IGR J17445-2747 — YET ANOTHER X-RAY BURSTER IN THE GALACTIC BULGE

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Abstract — The discovery of a type I X-ray burst from the faint unidentified transient source IGR J17445-2747 in the Galactic bulge by the JEM-X telescope onboard the INTEGRAL observatory is reported. Type I bursts are believed to be associated with thermonuclear explosions of accreted matter on the surface of a neutron star with a weak magnetic field in a low-mass X-ray binary. Thus, this observation allows the nature of this source to be established.

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INTRODUCTION

The X-ray source IGR J17445-2747 was discovered by the IBIS/ISGRI gamma-ray telescope (Lebrun et al. 2003; Ubertini et al. 2003) onboard the INTEGRAL observatory (Winkler et al. 2003) when analyzing the combined sky images (mosaics) obtained in the first two years of its in-orbit operation. In the second catalog of sources detected by this telescope (Bird et al. 2006) it is designated as a faint unidentified persistent source with a flux of $(6.8 \pm 0.8) \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ in the 20–40 keV energy band. In the succeeding catalogs (Bird et al. 2007, 2010; Krivonos et al. 2007, 2010) the source is already marked as a highly variable one. It was most active in February-March 2004 (Krivonos et al. 2010), when its 17–60 keV flux reached $(3.9 \pm 0.3) \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$. The second telescope onboard the INTEGRAL observatory, JEM-X (Land et al. 2013), sensitive in a softer (standard) X-ray band did not detect this outburst (Grebenev and Mereminskiy 2015).

Since the discovery of the source, attempts have been repeatedly made to improve its localization using focusing X-ray telescopes with grazing-incidence mirrors and to determine its nature. However, SWIFT-XRT (Land et al. 2007) and CHANDRA (Tomsick et al. 2008) observations did not bring clarity: only one source, though bright but laying outside the formal IBIS/ISGRI error circle of IGR J17445-2747 with a radius of 1′′ at 68% confidence, was detected (Krivonos et al. 2007). There was no reason to believe it to be associated with IGR J17445-2747: it had already become clear that IGR J17445-2747 is highly variable; therefore, it simply could be in the off-state during these rather short observations. Finally, in the archive of all XMM-Newton slew observations Malizia et al. (2010) found a bright transient source XMMSL1 J174429.4-274609 with a peak 0.2–12 keV flux of $\sim 1.6 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ and a dynamic range of variability of more than 40. Based on the coincidence, within the error limits, of the positions of the sources in the sky and their strong variability, Malizia et al. (2010) suggested that XMMSL1 J174429.4-274609 is a soft X-ray counterpart of IGR J17445-2747. Unfortunately, the peculiarities of the XMM–Newton operation in the slew mode degrade significantly the accuracy of source localization. A cross-correlation of the source positions from the slew catalog with optical catalogs (Saxton et al. 2008) showed that the 90%-confidence position error is 17″. This makes an optical identification of this source virtually impossible because of the high star density near the Galactic center, where it is located.

In this paper we report the detection of a type I X-ray burst from this source, which allows it to be identified with an accreting neutron star with a weak magnetic field in a low-mass X-ray binary (an X-ray burster). We have already published brief information about this event in Astronomer’s Telegrams (Mereminskiy et al. 2017a). The details of these ob-
IGR J17445-2747 — YET ANOTHER X-RAY BURSTER 657

Fig. 1. Time profile of the X-ray burst detected from IGR J17445-2747 on April 10, 2017, based on the sum of data from the two JEM-X modules. The energy band is 3–10 keV, the time resolution is 1 s. The solid line indicates a FRED (fast rise, exponential decay) model fit to the profile. The characteristic rise time is $\tau_r = 5.4 (-5.0/ + 0.2) \text{s}$, the exponential decay time is $\tau_d = 13.3 \pm 1.9 \text{s}$. The persistent emission from the source was subtracted.

servations and the results of subsequent studies of this source, in particular, its more accurate localization, are presented here.

THE BURST PROFILE AND LOCALIZATION

The burst was detected by the JEM-X telescope (or the Joint European X-ray Monitor, Lund et al. 2003) onboard the INTEGRAL observatory on April 10, 2017, during the scanning observations of the Galactic center region carried out at the request of R.A. Sunyaev (see Krivonos et al. 2012). This telescope is sensitive in the standard 3–35 keV X-ray band. It allows the sky to be imaged on the principle of a coded aperture in a field of view with a diameter of 13'2 FWHZ (the diameter of the fully coded region is 4'8) limited by the collimator. A gas chamber with an entrance window area of $\sim 490 \text{ cm}^2$ and an energy resolution $\Delta E/ E \sim 16\% \text{ FWHM}$ at 6 keV is used as a detector. The effective area at the center of the field of view is only $\simeq 75 \text{ cm}^2$, because more than 80% of the detector is blocked by the opaque mask and collimator elements. There are two identical telescope modules onboard; if they operate simultaneously, then the effective area is twice as large, $\simeq 150 \text{ cm}^2$. The JEM-X telescope has a fairly high angular resolution ($\sim 3.35 \text{ FWHM}$), which is important in investigating sky regions densely populated by X-ray sources (such as the Galactic center and bulge).

Figure 1 shows the burst time profile (the time dependence of the photon count rate). We see that it was characterized by a fast linear rise in count rate at the beginning and a slow exponential decay at the end. Fitting by the corresponding model (FRED) (the solid line in the figure) gave the characteristic rise and decay times of the count rate $\tau_r = C_{\text{max}}/(dC/dt) = 5.4 (-5.0/ + 0.2) \text{s}$ and $\tau_d = 13.3 \pm 1.9 \text{s}$. The maximum occurred at 18h37m49s UTC. The burst was detected by both JEM-X modules, and Fig. 1 presents their combined count rate. In Fig. 2 the count rates of the two modules are given separately and with a higher time resolution (0.5 s).

To determine the burst source, we constructed sky images in the JEM-X field of view (S/N maps) over the entire time of the telescope’s pointing at the region.
under consideration (scw: 180300330010, the exposure time is 1750 s) and within 13 s near the burst maximum (the time interval used is marked in Fig. 2 by the vertical dashed lines). The images were obtained in the 3–20 keV band. They are presented in Fig. 3. Although many bright known sources, including bursters, GX 3+1, KS 1741-293, A 1742-294, A 1743-288, and also the black hole candidate 1E 1740.7-2942 and the X-ray transient IGR J17445-2747, are seen in the first image (on the left), only one of them, namely IGR J17445-2747, the only source that is also present in the second image (on the right), can be responsible for the burst. It was detected at the level of S/N \( \approx 5 \) in the left image (over the entire observation) and at the level of S/N \( \approx 10 \) in the right one (during the burst). At this time the 3–10 keV photon flux from it was comparable to that from the Crab Nebula. The measured position of the burst source in the sky, R.A. \( = 266^\circ 133 \) and Decl. \( = -27^\circ 784 \) (epoch 2000.0), is consistent with the position of IGR J17445-2747 (its soft X-ray counterpart XMMSL1 J174429.4-274609) to within \( 1' \), corresponding to the typical JEM-X position error of sources with comparable significance (having the same S/N).

Note that in the combined mosaic of images obtained by JEM-X on April 7–11 (within R.A. Sunyaev’s observations and the observations carried out at the requests of J. Wilms and E. Kuulkers) the source is detected with a higher significance at S/N = 6.4 with a 5–10 keV flux \( F_X \approx (3.2 \pm 0.5) \times 10^{-11} \text{ erg s}^{-1} \text{cm}^{-2} \).

**IMPROVING THE POSITION BASED ON SWIFT-XRT DATA**

Immediately after the burst detection (Mereminskiy et al. 2017a) we initiated the SWIFT-XRT (Burrows et al. 2005) observations of IGR J17445-274 to determine its accurate position. Four observations were performed: on April 14 (four days after the burst), May 1, 6, and 15. The source in the field of view was detected only during the first two observations (ID: 00035353003, 00035353005) with a mean photon count rate of 0.80 \( \pm 0.04 \) and 0.10 \( \pm 0.01 \) counts s\(^{-1}\), respectively (Mereminskiy et al. 2017b). These observations allowed the source position to be improved (Mereminskiy et al. 2017b). Kennea et al. (2017) pointed out that the source position could be improved even more by reducing the systematic errors if the images obtained by SWIFT-UVOT simultaneously with SWIFT-XRT are used to tie to the known positions of bright stars (Goad et al. 2007; Evans et al. 2009). Kennea et al. (2017) determined the source position, R.A. \( = 266^\circ 12647 \) and Decl. \( = -27^\circ 76685 \), using only
the first observation. Subsequently, we repeated this procedure based on two observations of the source during which it was bright and found its coordinates: R.A. = 266°12649 and Decl. = -27°76686 (epoch 2000.0, an error of 2", a 90% confidence interval). Our measurements are consistent, within the error limits, with the results of Kennea et al. (2017).

Figure 4 shows the image (the distribution of the number of detected photons) of the sky field around IGR J17445-2747 obtained from its first two SWIFT-XRT observations (on April 14 and May 1, 2017). The image was taken in the 0.3-10 keV band. A bright source is clearly seen at the center. The error circles of the source localization by different telescopes are superimposed: the orange circle is for XMM-Newton from the First XMM-Newton slew catalog (Saxton et al. 2008), the yellow circle is for the same observatory from the data of the recently published Second XMM-Newton slew catalog and the green circle is from the SWIFT-XRT data obtained during the Galactic bulge survey by this telescope (Heinke et al. 2017).

Note a significant change (and improvement) of the source position in the Second XMM-Newton slew catalog compared to the First slew catalog. It should be noted also that the source hardness was at the level of 0.63 that is much higher than the mean hardness of sources in the catalog (see www.cosmos.esa.int/documents/332006/544078/hrplot.gif). At the same time, all the mentioned error circles capture the source only at the very edge, implying the possibility of the presence of other close transient sources distorting the localization results in this region. The small blue circle indicates the source position error from our observations. Obviously, this localization is much better than the previous ones and is the only one that allows an optical identification of the source to be attempted. Such attempts have already been made (Shaw et al. 2017; Chakrabarty et al. 2017), but the result obtained cannot yet be deemed unambiguous.

Apart from a more accurate localization of the source, the SWIFT-XRT observations allow the interstellar extinction in its direction to be estimated. For this purpose, we used the radiation spectra taken in the first two observations, on April 14 and May 1. The spectra were simultaneously fitted by the TBabs*powerlaw model from the XSPEC package (Arnaud et al. 1996), the slope and normalization of the power law for each spectrum were independent parameters, while the extinction was assumed to be the same. The abundances were assumed to be solar (Wilms et al. 2000), the cross-sections were taken from Verner et al. (1996), the Cash (1979) statistic was used for the fitting. In this way we managed to obtain a constraint on the hydrogen column density toward the source, \( N_H \approx (5.6 \pm 1.3) \times 10^{22} \text{ cm}^{-2} \). The slopes of the spectra (photon indices) agree between themselves: \( \alpha \approx 2.06 \pm 0.42 \) and \( 2.16 \pm 0.64 \) for the first and second spectra, respectively, while the 5–10

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**Fig. 3.** JEM-X sky images (S/N maps) in the 3–20 keV band obtained on April 10, 2017: (a) over the entire observation during which the burst was detected; (b) within 13 s near the burst maximum. The detected bright persistent sources are indicated in the left image. The white circle marks IGR J17445-2747.

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**Note:**

1. see www.cosmos.esa.int/web/xmm-newton/xmmsl2-ug
keV fluxes were $F_X \simeq 3.2^{+0.7}_{-0.6} \times 10^{-11}$ and $4.3^{+0.8}_{-0.6} \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$, suggesting a fast decay of the source. This is also confirmed by the absence of its detection in the last two observations; the $3\sigma$ limit on its flux on either of these days was $6 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$.

THE BURST SPECTRUM AND THE DISTANCE TO THE SOURCE

The profile of the X-ray burst from IGR J17445-274 has a shape typical for type I bursts: a fast ($\lesssim 5$ s) rise and a much slower ($\sim 15$ s) decay. Such bursts are a sign of a thermonuclear explosion of accreted matter on the surface of a neutron star with a weak magnetic field in a low-mass X-ray binary. This is also confirmed by the almost blackbody spectrum detected during the burst.

We reconstructed the burst spectrum in accordance with the procedure described in Grebenev and Mereminskiy (2015) in five channels from 4 to 14 keV for the same time interval near burst maximum as that used to construct the image (on the right) in Fig. 3 (marked by the vertical dashed lines in Fig. 2). A diagonal matrix based on the JEM-X observations of the Crab Nebula performed within several days before the burst detection (we selected the pointings in which the Crab Nebula was within 3$^\circ$ of the center of the field of view) was used to fit the spectrum. The resulting spectrum is presented in Fig. 5. We see that it is very soft, which the spectrum of a type I burst must be.

It was fitted by the TBabs*bbbodyrad blackbody model with absorption fixed at $N_H$ obtained during the SWIFT-XRT observation of the source; the blackbody temperature turned out to be $kT_{bb} \simeq 1.6 \pm 0.3$ keV. Assuming that the emission comes from the entire surface of the neutron star with a radius $R_{ns} = 12$ km and neglecting the spectrum distortions due to Comptonization, we can estimate the minimum distance to the source, $d_{\text{min}} \simeq 5$ kpc. The total bolometric flux at the burst maximum is $F_{bb} \simeq 2.1 \times 10^{-8}$ erg s$^{-1}$ cm$^{-2}$. Fitting the spectrum by the Wien law (Grebenev et al. 2002) gives the similar temperature $kT_W \simeq 1.60 \pm 0.25$ keV and bolometric flux $F_W = L_W/(4\pi d^2) \simeq 1.9 \times$
Fig. 5. Radiation spectrum near the burst maximum from the data of two JEM-X modules. The solid (green) line indicates a fit to the spectrum by a blackbody model with $kT_{bb} \simeq 1.6 \pm 0.3$ keV.

$10^{-8}$ erg s$^{-1}$cm$^{-2}$. The photospheric radius of the neutron star in this case occurs to be larger than the radius estimated in the limit of a blackbody model. Under the conditions of saturated Comptonization just the spectrum of the Wien shape must be formed, not the Planck (blackbody) one (Kompaneets, 1957).

The limiting luminosity of bursters during bursts is known to be restricted by the critical Eddington level on reaching which a rapid photospheric expansion of the neutron star and an outflow of matter begin (see, for example, Lewin et al., 1993). Although we did not reveal any evidence of a photospheric expansion in the burst time profile, we can estimate the maximum distance to IGR J17445-2747 $d_{\text{max}} \simeq 12.3$ kpc (for the accretion of pure helium) and $d_{\text{max}} \simeq 7.7$ kpc (for the accretion of matter with solar abundances) by assuming that the luminosity during the burst reached the Eddington level and that the neutron star mass is equal to the standard value $M = 1.4M_\odot$.

CONCLUSIONS

We reported the detection of a type I X-ray burst from the poorly studied transient X-ray source IGR J17445-2747 in the Galactic bulge, which allows it to be identified as a low-mass X-ray binary where the compact object is a neutron star. The high absorption on the line of sight, the closeness to the Galactic center direction, and the derived lower (5 kpc) and upper (12.3 kpc) limits on its distance make the location of this source in the Galactic bulge most probable.

This is not the first X-ray burster discovered by the INTEGRAL observatory. Previously, two hitherto unknown bursters, AX J1754.2-2754 and IGR J17380-3749, were revealed/discovered in the IBIS/ISGRI archival data by Chelovekov and Grebenev (2007, 2010) within the framework of a special program aimed at searching for type I X-ray bursts (Chelovekov et al. 2006, 2017; Chelovekov and Grebenev 2011). Five more bursters, XTE J1739-285, IGR J17254-3257 (1RXS J172525.5-325717), IGR J17464-2811 IGR J17597-2201, and 1RXS J180408.9-342058, were found by Brandt et al. (2005, 2006a, 2006b, 2007) and Chenevez et al. (2012) in the JEM-X data. In the case of IGR J17380-3749 and IGR J17464-2811 new sources were discovered due to the bursts, in the other cases the origin of the already known but unidentified sources was recognized (IGR J17597-2201 was discovered by the same INTEGRAL observatory but a few years before the burst observation, see Lutovinov et al. 2003). These discoveries show that many as yet unknown bursters with a low accretion (and luminosity) level can hide in the Galaxy. Years must elapse for the critical mass of mat-
ter needed for a thermonuclear explosion to be accumulated on their surface. X-ray bursts in these sources occur very rarely, but this is a real chance to detect them and to identify their nature and it should not be missed.

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