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# 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  $\mu\text{m}$ ) with the EMMI instrument on the 3.5m New Technology Telescope (NTT) at La Silla, NIR (1 – 2.5  $\mu\text{m}$ ) with the SOFI instrument on the NTT, and MIR (5 – 20  $\mu\text{m}$ ) 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

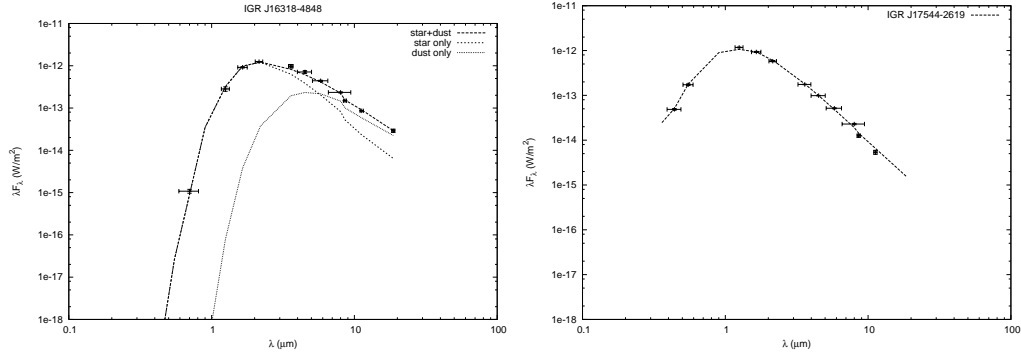
IGR J16318-4848 was the first source to be discovered by IBIS/ISGRI on *INTEGRAL* on 29 January 2003 [4]. *XMM-Newton* observations showed a strong absorption of  $N_{\text{H}} \sim 2 \times 10^{24} \text{ cm}^{-2}$  [5]. The accurate localisation by *XMM-Newton* allowed [6] to rapidly trigger ToO photometric 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 ( $K_s = 7.20$  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  $T = 23500 \text{ K}$ , radius  $R_{\text{star}} = 20.4R_{\odot}$ , and an extra component of temperature  $T = 900 \text{ K}$ , radius  $R = 12R_{\text{star}}$  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 ( $10^{22} \text{ cm}^{-2}$ ) [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  $25 - 28M_{\odot}$  and temperature of  $T \sim 31000 \text{ K}$ : 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  $T = 30500 \text{ K}$  and radius  $R_{\text{star}} = 21.9R_{\odot}$ . The absorption they derived was  $A_v = 5.9$  magnitudes and the distance  $D = 3.9 \text{ kpc}$ . The source does not exhibit any MIR excess (see Figure 1) [8]. In summary, IGR J17544-2619 is a HMXB at a distance of  $\sim 4 \text{ kpc}$ , 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.

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