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Unveiling the nature of the new transient IGR J19140+0951

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Abstract IGR J19140+0951 was discovered during the first observation campaign of the famous microquasar GRS1915+105 (PI Hannikainen) by INTEGRAL IBIS/ISGRI instrument. The source, which is 1° from GRS1915+105 (corrected position), shows high variations of its X-ray luminosity and spectral variations on timescales from seconds to hours. According to the early INTEGRAL (AO1) and further RXTE (AO8 and AO9) observations and regarding the spectral behavior and the timescale variability, we propose the source to be a galactic X-ray binary probably hosting a neutron star.

Key words: X-rays: binaries – X-rays: IGR J19140+0951 – Gamma-rays: observations

1 INTRODUCTION

The INTErnational Gamma-Ray Astrophysical Laboratory (*INTEGRAL*) was launched on 2002 Oct 17 in order to observe the sky between ~ 3 keV and ~ 10 MeV. In this study, we used the first layer detection (ISGRI) of the imager on board *INTEGRAL* IBIS (observing from 20 keV to 1 MeV) and one of the X-ray monitor (JEM X-2, working in the 3–35 keV range). For further explanation concerning both instruments, see Lebrun et al. 2003 for ISGRI and Lund et al. 2003 for JEM X. IGR J19140+0951 was discovered during the AO1 observation of GRS1915+105 (revolution 48) performed 2003 March 6 and 7 (Hannikainen, Rodriguez & Pottschmidt 2003, Hannikainen et al. 2004, see Fig. 1). Its early position was within the error box of a poorly studied *EXOSAT* source EXO 1912+097.

A Target of Opportunity (ToO) with the *Rossi X-ray Timing Explorer (RXTE)* was then activated a few days later, allowing the absorption column density to be estimated to $N_{\rm H} = 6 \times 10^{22}\,{\rm cm}^{-2}$ and the spectrum was well fit with a hard power law of photon index 1.6 (Swank and Markwardt 2003). Corbet et al. 2004 analyzing RXTE/ASM archive discovered a periodicity

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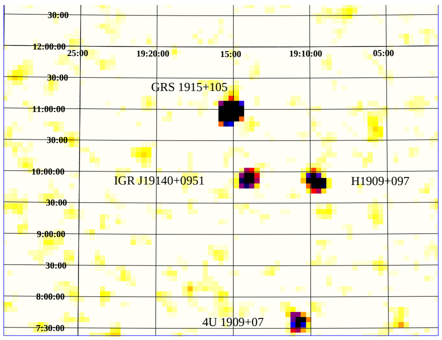

Fig. 1 20–30 keV IBIS/ISGRI image, showing clearly IGR J19140+0951 and GRS1915. The fov is 7° width and 5.3° height. Adapted from Hannikainen et al. 2004.

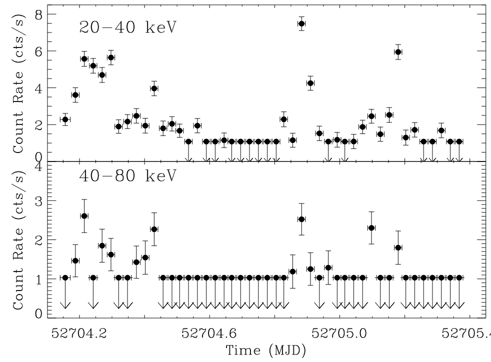

Fig. 2 20–40 keV (top) and 40–80 keV (bottom) ISGRI light curves. Bin-size = 2.2 ksec. Adapted from Hannikainen et al. 2004.

of 13.55 days, likely associated to the orbital motion of a binary system. We are leading an RXTE/INTEGRAL monitoring campaign, and present the very first RXTE observation here.

We will analyze in this paper the results coming from the early *INTEGRAL* observation of the source as well as the whole *RXTE* data sets available.

2 OBSERVATIONS AND DATA REDUCTION

INTEGRAL observed GRS1915+105 region using the hexagonal dither pattern during about 90 ksec (effective exposure $\sim$ 75 ksec). JEMX data were reduced using two different software packages : in order to obtain an accurate position of the source and as OSA3.0 was unable to detect spontaneously IGR J19140+0951 , we used the "JEM-X off-line software" (Lund et al. 2004). Concerning spectral extraction, we used the standard procedure (OSA 3.0), forcing the detection of the source at the position given by the previous method. For further explanation on the data reduction, see Hannikainen et al. 2004. The region of IGR J19140+0951 has been observed 3 times with RXTE : apart from the public ToO performed soon after the discovery of the source (AO8, duration 2.8 ksec) and the observations led during the AO9 (duration 7.8 ksec), we also used observation of EXO 1912+097 performed during AO7 (public data, 3.2 ksec) in order to compare the behaviors of both sources.

3 RESULTS

We show in Fig. 2 the 20–40 keV and 40–80 keV ISGRI light curves of IGR J19140+0951 during revolution 48. In this observation, the source flux is higher than the detection threshold (9–10 mCrab) in 70% of the observing time in the 20–40 keV range, reaching 70 mCrab in one occasion. A typical timescales for these variations is then the bin-size of the light curve, that is about 2 ksec.

3.1 Searching for an optical counterpart

3.1.1 refining the position

The early position of the source given in Hannikainen et al. 2003 was calculated using an early version of the analysis software (OSA 1.0) for ISGRI data reduction. We performed a new mosaic image using OSA 3.0 and a new best ISGRI position (J2000) was found in both lower energy bands : RA = $19^h14^m02.7^s \pm 2'$ and Dec = $9^o53'13'' \pm 2'$ (error at 90%). Independently and using "JEM-X off-line software" (Lund et al. 2004), we clearly detect the source in JEM-X data in 9 science windows (hereafter scw). Among those scw, the source was detected in two different energy bands three times, giving 12 independent detections to derive a best JEMX weighted mean position (J2000) : RA = $19^h14^m01^s \pm 9^s$ and Dec = $9^o53'21'' \pm 1.3'$ (error at 90%).Then with these two independent data sets we derived a new weighted mean position of the source (Cabanac et al. 2004) : **RA = $19^h14^m02^s$ and Dec = $9^o53.3'$** (1.3′ error at 90%).

3.1.2 optical/X-ray counterpart

In Fig 3. we superimposed the *INTEGRAL* error circle around the new source position on a red Palomar plate. Over 20 optical counterparts can be registered within it, showing that higher angular resolution instruments (Chandra or XMM) will be necessary to constrain the type of the counterpart. Fig 4. shows that the 6' error circle of EXO 1912+097 is compatible with the hypothesis that IGR J19140+0951 and EXO 1912+097 would be one and the same source.

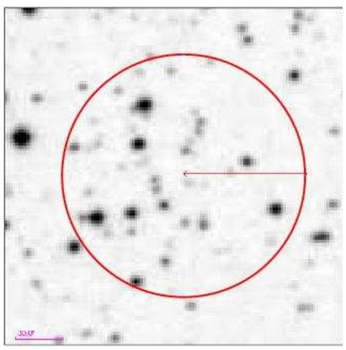

Fig. 3 DSS/POSSI red (E) plate of the IGR J19140+0951 region (image given by *Aladin* software). The 90% error circle of IGR J19140+0951 (1.3′) is superimposed.

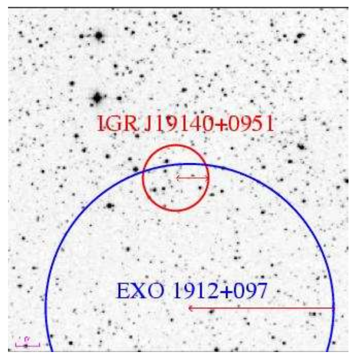

Fig. 4 EXO 1912+097 6′ error box superimposed to the previous image.

3.2 A galactic origin?

In order to constrain the origin of the source, we studied its timing behavior. *RXTE/PCA* light curve of the latest observations seems to show variations of the X-ray flux on 20s timescales (see Fig. 5). Moreover, we fit each IBIS spectra of the revolution 48 by a power law and the resulting photon index seems to vary rapidly (on a 2 ksec timescale, see Fig. 6). However, no *QPO* was found in the power spectral distribution. These rapid variations, together with the 13.56 days periodicity found in the *ASM* archive strongly suggests a galactic origin for IGR J19140+0951 .

3.3 Nature of the primary

3.3.1 INTEGRAL spectra

As *INTEGRAL* observations seem to exhibits variable behavior, we divided and summed up JEM X-2/IBIS spectra in two category :

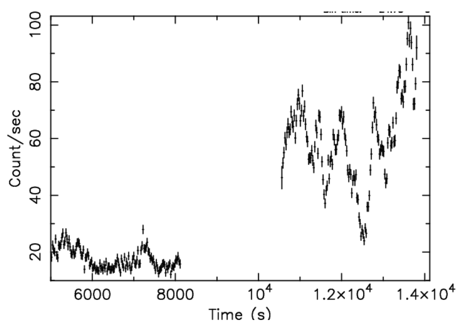

Fig. 5 PCA light curve in the 2–16 keV range. Bin-size is 24 seconds.

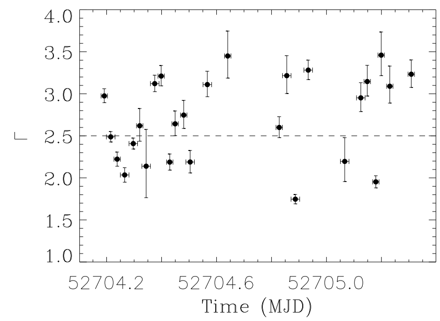

Fig. 6 Power law photon index versus time in IBIS/ISGRI spectra. Only good fit were kept.

Faint spectrum. This corresponds to the science windows where the 20–40 keV flux was less than 20 mCrab. It is well fit ($\chi^2 = 1.19$ (63 dof)) by a simple absorbed power law (photon index $\Gamma = 2.39 \pm 0.11$) and a black body (kT = $1.27^{+0.07}_{-0.08}$ keV).
Bright spectrum : This corresponds to observations where the 20–40 keV flux was greater than 20 mCrab. In that state, the power law behavior needs a rather low energy cutoff (required at 99.99% according to an F-test, with a cutoff energy of 49 ± 3 keV and a folding energy of 16^{+4}_{-7} keV). A comptonization model (comptt, Titarchuk, 1994) with a low electron temperature ($15.1^{+2.5}_{-1.6}$ keV) also fits the data well, whereas a black body is no longer required.

3.3.2 RXTE/PCA spectra : fainter states

RXTE/PCA observations were all performed when IGR J19140+0951 was in fainter states compared to the previous *INTEGRAL* observations. It shows (Fig. 7) that if a simple blackbody fits well the data of the first observation campaign, an energy cutoff is still required to fit the most recent data. The value found for the energy cutoffs are still rather low. The parameters given by the fit for EXO 1912+097 are still compatible with the hypothesis that IGR J19140+0951 would be the *hard X-ray* counterpart of this source.

Such low energy cutoff is more typical of X-ray emission by a neutron star binary (NSB) than a black hole binary (BHB) unless some BHB can present similar behavior (e.g XTE J1550–564, Rodriguez et al. 2003).

3.3.3 Luminosity criterion

Another way to constrain the type of the source is based on absolute luminosity. In a plot of the hard X-ray absolute luminosity of a source versus its soft component, neutron star and black hole binaries occupy two separated regions. Thus, we plotted the values obtained for both observations (*INTEGRAL* and *RXTE*) of IGR J19140+0951 on this diagram (see Fig. 8). In that case, IGR J19140+0951 seems to occupy in average the "neutron star region" unless the source is farther than 9 kpc and is in its brightest state.

4 CONCLUSIONS AND DISCUSSION

Combining JEM X-2 and IBIS data allowed us to obtain the most accurate position of IGR J19140+0951 since its discovery by *INTEGRAL*. The variability observed in X-ray flux in *INTEGRAL* data as far as in *RXTE/PCA* ones coupled with the 13.56 days periodicity

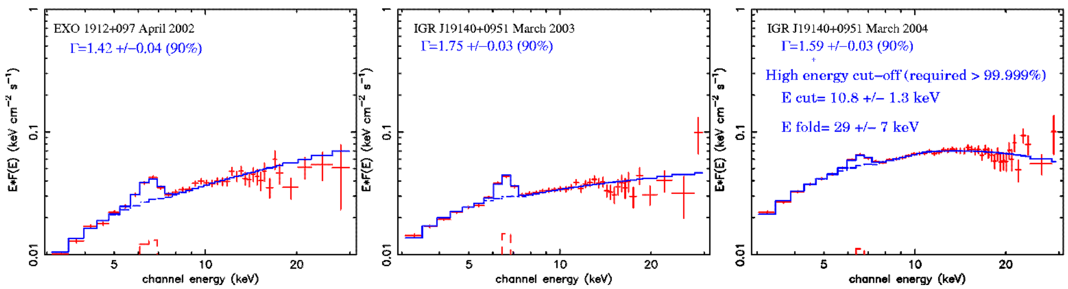

Fig. 7 *Left* : *RXTE/PCA* spectra of EXO 1912+097 (AO7). *Center* : AO8 *RXTE/PCA* spectrum of IGR J19140+0951 fit by a simple absorbed power law ($N_{\rm H}$ fixed to 6×10^{22}cm $^{-2}$). *Right* : One year later (AO9), the spectrum is better fit by a cutoff power law with low folding and cutoff energies.

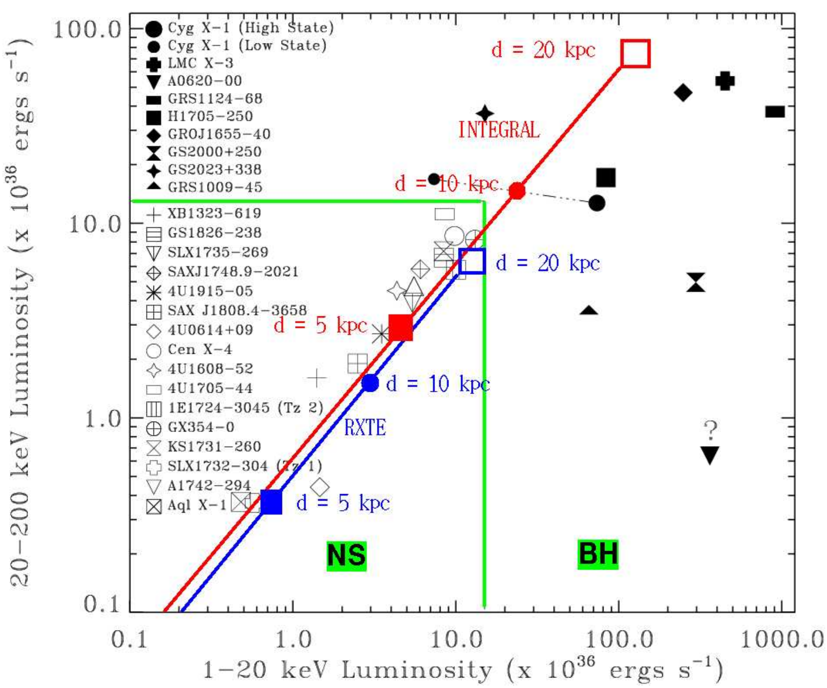

Fig. 8 Plot adapted from Barret et al. 2000 showing the 20–200 keV absolute luminosity of the source versus 1–20 keV absolute luminosity. Neutron star (NS) binaries occupy the low luminosity region (lower-left region in the diagram) whereas black hole (BH) binaries exhibits strong absolute luminosity (see however di Salvo et al. 2001). IGR J19140+0951 absolute luminosity has been superimposed for both *INTEGRAL* brightest state and *RXTE* observations. The lines represent the uncertainty on the distance of the source (fill squares are at 5 kpc, fill circles at 10 kpc and open squares are at 20 kpc which is the extremal value of the galaxy length along the line of sight).

observed in ASM archives seems to indicate a galactic origin for IGR J19140+0951 . In that way, searching for any secondary star in the X-ray binary system will require high angular resolution X-ray instruments considering the numerous optical counterpart registered within the IBIS error box.

The type of the primary can be constrained using both spectral and luminosity criterion. The requirement of a low energy cutoff in both *INTEGRAL* and RXTE spectra seems to favor a neutron star as primary. Moreover, this hypothesis is also consistent with the rather low absolute luminosity observed. However, we cannot exclude a black hole as the primary unless a mass function measurement of the system is performed.

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