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# Supergiant fast X-ray transients as an under-luminous class of supergiant X-ray binaries

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## Abstract

The usage of cumulative luminosity distributions, constructed thanks to the long-term observations available through wide field hard X-ray imagers, has been recently exploited to study the averaged high energy emission (>17 keV) from supergiant fast X-ray transients (SFXTs) and classical Supergiant High Mass X-ray Binaries (SgXBs). Here, we take advantage of the long term monitorings now available with *Swift*/XRT to construct for the first time the cumulative luminosity distributions of a number of SFXTs and the classical SgXB IGR J18027-2016 in the soft X-ray domain with a high sensitivity focusing X-ray telescope (0.3–10 keV).

By complementing previous results obtained in the hard X-rays, we found that classical SgXBs are characterized by cumulative distributions with a single knee around $\sim 10^{36}$–$10^{37}$ erg s$^{-1}$, while SFXTs are found to be systematically sub-luminous and their distributions are shifted at significantly lower luminosities (a factor of ~10–100). As the luminosity states in which these sources spend most of their time are typically below the sensitivity limit of large field of view hard X-ray imagers, we conclude that soft X-ray monitorings carried out with high sensitivity telescopes are particularly crucial to reconstruct the complete profile of the SFXT cumulative luminosity distributions.

The difference between the cumulative luminosity distributions of classical SgXBs and SFXTs is interpreted in terms of accretion from a structured wind in the former sources and the presence of magnetic/centrifugal gates or a quasi-spherical settling accretion regime in the latter.

*Keywords:* Neutron star; Accretion; X-ray binaries; High mass X-ray binaries; IGR J18027-2016

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## 1. Introduction

Most of the so-called “classical” Supergiant X-ray binaries (SgXBs) host a neutron star (NS) accreting material from the wind of its O–B supergiant companion. These sources are characterized by a nearly persistent X-ray luminosity of $L_X = 10^{35}$–$10^{37}$ erg s$^{-1}$ (mostly depending on their orbital period) and display variations in the X-ray intensity by as large as a factor of ~20–50 on time scales of hundreds to thousands of seconds. This pronounced variability is usually ascribed to the presence of inhomogeneities in the accreting medium (”clumps”; see, e.g., Negueruela et al.,

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2006, and references therein). Orbital periods measured for many of these systems range from a few to tens of days (see, e.g., Chaty, 2013], for a recent review). The presence of neutron stars could be firmly established in several cases thanks to the detection of X-ray pulsations (Liu et al., 2006). Measured spin periods are typically long, spanning from tens to several thousand seconds. Such slow rotations are ascribed to the effect of torque due to the wind accretion process (see, e.g., Shakura et al., 2013, and references therein).

Supergiant fast X-ray transients (SFXTs) are a sub-class of SgXBs (Ducci et al., 2014), sharing a number of similar properties with classical systems (Bozzo et al., 2013, e.g., similar orbital periods;) but displaying a much more pronounced variability in the X-ray domain. These sources spend most of their time in low luminosity states ($L_X = 10^{32}$–$10^{33}$ erg s$^{-1}$) and only sporadically undergo few hours-long outbursts reaching peak luminosities comparable to the persistent level of other SgXBs (Sguera et al., 2006). The criterion proposed to distinguish between classical systems and SFXTs is based on the larger dynamical range achieved by the latter sources. In particular, a source is classified as “intermediate SFXT” if a variability as large as a factor of $\gtrsim 100$ is recorded in the X-ray domain, and a proper SFXT if the dynamic range is significantly above this value (see, e.g., Romano et al., 2014, hereafter R14). Among all the known SFXTs, three of them displayed the largest dynamic range ($\geqslant 10^4$–$10^5$) and we thus refer to them from now onward as “SFXT prototypes”. These three sources are: IGR J08408-4532, XTE J1739-302, and IGR J17544-2619.

As inhomogeneities in the accreting material are not sufficient to account for the SFXT pronounced variability, the mechanism regulating the activity of these source is still a matter of debate (see, e.g., Bozzo et al., 2013, Chaty, 2013). Only in a few cases X-ray pulsations firmly established the presence of neutron stars in SFXTs, but the similarity of their X-ray spectra with those of other accreting neutron star systems convincingly led to the conclusion that SFXTs should also host the same kind of compact objects (Negueruela et al., 2006).

Large field-of-view (FoV) hard X-ray imagers, like the IBIS/ISGRI on-board *INTEGRAL* (20 keV–1 MeV; Ubertini et al., 2003, Lebrun et al., 2003) and the BAT on-board *Swift* (15–150 keV; Barthelmy et al., 2005), have been very efficient in catching a large number of sporadic SFXT outbursts and proved particularly well suited to study the brightest luminosity states achieved by these sources ($\gtrsim 10^{35}$ erg s$^{-1}$; see, e.g., Romano et al., 2014). The long-term monitoring data now available have been exploited to estimate the SFXT activity duty-cycle (DC; see, e.g., R14; Paizis and Sidoli, 2014, hereafter P14). The latter was found to be significantly lower (1–5%) in the hard X-ray domain than that of classical SgXBs ($\gtrsim 80\%$). By using all archival ISGRI data, P14 also reported a detailed comparison between the cumulative luminosity distributions of these two classes of sources. They showed that in the energy range 17–50 keV the distributions of SFXTs can be reasonably well described by a single power-law, while those of classical SgXBs are typically more complex, showing a knee at luminosities $\sim 10^{36}$ erg s$^{-1}$ and requiring at least two different power-laws to satisfactorily describe their profiles.

The fainter states of SFXTs can be accurately studied only by using pointed observations with focusing X-ray telescopes. Among these, XRT (Burrows et al., 2005) on-board *Swift* (Gehrels et al., 2004) proved to be particularly useful in carrying out long-term monitoring of the SFXTs, as it can take advantage of the unique scheduling flexibility of the *Swift* satellite. For most of the SFXTs, observations lasting 1 ks and achieving a limiting sensitivity comparable to the lowest emission level of these sources have been carried out twice a week from 2007 to present (Sidoli et al., 2008; Romano et al., 2009, 2011, 2014). These data provide now a sufficiently long baseline to be compared with the results obtained through wide FoV hard X-ray imagers. A first comparison was reported by R14. These authors showed that XRT data allow us to extend the estimation of the SFXT DC across 2 orders of magnitude more in X-ray luminosity compared to large FoV hard X-ray instruments. Their main finding is that a DC comparable to that of classical systems ($\gtrsim 70$–$80\%$) is recovered for the SFXTs when luminosities as low as $\sim 10^{32}$–$10^{33}$ erg s$^{-1}$ can be probed as lower limit for the calculation of the DC.

In this paper, we make use of the same XRT dataset as reported by R14 to construct the cumulative luminosity distributions of most of the currently known SFXT sources. We also present the analysis of the still unpublished XRT data of IGR J18027-2016, a classical SgXB monitored for a sufficiently long time with XRT to build a meaningful cumulative luminosity distribution. We compare the cumulative luminosity distributions of SFXTs and classical SgXBs available so far in the hard and soft X-rays, providing an interpretation for the two classes of objects in terms of different wind accretion scenarios.

## 2. *Swift* sample and data analysis

In order to produce the cumulative luminosity distributions of the currently known SFXTs, we made use of all available XRT data collected from 2007 to 2013 from the 10 sources listed in Table 1. This data-set is the same that has been presented by R14. It comprises:

- Data from the monitoring of the SFXTs IGR J16479-4514, XTE J1739-302, and IGR J17544-2619 carried out from 2007 October 26 to 2009 November 03.
- Data from the monitoring of AX J1841.0-0536 obtained from 2007 October 26 to 2008 November 15.
- Data from the monitoring of one complete orbit of the SFXTs IGR J18483-0311 (collected from 2009 June 11 to 2009 July 08), IGR J16418-4532 (carried out from 2011 February 18 to 2011 July 30), and IGR J17354-3255 (carried out from 2012 July 18 to 2012 July 28).