First hard X-ray detection and broad band X-ray study of the unidentified transient AX J1949.8+2534

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ABSTRACT
We present the results from INTEGRAL and Swift/XRT observations of the hitherto poorly studied unidentified X-ray transient AX J1949.8+2534, and on archival multiwavelength observations of field objects. Bright hard X-ray outbursts have been discovered above 20 keV for the first time, the measured duty cycle and dynamic range are of the order of ~4% and ≥630, respectively. The source was also detected during a low soft X-ray state (~2×10⁻¹² erg cm⁻² s⁻¹) thanks to a Swift/XRT followup, which allowed for the first time to perform a soft X-ray spectral analysis as well as significantly improve the source positional uncertainty from arcminute to arcsecond size. From archival near-infrared data, we pinpointed two bright objects as most likely counterparts whose photometric properties are compatible with an early type spectral nature. This strongly supports a High Mass X-ray Binary (HMXB) scenario for AX J1949.8+2534, specifically a Supergiant Fast X-ray Transient (more likely) or alternatively a Be HMXB.

Key words: X-rays: binaries – X-rays: individual: AX J1949.8-2534

1 INTRODUCTION

AX J1949.8+2534 is a hitherto poorly studied unidentified X-ray source. It was discovered during the ASCA Galactic Plane Survey (Sugizaki et al. 2001) whose observations were carried out from March 1996 to April 1999, covering the inner Galactic disk at |l|≤45° and |b|≤0°.4. The source was detected with a significance of 3.6σ and 21.6σ in the energy bands 0.7–2 keV and 2–10 keV, respectively. No spectral information is available, the reported 2–10 keV ASCA count rate (Sugizaki et al. 2001) converts into an absorbed X-ray flux of ~8×10⁻¹² erg cm⁻² s⁻¹ (~6×10⁻¹³ erg cm⁻² s⁻¹) if we assume a power law spectral shape with Γ=1 (Γ=2). The uncertainty on the source position is ~1′ as is typical for ASCA X-ray sources, this prohibits the search for counterparts at lower energies (i.e. optical and infrared) which is essential to firmly identify the nature of the source.

For many years, the ASCA detection represented the only information available in the literature. Interestingly, Sguera et al. (2015) have recently reported the first hard X-ray detection of AX J1949.8+2534 above 20 keV. Their communication contained only very short information about the hard X-ray activity detected by INTEGRAL, as obtained from analysis of near real time data pertaining to public observations of the Cygnus region.

Here we present the results of a more detailed spectral and temporal analysis of the consolidated INTEGRAL data pertaining to the outburst reported by Sguera et al. (2015), together with the investigation of additional archival INTEGRAL data, with the aim of finding further hard X-ray activity from the source. We also report a Target of Opportunity (ToO) observation made with the Swift satellite in order to refine the error circle to arcsecond size as well as to characterize for the first time the spectral shape in the soft X-ray band.

2 INTEGRAL

2.1 Data analysis

For our study, we used data collected 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). The reduction and analysis of the data have been performed by using the Offline Scientific Analysis (OSA) version 10.1. For IBIS/ISGRI spectral analysis we used the standard 13 energy channel
Table 1. Log of IBIS/ISGRI observations used for our study on AX J1949.8+2534. Orbits in boldface contain the IBIS/ISGRI detections reported in section 2.2. † Detection originally reported by Sguera et al. (2015).

| Telescope | Orbit Date       | Observation Target | Exposure (ks) |
|-----------|------------------|--------------------|---------------|
|           | 1600 18-20 Oct 2015 | Cyg X-1            | ~ 22          |
|           | 1601 22-23 Oct 2015 | Cyg X-1            | ~ 8           |
|           | 1602 23-25 Oct 2015 | GPS+Cyg X-1        | ~ 14          |
|           | 1603 26-28 Oct 2015 | GPS+Cyg X-1        | ~ 7           |
|           | 1605† 31 Oct - 02 Nov 2015 | GPS+Cyg X-1      | ~ 16          |
|           | 1606 03 Nov 2015   | GPS                | ~ 3.5         |
|           | 1607 05-07 Nov 2015 | GPS+Cyg X-1        | ~ 22          |
|           | 1609 12-13 Nov 2015 | Cyg X-1            | ~ 6           |
|           | 1610 14-15 Nov 2015 | Cyg X-1            | ~ 12          |
|           | 1611 18 Nov 2015   | GPS                | ~ 3.5         |
|           | 1613 23 Nov 2015   | GPS                | ~ 4           |
|           | 1614 24-26 Nov 2015 | GPS+Cyg X-1        | ~ 20          |
|           | 1615 01 Dec 2015   | GPS+Cyg X-1        | ~ 7           |
|           | 1618 05 Dec 2015   | GPS                | ~ 4           |
|           | 1619 09 Dec 2015   | GPS                | ~ 4           |
|           | 1621 13-15 Dec 2015 | Cyg X-1            | ~ 15          |
|           | 1624 21-23 Dec 2015 | GPS+Cyg X-1        | ~ 18          |
|           | 1626 26-28 Dec 2015 | ToO V404 Cyg      | ~ 17          |
|           | 1627 29-31 Dec 2015 | ToO V404 Cyg      | ~ 16          |
|           | 1628 31 Dec - 02 Jan 2016 | ToO V404 Cyg | ~ 18          |
|           | 1629 03-05 Jan 2016 | ToO V404 Cyg      | ~ 19          |
|           |                   |                    | ~ 255         |

Our total data set consists of all public observations which covered the Cygnus region (i.e. Galactic Plane Scans GPS, ToO observations of V404 Cyg and targeted observations of Cyg X–1) immediately before and after the hard X-ray detection of AX J1949.8+2534 reported by Sguera et al. (2015). The corresponding data set amounts to a total exposure of ~ 255 ks (see Table 1 for details).

We performed an analysis of the full data set on two different timescales, i.e. at ScW level as well as at revolution level, in order to search for newly discovered X-ray activity from the source detected with a significance equal or greater than at least 5σ and 7σ, respectively. Such detection thresholds are essential to avoid false detections/excesses caused by background noise (e.g. Bird et al. 2016). The search was initially performed in the energy band 22–60 keV; this choice takes into account the evolution of the IBIS/ISGRI energy threshold that occurred from revolution number ~ 900 on. When a significant detection was found, we have also checked the detection at higher energies (i.e. 60–100 keV) or in other different ranges (i.e. 22–30, 30–60 and 22–40 keV). We note that the sensitivity limit for a persistent source detected at 5σ level (22–60 keV) in only one ScW of about 2,000 s duration is ~ 18 mCrab (Krivonos et al. 2010).

The X-ray monitor JEM-X (Lund et al. 2003) makes observations simultaneously with IBIS/ISGRI, although with a much smaller Field of View (FoV), providing images in the softer energy band 3–35 keV. JEM-X data were analyzed when the source was in its FoV in order to search for X-ray activity in both the energy bands 3–10 keV and 10–20 keV.

Throughout the paper, the spectral analysis was performed using XSPEC version 12.9.0 and, unless stated otherwise, errors are quoted at the 90 per cent confidence level for one single parameter of interest.

2.2 Results

We report on newly discovered hard X-ray transient activity from AX J1949.8+2534, the first ever above 20 keV. Hard X-ray detections with IBIS/ISGRI were obtained by analyzing data in revolutions number 1605, 1628 and 1629. Table 2 reports a summary of the outbursts main characteristics.

| Orbit (n.) | Date (MJD) | Significance (σ) | Flux (mCrab) | Duration (days) |
|------------|------------|------------------|--------------|----------------|
| 1605       | 57327.35   | 7.1              | 10.0±1.4     | ~ 1.5          |
| 1628       | 57387.65   | 7.1              | 10.6±1.5     | ~ 2            |
| 1629       | 57390.31   | 7.3              | 9.5±1.3      | ~ 2            |

2.2.1 IBIS/ISGRI detection in revolution 1605

Firstly, we note that AX J1949.8+2534 was not detected in any single revolution from n. 1600 to n. 1603, nor in their mosaic for a total on source exposure of ~ 50 ks. As a result, we inferred a 3σ upper limit of ~ 2 mCrab (22–60 keV).

Conversely, AX J1949.8+2534 was detected with a significance of 7.1σ (22–60 keV) during revolution 1605 (~ 14 ks on-source exposure) from 2015 Nov 01 08:28 (UTC) to 2015 Nov 02 15:48 (UTC). No detection was obtained in the energy band 60–100 keV. The measured average 22–60 keV flux is 1.1×10–10 erg cm–2 s–1. The source was never significantly detected at ScW level (i.e. ~ 5σ) at any point of the observation, indicating that no major flaring activity took place on short timescales (i.e. ~ 2,000 s).

The extracted IBIS/ISGRI spectrum was fitted by a power law with Γ=2.9±0.8 (χ2=1.7, 4 d.o.f.) or alternatively by a thermal bremsstrahlung with kT=24.5±2 keV (χ2=1.5, 4 d.o.f.). The best fit was achieved by using a black body model (χ2=1.15, 4 d.o.f.) with kT=7.9±1.4 keV. The average 18–60 keV (20–40 keV) flux is 1.1×10–10 erg cm–2 s–1 (7.8×10–11 erg cm–2 s–1). Fig. 1 shows the black body data-to-model fit with the corresponding residuals.

The source was also in the JEM-X FoV during this observation, however in the combined JEM–X1+JEM–X2 mosaic it was not detected in both bands 3–10 keV and 10–20 keV (on-source exposure of ~ 4.8 ks). The inferred 3σ upper limit (3–10 keV) is of the order of ~ 2 mCrab or 4.4×10–11 erg cm–2 s–1.
AX J1949.8+2534 was not detected in any single revolution after n. 1605 (from n. 1606 to n. 1627), nor in their mosaic for a total on source exposure of \(\sim 150\) ks. We inferred a 3\(\sigma\) upper limit of \(\sim 1.2\) mCrab (22–60 keV). This, combined with the other upper limit from revolutions n. 1600 to 1603, allows us to confidently constrain the duration of the transient hard X-ray activity detected in revolution n. 1605 to no longer than \(\sim 1.5\) days.

### 2.2.2 IBIS/ISGRI detection in revolutions 1628 and 1629

Renewed hard X-ray activity from AX J1949.8+2534 was detected again by IBIS/ISGRI towards the end of Dec 2015. In fact, the source was detected in the energy band 22–60 keV in both revolutions n. 1628 (\(\sim 7.1\sigma\), \(\sim 18\) ks on-source exposure), and n. 1629 (\(\sim 7.3\sigma\), \(\sim 19\) ks on-source exposure), spanning the time range from 2015 Dec 31 15:40 (UTC) to 2016 Jan 05 10:37 (UTC). The source showed no sign of flux variation on revolution timescale since the 22–60 keV measured average fluxes are fully consistent with each other within their uncertainties (10.6\(\pm\)1.5 mCrab and 9.5\(\pm\)1.3 mCrab, respectively). Unfortunately, the source was not in the IBIS/ISGRI FoV again throughout revolutions after n. 1629 so we cannot constrain the duration of this latest transient hard X-ray activity, we can only infer a lower limit of \(\sim 4\) days.

We stacked the data for revolutions n. 1628 and 1629 with the aim of increasing the statistics of the detection. AX J1949.8+2534 was detected in the mosaic with a significance of 9.8\(\sigma\) (22–60 keV) for a total on-source exposure of \(\sim 37\) ks. No detection was obtained in the higher energy band 60–100 keV. The 22–60 keV measured average flux is 9.30\(\pm\)0.95 mCrab which is fully compatible within the errors with that measured during the hard X-ray activity detected two months earlier during revolution n. 1605. The source was never in the JEM–X FoV during these latest observations.

We performed an investigation at ScW level of both revolutions n. 1628 and 1629 with the aim of searching for possible flaring activity on short timescales (i.e. \(\sim 2,000\) s). Interestingly, we found that the source was occasionally bright enough to be significantly detected even at ScW level during the course of the observations. Table 3 lists the single ScWs during which significant detections (i.e. \(\geq 5\sigma\)) were achieved. In particular, we focussed our attention on the four consecutive ScWs from n. 20 to 23 in revolution n. 1629 (they span a continuous temporal range of \(\sim 3.5\) hours) in order to extract an IBIS/ISGRI light curve with a fine temporal bin of 200 s. As it can be seen from Fig. 2, AX J1949.8+2534 mainly shows an enhanced and rather constant flux with no major sign of flares. Only towards the end of the light curve is there sign of possibly a couple of short flares on \(\sim 200\) s timescale, the strongest one (having a significance of 4.7\(\sigma\)) reached a peak-flux of 180\(\pm\)38 mCrab or \((2.4\pm0.4)\times10^{-9}\) erg cm\(^{-2}\) s\(^{-1}\) (22–60 keV). To establish if the source statistically varied during the entire light curve, we fitted it with a constant and applied the \(\chi^2\) test. It was found a chance probability of 0.4 that this results is due to chance, i.e. the source is variable at only 60% confidence level which reject the hypothesis of variability. We have also made a mosaic of such four consecutive ScWs, this yielded to a source detection of \(\sim 11\sigma\) (22–60 keV). Given the good
statistics, we extracted an IBIS/ISGRI spectrum which was best fit by a black body ($\chi^2_{\nu}=0.9$, 4 d.o.f., see Fig. 3) with $kT=8.6^{+1.4}_{-1.2}$ keV and average 18–60 keV (20–40 keV) flux of $\sim 6 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ ($\sim 4 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$). We note that both a thermal bremsstrahlung ($\chi^2_{\nu}=0.6$, 4 d.o.f.) and a power law ($\chi^2_{\nu}=0.75$, 4 d.o.f.) provided a good description of the spectrum as well, with best fit parameter values equal to $kT=34^{+23}_{-11}$ keV and $\Gamma=2.5\pm0.5$, respectively. All such best fit parameter values are consistent, within their uncertainties, with those obtained from the detection during revolution n. 1605.

### 2.2.3 IBIS/ISGRI refined position and upper limit

In order to get the most refined IBIS/ISGRI position of the source, we made a mosaic summing all the three revolutions 1605, 1628 and 1629. AX J1949.8+2534 was detected at 11.2$\sigma$ level (22–60 keV) with a total on-source exposure of $\sim 50$ ks. Fig. 4 shows the corresponding significance map. The best position is RA=$297^{h}49^{m}$ and Dec=$25^{\circ}57^{\prime}$ with a 90% confidence error circle radius equal to 2$^{\prime}$.

AX J1949.8+2534 is not listed in the latest published IBIS/ISGRI catalog (Bird et al. 2016) despite extensive INTEGRAL coverage of its sky region ($\sim 2$ Ms up to revolution n. 1000 considered in Bird et al. 2016) and this information can be used to infer an upper limit on its persistent hard X-ray emission. By additionally considering the source exposure from our present dataset ($\sim 0.25$ Ms), we can infer a 3$\sigma$ upper limit of $\sim 0.4$ mCrab or $3.2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ (20–40 keV) for persistent emission. When assuming the source peak flux as measured by IBIS/ISGRI from the outburst reported in section 2.2.2, we can infer a dynamic range of $\geq 625$

### 3 SOFT X-RAY OBSERVATIONS

#### 3.1 Swift/XRT

Following the two newly discovered IBIS/ISGRI detections of AX J1949.8+2534 reported here, we triggered a ToO observation of the sky region with the Swift satellite (Gehrels et al. 2004) with the main aims to i) refine the position of the source with a much higher accuracy; ii) perform a spectral analysis in soft X-rays for the first time. The observation was performed on 2016, April 25 (ID: 00034497001).

Standard data reduction and analysis were performed using HEASOFT version 6.18 together with the most updated Swift/XRT calibration files. The XRT data were reprocessed using xrtpipeline (v0.13.2).

The Swift/XRT (PC) observation resulted in a net exposure time of 2,929 s, and it detected a faint X-ray counterpart ($\leq 5\sigma$, 0.3–10 keV) within both the IBIS/ISGRI and ASCA error circles (see Fig. 5). The best determined XRT position is at R.A. (J2000) = 19$^h$49$^m$55$^{s}$19 Dec (J2000) = +25$^\circ$33$^{\prime}$57$^{\prime\prime}$5 with an error radius of 3$^{\prime}\prime$.7 (90% confidence) using the XRT–UVOT alignment and matching UVOT field sources to the USNO-B1 catalog (see Evans et al. 2009 and http://www.swift.ac.uk/user_objects).

We then extracted counts from a circle with a radius of 20 pixels centered on the source position, together with a background from an annular region centered on the source position, with inner and outer radii of 30 and 60 pixels, respectively. The source net count rate in the energy range 0.3–10 keV was $(8.08\pm1.71) \times 10^{-3}$ counts s$^{-1}$.

Given the low statistics, we rebinned the spectrum to 1 count bin$^{-1}$ and adopted Cash statistics (Cash 1979) in xspec. The Swift/XRT spectrum was well fitted by an absorbed power law ($C$-Stat = 20.8, 24 d.o.f.) where the absorption $N_H$ was fixed at $1.18 \times 10^{22}$ cm$^{-2}$ (the total Galactic absorption in the source direction, Willingale et al. 2013). We obtained a photon index of $\Gamma=0.2\pm0.9$. The 0.3–10 keV observed flux was $1.8 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ corrected for the absorption.

#### 3.2 Chandra

The ACIS High Resolution Camera onboard Chandra (Weisskopf et al. 2000) observed AX J1949.8+2534 on 2008 Feb 08 for a total exposure time of $\sim 1.16$ ks. This targeted observation was performed in the context of the ChIcAGO survey.
It is very faint in the $K$ circles at 90% and 95% confidence, superimposed on the $''$ the 90% confidence error circle (radius of 3 $''$ band UKIDSS image. We note that source n. 1 is located at ChI 194951+2534 position of AX J1949.8+2534. We used the count rate of listed in Table 4 as n. 1. Fig. 6 shows both the XRT side the 90% confidence the UKIDSS Galactic Plane Survey (Lucas et al. 2008) inside only one near infrared (NIR) source has been detected byvey limit as reported in Monet et al. (2003). Conversely, a lower limit of $V$>21 can be inferred from the USNO survey limit as reported in Monet et al. (2003). Conversely, only one near infrared (NIR) source has been detected by the UKIDSS Galactic Plane Survey (Lucas et al. 2008) inside the 90% confidence XRT error circle, such object is listed in Table 4 as n. 1. Fig. 6 shows both the XRT error circles at 90% and 95% confidence, superimposed on the $K$ band UKIDSS image. We note that source n. 1 is located at $''$ distance from the XRT coordinates centroid, i.e. on the 90% confidence error circle (radius of $''$, solid circle). It is very faint in the $K$ band (magnitude of $''$, as such it is not evident in the image) and it is undetected in the $J$ and $H$ bands. As a consequence we consider very unlikely the possibility that this extremely faint object could be a reliable NIR counterpart of AX J1949.8+2534. For the sake of completeness, in Fig. 6 we note that a few brighter infrared

| n.      | name                  | J         | H       | K       | offset | Q     | Spectral Type | $A_v$ | d   |
|---------|-----------------------|-----------|---------|---------|--------|------|--------------|-------|-----|
| 1       | J194955.02+253354.6   | >19.9     | >19.0   | 17.78±0.142 | 3.66$''$ | 0.17 | late type    | B0V   | 7.1 | 17.3 |
| 2       | J194954.99+253400.2   | 17.09±0.015 | 16.18±0.013 | 15.743±0.022 | 3.78$''$ | 0.01 | B0V         | 7.1   | 17.3| 1.3  |
| 3       | J194955.12+253401.4   | 14.88±0.003 | 14.263±0.003 | 13.902±0.005 | 4.02$''$ | 0.22 | K0V         | 4.4   | 1.3 |
| 4       | J194955.31+253353.8   | 17.102±0.015 | 15.878±0.010 | 15.285±0.015 | 4.02$''$ | 0.09 | B0.5Ia      | 7.2   | 8.8 |
| 5†      | J194955.42+253359.9   | 9.900±0.022 | 9.071±0.016 | 8.637±0.018 | 4.02$''$ | 0.00 | B0.5Ia      | 7.2   | 8.8 |

4 SEARCH FOR INFRARED, OPTICAL AND RADIO COUNTERPARTS

The identification of lower energy counterparts represents a mandatory step in determining the nature of unidentified Galactic X-ray sources. To this aim, we obtained with Swift/XRT a 90% confidence source positional accuracy of $''$ which significantly improves the previously available ASCA uncertainty of $''$. This allowed us to perform for the first time a search for counterparts from radio to optical bands, by using all the available catalogs in the HEASARC database.

No catalogued radio and optical source is located within the arcsecond sized XRT error circle. In the optical V band, a lower limit of $V$>21 can be inferred from the USNO survey limit as reported in Monet et al. (2003). Conversely, only one near infrared (NIR) source has been detected by the UKIDSS Galactic Plane Survey (Lucas et al. 2008) inside the 90% confidence XRT error circle, such object is listed in Table 4 as n. 1. Fig. 6 shows both the XRT error circles at 90% and 95% confidence, superimposed on the $K$ band UKIDSS image. We note that source n. 1 is located at $''$ distance from the XRT coordinates centroid, i.e. on the 90% confidence error circle (radius of $''$, solid circle). It is very faint in the $K$ band (magnitude of $''$, as such it is not evident in the image) and it is undetected in the $J$ and $H$ bands. As a consequence we consider very unlikely the possibility that this extremely faint object could be a reliable NIR counterpart of AX J1949.8+2534. For the sake of completeness, in Fig. 6 we note that a few brighter infrared
sources are located at \(\sim 4''\) distance from the XRT centroid, i.e. slightly outside the 90\% confidence error circle (radius of 3\,'′.7, solid circle) and well inside the 95\% confidence XRT error circle radius of 4''2 (dashed circle). Such objects are listed in Table 4 with numbers from 2 to 5.

If we use the reddening-free NIR diagnostic Q of Negueruela \& Schurch (2007) for the objects n. 2 and n. 4 in Table 4, then we find that none of them has a Q value typical of early-type stars (i.e. \(q \leq 0\)). As a matter of fact, they show Q values of 0.17 and 0.22 respectively, which are much more similar to those of intermediate or late type stars. For example, if we consider the brightest infrared object among the two (n. 4), then we find that it is compatible with being a star of spectral type K0V with a reddening of \(A_v = 4.4\) mag, located at a distance of \(\sim 1.3\) kpc. Its implied V magnitude is \(\sim 23.4\), which is consistent with not detecting it in the V band according to the USNO catalog. As for the brightest infrared object (n. 5), it is also reported in the 2MASS infrared source catalog (namely J19495543+2533599) with magnitudes equal to \(J = 9.900 \pm 0.022, H = 9.071 \pm 0.016\) and \(K = 8.637 \pm 0.018\) as well as in the optical USNO-B1.0 catalog (1155–024115) with magnitudes of \(I = 12.87, R_2 = 14.62, B_2 = 17.35\). Notably, its Q value (0.09) is typical of early-type stars (Negueruela \& Schurch 2007). Moreover, by comparing its K magnitude with the right panel of Fig. 1 in Reig \& Milonaki (2016) we note that it is located inside the box populated by blue supergiants. In fact, we found that the observed \(K\) and \(J\) magnitudes and the observed \(J – K\) color are compatible with a B0.5Ia spectral type supergiant star, for a distance of \(\sim 8.8\) kpc and a reddening of \(A_v = 7.2\) mag. Its implied apparent V magnitude is \(\sim 15\), which is consistent with the detection of the source as reported in the USNO catalog. Finally, also the infrared object n. 3 is characterized by a Q value (0.01) typical of an early-type star. In this case, its observed NIR magnitudes are not compatible with being a supergiant star since this would require an extremely large distance (\(\sim 70\) kpc, i.e. object outside the Galaxy) and an high extinction (\(A_v = 6.7\) mag). On the other hand, it is more compatible with being a main sequence B0V spectral type star, for a distance of \(\sim 17.3\) kpc and a reddening of \(A_v = 7.1\) mag, the implied apparent V magnitude is \(\sim 19.3\), which is consistent with the detection of the source as reported in the USNO catalog with a B magnitude equal to \(\sim 19\).

5 DISCUSSION

We have presented mainly IBIS/ISGRI results on newly discovered hard X-ray activity from the unidentified transient AX J1949.8+2534, the first ever emission to be reported above 20 keV. Hard X-ray outbursts have been detected twice, on November 2015 and January 2016, respectively. Furthermore, we point out that we have searched the entire currently available IBIS/ISGRI public data archive (revolution 25–1619, Paizis et al. 2013, 2017) for possible additional outbursts of AX J1949.8+2534. No detections have been found at ScW level above a significance value of \(\sigma_T\) in both energy bands 22–50 and 50–100 keV. The source exposure time obtained from the entire archive is of the order of \(\sim 7\) Ms. The inferred duty cycle is as low as \(\sim 4\%\).

We can use all the collected multiwavelength data to consider the possible nature of AX J1949.8+2534.

5.1 Low Mass X-ray Binary or Cataclysmic Variable?

As we noted before, two NIR objects, compatible with being late type spectral stars, are present within the 95\% confidence XRT error circle (n. 2 and n. 4 in Table 4 and Fig. 6). In principle, this could suggest a Low Mass X-ray Binary nature (LMXB) or alternatively a Cataclysmic Variable one (CV). However, in the following we show that both such scenarios suffer serious drawbacks when broad-band X-ray results are taken into account.

The LMXB hypothesis is incompatible with both the very hard X-ray spectrum measured by Swift/XRT (i.e. \(\Gamma \sim 0.2\)) as well as with the particularly short duration of the hard X-ray activity detected by IBIS/ISGRI (\(\sim 1.5\) days, in the only case when it was possible to firmly constrain the duration). In fact, transient LMXBs are know to display X-ray outbursts whose duration is typically of the order of weeks/months, they are characterized by soft X-ray spectra below 10 keV (due to disk black body emission). From Table 4, we note that the two NIR objects compatible with a late type nature (i.e. n. 2 and n. 4) are particularly weak. If we consider as possible counterpart the brightest among the two (n. 4) then we showed that it is compatible with a late type star located at \(\sim 1.3\) kpc. The corresponding average X-ray luminosities during the two hard X-ray outbursts detected by IBIS/ISGRI are of the order of \(\sim 2 \times 10^{34}\) erg s\(^{-1}\). This is way too low if compared to typical luminous X-ray outbursts from LMXBs (up to \(\sim 10^{37}–38\) erg s\(^{-1}\)). For the sake of completeness, we note that recently a growing number of LMXBs have been found to show outbursts reaching peak X-ray luminosity of only \(\sim 10^{34}–36\) erg s\(^{-1}\) in the soft X-ray band 2–10 keV. They belong to a more general class of X-ray transients dubbed as Very Faint X-ray Transients (VFXTs), which are believed to be the the faintest known X-ray accretors (Degenaar \& Wijnands 2009, 2011). If we extrapolate the IBIS/ISGRI spectral shape of AX J1949.8+2534 in outbursts to the 2–10 keV X-ray flux, then we obtain a 2–10 keV X-ray luminosity (at 1.3 kpc) of the order of \(\sim 2 \times 10^{33}\) erg s\(^{-1}\), i.e. lower than that typical of VFXTs. With all the above information at hand a LMXB nature for AX J1949.8+2534 seems to be not viable.

Alternatively, we are left with the CV hypothesis. In principle, both the Swift/XRT and IBIS/ISGRI spectral X-ray characteristics are compatible with this scenario (Barlow et al. 2006, Landi et al. 2009). However, we note that to date all the CVs detected by both IBIS/ISGRI and Swift/BAT above 20 keV are weak persistent hard X-ray sources with typical luminosities in the range \(\sim 10^{32–34}\) erg s\(^{-1}\) (Barlow et al. 2006, Revnivtsev et al. 2008, Brunschweiger et al. 2009). No CV has never been detected as a transient hard X-ray source. This is completely at odds with the short transient behavior of AX J1949.8+2534 as observed by IBIS/ISGRI. Moreover, if we consider the brightest NIR object compatible with a late type nature (n. 4), then it is compatible with a late type M5V main sequence star (which is typical of CVs, Smith et al. 1998) located at \(\sim 230\) pc. Consequently, the IBIS/ISGRI upper limit on the persistent hard X-ray emission of AX J1949.8+2534 would translate into a 20–40 keV luminosity of \(\lesssim 2 \times 10^{33}\) erg s\(^{-1}\), i.e. significantly lower than typical measurements obtained to date with both IBIS/ISGRI and Swift/BAT. The same holds for
the \textit{Swift}/XRT detection whose soft X-ray flux would translate into a luminosity of $\sim 1.2 \times 10^{33}$ erg s$^{-1}$. All the above results point to largely disfavor the CV interpretation for AX J1949.8+2534.

5.2 High Mass X-ray Binary

The location of the source on the Galactic plane (b~0.3°) and both \textit{Swift}/XRT and IBIS/ISGRI spectral characteristics (especially the hardness of the soft X-ray spectrum, i.e. $\Gamma$~0.2) are fully compatible with a High Mass X-ray Binary nature (HMXB). In particular, the hard X-ray transient behavior (e.g. dynamic range $\geq 620$ and duration of $\sim 1.5$ days and $\geq 4$ days from the two IBIS/ISGRI detected activities, respectively) could be typical of the Be HMXB class. In addition we note that mentioned X-ray characteristics are comparable as well with a Supergiant Fast X-ray Transients nature (SFXTs, Sguera et al. 2008), which are a newly discovered class of HMXBs (Sguera et al. 2005, 2006, Negueruela et al. 2005).

Although classical SFXTs usually display above 20 keV hard X-ray outbursts lasting much less than a day, 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; IGR J17354—3255, Sguera et al. 2011), i.e. comparable to the duration of the hard X-ray activity detected from AX J1949.8+2534.

We must note that, in principle, this proposed HMXB interpretation could suffer some drawbacks when NIR data are combined with the 90% confidence XRT positional uncertainty. In fact, searching within the latter, we pinpointed only one very faint NIR object (n. 1 in Table 4), whose magnitudes and colors are not compatible with being an early type spectral star, i.e. at odds with an HMXB nature. However, slightly outside the 90% confidence XRT error circle (radius of $3'$.7) we note the presence of two bright NIR sources (n. 3 and n. 5) located at 4$''$ distance from the XRT centroid, i.e. well inside the 95% confidence XRT positional uncertainty (radius of $4''$.2). Both have observed $K$ and $J$ magnitudes and $J-K$ color compatible with an early type nature.

Specifically, the characteristics of the NIR object n. 3 are compatible with a main sequence early type spectral star (B0V), supporting a Be HMXB scenario. If we consider its calculated distance of $\sim 17.3$ kpc, then the two hard X-ray outbursts detected by IBIS/ISGRI from AX J1949.8+2534 would have a 18–60 keV average (peak) luminosity of $4 \times 10^{36}$ erg s$^{-1}$ (2 $\times 10^{37}$ erg s$^{-1}$), both such values are typical of periodic type I X-ray outbursts from Be HMXBs. As for the soft X-ray band, the measured \textit{Swift}/XRT flux translates into a luminosity of $\sim 2 \times 10^{34}$ erg s$^{-1}$, which is fully compatible with the so-called intermediate intensity X-ray state during which typical SFXTs spend the majority of their time (Sidoli et al. 2008). In this context, we note that the prolonged duration of the hard X-ray activity discovered from AX J1949.8+2534 ($\sim 1.5$ and $\geq 4$ days, respectively) is at odds with the much shorter durations typically marking outbursts from classical SFXTs above 20 keV (i.e. a few hours). A similar characteristic was previously reported only for a few other SFXT sources. Our new findings on AX J1949.8+2534 could strengthen the idea that unusually long hard X-ray outbursts would not be particularly exceptional among the class of SFXTs.

6 CONCLUSIONS

We reported on the IBIS/ISGRI discovery of two new hard X-ray outbursts from the unidentified transient AX J1949.8+2534, the first ever emission to be detected above 20 keV. A follow-up observation of the sky region with the \textit{Swift} satellite allowed for the first time to perform a soft X-ray spectral analysis as well as significantly improve the positional uncertainty to arcsecond size. This permitted us to pinpoint two bright infrared sources as most likely candidate counterparts. Both are compatible with being early type spectral stars hence supporting an HMXB nature, specifically an SFXT (more viable) or alternatively a Be HMXB. Further detailed NIR or optical spectroscopy is mandatory to confirm their putative supergiant and Be nature, respectively. Unfortunately, we can go no further on this issue because the current X-ray positional uncer-
tainty (3″.7) prevents us from unambiguously pinpointing the correct single NIR counterpart. Additional X-ray observations of AX J1949.8+2534 using *Chandra*, for example, are strongly needed in order to achieve a finer position with an associated smaller error circle.

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