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Faint Galactic X–ray Binaries

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Abstract. We present a short overview of the properties of faint Galactic X–ray binaries. We place emphasis on current classification scenarios. One of the important parameters for the faint sources is their intrinsic luminosity. In the case of low–mass X–ray binaries it has recently been realised that besides a phase of radius expansion, the duration of type I X–ray bursts can be used as a primer for the source luminosity in some cases. Further, we show that a very low equivalent width of hydrogen and helium emission lines in the optical spectrum alone is not a tell–tale sign for an ultra–compact system. Finally, we list and discuss some unusual sources that could be X–ray binaries.

1. Introduction

In recent years many new and often faint X–ray binaries have been discovered. Sources are found in the deep images made in hard X–rays by INTEGRAL and in images obtained by *Swift*, XMM-*Newton* and *Chandra*. The sensitivity to soft X–rays of the CCD instruments on board the latter satellites as well as their small point–spread function allows for optical or near–infrared identification of the counterpart to the X–ray source which is essential for source classification. Especially for sources in the Galactic plane, crowding often requires the superb *Chandra* positional accuracy and precludes the use of the existing optical and near–infrared sky survey data such as that of the (S)DSS and 2MASS. Although, in the case of obscured high–mass X–ray binaries as well as the supergiant fast X–ray transients, lower resolution X–ray images together with especially 2MASS often provide a fair assessment of the source type. There are currently several programs providing identifications of the newly discovered sources (e.g. see various contributions to these proceedings and Steeghs et al. 2005a, Steeghs et al. 2005b, Torres et al. 2007b, Torres et al. 2007a, Tomsick et al. 2006, Masetti et al. 2008, Chaty et al. 2008 to cite just a few).

2. Identification

The increase of the sample of sources has also enlarged the covered parameter space. New sources sometimes display rare phenomena and properties that were thought to be unique for a certain class turned out to be more common. For instance, more and more faint transient and faint persistent low–mass X–ray binaries have been identified (Muno et al. 2003a, King & Wijnands 2006, in't Zand et al. 2007, and Wijnands 2008 these proceedings). In addition, there have been several new long–duration transients (e.g. the transient Z source XTE J1701–462; Homan et al. 2007), of which two sources still remain active today (the black hole candidate SWIFT J1753.5–0127, see Figure 1, and the accretion powered ms X–ray pulsar HETE J1900.1–2455; Galloway et al. 2007). Two new groups of high–mass X–ray binaries have recently been identified. The obscured high–mass X–ray binaries (e.g. IGR J16318–4848; Walter et al. 2003) and the supergiant fast X–ray binaries (e.g. Sguera et al. 2005, Negueruela et al. 2007).

Many new X–ray sources have been discovered in the *Chandra* survey described in Wang et al. (2002) and Muno et al. (2003b). Considerable effort has gone into the source classification but the large extinction and source crowding in fields near the Galactic Centre hamper the identifications (Bandyopadhyay et al. 2005, but see Eikenberry et al. 2006 and Eikenberry et al. these proceedings). Considerable effort is also put–in in the ChamPlane survey (Grindlay et al. 2005, Laycock et al. 2005).

As was indicated in a recent paper by Mukai et al. (2008), some of the faint X–ray transients found towards the Galactic Centre might be dwarf Novae in outburst. In the absence of the tell–tale signs of a neutron star (pulsations, type I X–ray bursts) a good way to distinguish between a nova or a low–mass X–ray binary origin is to look at the ratio of the X–ray and optical luminosity and at the equivalent width of the hydrogen and helium emission lines in the optical spectra. One can determine the equivalent width of the emission lines that are typically found in interacting and active binaries and AGN even with medium resolution spectra. The equivalent width, the ratio of optical and X–ray flux (and hence optical and X–ray luminosity), and the estimate of the optical magnitude of the source allow one to classify the sources. For instance, for a given optical to X–ray flux ratio the equivalent width of H and He emission lines in cataclysmic variables is much larger than that of low–mass X–ray binaries (Patterson & Raymond 1985, van Paradijs & McClintock 1995).

High–mass X–ray binaries can be separated from cataclysmic variables and low–mass X–ray binaries by the fact that their optical and/or near–infrared counterparts are several magnitudes brighter. Even when extinction is high and the distance large a near–infrared (K–band) image will reveal a bright counterpart if the source is a high–mass X–ray binary (e.g. Walter et al. 2003, Negueruela & Smith 2006, Tomsick et al. 2006). Finally, often excess extinction over the Galactic interstellar value is found, implying that the extinction is intrinsic to the source. A large amount of local extinction points to a high–mass rather than a low–mass system. However, care should be taken as variations in the extinction can be large and on much smaller scales than provided by the Dickey & Lockman (1990) or Schlegel et al. (1998) maps (e.g. see the work of Gosling et al. 2006).

3. The Luminosity of Faint Sources

One of the important unknown parameters of the faint persistent and transient sources is their intrinsic luminosity. Do these sources appear faint due to e.g. their large distances, a large interstellar extinction, or due to inclination effects, or are they intrinsically weak?

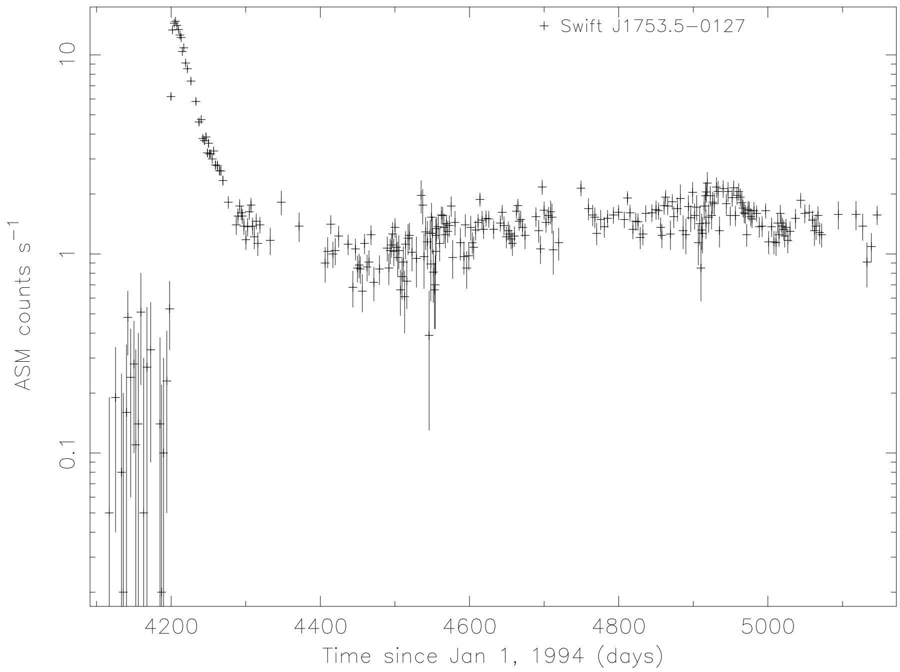

Figure 1. Light curve of the black hole candidate Swift J1753.5–0127 obtained by the All Sky Monitor onboard the Rossi X–ray timing Explorer. The source is a long–duration transient where the outburst lasts several years (see also Cadolle Bel et al. 2007).

It is well known that inclination effects can be important. In high inclination systems the accretion disk can occult part of the inner disk from our view which can lead to a lower apparent luminosity. Similarly, (mild) beaming effects (King 2002) and scattering could be important (Milgrom 1978, Lapidus & Sunyaev 1985, Fujimoto 1988, Narayan & McClintock 2005). Nevertheless, inclination and beaming effects are not a likely explanation for the faintness of all the faint sources that are found.

An existing method to determine distances in neutron star low–mass X–ray binaries relies on the occurrence of photospheric radius expansion thermonuclear explosions on the surface of low magnetic field accreting neutron stars (so called type I X–ray bursts, for a calibration of the distance scale, theoretical background and applications see Kuulkers et al. 2003, Galloway et al. 2003, 2006, Jonker & Nelemans 2004). In order to determine whether the photosphere undergoes radius expansion one needs to obtain X–ray data with at least modest energy resolution. However, both recent observational and theoretical work on these type I X–ray bursts show that they can be used to infer whether a source is intrinsically faint or not without the need for photospheric radius expansion bursts (Peng et al. 2007, in't Zand et al. 2007). If the burst duration of a type I X–ray burst is longer than a few minutes it implies that a rather thick layer of accreted material has been burned in the thermonuclear explosion. The conditions to build up such a thick layer require a luminosity below a few percent of Eddington. in't Zand et al. (2007) applied this method, as well as the distance derived from radius expansion bursts (when present), and concluded that the intrinsic luminosity of a sample of faint persistent sources is low. At such low luminosities it is difficult for the accretion disk to be fully ionized, hence these systems should be transients unless they are ultra–compact X–ray binaries with orbital periods less than $\sim$1 hr.

In optical spectroscopic observations obtained with the VLT of one of the sources studied by in't Zand et al. (2007), 1A 1246–599 (Bassa et al. 2006, In 't Zand et al. submitted), the

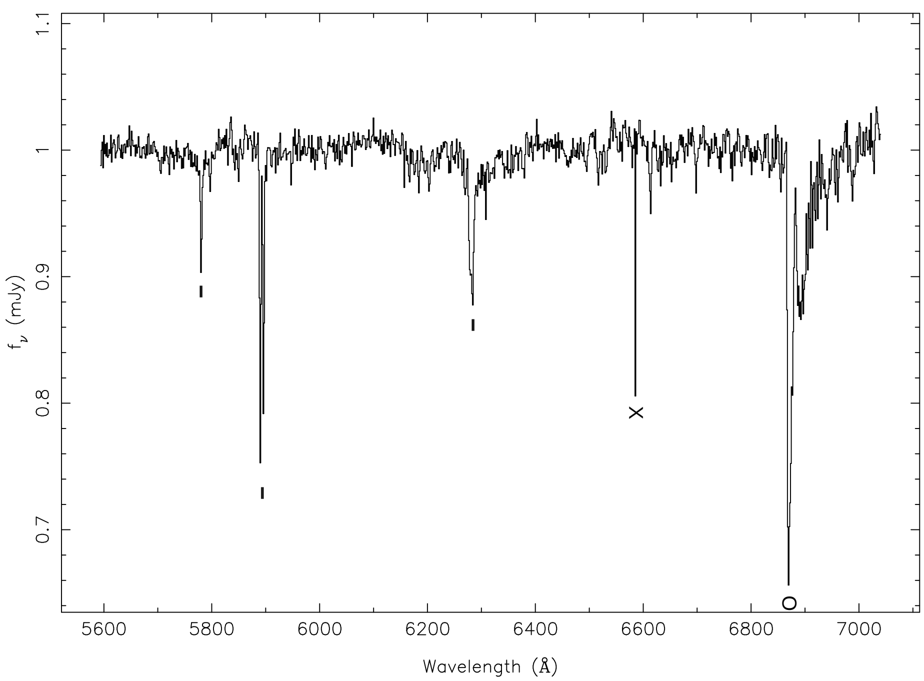

Figure 2.   Optical spectrum of the counterpart of Swift J1753.5–0127 obtained with the LDSS–3 spectrograph mounted on the 6.5 m Magellan Clay telescope on June 25th 2006 1:45-5:15UT. This spectrum is the average of 13×600 s exposures. Observing conditions were good with seeing around 0.9-1.0". The VPH-Blue grism was employed with a 0.75" slit. The small vertical bars indicate absorption lines caused by interstellar absorption. The cross indicates a spike that is caused by a CCD defect and the open circle indicates a feature caused by telluric absorption.

hydrogen and helium emission lines normally found in low–mass X–ray binaries are not detected down to equivalent width limits that are much lower than those observed in low–mass X–ray binaries that have orbital periods in excess of a few hrs (see also Nelemans & Jonker 2005, Nelemans et al. 2006). This, together with the low optical brightness of the source strongly argues for an ultra–compact X–ray binary nature of this source. Interestingly, in an optical spectrum of the transient black hole candidate Swift J1753.5–0127 we also did not find evidence for hydrogen or helium emission lines (see Figure 2, Cadolle Bel et al. 2007), however, the orbital period of this system is 3.2 hours (Zurita et al. 2007). Therefore, the absence of hydrogen and or helium emission lines alone cannot be used as evidence for an ultra–compact nature of the source. Furthermore, earlier in the outburst optical spectra of Swift J1753.5–0127 did show Hα emission (Torres et al. 2005, Cadolle Bel et al. 2007).

In the case of high–mass X–ray binaries the distance can be estimated in a crude way by using the approximate location of spiral arms and the Galactic position of the source. These relatively young and massive systems reside close to spiral arms. Some sources appear faint due to the fact that the interstellar extinction causes a reduction in the observed amount of soft X–rays. However, even though many of the faint obscured sources discovered by INTEGRAL appear faint in the soft X–ray bands due to the large extinction, the extinction is much less important above a few keV and many of these sources have luminosities above 1×10^{35} erg cm^{-2} s^{-1}(e.g. Walter et al. 2003, in't Zand et al. 2006). Hence, observing at high X–ray energies reduces/eliminates the effects of extinction.

4. Outliers; Rare Transients

The diversity among the properties of X–ray binary transients is large. Nevertheless, recently a handful of transients has been described that do not fit the known categories. In Table 1 we list the ones currently known to us.

Table 1. Rare transients

Source name	Peak flux	Reference
Swift J1749.4-2807	2×10^{-8} erg cm^{-2} s^{-1}(15–50 keV)	Wijnands et al. 2007
Swift J195509.6+261406	5×10^{-8} erg cm^{-2} s^{-1}(15–150 keV)	Kasliwal et al. 2007
XTE J1901+014*	0.5-1 Crab	Karasev et al. 2007
IGR J11321-5311	2.2×10^{-9} erg cm^{-2} s^{-1}(20–300 keV)	Sguera et al. 2007
Ginga Burst 900129	–	Strohmayer et al. 1995

* Possible fast supergiant transient?

Wijnands et al. (2007) classify Swift J1749.4-2807 as a fast transient low–mass X–ray binary at a distance of 6.7±1.3 kpc. They interpret the Swift/BAT trigger as due to a type I X–ray burst. The evidence they provide to support their claim comes from the XMM-*Newton* discovery of a point source at the position of the Swift/XRT afterglow both 6 years before the burst as well as 4 months after the burst (Wijnands et al. 2007). The Swift/XRT afterglow emission decreased at a huge rate (a factor 1000 in less than a day). This observation increases the parameter space of the decay rate of low–mass X–ray binary transients enormously (the black hole transient XTE J1908+094 showed a decay rate of a factor of 750 in less than 24 days; Jonker et al. 2004).

Like Swift J1749.4-2807, Swift J195509.6+261406 was first reported to be a Gamma–ray Burst (GRB; Pagani et al. 2007). However, the subsequent Swift/XRT and near–infrared monitoring (Kasliwal et al. 2007) showed that the afterglow was unlike that of a GRB. Kasliwal et al. (2007) propose the source to be a black hole X–ray transient. If indeed low–mass X–ray binaries are responsible for the two Swift events noted above they can by extension also be responsible for the other events listed in Table 1. An alternative interpretation for some of the events in Table 1 is that they are caused by a Soft Gamma–ray Repeater or an Anomalous X–ray Pulsar (SGR, AXP; Woods & Thompson 2006).

Finally, we repeat that some of the (obscured) fast hard X–ray transients that have been discovered in recent years also exhibit large fast flares (Smith et al. 2006), hence such sources could be responsible for some of the transient events reported above, most notably XTE J1901+014 and IGR J11321–5311. However, the hard X–ray spectrum of IGR J11321–5311 shows an upturn at the lowest energies that are covered by the INTEGRAL/ISGRI instrument which is not found in the other fast hard X–ray transients. Furthermore, for most of the supergiant fast X–ray transients multiple outbursts have been detected (e.g. Sguera et al. 2005; Negueruela et al. 2007). So far, that is not the case for the systems listed in Table 1. Finally, there is no strong candidate for a supergiant counterpart in the 2MASS catalogue (Skrutskie et al. 2006) in the INTEGRAL error circle of IGR J11321–5311 (see Figure 3). In the direction of the transient there is a dark cloud encompassing the full area shown in Figure 3 (the dark cloud is centered on l=291.10, b=7.85 which is close to star 3 in Figure 3; Feitzinger & Stuewe 1984; Ramesh 1994). Due to the probably close proximity of the cloud (<400 pc; Ramesh 1994), it is likely that the hard X–ray transient is located behind this cloud. Since the extinction caused by the dark cloud will cut out the UV light all the objects detectable in the Swift $UVW2$ image should be foreground objects. If so, then there are no bright 2MASS objects located in the INTEGRAL error circle and behind the dark cloud

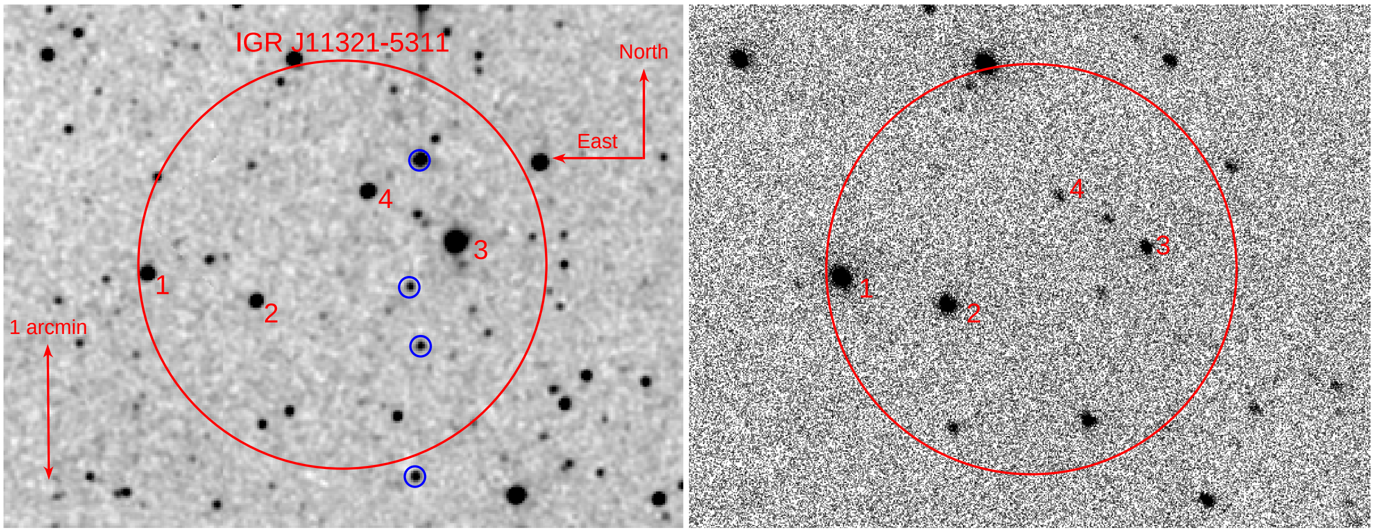

Figure 3. *Left panel:* Near–infrared 2MASS image (K–band) of the field of IGR J11321-5311. *Right panel:* Swift/UVOT $UVW2$–band image of the same area, showing that the stars labelled 1 through 4 are in the foreground of the dark cloud that is centered near star 3 and encompasses the whole field of view displayed here (Feitzinger & Stuewe 1984; Ramesh 1994). The four encircled stars are not listed in the 2MASS catalogue, even though they are significantly detected.

that suggest a supergiant. Note that the sources encircled in the *left* panel in Figure 3 have not been identified in the 2MASS catalogue. Due to the fact that these sources all lie along the direction of the trail caused by a very bright star just off the top the displayed field, we speculate that this is due to the presence of this bright star (2MASS J11321193–5309324; K=5.771). Since this star is only just outside the 90% confidence error circle we cannot exclude that this source is the counterpart to IGR J11321–5311. Note, however, that it is also detected in the UVOT image.

The deep limits on the near–infrared counterpart in quiescence of Swift J195509.6+261406 and the known interstellar extinction do exclude the possibility of a early type star as the counterpart to Swift J195509.6+261406 (see Kasliwal et al. 2007).

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