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Lessons learned from ESA INTEGRAL satellite on blazars

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The ESA INTEGRAL satellite is now about 7 years in orbit, delivering data on various astrophysical objects. We refer on analysis of the ESA INTEGRAL satellite data for specific class of active galactic nuclei – blazars. These objects represent promising sources to be observed by INTEGRAL, especially during their active states. We show indications that blazars may be visible by IBIS gamma–ray telescope during their active states. In addition, suitable strategy for the future analysis is proposed and discussed.

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1. Introduction

Blazars represent the most extreme class of active galaxies, they are powerful and variable. They are observed in all wavelength bands - from radio through VHE gamma frequencies, with maximum spectral output and largest variability often at gamma ray energies. 66 blazars were identified as sources of $\geq$ 100 MeV emission by EGRET aboard CGRO (Hartman, [2]) and 6 blazars were identified as VHE gamma sources ($\geq$350 GeV) by Cerenkov telescopes (Krawczynski, [3]). It is obvious that blazars represent suitable targets for INTEGRAL satellite (Winkler et al., [9]) especially during active states (flares). The INTEGRAL observations are basically divided into the following categories: (i) AO Program (allocated pointed observations), (ii) Core Program CP (Galactic Plane Scans, Galactic Center Deep Exposure,...), and (iii) Objects inside FOV of AO observations.

2. INTEGRAL Core Programme Observations

Blazars in the INTEGRAL Galactic Plane Scans (GPS) represent a promising group of objects for the study within the INTEGRAL CP. The GPS zone is usually neglected by extragalactic astronomers due to heavy obscuration: in optical, $\sim$20% of the sky is obscured by our Galaxy, while the gamma–ray telescopes on board INTEGRAL allow detectability of up to few mCrabs in the most exposed GPS regions (Fig. 1). Seven optically bright (with V$\leq$17 mag, to be detected by the INTEGRAL OMC camera) blazars were identified within galactic scans of INTEGRAL, namely: 1ES 0647+250, PKS 0823-223 (no gamma from EGRET, gravitation lensing candidate), 1ES 2344+514 (TeV gamma ray source, very close), 8C 0149+710 (BL Lac candidate?), 4C 47.08, 87GB 02109+5130 (poorly understood blazar, TeV candidate), and BL Lac (the prototype). While the prototype object BL Lac is well studied, most of the INTEGRAL GPS blazars are poorly investigated and poorly understood so far. The study with Sonneberg Observatory Archival Plates reveals that most of these objects are optically variable, hence a gamma ray variability can be expected. Below the detection limit of the INTEGRAL OMC on board camera is blazar NRAO530 (1730-130), which is an example of blazar with violent optical activity (4 mag within 1 month). In flare, the object is expected to be much brighter also in gamma. This strengthens the role of optical monitoring and ToO program - the flare can be recognized by optical monitoring with small (D $\sim$50 cm) telescopes. As an example, the serendipitous detection of high-z blazar PKS2149-306 (z=2.345) in hard X-rays by IBIS can be mentioned (Bianchin et al., 2008). All the above mentioned blazars in INTEGRAL GPS have been investigated with INTEGRAL CP data (IBIS and JEM-X telescopes). We have developed method for data mining (IBIS and JEM-X data) in archival data for faint sources which has resulted in several positive detection by high energy instruments on board INTEGRAL (e.g. Mrk 501, Fig. 5). We have found variability and spectral changes for BL Lac (Figs. 3 and 4) and we have confirmed that for several blazars the hard X-ray activity is related to optical activity (e.g. 1ES1959+650, Fig. 6). For many targets, the quiet level is still below the sensitivity threshold of the high-energy instruments. However, the positive detection may be possible in the future as (i) there will be more cumulative time available and (ii) the probability to see a blazar during a flare (and hence much brighter) will also increase with time. A detailed analysis of archival IBIS data for Fermi detected blazars is recently reported by Beckmann et al. (2009) and

Figure 1: The IBIS coverage map for blazars from Veron-Cetty catalogue detected by INTEGRAL. The structures in blazar distribution are caused by selection effect due to non-homogeneous coverage of large surveys.

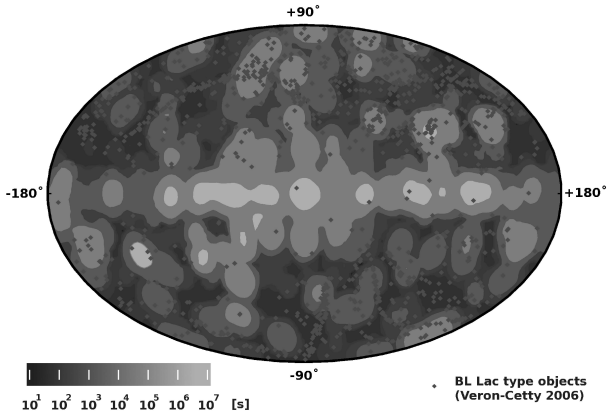
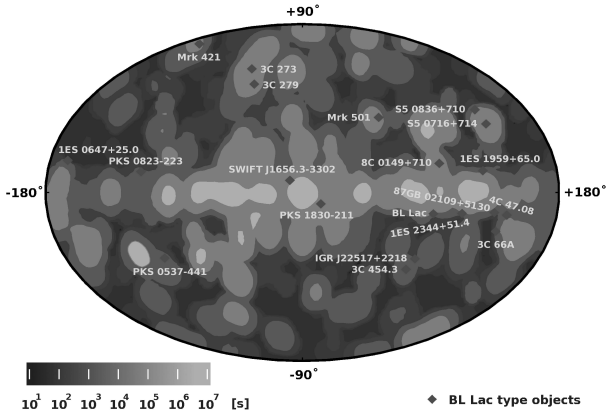


Figure 2: The IBIS telescope coverage map for blazars detected by INTEGRAL.



states positive detection of 20 blazars above 20 keV. The Fig. 2 shows the IBIS coverage map for 21 INTEGRAL blazars.

3. INTEGRAL AO Observations

The AO-2 ToO blazar observation No. 220049 by Pian et al. ([4]) was based on extended optical and/or X-ray monitoring (RXTE ASM and others) of flaring activity of a large list of blazars and, alternatively, on soft gamma-ray monitoring by INTEGRAL itself Blazar S5 0716+714 is a BL Lac object, monitored by Whole Earth Blazar Telescope (Villata et al.,[7]). The ToO was triggered by its optical activity - 2 outbursts up to the extreme level of R = 12.1 mag (historical maximum, light increase by 1 mag in 2 weeks and 2 magnitudes in 4 months) The object was observed in April 2–7, 2004, at higher gamma-ray state than in Oct 2000 (BeppoSAX ToO, Tagliaferri et al., [5]) (R=12.5 versus 12.1). S5 0716+714 was detected only by IBIS ISGRI at 4.5 sigma, in 30-60 keV band, for a count rate of 0.11 counts/s (exposure 280 ksec). No signal above 60 keV

Figure 3: The IBIS light curve for BL Lac. The spectral changes of the source are obvious (left). The composition of INTEGRAL public data used (right)

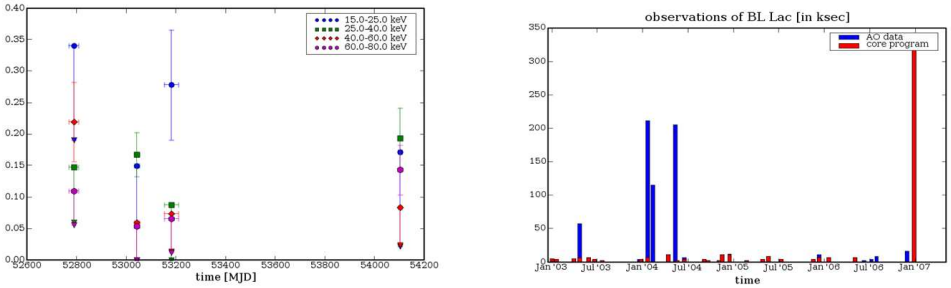
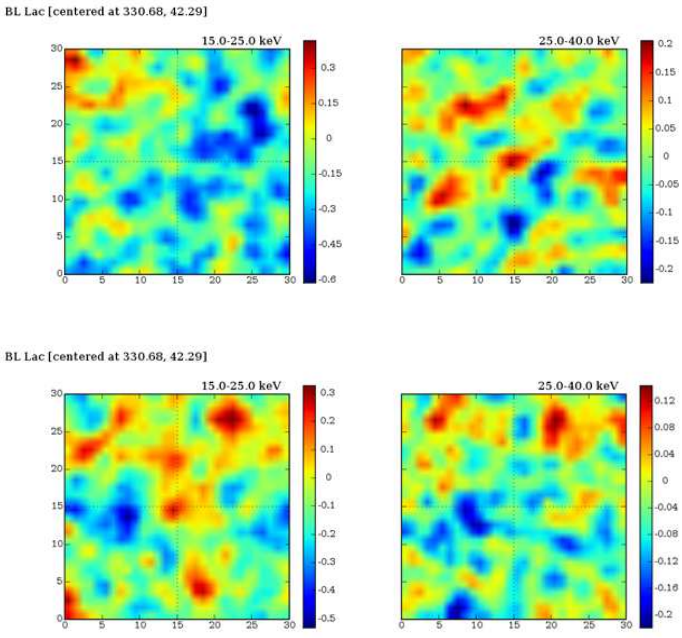


Figure 4: The IBIS mosaic images for BL Lac for two different time intervals. The spectral changes of the source are obvious. Top: MJD interval 54085.82-54113.01 i.e. 27.19 days, size 88 x 120 [pixels 0.082 x 0.082 deg] – exposure 280.888 ksec, 15.0-25.0 keV : no peak – upper limit 0.086 ct/s, 25.0-40.0 keV : peak 0.193 $\pm$ 0.0484 ct/s. Bottom: MJD interval 52985.44-53045.66 i.e. 60.22 days, size 88 x 120 [pixels 0.082 x 0.082 deg] – exposure 459.019 ksec, 15.0-25.0 keV : peak 0.278 $\pm$ 0.0874 ct/s, 25.0-40.0 keV : no peak – upper limit 0.088 ct/s



was detected. The spectrum extraction was possible for additional source in the field, namely S5 0836+710 (high z blazar of the FSRQ sub–class): single power–law spectrum (Pian et al., [4]). This observation clearly confirmed that even with relatively short exposures, the INTEGRAL is an efficient tool to study bright AGNs at high Galactic latitudes.

INTEGRAL AO-3 ToO observation by the same collaboration was performed on 3C454.3 (z=0.859, Foschini et al. ([1]). This ToO was triggered by high optical (T. Balonek, VSNET alert) and X-ray (BAT Swift) activity of the source. The INTEGRAL observation started 2005 May 15,

Figure 5: The most significant result of the procedure of searches for faint sources. The flux corresponding to the excess in lower spectral band for Mrk 501 is (1.57 ± 0.24) $10^{-11} ergcm^{-2}s^{-1}$. The coordinates of the images are given in pixels, one pixel being 4.9 arcmin; mosaics are centered on the catalogue position of the source.

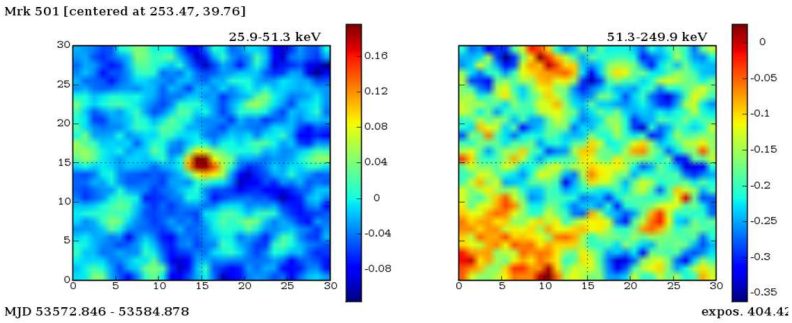
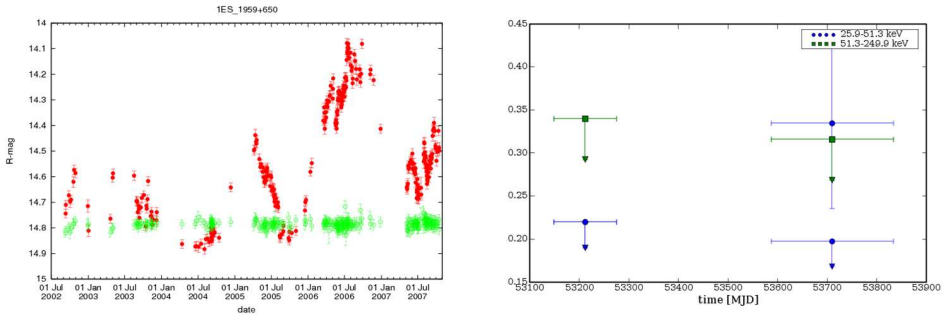


Figure 6: Blazar 1ES 1959+650 is a variable (both in optical light and in hard X–rays) object visible in 2006 only, invisible in total mosaics and/or other periods. Blazar is in IBIS visible only in data set corresponding to optical flare. This is a possible explanation why blazar gamma–ray sky by EGRET and by INTEGRAL are different.



at 18:40 UT, with exposure of 200 ksec. The source was clearly detected by IBIS/ISGRI in the 20-40 and 40-100 keV energy bands, with a significance of 20 and 15 sigma. The observed fluxes were 1.02 ± 0.05 cts/s = 9.4 ± 0.5 mCrab in 20-40 keV, 1.00 ± 0.08 cts/s = 13 ± mCrab in 40-100 keV, and 1.6x$10^{-10} ergcm^{-2}s^{-1}$ in 20-100 keV band. The observed spectrum was flat, with photon index 2.2 ± 0.2 and normalization 0.13 (+0.10 -0.06) $phcm^{-2}s^{-1}keV^{-1}$. The allocated 200 ks were however not enough to detect the object up to 400 keV, more than 400ks would be necessary for that. It is important to continue the future INTEGRAL AO observations of blazars with longer exposures in order to fully show the importance of scientific study of blazars with this satellite. The importance of INTEGRAL and Swift observations of blazars in outbursts for tests of blazar models was discussed in detail by Pian et al. (2008). Blazar 3C 454.3 was recently observed as an INTEGRAL ToO again following the gamma-ray superflare above 100 MeV on 2009-12-01 (Vercellone et al., 2009) with an 20–40 keV flux of 13 mCrab and 4–100 keV flux of 16 mCrab.

An ToO observation of bright blazar Mrk 421 during a flare was performed in 2006 lasting 829 ksec and during this time several flares were observed by IBIS and JEM-X telescopes (Lichti et al., 2008). The source was observed from optical up to TeV energies.

Another INTEGRAL ToO observation in 2009 focused on blazar 3C279 reflecting high-energy

activity of this source detected by Fermi. The INTEGRAL observation confirmed the target as a hard X-ray source with a hard spectral slope of power-law index 1.3, the hardest one measured by INTEGRAL yet (Iafrate et al., 2009).

4. Conclusion

For blazars in GPS, few positive detections by high–energy instruments on INTEGRAL have been confirmed by method of data mining for faint sources. For remaining targets, the quiet level is still below the sensitivity threshold of the instruments, but the positive detection may be possible in the future as: (i) there will be more cumulative time available, and (ii) the probability to see a blazar during a flare (and hence much brighter) will also increase with time. For the AO blazar observation, it has been confirmed that with relatively short exposures the INTEGRAL is efficient tool to study bright AGNs at high Galactic latitudes. This also confirms the importance of high–energy instruments with large FOV and good angular resolution. **Acknowledgement.** We acknowledge the support provided by the ESA PECS Project 98023. Some parts of this study are linked to the project 205/08/1207 by the Grant Agency of the Czech Republic.

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