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IGR J12319–0749: evidence for another extreme blazar found with *INTEGRAL*

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ABSTRACT

We report on the identification of a new soft gamma-ray source, IGR J12319–0749, detected with the IBIS imager on board the *INTEGRAL* satellite. The source, which has an observed 20–100 keV flux of $\sim 8.3 \times 10^{-12}$ erg cm^{-2} s^{-1}, is spatially coincident with an AGN at redshift z = 3.12. The broad-band continuum, obtained by combining XRT and IBIS data, is flat (Γ=1.3) with evidence for a spectral break around 25 keV (100 keV in the source rest frame). X-ray observations indicate flux variability which is further supported by a comparison with a previous ROSAT measurement. IGR J12319–0749 is also a radio emitting object likely characterized by a flat spectrum and high radio loudness; optically it is a broad-line emitting object with a massive black hole (2.8×10^9 solar masses) at its center. The source Spectral Energy Distribution is similar to another high redshift blazar, 225155+2217 at z = 3.668: both objects are bright, with a large accretion disk luminosity and a Compton peak located in the hard X-ray/soft gamma-ray band. IGR J12319–0749 is likely the second most distant blazar detected so far by *INTEGRAL*.

Key words. gamma-rays: observations, X-rays: galaxies - galaxies: active: individual: IGR J12319–0749

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1. Introduction

Blazars are the most powerful of all Active Galactic Nuclei (AGNs); their continuously emitting radiation covers the entire electromagnetic spectrum from radio to gamma-ray frequencies. Because of their enormous luminosities, blazars are visible to very large distances/redshifts. In the widely adopted scenario of blazars, a single population of high-energy electrons in a relativistic jet radiate from the radio/FIR to the UV/soft-X-ray through the synchrotron process and at higher frequencies through inverse Compton (IC) scattering soft-target photons present either in the jet (synchrotron self-Compton [SSC] model), in the surrounding material (external Compton [EC] model), or in both (Ghisellini et al. 1998 and references therein). Therefore a strong signature of the blazar nature of a source is a double peaked structure in the Spectral Energy Distribution (SED), with the synchrotron component peaking anywhere from infrared to X-rays and the Compton component extending up to GeV or even TeV gamma-rays. To explain all the different SEDs observed in blazars, Fossati et al. (1998) proposed the blazar sequence, which claims an inverse relation between peak energies and source luminosity: the more luminous sources have both synchrotron and Compton peaks at lower energies than their fainter (and generally at lower redshifts) counterparts. Within the blazar population, high redshift objects, which belong to the class of flat spectrum radio Quasars (FSRQ), tend to be the most luminous ones. Recently, Ghisellini et al. (2010) showed that the hard X-ray selected blazars at high redshifts are those with the most powerful jets, the most luminous accretion disks and the largest black hole masses. In other words, they are among the most extreme blazars, even more extreme than those selected in other wavebands like the gamma-ray region explored by *Fermi*/LAT.

Theoretically, this can be understood on the basis of the blazar sequence and indeed can be considered a proof of its validity: the high energy peak in the SED of the most powerful blazars is in the hard X-ray/MeV range. As a consequence, these objects are more luminous in the 20–100 keV band than above 100 MeV, and thus become detectable in the hard X-ray surveys even if they are undetected in the gamma-ray ones. Taken from another point of view, this also means that a survey in hard X-rays is more efficient in finding the most powerful blazars lying at the highest redshifts.

Within the *Swift*/BAT sample, there are 10 blazars (all FSRQs) at redshift greater than 2, of which five have a redshift between 3 and 4 (Ghisellini et al. 2010). Within the *INTEGRAL*/IBIS surveys we have 8 blazars at $z \geq 2$ of which 2 are located between 3 and 4 (Malizia et al. 2012).

Here, we provide evidence for the discovery with *INTEGRAL* of yet another powerful blazar, IGR J12319–0749 associated with a quasar at z = 3.12; we present a set of follow-up observations with *Swift*/XRT/UVOT, provide the first combined X/gamma-ray spectrum of the source and discuss its non simultaneous SED. This is likely the second most distant blazar ever detected by *INTEGRAL*.

2. *INTEGRAL* data

IGR J12319–0749 was reported for the first time as a high energy emitter by Bird et al. (2010) in the 4th *INTEGRAL*/IBIS catalogue. The source is detected with a significance of $\sim 4.8\sigma$ at a position corresponding to R.A.(J2000) = $12^{h}31^{m}54^{s}.5$ and Dec.(J2000) = $-07°48'57''.6$ with an associated positional un-

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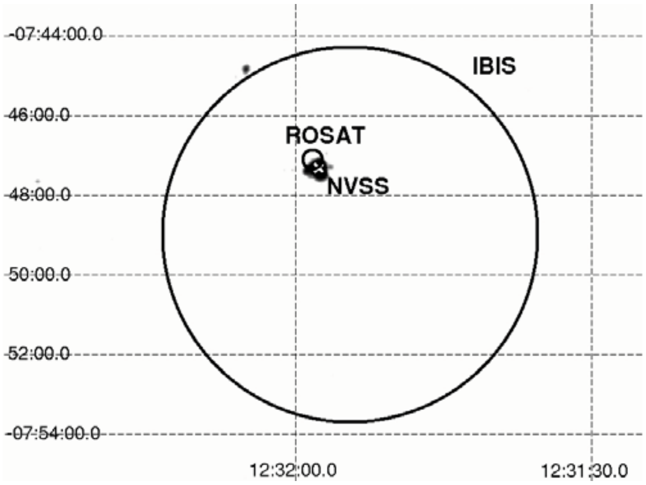

Fig. 1. XRT 0.3–10 keV image of the region surrounding IGR J12319–0749. The big circle corresponds to the IBIS positional uncertainty, while the cross indicates the location of the radio source NVSS J123157–074717; the small circle represents the positional uncertainty of the faint ROSAT source.

certainty of 4.7′ (90% confidence level); the source location is 54.8 degrees above the Galactic plane, strongly suggesting an extragalactic nature.

The IBIS spectrum was extracted using the standard Off-line Scientific Analysis (OSA version 7.0) software released by the Integral Scientific Data Centre. Here and in the following, spectral analysis was performed with XSPEC v.12.6.0 package and errors are quoted at 90% confidence level for one interesting parameter ($\Delta\chi^2 = 2.71$). A simple power law provides a good fit to the IBIS data (χ^2=10.4 for 8 d.o.f.) with a photon index $\Gamma=2.80^{+1.35}_{-0.94}$ and an observed 20–100 keV flux of 8.3×10^{-12} erg cm^{-2} s^{-1}.

Within the IBIS positional uncertainty, we find a Faint ROSAT Source 1RXS J123158.3–074705, located with an uncertainty of 15″ (Voges et al. 2000). This object probably coincides with the radio source NVSS J123157–074717 (Condon et al. 1998), which is located 15″.8 away, i.e. just outside the ROSAT error circle (see Figure 1); this radio source has recently been optically classified by us and found to be a QSO at $z = 3.12$ (Masetti et al. 2012).

Although the association between IGR J12319–0749 and this radio/X-ray high redshift QSO is intriguing, it cannot be considered secure as 1) there are other potential candidates in the IBIS error circle, for example at radio frequencies, which could emerge at higher X-ray energies and 2) it is surprising to detect such a distant object in a relatively short IBIS exposure (1256 ks).

For this reason, we have requested and obtained follow-up observations of IGR J12319–0749 with the X-ray telescope (Burrows et al. 2005) on board the *Swift* satellite (Gehrels et al.2004).

3. *Swift* observations and data reduction

During the period March 27 and July 14, 2011 XRT carried out seven observations of the sky region containing IGR J12319–0749 for a total exposure of ~4 ks (see Table 1 for details on individual measurements). XRT data reduction was performed using the XRTDAS standard data pipeline package (XRTPIPELINE v. 0.12.6), in order to produce screened event files. All data were extracted only in the Photon Counting (PC) mode (Hill et al. 2004), adopting the standard grade filtering (0–12 for PC) according to the XRT nomenclature.

Events for spectral analysis were extracted within a circular region of radius 20″ (which encloses about 90% of the PSF at 1.5 keV, Moretti et al. 2004) centered on the source position. The background was extracted from various source-free regions close to the X-ray source using both circular/annular regions with different radii, in order to ensure an evenly sampled background. In all cases, the spectra were extracted from the corresponding event files using XSELECT software and binned using GRPPHA in an appropriate way, so that the χ^2 statistic could be applied. We used the latest version (v.011) of the response matrices and create individual ancillary response files (ARF) using XRTMKARF v.0.5.8. In all our fitting procedures we have used a Galactic column density which in the direction of IGR J12319–0749 is 1.7×10^{20} cm^{-2} (Kalberla et al. 2005).

The XRT images extracted in the 0.3–10 keV band were searched for significant excesses (above 2.5 sigma level) falling within the IBIS 90% confidence error circle; only one source was clearly detected in each individual observation, as well as in the combined image (see Figure 1). This source is located at R.A.(J2000) = $12^h31^m57^s.67$ and Dec.(J2000) = −07°47′19″.2 with a positional uncertainty of 3.8″ (90% confidence level) which makes this X-ray source compatible with the faint detection reported by ROSAT. It also coincides with the NVSS/QSO object mentioned above; since this is the only source detected in X-rays, we assume that it is the true counterpart of the IBIS object.

Table 1 reports for each X-ray measurement, the observation date, the relative exposure, the net count rate in the 0.3–10 keV energy band, and the detection significance. There is some evidence that the source flux underwent some changes over the XRT monitoring with the most evident variation occurring between observation #2 and #7, i.e. over a few months period. Variability in QSO is not unexpected and can be used to characterise further this new gamma-ray source.

The UVOT instrument (Roming et al. 2005) observed IGR J12319–0749 in conjunction with the XRT for all of the observations listed in Table 1. Each observation consists of one or more exposures with a single UVOT filter. The data were analysed using the latest HEASoft tools and calibration products following the methods described by Poole et al. (2008) and Breeveld et al. (2010). A 3″ source aperture centered on the X-ray position[1] and a surrounding annulus background region were used for all the exposures; the usual corrections including dead time, coincidence loss, and aperture loss were made. Magnitudes were obtained from the observed count rates using the latest zero points (Breeveld et al. 2011) and are reported in Table 1 for each observation. To convert to AB magnitudes, 1.02, 1.51, and 1.69 should be added to the reported u, uvw1, and uvw2 magnitudes respectively (Breeveld et al. 2011). The source was only detected in the u filter in observation #4 and #7 while 90% confidence upper limits for either the uvw1 or uvw2 filters are listed for the other measurements. Count rates were also converted to fluxes using the prescription of Poole et al. (2008).

[1] When detected, the UVOT source is only 0.4 arcsec from the X-ray position.

4. X-ray spectral analysis and results

The spectral analysis of the XRT data indicated that the soft X-ray spectrum during observation #1 and #4, i.e. the two with the best statistical significance, is hard and bright: a simple power law fit to these two measurements provides $\Gamma = 0.96^{+0.32}_{-0.34}$ and $\Gamma = 1.53 \pm 0.28$, together with a 2–10 keV flux of $\sim 5.7 \times 10^{-12}$ and $\sim 2.6 \times 10^{-12}$ erg cm^{-2} s^{-1}, respectively. Note that for simplicity, here and in the following all modelling has been carried out in the observer's rest frame.

The 0.1–2.4 keV band flux is at around $1.4 - 1.5 \times 10^{-12}$ erg cm^{-2} s^{-1} to be compared with the lower ROSAT flux which is in the range 0.4-1 $\times 10^{-12}$ erg cm^{-2} s^{-1} depending on the source spectrum[2]; this comparison provides another indication that the source might be variable in soft X-rays.

To better characterise the QSO's X-ray spectrum and in view of the fact that the IBIS detection is over a few revolutions, i.e provides an average flux, we have also combined all seven XRT spectra and repeated the spectral analysis. The fit to the average XRT spectrum provides a photon index $\Gamma = 1.32 \pm 0.14$ and a 2–10 keV flux of $\sim 3.3 \times 10^{-12}$ erg cm^{-2} s^{-1}.

Finally, a joint spectral fit to the average XRT and IBIS data was also attempted. To account for possible calibration mismatch between the two instruments and/or variability between the two datasets, we introduced a constant C which was left free to vary. A simple power law provides an acceptable fit with $\Gamma = 1.35 \pm 0.14$, $C = 0.8^{+0.67}_{-0.38}$ and $\chi^2 = 31.4$ for 22 d.o.f. Since in the data to model ratio, there is some evidence for a high energy cut-off (E_C), we have also fitted the source broad-band spectrum with a cut-off power law: in this case, $\Gamma = 1.24^{+0.17}_{-0.19}$, $C = 2.53^{+5.24}_{-1.55}$, E_C=$24.5^{70.6}_{-14.6}$, and the $\chi^2 = 25.7$ for 21 d.o.f. (see Figure 2). With respect to a simple power law the $\Delta\chi^2$ is 5.7 for 1 extra parameter, which implies a fit improvement at a confidence level of around 96%, not highly significant, but still suggestive that a spectral change might be present in the spectrum of IGR J12319–0749. In the source rest frame this change would be located at around 100 keV.

Assuming that this broad-band fit represents the average state of the source, we obtain observer frame luminosities[3] of 2.8×10^{47} erg s^{-1} in the X-ray (2–10 keV) band and 7.3 $\times 10^{47}$ erg s^{-1} at hard X-rays (20–100 keV), i.e. IGR J12319–0749 has a high energy luminosity similar to those observed in the Ghisellini et al. (2010) sample of high redshifts blazars.

5. Is IGR J12319-0749 another powerful blazar?

The source is reported in the NED database[4] as NVSS J123157–074717, but with no reference, while it is not contained in the SIMBAD archive; despite being potentially quite a powerful AGN, it has never been studied before. Nonetheless, the sparse information available is sufficient to characterise broadly this new gamma-ray source.

The NVSS (NRAO VLA Sky Survey, Condon et al. 1998) image of IGR J12319–0749 shows the source to be core dominated with no extended radio features and a 1.4 GHz flux of 59.8±1.8 mJy. The source is also listed in the FIRST survey with a similar 1.4 GHz flux (60.99±0.16 mJy, White et al. 1997). No other detection is reported at radio frequencies preventing a measurement of the source spectrum and an estimate of the radio loudness defined as $RL = L_{5GHz}/L_B$. Despite this, we can make some guesses on the source spectral shape at radio frequencies considering that IGR J12319–0749 has not been detected in the Australian Telescope 20GHz (AT20G) survey posing a limit of 40 mJy to its flux at this frequency (Murphy et al. 2010). Assuming $S_\nu \propto \nu^\alpha$ and the information available, we estimate that α is ≤ -0.15; this makes the source compatible with being a flat spectrum radio QSO[5]. Furthermore, by evaluating the source B magnitude flux we should also be able to put a limit on the source radio loudness. IGR J12319–0749 is listed in the USNO–B1.0 catalogue (Monet et al. 2003) with a B magnitude in the range 19.7–19.8 while the R and I magnitudes are ∼19.7 and ∼18.2 respectively. Using the standard photometric system conversion from magnitude to flux (Zombeck 1990), we estimate a B flux in the range 0.05–0.06 mJy; extrapolating the 1.4 GHz flux to 5 GHz using the limit obtained on the radio spectral index, it is possible to estimate loosely that the radio loudness is ≤1000, sufficiently high to suggest that the source maybe a radio loud AGN[6].

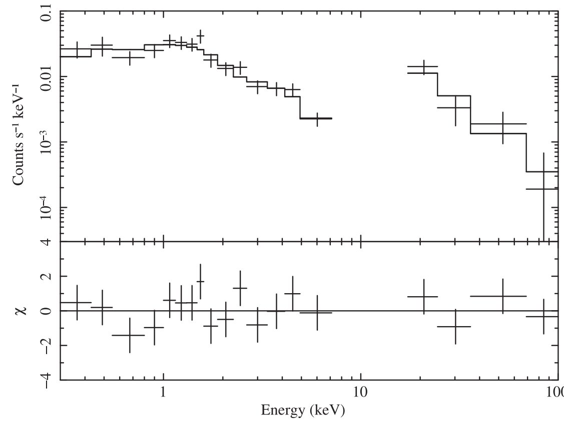

Fig. 2. X-ray spectrum of IGR J12319–0749 fitted with a cut-off power law.

IGR J12319–0749 is not reported in the near infrared 2MASS survey, with upper limits to the J, H, K flux of ∼17.1, ∼16.4, and ∼15.3 magnitudes, respectively (Skrutskie et al. 2006) .

Optically, the source is classified as a broad emission line AGN (FWHM = 5600 km s^{-1}) by Masetti et al. (2012); these authors further estimate the mass of the black hole at the center of the QSO to be 2.8×10^9 solar masses, i.e. quite a massive black hole similar to those found in other high redshift blazars discovered in hard X-ray surveys (Ghisellini et al. 2010, De Rosa et al. 2012) .

At high energies, the source is bright with a hard X-ray spectral shape ($\Gamma = 1.2 - 1.3$) and some indication of flux variability. There is marginal evidence in the combined XRT/IBIS data for a spectral break at around 100 keV (source rest frame) which could be interpreted as a peak in the spectral energy distribution.

Taken all together, the observed properties suggest that IGR J12319–0749 could be a bright blazar, in which the emission is relativistically beamed and the SED is double peaked. In Figure 3 (left side), we construct the non-simultaneous (source rest frame) SED of this object by combining all data gathered in

[2] see http://www.xray.mpe.mpg.de/rosat/survey/rass-fsc/ for further information

[3] We adopt H_o = 71 km s^{-1} Mpc^{-1}, Ω_Λ = 0.73 and Ω_M = 0.27.

[4] available at http://ned.ipac.caltech.edu/.

[5] Flat spectrum radio sources have $\alpha \geq -0.5$ (Massardi et al. 2011)

[6] Radio loud AGN have RL values in the range 10–100 (Kellerman et al. 1989)

Table 1. *Swift* detections.

Observation	Date	XRT Exposure[a] (sec)	XRT Count Rate[b] (10^{-3} counts s^{-1})	XRT σ	UVOT mag
#1	27/03/2011	972	83.2± 9.3	8.9	w1≤21.18
#2	10/05/2011	287	109.0±19.8	5.5	w1≤21.28
#3	25/06/2011	344	51.2±12.4	4.1	w2≤21.43
#4	28/06/2011	1702	77.7±6.8	11.4	u=19.35±0.08
#5	29/06/2011	189	74.0±19.8	3.7	w2≤ 22.49
#6	05/07/2011	129	51.2±20.6	2.5	w1≤20.33
#7	14/07/2011	341	37.0±10.6	3.5	u=$19.81^{+0.35}_{-0.27}$

[a] Total on-source exposure time;
[b] The count rate is estimated in the 0.3–10 keV energy range.

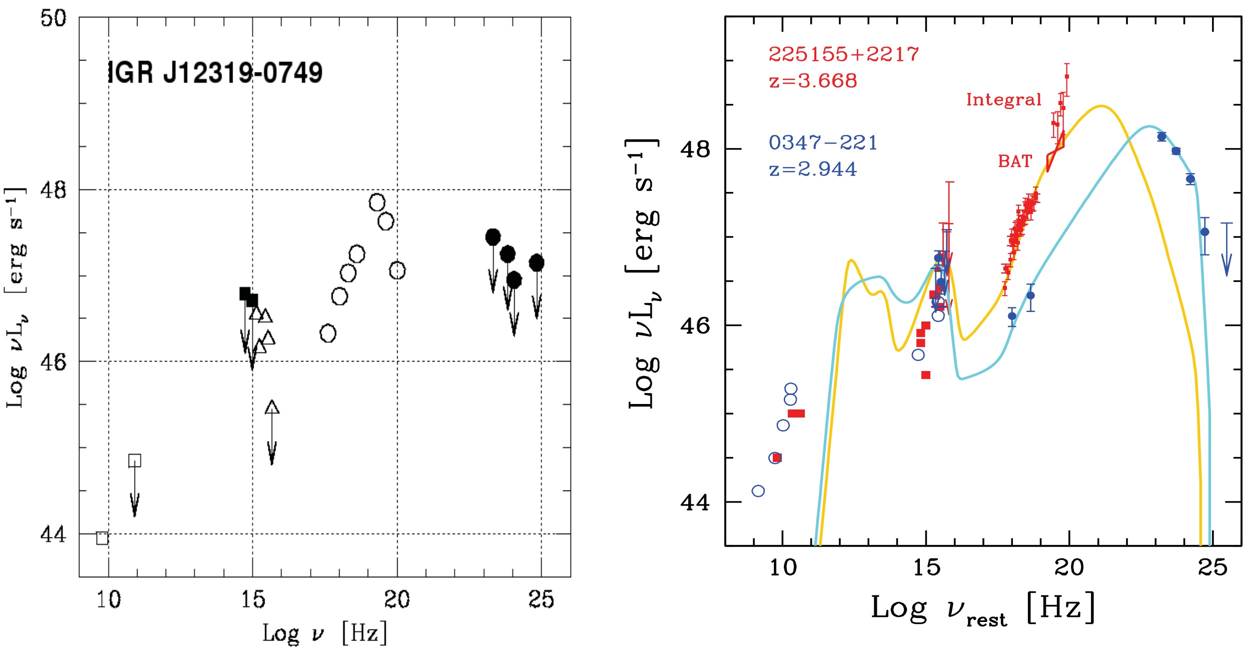

Fig. 3. *Left*: Non simultaneous SED (source rest frame) of IGR J12319–0749; data and references are discussed in the text. *Right*: SED (source rest frame) of two high-z QSOs (225155+2217 at z = 3.668, and 0347–221 at z = 2.944) from Ghisellini (2011).

this work; the optical UVOT data are not corrected for Galactic reddening which is however small in the source direction (less than 10% in B). To cover as many frequencies as possible we have also used upper limits obtained from the latest *Fermi* survey (Abdo et al. 2012). We adopt the cut-off power law model to describe the combined *Swift*/XRT and *INTEGRAL*/IBIS spectrum. Although the data are sparse and not simultaneous, the source SED resembles that of a blazar with the synchrotron peak located between radio and near-infrared frequencies and the Compton peak in the hard X-ray band. For comparison, we show on the right side of Figure 3 a plot taken from Ghisellini (2011) which describes the SED (also source rest frame) of two high-z blazars together with a single leptonic model fit to their data: one source (225155+2217 at z = 3.668) has been detected by *INTEGRAL*/IBIS and *Swift*/BAT but not by *Fermi*/LAT, the other (0347–221 at z = 2.944) has been seen by LAT but not by IBIS or BAT. IGR J12319–0749 is more similar to 225155+2217 (see also Lanzuisi et al. 2012) than to 0347–221. It shows a similar overall brightness, Compton peak location and is not detected by *Fermi*/LAT.

From the available optical/UV data and reported black hole mass, it is possible to evaluate that the source accretion disk is emitting at 10% or more of the Eddington luminosity (see Figure 3, right panel). This is similar to other high-z blazars discovered by hard X-rays surveys, which tend to have black holes with M greater than 10^9 solar masses and disks emitting close or above 10% of the Eddington limit.

6. Conclusions

Through X-ray follow-up observations with *Swift*/XRT, we have been able to likely identify the newly discovered *INTEGRAL* source, IGR J12319–0749, with a radio source coincident with an AGN at z = 3.12. This would make IGR J12319–0749 the second most distant object so far detected by *INTEGRAL*.

The source probably belongs to the class of flat spectrum radio QSO: it is a broad line AGN with a huge black hole at its center; it is likely radio loud and it shows variability at X-ray energies. The source SED is also similar to another high-z source

(225155+2217) discovered by means of hard X-ray observations: it has a similar brightness and disk luminosity, a Compton peak location in the hard X-ray soft gamma-ray domain and is not detected by *Fermi*/LAT. We conclude that this is likely another example of an extreme blazar, i.e. those showing the most powerful jets, the most luminous accretion disks and the largest black hole masses. This finding further supports the claim that the hard X-ray waveband is the most efficient to discover such powerful AGN.

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