PROCEEDINGS OF SCIENCE

INTEGRAL, SWIFT and RXTE observations of the 518 Hz accreting transient pulsar Swift J1749.4−2807

Carlo Ferrigno[*,a] **E. Bozzo,**[a] **M. Falanga,**[b] **L. Stella,**[c] **S. Campana,**[d]**,T. Belloni,**[d] **G. L. Israel,**[c] **L. Pavan,**[a] **E. Kuulkers,**[e] **A. Papitto** [fg]

[a] *ISDC Data Center for Astrophysics chemin d'Écogia, 16 CH-1290, Versoix, Switzerland.*
[b] *International Space Science Institute (ISSI) Hallerstrasse 6, CH-3012 Bern, Switzerland.*
[c] *INAF - Osservatorio Astronomico di Roma, Via Frascati 33, I-00044 Rome, Italy*
[d] *INAF - Osservatorio Astronomico di Brera, via Emilio Bianchi 46, I-23807 Merate (LC), Italy*
[e] *ESA, European Space Astronomy Centre (ESAC), PO Box 78, E-28691 Villanueva de la Cañada (Madrid), Spain*
[f] *Università degli Studi di Cagliari, Dipartimento di Fisica, SP Monserrato-Sestu, KM 0.7, I-09042 Monserrato (CA), Italy*
[g] *INAF, Osservatorio Astronomico di Cagliari, Poggio dei Pini, Strada 54, I-09012 Capoterra (CA), Italy*
E-mail: `Carlo.Ferrigno@unige.ch`

Swift J1749.4−2807, previously known as a burst-only source, was discovered in a high X-ray-active state, during an *INTEGRAL* observations of the Galactic bulge on 2010 April 10. Pulsations at 518 Hz were discovered in the *RXTE* data, confirming previous suggestions of possible associations between burst-only sources and accreting millisecond X-ray pulsars. The subsequent discovery of X-ray eclipses made Swift J1749.4−2807 the first eclipsing accreting millisecond X-ray pulsar. In this proceeding, we report on the results of a monitoring campaign on the source, carried out for about two weeks with the *Swift*, *INTEGRAL*, and *RXTE* satellites. The observations showed that the X-ray spectrum (energy range 0.5–40 keV) of Swift J1749.4−2807 during the entire event was accurately modeled by an absorbed power-law model ($N_{\rm H}\simeq3\times10^{22}$ cm^{-2}, $\Gamma\simeq1.7$). X-ray eclipses were also detected in the *Swift* data and provides a clear evidence of a dust-scattering halo located along the line of sight to the source. Only one type-I X-ray burst was observed throughout the two-weeks long monitoring. The X-ray flux of Swift J1749.4−2807 decayed below the detection threshold of *Swift* /XRT about 11 days after the discovery, in a exponential fashion (e-folding time of τ=12^{+7}_{-3} days).

8th INTEGRAL Workshop "The Restless Gamma-ray Universe"
September 27-30 2010
Dublin Castle, Dublin, Ireland

[*]Speaker.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence.

PoS(INTEGRAL 2010)148

1. Introduction

Low mass X-ray binaries (LMXBs) consist of a low-mass donor star (<1 $M_{\odot}$) and a compact object that accretes matter through an accretion disk. Most LMXBs are transients, i.e. they undergo week-to-month long outbursts during which the accretion takes place at high rates (see e.g. Campana et al., 1998, for a review). The outbursts of transient LMXBs are usually interpreted in terms of disk instability models (see e.g., Frank et al., 2002). In a number of these sources, an accreting neutron star (NS) as a compact object has been unambiguously identified by the detection of type-I X-ray bursts and/or coherent pulsations (see e.g. Strohmayer & Bildsten, 2006, for a review).

In this proceeding, we report on the recent discovery of an intense X-ray activity from the burst-only source Swift J1749.4−2807 (see Cornelisse et al., 2004, and references therein for the discovery of burst-only sources). We study its timing and spectral properties exploiting all the available *Swift*, *INTEGRAL*, and *RXTE* data. For the full detail of the analysis see Ferrigno et al. (2010). The results presented here provide a strong support in favor of the association between burst-only sources and AMSPs.

Swift J1749.4−2807 was discovered in 2006 during a bright type-I X-ray burst that was initially recorded as a potential gamma ray burst (GRB060602B, Wijnands, 2009). The source X-ray flux decayed in an approximately power-law fashion (with index ∼-1), fading below the detection threshold of *Swift*/XRT in less than 10^6 s. The BAT spectrum extracted at the peak of the type-I X-ray burst provided an upper limit to the source distance of 6.7 ± 1.3 kpc (Wijnands, 2009; Campana, 2009). The estimated X-ray luminosity was $\sim 10^{36}$ erg/s at the peak ot the outburst and $\sim 10^{32}$ erg/s in the latest *Swift* observation available; the latter is compatible with the source quiescent luminosity during three *XMM-Newton* serendipitous observations (Wijnands, 2009).

Swift J1749.4−2807 was detected again in a high X-ray luminosity state on 2010 April 10, during the *INTEGRAL* Galactic bulge monitoring program (Pavan et al., 2010). *Swift* and RXTE target of opportunity observations (ToO) monitored the source outburst for about two weeks. *RXTE* observations detected coherent pulsations in the X-ray emission of the source at 518 Hz and its second harmonic (Altamirano et al., 2010a; Bozzo et al., 2010). Markwardt et al. (2010b) derived a precise orbital solution, and found that this source is the AMSP with the longest orbital period (8.8168 hr), excluding the peculiar case of Aql X-1 (18.95h; Welsh, 2000). The solution implied a mass function of $0.05463 \pm 0.00008\,M_{\odot}$ and a rather large minimum mass for the companion of 0.475 $M_{\odot}$ (assuming a NS of $1.4 M_{\odot}$). The discovery of an X-ray eclipse in the *RXTE* light curve was reported by Markwardt et al. (2010a); this is the first eclipse observed from an accreting millisecond X-ray pulsar.

2. Results

2.1 *INTEGRAL*: the broad band spectrum.

INTEGRAL data were analyzed using the OSA software (v.9 Courvoisier et al., 2003). We considered data from both IBIS/ISGRI (Lebrun et al., 2003) and JEM-X2 (Lund et al., 2003) in the 20–40 keV and 3–23 keV energy ranges, respectively. The simultaneous ISGRI+JEM-X2 spectra could be reasonably well described by a cutoff power-law model of photon index 1.3-1.6 (we fixed the cutoff energy at 20 keV and the absorption column density at 3×10^{22} cm^{-2}); the estimated flux

PoS(INTEGRAL 2010)148

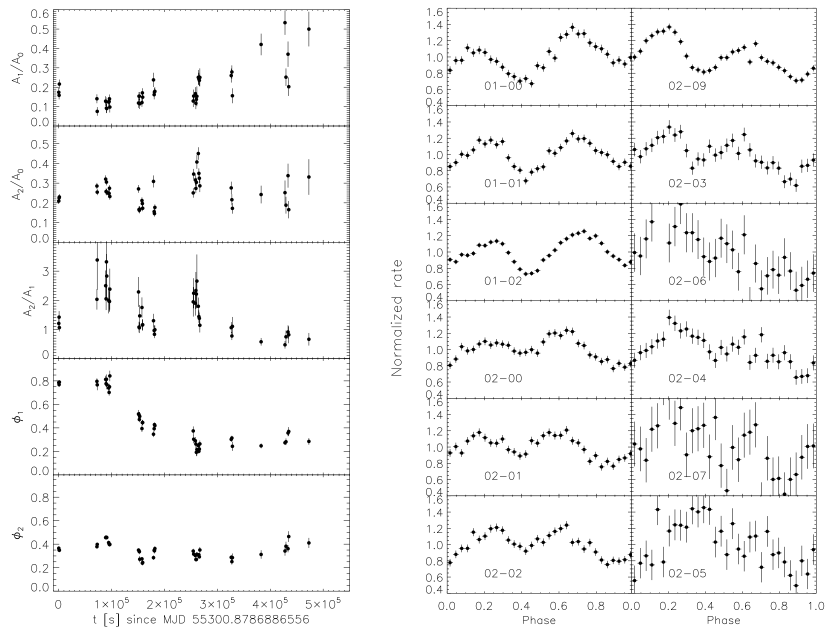

Figure 1: Left panel: Fourier analysis of the pulsed signal throughout the *RXTE* monitoring of Swift J1749.4−2807 : $A_{0,1}$ are the powers of the first two Fourier coefficients, $\phi_{1,2}$ their phases. The pulse profiles have been rebinned to obtain a S/N at least 50 and only detections at more than 3σ of $A_{1,2}$ are reported. Right panel: pulse profiles of Swift J1749.4−2807 in the *RXTE* observations (the observation ID. is indicated in each figure) normalized for the corresponding average count-rate and folded with respect to the same reference time (53 888.9854166670 MJD). The energy band is 3–23 keV (data from PCU2). In the observation 02-02, the eclipse was excluded.

was 3×10^{-10} erg/s/cm^2 (3-20 keV). For these observations, we also extracted an event list from the entire JEM-X2 detector in the 3–20 keV band to search for type-I X-ray bursts. Only one burst was detected (see also Chenevez et al., 2010).

2.2 *RXTE*: spectrum, pulse profiles and eclipses.

RXTE /PCA (Jahoda et al., 1996) data analysis was carried using HEASOFT (V 6.7). We excluded from the spectral analysis, performed using the `standard2` mode, the data from the PCU0 detector and we considered only data from the upper anode layer. We used the latest observations, performed after 2010 April 20 to estimate and eliminate the contribution of the Galactic ridge emission (Valinia et al., 1998) for the utilized PCU configurations. All the spectra were fit within XSPEC in the 3-23 keV energy range using an absorbed power-law model ($N_{\rm H} \simeq 3\times10^{22}\,{\rm cm}^{-2}$, $\Gamma \simeq 1.7$), which always provided satisfactory fits.

For the timing analysis, we used the *RXTE* event data (mode `E_125us_64M_0_1s`) in all the active PCUs and layers, to maximize the S/N. To study the variations in the amplitude of the fundamental and second harmonic, we used the ephemeris reported by Markwardt et al. (2010b) and folded the light curves into time intervals of 100 s to produce in each interval a pulse profile in 32 phase bins. We rebinned these pulses adaptively to compute the characteristic amplitude and phase of the first two Fourier components (Fig 1, left panel). The relative power of the two

PoS(INTEGRAL 2010)148

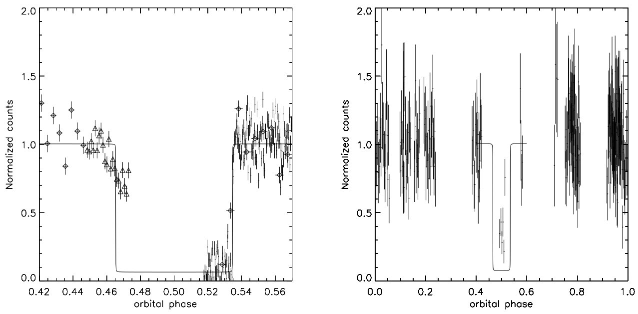

Figure 2: *Left*: *RXTE* orbital folded light curve of Swift J1749.4−2807. Diamonds refer to the observation 95085-09-02-04, triangles to 95085-09-02-11, and the other points to the observation 95085-09-02-02. The light curves are normalized to the average values outside the eclipse and rebinned to obtain a S/N≃8 in each time bin. *Right*: *Swift* /XRT folded light curve of Swift J1749.4−2807 (0.3-10 keV). The eclipse occurred during the observation ID. 00031686002. In both panels, the solid line is the shape of the eclipse determined from the *RXTE* observation 95085-09-02-02.

components, A_1/A_2, varies with time: the second harmonic was clearly dominant during the early stage, before 2010 April 18, (i.e. $t < 3 \times 10^5$ s in Fig. 1, left panel), while the fundamental became more prominent in the later stages, ($t > 3 \times 10^5$ s in Fig. 1, left panel).

We also studied the source pulse profile in different energy bands; the results are shown in Fig. 1, right panel, where the pulses are phase connected, since the folding reference time is the same. The double peak structure of the pulse profile visible in this figure during some observations explains the corresponding higher power in the second harmonic with respect to the fundamental spin frequency, and naturally suggests that we are observing at the same time the emission from the two polar caps of the NS. The pulse profile evolution might be due to a variation in the accretion flow geometry in the vicinity of the polar caps of the NS, or alternatively to the occultation of at least part of one polar cap by the inner region of the accretion disk.

To search for X-ray eclipses, the light curves with 1 s time resolution were background subtracted, barycentered and folded by using the orbital solution reported by Markwardt et al. (2010b). We found two egresses and one ingress; no other orbital feature was detected. To determine the parameters of the eclipse, we separately fit the light curves extracted from the three observations with the rectangular step function (see e.g., Mangano et al., 2004) and found durations of 2190 ± 4 s, 2163 ± 17 s and 2260 ± 80 s, which are all compatible with each other within the errors. The duration of the egress is constrained by the first observation to be shorter than 2 s (Fig. 2, left panel).

2.3 *Swift*: discovery of a scattering halo.

We analyzed the *Swift* /XRT (Gehrels et al., 2004) data using standard procedures (Burrows et al., 2005) and the latest calibration files available. The *Swift* /XRT light curves were folded at the orbital period of the source (see Sect. 2.2) to search for X-ray eclipses. An eclipse occurred during observation ID. 00031686002, as shown in Fig. 2, where we can appreciate a residual X-ray flux during the eclipse. To clarify its origin, we show in Fig. 3 four images of the source: the two images at the top were accumulated during the time interval in which the X-ray source was eclipsed (total exposure time 840 s) and are in the 0.3–5.0 keV and 5–10 keV energy bands. The source

PoS(INTEGRAL 2010)148

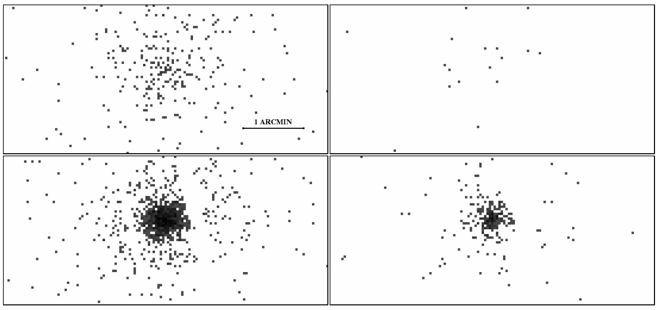

Figure 3: Upper panels: *Swift* /XRT image of Swift J1749.4−2807 extracted during the eclipse in the observation ID. 00031686002 (exposure time 840 s). The left (right) panel shows the image of the source in the 0.3-5 keV (5-10 keV) energy band. The black line corresponds to a distance of 1 arcmin in the images. A source is detected at low energies, but not at high energies. Lower panels: the same as for the upper panel, but the images were extracted during the same observation outside the eclipse (exposure time 840 s). From this image, it is clear that the in-eclipse PSF looks more extended than the point-like PSF observed out of eclipse.

is clearly detected in the lower energy image. The other two images were extracted in the same observation and energy bands, but during the 840 s preceding the eclipse. These figures suggest that the source was not point-like, but slightly extended (by a few arcminutes), especially at lower energies, as confirmed by the comparison of the radial distribution of photons with the theoretical point spread function. Therefore, the residual emission around the source was most likely due to the effect of a scattering halo located halfway to Swift J1749.4−2807 (see e.g., Predehl & Schmitt, 1995). According to this interpretation, soft X-ray photons emitted when the source is outside the eclipse are scattered along our line of sight by interstellar dust, reaching us during the obscuration of the X-ray source, as a results of the longer path that they follow. The effect is more prominent at lower energies, because of the energy dependence of the scattering cross-section.

2.4 Outburst decay profile.

In Fig. 4, left panel, we show the evolution in the X-ray flux of Swift J1749.4−2807 during the outbursts in 2010, derived from the monitoring performed with *INTEGRAL*, *RXTE*, and *Swift*. The source flux decreased by three orders of magnitude in less than 15 days, displaying a quite clear exponential decay. A fit with an exponential function to the *Swift* data gave an e-folding time of τ=12^{+7}_{-3} days ($\chi^2_{\rm red}$/d.o.f.=15.2/4). Even though the $\chi^2_{\rm red}$ is not formally acceptable, we checked that this is due to the relatively large scatter in the Swift points during the steep decay.

In the right panel of Fig. 4, we also report for comparison the outburst occurred in 2006, observed by *Swift* /XRT, together with the X-ray fluxes measured in 2010. In both cases, the times of the observations were scaled to the time of the type-I X-ray burst that was detected during each outburst. We note that the outburst in 2010 lasted longer than the one in 2006 (a factor of $\sim$2), was characterized by a higher averaged X-ray luminosity, and the decrease in the X-ray flux with time was slower. In both cases, the light curve was not smooth.

PoS(INTEGRAL 2010)148

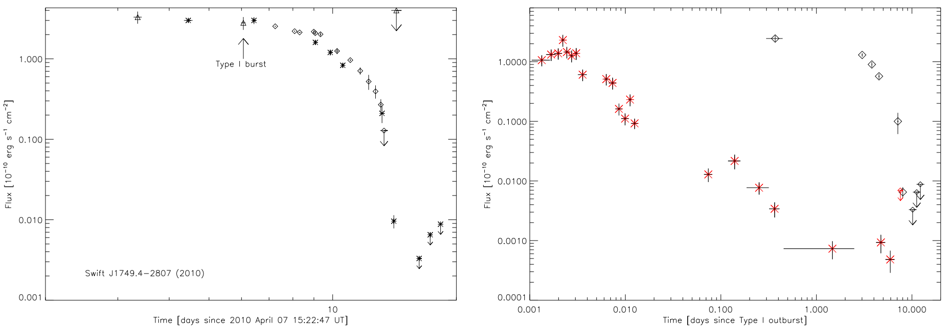

Figure 4: *Left*: Long-term light curve of the outburst of Swift J1749.4−2807 in 2010. Stars, triangles and diamonds represent respectively *Swift*, *INTEGRAL*, and *RXTE* observations. The downward arrows indicate the upper limits to the source X-ray flux. All the fluxes are in the 3-20 keV energy band and have not been corrected for absorption. We converted *Swift*/XRT fluxes from the 0.5-10 keV energy band to the energy band 3-20 keV by using the spectral model of each observation and the online tool WEBPIMMS (http://heasarc.nasa.gov/Tools/w3pimms.html). The errors on the fluxes are given at 90% c.l. The large upward arrow indicates the time of the type I X-ray burst. *Right*: The outburst of Swift J1749.4−2807 occurred in 2006 as observed by *Swift*/XRT (red stars). Here the fluxes are in the 0.3-10 keV energy band. For comparison, we report in this panel the *Swift*/XRT observation in the same energy range carried out during the outburst in 2010 (in black diamonds). The times of the observations in 2006 and 2010 have been scaled to the corresponding type-I X-ray burst detected during each event.

Acknowledgments

EB and CF thank N. Gehrels and the *Swift* team for their availability and prompt response in carrying out follow-up observations of Swift J1749.4−2807.

References

Altamirano, D. et al. 2010a, Astr. Tel. 2565

Bozzo, E., et al. 2010, Astr. Tel. 2567

Burrows, D.N. et al. 2005, SSRv, 120, 165

Campana, S. et al. 1998, A&ARv, 8, 279

Campana, S. 2009, ApJ, 699, 1144

Chenevez, J. et al. 2010, Astr. Tel. 2561

Cornelisse, et al. 2004, NuPhS, 132, 518

Courvoisier, T. J.-L., et al. 2003, A&A, 411, 53

Ferrigno, C., et al. 2010, A&A, in press

Frank, J., King, A., Raine, D. 2002, Accretion Power in Astrophysics (Cambridge University Press), p. 110

Gehrels, N. et al. 2004, ApJ, 611, 1005

Jahoda, K. et al. 1996, SPIE, 2808, 59

Lebrun, F. et al. 2003, A&A, 411, 141

Lewin, W.H.G., van Paradijs, J., Taam, R.E. 1993, SSRv, 62, 223

Lund, N. et al. 2003, A&A, 411, 231

Mangano, V., Israel, G. L., Stella, L. 2004, A&A, 419, 1045

Markwardt, C.B., et al. 2010a, Astr. Tel. 2576

Markwardt, C.B., et al. 2010b, ApJL, 717, L149-L153.

Pavan, L. et al. 2010, Astr. Tel. 2548

Predehl, P. & Schmitt, J.H.M.M. 1995, A&A, 293, 889

Strohmayer, T.E. & Bildsten L. 2006, in Compact stellar X-ray sources, Ed. Walter Lewin & Michiel van der Klis (Cambridge University Press), p. 113-156

Valinia, A. & Marshall, F.E. 1998, ApJ, 505, 134

Welsh, W. F. et al., 2000, AJ, 120, 943

Wijnands, R. et al. 2009, MNRAS, 393, 126

PoS(INTEGRAL 2010)148