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Letter to the Editor

Detection of X-ray bursts in the globular cluster NGC 6652

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Abstract. Two type I X-ray bursts were detected from a position consistent with the transient X-ray source in NGC 6652 with the Wide Field Camera of the BeppoSAX satellite, strongly suggesting that this transient is a neutron star. Our detection brings to ten the number of X-ray sources in globular clusters in which a type I X-ray burst has been seen, out of twelve known bright sources. The statistical evidence that the fraction of low-mass X-ray binaries which contain a black hole accretor is smaller in globular clusters than in the galactic disk is suggestive, but as yet not compelling.

Key words: X-rays: bursts – globular clusters: NGC 6652

1. Introduction

The details of the formation mechanism of low-mass X-ray binaries, in the galactic disk and in globular clusters, are not well understood. It is thought that low-mass X-ray binaries evolve directly from binaries in the galactic disk, but originate from close stellar encounters in globular clusters in which a neutron star captures a low-mass star via tidal energy dissipation – a tidal capture – or in which a neutron star takes the place of a binary member in a three-body encounter – an exchange collision (see reviews by Verbunt 1993, Hut et al. 1992). It has been suggested that close stellar encounters may also produce low-mass X-ray binaries in the galactic disk, in open clusters (Mardling 1996).

A key observation that any formation theory must answer is the relative frequency of low-mass X-ray binaries with a black hole and with a neutron star as accreting object. In the galactic disk, an increasing number of low-mass X-ray binaries with an accreting black hole has been found in the last years. Interestingly, *all* of these are transient systems, in which the X-ray and optical luminosities are high only during outbursts, and rather

low in the quiescent intervals between the outbursts. Since we do not know the distribution of the durations of the inter-outburst intervals (the observations obviously being biased to short intervals) the total number of low-mass X-ray binaries with a black hole cannot be estimated accurately; but it is quite possible that their number is of the same order of magnitude as that of low-mass X-ray binaries with a neutron star (for reviews see Tanaka & Shibazaki 1996, or Chen, Shrader & Livio 1997).

In contrast, none of the X-ray sources in globular clusters has so far been found to contain a black hole (Hut et al. 1992; Verbunt et al. 1995). Twelve X-ray sources in globular clusters have shown X-ray luminosities $L_X \gtrsim 10^{36}$erg s^{-1}, of which seven are permanently bright, and five transients. Type I X-ray bursts, thought to be caused by thermonuclear flashes on or near a neutron star identifying the accreting object unambiguously as a neutron star, have been detected in all permanently bright sources in globular clusters and in the transients in Terzan 5 and Liller 1. The nature of the accreting object in the remaining three transients, in NGC 6440, NGC 6652 and Terzan 6 is still unknown. If the same statistics would apply in globular clusters as in the galactic disk, these transients have a relatively high probability of containing a black hole compared to that of the permanently bright sources.

In this article we discuss the first time discovery of two type I X-ray bursts in the transient X-ray source in NGC 6652. This X-ray source was detected with HEAO-1 (Hertz & Wood 1985) and shown to be associated with the globular cluster on the basis of the data from the ROSAT All-Sky Survey (Predehl et al. 1991, Verbunt et al. 1995). The X-ray spectrum between 0.1-2.5 keV can be described with a powerlaw $f_\nu \propto \nu^{-1.07}$ (where f_ν is the energy flux), absorbed by a column of $n_H = 6.7 \times 10^{20}$cm^{-2} (Johnston et al. 1996). The X-ray luminosity was about the same during the ROSAT Survey in September 1990 and during the ROSAT pointing in April 1992, at $L_X(0.5 - 2.5 \text{ keV}) = 1.3 \times 10^{36}$erg s^{-1} (for a distance of 14.3 kpc; Djorgovski 1993). This is about ten times more luminous than observed with HEAO-
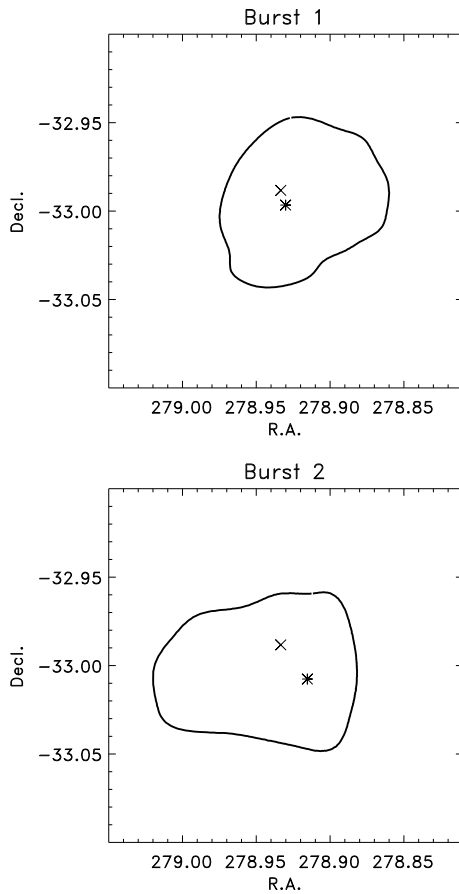
Burst 1

Burst 2

Fig. 1. Celestial maps of 68% confidence level regions of burst 1 and 2 for equinox 2000.0. The crosses in both maps indicate the position of the X-ray source in NGC 6652 according to Johnston et al. (1996) and the asterixes the best fit positions for the BeppoSAX-WFC data

Table 1. Main characteristics per BeppoSAX-WFC camera

Field of view	$40^{\rm o} \times 40^{\rm o}$ (3.7% of entire sky)
Angular resolution	5 arcmin on axis
Source location accuracy	>0.6 arcmin (68% conf. level)
Detector technology	Multi-wire prop. Xenon counter
Photon energy range	2 to 25 keV (read out in 31 channels)
Energy resolution	18% at 6 keV
Time resolution	0.5 ms

center field where the sensitivity is about two times less than at high galactic latitudes far from bright sources.

Detector data contain an image of the sky which is coded with the aperture pattern. The reconstruction of the sky image involves an algorithm whose basic component is a cross-correlation of the detector data with the aperture pattern (Jager et al. 1997). This algorithm is optimum for point sources but not necessarily for diffuse sources. In the case of WFC the reconstruction can be performed with an arbitrary time and photon energy resolution within the limitations given in Table 1. The position and intensity of any point source is determined by modeling through a point spread function (PSF). The full-width at half maximum of the PSF is smallest on-axis at about 5 arcmin. The point source location accuracy is an order of magnitude better (e.g., In 't Zand et al. 1997).

NGC 6652 is located 11.5 degrees from the galactic center. Therefore, it was often observed as part of a monitoring campaign on the region around the galactic center. During the fall of 1996 a total coverage of about 7×10^5 s was obtained on this part of the sky during about 24 days. During the spring of 1997 this was about 4×10^5 s during about 15 days. A small level of emission was detected from NGC 6652 in a combination of all data of 3.0 ± 0.4 mCrab in 2 to 8 keV (1 Crab unit is the intensity of the Crab X-ray source whose flux is 1.8×10^{-8} erg cm^{-2} s^{-1} between 2 and 8 keV).

Routinely, all data of each camera are systematically searched for burst phenomena by analyzing the time profile of the total detector in the full bandpass with a time resolution of 1 s. Enhancements beyond 5σ above a background modeled to vary linearly with time are searched for on time scales of up to 48 s. For the observations discussed here this implies an on-axis sensitivity of about 0.6 Crab units (2-25 keV) in 1 s to 0.1 Crab in 48 s. If a burst is found, a reconstructed sky image is generated for the time interval when the burst occurs, another sky image is generated for a long time interval (usually ten times as long as the burst time interval) right before the burst time, the latter image is normalized and subtracted from the former and this image is searched for point sources with intensity increases equivalent to the increase found in the time profile of the detector. The image subtraction is not necessary but facilitates quick identification in case there are many point sources in the FOV (like is the case in the observations relevant to NGC 6652). So far, over 300 bursts were found and identified in all observations (Cocchi et al. 1997). Two of these were found at a position consistent with NGC 6652. Fig. 1 presents the error boxes of the
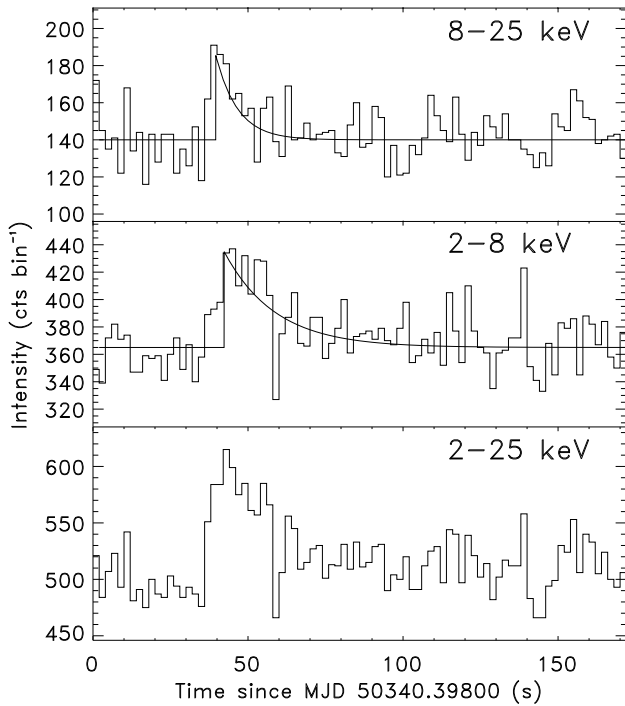
1 in August 1977 to April 1978, which is why Verbunt et al. (1995) classify this source as a transient.

The observations and data analysis are described in Sect. 2, and a brief discussion follows in Sect. 3.

2. Observations and data analysis

The BeppoSAX Wide Field Camera instrument (WFC, Jager et al. 1997) consists of two identically designed coded aperture cameras. The main characteristics of each camera are summarized in Table 1. The field of view (FOV) of this instrument is the largest of any flown X-ray imaging device. This implies an exceptional capability to find short duration and weak transient events. With regards to the sensitivity it is important to realize that an imaging device based on the coded aperture principle has one very basic difference with direct-imaging devices such as X-ray mirror telescopes: there is cross-talk between FOV positions located much further from each other than the angular resolution. In the case of WFC, there is a degradation in sensitivity to any sky position within 20$^{\rm o}$ from a bright source. This has a relatively large impact on observations of the crowded galactic

Fig. 2. Time profile of the first burst, per each of two bandpasses and for the complete WFC bandpass. The bin time is 2 s. The smooth curves are exponential models for the appropriate time profiles (see text)

Fig. 3. Time profiles of the second burst

Table 2. Characteristics of two bursts

Parameter	Burst 1	Burst 2
Start time (MJD)	50340.39842	50342.54744
Instrument	WFC2	WFC1
Best fit R.A. (Eq. 2000.0)	18h 35m 43s	18h 35m 40s
Best fit Decl.	-32º 59' 48"	-33º 00' 27"
Peak intensity (Crab, 2-8 keV)	0.5±0.1	0.6±0.1
Decay time τ (s, 2-8 keV)	16.4±5.0	27.2±6.8
Decay time τ (s, 8-25 keV)	7.0±2.4	9.9±3.6

bursts. The times, peak intensities and best-fit positions of the two bursts are given in Table 2.

Both bursts are relatively weak, the signal-to-noise ratio of the image being around 6. Consequently, the extraction of meaningful time-dependent spectral decoded information is not possible. As an alternative, we analyze time profiles directly of the detector for the part illuminated from the sky position of NGC 6652 in two photon energy bands. By imposing less constraints on the time profile one, on the one hand, preserves the little available statistics but, on the other hand, ends up with a time profile that includes the combined flux from all sources that illuminate the same part of the detector. We regard the latter disadvantage as not important because the bursts are a coherent and clearly recognizable signal which can only be due to a single source of emission and the identification of the whole burst with the source is unambiguous. Figs. 2 and 3 present the time profiles for the bursts.

The time profiles were tested for the evidence of spectral changes. They were modeled with an exponential decay func-
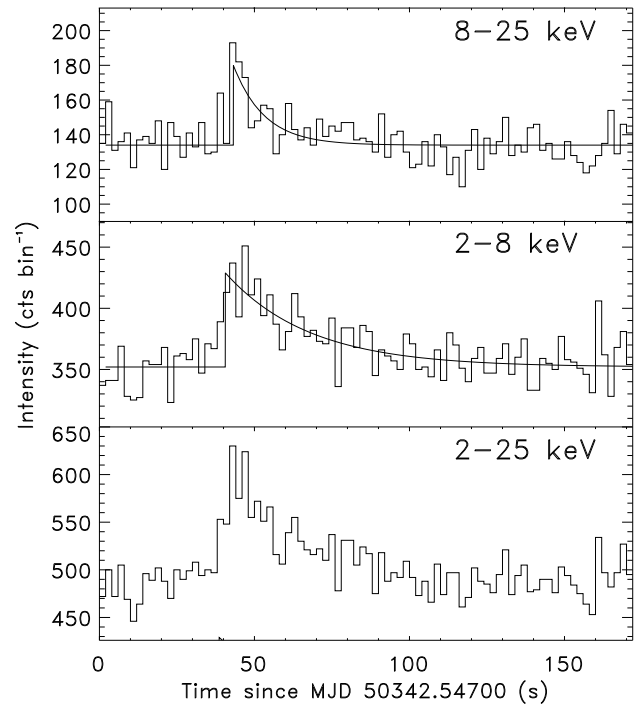
tion with 4 parameters: peak intensity, onset time of exponential, e-folding decay time τ and background level. The results for τ for both energy ranges and the peak intensity in 2-8 keV are given in Table 2. In both cases the ratio of the decay time between the upper and lower energy band is 0.4±0.2. We regard this as good evidence for the presence of spectral softening in bursts from NGC 6652.

The small statistical quality of the data do not permit an analysis of the time-dependent decoded (background-subtracted) spectrum. This is somewhat different for the average spectrum over both bursts. We fitted a number of simple spectral models to the spectrum. The models are described by 4 parameters and only the normalization was allowed to differ between both bursts. All of the models fit the data equally well with a reduced χ^2 value of 0.9 for 58 independent PHA bins. The data does not allow to single out a best fit model. Nevertheless, if we assume that a black body model applies with absorption by cold interstellar matter according to the model of Morrison & McCammon (1983) the temperature is reasonably well constrained to 2.6 ± 0.4 keV. If the black body radiation is isotropic and the distance is 14.3 kpc, we find a bolometric luminosity averaged over the first 16 s of each burst of 2×10^{38} ergs s^{-1} and a radius of the emitting region of 6 ± 2 km.

3. Discussion

There are two types of X-ray bursts with durations less than a few minutes (see review by Lewin, Van Paradijs & Taam 1995). Type II bursts have only been seen from the rapid burster and GRO J1744-28 (Kouveliotou et al. 1996) and have spectra similar to the underlying persistent emission. They are thought to

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be due to accretion instabilities. Type I bursts are attributed to thermonuclear flashes on or near a neutron star surface. Detection of type I bursts is, therefore, a strong indicator for a neutron star. One diagnostic clearly distinguishes type I from type II bursts: spectral softening is only seen in type I bursts. The two bursts reported here are identified as type I bursts. The average black body temperature during both bursts is consistent with such measurements in other type I bursts. We conclude that there is strong evidence for the neutron star nature of this X-ray source. The inferred size of the emitting region for the black body radiation is consistent with a neutron star interpretation.

The ROSAT spectrum (see Sect. 1) translates into a 2 to 8 keV intensity of 2.8 mCrab. This is consistent with the low level emission detected with BeppoSAX-WFC. This means that, if NGC 6652 is an X-ray transient source, either since 1990 one happened to catch it three times during an on state or it is a long-duration transient. The latter is not uncommon for bright LMXB galactic transients as exemplified by GRO J1655-40 and KS 1731-260 which have been in an on state for years (e.g., Chen et al. 1997).

In the galactic disk, about 100 low-mass X-ray binaries are known, 60 of which are permanently bright. Type I X-ray bursts have been detected in about 20 of the permanent and 13 of the transient sources in the galactic disk according to the tabulation by Van Paradijs (1995). The brighter permanent sources do not show type I X-ray bursts: in these the thermonuclear fusion of helium into carbon is continuous rather than in bursts (Lewin et al. 1995). With the discovery of X-ray bursts in NGC 6652 X-ray bursts have been detected in ten out of twelve bright X-ray sources in globular clusters. Thus the fraction of sources in which an type I X-ray burst has been detected is higher in globular clusters than in the disk; this may be explained, partially by the larger observational interest in globular cluster sources, and partially through the fact that none of the sources in the globular clusters are in the high-luminosity range where type I bursts do not occur.

Amongst the about 40 transient low-mass X-ray binaries in the galactic disk, some 7 have been shown to harbour compact stars with masses deemed too high for a neutron star. These systems are thought to harbour black holes, and indeed no type I X-ray burst has been detected in any of them. Various other transients are candidate black holes on the basis of the spectral properties of their X-ray outbursts; as many as 70% of the X-ray transients might harbour a black hole (see Table 4 in Chen et al. 1997). If the statistics in globular clusters were the same, three or four black hole transients could be expected in this optimistic estimation. The probability of finding zero would then be about 5%, a 2-σ indication that the distribution in globular clusters differs from that in the galactic disk. These statistics are subject to uncertainties. For instance, the estimate that 70% of the X-ray transients in the galactic disk harbour a black hole may be an over-estimate, since the spectral characteristics are suggestive evidence, but no proof for a black hole.

The formation of low-mass X-ray binaries is different in globular clusters than in the disk. Tidal capture and exchange encounters favour the capture of more massive stars, and thus of black holes above neutron stars. One may thus predict a larger presence of black holes in the X-ray binaries in globular clusters than in the galactic disk. The formation mechanisms of low-mass X-ray binaries in globular clusters are not understood well enough to allow reliable estimates of this effect but it is interesting to note that it is contrary to what observations suggest.

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