SUPERGIANT FAST X-RAY TRANSIENTS: A COMMON BEHAVIOUR OR A CLASS OF OBJECTS?

Ignacio Negueruela[1,2], David M. Smith[3], José Miguel Torrejón[1], and Pablo Reig[4]

[1]*Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal, Universidad de Alicante, Apartado 99, E03080 Alicante, Spain*
[2]*Department of Physics and Astronomy, The Open University, Walton Hall, Milton Keynes MK7 6AA, United Kingdom*
[3]*Physics Department & Santa Cruz Institute for Particle Physics, University of California Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, U.S.A.*
[4]*IESL (FORTH) & Physics Department.,University of Crete, PO Box 2208, 71003 Heraklion, Crete, Greece*

ABSTRACT

INTEGRAL monitoring of the Galactic Plane is revealing a growing number of recurrent X-ray transients, characterised by short outbursts with very fast rise times ($\sim$ tens of minutes) and typical durations of a few hours. A substantial fraction of these sources is associated with OB supergiants and hence defines a new class of massive X-ray binaries, which we call Supergiant Fast X-ray Transients. Characterisation of the astrophysical parameters of their counterparts is underway [1]. So far, we have found a number of late O and early B supergiants of different luminosities at a large range of distances. Nothing in their optical properties sets them apart from classical Supergiant X-ray Binaries. On the other hand, there is now rather concluding evidence that persistent supergiant X-ray binaries also show fast outbursts. This suggests a continuum of behaviours between typical persistent supergiant systems and purely transient systems, but offers very little information about the physical causes of the outbursts.

Key words: binaries: close — stars: supergiants – X-rays: binaries.

1. INTRODUCTION

High Mass X-ray Binaries (HMXBs) are X-ray sources composed of an early-type massive star and an accreting compact object. Most known HMXBs are Be/X-ray binaries, systems consisting of a neutron star accreting from the disc around a Be star. Even though a few Be/X-ray binaries are persistent weak X-ray sources (with $L_{\rm X} \sim 10^{34}\ {\rm erg\,s^{-1}}$), the majority are transients, displaying bright outbursts with typical duration of the order of several weeks.

[1]Partially based on observations collected at the European Southern Observatory, Paranal, Chile (ESO 077.D-0055,274.D-5010), the Nordic Optical Telescope (NOT) and the South African Astronomical Observatory.

The second major class of HMXBs contains early-type supergiants. These objects are hence known as Supergiant X-ray Binaries (SGXBs). The compact object is fed by accretion from the strong radiative wind of the supergiant. These objects are persistent sources, with luminosities around $L_{\rm X} \sim 10^{36}\ {\rm erg\,s^{-1}}$, very variable on short timescales, but rather stable in the long run. About a dozen SGXBs were known before the launch of *INTEGRAL*, most of them having been discovered in the early days of X-ray astronomy. This low number was generally attributed to a real scarcity of such systems, as the short duration of the supergiant phase would result in very short lifetimes. Since the launch of *INTEGRAL*, however, the situation has changed dramatically, as several new sources have been detected displaying the typical characteristics of SGXBs [34]. In most cases, the sources had not been detected by previous missions due to high absorption, which renders their spectra very hard.

Moreover, a second major class of SGXBs has emerged. These systems, instead of being persistent X-ray sources, are detected as transients, characterised by very short outbursts ($\sim$hours) separated by long ($\sim$ months) quiescence periods [22, 23]. There are many candidates to belong to this class [23], but so far only two objects have been well characterised.

2. THE PROTOTYPES

2.1. XTE J1739$-$302 = IGR J17391$-$3021

XTE J1739$-$302 was discovered during an outburst in August 1997 [26]. Further observations with *RossiXTE*, and also with *ASCA*, showed it to be an unusual kind of transient [27], with very short outbursts. *INTEGRAL* observations showed that these outburst last only a few hours [16, 22]. Monitoring of the Galactic Centre region with *INTEGRAL* reveals that flares are rare, with typical intervals between outbursts of several months [22].

The outbursts start with a very sharp rise (with a timescale < 1 h) and sometimes show complex structure, with several flare-like peaks [16, 22]. The X-ray spectrum during the outbursts is generally very absorbed, though the absorption is variable. Good fits can be achieved with either a power law with a high-energy cut-off or a thermal bremsstrahlung model with $kT \sim 20$ keV [27, 16].

The source was not detected during most of an *ASCA* pointing in March 1999 (with an upper limit $L_{\rm X} < 10^{33}$ erg s^{-1}), but went into outburst at the end of the same observation. *Chandra* detected the source at a moderate luminosity $L_{\rm X} \sim 10^{34}$ erg s^{-1}, allowing the identification of the counterpart [27]. VLT/FORS1 spectra taken in May 2004 show the counterpart to be an O8 Iab(f) star, placed at a distance ≈ 2.6 kpc [19]. Interstellar absorption is much lower than the absorption implied by X-ray spectral fits. At this distance, the luminosity at the peak of the outbursts approaches $L_{\rm X} \sim 10^{36}$ erg s^{-1}.

2.2. IGR J17544−2619

IGR J17544−2619 was discovered by *INTEGRAL* on 2003 September 17th, when it showed two flares lasting ~ 2 h and ~ 8 h [31, 7]. On 2004 March 8th, it showed a complex outburst lasting more than 8 h [8]. So far, 5 outbursts from this system have been observed by *INTEGRAL* [23]. In outburst, the spectrum is hard and moderately absorbed, with evidence for some variation in the amount of absorbing material.

The source was observed by *XMM-Newton* on 2003 September 11th and 17th and in both cases seen at $L_{\rm X} \sim 10^{35}$ erg s^{-1} [3], though it was not detected during a serendipitous observation in March 2003 ($L_{\rm X} \lesssim 2 \times 10^{32}$ erg s^{-1}). *Chandra* observed it on 2004 July 3rd, in a very different state, with $L_{\rm X} \sim 5 \times 10^{32}$ erg s^{-1} and displaying a soft spectrum [10].

The counterpart to the source has been unambiguously identified with the *XMM-Newton* and *Chandra* positions. The counterpart is an O9 Ib supergiant, at a distance of ~ 3 kpc [20].

3. THE FAST X-RAY TRANSIENTS

Because of their properties, XTE J1739−302 and IGR J17544−2619 have been termed Supergiant Fast X-ray Transients (SFXTs) by [27]. A number of sources have displayed similar X-ray lightcurves, characterised by low-level or undetectable quiescence levels and repeated short X-ray outbursts, among which are IGR J16479−4514, AX J1749.1−2733, SAX J1818.6−1703 and AX J1841.0−0536 [22, 23]. The last two sources are known to be associated with massive stars.

Three other sources have only been observed to flare once, but are believed to be associated with supergiants. They are IGR J08408−4503, seen by *INTEGRAL* [4] and later detected by *Swift* at the position of the O8.5 Ib supergiant HD 74194 [13], IGR J16465−4507 and AX 1845.0−0433.

Many other systems have shown short outbursts that resemble those of the known SFXTs [see 23, 27]. Of special interest is IGR J11215−5952, a source displaying short outbursts every 329 d [25, 28], identified with the B supergiant HD 306414.

4. NEW DATA

4.1. IGR J16465−4507

IGR J16465−4507 was discovered by *INTEGRAL* during an X-ray flare on 2004 September 7th [15]. A subsequent *XMM-Newton* observation [17] revealed that the source is a pulsar with $P_{\rm spin} = 228$ s and is extremely absorbed ($N_{\rm H} \sim 7 \times 10^{23}$ cm^{-2}). The *XMM-Newton* position allows the identification of a counterpart. Our new VLT/FORS1 spectrum reveals that this object is a B0.5 Ib supergiant. Lacking accurate photometry, we estimate its distance at ~ 8 kpc.

4.2. SAX J1818.6−1703

SAX J1818.6−1703 was discovered by *BeppoSAX* during a strong short outburst (with a rise time of ~ 1 h), in March 1998 [11]. *INTEGRAL* detected a double-peaked outburst in September 2003 [6] and two more in October 2003 [22]. Other fast outbursts have been observed with the ASM on *RossiXTE* [22].

The X-ray lightcurve of SAX J1818.6−1703 is typical of a SFXT. The X-ray spectrum is very hard [6]. We have found an obscured supergiant close to the centre of the error circle for SAX J1818.6−1703 and believe that this is its correct counterpart [18]. A spectrum of this object is shown in Fig. 1.

4.3. AX J1841.0−0536

AX J1841.0−0536 was observed as a violently variable transient by *ASCA* in April 1994 and then again in October 1999 [1]. The source showed multi-peaked flares with a sharp rise (tenfold increase in count-rate over ~ 1 h). Analysis of the *ASCA* data revealed that the source is a pulsar with $P_{\rm spin} = 4.7$ s. The spectrum can be fit by an absorbed power law plus iron line [1]. Three flares from this source have been observed by *INTEGRAL* [23]. Its spectrum displays a hard tail up to at least 80 keV.

A *Chandra* observation of the field allowed the localisation of the counterpart to AX J1841.0−0536 [9]. Our new VLT/FORS1 spectrum shows this object to be a B0.2 Ib supergiant.

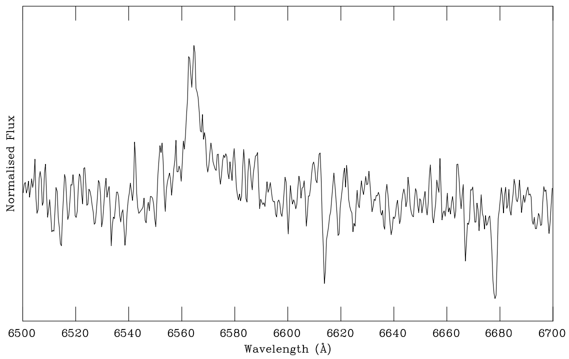

Figure 1. Intermediate resolution spectrum of the likely counterpart to SAX J1818.6−1703, taken with the NOT on June 2006. Hα *is emission, but the* He I *6678Å line is strongly in absorption. No* He II *6683Å line is visible in its vicinity, indicating that this object is O9 or later. A lower resolution spectrum taken with the VLT can be used to constrain the spectral type to be earlier than B1.*

4.4. AX 1845.0−0433

AX 1845.0−0433 was discovered by *ASCA* during a strong flare in 1993. The outburst consisted of a very fast rise (on the order of a few minutes) followed by a number of peaks during the next few hours. The spectrum was well fit by an absorbed power law [35]. The *ASCA* error circle was studied by Coe et al. [2], who found only one remarkable object, a late O-type supergiant. Our new VLT/FORS1 spectrum shows this object to be an O9 Ia supergiant at an estimated distance of $\sim$ 7 kpc.

5. PERSISTENT TRANSIENTS AND OUTBURSTING PERSISTENT SOURCES

From the data on *INTEGRAL* monitoring of SFXTs [23], IGR J16479−4514 appears to be the most active fast transient with 10 short outbursts observed in two years. On the other hand, IGR J16479−4514 is given as a persistent source by Walter et al. [34]. Obviously, the difference between persistent and transient behaviour may depend on the detection level, but here we have a source with a detectable quiescence level producing frequent short outbursts.

Conversely, at least three classical SGXBs have been observed to undergo flares on a timescale comparable to those seen in SFXTs. These are Vela X-1, 1E 1145.1-6141 and Cyg X-1 [see 27, for references]. Similarly, IGR J16418−4532, one of the new persistent sources listed by Walter et al. [34], has also shown an SFXT-like flare [23]. There are good reasons to believe that IGR J16195−4945 is a persistent source [33], but it has also shown a flare [23]. Another source proposed as a SFXT, XTE J1743-363 [23], has been observed during the *RXTE* Galactic bulge scan program to show violent variability with many spikes, with a lightcurve which seems intermediate between persistent and SFXT behaviour (C. Markwardt, private communication).

6. IGR J11215−5952

IGR J11215−5952 was discovered during a brief flare in April 2005 [14]. Its association with the bright supergiant HD 306414 has been confirmed by a *SWIFT* observation [30]. Analysis of the *INTEGRAL* lightcurve for this source [25] found three short ($\sim$ 2 d) outbursts separated by $\sim$ 330 d. A *RossiXTE* ToO observation of the source 330 d after the previous outburst resulted in the detection of a new 2-day-long rather bright ($L_{\rm X} \sim 10^{36}{\rm erg\,s^{-1}}$) outburst centred on March 17th, 2006 [28] . These observations not only confirm the periodicity, but also show that the compact object in IGR J11215−5952 is a NS, as an X-ray pulse is almost certainly seen [29].

A new spectrum of the counterpart, HD 306414, was taken with the 1.9-m telescope at the South African Astronomical Observatory in May 2006 (Fig. 2). We derive a spectral type B0.7 Ia, in good agreement with previous works, and estimate the distance at ~ 8 kpc

IGR J11215−5952 presents strong similarities to SFXTs, including the short outbursts peaking at $L_{\rm X} \sim 10^{36}{\rm erg\,s^{-1}}$, separated by long periods of quiescence. Moreover, these outbursts present irregular lightcurves, containing several independent flares. On the other hand, these outbursts last on average 2.5 d, as compared to 2 – 8 h for more typical SFXTs, and are separated by a fixed gap. The existence of this periodicity in the occurrence of the outbursts sets strong constraints on the possible outburst mechanisms, but, at the same time, sets IGR J11215−5952 apart from other SFXTs.

7. CONCLUSIONS

A flurry of recent results confirms without any doubt that *INTEGRAL* has found a class of transient supergiant systems which was not suspected to exist before. However, we have not found yet any telling characteristic of this new class beyond the presence of short outbursts. Rather it seems that there is a continuum in possible behaviours between persistent sources (perhaps occasionally presenting a flare) and transient systems (at least sometimes) undetectable in quiescence. The physical mechanism causing these flares is unknown and the discovery of a recurrent periodic flaring system, IGR J11215−5952, has only served to cast more doubts on this issue.

In any case, the number of systems with short outbursts is increasing steadily and it seems now clear that many more flaring systems may lie hidden in the Galactic plane.

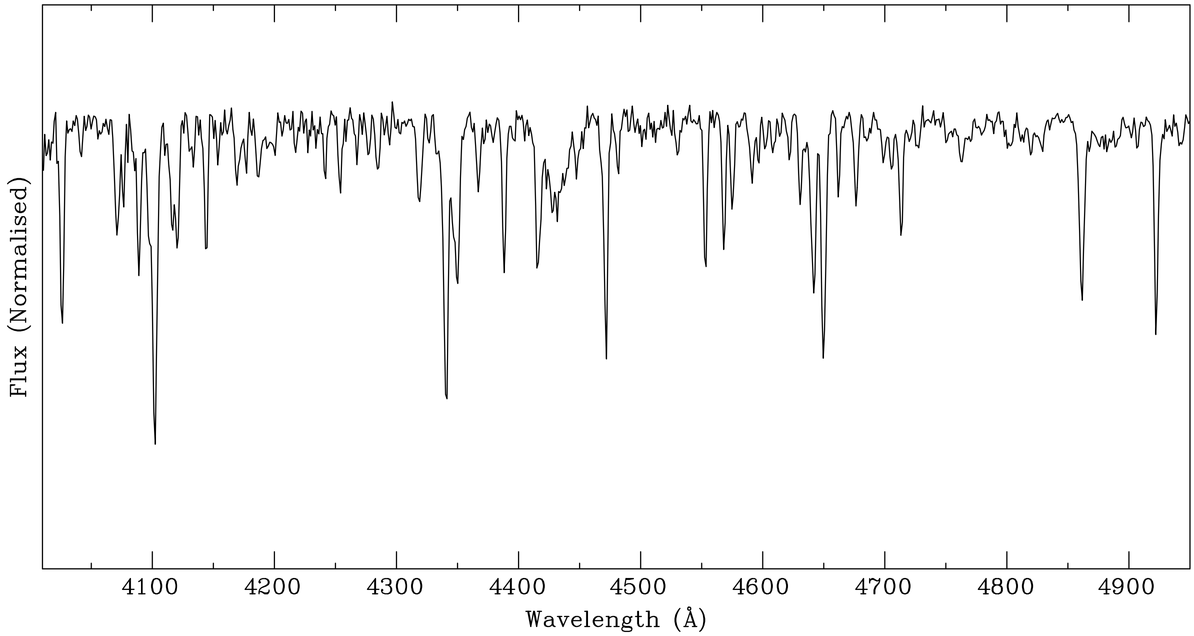

Figure 2. Classification spectrum of HD 306414, the optical counterpart to IGR J11215−5952. The presence of a very weak He II *4686Å line puts the spectral type at B0.7 Ia, rather than the B1 Ia derived from lower resolution spectra. The intensity of* Si IV*,* Si III *and* O II *features shows that this is a very luminous supergiant of luminosity class Ia.*

8. NOTE ADDED IN PROOF

Since this paper was submitted, [24] have reported repeated flaring activity from AX 1845.0−0433 and an accurate position that identifies it with the O9 Ia supergiant discussed here. This object is hence an SFXT. IGR J08408−4503 has also been confirmed as an SFXT by detection of further flares [5]. A *Chandra* localisation has identified SAX J1818.6−1703 with the obscured supergiant proposed here [12]. IGR J11215−5952 has displayed a new outburst, allowing a firm detection of a pulse period ($P_{\rm spin} = 186.8 \pm 0.3$, [32]). The outburst, occurring 329 d after the previous one, was observed to be followed by low flux X-ray emission lasting ~ 10 d [21].

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