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Hard X-ray monitoring of HMXB with Swift-BAT: a systematic search to reveal long term periodicities

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The Burst Alert Telescope on board Swift has been performing a continuous monitoring of the sky in the hard X-ray energy range (15-150 keV) since November 2004. The telescope, thanks to its large field of view (1.4 sr half-coded) and its pointing strategy, covers a fraction between 50 and 80 per cent of the sky every day. This has allowed the quite continuous monitoring of many Galactic sources. The analysis of their long term light curves allows us to investigate the intrinsic emission variability, search for long periodicities (orbital periods) and discover the presence of eclipse events. The role of Swift-BAT is therefore fundamental to unveil the geometry of those binary systems (recently discovered by INTEGRAL) that, because of the high value of their absorption column density along the line of sight, are undetected by softer X-ray all-sky monitors. We present some timing results obtained on IGR sources through the BAT monitoring.

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1. Introduction

The IBIS/ISGRI telescope [1] on board the INTEGRAL satellite [2] has allowed the detection of a large number of new sources (~ 500) most of which characterized by a strong intrinsic absorption ($N_H > 10^{22}$ cm^2). About $\sim 26\%$ of these source are associated with Galactic sources and in particulat 56 sources are identified as binary systems with a supergiant companion.

The Burst Alert Telescope (BAT, [3]) on board the *Swift* satellite [4], thanks to its large field of view (1.4 steradian half coded) and its pointing strategy covers a fraction of between 50% and 80% of the sky every day allowing a long and continuous monitoring in the X-ray energy range 15–150 keV. The BAT data offer an inportant tool to investigate the intrinsic emission variability of these sources, providing the history of their long-term emission with a good time coverage and in an energy range where absorption does not prevent their detection. We are performing a systematic study of the BAT light curves of the new INTEGRAL HMXB sources to search for orbital period periodicities. In this paper we present some timing results on the following INTEGRAL sources: IGR J16493–4348, IGR J16465–4507, IGR J05007–7047 and IGR J17354–3255.

2. BAT survey data

The results presented in this paper are obtained by the analysis of the BAT survey data collected during the first 54 months of the Swift mission. These data were processed with a dedicated software [5] that performs screening, mosaicking and source detection on data from coded mask instruments. IGR J16493-4348, IGR J16465-4507, IGR J05007-7047 and IGR J17354-3255 were detected in the 54 months BAT all-sky sky map with a significance maximized in the 15–50 keV band of 20.8, 13.7, 16.1 and 18.9 standard deviations, respectively.

3. Timing Analysis

3.1 Method

Timing analysis was performed by applying the folding technique on the 15–50 keV BAT light curves and searching in the period range between 0.5 and 100 days. The average rate in each profile phase bin was evaluated by weighting the rates by the inverse square of its statistical error

$$R_j = \frac{\sum r_i/er_i^2}{\sum 1/er_i^2} \tag{3.1}$$

where R_j is the average rate in the j-th phase bin of the trial profile, r_i is the rate of the light curve bin whose phase falls into the j-th phase bin and er_i is the statistical error. The error on R_j is $(\sqrt{\sum 1/er_i^2})^{-1}$.

3.2 IGR J16493-4348

This source was discovered by INTEGRAL in 2004 [6]. A follow-up observation with *Chandra* found a soft X-ray counterpart (RA(J2000) = $16^h\ 49^m\ 26.92^s$; Dec(J2000) = -43° 49' 8.96" [7]) allowing the optical association with 2MASS J1642695–4349090, a B0.5 Ib supergiant [8].

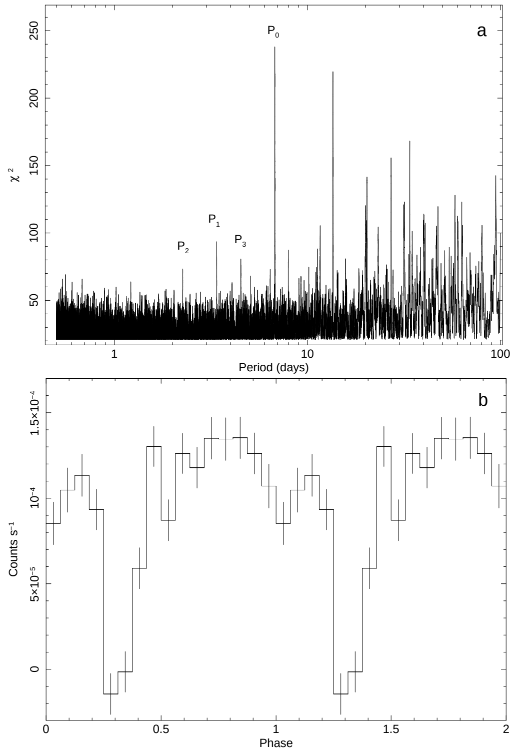

Figure 1: **a**: Periodogram of *Swift*-BAT (15–50 keV) data for IGR J16493–4348. **b**: Light curve folded at a period $P_0 = 6.783$ days, with 16 phase bins.

The periodogram (Fig. 1, (a)) obtained by the folding procedure on the BAT light curve shows several features. The highest, with a χ^2 value of ~ 240, is at $P_0 = 6.782 \pm 0.002$ d. The error is the period resolution evaluated as $P^2/(N\,\Delta T_{BAT})$ d, where $N = 16$ is the number of trial profile phase bins, and ΔT_{BAT} is the data span length (~ 20.000 days). The significance of P_0 is evaluated as ~ 8.5 standard deviations in Gaussian statistics. We also see other evident features at periods multiple of P_0 and at period tied to P_0 as P_1 (=$P_0/2$) due to the presence of the deep eclipse, still visible in the light curve folded at half of the period, P_2 (~ 2.27d$= (1/P_0 + 1/P_1)^{-1}$) and P_3 (~ 4.54d$= [(1/P_0 + 1/P_1)/2]^{-1}$) due to beat frequencies between P_0 and P_1. The pulsed profile (Fig. 1, b) folded at P_0 with T_{epoch}=54173.757 MJD shows a flat intensity level, abruptly broken by a deep full eclipse at phase 0.319 ± 0.015 corresponding to MJD $(54175.92 \pm 0.10) \pm n{\times}P_0$ MJD.

3.3 IGR J16465-4507

IGR J16465–4507. This source was discovered by INTEGRAL in 2004 [9]. Follow-up observations with XMM-Newton revealed pulsations at 228±6 s [10] and allowed the identification of the optical counterpart with 2MASS J16463526–4507045 [11] classified as a B0.5 Ib supergiant at a distance of ~ 8 kpc [12] or as a O9.5 Ia supergiant at a distance of $9.5^{+14.1}_{-5.7}$ kpc [13].

Figure 2 (a) shows the periodogram obtained folding the BAT data of IGRJ16465-4507. We find significant evidence for periodicity ($\chi^2 \sim 270$) at a period of $P_0 = 30.243 \pm 0.035$ days (the two features at higher periods are multiple of P_0). The significance of P_0 is 3.7 standard deviations.

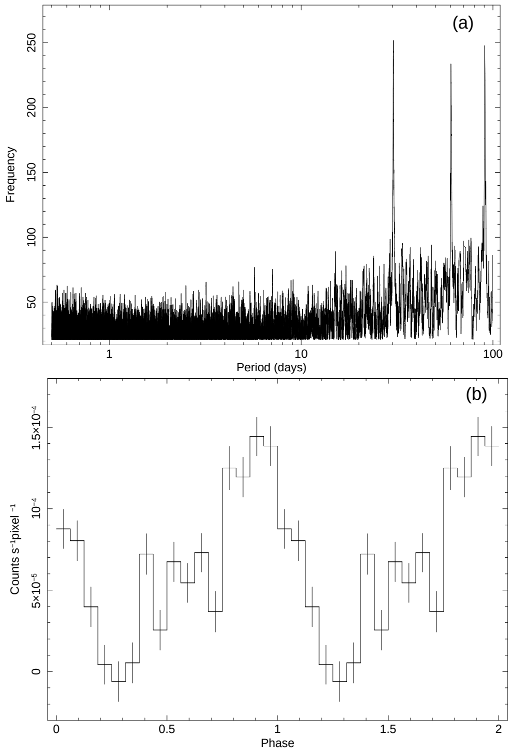

Figure 2: **a**: Periodogram of *Swift*-BAT (15–50 keV) data for IGR J16465–4507. **b**: Light curve folded at a period $P_0 = 30.243$ day, with 16 phase bins.

Figure 2 (b) shows the pulsed profile folded at P_0. There is clear evidence for a large phase interval ($\sim$20%) with an emission intensity consistent with zero, whose epoch centroid, evaluated by fitting the data around the dip with a Gaussian function, is at phase 0.297 ± 0.015, corresponding to MJD (52730.6±0.5) $\pm nP_{\rm orb}$.

3.4 IGR J05007-7047

IGR J05007-7047, located in the Large Magellanic Cloud, was detected with INTEGRAL in the 17-60 keV band [14] with a flux of 1.2×10^{-11} erg cm^{-2} s^{-1}, corresponding to a luminosity of 3.6×10^{36} erg s^{-1}, assuming a distance of 50 kpc. A dedicated *Chandra* observation allowed its association with the relatively bright blue (V=14.8, B-V=-0.01) star USNO-B1.0 0192-0057570 [15] of spectral type B2 III [16] at a redshift consistent with that of LMC.

Figure 3 (a) shows the periodogram obtained for IGR J05007-7047. We find significant evidence for the presence of a periodicity ($\chi^2 \sim 210$) at a period of $P_0 = 30.77 \pm 0.03$ days. The other two significant features in the periodogram correspond to 2P_0 and 3P_0. The significance of P_0 is $\sim$ 7 standard deviations. The pulsed profile (Fig. 3, b) folded at P_0 with $T_{\rm epoch} = 54159.75324287$ MJD, shows a roughly sinusoidal modulation with a minimum value consistent with zero intensity. The centroid of the minimum, evaluated by fitting the data around the dip with a Gaussian model is at phase 0.23 ± 0.02 corresponding to MJD $(54166.8 \pm 0.6) \pm n \times P_0$ MJD.

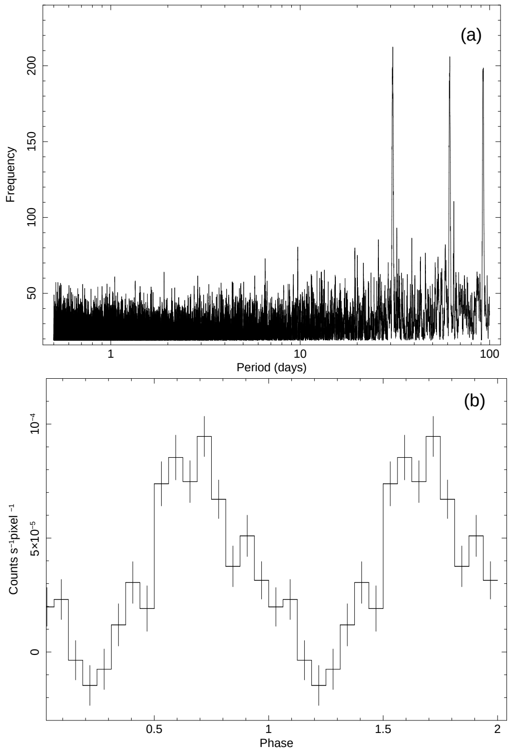

Figure 3: **a**: Periodogram of *Swift*-BAT (15–50 keV) data for IGR J05007-7047. **b**: *Swift*-BAT Light curve folded at a period $P = 30.77 \pm 0.01$ day, with 16 phase bins.

3.5 IGR J17354-3255

IGR J17354-3255 was discovered during the INTEGRAL Galactic Bulge monitoring program [17, 18]. The source has also a possible, highly variable, γ-ray counterpart detected with the Agile satellite (AGL J1734-3310, [19]).

The periodogram obtained for IGR J17354-3255 (Figure 4, a) shows significant evidence for the presence of a periodicity ($\chi^2 \sim 121$) at a period of $P_0 = 8.448 \pm 0.002$ days. The other significant features that appear in the periodogram corresponds to multiples of P_0 (up to $8P_0$). The significance of P_0 is ~ 4 standard deviations. The pulsed profile (Fig. 4, b) folded at P_0 with T_{epoch}=54175.15952181 MJD, shows a modulation with a minimum value consistent with zero intensity. The centroid of the minimum, evaluated by fitting the data around the dip with a Gaussian model is at phase 0.78 ± 0.02 corresponding to MJD $(54181.75 \pm 0.17) \pm n \times P_0$ MJD.

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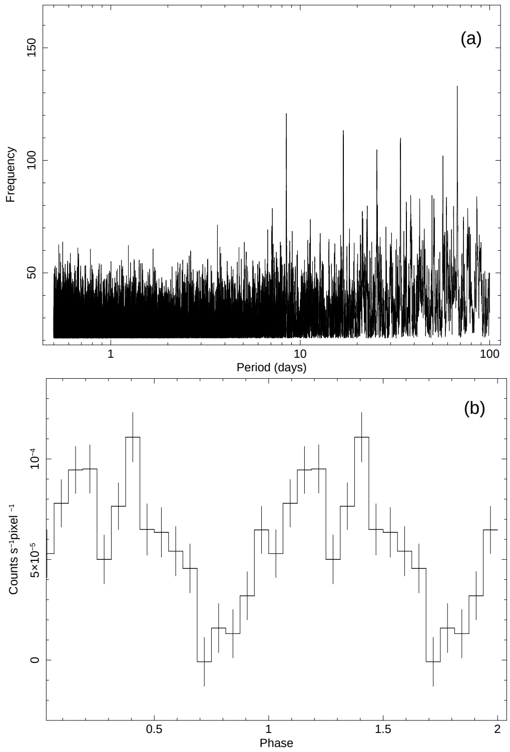

Figure 4: **a**: Periodogram of *Swift*-BAT (15–50 keV) data for IGR J17354-3255. **b**: *Swift*-BAT Light curve folded at a period $P = 8.452 \pm 0.002$ day, with 16 phase bins.

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