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INTEGRAL and *Swift/XRT* observations of the SFXT IGR J16479−4514: from quiescence to fast flaring activity

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We present results from a long term monitoring of the SFXT IGR J16479–4514 with detailed spectral and timing informations on 19 bright fast X-ray flares, 10 of which newly discovered. We also report results on the quiescent X-ray emission. We show that the fast flares from IGR J16479–4514 are detected typically every ∼1-2 days. Occasionally the source is in a quiescent state with typical luminosity $\sim 10^{34}$ erg s^{-1}, the longest period of inactivity sampled by our monitoring is ∼ 12 days. The quiescent luminosity is about 2 orders of magnitude greater than that typical of other known SFXTs while its broad band X-ray spectrum has a shape very similar to that during fast X-ray transient activity, i.e. a rather steep power law with with $\Gamma \sim 2.6$. Our findings suggest that during the quiescence of IGR J16479−4514, the compact object is still close to the supergiant donor star and so it is still accreting a significant amount of material from its wind but not in the form of clumps as during fast X-ray flares. This would explain the same spectral shape seen in quiescence and during flares since the emission mechanism should be the same, i.e. accretion onto the compact object.

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1. Introduction

The INTEGRAL satellite (Winkler et al. 2003) has been launched in 2002 and since then it is playing a key role in discovering many new High Mass X-ray Binaries (HMXBs) thanks to its large field of view, continous monitoring of the galactic plane and good sensitivity. The majority of these systems turned out to be persistent Supergiant High Mass X-ray Binaries (SGXBs) which escaped previous detection because of their very obscured nature (e.g. Walter et al. 2006). The remaining ones, named Supergiant Fast X-ray Transients (SFXTs, Negueruela et al. 2006, Sguera et al. 2005, 2006), were missed before because of their very low level of quiescent X-ray luminosities ($\sim 10^{32}$–10^{33} erg s^{-1}) occasionally interrupted by fast X-ray flares lasting typically less than a day and reaching peak luminosities of $\sim 10^{36}$ erg s^{-1}. This peculiar transient behaviour was never seen before from classical persistent SGXBs which are characterized by X-ray luminosities in the range 10^{36}–10^{38} erg s^{-1}.

IGR J16479−4514 was discoverd by INTEGRAL during observations performed between August 8–10 2003 (Molkov et al. 2003). Subsequently Sguera et al. (2005, 2006) unveiled its fast X-ray transient nature reporting several fast flares which strongly suggested a SFXT nature. This was later confirmed by optical and near/mid infrared observations of the source which lead to the identification of its counterpart with a supergiant star (O8.5I) at a distance of $\sim$ 4.9 kpc (Chaty et al. 2008).

Here we report on the characteristics of 10 newly discovered fast flares detected by IBIS and provide for the first time 20–60 keV spectral information for the set of 19 flares detected so far; for one such flare we also report and discuss the broad band X-ray spectrum obtained combining simultaneous *Swift*/XRT, JEM-X and ISGRI data. Moreover we present the broad band spectral data on the quiescent X-ray emission of IGR J16479−4514 which is a very rare information on SFXTs on account of their very recent discovery as class of sources.

2. Timing analysis

The ISGRI long term light curve (20–60 keV) of IGR J16479−4514 on ScW timescale is shown in Fig. 1, where the black line represents the 2σ upper limit at the ScW level ($\sim$10 mCrab or 1.2×10^{-10} erg cm^{-2} s^{-1}). Most of the time the source is below the instrumental sensitivity of ISGRI; sporadically it undergoes fast X-ray flares. In particular we considered those outbursts having a peak flux greater than $\sim$ 30 mCrab or 3.6×10^{-10} erg cm^{-2} s^{-1} (20–60 keV), this peak flux value is represented in Fig. 1 by the broken line. We adopt a conservative peak flux threshold for flare recognition in order to pick up flare bright enough to extract a meaningful ISGRI spectrum. By applying this criterium, a total of 19 fast X-ray flares have been detected and they are listed in Table 1. In particular, ten new flares are reported here for the first time (N. 6,7,10,11,12,14,15,16,17,19 in Table 1).

On the basis of Table 1, although the typical flare duration is only a few hours, we note that the source occasionally displays activity over a period of a few days. The typical peak flux is in a narrow range $\sim$40–80 mCrab (20–60 keV) but occasionally much brighter flares occur. A detailed analysis of Fig. 1 indicates that the typical flare recurrence time is $\sim$1-2 days: 19 flares were detected over a total exposure of $\sim$ 23 days. To search for real evidence of periodicity, we

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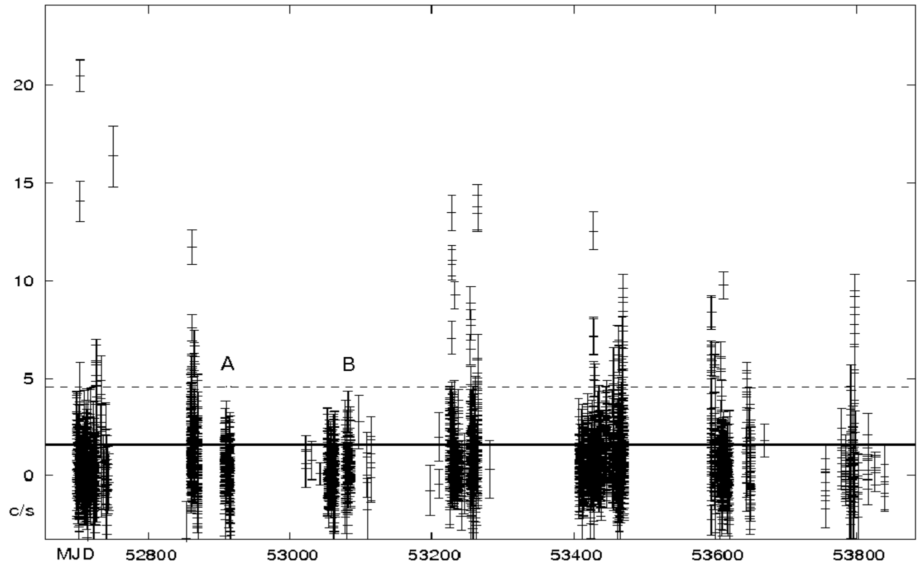

Figure 1: ISGRI long term light curve (20–60 keV) of IGR J16479−4514. Time and flux axis are in MJD and count s^{-1}, respectively. Each data point represents the average flux during one ScW ($\sim$ 2000 seconds).

further used the Lomb-Scargle method with the fast implementation of Press & Rybicki (1989) and Scargle (1982) but no indication of periodicity was found in the range 1–300 days. We also searched a 1 second bin time ISGRI light curve of all brightest outbursts in Table 1 (N. 1,6,9,10,18) for pulsations but none were found.

A deeper inspection of Fig. 1 also shows that the source occasionally enters long periods during which the flux level is very low, i.e. never greater than $\sim$10 mCrab (for example, blocks A and B in Fig. 1). Although no evident flaring activity is visible, it is possible that the source is still active and it produces weaker sub-flares at the limit of the IBIS detectability. However, since the source reaches its lowest flux during such periods, we tentatively associate them to the source quiescence which must be well below $\sim$ 10 mCrab (20–60 keV).

Flare N. 18 in Table 1 is particularly interesting because it was discovered by *Swift*/BAT (15–50 keV) which promptly triggered the *Swift*/XRT observation (1–8 keV) that caught the flare only during its decay phase (Kennea et al. 2005). Here we report for the first time on the simultaneous JEM-X and ISGRI detection of such flare which provides a light curve (200 seconds bin time) in two different energy bands: 10–20 keV (JEM-X) and 20–60 keV (ISGRI) as reported in Fig. 2.

During the four *Swift*/XRT observations (see Table 2), IGR J16479−4514 showed flaring activity only at the beginning of OBS1 (see bottom Fig. 2) where two X-ray flares are evident. Apart from the first flare previously cited, a second one started $\sim$ 4,000 seconds later with a duration of $\sim$ 1,000 seconds. It was outside the JEM-X FOV while it may be present in the ISGRI light curve (see top Fig. 3) however without sufficient statistical significance for a secure claim because it was too faint (average flux $\sim 2\times10^{-11}$ erg cm^{-2} s^{-1}, 1–9 keV). No more flaring activity was detected in the remaining part of OBS1 nor in the following *Swift*/XRT pointings (OBS2/3/4) and the source

Table 1: Summary of all IBIS detections of fast hard X-ray flares from IGR J16479−4514. The table lists the date of their peak emission, approximative duration of the entire flaring activity, flux and luminosity at the peak (20–60 keV), spectral parameters of the bremsstrahlung and power law spectral fits with their corresponding χ^2_ν and d.o.f. in parenthesis, and finally reference to the discovery paper of each flare.

N.	date (UTC)	duration (hours)	peak flux (20–60 keV) (mCrab)	peak lum⋆ (20–60 keV) (10^{36} erg s^{-1})	KT$_{BR}$ (keV)	Γ	ref
1	5 Mar 2003, ∼14:00	∼0.5	∼560	∼ 19	$21^{+3}_{-2.5}$ (0.56,14)	2.9±0.2 (0.87,14)	1
2	28 Mar 2003, ∼8:30	∼1.5	∼40	∼ 1.3			1
3	21 Apr 2003, ∼9:00	∼0.5‡	∼100	∼ 3.4	21^{+6}_{-11} (0.6,14)	$3^{+0.5}_{-0.6}$ (0.54,14)	1
4	10 Aug 2003, ∼12:00	∼60	∼70	∼ 2.4			4
5	14 Aug 2003, ∼1:00	∼2‡	∼40	∼ 1.3			1
6	11 Aug 2004, ∼7:00	∼8	∼80	∼ 2.7	30^{+15}_{-8} (0.74,14)	2.5±0.4 (0.72,14)	3
7	15 Aug 2004, ∼17:00	∼2	∼55	∼ 1.8	∼ 40 (1.1,14)	2.3±0.9(1.06,14)	3
8	7 Sep 2004, ∼2:00	∼2	∼80	∼ 2.7	44^{+32}_{-14} (0.65,14)	2.2±0.3 (0.65,14)	2
9	16 Sep 2004, ∼17:00	∼2.5	∼120	∼ 4		2.6±0.2 (1.06,14)	2
10	27 Feb 2005, ∼14:30	∼3	∼75	∼ 2.5	46^{+40}_{-17} (0.93,20)	2.2±0.45 (1.01,20)	3
11	27 Mar 2005, ∼19:00	∼1	∼40	∼ 1.3			3
12	3 Apr 2005, ∼00:00	∼2	∼45	∼ 1.5			3
13	4 Apr 2005, ∼03:00	∼9‡	∼45	∼ 1.5	29^{+15}_{-8} (1.02,14)	2.6±0.4 (1.01,14)	2
14	9 Apr 2005, ∼12:00	∼50	∼60	∼ 2			3
15	12 Aug 2005, ∼19:00	∼9‡	∼55	∼1.8	$26^{+21}_{-8.5}$ (0.6,8)	2.5±0.5 (0.6,8)	3
16	17 Aug 2005, ∼21:30	∼8	∼40	∼ 1.3			3
17	26 Aug 2005, ∼05:00	∼6	∼40	∼ 1.3			3
18	30 Aug 2005, ∼04:00	∼0.5	∼180	∼ 6	38^{+20}_{-11} (0.65,19)	2.3±0.35 (0.8,19)	5
19	3 Mar 2006, ∼09:30	∼3‡	∼60	∼ 2			3

‡ = lower limit on the duration, ⋆ = assuming a distance of ∼ 4.9 kpc (Chaty et al. 2008).
(1) Sguera et al. 2005; (2) Sguera et al. 2006; (3) this paper; (4) Molkov et al. 2003; (5) Kennea et al. 2005.

Table 2: Summary of *Swift*/XRT observations of IGR J16479−4514. The table lists the exposure time and the date of each observation, the average X-ray flux and the corresponding luminosity (1–9 keV), the photon index Γ of the absorbed power law best fit spectrum with the corresponding χ^2_ν and d.o.f. in parenthesis, and finally the total absorption N_H.

No.	expo (ks)	OBS date (UTC)	average flux (1–9 keV) (erg cm^{-2} s^{-1})	average lum⋆ (1–9 keV) (erg s^{-1})	Γ	N_H 10^{22} (cm^{-2})
OBS1 (decay flare N. 18)	0.5	30 Aug 2005	$\sim 1.1\times10^{-10}$	$\sim 3.2\times10^{35}$	Γ=1.1±0.8 (0.99,20)	$8.5^{+6.5}_{-4.5}$
OBS1 (quiescence)	8	30 Aug 2005	$\sim 6\times10^{-12}$	$\sim 1.7\times10^{34}$	Γ=0.75±0.6 (0.45,19)	$4.5^{+2.2}_{-1.3}$
OBS2	6.4	10 Sep 2005	$\sim 2.6\times10^{-11}$	$\sim 7.4\times10^{34}$	Γ=1.35±0.4 (0.9,54)	$9.5^{+2.2}_{-1.9}$
OBS3	4.1	14 Sep 2005	$\sim 2\times10^{-12}$	$\sim 5.7\times10^{33}$	Γ ∼0.6 (0.6,17)	∼5
OBS4	5.4	18 Oct 2005	$\sim 7.5\times10^{-12}$	$\sim 2.1\times10^{34}$	Γ=1.8±0.9 (0.55,17)	8.4^{+5}_{-4}

⋆ = assuming a distance of ∼ 4.9 kpc (Chaty et al. 2008, Rahoui et al. 2008).

appeared to have reached its likely quiescent state with a typical 1–9 keV luminosity of $\sim 10^{34}$ erg s^{-1} (see Table 2).

3. X-ray spectral analysis

3.1 Flares

To date ISGRI spectral information on flares from SFXTs is sparse, however in the case of IGR J16479−4514 the large number of bright flares allows a proper study to be performed. For the majority of flares reported in Table 1 we were able to extract an ISGRI spectrum and perform a fit with two different spectral models: power law and bremsstrahlung. Spectral parameters, χ^2_ν and corresponding degree of freedom (d.o.f) are all listed in Table 1. A discrimination between these two models on a statistical basis is not possible because all fits give acceptable and comparable χ^2_ν; the bremsstrahlung temperatures and power law indices fall in a narrow range of kT=21–46 keV and Γ=2.2–3 and this suggests constancy in shape (but not flux) of the source spectra from flare to flare. Bearing this in mind and in order to improve the statistics, ISGRI spectra from all flares were fit together using the two models previously adopted; the bremsstrahlung model provided a kT=$27^{+3.2}_{-3.6}$ keV (χ^2_ν=0.9, 109 d.o.f.) while the power law gave a Γ=2.66$\pm$0.13 (χ^2_ν=0.95, 109 d.o.f.).

Next we analysed in detail flare N. 18 using all avaliable data. An absorbed power law fit to the *Swift*/XRT data alone (relative to only the first flare in bottom Fig. 2) provided a flat photon index and absorption N_H (see Table 2) in excess to the galactic value, which along the line of sight is 2.1×10^{22} cm^{-2}. JEM-X data alone are also well fit by a power law with photon index Γ=2.2$\pm$0.2, a value very similar to that found by ISGRI. We subsequently performed the broad band spectral analysis over the 2–60 keV energy range; an absorbed power law provides a meaningful fit to the data (χ^2_ν=0.9, 154 d.o.f.) with Γ=2.5$\pm$0.2 and N_H=16$\pm$3$\times10^{22}$ cm^{-2}, Fig. 3 (top) displays such unfolded broad band spectrum. No cut-off is statistically required in the data fit. The total N_H inferred from the absorbed power law broad band fit is much higher than that obtained from individual *Swift*/XRT spectral fits; such high N_H could explain why the *Swift*/XRT spectrum have a rather hard photon index compared to the steeper JEM-X/ISGRI spectra. Moreover, an absorbed bremsstrahlung model fits equally well the data (χ^2_ν=1.05, 154 d.o.f., kT=$19^{+6.3}_{-4.3}$, N_H=$9^{+2.5}_{-2}$ $\times10^{22}$ cm^{-2}).

3.2 Quiescence

From the long term light curve of IGR J16479−4514, we individuated a total of $\sim$ 530 pointings during which the source is not significantly detected in any individual ScW (see blocks A and B in Fig. 1); however a mosaic of all these ScWs provided a clear detection of the source at $\sim$ 9σ level in the 20–60 keV band. The extracted spectrum is equally well fit using a power law (Γ=2.5$\pm$1, χ^2_ν=0.2, 4 d.o.f.) and a bremsstrahlung (kT=30^{+47}_{-14} keV, χ^2_ν=0.2, 4 d.o.f.). The average 20–60 keV flux and luminosity are $\sim 1.7\times10^{-11}$ erg cm^{-2} s^{-1} and $\sim5\times10^{34}$ erg s^{-1}.

The soft X-ray properties of the quiescence as detected by *Swift*/XRT can be safely associated to OBS2/3/4 and to the final part of OBS1. The typical quiescent X-ray luminosity is $\sim\ \times10^{34}$ erg s^{-1} (1–9 keV). All spectra pertaining to these observations are best fit by an absorbed power law model (see Table 2); the values of the photon index are compatible within the uncertainties indicating that the source may be characterized by the same rather hard spectral shape during quiescence and also during the decay phase of flare N. 18.

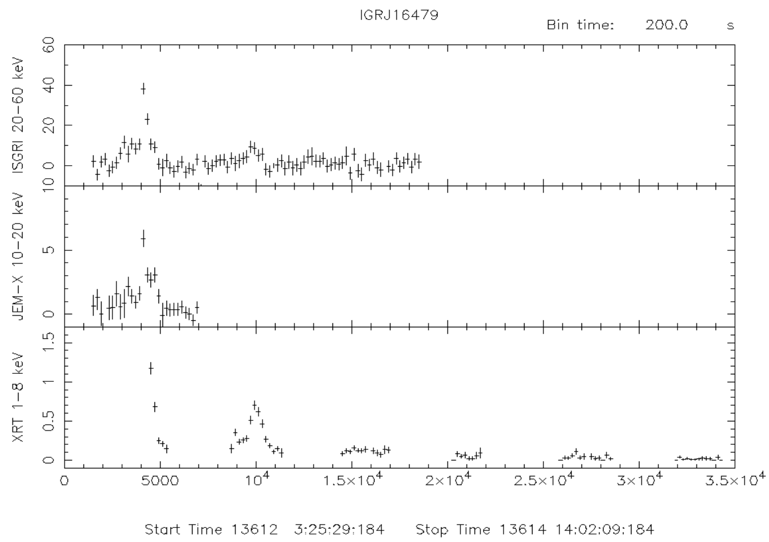

Figure 2: ISGRI (top), JEM-X (middle) and *Swift/XRT* (bottom) simultaneous light curves of the flare N. 18 in Table 1. The bin time is 200 seconds.

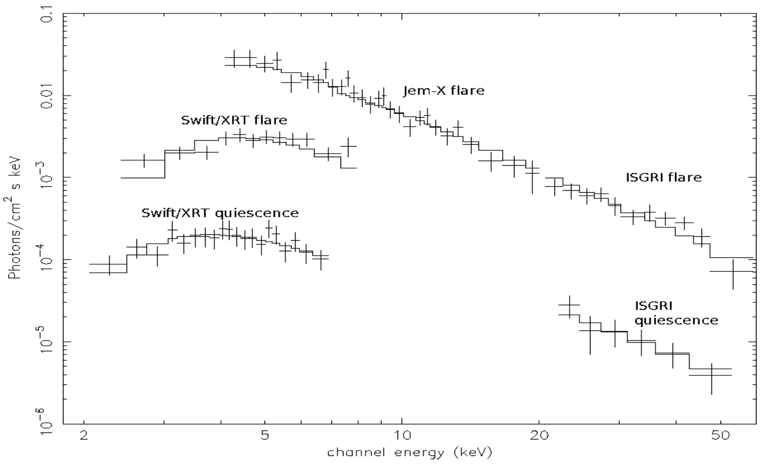

Figure 3: Unfolded broad band spectrum (2–60 KeV) of flare N.18 in Table 1 (top) and of the quiescent emissiom (bottom).

We combined the *Swift*/XRT spectrum of OBS4 with that of ISGRI in quiescence to obtain broad band energy information over the 2–60 keV band. The underlyng assumption is that the spectral shape of the source did not change during the time interval between the *Swift*/XRT and the IBIS observations, which is reasonable given the constancy in shape seen both by IBIS and *Swift*/XRT. The best fit is provided by an absorbed power law model (χ^2_ν=0.5, 22 d.o.f.) with Γ=2.2$\pm$0.75 and a total N_H=$9^{+4.0}_{-3.5}$ $\times 10^{22}$ cm^{-2}. Fig. 3 (bottom) displays the unfolded broad band spectrum. Also in this case, the bremsstrahlung provided a comparably good fit (χ^2_ν=0.4, 22 d.o.f.), however the temperature was not well constrained (kT$\sim$ 20 keV). We point out that the broad band X-ray spectral shapes of the source in quiescence and during flaring activity are very similar, as it can be clearly noted in Fig. 3.

4. Discussion

We presented results from a long term monitoring of IGR J16479−4514 with detailed informations on 19 bright flares. The flares are detected typically every ∼1-2 days, this makes IGR J16479−4514 the SFXT with the highest duty cycle so far seen. The typical flare duration is only a few hours but occasionally longer flaring activity has been detected. The quiescent X-ray luminosity of the source is typically $\sim 10^{34}$ erg s^{-1}, about two orders of magnitude higher than that typical of other SFXTs. The longest period of inactivity sampled by our monitoring is ∼ 12 days. Detailed X-ray spectral analysis shows that the shape of the source in quiescence and during flares is identical (i.e a rather steep power law with $\Gamma \sim 2.6$), despite large excursions in flux. Our findings suggest that during the quiescence of IGR J16479−4514, the compact object is still close to the supergiant donor star and so it is still accreting a significant amount of material from its wind but not in the form of clumps as during fast X-ray flares. This would explain the same spectral shape seen in quiescence and during flares since the emission mechanism should be the same, i.e. accretion onto the compact object. Consecutively, the system should be characterized by an orbital period no longer than ∼ 20 days otherwise it would be in quiescence for longer intervals and with lower X-ray luminosity than those effectively observed.

The accumulation of exposure time and longer temporal coverage of the source by IBIS is very likely to further increase the possibility of discovering the orbital period of IGR J16479−4514 which could provide a key information to study and understand the physical reasons behind its very unusual X-ray behaviour.

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