSAX* satellite is the study of the timing/spectral behavior of both transient and persistent sources of the Galactic Bulge region, X-ray binaries in particular, on time scales from seconds to years. To this end, an observation program of systematic monitoring of the Sgr A sky region is being carried out (e.g. Heise 1998). The WFCs consist of two identical coded mask telescopes (Jager et al. 1997) pointing in opposite directions. Each camera covers a $40° \times 40°$ field of
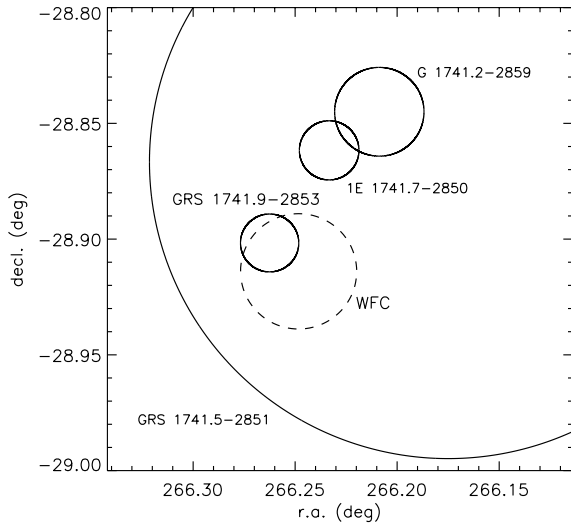
Fig. 1. A plot of source error circles (J2000, 90% confidence) in the GRS 1741.9−2853 sky region. The dashed circle refers to the WFC observed bursting source.

Fig. 2. Time profiles of the three observed bursts. Energy ranges maximizing the S/N ratio were selected.

Table 1. Summary of the characteristics of the observed bursts

parameter	Burst 1	Burst 2	Burst 3
Burst date	Aug. 22	Aug. 24	Sep. 16
Burst UT time (h)	23.4130	3.7972	9.6103
e-folding time (s)	$\gtrsim 8.8 \pm 2.5$	11.0 ± 1.7	16.0 ± 1.5
peak intensity [a]	$\gtrsim 384 \pm 62$	547 ± 56	983 ± 69
kT (keV)	1.78 ± 0.16	$2.26^{+0.14}_{-0.13}$	1.94 ± 0.07
Reduced χ^2 [b]	1.23	1.15	0.95
$R_{km}/d_{10 \text{ kpc}}$	$7.9^{+2.1}_{-1.4}$	$6.3^{+1.0}_{-0.8}$	$10.4^{+0.9}_{-0.8}$
N_H (10^{22}cm^{-2})	$10.2^{+10.1}_{-9.7}$	36^{+21}_{-13}	$10.3^{+3.7}_{-2.7}$
steady emission [c]	3	3	10

[a] in mCrab, 3–28 keV band;

[b] 26 d.o.f.;

[c] 3σ upper limits, in mCrab, 2–10 keV.

view, the largest ever flown for an arcminute resolution X-ray imaging device. With their source location accuracy in the range $1'$–$3'$ (99% confidence), a time resolution of 0.244 ms at best, and an energy resolution of 18% at 6 keV, the WFCs are very effective in studying X-ray transient phenomena in the 2–28 keV bandpass. The imaging capability and the good instrument sensitivity (5–10 mCrab in 10^4 s) allow an accurate monitoring of complex sky regions, like the Galactic bulge. The data of the two cameras are systematically searched for bursts and flares by analyzing the time profiles of the detectors in the 2–11 keV energy range with a time resolution down to 1 s. Reconstructed sky images are generated for any statistically meaningful event, to identify possible bursters. The accuracy of the reconstructed position, which of course depends on the burst intensity, is typically better than $5'$. This analysis procedure demonstrated its effectiveness throughout the Galactic Bulge WFC monitoring campaigns (e.g. Cocchi et al. 1998a), leading to the identification of ~ 700 X-ray bursts (156 of which from the *Bursting Pulsar* GRO J1744−28) in a total of about 2×10^6 s net observing time. A total of 13 new X-ray bursting sources were found, thus enlarging the population of the bursters by $\sim 30\%$ (Heise et al. 1999, Ubertini et al. 1999).

GRS 1741.9−2853 is in the field of view whenever the WFCs point at the Galactic Centre region, being only $\sim 10'$ away from the Sgr A position. No steady emission was observed during the whole WFC monitoring campaign. Typical 2–10 keV 3σ upper limits of ~ 3 mCrab were derived (see Table 1).

Three X-ray bursts were detected at a position consistent with that of GRS 1741.9−2853 in two different observations (Aug. 21.774–31.519 and Sep. 13.408–18.254) during the Fall 1996 monitoring campaign. Due to the *BeppoSAX* orbit characteristics, the source covering efficiency during an observation is in average $\sim 53\%$, so other bursts could be missed. The averaged error circle obtained for the position of the bursting source
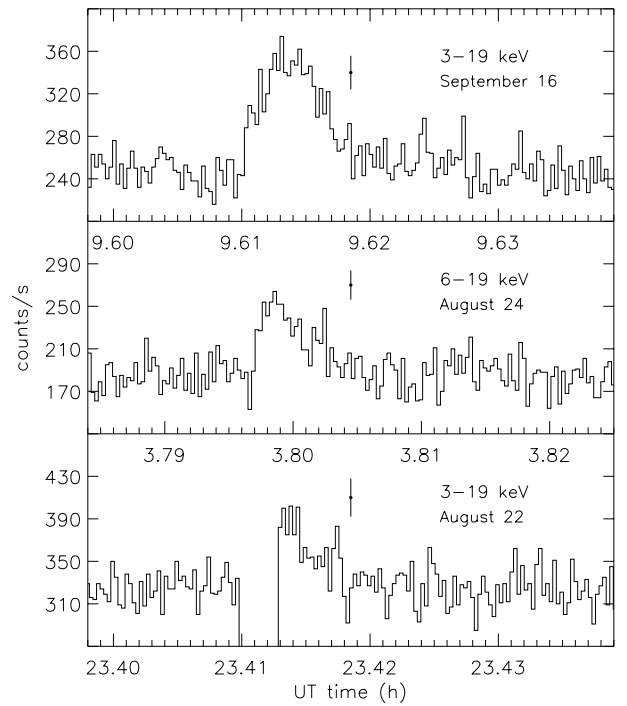
is shown in Fig. 1. None of the observed bursts can be associated to other known sources. In Fig. 2 the time profiles of the three bursts are displayed. The August 22 burst occurred in coincidence with a ~ 10 s telemetry gap and some seconds of data belonging to the leading part of the burst are missed. So we can not determine the burst on-time with sufficient accuracy. The characteristics of the observed bursts are summarized in Table 1. An accurate search for bursts from GRS 1741.9−2853 was performed on all the data available from the 1996–1998 *BeppoSAX*-WFC Galactic Bulge monitoring campaigns but no other events were observed.
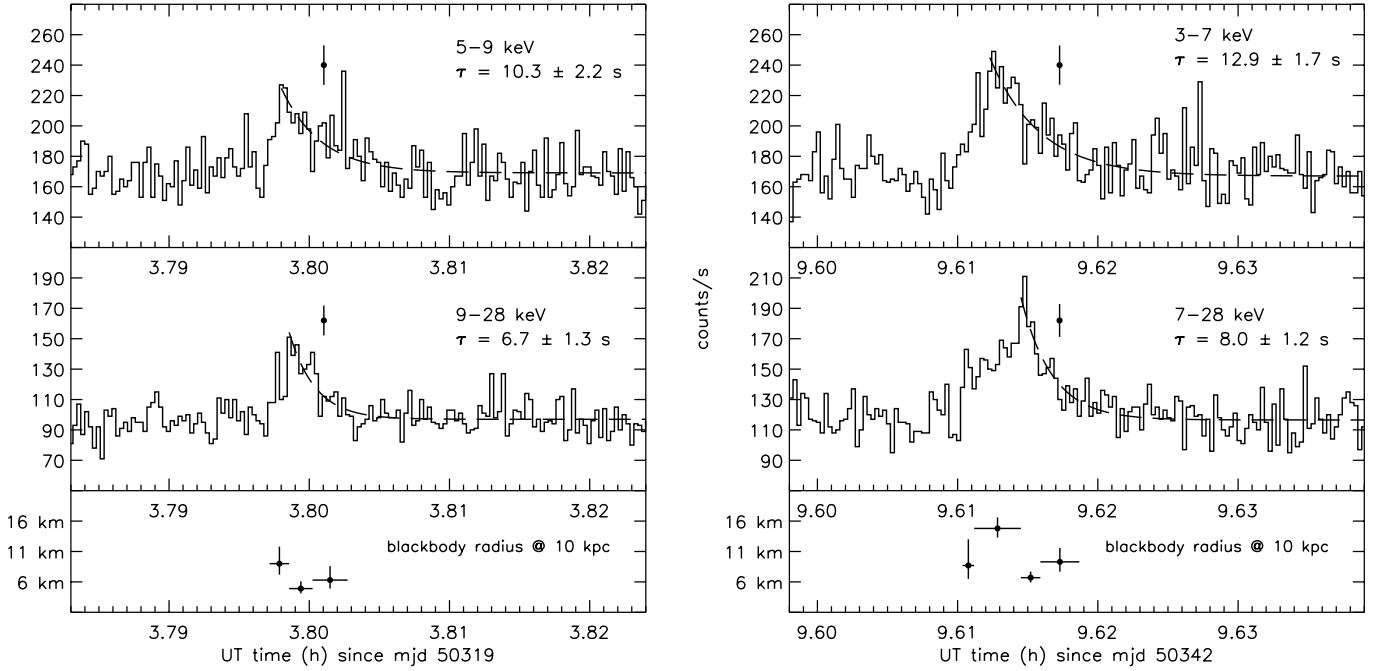
Fig. 3. Energy resolved time histories of August 24 and September 16 bursts. The dashed curves are exponential decay fits of the profiles. In the lower panels the time histories of the blackbody radii are also displayed.

Table 2. Time resolved spectral analysis of bursts 2 and 3

time range[a]	kT (keV)	$R_{km}/d_{10\ kpc}$	$\chi_r^{2\ [b]}$
	August 24 burst		
$T_0 \div T_0 + 5s$	$1.96^{+0.21}_{-0.18}$	$9.0^{+2.8}_{-1.8}$	1.09
$T_0 + 5s \div T_0 + 11s$	$2.70^{+0.25}_{-0.22}$	$4.9^{+1.2}_{-0.8}$	0.96
$T_0 + 11s \div T_0 + 20s$	$2.11^{+0.27}_{-0.22}$	$6.3^{+2.3}_{-1.4}$	0.72
	September 16 burst		
$T_0 \div T_0 + 3s$	$1.96^{+0.33}_{-0.29}$	$8.7^{+4.3}_{-2.2}$	0.95
$T_0 + 3s \div T_0 + 15s$	$1.71^{+0.09}_{-0.08}$	$14.8^{+1.8}_{-1.5}$	1.34
$T_0 + 15s \div T_0 + 20s$	$2.62^{+0.17}_{-0.16}$	$6.7^{+1.0}_{-0.8}$	0.81
$T_0 + 20s \div T_0 + 30s$	$1.82^{+0.17}_{-0.16}$	$9.3^{+2.3}_{-1.6}$	1.01

[a] T_0 indicates the burst time (see Table 1);
[b] 27 d.o.f.

3. Data analysis

Energy resolved time analysis of the bursts was performed to study the spectral evolution of the observed events. Due to the above mentioned missing data in the August 22 burst observation, only the August 24 and September 16 bursts were analyzed this way (see Fig. 3). The time histories of the bursts are constructed by accumulating only the detector counts associated with the shadowgram obtained for the sky position of the analyzed source, thus improving the signal to noise ratio of the profile. The background is the sum of (part of) the diffuse X-ray background, the particles background and the contamination of other sources in the field of view. Source contamination is the dominating background component for crowded sky fields like

the Galactic Bulge. Nevertheless, the probability of source confusion during a short time-scale event (10–100 s) like an X-ray burst is negligible.

The burst spectra of GRS 1741.9−2853 are consistent with absorbed blackbody radiation with average color temperatures of ∼ 2 keV. A summary of the spectral parameters of the three bursts is given in Table 1. The value of the N_H parameter obtained for the August 24 burst is higher with respect to the August 22 and September 16 ones. For burst 2, freezing the N_H value to the average value of burst 1 and 3 (10.3×10^{22}cm^{-2}) leads to higher values of the reduced χ^2 (1.30 for 27 d.o.f.), to an higher blackbody temperature (2.64 ± 0.15 keV) and to a lower blackbody radius (3.9 ± 0.4 km at 10 kpc). Conversely, if we assume that all the three bursts had in average the same characteristics (color temperature and radius of the emitting sphere), this implies a 1-day time-scale N_H variability of a factor of ∼ 3.

Time-resolved spectra were accumulated for burst 2 and 3, in order to study the time evolution of their spectral parameters. To better constrain the fits, the N_H parameter was kept fixed, according to the values obtained for the total bursts, i.e. 36.0×10^{22}cm^{-2} and 10.3×10^{22}cm^{-2} for burst 2 and burst 3 respectively. Blackbody spectra allow to determine the relationship between the average radius of the emitting sphere R_{km} (in units of km) and the source distance $d_{10\ kpc}$ (in units of 10 kpc). In Fig. 3 and in Table 2 the time histories of the measured $R_{km}/d_{10\ kpc}$ ratios are shown, assuming isotropic emission and not correcting for gravitational redshift and conversion to true blackbody temperature from color temperature (see Lewin et al. 1993 for details). A radius expansion of a factor of ∼ 2 is observed in the September 16 burst.

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4. Discussion

On the basis of their spectral and timing properties, we interpret the three bursts detected from GRS 1741.9−2853 as type-I X-ray bursts, typically associated to low-mass binary (LMXB) systems (see Lewin et al. 1995 for a review). The blackbody emission and the measured color temperatures of ~ 2 keV are consistent with this hypothesis. Spectral softening is observed in the time resolved spectra of the bursts (Table 2). Moreover, the bursts time profiles can be fitted with exponential decays whose characteristic times are energy dependent, being shorter at higher energies (see Fig. 3). Type-I bursts strongly suggest a neutron star nature for the binary system. This indicates GRS 1741.9−2853 is a transient neutron-star LMXB.

The photospheric radius expansion derived from the time resolved spectral analysis of the brightest burst (burst 3) can be interpreted as adiabatic expansion during an high luminosity (super-Eddington) type-I burst. Actually, the 7–28 keV time history of the September 16 burst (Fig. 3, right panel) shows a top-flattened and perhaps double-peaked profile which is typical of super-Eddington events (e.g. Lewin et al. 1995). Eddington-luminosity X-ray bursts can lead to an estimate of the source distance. Assuming a 2×10^{38} erg s^{-1} Eddington bolometric luminosity for a 1.4 M$_\odot$ neutron star, and taking into account the observed peak flux of burst 3 which extrapolates to an unabsorbed bolometric luminosity of 527 ± 42 mCrab ($3.26 \pm 0.26 \times 10^{-8}$ erg cm^{-2} s^{-1}), we obtain $d = 7.2 \pm 0.6$ kpc. If we adopt the average luminosity of super-Eddington bursts proposed by Lewin, van Paradijs, & Taam (1995) ($3.0 \pm 0.6 \times 10^{38}$ erg s^{-1}) the distance value becomes $d = 8.8 \pm 1.2$ kpc, indicating GRS 1741.9−2853 to be very close to the Galactic Centre. Assuming a Crab-like spectrum, for the source bolometric luminosity we derive an upper limit of $\sim 1.6 \times 10^{36}$ erg s^{-1} during the bursting activity (August-September 1996). We also obtain an average radius of ~ 6 km for the blackbody emitting region during the bursts, a value supporting the neutron-star nature of the collapsed object.

Taking into account the intensity and the spectrum observed in the 1990 outburst (Sunyaev 1990), we can also derive a peak bolometric luminosity of $\sim 2 \times 10^{36}$ erg s^{-1}, which extrapolates to an accretion rate of $\lesssim 3 \times 10^{-10}$ M$_\odot$ y^{-1} for a canonical 1.4 M$_\odot$ neutron star. These values are common among low luminosity LMXB transients (e.g. Tanaka & Shibazaki 1996, Chen et al. 1997).

During the past two decades, bursting activity from LMXB transients has been reported in about 10 cases (e.g. Rapid Burster, Aql X-1, Cen X-4, 0748−673, 1658−298, see Hoffman et al. Lewin 1978, Tanaka & Shibazaki 1996, Lewin et al. 1995, and references therein), thus indicating the sources to be neutron-star binaries. Among the LMXB transients less than $\sim 50\%$ of sources ($\simeq 30\%$, according to Chen et al. 1997, $\simeq 45\%$, according to Tanaka & Shibazaki 1996) are neutron-star systems, the rest being black hole (BH) binaries. All the BH candidates in LMXB systems are transient sources.

The recent (1996–1999) *BeppoSAX*-WFC results report on several observations of type-I X-ray bursts in transient sources (e.g. SAX J1750.8−2900, SAX J1806.5−2215, SAX J1753.5−2349, SAX J1808.4−3658, RX J170930.2−263927, SAX J1810.8−2609, see Heise et al. 1999, Ubertini et al. 1999). Conversely, no firm LMXB BH candidate was established. This could imply the population of black hole LMXB to be overstimated, since most of them are suggested as BH candidates on the basis of their spectral characteristics only. Actually, for only 7 out of about 40 known transient LMXB the available mass functions suggest BH systems (Chen et al. 1997).

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