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Chasing candidate Supergiant Fast X-ray Transients in the 1,000 orbits *INTEGRAL*/IBIS catalog

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ABSTRACT
We report results from an investigation at hard X-rays (above 18 keV) and soft X-rays (below 10 keV) of a sample of X-ray transients located on the Galactic plane and detected with the bursticity method, as reported in the latest 1,000 orbits *INTEGRAL*/IBIS catalog. Our main aim has been to individuate those with X-rays characteristics strongly resembling Supergiant Fast X-ray Transients (SFXTs). As a result, we found four unidentified fast X-ray transients which now can be considered good SFXT candidates. In particular, three transients (IGR J16374−5043, IGR J17375−3022 and IGR J12341−6143) were very poorly studied in the literature before the current work, and our findings largely improved the knowledge of their X-ray characteristics. The other transient (XTE J1829−098) was previously studied in detail only below 10 keV, conversely the current work provides the first detailed study in outburst above 18 keV. In addition we used archival infrared observations of the transients to pinpoint, among the field objects, their best candidate counterpart. We found that their photometric properties are compatible with an early type spectral classification, further supporting our proposed nature of SFXTs. Infrared spectroscopy is advised to confirm or disprove our interpretation. The reported findings allowed a significant increase of the sample of candidate SFXTs known to date, effectively doubling their number.

Key words: X-rays: binaries – X-rays: individual:

1 INTRODUCTION

The X-ray sky is extremely variable, markedly characterized by many transient sources which suddenly turn on and then disappear on short (hours) or long (weeks, months) timescales. Especially above 20 keV, such variability has not been fully exploited yet since to date hard X-ray surveys have mostly explored the persistent sky. Indeed several *INTEGRAL*/IBIS and *Swift*/BAT hard X-ray catalogs have been published in the literature, mainly devoted to search for persistent sources detected by accumulating as much exposure as possible (e.g. Bird et al. 2006, 2007, 2010, Kyuseok et al. 2018, Krivonos et al. 2017, Baumgartner et al. 2013). As a drawback, this approach could eventually lead to difficulties in detecting transient objects. For example, a transient found in early catalogues may have, after long periods of quiescence, an undetectable low mean flux over the full data set and so may drop below the detection threshold. Other transients may not be detected at all simply because the search is not optimized for the particularly short timescale over which they were active.

To search for transient/variable hard X-ray sources in a systematic way, Bird et al. (2010, 2016) have specifically developed a method which optimizes their detection time-scale. It is the so-called bursticity method where the *INTEGRAL*/IBIS light curve for each source is scanned with a variable-sized time window to search for the best source significance value. Then the duration and time interval, over which the source significance is maximized, is recorded. As pointed out by Bird et al. (2010, 2016), the impact of this method has been very significant since it allowed to recover hundreds of transient sources which otherwise would have been missed in the *INTEGRAL*/IBIS surveys. They constitute an heterogeneous sample of transient/variable objects (most of which still unidentified), especially in term of duration which ranges from very few hours to several months. The identification of these transient sources is much more difficult with respect to persistent ones as X-ray and optical/infrared follow-ups rarely provide a clear counterpart; this is because the source very likely may be in quiescence (and so undetectable) since the original *INTEGRAL* detection. Despite these difficulties, such objects listed in the latest 1,000 orbits *INTEGRAL*/IBIS catalog (Bird et al. 2016) are very interesting because it is most probably among them that peculiar sources, or even a new class of objects, could emerge (e.g. Sguera et al. 2005, 2006).

Here we report results from our study focussed on the search for fast hard X-ray transients (i.e. duration less than a very few days) among the entire list of transient/variable sources found with the bursticity method, as reported in the 1,000 orbits *INTEGRAL*/IBIS catalog (Bird et al. 2016). From such list, we have extracted a sample of 27 objects satisfying the following criteria: i) location on the Galactic plane at b$\leq$10°, ii) duration of the outburst activity less than $\simeq$ 4 days, as recorded from the bursticity method, iii) unidentified nature, with unknown counterpart at lower energies. When available, we have used archival soft X-ray observations (0.3–10 keV) which are useful to reduce the error circles to arcsecond sizes. This latter step is mandatory to unequivocally individuate the infrared/optical counterpart of the source by using archival data. All the collected information (e.g. temporal and spectral X-ray characteristics, duty cycle value, spectral type of the candidate infrared/optical counterpart) have been used to individuate, among the 27 objects, those with characteristics strongly resembling Supergiant Fast X-ray Transients (SFXTs, Sguera et al. 2005, 2006, Negueruela et al. 2006), which are a newly discovered class of transient High Mass X-ray Binaries (HMXBs) showing a peculiar X-ray behavior (for recent reviews see Sidoli 2017, Martinez-Nunez et al. 2017, Walter et al. 2015). Using this approach we were able to individuate four unidentified transients, from the original sample of 27 objects, which can be considered good candidate SFXTs. All the pertaining results are reported in Section 3.

2 OBSERVATIONS AND DATA REDUCTION

Throughout the paper, spectral analysis was performed using XSPEC version 12.9.0 and, unless stated otherwise, the uncertainties are given at 90% confidence for one interesting parameter.

In order to find the lower energy counterparts of each transient source considered in this work, we mainly used near infrared (NIR) archival information from surveys which nominally cover the Galactic plane: UKIDSS GPS (Lucas et al. 2008), VVV (Vista Variables in the Via Lactea, Minniti et al. 2010), GLIMPSE (Galactic Legacy Infrared Midplane Extraordinaire, Churchwell et al. 2009), 2MASS (Skrutskie et al. 2006). All such surveys have different depth, spatial and temporal coverage of the Galactic plane, hence each offers specific and complementary advantages in the search for the NIR counterparts.

2.1 INTEGRAL

SFXT hunting is not an easy task because of their very transitory nature and very low duty cycle, e.g. (0.1–5)% (Sidoli & Paizis 2018). Notably the IBIS/ISGRI instrument on board *INTEGRAL* has repeatedly proven its suitableness for the discovery of new SFXTs. Its instrumental characteristics (especially the good sensitivity on short timescales and the very large field of view, FoV) as well as its observational strategy (regular monitoring of the entire Galactic plane with many Ms of exposure time) are particularly suited in serendipitously detecting short duration random sources such as SFXTs.

The temporal and spectral behaviour of each transient source investigated in this work has been studied in detail with the ISGRI detector (Lebrun et al. 2003), which is the lower energy layer of the IBIS coded mask telescope (Ubertini et al. 2003) onboard *INTEGRAL* (Winkler et al. 2003, 2011). In order to infer their duty cycles, we have used the *INTEGRAL* public-data archive described in Paizis et al (2013, 2016).

INTEGRAL observations are divided into short pointings (Science Windows, ScWs) whose typical duration is $\sim$ 2,000 seconds. Spectra and light curves were extracted during the detected outbursts, the data reduction was carried out with the release 10.2 of the Offline Scientific Analysis software (OSA, Courvoisier et al. 2003). The IBIS/ISGRI systematics, which are typically of the order of 1%, were added to all extracted spectra. IBIS/ISGRI flux maps for each ScW during which the source was detected in outbursts were generated in the energy band that maximize the significance detection value, i.e. 18–60 keV. Count rates at the position of the source were extracted from individual ScW flux maps, to build light curves at ScW level. We applied a 12° limit because the response of IBIS/ISGRI is not well modelled at large off-axis values and this may introduce a systematic error in the measurement of the source fluxes.

Images from the X-ray Monitor JEM–X (Lund et al. 2003) were created for all the IBIS/ISGRI outbursts reported in this work, only in two cases they were inside the JEM–X FoV.

2.2 *Swift*/XRT

The Neil Gehrels Swift observatory (hereafter *Swift*, Gehrels et al. 2004) carries three instruments, one of which is the X-ray Telescope XRT (Burrows et al. 2005). We used archival *Swift*/XRT observations covering the position of the sources, they were reprocessed with standard procedures using XRTPIPELINE v0.13.4 included in the *HEASoft* software package version 6.25. The low count rate of these sources allowed us to consider photon-counting data (PC) only. We used the appropriate spectral redistribution matrices available in the Calibration Database maintained by the High Energy Astrophysics Science Archive Research Center (HEASARC). Source events were extracted from a circular region with a radius of 20 pixels, local background events were taken within annular regions centred on the source (with inner and outer radii of 30 and 60 pixels respectively). When fitting the X-ray spectra in XSPEC, we adopted the photoelectric absorption cross sections of Verner et al. (1996) and the interstellar abundances of Wilms et al. (2000), and the model TBABS.

The spectra were rebinned such that at least 20 counts per bin were present, to apply the χ^2 statistics, and analysed in the energy range 0.3–10 keV.

The uncertainties on the source fluxes have been calculated fixing both low energy absorption and photon index to their most extreme values from their confidence contour levels (at 99%), then re-fitting the spectra to get the appropriate power law normalization.

3 RESULTS

In the following we report results on the 4 unidentified hard X-ray transients selected with the methodology described at the end of section 1: IGR J16374−5043, IGR J17375−3022, IGR J12341−6143 and XTE J1829−098.

3.1 IGR J16374−5043

IGR J16374−5043 was discovered with *INTEGRAL* in 2010 August during transient activity characterized by a short flare (Pavan et al. 2010). A subsequent *Swift*/XRT follow-up, performed $\sim$ 1.5 days later, detected a fading soft X-ray counterpart (Bozzo et al. 2010). Such reported brief communications (astronomer's telegrams) contained only very short information about IGR J16374−5043, in particular the transient hard X-ray activity detected by *INTEGRAL* was obtained from analysis of near real time data. On the basis of its variability, IGR J16374−5043 was selected by Cowperthwaite et al. (2013) as member of a large sample of objects investigated for a possible gamma-ray blazar nature, but for IGR J16374−5043 such investigation was unsuccessful.

Here we present the results of a more detailed spectral and temporal analysis of the consolidated *INTEGRAL* data, together with a detailed investigation performed by using archival *Swift*/XRT as well as optical/infrared data.

3.1.1 INTEGRAL

IGR J16374−5043 is listed in the latest *INTEGRAL/IBIS* catalog (Bird et al. 2016) as a transient hard X-ray source found with the bursticity method. It is located on the Galactic plane at b$\sim$−2°.5. The outburst activity started on MJD 55430 or 22 August 2010 (satellite revolution 959), the source was best detected by IBIS/ISGRI in the energy band 18–60 keV with a significance of $\sim$ 12σ (3.5 ks effective exposure on-source). No detection was achieved in the higher energy band 60–100 keV.

The IBIS/ISGRI light curve at ScW level (Fig. 1) clearly shows a fast X-ray flaring behaviour which reached at its peak a flux of 96±13 mCrab (18–60 keV) or $\sim$1.2×10^{-9} erg cm^{-2} s^{-1}. The duration can be well constrained as $\sim$ 12 hours. The source was still in the IBIS/ISGRI FoV before and after the temporal interval shown in the light curve, however there was no sign of significant flaring activity.

We extracted the average IBIS/ISGRI spectrum during the outburst. The best fit is achieved with a power law model (Γ=2.1±0.4, χ^2_ν=0.9, 7 d.o.f.) The average 18–60 keV (20–40 keV) flux is $\sim$ 3.2×10^{-10} erg cm^{-2} s^{-1} (2×10^{-10} erg cm^{-2} s^{-1}). Fig. 2 shows the power law data-to-model fit with the corresponding residuals.

IGR J16374−5043 is not detected as a persistent source in the *INTEGRAL/IBIS* catalog of Bird et al. (2016), despite extensive coverage of its sky region ($\sim$4.5 Ms). This information can be used to infer a 3σ upper limit on its

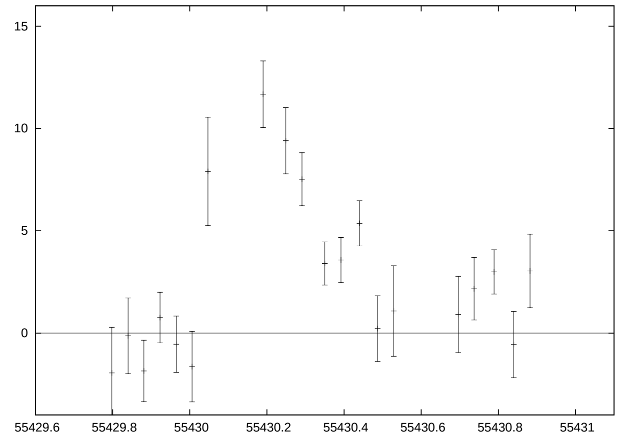

Figure 1. IBIS/ISGRI light curve of IGR J16374−5043 (18–60 keV) at ScW level (2,000 s) during the detected outburst activity

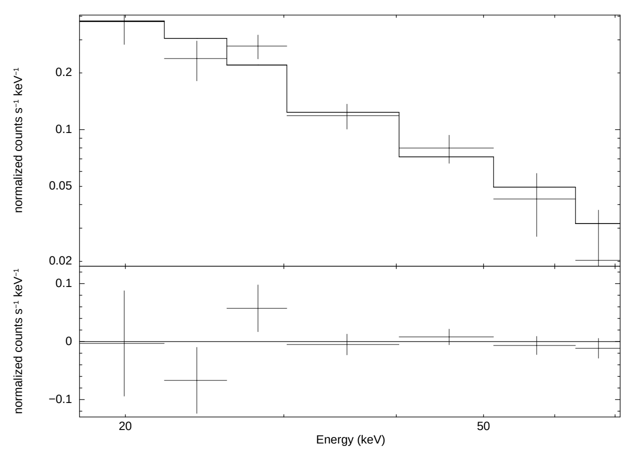

Figure 2. IBIS/ISGRI spectrum of IGR J16374−5043 extracted during the outburst, it is best fitted by a power law model. The lower panel shows the residuals from the fit.

persistent hard X-ray emission, which is of the order of 0.3 mCrab or 2.3×10^{-12} erg cm^{-2} s^{-1} (20–40 keV). When assuming the source peak flux as measured by IBIS/ISGRI from the outburst, we can derive a source dynamic range $\geq$ 520.

Following Paizis et al. (2013, 2016), we have searched the entire currently available IBIS/ISGRI public data archive from revolution 25 (Dec 2002) to 1919 (Feb 2018) for possible additional short outbursts of IGR J16374−5043 detected at ScW level. No significant detections have been obtained, which could have been associated with very short flares, above a significance value of 6σ in different energy bands (22–50, 18–50 and 50–100 keV). The source exposure time from the entire public archive is of the order of $\sim$ 10.5 Ms. The inferred duty cycle is $\sim$ 0.4%.

3.1.2 Archival Swift/XRT and infrared/optical data

The *Swift* satellite (Gehrels et al. 2004) performed a ToO observation of IGR J16374−5043 $\sim$ 1.5 days later its discov-

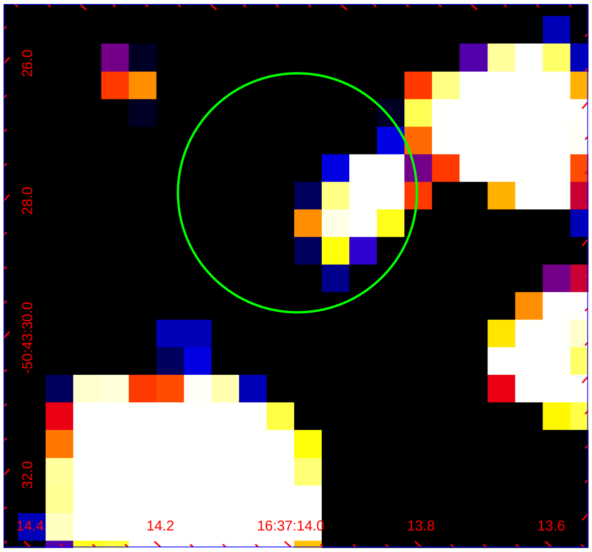

Figure 3. *Spitzer* infrared map from the GLIMPSE survey (3.6 μm band) of the sky region around IGR J16374−5043, superimposed on the *Swift*/XRT error circle at 90% confidence level

ery with *INTEGRAL*. The source was observed with the X-ray instrument XRT on 23 Aug 2010 at 16:43:00 UTC (150 s exposure, 3.2σ detection, 0.3–10 keV) and 24 Aug 2010 at 00:29:00 UTC (1.8 ks exposure, 6.3σ detection, 0.3–10 keV). The exposure time of the first snapshot (obs ID 31796001) is too short to detect the source, so we focussed on the spectroscopy of the second observation (obs ID 31796002), leading to a net count rate of $(2.09\pm0.35)\times10^{-2}$ counts s^{-1} (0.3–10 keV, but note that below ∼1.4 keV there are no significant counts). Adopting Cash statistic in XSPEC, after binning the spectrum at 1 count bin^{-1}, we fitted it with an absorbed power-law model. We could place only an upper limit to the absorbing column density ($N_H < 4 \times 10^{22}$ cm^{-2}), while the photon index was equal to $0.76^{+1.70}_{-0.56}$ (C-stat = 31.03 for 30 d.o.f). This model resulted into an observed flux equal to 3×10^{-12} erg cm^{-2} s^{-1} (1–10 keV). Such relatively low flux clearly indicates a rapid fading of the source observed after only ∼ 1.5 days after the outburst detected by *INTEGRAL*.

The best determined *Swift*/XRT position is at R.A. (J2000)=$16^{h}37^{m}13^{s}.39$ Dec (J2000)=$-50°43'32''.6$ with a 90% confidence error circle radius of $2''.6$ (using the XRT-UVOT alignment and matching UVOT field sources to the USNO-B1 catalog, see Evans et al. 2009). Such refined position allows us to perform a search for counterparts in the optical/infrared bands, by using all the available catalogues in the HEASARC data base. As a result, we found that only one infrared source is located within the XRT error circle (at $1''.5$ from its centroid), as detected by *Spitzer* during the mid-infrared (MIR) survey GLIMPSE (Galactic Legacy Infrared Midplane Extraordinaire). Such survey spans ∼ 130° in longitude (65° on either side of the center of the Galaxy) and ∼ 4° in latitude, providing magnitude measurements in four different MIR wavelengths (3.6 μm, 4.5 μm, 5.8 μm, and 8 μm). The pinpointed best candidate MIR counterpart (source ID G334.8024-02.3838) has magnitude of 14.8 (3.6 μm) and 14.6 (4.5μm). Fig. 3 shows the XRT error circle at 90% confidence ($2''.6$ radius), superimposed on the 3.6μm band *Spitzer* image. It is worth noting that even if we consider the larger error circle at 99% confidence ($3''.7$ radius), the MIR source G334.8024-02.3838 is still the only object located inside of it. In the NIR band (from 1.2μm to 2.1μm) measurements from the surveys UKIDSS GPS and VVV are not available since the source position was not covered by their survey area. Conversely, it was covered by the 2MASS all-sky survey with a spatial resolution comparable to that of *Spitzer*. The source is not listed in the 2MASS catalog whose limiting magnitudes are 15.8, 15.1 and 14.3 in the bands J, H, K, respectively. However we noted that the source is visible in the downloaded 2MASS JHK field images, although it must be weak with magnitudes below the catalog threshold. This, in conjunction with the *Spitzer* detection, likely suggests a very strong reddening. Unfortunately, obtaining useful magnitude estimates is not possible due to strong contamination from a bright nearby source.

As for the optical band, we note that the MIR source G334.8024-02.3838 is listed in the *GAIA* catalog Data Release 2 (source ID 5940285090075838848) with distance and magnitudes equal to $3.1^{+2.8}_{-1.6}$ kpc, G=19.8, G_{BP}=20.8 and G_{RP}=18.4, respectively. We note that *GAIA* mean G passband covers a wavelength range from the near ultraviolet (roughly 330 nm) to the near infrared (roughly 1050 nm). The other two passbands, G_{BP} and G_{RP}, cover smaller wavelength ranges, from approximately 330 to 680 nm, and 630 to 1050 nm, respectively (Weiler 2018). If we assume the *GAIA* optical source as counterpart of IGR J16374−5043, then the 18–60 keV IBIS/ISGRI average (peak) luminosity measured during the outburst is $\sim 4\times10^{35}$ erg s^{-1} (1.5×10^{36} erg s^{-1}). Conversely, the 3σ upper limit on the persistent hard X-ray emission translates into a X-ray luminosity $\leq 2.7\times10^{33}$ erg s^{-1}. Finally, the 1–10 keV luminosity during the *Swift*/XRT detection is equal to $\sim 3.4\times10^{33}$ erg s^{-1}.

3.2 IGR J17375−3022

IGR J17375−3022 is a transient hard X-ray source discovered with *INTEGRAL* in October 2008 during satellite revolution 732 (Ricci et al. 2008). The source was not detected in the previous revolution as well as in the following ones (Cadolle Bel et al. 2008, Ricci et al. 2008). A *Swift*/XRT follow-up was performed a few days later the *INTEGRAL* discovery, allowing to pinpoint a fading soft X-ray counterpart (Beckmann et al. 2008). Notably, about six months later (in April 2009) the source was detected by chance with *XMM-Newton* while performing a slew between targets. The inferred 2–10 keV flux was of the order of $\sim10^{-10}$ erg cm^{-2} s^{-1} (Saxton et al. 2009). All the above information have been reported through brief communications, in particular the transient hard X-ray activity detected by *INTEGRAL* was obtained from analysis of near real time data. To date no detailed temporal/spectral analysis of the source has been reported in the literature, Here, we present the results of a detailed temporal/spectral analysis of the consolidated *INTEGRAL* data, together with a detailed investigation of all available archival *Swift*/XRT observation (never published before) as well as archival optical/infrared data.

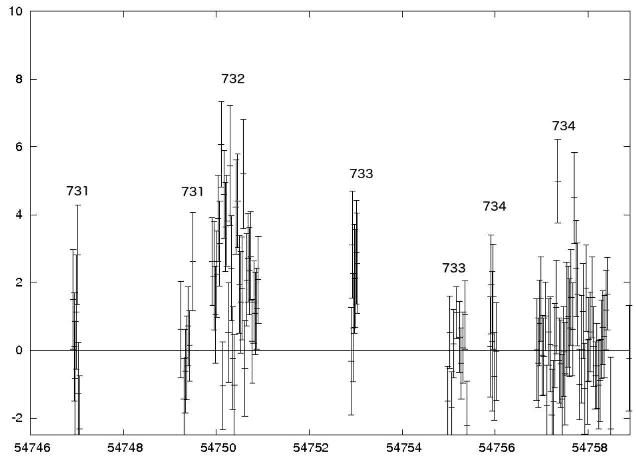

Figure 4. IBIS/ISGRI light curve (18–60 keV) at ScW level ($\sim$ 2,000 s bin time) of IGR J17375−3022 covering the period from revolution 731 to 734

3.2.1 INTEGRAL

IGR J17375−3022 is listed in the latest IBIS/ISGRI catalog (Bird et al. 2016) as a transient hard X-ray source detected with the bursticity method. Its outburst activity started around the beginning of satellite revolution 732 (MJD 54749.9 or 10 October 2008 21:30 UTC), during which the most significance detection was obtained in the band 18–60 keV (8.8σ, 18.5 ks effective exposure on-source). The average flux was measured as 9.7$\pm$1.1 mCrab or 1.2×10^{-10} erg cm $^{-2}$ s^{-1} (18–60 keV). No significant detection was achieved in the higher energy band 60–100 keV.

The source was also in the JEM–X1 FoV for a total effective exposure of $\sim$ 12 ks, however it was not detected in both energy bands 3–10 keV and 10–20 keV. The inferred 3σ upper limit is of the order of $\sim$ 6 mCrab or 9×10^{-11} erg cm^{-2} s^{-1} (3–10 keV).

Fig. 4 shows the IBIS/ISGRI light curve at ScW level, covering observations from revolution 731 to 734. Hard X-ray activity is particularly evident during revolution 732, when the source was significantly detected as reported in the previous paragraph. It reached a peak flux of 27.4$\pm$5.7 mCrab or $\sim$ 3.6×10^{-10} erg cm^{-2} s^{-1} (18–60 keV). Conversely, in the mosaic significance images pertaining to revolutions immediately before (731, 8 ks on source) and after (733, 12.5 ks on source), the source was not significantly detected; we inferred 18–60 keV 3σ upper limits of $\sim$ 5 mCrab and $\sim$ 4 mCrab, respectively. A deeper upper limit of $\sim$ 2 mCrab was obtained by summing together consecutive revolutions 733 and 734 (45 ks on source). Considering such results, we can firmly constrain the duration of the outburst activity in the range 1–3 days.

The IBIS/ISGRI spectrum extracted during the outburst is best fitted with a power law model (Γ=1.8$\pm$0.4, χ^2_ν=1.0, 5 d.o.f.). The average 18–60 keV (20–40 keV) flux is $\sim$ 1.2×10^{-10} erg cm^{-2} s^{-1} (7×10^{-11} erg cm^{-2} s^{-1}).

IGR J17375−3022 is not detected as a persistent source in the IBIS/ISGRI catalogue of Bird et al. (2016), despite extensive coverage of its sky region ($\sim$11.6 Ms). We inferred a 3σ upper limit on its persistent hard X-ray emission equal to 0.2 mCrab or 1.5×10^{-12} erg cm $^{-2}$ s^{-1} (20–40 keV). When assuming the source peak flux as measured by IBIS/ISGRI from the outburst, we can infer a dynamic range $\geq$ 530.

Following Paizis et al. (2013, 2016), we have searched the entire currently available IBIS/ISGRI public data archive from revolution 25 (Dec 2002) to 1919 (Feb 2018) for possible additional short outbursts of IGR J17375−3022 detected at ScW level. No detection has been obtained (which could have been associated with very short flares) above a significance value of 6σ in different energy bands (22–50, 18–50 and 50–100 keV). The source exposure time from the entire public archive is of the order of $\sim$ 27.8 Ms. The inferred duty cycle is $\sim$ 0.9%

Table 1. Summary of *Swift/XRT* observations of IGR J17375−3022

N.	Obs ID	start time (UTC)	exp (ks)	offset (arcmin)
1	00043581001	2012-09-11 02:42:00	0.6	8.0
2	00043580001	2012-09-11 03:03:00	0.5	9.0
3	00031278003	2009-04-28 16:55:00	1.1	1.6
4	00031278001	2008-10-14 13:58:00	2	0.4
5	00031278002	2008-10-14 17:26:00	8	2.8

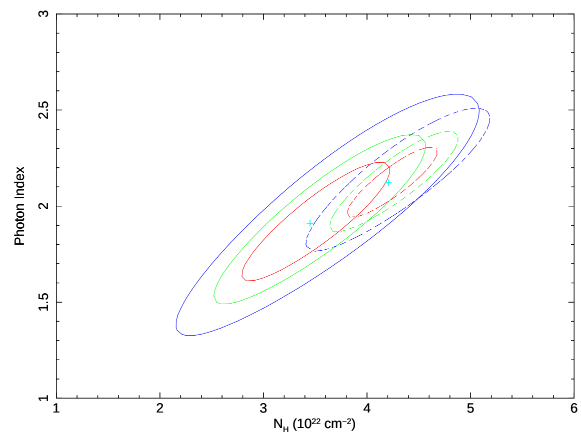

Figure 5. Confidence contour levels (68%, 90% and 99%) for the two parameters of the absorbed power law model applied during the spectroscopy of IGR J17375−3022 *Swift*/XRT observations ID 31278001 (solid lines) and 31278002 (dashed lines).

3.2.2 Archival Swift/XRT and infrared/optical data

The sky position of IGR J17375−3022 was covered by the *Swift* observations reported in Table 1. Obs n. 5 is reported by Beckmann et al. (2008) in a short communication as follow-up to the *INTEGRAL* source discovery. All the remaining observations were never reported in the literature.

We note that the source is detected only during two observations, n. 4 (obs ID 31278001) and n. 5 (obs ID 31278002), with a 0.3–10 keV count rate of 0.356$\pm$0.013 and 0.227$\pm$0.054 counts s^{-1}, respectively.

The results obtained fitting the spectra with an absorbed power law model are the following. During the first observations we measured a low energy absorption N_H=$(3.5^{+0.8}_{-0.7})\times10^{22}$ cm^{-2} and a power law Γ=$1.91^{+0.35}_{-0.32}$

(χ^2_ν/dof=1.128/32). The observed flux, not corrected for the absorption, is equal to 3.2×10^{-11} erg cm^{-2} s^{-1} in both energy bands 0.3–10 keV and 1–10 keV. Conversely, the unabsorbed fluxes are 7.3×10^{-11} erg cm^{-2} s^{-1} (0.3–10 keV) and 5.1×10^{-11} erg cm^{-2} s^{-1} (1–10 keV).

The spectral analysis of the second observation provided the following parameters for the power law model: $N_H=(4.2\pm0.5)\times10^{22}$ cm^{-2} and $\Gamma=2.1\pm0.2$ (χ^2_ν/dof=0.786/82) with an observed flux of 2.0×10^{-11} erg cm^{-2} s^{-1}, again in both energy ranges. The estimated unabsorbed fluxes were 6×10^{-11} erg cm^{-2} s^{-1} (0.3–10 keV) and 3.6×10^{-11} erg cm^{-2} s^{-1} (1–10 keV). In Fig. 5 we show the confidence contour levels of the absorbing column density and power law photon index in both observations.

From the observation n. 3 (obs ID 31278003), we estimated a Bayesian 95% upper limit (Kraft et al. 1991) to the source count rate of 0.0028 counts s^{-1}. We used it in WeBPIMMS in order to estimate a 0.3–10 keV observed (unabsorbed) upper limit flux of 2.5×10^{-13} erg cm^{-2} s^{-1} (6.3×10^{-13} erg cm^{-2} s^{-1}). We assumed the same spectral model as from the previous *Swift*/XRT observations. When considering the highest source flux, as measured by *Swift*/XRT in the observation n. 5, we can infer a dynamic range of $\geq$130. As for the remaining two observations (n. 1 and 2) with large off axis angle and very low exposure, we estimate the following shallower 95% Bayesian upper limits for the source count rate: $<$ 0.006 counts s^{-1} (obs ID 00043580001) and $<$ 0.005 counts s^{-1} (obs ID 00043581001).

We calculated the enhanced source XRT position where the astrometry is derived using UVOT field sources (Evans et al. 2009)*: R.A. (J2000)=$17^h37^m33\overset{s}{.}79$ Dec (J2000)=$-30^\circ23'13\overset{''}{.}8$ with a 90% confidence (99%) error radius of $1''.4$ ($2''.0$). Such refined position allows us to perform a search for counterparts in the optical/infrared bands, by using all the available catalogues in the HEASARC data base.

No catalogued optical source is located within the XRT error circle, according to the USNO catalog. In the optical V band, a lower limit of V>21 can be inferred from the survey limit as reported in Monet et al. (2003). Conversely, 8 NIR sources are located inside the 99% confidence XRT error circle, as listed by the UKIDSS GPS Data Release 6. This survey, which started in 2005 May, covered about 1,800 square degrees of the Galactic plane in the J, H, and K filters (from 1 to 3 μm) with an angular resolution of 0.8 arcsec and down to a magnitude depth of $\sim$19, i.e. 3 magnitudes deeper and more than a factor of 2 sharper than previous infrared surveys such as GLIMPSE or 2MASS. Importantly, the subarcsecond spatial resolution of UKIDSS is particularly suited to identify the correct NIR candidate counterpart to the hard X-ray source. All such objects are listed in Table 2, while Fig. 6 shows the XRT error circles superimposed on the UKIDSS image (*K* band).

In Table 2, we note that sources n. 1, 3, 4 (located inside the 90% confidence XRT error circle) and 7, 8 (located outside the 90% confidence XRT error circle but inside the 99% one) are particularly faint in the *J* band and even undetected in the *H* and *K* bands. Conversely, the remaining objects (n. 2, 5 and 6) are the brightest ones and below we investigate the possibility that they could be (or not) the best candidate counterparts.

* http:/www.swift.ac.uk/user_objects

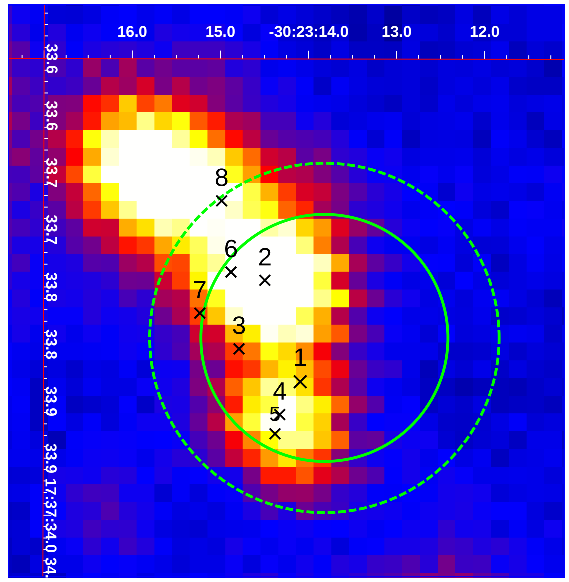

Figure 6. UKIDSS infrared map (K band) of the sky region around IGR J17375−3022, superimposed on the *Swift*/XRT error circles at 90% and 99% confidence level. Sources numbered from 1 to 8 are listed in Table 2

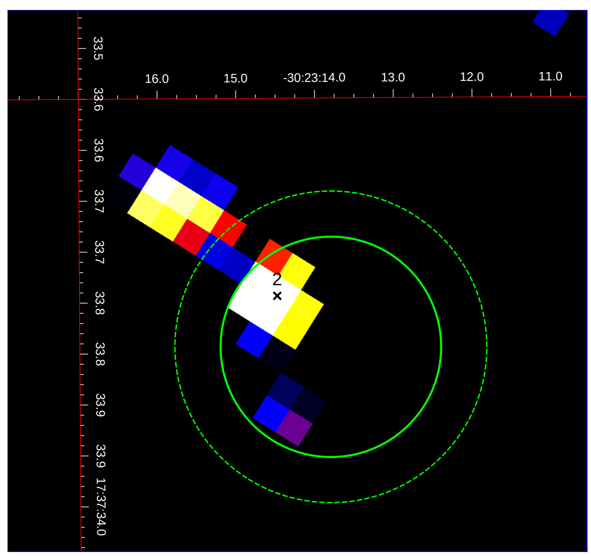

Figure 7. VVV infrared map (K band) of the sky region around IGR J17375−3022, superimposed on the *Swift*/XRT error circles at 90% and 99% confidence level

As for the brightest infrared object detected by UKIDSS (n. 2 in table 2), we note that it is also reported in the NIR catalog VVV Data Release 2 (Minniti et al. 2017) as J173733.74−302314.55. The same does not hold for all the remaining infrared sources listed in table 2. The angular separation between the two corresponding coordinate centroids is only $0.''08$. If we consider both the nominal positional accuracy of UKIDSS ($0''.1$, but it deteriorates to $0''.3$ near the Galactic bulge, Lucas et al. 2008) and of VVV ($0''.17$)

Table 2. List of NIR sources (as taken from the UKIDSS GPS) located inside the 90% confidence error circle (from n. 1 to n. 6) and 99% confidence error circle (from n. 7 to n. 8) of IGR J17375−3022. The table lists their JHK magnitudes (lower limits are derived according to Lawrence et al. 2007), offset from the XRT coordinates and Q value. † source also reported in the VVV survey as J173733.74-302314.55.

n.	name	J (mag)	H (mag)	K (mag)	offset	Q
1	J173733.83-302314.0	22.144±3.645	>19.0	>18.8	0.54″	
2†	J173733.74-302314.4	14.953±0.006	13.397±0.004	12.785±0.004	0.96″	0.09
3	J173733.80-302314.7	19.759±0.406	>19.0	>18.8	0.96″	
4	J173733.86-302314.3	16.190±0.017	>19.0	13.922±0.012	1.02″	
5	J173733.87-302314.3	16.563±0.022	14.721±0.012	13.834±0.012	1.26″	0.16
6	J173733.73-302314.8	17.645±0.058	13.510±0.004	12.750±0.005	1.32″	2.69
7	J173733.77-302315.2	>19.9	>19.0	>18.8	1.44″	
8	J173733.67-302314.9.	18.482±0.125	>19.0	>18.8	1.92″	
†	VVV J173733.74-302314.55	14.910±0.026	13.342±0.016	12.569±0.012	0.96″	0.09

then we can safely state that we are dealing with the same NIR source detected by both UKIDSS and VVV. The Vista Variables in the Via Lactea (VVV) is foremost a multi-epoch survey of the inner regions of the Milky Way (bulge and adjacent sections of the Galactic plane) started in 2010 and spanning about five years. It was designed to complement other NIR single epochs survey (e.g. UKIDSS) providing time domain information. Fig. 7 shows the VVV infrared map (K band) of the sky region around IGR J17375−3022 superimposed on the *Swift*/XRT error circles at 90% and 99%. It is evident that J173733.74-302314.55 is the only detected NIR object inside of it.

If we calculate the reddening-free NIR quantity Q (Negueruela & Schurch 2007) with the extinction law of Fitzpatrick (1999), we note in table 2 that sources n. 5 and 6 have a Q value typical of intermediate or late type stars (Negueruela & Schurch 2007). Conversely, the Q value of source n. 2, calculated with the VVV magnitudes, is typical of early-type stars OB . Following this latter indication, we can obtain a rough estimate of the distance of source n. 2 (and its extinction, A_V) from its J,H,K magnitudes as reported in table 2 and measured by VVV, assuming a stellar B spectral type and a specific luminosity class. In the hypothesis of a supergiant nature (for instance a B0.5Ib star with an absolute magnitude M_V=−6.8 mag, V-K=−0.7 and V-J=−0.54), it should be located at a distance d∼26 kpc (and with an A_V ∼14.5 mag) to match with the VVV near infrared magnitudes. On the other hand, a B0V star (in the hypothesis of a Be HMXB nature, without taking into account the possible contribution from the Be decretion disc) should be placed at ∼6 kpc distance (A_V ∼15 mag). An intermediate distance of ∼10 kpc is allowed if we assume a giant nature for the B-type companion star.

In the light of the findings reported above, we propose the infrared source n.2 (which is the brightest one inside the X-ray error circle) as best candidate counterpart of IGR J17375−3022 at lower frequencies, to date. All fainter infrared objects reported in Table 2 should be located much farther away to reconcile with the observed magnitudes in these cases (e.g. making unlikely a supergiant donor). Additional X-ray observations are strongly needed (e.g. with *Chandra*) in order to achieve a finer position which could confirm or reject our proposed counterpart.

3.3 IGR J12341−6143

3.3.1 INTEGRAL

IGR J12341−6143 is a very poorly studied hard X-ray transient. To date, no detailed information have been reported in the literature yet. The source has been discovered with *INTEGRAL* as listed in the latest IBIS catalog of Bird et al. (2016). IGR J12341−6143 was not detected as a persistent source despite extensive coverage of its sky region (∼3.5 Ms), the corresponding 3σ upper limit is equal to 0.2 mCrab or 1.5×10^{-12} erg cm^{-2} s^{-1} (20–40 keV). Conversely, IGR J12341−6143 was detected with the bursticity method as a transient hard X-ray source. Its outburst activity started on MJD 54649.9 (2 July 2008 21:36 UTC) during satellite revolution 698. The active source was in the IBIS/ISGRI FoV until MJD 54650.7, for an effective exposure time of 21 ks. It was detected at ∼ 6σ level in the energy band 18–60 keV, with a measured flux of 5.6±0.9 mCrab. No significant detection was achieved in the higher energy band 60–100 keV. The obtained IBIS/ISGRI coordinates are RA=188°.545 DEC=−61°.708 with an error circle radius of 3′.98 at 90% confidence level.

Fig. 8 shows the 18–60 keV IBIS/ISGRI light curve at ScW level, covering observations from revolution 696 to 699. Hard X-ray activity is evident during revolution 698, when the source was discovered and significantly detected as reported in the previous paragraph. It reached a peak flux of 15.4±4.4 mCrab or ∼ 2×10^{-10} erg cm^{-2} s^{-1} (18–60 keV). When assuming the source upper limit on its persistent emission, we can infer a dynamic range ≥ 80. We note that the source was not significantly detected in the mosaic significance images pertaining to revolutions immediately after (699, ∼ 17 ks effective exposure), and before (696, ∼ 16 ks effective exposure), when it was again in the IBIS/ISGRI FoV. We derived a similar 18–60 keV 3σ upper limit of ∼ 2 mCrab during each single revolution. Considering such findings, we can firmly constrain the duration of the outburst activity of IGR J12341−6143 in the range 0.8–8 days.

The IBIS/ISGRI spectrum extracted during the outburst is best fitted with a thermal bremsstrahlung model with temperature kT=14^{+19}_{-7} keV (χ^2_ν=1.02, 3 d.o.f.). The average 18–60 keV (20–40 keV) flux is equal to ∼ 5.2×10^{-11} erg cm^{-2} s^{-1} (3.6×10^{-11} erg cm^{-2} s^{-1}). Fig. 9 shows the

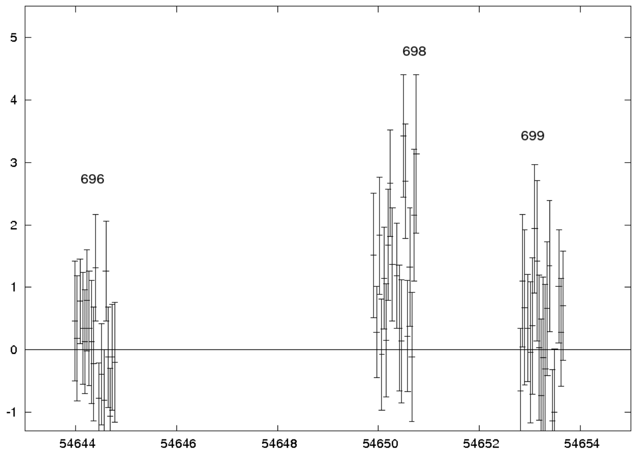

Figure 8. IBIS/ISGRI light curve (18–60 keV) at ScW level of IGR J12341−6143 covering the period from revolution 696 to 699

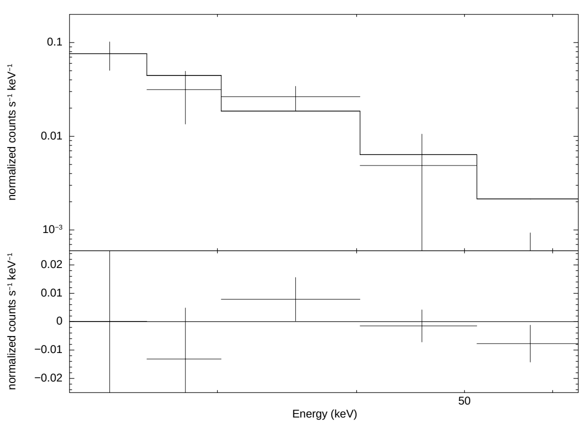

Figure 9. IBIS/ISGRI spectrum of IGR J12341−6143 extracted during the outburst, it is best fitted by a bremsstrahlung model. The lower panel shows the residuals from the fit

bremsstrahlung data-to-model fit with the corresponding residuals. Alternatively, a power law model provides a reasonable description (χ^2_ν=1.2, 3 d.o.f.) with a soft photon index not well constrained (Γ=$3.7^{+2.0}_{-1.3}$).

IGR J12341−6143 was also in the JEM–X1 FoV during the detected outburst activity in revolution 698, for an effective exposure of ∼ 17 ks. The source was barely detected at ∼ 4σ level in the energy band 3–10 keV, no significant detection was achieved in the higher energy band 10–20 keV. The measured 3–10 keV flux is equal to 3.7±0.9 mCrab or ∼ 5.5×10^{-11} erg cm^{-2} s^{-1}. Unfortunately the source was too faint and the very low statistics prevented the extraction of a meaningful spectrum and a proper study of the source.

Following Paizis et al. (2013, 2016), we have searched the entire currently available IBIS/ISGRI public data archive from revolution 25 (Dec 2002) to 1919 (Feb 2018) for possible additional short outbursts of IGR J12341−6143 detected at ScW level. No detection has been obtained (which could have been associated with very short flares) above a significance value of 6σ in different energy bands (22–50, 18–50 and 50–100 keV). The source exposure time from the entire archive is of the order of ∼ 7.7 Ms. The inferred duty cycle is ∼ 0.9%

3.3.2 Targeted Swift/XRT observation

Before our work, the field position of IGR J12341−6143 has never been covered below 10 keV by any soft X-ray mission. Hence we asked for a ToO observation of the sky region with the *Swift* satellite, with the aim of eventually obtaining for the first time useful information from the soft X-ray band. The *Swift*/XRT ToO observation was performed on 4 Sep 2019 at 23:11:34 UTC with an exposure of ∼ 1 ks. The source was not detected, nonetheless the observation was useful to estimate the Bayesian 95% upper limit (Kraft et al. (1991) to the source count rate equal to 0.005 counts/s. Using WebPIMMS, it converts into a flux of 4.6×10^{-13} erg cm^{-2} s^{-1} by adopting the average absorbing column density along the line of sight (Dickey & Lockman1990) and a power-law photon index of 1. When assuming the outburst source flux, as measured by *INTEGRAL*/JEM–X in a similar energy band, we can infer a dynamic range ≥ 120.

To date, the only usable source position is that provided by IBIS/ISGRI with a large error circle radius of ∼ 4′. Since IGR J12341−6143 is located on the Galactic plane in a very crowded sky field, the lack of an accurate arcsecond sized localization prevents us from pinpointing the correct unique NIR/optical counterpart among the several tens candidates.

3.4 XTE J1829−098

XTE J1829−098 is a transient X-ray pulsar (7.8 s) discovered in outburst by *RXTE*/PCA on July 2004 during scans of the Galactic plane (Markwardt et al. 2004). The 2–10 keV flux was of the order of 1.0×10^{-10} erg cm^{-2} s^{-1}, the X-ray spectrum was hard and absorbed. From regular *RXTE*/PCA monitoring observations of the source, Markwardt et al. (2009) estimated a typical outbursts duration of ∼ 7 days. The source has been serendipitously observed by both *XMM*-Newton and *Chandra* in several occasions (Halpern et al. 2007), providing measurements of both deep upper limit (2.5×10^{-14} erg cm^{-2} s^{-1}) and moderate X-ray fluxes (∼ 5×10^{-11} erg cm^{-2} s^{-1}). Notably, the inferred dynamic range of the source is particularly high, i.e. ∼ 6,800. The accurate *Chandra* localization allowed the identification of the likely infrared counterpart whose spectral type and luminosity class are still unknown although its characteristics seems to be typical of an highly reddened O or B star (Halpern et al. 2007). At the beginning of August 2018 MAXI/GSC detected renewed X-ray activity from the source which reached a 4–10 keV flux of 24±4 mCrab (Nakajima et al. 2018). Such detection triggered a ToO observation with *NuSTAR* (16 Aug 2018) which measured an average 3–79 keV flux of ∼ 3×10^{-10} erg cm^{-2} s^{-1} (Shtykovsky et al. 2018). In particular, in the source spectrum a cyclotron absorption line was detected at E_{cyc} ∼ 15 keV. All the above findings clearly indicate a firm HMXB nature for the source.

Here we present the *INTEGRAL* results of a detailed spectral and temporal analysis of the source in outburst, which is the first ever study temporally covering an entire outburst above 20 keV. In addition, we performed an investigation of all available *Swift*/XRT archival observations (not published yet) as well as archival infrared data.

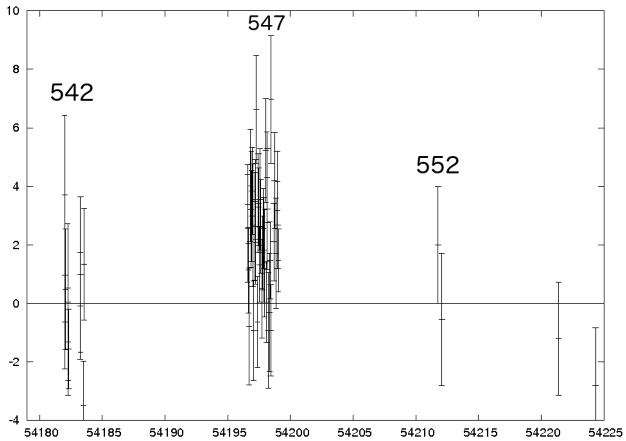

Figure 10. IBIS/ISGRI light curve (18–60 keV) at ScW level of XTE J1829−098 covering the period from revolution 542 to 552

3.4.1 INTEGRAL

XTE J1829−098 is reported in the latest *INTEGRAL/IBIS* catalog by Bird et al. (2016) as a transient hard X-ray source detected with the bursticity method. Its outburst activity started around MJD 54195 (or 5 April 2007) during satellite revolution 547. The source was detected at 10.4σ level (18–60 KeV, $\sim$ 19 ks effective exposure on-source), no significant detection was achieved in the higher energy band 60–100 keV. The average flux was 10.80±1.04 mCrab or $\sim$ 1.4×10^{-10} erg cm^{-2} s^{-1} (18–60 keV).

Fig. 10 shows the 18–60 keV IBIS/ISGRI light curve at ScW level, covering observations from revolution 542 to 552. Hard X-ray activity is evident during revolution 547, when the source was significantly detected as reported in the previous paragraph. It reached a peak flux of 31.4±9.8 mCrab or $\sim$ 4.1×10^{-10} erg cm^{-2} s^{-1} (18–60 keV). Unfortunately the *INTEGRAL* temporal coverage of the outburst is not particularly good, in fact there are gaps in the light curve since for several days the source was not in the IBIS/ISGRI FoV before and after revolution 547. When the source was again in the FoV (revolutions 542 and 552) it seems that it was not active anymore, although this cannot be firmly claimed because only few ScWs are available. Based on the *INTEGRAL* data coverage, the duration of the outburst activity can be loosely constrained in the range 3–25 days. In this context, *Swift/BAT* data can be helpful since the BAT instrument provides a continuos time coverage of the source activity with no temporal gaps. From the *Swift*/BAT archive, we downloaded the 15–50 keV source light curve on daily time-scale, and we checked if the source was active or not during the temporal range corresponding to the gaps of the IBIS/ISGRI light curve. No significant hard X-ray activity was evident, suggesting that the duration of the outburst was very likely of the order of 3–4 days. This is roughly the same order of duration typically estimated by Markwardt et al. (2009) from RXTE/PCA monitoring observations ($\sim$ 7 days).

The IBIS/ISGRI spectrum extracted during the outburst is well fitted with a power law model (Γ=3.3±0.6, χ^2_ν=1.1, 3 d.o.f.). The average 18–60 keV flux is $\sim$ 9.2×10^{-11} erg cm^{-2} s^{-1}. Alternatively, a thermal bremsstrahlung model provides a reasonable fit with kT=15^{+7}_{-4} keV (χ^2_ν=0.6, 3 d.o.f.).

Table 3. Summary of *Swift/XRT* observations of XTE J1829−098

N.	Obs ID	start time (UTC)	exp (ks)	offset (arcmin)
1	00087499003	2019-03-21 12:27:00	1	8.8
2	00087498002	2018-02-21 05:03:00	0.7	7.2
3	00010806001	2018-08-24 09:10:00	0.5	2.6
4	00087498001	2017-10-07 12:27:00	4.2	8.9
5	00034147001	2015-11-05 18:15:00	0.5	9.8
6	00044284001	2012-11-11 14:20:00	0.5	8.2
7	00044277001	2011-05-16 03:27:00	0.5	9.3

XTE J1829−098 is not detected as a persistent source in the *INTEGRAL/IBIS* catalogue of Bird et al. (2016), despite extensive coverage of its sky region ($\sim$ 4.8 Ms). We inferred a 3σ upper limit on its persistent hard X-ray emission equal to 0.3 mCrab or 3.8×10^{-12} erg cm $^{-2}$ s^{-1} (20–40 keV). When assuming the source peak flux as measured by IBIS/ISGRI from the outburst, we can infer a source dynamic range $\geq$ 110.

Following Paizis et al. (2013, 2016), we have searched the entire currently available IBIS/ISGRI public data archive from revolution 25 (Dec 2002) to 1919 (Feb 2018) for possible additional short outbursts of XTE J1829−098 detected at ScW level. No additional detections have been obtained above a significance value of 6σ at ScW level in different energy bands (22–50, 18–50 and 50–100 keV). The source exposure time from the entire archive is of the order of $\sim$ 8.2 Ms. The inferred duty cycle is $\sim$ 4.2%

3.4.2 Archival Swift/XRT observations

The sky position of XTE J1829-098 fell within the *Swift*/XRT FoV several times, as reported in Table 3. To date none of such observations has been reported in the literature.

We note that only during one observation (n. 3, obs ID 00010806001) was the source detected and a meaningful spectroscopy possible. Given the very short exposure (T_{exp}=534 s) and the faint source intensity (net count rate 0.314±0.025 counts s^{-1}), we adopted Cash statistics when fitting the spectrum with an absorbed power law model. Also in this case, no significant net counts were observed below $\sim$1 keV with *Swift*. We obtained an absorbing column density N_H=(10^{+6}_{-4})$\times10^{22}$ cm^{-2}, a photon index Γ=$1.1^{+0.9}_{-0.8}$ (C-stat = 171.80 for 421 dof), resulting in an observed flux of 4.8×10^{-11} erg cm^{-2} s^{-1} (in both 0.3–10 keV and 1–10 keV bands). The unabsorbed fluxes are 8.7×10^{-11} erg cm^{-2} s^{-1} (0.3–10 keV) and 7.9×10^{-11} erg cm^{-2} s^{-1} (1–10 keV).

In all the remaining observations listed in Table 3, the source was not detected. However we note that in all but one observation the exposure time was particularly low (i.e. 0.5–1 ks). We estimated the Bayesian 95% upper limit (Kraft et al. (1991) to the source count rate from the observation with the longer exposure (4.2 ks, n. 4, obs ID 00087498001). It was equal to 0.0025 count/s. Using WebPIMMS, it con-

Table 4. Summary of characteristics related to the studied X-ray transients and to their outbursts

name	duration (days)	outburst average flux (18–60 keV) (erg cm^{-2} s^{-1})	ouburst average luminosity (18–60 keV) (erg s^{-1})	duty cycle	dynamic range (> 18 keV)	dynamic range (0.3–10 keV)
IGR J16374−5043	0.5	3.2×10^{-10}	4×10^{35}	0.4%	>522	
IGR J17375−3022	1–3	1.2×10^{-10}	9.7×10^{36}	0.9%	>533	>130
IGR J12341−6143	0.8–8	5.2×10^{-11}		0.9%	>77	>120
XTE J1829−098	4	9.2×10^{-11}	3.5×10^{36}	4.2%	>110	6,800

verts into an observed (unabsorbed) 0.3–10 keV flux of $\sim 4\times10^{-13}$ erg cm^{-2} s^{-1} ($\sim 7.6\times10^{-13}$ erg cm^{-2} s^{-1}). We assumed the same spectral model as from the *Swift*/XRT observation n. 3.

3.4.3 Investigation at lower frequencies with archival data

Halpern et al. (2007), using the precise *Chandra* localization of XTE J1829−098, individuated its probable infrared counterpart through images in the K and H bands as obtained with the MDM 2.4 m telescope on 17 Jun 2005. The measured magnitudes were H∼13.9 and K∼12.7, no measurement was obtained in the J band. Back in 2005, no additional infrared measurements were available from other infrared surveys, e.g. the UKIDSS survey started on 2005. Currently, we note that the infrared counterpart proposed by Halpern et al. (2007) has been also detected during the UKIDSS GPS data release 6 with magnitudes J=16.147±0.009, H=14.064±0.003, K=12.591±0.002. If we use the reddening-free NIR diagnostic Q (Negueruela & Schurch 2007) with the extinction law of Fitzpatrick (1999), we note that it has a Q value of –0.7 which is very typical of early-type OB stars. In particular, the negative value strongly indicates an infrared excess.

Adopting the UKIDSS infrared magnitudes of such proposed counterpart, we can obtain a rough idea about its distance: if we assume a supergiant B0.5Ib star (with $M_V=-6.8$ mag, V-K=−0.7 and V-J=−0.54), the source should be located at a distance d∼18 kpc (with $A_V \sim 21$ mag). This implies a V magnitude fainter than V∼30–31 mag. A main sequence B0 star (assuming $M_V=-4$ mag, V-K=−0.9 and V-J=−0.7), would imply a distance d∼4.5 kpc (with $A_V \sim 22$ mag), while a giant B0 star (assuming $M_V=-5$ mag, V-K=−0.8 and V-J=−0.7), would be located at about 8 kpc.

3.5 Search for periodicities

We performed a timing analysis using the Lomb–Scargle method (Lomb 1976; Scargle 1982) of the long term *INTEGRAL*-IBIS and *Swift*-BAT light curves of the sources under study, in order to search for periodicities which could eventually be ascribed to their orbital periods.

For all four sources, the long term IBIS/ISGRI ScW light curves (18–60 keV) cover the observational period from 2003 March to 2015 January. We applied standard optimum filtering in order to exclude poor quality data points which could eventually disrupt the periodic signal (see Goossens et al. 2013 and Sguera et al. 2007 for details). Periodicities were searched for in the range 1–100 days, but none were found.

The public access *Swift*/BAT light curves (15–50 keV) on daily timescale of all sources but IGR J12341−6143 were also searched for periodic signals in the range 2–250 days, but none were found.

4 DISCUSSION

Table 4 provides a summary of the X-ray characteristics of the four transients. Although all the reported information do not allow a firm identification of their nature, in the following we use them to obtain hints and/or indications on the most likely class of X-ray sources to which they could belong to.

IGR J16374−5043 has been detected only once (when discovered) during a bright (peak-flux of $\sim10^{-9}$ erg cm^{-2} s^{-1}) and short (∼12 hours) X-ray flare, strongly resembling those from SFXTs. The low duty cycle and high dynamic range above 18 keV, the hard X-ray spectral shape in the soft X-ray band, all are very typical of SFXTs as well (Sidoli & Paizis 2018, Sguera et al. 2008). We individuated a single optical/infrared source inside the arcsecond sized *Swift*/XRT error circle, as detected by *Spitzer* and *GAIA*, which is the likely the counterpart at lower frequencies. *GAIA* measured a distance of ∼ 3.1 kpc, the corresponding average X-ray luminosities during the outburst (18–60 keV, 4×10^{35} erg s^{-1}) and during the rapid fading phase (1–10 keV, 3.4×10^{33} erg s^{-1}) are typical of SFXTs. The infrared counterpart is bright in the MIR (as detected by Spitzer) while it is weaker in the NIR (e.g. 2MASS), suggesting that it is affected by high intrinsic extinction. In the light of the above findings, IGR J16374−5043 can be considered a strong SFXT candidate. NIR spectroscopy of the proposed counterpart is needed to definitely confirm this suggested nature.

IGR J17375−3022 is a hard X-ray transient whose detected bright outburst had a duration constrained by *INTEGRAL* observations in the range 1–3 days, i.e. similar to a few firm SFXTs (e.g. AX J1949.8+2534, Sguera et al. 2017; IGR J17354−3255, Sguera et al. 2011). Furthermore the low duty cycle, high dynamic range and spectral shape of the source, all are very typical of SFXTs as well. We individuated an early type OB objects inside the arcsecond sized *Swift*/XRT error circle, as detected by UKIDSS/VVV surveys in the infrared, which we proposed as the best candidate counterpart at lower frequencies, to date. In the hypothesis of a supergiant nature for this donor star, we found that it should be located at ∼ 26 kpc: the corresponding luminosities in outburst (18–60 keV, 9.7×10^{36} erg s^{-1}; 0.3–10 keV, 2.6×10^{36} erg s^{-1}) and during the lowest X-ray state (0.3–10 keV, $<2\times10^{34}$ erg s^{-1}) are typical of SFXTs. Such large distance would place the source in the outer arm of the Galaxy, much like a few other cases of distant SFXTs, e.g. IGR J18462−0223 (Sguera et al. 2013) and IGR J16418−4532 (Drave et al. 2013). It is likely that, due to the relatively large distance of the source, only the brightest outbursts with $L_X \geq 10^{36}$ erg s^{-1} (like the one reported in this study) are detectable by *INTEGRAL* while the lower intensity ones ($L_X \sim 10^{35-36}$ erg s^{-1}) could be too faint to be detected at energies above 18 keV. Overall, IGR J17375−3022 can be considered a good candidate SFXT. Additional observations are strongly needed: i) in the X-ray band in order to achieve a sub-arcsecond sized position which would allow to pinpoint a unique infrared counterpart, ii) in the infrared band in order to unveil the nature of the proposed best candidate counterpart through spectroscopy.

IGR J12341−6143 has been discovered by *INTEGRAL* during an outburst whose duration is constrained in the range 0.8–8 days. Such interval is compatible with both SFXTs (i.e. lower part of the interval) or alternatively Be HMXBs (i.e. higher part of the interval). The spectral shape above 18 keV is very similar to HMXBs in general, in particular the low duty cycle is more typical of SFXTs rather than Be HMXBs. Unfortunately useful information below 10 keV are not available since the only observation performed to date (and reported in our work) did not provide any detection. Consecutively, the only usable source position is that provided by IBIS/ISGRI with an error circle radius of $\sim 4'$, i.e. way to much large to pinpoint a unique NIR/optical counterpart. In the light of the findings above, the most probable nature for the source is a HMXB, both SFXT and Be HMXB are a viable scenario.

The X-ray properties of the source XTE J1829−098, especially its pulse period and the cyclotron line, indicate a firm HMXB nature. Discovered in 2004, the source is characterized by a remarkable dynamic range of $\sim$ 6,800 below 10 keV. A typical duration of $\sim$ 7 days has been estimated for its outbursts through *RXTE* monitoring. To date only one detection above 20 keV is reported in the literature, as obtained during a short *NuSTAR* ToO observation in 2018 in response to a MAXI trigger of outburst activity. From archival *INTEGRAL* data, we reported on the second detection ever above 20 keV obtained during an outburst in April 2007, the first ever outburst studied at hard X-rays during its entire duration. The latter was of the order of a few days ($\sim$ 4), constraining the typical historical duration of outbursts from the source in the range $\sim$ 4–7 days. This is apparently at odds with the typical duration of classical outbursts from SFXTs (i.e. less than a day). However a few other SFXTs are known to show unusually longer hard X-ray activity exceptionally lasting several days, e.g. IGR J18483−0311 (Sguera et al. 2015), AX J1949.8+2534 (Sguera et al. 2017), IGR J17354−3255 (Sguera et al. 2011), IGR J17503−2636 (Ferrigno et al. 2019), i.e. comparable to the duration of the hard X-ray activity usually detected from XTE J1829−098. In addition, we note that the dynamic range of the source (very high in the soft X-ray band), its duty cycle, its spectral shape, all are consistent with a SFXT nature as well. Inside the sub-arcsecond sized *Chandra* error circle there is a unique and bright infrared counterpart (Halpern et al. 2007). We found that it is very likely an early type OB star. In the hypothesis of a supergiant nature, it should be located at $\sim$ 18 kpc: we found that the corresponding source luminosities in outburst (18–60 keV, 3.5×10^{36} erg s^{-1}; 0.3–10 keV, 6.6×10^{36} erg s^{-1}) and during the lowest X-ray state (0.3–10 keV, $\sim 1.0\times10^{33}$ erg s^{-1}) are very typical of SFXTs. Overall, XTE J1829−098 can be considered a good candidate SFXT. Alternatively, we point out that in principle the hypothesis of a Be HMXB nature is viable as well. In this case, the infrared counterpart would be located at $\sim$ 4.5 kpc. However, in this scenario the corresponding outburst X-ray luminosities ($\sim 10^{35}$ erg s^{-1}) and durations (4–7 days) are about one order of magnitude lower that typical values of classical Be HMXBs.

5 SUMMARY AND CONCLUSIONS

We performed a systematic study of the entire sample of unidentified fast hard X-ray transients located on the Galactic plane and detected with the bursticity method, as reported in Bird et al. (2016). Our main aim was to individuate those with X-ray characteristics strongly resembling Supergiant Fast X-ray Transients.

We found that IGR J16374−5043 and IGR J17375−3022, which before our current work were very poorly studied in the literature, now can be considered strong candidate SFXTs. IGR J12341−6143 was also very poorly studied in the literature before our work. We found that its characteristics (in particular the outburst duration) are compatible with both SFXT and Be HMXB scenarios. Finally, before our current work the transient HMXB XTE J1829−098 was studied in detail below 10 keV and conversely it was poorly investigated above 18 keV. Our study above 18 keV, in conjunction with archival infrared data, allows for the first time to consider it as good candidate SFXT, although a Be HMXB nature cannot be entirely excluded.

To date, about 14 firm SFXTs have been reported in the literature along with a smaller number of candidates ($\sim$ 4). One of the main aims of the current studies on SFXTs is to increase the sample of firm objects, this is mandatory for population studies e.g. to establish whether SFXTs are a homogeneous class or display a variety of different X-ray characteristics. In this context, the findings of our work significantly increase the sample of candidate SFXTs, effectively doubling their number. NIR spectroscopy of the proposed candidate counterparts is strongly needed in order to firmly confirm (or reject) our suggested nature of SFXTs. It seems plausible that other SFXTs wait to be discovered in our Galaxy. Further exploitations of the entire *INTEGRAL* data archive, which in the meanwhile doubled its dataset since the latest published *INTEGRAL*/IBIS catalog, may yield additional discoveries of this kind of interesting and peculiar X-ray transients.

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