Swift-BAT HARD X-RAY SKY MONITORING UNVEILS THE ORBITAL PERIOD
OF THE HMXB IGR J18219−1347

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ABSTRACT

IGR J18219−1347 is a hard X-ray source discovered by INTEGRAL in 2010. We have analyzed the X-ray emission of this source exploiting the Burst Alert Telescope (BAT) survey data up to 2012 March and the X-Ray Telescope (XRT) data that include also an observing campaign performed in early 2012. The source is detected at a significance level of ~13 standard deviations in the 88 month BAT survey data, and shows a strong variability along the survey monitoring, going from high intensity to quiescent states. A timing analysis on the BAT data revealed an intensity modulation with a period of $P_0 = 72.44 \pm 0.3$ days. The significance of this modulation is about seven standard deviations in Gaussian statistics. We interpret it as the orbital period of the binary system. The light curve folded at $P_0$ shows a sharp peak covering ~30% of the period, superimposed to a flat level roughly consistent with zero. In the soft X-rays the source is detected only in 5 out of 12 XRT observations, with the highest recorded count rate corresponding to a phase close to the BAT folded light-curve peak. The long orbital period and the evidence that the source emits only during a small fraction of the orbit suggests that the IGR J18219−1347 binary system hosts a Be star. The broadband XRT+BAT spectrum is well modeled with a flat absorbed power law with a high-energy exponential cutoff at ~11 keV.

Key words: X-rays: binaries – X-rays: individual (IGR J18219−1347)

Online-only material: color figure

1. INTRODUCTION

The INTEGRAL observatory (Winkler et al. 2003) with the IBIS/ISGRI telescope (Ubertini et al. 2003; Lebrun et al. 2003) and the Swift observatory (Gehrels et al. 2004) with the Burst Alert Telescope (BAT; Barthelmy 2005) are performing a continuous monitoring of the sky in the hard X-ray energy band offering a long-term database for the activity of the X-ray sources and a large number of new detections of transient or very faint accreting sources. Most of the recently discovered high-mass X-ray binaries (HMXBs) are characterized by high local absorption ($N_H > 10^{22} \text{ cm}^{-2}$) that prevented their detection by past soft X-ray monitoring. The BAT telescope is complementary to IBIS/ISGRI for the study of the temporal behavior of these sources as it covers a fraction between 50% and 80% of the sky every day due to its large field of view (1.4 sr half-coded) and to its pointing strategy. The long (since 2004 December 15) and continuous monitoring has allowed us to investigate the intrinsic emission variability and to search for the presence of long periodicities, unveiling the binary nature of many INTEGRAL sources (e.g., Corbet & Krimm 2009, 2010; Corbet et al. 2010a, 2010b, 2010c, 2010d, 2010e; Cusumano et al. 2010; La Parola et al. 2010; D’Alì et al. 2011).

In this Letter, we analyze the soft and hard X-ray data collected by Swift on IGR J18219−1347. The source was discovered by INTEGRAL (Krivonos et al. 2010) and it was associated with XMMSL1 J182155.0−134719 because of a spatial coincidence. A Two Micron All Sky Survey (2MASS) object (2MASS 18215463−1347232) found within the XMM counterpart position error box was initially identified as the infrared counterpart of the INTEGRAL source (Landi et al. 2011). IGR J18219−1347 was also detected by BAT (Krimm et al. 2012) at the end of 2012 January, with an intensity rising of a factor of 10 in seven days: the average 17–60 keV flux was $2 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$, more than 25 times the flux measured by INTEGRAL (Krivonos et al. 2010). The BAT detection triggered a Swift X-Ray Telescope (XRT; Burrows et al. 2005) follow-up observing campaign allowing to obtain a refined position with a localization accuracy of 1.7, confirming the soft X-ray counterpart XMMSL1 J182155.0−134719 and rejecting the infrared counterpart candidate 2MASS 18215463−1347232 (Krimm et al. 2012). The Swift-XRT observations also revealed strong evidence for variability with an intensity variation at least of a factor of 50. A follow-up observation with Chandra found a soft X-ray counterpart at a position of $\text{R.A.}=18^h20^m54.82^s$, decl.$\text{J2000}=-13^\circ47'26.7''$ with a localization accuracy of 0.64, thus reducing the area of position uncertainty of a factor of six (Karasev et al. 2012). The Chandra source was cross-correlated with the UKIDSS6 sky survey data allowing to identify an infrared source at $\text{R.A.}=18^h20^m54.766^s$, decl.$\text{J2000}=-13^\circ47'26.77''$, at a distance of ~0.8, with magnitudes $J=18.00$, $H=16.01$, and $K=14.44$, as the likely counterpart. An accurate study of the profile of the image of this source showed, however, that it is likely the superposition of two sources that cannot be separated because of the spatial resolution of the infrared data.

The broadband (0.5–150 keV) spectral obtained combining Swift-XRT and INTEGRAL/IBIS data was modeled with an

6 http://www.ukidss.org/index.html
absorbed power law (\(N_H \sim 3 \times 10^{22} \text{ cm}^{-2}\), photon index \(\sim 1\), and an exponential cutoff at \(\sim 6\) keV; Karasev et al. 2012). The information derived from the broadband spectral analysis and the strong variability suggested that IGR J18219−1347 belongs to the class of the HMXBs.

This Letter is organized as follows. Section 2 describes the data reduction. Section 3 reports on the timing analysis. In Section 4 we describe the spectral analysis and in Section 5 we briefly discuss our results.

2. DATA REDUCTION

The BAT survey data (15–150 keV) of the first 88 months of the Swift mission (2004 December–2012 March) were retrieved from the HEASARC public archive and processed with a software (Segreto et al. 2010) dedicated to the analysis of data of coded mask telescopes. The code performs screening, mosaicking, and source detection and produces scientific products of any detected source. IGR J18219−1347 was detected in the 15–150 keV energy band at a significance of 12.0 standard deviations, with a maximum of significance (12.7 standard deviations) in the 15–45 keV energy band. Figure 1 (left) shows the 15–45 keV significance sky map (exposure time of 28.1 Ms) centered in the direction of IGR J18219−1347. We extracted the background subtracted spectrum of the source averaged over the entire survey and the light curve in the 15–45 keV energy range with the maximum available time resolution (\(\sim 300\) s). The time tag of each bin of the light curve was corrected to the solar system barycenter using the JPL DE-200 ephemeris (Standish 1982) and the task EARTH2SUN.

Swift-XRT observed the field of IGR J18219−1347 on 2010 March 5 in the Photon Counting (PC) mode without detecting any source (Obs. 0 in Table 1). Two years later (2012 February 15), following the detection of the source as a transient by BAT, a one month target of opportunity campaign was activated. The source was observed in the PC mode in the first observation (Obs. 1 in Table 1) and in the Windowed Timing (WT) mode (Hill et al. 2004) in the following observations (Obs. 2–11 in Table 1). The XRT data were processed with standard procedures (XRTPIPELINE v.0.12.4), filtering, and screening criteria, using ftools in the Heasoft package (v 6.8). We adopted standard grade filtering 0–12 and 0–2 for PC and WT data, respectively. IGR J18219−1347 was detected only in 5 out of 11 observations. Table 1 reports the details on the Swift-XRT observations and the relevant count rate. Figure 1 (right) shows the 0.2–10 keV XRT image from ObsID 00032285001 where a source consistent in position to the likely soft X-ray counterpart XMMSL1 J182155.0−134719 is detected with a significance of

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**Table 1**

| Obs. # | Instrument Mode | Obs ID       | \(T_{\text{start}}\) (TDB) | \(T_{\text{elapsed}}\) | Exposure (s) | Rate (counts s\(^{-1}\)) | Orb. Phase |
|-------|-----------------|--------------|-----------------------------|-------------------------|--------------|-------------------------|------------|
| 0     | XRT-PC          | 00031649001  | 55260.7956                  | 17647.1                 | 1253.7       | <0.002                  | 0.86       |
| 1     | XRT-PC          | 00032285001  | 55972.2877                  | 39461.7                 | 1183.7       | 0.17 ± 0.01             | 0.68       |
| 2     | XRT-WT          | 00032285002  | 55978.6860                  | 24777.1                 | 2691.8       | 0.0682 ± 0.009          | 0.81       |
| 3     | XRT-WT          | 00032285003  | 55981.7045                  | 12850.7                 | 1786.2       | 0.056 ± 0.012           | 0.77       |
| 4     | XRT-WT          | 00032285004  | 55984.1737                  | 24217.0                 | 2935.5       | <0.025                  | 0.84       |
| 5     | XRT-WT          | 00032285005  | 55987.6437                  | 13019.6                 | 1476.7       | 0.027 ± 0.009           | 0.89       |
| 6     | XRT-WT          | 00032285006  | 55990.5850                  | 24750.7                 | 1247.3       | 0.022 ± 0.011           | 0.93       |
| 7     | XRT-WT          | 00032285007  | 55993.0593                  | 7396.7                  | 2797.1       | <0.022                  | 0.96       |
| 8     | XRT-WT          | 00032285008  | 55996.0047                  | 5457.5                  | 1462.8       | <0.027                  | 0.01       |
| 9     | XRT-WT          | 00032285009  | 55999.0754                  | 24613.9                 | 2604.3       | <0.021                  | 0.05       |
| 10    | XRT-WT          | 00032285010  | 56003.765                   | 18656.8                 | 3048.0       | <0.021                  | 0.11       |
| 11    | XRT-WT          | 00032285011  | 56005.7693                  | 7452.3                  | 2814.0       | <0.024                  | 0.14       |

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7 http://heasarc.gsfc.nasa.gov/docs/archive.html

8 http://heasarc.gsfc.nasa.gov/ftools/fhelp/earth2sun.txt
3. TIMING ANALYSIS

We analyzed the long-term BAT light curve to search for periodic intensity modulation using the epoch-folding method (Leahy et al. 1983). The 15–45 keV BAT light curve was folded with different trial periods $P$ from 0.5 days to 500 days with a step of $P^2/(N \Delta T)$, where $N = 16$ is the number of trial profile phase bins and $\Delta T = 211.7$ Ms is the data time span. To build profiles for each trial period, we applied a weighing procedure (e.g., Cusumano et al. 2010) suitable for background-dominated data with a large span of count rate errors. Figure 2(a) shows the periodogram, where several features emerge. The highest one has a $\chi^2$ value of $\sim 358$ and corresponds to a period of $P_0 = 72.44 \pm 0.3$ days. From fitting the peak profile with a Gaussian function, we derived a $P_0$ centroid and a standard deviation of 72.44 days and 0.3 days, respectively. We see also other evident features at periods multiples of $P_0$ ($P_1, P_2, P_3, P_4,$ and $P_5$ in Figure 2(a)) and at the sub-multiple $P_0/2$. The intensity profile (Figure 2(b)) folded at $P_0$ with $T_{\text{epoch}} = 54619.3125$ shows a peak that covers 30% of the period, over a flat level consistent with zero. To evaluate the phase position of the peak centroid, we have built a pulse profile folding BAT data with a minimum of 20 counts per energy channel, in order to allow the use of the $\chi^2$ statistics.
$P_0$, $N = 30$ phase bins, and fit the peak with a Gaussian model: the centroid is at phase $0.510 \pm 0.004$ corresponding to MJD (54656.26 ± 0.29) $\pm n P_0$. The presence of the feature at $P_0/2$ is a direct consequence of the sharp and narrow peak shown in Figure 2(b): folding with a period equal to $P_0/2$ this peak will be added coherently to the profile every two cycles, producing a feature in the periodogram with an intensity significantly lower with respect to the main feature.

As a consequence of the source variability and of the presence of a periodic signal, the average $\chi^2$ in the periodogram is far from the average value expected for white noise ($N = 1$) and the $\chi^2$ statistics cannot be applied. The significance of the observed feature shall be evaluated with respect to the average level of the periodogram noise. For this reason, we fitted the periodogram with a second-order polynomial and subtracted the best fit ($F_\chi^2$) to the $\chi^2$ distribution. The $z = \chi^2 - F_\chi^2$ distribution has a value of $\sim 304$ at $P_0$. We therefore have built the histogram of the $z$ distribution (Figure 2(c)) extracting the values only from 22 to 122 days (where the noise level is quite consistent with the noise level at $P_0$) and excluding the interval around $P_0$ and around $P_0/2$. We fit the tail ($z > 10$) of this distribution with an exponential function. The resulting best-fit model is plotted in Figure 2(c). We have evaluated the area under the histogram dividing it into two parts: from its left boundary up to $z = 10$, we have summed the contribution of each single bin; beyond $z = 10$ up to infinity, we have integrated the best-fit exponential model. Therefore, we evaluated the integral of the best-fit exponential function beyond 304 and normalized it to the total area of the histogram. The result ($6.7 \times 10^{-12}$) is the probability of chance occurrence of a $z$ equal to or larger than 304 or a $\chi^2$ equal to or larger than 358 and it corresponds to a significance for the detected feature of $\sim 7$ standard deviations in Gaussian statistics.

Figure 2(d) shows the 15–45 keV light curve of IGR J18219–1347 with a bin time of $P_0/5$. To visually show the periodicity in the BAT light curve, we overplotted vertical shaded bars spaced by $P_0$ and in phase with the peak of the BAT folded profile (Figure 2(b)). Table 1 reports the phase corresponding to each XRT observation relevant to the BAT light-curve profile in Figure 2(b). We observe that the pointing with the highest count rate corresponds to the phase closest to the peak, while upper limits correspond to orbital phases farther from the peak. The statistics of the source in the XRT data set both in PC and in the WT mode is too low to allow for timing analysis finalized to the search for a pulsation.

4. BROADBAND SPECTRAL ANALYSIS

Broadband spectral analysis was performed using the XRT data relevant to the observations with the source detected above two standard deviations (Obs. 1 in the PC mode and Obs. 2, 3, 5, and 6 in the WT mode that were summed into a single spectrum because the statistics of each single WT data set is too low to build a significant spectrum; see Table 1 and Section 2) and the BAT hard X-ray spectrum averaged over the 88 months of monitoring, selecting only intervals corresponding to the phase of the peak. We assumed no significant spectral variability among the XRT observations and during the BAT monitoring. A preliminary analysis was made to verify that this assumption was indeed valid. The XRT spectra in the PC mode and WT mode were fitted simultaneously with an absorbed power law with the absorption hydrogen column and the photon index parameters forced to have the same value in both data sets. The best-fit residuals showed the same trend for both data sets, with a best-fit photon index equal to $-0.2^{+0.9}_{-0.4}$ and absorbing column density equal to $3.3^{+3}_{-1} \times 10^{22}$ cm$^{-2}$. Six BAT spectra were produced to verify the assumption of non-variability both during the 88 month monitoring (dividing it into four 22 month long intervals) and/or during different phase intervals of Figure 2(b) (selecting the two spectra corresponding to phase intervals 0.4375–0.625 and 0.625–1.375). These spectra were fitted with a power-law model and, as above, the photon index was constrained to have the same value for all the spectra without any constraint for the normalization parameters. The best-fit residuals show the same trend for all the data sets, with best-fit photon index 2.64 ± 0.14.

Therefore, assuming no significant spectral variability during the BAT monitoring and between the XRT spectra, we performed a broadband spectral analysis coupling the soft X-ray spectra with the BAT spectrum selected in phase with the peak in the folded profile (phase intervals 0.4375–0.625 in Figure 2(b)) introducing in the model a multiplicative factor to take into account both an intercalibration factor between the two telescopes and the different average flux level among the three data sets. An absorbed power-law model gave an unacceptable $\chi^2$ of 89.21 (52 dof). This was expected because of the difference in photon index found in the analysis performed separately for the XRT and BAT data sets. The broadband spectrum resulted indeed well fitted ($\chi^2 = 61.7$ (51 dof)) adding to the power law a high-energy exponential cutoff (phabs*cutoffpl model). Figure 3 shows the combined XRT and BAT energy distribution with best-fit model (top panel) and residuals in units of standard deviations (bottom panel). Table 2 reports the best-fit parameters (quoted errors are given at 90% confidence level).

5. DISCUSSION AND CONCLUSIONS

We have presented the results obtained from the analysis of the data collected by Swift on IGR J18219–1347. The first 88 months of BAT survey data show a strong emission variability in the hard X-ray energies with the source going from quiescent to high emission states. The timing analysis performed on the BAT data unveils a periodic modulation of $P_0 = 72.44$ days that we interpret as the orbital period of binary system. The profile obtained folding the BAT light curve at $P_0$ shows a flat plateau consistent with the source being in a quiescent state, and a narrow peak lasting only 30% of the orbital period. The brightness enhancement on 2012 February 6
The broadband (0.2–150 keV) spectrum of IGR J18219–1347 is well modeled with a flat absorbed power law with a high-energy exponential cutoff at \( \sim 11 \) keV. The column density is \( \sim 4.3 \times 10^{22} \) cm\(^{-2}\), which is a factor of \( \sim 3 \) larger than the Galactic value in the direction of the source (1.3 \( \times 10^{22} \) cm\(^{-2}\); Dickey & Lockman 1990). This suggests an additional intrinsic absorption in the environment of the binary system. These spectral results are in agreement with those reported by Karasev et al. (2012) from the analysis of the XRT/Swift and IBIS/INTEGRAL data.

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Table 2  
Best-fit Spectral Parameters

| Parameter  | Best-fit Value | Units |
|------------|---------------|-------|
| \( N_H \)  | \( 4.3^{+1.8}_{-1.7} \times 10^{22} \) | cm\(^{-2}\) |
| \( \Gamma \) | \( -0.1^{+1.1}_{-0.6} \) | |
| \( E_{\text{cut}} \) | \( 11^{+6}_{-5} \) | keV |
| \( N \) | \( (7^{+9}_{-2}) \times 10^{-4} \) | photons keV\(^{-1}\) cm\(^{-2}\) s\(^{-1}\) at 1 keV |
| \( C_{\text{XRT-WT}} \) | \( 0.26 \pm 0.05 \) | |
| \( C_{\text{BAT}} \) | \( 0.33^{+0.01}_{-0.02} \) | |
| \( F_{(0.2–10 \text{ keV})} \) | \( 4.25 \times 10^{-11} \) | erg s\(^{-1}\) cm\(^{-2}\) |
| \( F_{(15–150 \text{ keV})} \) | \( 4.23 \times 10^{-11} \) | erg s\(^{-1}\) cm\(^{-2}\) |
| \( \chi^2 \) | \( 61.7 \) (51 dof) | |

Notes. \( C_{\text{XRT-WT}} \) and \( C_{\text{BAT}} \) are the constant factors to be multiplied to the model in order to match the XRT-WT and BAT data, respectively. We report unabsorbed fluxes for the standard XRT (0.2–10 keV) and BAT (15–150 keV) energy bands.