THE INTEGRAL SOURCE IGR J16328−4726: A HIGH-MASS X-RAY BINARY FROM THE BEPPOSAX ERA

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ABSTRACT

We report on temporal and spectral analysis of the INTEGRAL fast transient candidate IGR J16328−4726 observed with BeppoSAX in 1998 and more recently with INTEGRAL. The MECS X-ray data show a frequent microactivity typical of the intermediate state of supergiant fast X-ray transients and a weak flare with a duration of ∼4.6 ks. The X-ray emission in the 1.5−10 keV energy range is well described through the different time intervals by an absorbed power-law model. Comparing spectra from the lower emission level up to the peak of the flare, we note that while the power-law photon index was constant (∼2), the absorption column density varied by a factor of up to ∼6−7, reaching a value of ∼2 × 10^23 cm^−2 at the peak of the flare. Analysis of the long-term INTEGRAL/IBIS light curve confirms and refines the proposed ∼10.07 day period, and the derived ephemeris places the BeppoSAX observations away from periastron. Using the near- and the mid-IR available observations, we constructed a spectral infrared distribution for the counterpart of IGR J16328−4726, allowing us to identify its counterpart as a high-mass OB type star and to classify this source as a firm HMXB. Following the standard clumpy wind theory, we estimated the mass and the radius of the clump responsible for the flare. The obtained values of M_{cl} ≃ 4 × 10^{22} g and R_{cl} ≃ 4.4 × 10^6 km are in agreement with expected values from theoretical predictions.

Key words: stars: massive – stars: neutron – X-rays: binaries – X-rays: individual (IGR J16328−4726)

Online-only material: color figures

1. INTRODUCTION

The X-ray fast transient source IGR J16328−4726 was discovered by Bodaghee et al. (2007). Fiocchi et al. (2010), making use of the IBIS/INTEGRAL data, tentatively classified it as a supergiant fast X-ray transient (SFXT) candidate on the basis of its transient and recurrent nature, the spectral properties observed during the outbursts which lasted only a few tens of minutes/hours, its location in the Galactic plane, the faint quiescent emission (∼2.5 × 10^{-12} erg s^{-1} cm^{-2}), and a flux dynamic range > 170 in the 0.3−10 keV (XRT/Swift) and > 165 in the 20−50 keV (IBIS/INTEGRAL) bands. The source characteristics and behavior are reported in Fiocchi et al. (2010) and references therein. An additional detection was reported in the Swift BAT 54 month all-sky survey (Cusumano et al. 2010) with an averaged flux of (3.2 ± 0.8) × 10^{-11} erg cm^{-2} s^{-1} in the 15−70 keV energy band.

The physical mechanism producing short X-ray flares of the SFXTs is still under discussion, and several scenarios have been proposed. The most frequently discussed scenario is the clumpy stellar wind model (in’t Zand 2005; Walter & Zurita Heras 2007) where dense clumps in an isotropic stellar wind cause short X-ray flares when they accrete onto a neutron star (NS). Several SFXT systems can be explained by an eccentric NS orbit around a massive star with a disk-like anisotropic stellar wind (Sidoli et al. 2007). The SFXT emission could also be explained by a gating effect caused by the extremely strong NS magnetic field (≈ 10^{14} G) and rotational properties (Bozzo et al. 2008a).

Proximity to the black hole candidate 4U 1630−47 has its location in the Galactic plane, the faint quiescent emission (∼2.5 × 10^{-12} erg s^{-1} cm^{-2}), and a flux dynamic range > 170 in the 0.3−10 keV (XRT/Swift) and > 165 in the 20−50 keV (IBIS/INTEGRAL) bands. The source characteristics and behavior are reported in Fiocchi et al. (2010) and references therein. An additional detection was reported in the Swift BAT 54 month all-sky survey (Cusumano et al. 2010) with an averaged flux of (3.2 ± 0.8) × 10^{-11} erg cm^{-2} s^{-1} in the 15−70 keV energy band.

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2. INTEGRAL OBSERVATIONS AND DATA ANALYSIS

The INTEGRAL data set used included all public data available for the period up to 2010 September 30 (MJD 52650 through MJD 55469). The total on-source exposure on IGR J16328−4726 during this period was ∼9.2 Ms. Light curves for both IGR J16328−4726 and 4U 1630−47 were extracted from science window (pointing) images constructed using the standard OSA9 analysis software in the 18−60 keV energy band. The light curves were then filtered to remove science windows (ScWs) with an exposure of less than 200 s and/or in which the sources were at an off-axis angle of greater than 12 deg as such ScWs have large intrinsic uncertainties in flux measurement. The final, filtered IGR J16328−4726 light curve has an on-source exposure of ∼7.1 Ms. We performed a timing analysis on the derived IGR J16328−4726 light curve using standard Lomb–Scargle techniques (Lomb 1976; Scargle 1982) to search for periodic signals in the data and Monte Carlo randomization to determine both the significance of and uncertainty in the derived periodicities (for further information on the randomization techniques applied, see Drave et al. 2010 and references therein).

3. INTEGRAL TIMING ANALYSIS

The Lomb–Scargle periodogram of the 18−60 keV IBIS/ISGRI light curve of IGR J16328−4726 (Figure 1, left panel) shows the detection of a period at 10.068 days, which we interpret as the likely orbital period. A randomization Monte Carlo determined the σ uncertainty on that period to be 10.068 ± 0.002 days. This period is consistent, within errors, with that reported in Corbet et al. (2010) and provides an independent confirmation of the orbital period of the binary system.
The detection in that work used a Swift/BAT data set spanning MJD 53359 through MJD 55104. This data set began after the last period of high X-ray activity in 4U 1630−47 ceased at ∼MJD 53300. The INTEGRAL/IBIS data set used in this work does span the earlier region of high activity of 4U 1630−47. However, there is only a small amount of contamination from this bright source in the IGR J16328−4726 light curve and a comparative analysis performed using only data from the same MJD range as Corbet et al. (2010) provided a consistent detection of the period. The higher exposure in the full data set allowed a more accurate determination of the period and its uncertainty, however, and therefore it is this data set that is used in the remainder of this work.

Folding the light curve using the best orbital period determination of 10.068 days and a zero-phase ephemeris of MJD 52651.164 yields the folded light curve shown in Figure 1 (right panel). This shows a single broad emission profile is similar to those observed from other SFXTs such as 4U 1630−47. The shape of the profile is similar to those observed from other SFXTs such as IGR J17544−2619 (Clark et al. 2009) and IGR J16465−4507 (Clark et al. 2010). The times of the BeppoSAX observations within this orbital phase using the stated ephemeris are also indicated.

4. BeppoSAX OBSERVATIONS AND DATA ANALYSIS

Results presented here are from the Low Energy Concentrator Spectrometer (LECS; Parmar et al. 1997) and the Medium Energy Concentrator Spectrometer (MECS; Boella et al. 1997) on board BeppoSAX. The High Pressure Gas Scintillation Proportional Counter (HPGSPC; Manzo et al. 1997) and the Phoswich Detection System (PDS; Frontera et al. 1997) instruments were not considered as their field of view also included emission from the nearby black hole candidate 4U1630−47.

The LECS and MECS event files and spectra were generated with the Supervised Standard Science Analysis (Fiore et al. 1999). The MECS spectra were accumulated in circular regions of 4′ radius and publicly available response matrices were used. The off-axis corrections have been taken into account using the apposite response matrices.

The point-spread function (PSF) of the MECS instruments has been modeled as the sum of two components: a Gaussian describing mainly the detector PSF and a King profile describing mainly the optics PSF (Boella et al. 1997). The final result is a fully analytic differential PSF with a width of 2.5 at 6.4 keV, 80% of encircled energy radius. Since the distance between the black hole 4U 1630−47 and IGR J16328−4726 is ∼14′, the black hole contribution within the spectral extraction radius of the IGR J16328−4726 is widely below 1% (this being the systematic error added to the data following the indications given in Fiore et al. 1999 for the standard spectral analysis).

In the archival MECS images (1.5–10 keV), IGR J16328−4726 was detected above 5σ during three different observations performed on 1998 March 7 12:23:21.0 UTC, 1998 March 19 14:52:11.0 UTC, and 1998 March 26 17:16:48.5 UTC. The LECS image analysis (0.5–3.5 keV) showed that IGR J16328−4726 was not detected above 5σ during these three observations. Log of these observations are shown in Table 1, reporting start times, exposure times, and the IGR J16328−4726 count rate for each observations.

5. THE BEPPOSAX MECS RESULTS

Figure 2 (upper panel) shows the MECS light curve of IGR J16328−4726 with a bin size of 300 s. As previously observed by IBIS on board the INTEGRAL satellite (Fiocchi et al. 2010), the source shows highly recurrent microactivity with durations from tens of minutes to several hours.

To search for spectral changes, we accumulated X-ray spectra during several time intervals, as indicated on the light curve.
The X-ray spectra are all well fitted by an absorbed power law in the 1.5–10 keV energy range. Details of the time intervals and results of this analysis for each selected period are reported in Table 2.

Figure 3 (left panel) shows the MECS spectra and residuals with respect to the absorbed power-law models at the peak of emission (phase G) and at the lowest emission level (phase L), indicated with squares and stars, respectively. A plot of the evolution of the spectral parameters of the source is provided in Figure 4. The power-law photon index remained fairly constant (see Figure 4, right panel) including both the MECS and IBIS data from Fiocchi et al. (2010), whereas the absorption column density underwent changes (Figure 4, left panel). In particular, we measured a large increase (factor of ~6–7) in the absorption column density from the lower emission level (phase L) up to the peak of the flare (period G) when the column density reached a value of ~2 × 10^{23} cm^{-2}. To test the significance of the measured variation in the absorption column density, we report in Figure 3 the N_{H}–flux parameters’ confidence contours for the relevant spectra in phases G and L (middle and right panels). The contours correspond to 68%, 90%, and 99% confidence level. A very significant increase in the absorption column density with the unabsorbed fluxes is clearly detected. Although adding an iron line does not significantly improve the fit, we considered this component to estimate the iron line equivalent width upper limits. With the iron line centroid fixed at 6.5 keV, we obtained equivalent width upper limits of 440 eV and 262 eV (3σ confidence level) for the peak of the flare (period G) and the lower emission level (phase L), respectively.

6. SUMMARY OF THE MAIN OUTBURST CHARACTERISTICS

The MECS light curve of IGR J16328−4726 (Figure 2) shows highly recurrent microactivity with durations of tens of minutes and a strong outburst (its peak is reported as epoch G in Figure 2). During the outburst detected with the MECS instrument, the source was not significantly detected (>5σ) in
the corresponding LECS image that had an exposure time of 775 s.

The spectral analysis of the outburst peak is reported in Table 2 (period G) for comparison with other activity periods of the IGR J16328−4726 and is summarized in Table 3, where we reported start time, duration, and spectral parameters. Using these values and assuming a distance of 3 kpc and 10 kpc, the X-ray luminosity (2−10 keV) spans from $10^{35}$ to $10^{36}$ erg s$^{-1}$, respectively.

To determine the best position, and as the source is highly absorbed, we extracted the MECS image in the 4−10 keV energy band during its outburst (G period reported in Figure 2). IGR J16328−4726 was detected at $(51.5 \pm 3.0) \times 10^{-2}$ counts s$^{-1}$ at R.A.(J2000) = 16°32′38.1 ″ and decl.(J2000) = $-47°23′56.8″$ with a error box of 35 arcsec (Figure 2, lower panel). Note that the circle reported in this figure is the radius for spectral extraction and not the position error box.

7. INFRARED IDENTIFICATION

The transient X-ray source IGR J16328−4726 has been identified with the near-IR source 2MASS16323791−4723409 (Grupe et al. 2009), shown in Figure 5 (left panel). The 2MASS catalog reports only the J magnitude and gives an upper limit in H and K. From the images we have obtained the complete photometry of this source using the calibration reported in the headers. The measured magnitudes are $J = 14.32 \pm 0.06$, $H = 12.29 \pm 0.03$, and $K = 11.19 \pm 0.02$. The source is reported in the DENIS survey as J1632379−472341 and has also been detected by the Spitzer/GLIMPSE survey. The magnitudes reported in the four IRAC bands obtained from the GLIMPSE catalog (G336.7492+00.4223) are $M_{3.6,\mu m} = 2.1 \pm 0.05$, $M_{4.5,\mu m} = 9.81 \pm 0.06$, $M_{5.8,\mu m} = 9.63 \pm 0.05$, and $M_{8.0,\mu m} = 9.52 \pm 0.04$. From the observed near-IR colors of the source $J - H = 2.03 \pm 0.06$ and $H - K = 1.10 \pm 0.03$, we derive a visual extinction of $A_V = 20$. The source is not detected in the I band (DENIS survey) and it is not reported in other optical catalogs. Combining the near- and the mid-IR observations we have obtained the spectral infrared distribution for IGR J16328−4726, shown in Figure 5 (right panel) as open and filled circles. Using the reddening law derived by Rieke & Lebofsky (1985), we have de-reddened the observed spectral infrared distribution for IGR J16328−4726.
Figure 5. Left panel: color-coded 2MASS image centered on IGR J16328−4726 made from J(blue), H(green), and K(red) individual images. The circle is the XRT uncertainty at 99% confidence level from Grupe et al. (2009). Right panel: the infrared energy distribution of the IGR J16328−4726 counterpart.

(A color version of this figure is available in the online journal.)

Table 2

| Interval | OBS. Tstart | Interval Tstart | Tstart Phase | Exp. (s) | Rates (10^{-2} counts s^{-1}) | \(N_H\) (10^{22} cm^{-2}) | \(\Gamma\) | \(F_{\text{unabs}}\) (10^{-12} erg cm^{-2} s^{-1}) | \(\chi^2/\text{dof}\) |
|----------|-------------|----------------|-------------|---------|-------------------------------|--------------------------|-----|-----------------------------|----------------|
| A        | 1998 Mar 07 | 50879.563      | 0.036       | 1521.2  | 7.5 ± 0.2                     | 7.7 ± 1.5                | 2.0 ± 0.3 | 12.7_{-1.5}^{+2.0}          | 80/105         |
| B        | 1998 Mar 7  | 50879.901      | 0.070       | 4713.5  | 7.1 ± 0.4                     | 9.5_{-2.8}^{+3.6}        | 2.4_{-0.6}^{+0.7}      | 13.4_{-3.1}^{+5.7}         | 42/54          |
| C        | 1998 Mar 7  | 50879.988      | 0.079       | 1582.1  | 14.9 ± 0.9                    | 14.9_{-7.5}^{+11.6}      | 1.7_{-0.9}^{+1.2}      | 34.6_{-11}^{+40}           | 29/36          |
| D        | 1998 Mar 7  | 50880.041      | 0.084       | 4308.9  | 8.2 ± 0.4                     | 9.5_{-4.6}^{+3.5}        | 2.2_{-0.5}^{+0.7}      | 15.3_{-3.6}^{+7.2}          | 29/36          |
| E        | 1998 Mar 19 | 50891.681      | 0.240       | 3210.9  | 11.1 ± 0.6                    | 10^{-5}_{-3}             | 2.2 ± 0.6                | 29_{-5}^{+9}           | 31/53          |
| F        | 1998 Mar 19 | 50891.748      | 0.247       | 9577.5  | 7.0 ± 0.3                     | 7.4_{-2.5}^{+2.0}        | 2.0 ± 0.4                | 11.3_{-1.8}^{+2.7}          | 69/93          |
| G        | 1998 Mar 19 | 50891.949      | 0.267       | 1614.9  | 30.1 ± 1.4                    | 18.9_{-4.3}^{+4.7}       | 2.0 ± 0.5                | 104_{-27}^{+50}           | 42/67          |
| H        | 1998 Mar 19 | 50891.968      | 0.269       | 1569.6  | 14.0 ± 0.8                    | 8.8_{-4.6}^{+7.9}        | 1.8 ± 0.8                | 23.4_{-6.5}^{+19.0}         | 33/33          |
| I        | 1998 Mar 19 | 50892.029      | 0.274       | 6534.1  | 8.9 ± 0.4                     | 10.0_{-2.7}^{+3.6}       | 2.1 ± 0.5                | 17.4_{-3.4}^{+5.8}          | 60/85          |
| L        | 1998 Mar 26 | 50898.720      | 0.939       | 28460.6 | 2.8 ± 0.1                     | 3.3 ± 1.3                | 1.7 ± 0.3                | 3.4 ± 0.4                 | 70/101         |

Notes. The continuum spectral model is an absorbed power law. Here, \(N_H\) is the absorption column density, \(\Gamma\) is the power-law photon index, \(F_{\text{unabs}}\) is the unabsorbed flux in the 1.5–10 keV band. In the last column we report the value of the \(\chi^2/\text{dof}\) for each spectrum. Exp. is the good time interval for the spectral extraction.

Table 3

| OBS. Tstart UTC | Duration (ks) | Integration Time (s) | \(N_H\) (10^{22} cm^{-2}) | \(\Gamma\) | \(F_{\text{unabs}}\) (10^{-12} erg cm^{-2} s^{-1}) | Lum_{2–10keV} (erg s^{-1}) | \(\chi^2/\text{dof}\) |
|-----------------|---------------|---------------------|--------------------------|-----|-----------------------------|--------------------------|----------------|
| 1998 Mar 19 14:52:11.0 | 4.6 | 1614.9 | 18.9_{-3.8}^{+4.7} | 2.0 ± 0.5 | 104_{-27}^{+50} | 10^{35} | 42/67 |

Notes. The continuum spectral model is an absorbed power law. The \(N_H\) is the absorption column density, \(\Gamma\) is the power-law photon index, \(F_{\text{unabs}}\) is the unabsorbed flux in the 1.5–10 keV band. Outburst duration is the extrapolated activity period assuming as beginning of the outburst the first bin during which the source was detected while the integration time is the good time interval for the spectral extraction.
as an OB star. In addition, the de-reddened NIR colors of \((J−H)_{0} = −0.11 \pm 0.06\) and \((H−K)_{0} = −0.12 \pm 0.03\) are compatible with both OB supergiant and OB main sequence, when compared with the colors for supergiant and main-sequence stars reported by Ducati et al. (2001). Although IR spectroscopy of this source is needed to confirm this result, the X-ray behavior and infrared analysis strengthen the idea that this source is an SFXT candidate.

8. DISCUSSION

The INTEGRAL satellite has modified our understanding of high-mass binary systems, showing the existence of a new population of compact objects orbiting around a massive supergiant star and exhibiting unusual properties, being either extremely absorbed or characterized by very short and intense flares.

The SFXTs are characterized by short and bright flares, each with a duration between \(10^{2}\) and \(10^{4}\) s, reaching \(10^{36−37}\) erg s\(^{-1}\) at their peak. In these transients, both the duration and shape of the bright flares are variable and the mechanism producing the transient emission is still not clear. X-ray spectra (0.1–100 keV) during flares are well described either by a flat power law below 10 keV (Sidoli et al. 2006), with a photon index of 0–1 and a high-energy cutoff around 10–30 keV, or by a bremsstrahlung model with a temperature of 15–40 keV. A low-intensity flaring, corresponding to an intermediate state between the quiescence and the flare peaks, is usually present, characterized by an X-ray luminosity of \(10^{33−34}\) erg s\(^{-1}\), as discovered thanks to XRT/Swift monitoring campaign of SFXTs (Romano et al. 2010, 2011). In this state, the X-ray spectrum is softer, with an absorbed power law with photon index of 1–2 (Sidoli et al. 2008; Romano et al. 2010). At the moment there are 11 firm established SFXTs and a similar number of candidates (Sidoli 2011).

A time-resolved BeppoSAX spectral analysis of IGR J16328−4726 covering a significant range of orbital phases shows that the source X-ray emission could be well described in the different selected time intervals by an absorbed power-law model. While the photon index of the power law remained constant, the absorption column density was highly variable. We measured a significant rise in the \(N_{\text{H}}\) from \(3 \times 10^{20}\) to \(10^{22}\) cm\(^{-2}\) across the transition from the low emission level (phase L) to the peak of the flare seen by SAX (phase G). We note that this does not correspond to the assumed periastron of the system based on the peak of the folded IBIS light curve but is likely associated with the accretion of a well-defined clump of wind. Similar behavior is usually observed during the occurrence of X-ray eclipses in some of the sgHMXBs and SFXTs (Bozzo et al. 2008, 2011). The NS could be obscured by its supergiant companion and for this reason the X-ray emission, produced by the accretion close to the surface of the NS, is progressively absorbed in the photosphere of the supergiant star.

With this source being confirmed as an HMXB, its location is possibly associated with the spiral arms of our Galaxy, as usually observed with INTEGRAL HMXB population (Dean et al. 2005; Lutovinov et al. 2005; Bodaghee et al. 2007, 2012). Assuming a distance of 3 kpc and 10 kpc for the spiral structure of the Galaxy, the X-ray luminosity (2–10 keV) during the flare spans from \(10^{35}\) to \(10^{38}\) erg s\(^{-1}\), respectively. During the low emission level these values span from \(4 \times 10^{33}\) to \(4 \times 10^{34}\) erg s\(^{-1}\). The X-ray characteristics observed with BeppoSAX show the frequent microactivity typical of the intermediate state, with a luminosity value lying between the quiescence and the flare peaks, and a soft X-ray spectrum (\(\Gamma \sim 2\)).

Soon after the discovery of SFXT, to explain the bright and short outbursts, in’t Zand (2005) proposed the sudden accretion of material from the clump wind of the supergiant; Negueruela et al. (2006) suggested that SFXTs orbits should be highly eccentric to explain the low luminosity in quiescence. Later, the idea of a clump and spherically symmetric wind was associated with an eccentric and/or wide orbit (Walter & Zurita Heras 2007; Negueruela et al. 2007). Based on the shape of the light curve observed during the 2007 outburst from the SFXT IGR J11215−5952 displaying periodic outbursts, Sidoli et al. (2007) proposed the presence of a second denser wind component in the form of an equatorial wind disk from the supergiant donor, inclined with respect to the orbital plane. The flaring activity was explained with a wind that is inhomogeneous and anisotropic.

All models predict that fast X-ray flares can be produced by sporadic capture and accretion onto the NSs hosted in the SFXTs.

The wind accretion theory allows us to estimate the physical and geometrical parameters of the clumpy stellar wind responsible for the transient emission. The duration of the main observed flare during the BeppoSAX observation of our source (phase G) is \(\Delta t_{\text{flare}} \sim 4.6\) ks, a typical timescale on which the NS crosses a dense clumpy stellar wind. Neglecting the orbital velocity of the NS as reported in Lépine & Moffat (2008), from the duration of the flare we obtain the radius of the clump accreted by the NS:

\[
R_{\text{cl}} \simeq 1/2 v_{\text{w}} \Delta t_{\text{flare}},
\]

where \(v_{\text{w}}\) is the relative velocity between the clump and the NS.

During the time of the NSs’ periastron passage, the absorption column density increases and it could be computed from the Equation (4) given in Bozzo et al. (2011):

\[
N_{\text{H}} \simeq 1.3 \times 10^{22} v_{\text{w}}^{-4} d_{\text{kpc}}^{-2} \text{cm}^{-2},
\]

where \(d_{\text{kpc}}\) is the source distance in units of 3 kpc and \(v_{\text{w}}\) is the wind velocity in \(10^{3}\) cm s\(^{-1}\). Using the \(N_{\text{H}}\) measured by the spectral analysis at the peak of the flare \(\sim 1.9 \times 10^{23}\) cm\(^{-2}\) and assuming a distance of 3 kpc, Equation (2) allows us to estimate a wind velocity of \(\sim 1900\) km s\(^{-1}\). This value agrees with the \(\beta\)-velocity law (Castor et al. 1975) which gives a typical velocity of \(1000−2000\) km s\(^{-1}\) for an OB supergiant and for a companion star losing mass in the form of a steady, homogeneous, and spherically symmetric wind.

Assuming this wind velocity, we found the radius of the clump accreted by the NS as \(R_{\text{cl}} \sim 1/2 v_{\text{w}} \Delta t_{\text{flare}} \sim 4.4 \times 10^{8} \text{km}\). In the framework of the Bondi–Hoyle–Lyttleton accretion theory, since only matter within a distance smaller than the accretion radius is accreted, the mass of the clumpy stellar wind is

\[
M_{\text{cl}} = (R_{\text{cl}}/R_{\text{acc}})^{3} M_{\text{acc}},
\]

where \(M_{\text{acc}} = 2GM_{\text{NS}}/v_{\text{w}}^{2} \simeq 1.0 \times 10^{8} \text{km}, M_{\text{NS}} = 1.4 M_{\odot}\), and \(M_{\text{acc}}\) is the mass accreted during the flare. The X-ray flux extrapolated in 0.1−10 keV energy range during the flare \(F_{\text{unabs}} = L_{\text{x}}/(4\pi d^{2}) = (GM_{\text{NS}} M_{\text{acc}}/(R_{\text{NS}})) / (4\pi d^{2})\) and the continuity equation \(M_{\text{acc}} = \rho v_{\text{w}} \pi R_{\text{acc}}^{2}\) (where \(d\) is the source distance and \(R_{\text{NS}} = 10\) km is the NS radius) allowed to estimate the mass accreted onto the NS. We derived \(M_{\text{acc}} = 10^{-8} M_{\odot} \text{year}^{-1}\) (for a distance of 3 kpc) and \(M_{\text{acc}} \simeq 2.5 \times 10^{19} \text{g}\), thus

\[
M_{\text{cl}} = (R_{\text{cl}}/R_{\text{acc}})^{2} M_{\text{acc}} \simeq 6 \times 10^{22} \text{g}.
\]
Ducci et al. (2009) computed the expected clump characteristics in the framework of the Bondi–Hoyle accretion theory taking into account the presence of clumps. The expected values of $M_{cl}$ and $R_{cl}$ according to this clumpy wind model are in agreement with the measured values for IGR J16328$-4726$. We conclude that IGR J16328$-4726$ can be added to the list of SFXTs as it shows all of the characteristics typical of that class of object.

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REFERENCES

Bodaghee, A., Courvoisier, T. J.-L., Rodriguez, J., et al. 2007, A&A, 467, 585
Bodaghee, A., Tomsick, J. A., Rodriguez, J., & James, J. B. 2012, ApJ, 744, 108
Boella, G., Butler, R. C., Perola, G. C., et al. 1997, A&AS, 122, 299
Bozzo, E., Falanga, M., & Stella, L. 2008, ApJ, 683, 1031
Bozzo, E., Giunta, A., Cusumano, G., et al. 2011, A&A, 531, 130
Castor, J. I., Abbott, D. C., & Klein, R. I. 1975, ApJ, 195, 157
Clark, D. J., Hill, A. B., Bird, A. J., et al. 2009, MNRAS, 399, 113
Clark, D. J., Sguera, V., Bird, A. J., et al. 2010, MNRAS, 406, 75
Corbet, R. H. D., Barthelmy, S. D., Baumgartner, W. H., et al. 2010, ATel, 2588
Cusumano, G., La Parola, V., Segreto, A., et al. 2010, A&A, 510, 48
Dean, A. J., Bazzano, A., Hill, A. B., et al. 2005, A&A, 443, 485
Drave, S. P., Clark, D. J., Bird, A. J., et al. 2010, MNRAS, 409, 1220
Ducati, J. R., Bevilacqua, C. M., Rembold, S. B., et al. 2001, ApJ, 558, 309
Ducci, L., Sidoli, L., Mereghetti, S., Paizis, A., & Romano, P. 2009, MNRAS, 398, 2152
Fiocchi, M., Sguera, V., Bazzano, A., et al. 2010, ApJ, 725, 68
Fiore, F., Guainazzi, M., & Grandi, P. 1999, Cookbook for BeppoSAX NFI Spectral Analysis (www.asdc.asi.it/bepposax/software/cookbook)
Frontera, F., Costa, E., dal Fiume, D., et al. 1997, A&AS, 122, 357
Grupe, D., Kennea, J., Evans, P., et al. 2009, ATel, 2075
in’t Zand, J. J. M. 2005, A&A, 441, L1
Lépine, S., & Moffat, A. F. J. 2008, AJ, 136, 548
Lomb, N. R. 1976, Ap&SS, 39, 447
Lučinov, A., Revnivtsev, M., Molkov, S., et al. 2005, A&A, 430, 997
Manzo, G., Giarrusso, S., Santangelo, A., et al. 1997, A&AS, 122, 341
Negueruela, I., Smith, D. M., Harrison, T. E., & Torrejón, J. M. 2006, ApJ, 638, 982
Negueruela, I., Smith, D. M., Torrejon, J. M., & Reig, P. 2007, in Proc. VI INTEGRAL Workshop on the Obscured Universe, ed. S. Grebenev, R. Sunyaev, & C. Winkler (ESA SP-622; Noordwijk: ESA), 255
Parmar, A. N., Martin, D. D. E., Bavdaz, M., et al. 1997, A&AS, 122, 309
Ricke, G. H., & Lebsky, M. J. 1985, AJ, 88, 618
Romano, P., Sidoli, L., Ducchi, L., et al. 2010, MNRAS, 401, 1564
Romano, et al. 2011, 2011 Fermi Symposium Proceedings, eConf C110509 (arXiv:1111.0698)
Scargle, J. D. 1982, ApJ, 263, 835
Sidoli, L. 2011, in PoS, Extremsky 2011 (Trieste: SISSA), 010
Sidoli, L., Paizis, A., & Mereghetti, S. 2006, A&A, 450, L9
Sidoli, L., Romano, P., Mangano, V., et al. 2008, ApJ, 687, 1230
Sidoli, L., Romano, P., Mereghetti, S., et al. 2007, A&A, 476, 1307
Walter, R., & Zurita Heras, J. 2007, A&A, 476, 335