How to reveal the mysteries of the most obscured high-energy sources of our Galaxy, discovered by INTEGRAL?

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Abstract. A new type of high-energy binary systems has been revealed by the *INTEGRAL* satellite. These sources are in the course of being unveiled by means of multi-wavelength optical, near- and mid-infrared observations. Among these sources, two distinct classes are appearing: the first one is constituted of intrinsically obscured high-energy sources, of which IGR J16318-4848 seems to be the most extreme example. The second one is populated by the so-called supergiant fast X-ray transients, with IGR J17544-2619 being the archetype. We report here on multi-wavelength optical to mid-infrared observations of these systems. We show that in the case of the obscured sources our observations suggest the presence of absorbing material (dust and/or cold gas) enshrouding the whole binary system. We then discuss the nature of these two different types of systems.

INTRODUCTION

The *INTEGRAL* observatory has performed a detailed survey of the galactic plane and the ISGRI detector on the IBIS imager has discovered many new high energy sources, most of all reported in [1] (and http://isdc.unige.ch/∼rodrigue/html/igrsources.html). The most important result of *INTEGRAL* to date is the discovery of many new high energy sources –concentrated in the Galactic plane, and some in the Norma arm (see e.g. [2])–, exhibiting common characteristics which previously had rarely been seen. Most of them are high mass X-ray binaries (HMXBs) hosting a neutron star orbiting around an O/B companion, in some cases a supergiant star. They divide into two classes: some of the new sources are very obscured, and exhibiting a huge intrinsic and local extinction, and the others are HMXBs hosting a supergiant star and exhibiting fast and transient outbursts: an unusual characteristic among HMXBs: they are therefore called Supergiant Fast X-ray Transients (SFXTs, [3]). High-energy observations are not sufficient to reveal the nature of the newly discovered sources, since the *INTEGRAL* localisation ($\sim 2'$) is not accurate enough to unambiguously pinpoint the source at other wavelengths. Once X-ray satellites such as *XMM-Newton*, *Chandra* or *Swift* provide an arcsecond position, the hunt for the optical counterpart of the source is open. However, the high level of absorption towards the galactic plane makes the near-infrared (NIR) domain more efficient to identify these sources. We first report on multi-wavelength observations of two sources belonging to each class described above, then give general results on *INTEGRAL* sources, before discussing them and concluding.

OBSERVATIONS AND RESULTS

The multiwavelength observations described here were performed at the European Southern Observatory (ESO), using Target of Opportunity (ToO) and Visitor modes, in 3 domains: optical ($400-800\,\mu$m) with the EMMI instrument on the 3.5m New Technology Telescope (NTT) at La Silla, NIR ($1-2.5\,\mu$m) with the SOFI instrument on the NTT, and MIR ($5-20\,\mu$m) with the VISIR instrument on Melipal, the 8m Unit Telescope 3 (UT3) of the Very Large Telescope (VLT) at Paranal (Chile). These observations include photometry and spectroscopy on 20 *INTEGRAL* sources in order to identify their counterparts, the nature of the companion star, derive the distance, and finally characterise the presence and temperature of their circumstellar medium.

IGR J16318-4848: extreme among the obscured high-energy sources

IGR J16318-4848 was the first source to be discovered by IBIS/ISGRI on *INTEGRAL* on 29 January 2003 [4]. *XMM-Newton* observations showed a strong absorption of $N_{\rm H} \sim 2 \times 10^{24}$ cm^{-2} [5]. The accurate localisation by *XMM-Newton* allowed [6] to rapidly trigger ToO photometric and spectroscopic observations in optical and NIR, leading to the discovery of the optical counterpart and to the confirmation of the NIR one found by [7]. The extremely bright NIR source (Ks = 7.20 magnitudes) exhibits an unusually strong intrinsic absorption of $A_v = 17.4$ magnitudes, much stronger than the absorption along the line of sight of $A_v = 11.4$ magnitudes, but still 100 times lower than the absorption in X-rays! This led [6] to suggest that the material absorbing in the X-rays was concentrated around the compact object, while the material absorbing in the optical/NIR was enshrouding the whole system. The NIR spectroscopy revealed an unusual spectrum, with many strong emission lines, originating from a highly complex and stratified circumstellar environment, of various densities and temperatures, suggesting the presence of an envelope and strong stellar outflow, responsible for the absorption. Only luminous early-type stars such as supergiant sgB[e] show such extreme environments, and [6] concluded that IGR J16318-4848 was an unusual HMXB. Combining these optical and NIR data with MIR observations, and fitting these observations with a model of a sgB[e] companion star, allowed [8] to show that IGR J16318-4848 exhibits a MIR excess (see Figure 1), that they interpret as being due to the strong stellar outflow emanating from the sgB[e] companion star. They found that the companion star had a temperature of T = 23500 K, radius $R_{star} = 20.4 R_\odot$, and an extra component of temperature T = 900 K, radius $R = 12 R_{star}$ and $A_v = 17.6$ magnitudes. The extension of this extra component seems to suggest that it enshrouds the whole binary system, as would do a cocoon of gas/dust. In summary, IGR J16318-4848 is an HMXB system, located at a distance between 1 to 6 kpc, hosting a neutron star (probably) and a sgB[e] star, and the whole binary system seems to be surrounded by a dense and absorbing circumstellar material envelope or cocoon, made of cold gas and/or dust. This source exhibits so extreme characteristics that it might not be fully representative of the other obscured sources.

IGR J17544-2619: archetype of the Supergiant Fast X-ray Transients

The Supergiant Fast X-ray Transients (SFXTs) constitute a new class of sources identified among the recently discovered *INTEGRAL* sources, whose common characteristics are: they exhibit rapid outbursts lasting only hours, a faint quiescent emission, their high energy spectra require a BH or NS accretor, and they host O/B supergiant companion stars. Among these sources, IGR J17544-2619, a bright recurrent transient X-ray source discovered by *INTEGRAL* on 17 September 2003 [9], seems to be the archetype. Observations with *XMM-Newton* have shown that it exhibits a very hard X-ray spectrum, and a faint intrinsic absorption (10^{22} cm^{-2}) [10]. Its bursts last for hours, in-between bursts it exhibits long quiescence periods, and a long outburst period of 165 days [3]. The nature of the compact object is probably a neutron star [11]. [12] managed to get optical/NIR ToO observations only one day after the discovery of this source. They identified a likely counterpart inside the *XMM-Newton* error circle, confirmed by *Chandra* accurate localization. Spectroscopy showed that the companion star was a blue supergiant of spectral type O9Ib, with a mass of $25-28 M_\odot$ and temperature of T $\sim$ 31000 K: the system is therefore an HMXB [12]. [8] combined optical, NIR and MIR observations and showed that they could accurately fit the observations with a model of an O9Ib star: temperature T = 30500 K and radius $R_{star} = 21.9 R_\odot$. The absorption they derived was $A_v = 5.9$ magnitudes and the distance D = 3.9 kpc. The source does not exhibit any MIR excess (see Figure 1) [8]. In summary, IGR J17544-2619 is a HMXB at a distance of $\sim$4 kpc, constituted of an O9Ib supergiant, with a mild stellar wind and a compact object which is probably a neutron star, without any absorbing material.

General results on *INTEGRAL* sources and discussion

In order to better characterize this population, [13] and [8] have studied a sample of 20 *INTEGRAL* sources belonging to both classes described above. The optical/NIR study allowed [13] to identify or confirm the identification of the counterpart, and to show that most of these systems are HMXBs, containing massive and luminous early-type companion stars. By fitting the spectral energy distributions of these sources from optical to MIR, [8] showed that i. most of them exhibit an intrinsic absorption and ii. three of them exhibit a MIR excess, that they suggest to be due to the presence of a cocoon of dust and/or cold gas enshrouding the whole binary system (see also [14]). These results confirm the existence in the Galaxy of a dominant population of a previously rare class of high-energy binary systems,

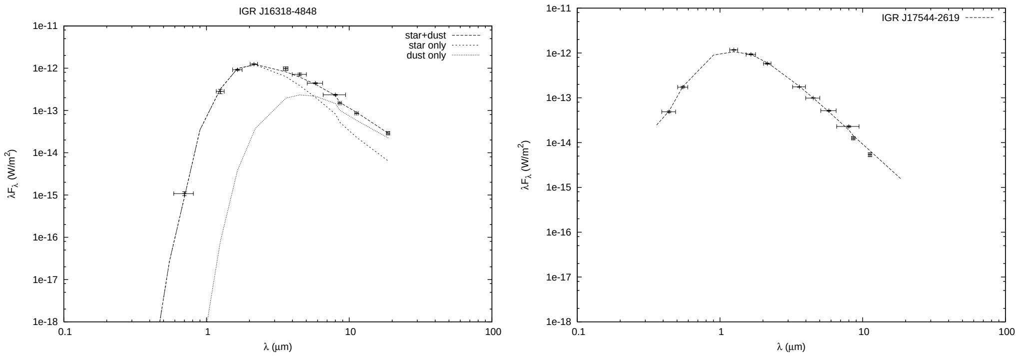

FIGURE 1. Optical to MIR SEDs of IGR J16318-4848 (left) and IGR J17544-2619 (right), including data from ESO/NTT, VISIR on VLT/UT3 and *Spitzer* [8]. IGR J16318-4848 exhibits a MIR excess, interpreted by [8] as the signature of a strong stellar outflow coming from the sgB[e] companion star [6]. On the other hand, IGR J17544-2619 is well fitted with only a stellar component corresponding to the companion star spectral type (O9Ib) [12].

constituted of supergiant HMXBs with high intrinsic absorption for some of them [13] [8]. Fundamental differences exist between obscured sources and SFXTs, and one possibility to explain those is to invoke a different geometry of the binary systems, or a different extension of a wind/cocoon enshrouding either the companion star or the whole system [14]. It is now clear that a careful study of this new population will provide a better understanding of the formation and evolution of such short-living HMXBs of our Galaxy, and will allow in the future stellar population models to better take these systems into account, to assess a realistic number of high-energy binary systems in our Galaxy. Our final word is that the GLAST satellite will certainly discover such new and unexpected objects, and that, as for these obscured high-energy sources, only a multiwavelength study will allow to reveal their nature.

ACKNOWLEDGMENTS

SC would like to thank the organisers for the opportunity to report on these exciting results on newly discovered *INTEGRAL* sources and for organizing a press conference on this subject. SC is grateful to Juan-Antonio Zurita Heras for useful comments on the manuscript, and to Farid Rahoui for making the SEDs of Figure 1. Based on observations collected at the European Southern Observatory, Chile (proposals ESO N° 070.D-0340, 071.D-0073, 073.D-0339, 075.D-0773 and 077.D-0721).

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