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Lessons learned from ESA INTEGRAL: cataclysmic variables and blazars

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Abstract. The results of investigations of cataclysmic variables and blazars with the ESA INTEGRAL satellite are briefly presented and discussed. It is evident that the satellite serves as an efficient tool to study some of these objects, e.g. cataclysmic variables containing a magnetic white dwarf and blazars in outbursts.

Key words. High-energy sources – Stars: Cataclysmic Variables – Satellites: INTEGRAL – blazars

1. Introduction

The ESA INTEGRAL (The International Gamma-Ray Astrophysics Laboratory) satellite is now more than 6 years in the orbit. There are four co-aligned instruments onboard the INTEGRAL: (1) gamma-ray imager IBIS (15 keV–10 MeV, field 9 deg, 12 arcmin FWHM), (2) gamma-ray spectrometer SPI (12 keV–8 MeV, field 16 deg), (3) X-ray monitor JEM-X (3–35 keV, field 4.8 deg), and (4) optical monitoring camera OMC (Johnson *V* filter, field 5 deg) (Winkler et al. 2003).

2. CVs, symbiotics, and INTEGRAL

Detection in the keV–MeV passbands by INTEGRAL represents an important supplement to the science of cataclysmic variables (CVs), since before, there was an observational energy gap between the region covered by X-ray satellites and by ground-based Cherenkov telescopes. In total, $\sim$ 335 CVs brighter than 17.5 mag(V) at least during maxima of their long-term activity and located within -14 deg $< b_{\mathrm{II}} <$ $+14$ deg are contained in The Catalog and Atlas of CVs (Downes et al. 2001) (this number excludes classical novae brighter than 17.5 mag(V) only during explosion and steadily fainter than 17.5 mag(V) after return to quiescence). The best coverage is available for CVs lying toward the Galactic center. The observations of the hard part of the bremsstrahlung spectrum (most sensitive to the temperature variations) represent an important input for the physical analyzes of these objects. INTEGRAL is suitable for: (a) detection of the populations of CVs and symbiotics with the hard X-ray spectra, (b) simultaneous observations in the optical and hard X-ray regions, and (c) long-term observations with OMC, including a search for rapid variations in observing series during a science window.

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3. The CV observations by INTEGRAL

32 CVs have been detected by the INTEGRAL IBIS gamma-ray telescope so far (more than expected, almost 10 percent of the INTEGRAL detections). 22 CVs were seen by IBIS and identifed by IBIS team (Barlow et al. 2006, Bird et al. 2007) and by our team (Galis 2008), based on the correlation of the IBIS data and the Downes CV catalogue (Downes et al. 2001). Four sources are CV candidates revealed by optical spectroscopy of IGR sources (Masetti et al. 2006). They are mainly magnetic systems: 22 are confirmed or probable IPs, 4 probable magnetic CVs, 3 polars, 2 dwarf novae, 1 unknown. At least in some cases, the hard X-ray fluxes of CVs seen by INTEGRAL exhibit time variations, very probably related to activity/inactivity states of the objects. The spectra of CVs observed by IBIS are similar in most cases. Powerlaw or thermal bremsstrahlung model compare well with the previous high-energy spectral fits (de Martino et al. 2004, Suleimanov et al. 2005, Barlow et al. 2006). The group of IPs represents only ~2 percent of the catalogued CVs, but dominates the group of CVs detected by IBIS. More such detections and new identifications can be hence expected, as confirmed by our search for IPs in the IBIS data which provided 6 new detections (Galis et al. 2008). Many CVs covered by Core Program (CP) remain unobservable by IBIS because of short exposure time, but new ones have been discovered. IBIS tends to detect IPs and asynchronous polars: in hard X-rays, these objects seem to be more luminous (up to the factor of 10) than synchronous polars. Detection of CVs by IBIS typically requires 150–250 ksec of exposure time or more, but some of them remained invisible even after 500 ksec. This can be related to the activity state of the sources – the hard X-ray activity is variable. There is an indication for a hard X-ray flare in a CV system, namely V1223 Sgr, seen by IBIS (a flare lasting for ~3.5 hr during revolution 61 (MJD 52743), with the peak flux ~ 3 times of average (Barlow et al. 2006)). These flares were seen in the optical already in the past by a ground-based instrument (duration of several hours) (van Amerongen & van Paradijs 1989). Similar flares are known also for another IPs in the optical, but not in hard X-rays. An example is TV Col (Hudec et al. 2005), where 12 optical flares have been observed so far, five of them on archival plates from the Bamberg Observatory. TV Col is an IP and the optical counterpart of the X-ray source 2A0526–328 (Cooke et al. 1978). This is the first CV discovered through its X-ray emission, newly confirmed as INTEGRAL source. The physics behind the outbursts in IPs is either the disk instability or an increase in the mass transfer from the secondary.

4. Selected targets

4.1. V1223 Sgr

This is the brightest CV seen by IBIS INTEGRAL so far. It is a bright X-ray source (4U 1849–31). Prominent long-term brightness variations are as follows: (a) outburst with a duration of ~6 hr and amplitude about 1 mag (van Amerongen & van Paradijs 1989), (b) episodes of deep low states (decrease by several magnitudes) (Garnavich & Szkody 1988). With IBIS, the binary is visible up to the 60–80 keV energy band; the gamma-ray light curve based on IBIS data is shown in Figure 1. For this source, valuable optical data have been provided also by the INTEGRAL OMC camera, allowing simultaneous miltispectral analysis (Fig. 2).

4.2. V709 Cas = RX J0028.8+5917

This source was recognized as an IP following its detection in the ROSAT All Sky Survey as RXJ0028.8+5917 (Motch et al. 1996). A follow–up 18 ksec pointed observation with the ROSAT PSPC revealed a pulse period of 312.8 s and a conventional hard IP X-ray spectrum. Motch et al. (1996) subsequently noted that RX J0028.8+5917 was probably coincident with the previously catalogued sources detected by HEAO-1 (1H 0025+588), Uhuru (4U 0027+59) and Ariel V (3A 0026+593), and identified the X-ray source with a 14th magnitude blue star, V709 Cas. The optical spectra of this star show radial velocity varia-

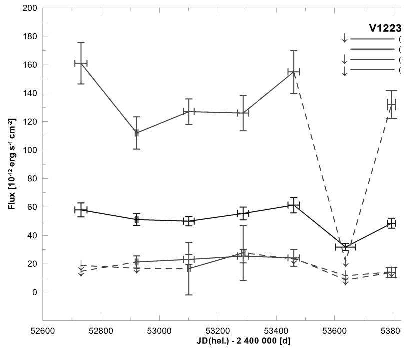

Fig. 1. The IBIS gamma–ray light curve for V1223 Sgr. The fluxes especially in (15 - 25) keV and (25 - 40) keV bands are long-term variable with significant drop around MJD 53 650. Optical variations are correlated with the changes in (15 - 25) keV, (25 - 40) keV and (40 - 60) keV spectral bands with correlation coefficient 0.81, 0.82 and 0.89, respectively. The fluxes from INTEGRAL/JEM-X were persistent within their errors in monitored time period

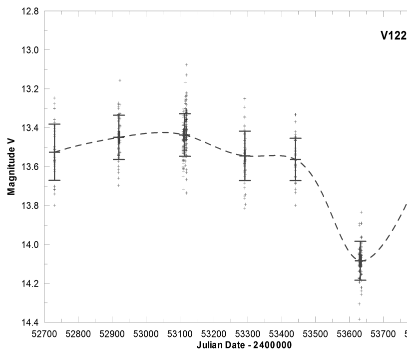

Fig. 2. The OMC optical (V band) light curve for V1223 Sgr.

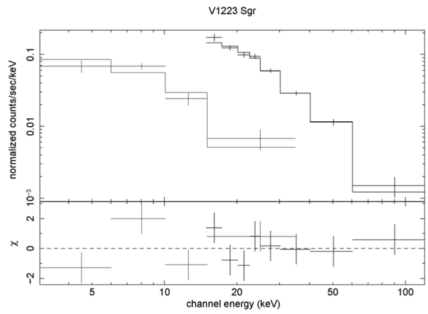

Fig. 3. The IBIS and JEM-X spectra for V1223 Sgr fitted by a thermal bremsstrahlung model.

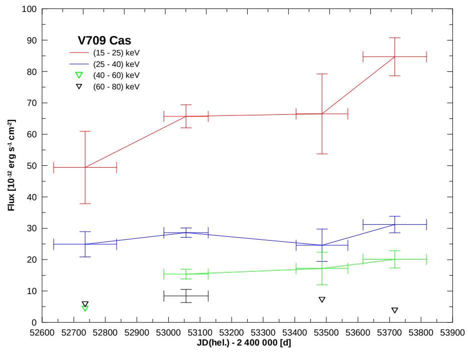

Fig. 4. The gamma–ray light curve for V709 Cas. The IBIS data were used.

tions with periods of either 5.4 hr or 4.45 hr, the two being one day aliases of each other (Motch et al. 1996). One of these periods is assumed to be the orbital period of the system. This is hence one of optically brightest CV in the INTEGRAL IBIS CV sample. It is visible up to ~60 keV (Fig. 4). We detect a probable increase in intensity on the scale of 100 days, most significant in the lowest spectral band (which is however also the most problematic for the calibration).

4.3. V834 Cen

The optical light curve of V834 Cen during the lifetime of INTEGRAL shows active and inactive states. V834 Cen is a polar of AM Her class. This polar was probably detected by IBIS since it was in high (active, both optical and gamma-ray) state. This may explain why some CVs have been detected by IBIS and some not. Optical monitoring of sources is important as it can indicate active intervals when the object is expected to be active also in gamma-rays.

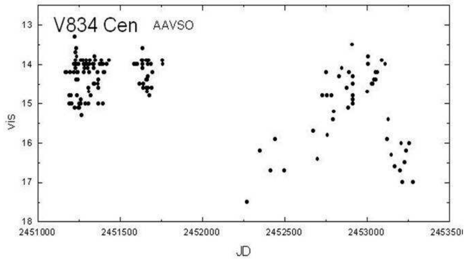

Fig. 5. The AAVSO light curve for V834, a cataclysmic gamma-ray loud variable detected by the ESA INTEGRAL satellite. The active state around JD 2453000 represents the time period when the source was detected in gamma-rays, while it remained undetected at times when the source was in the inactive state.

5. Symbiotic systems as hard X–ray sources

In addition to CVs, 3 symbiotic systems have been detected by INTEGRAL in hard X-rays. Symbiotic variable stars represent a heterogeneous group. They are often represented by a late-type giant transferring mass onto a compact object (a white dwarf or a neutron star) via a strong stellar wind (more than 100 symbiotics are known). Most symbiotics are the long-period cousins of CVs and X-ray binaries. Dramatic variability on a large range of time scales (from less than a minute to years and decades) has been detected in these systems. Symbiotic systems have until recently been thought to produce predominantly soft X-rays. With INTEGRAL and Swift, however, at least three symbiotics have been found with an emission out to about 60 keV (e.g. RT Cru). The origin of such hard X-ray emission from these accreting, presumably non-magnetic white dwarfs is not yet firmly explained. Possible explanations include: 1) boundary-layer emission from accretion onto a near-Chandrasekhar-mass white dwarf; 2) non-thermal emission from a jet; and 3) emission from an accretion column on a white dwarf not previously recognized as magnetic. Symbiotics recognized as hard-X-ray emitters include RT Cru and CD–57 3057 identified with IGR sources (Masetti et al. 2006).

Table 1. Cataclysmic Variables detected in hard X-rays by INTEGRAL IBIS (ISGRI).The newly detected objects are emphasised.

Detected CVs

GCVS Name	RA (2000)	DEC (2000)	Object Type
IGR J00234+6141	00:22:57.63	+61:41:07.8	dq
V709 Cas	00:28:48.84	+59:17:22.3	dq
XY Ari	02:56:08.10	+19:26:34.0	dq
GK Per	03:31:12.01	+43:54:15.4	na/dq
V1062 Tau	05:02:27.47	+24:45:23.4	dq
TV Col	05:29:25.52	-32:49:04.0	dq
IGR J05346-5759	05:34:50.60	-58:01:40.7	vy:
BY Cam	05:42:48.77	+60:51:31.5	am
MU Cam	06:25:16.18	+73:34:39.2	dq
IGR J08390-4833	08:38:49.11	-48:31:24.7	cv
XSS J12270-4859	12:27:58.90	-48:53:44.0	dq
V834 Cen	14:09:07.30	-45:17:16.2	am
IGR J14536-5522	14:53:41.06	-55:21:38.7	dq
IGR J15094-6649	15:09:26.01	-66:49:23.3	dq
NY Lup	15:48:14.59	-45:28:40.5	dq
IGR J16167-4957	16:16:37.20	-49:58:47.5	dq:
IGR J16500–3307	16:49:55.64	–33:07:02.0	dq
V2400 Oph	17:12:36.43	-24:14:44.7	dq
IGR J17195-4100	17:19:35.60	-41:00:54.5	dq:
IGR J17303-0601	17:30:21.90	-05:59:32.1	dq
V2487 Oph	17:31:59.80	-19:13:56.0	na
AM Her	18:16:13.33	+49:52:04.3	am
IGR J18173-2509	18:17:22.25	-25:08:42.9	cv
V1223 Sgr	18:55:02.31	-31:09:49.6	dq
IGR J19267+1325	19 26 27.03	+13 22 03.2	cv
V1432 Aql	19:40:11.42	-10:25:25.8	am
V2306 Cyg	19:58:14.48	+32:32:42.2	dq
V2069 Cyg	21:23:44.84	+42:18:01.8	dq:
IGR J21335+5105	21:33:43.65	+51:07:24.5	dq
SS Cyg	21:42:42.80	+43:35:09.9	ugss
FO Aqr	22:17:55.39	-08:21:03.8	dq
AO Psc	22:55:17.99	-03:10:40.0	dq

6. INTEGRAL blazars

From the extragalactic HE sources, blazars belong to the most important and also optically violently variable objects. Below we list a few examples of blazars analyzed with INTEGRAL observations. We focus on objects found by data mining in INTEGRAL archive for faint and hidden objects, for more details on blazar analyses with INTEGRAL see Hudec et al. 2007. In addition to that, successful blazar observations were performed mostly in the ToO regime, the large collaboration led by E. Pian can serve as an example (Pian et al. 2007).

Table 2. The list of blazars observed by the INTEGRAL satellite in hard X-rays (IBIS ISGRI)

source	RA	DEC	Gal coord.		z	type
1ES 0647+250	06 50 46.6	+25 03 00	190.283	10.996	0.2030	BL Lac
PKS 0823-223	08 26 01.5729	-22 30 27.204	243.990	8.930	0.9100	possible Q
1ES 2344+514	23 47 04.919	+51 42 17.87	112.892	-9.908	0.0440	BL Lac
8C 0149+710	01 53 25.8511	+71 15 06.463	127.920	8.983	0.0220	Q
4C 47.08	03 03 35.2422	+47 16 16.276	144.986	-9.863	0.4750	BL Lac
87GB 02109+5130	01 03 28.1	+43 22 59				BL Lac
BL Lac	22 02 43.2914	+42 16 39.980	92.590	-10.441	0.0688	BL Lac
S5 0716+714	07 21 53.4485	+71 20 36.363	143.981	28.018	0.3000	BL Lac
S5 0836+710	08 41 24.3653	+70 53 42.173	143.541	34.426	2.1720	Q
3C 454.3	22 53 57.7479	+16 08 53.561	86.111	-38.184	0.8590	Q
3C 279	12 56 11.1665	-05 47 21.525	305.104	57.062	0.5362	Q
3C273	2 29 06.6997	+02 03 08.598	-11.010	4.380	0.1583	Q
PKS1830-211	18 33 39.888	-21 03 39.77	12.166	-5.712	2.5070	Q
Mrk421	11 04 27.3139	+38 12 31.799	179.832	65.032	0.0300	BL Lac
J1656.3-3302	16 56 19.2	-33 01 48	350.604	6.361		?
IGR J22517+2218	22 51 53.498	+22 17 37.29	89.690	-32.750	3.6680	Q
PKS0537-441	05 38 43.5	-44 05 05	250.078	-31.110	0.8960	BL Lac
3C 66A	02 22 39.6115	+43 02 07.799	140.143	-16.767	0.4440	Blazar
Mrk 501	16 53 52.2167	+39 45 36.609	63.600	38.859	0.0336	BL Lac
1ES2344+514	23 47 04.919	+51 42 17.87	112.892	-9.908	0.0440	BL Lac
1ES 1959+650	19 59 59.8521	+65 08 54.653	98.003	17.670	0.0480	Blazar

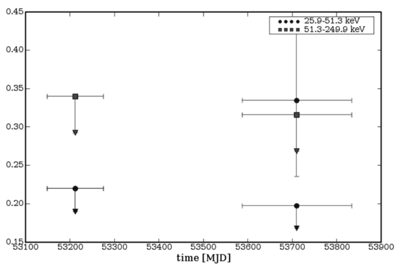

Fig. 6. The IBIS gamma-ray light curve of 1ES 1959+650. Blazar is in INTEGRAL gamma-ray imager IBIS visible only in data set corresponding to optical flare.

6.1. 1ES 1959+650

This blazar is a gamma-ray loud variable object visible by IBIS in 2006 only, invisible in total mosaics and/or other periods. The optical light curve available for this light curve confirms the relation of active gamma-ray and active optical state.

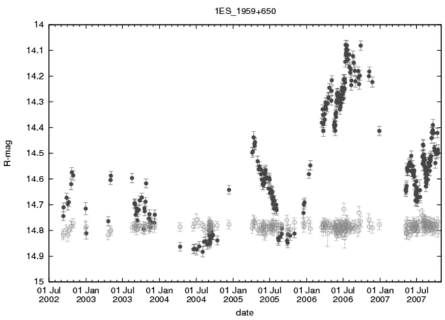

Fig. 7. The optical light curve of blazar 1ES 1959+650 (Tuorla Observatory blazar monitoring program). In hard X-rays (IBIS), the blazar is visible only during the large optical flare in the 2nd half of 2006.

6.2. 3C66A

This blazar is visible by IBIS gamma-ray imager onboard INTEGRAL only during the optical flare shown below and is invisible other times. This confirms the importance of monitoring of the object in the optical light.

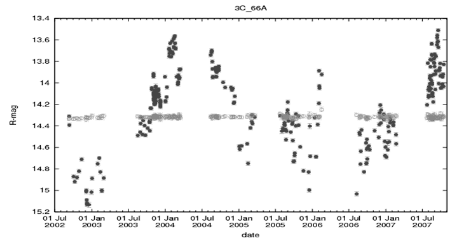

Fig. 8. The optical light curve of blazar 3C66A (Tuorla Observatory blazar monitoring program).

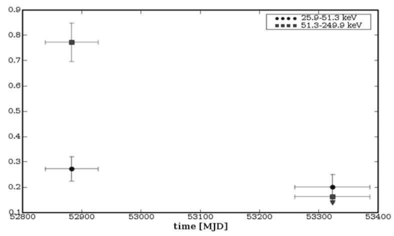

Fig. 9. The IBIS gamma-ray light curve of blazar 3C66A.

7. Conclusions

INTEGRAL is an effective tool to study CVs and blazars in hard X–rays: 21 blazars, 32 CVs and 3 symbiotics were detected so far. There is also an increasing probability of detecting the objects in outbursts and high states. The simultaneous hard X-ray and optical monitoring of CVs and blazars can provide valuable inputs for better understanding of involved physical processes.

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