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Lessons learned from ESA INTEGRAL: Cataclysmic Variables

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The results of analyses of cataclysmic variables and related objects with the ESA INTEGRAL satellite with emphasis on IBIS hard X–ray data are briefly presented and discussed. It is evident that the satellite serves as an efficient tool to study these objects, especially cataclysmic variables containing a magnetic white dwarf.

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1. Introduction

The ESA INTEGRAL (The International Gamma-Ray Astrophysics Laboratory) satellite is now more than 7 years in the orbit. There are four co-aligned instruments on board 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). These experiments allow simultaneous observation in the optical, medium X-ray, hard X-ray, and gamma spectral region (or at least a suitable upper limit) for each object, assuming that it is inside the field of view. The basic codes of observations are as follows: (a) Regular (weekly) Galactic Plane Scans (GPS) (-14 deg $< b_{\mathrm{II}} < +14$ deg), (b) Pointed observations (AO), (c) Targets of opportunity (ToO). In this paper we deal with observations and analyses of cataclysmic variables (CVs) and related objects. Positive detection in the keV–MeV passband 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). Also CVs with a slightly larger b_{II} are expected to be scanned because of of INTEGRAL's large field of view. Currently The best coverage is available for CVs lying toward the Galactic center. Some CVs far from the Galactic plane lie in the fields scheduled for pointed AO observations of other kinds of objects. INTEGRAL is able to provide simultaneous information in the optical, medium X-ray, hard X-ray, and gamma spectral region (or at least a suitable upper limit) for each CV in each scan or field. 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. In addition, the OMC observations can be used also for the systems below the detection limit in hard X-rays.

2. The CV observations by INTEGRAL

The number of CVs within the IBIS detection limit is a surprise: 32 CVs have been detected by the INTEGRAL IBIS gamma-ray telescope so far (more than expected, almost 10 percent of the INTEGRAL detections, see also Fi. 5). 22 CVs were seen by IBIS and identified 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 intermediate polars (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

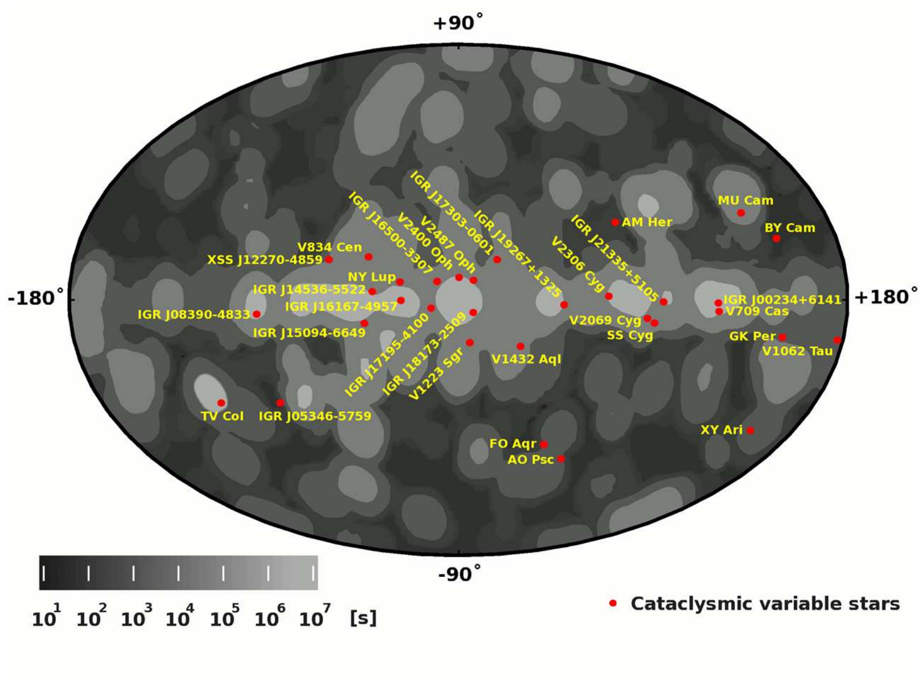

Figure 1: Preview of 32 CVs observed by INTEGRAL IBIS sky coverage (up to March 2009).

objects. The spectra of CVs observed by IBIS are similar in most cases. Power law 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 cataloged 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), see also Fi. 6. 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). This confirms the importance of the OMC-like instrument (preferably with the same FOV as gamma–ray telescope) on board gamma-ray satellites: even with the *V* limiting mag 15, it can provide valuable optical simultaneous data to the gamma-ray observations. 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,

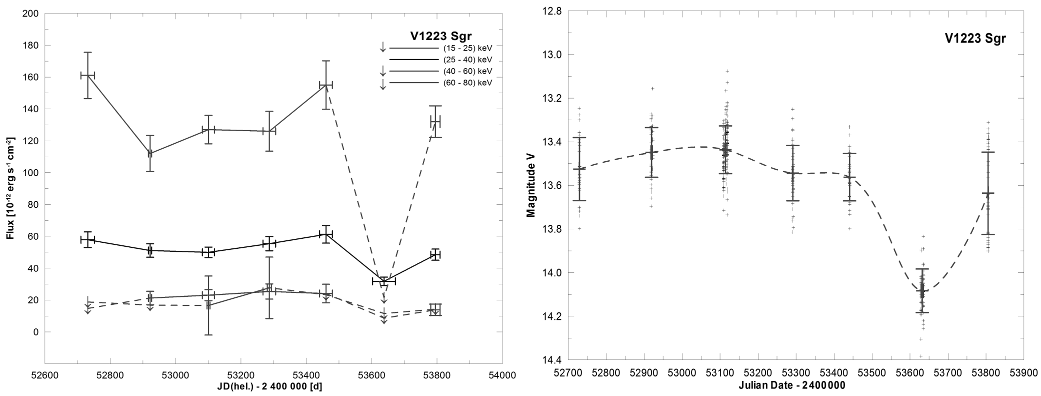

Figure 2: Left: The IBIS gamma–ray light curve for V1223 Sgr. The fluxes especially in (15 - 25) keV and (25 - 40) keV bands are long-term variable with significant drop around MJD 53 650. Optical variations are correlated with the changes in (15 - 25) keV, (25 - 40) keV and (40 - 60) keV spectral bands 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. Right: The OMC optical (V band) light curve for V1223 Sgr.

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.

3. Selected objects

V1223 Sgr. With a 32 sigma detection, 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 2 (left part). For this source, valuable optical data have been provided also by the INTEGRAL OMC camera, allowing simultaneous miltispectral analysis (Fig. 2 right part). The object is detectable also with JEM-X X–ray monitor, allowing the full INTEGRAL spectrum to be plotted and investigated (Fig. 3 left part).

V709 Cas. 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 cataloged 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 variations 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. 3 right part). 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).

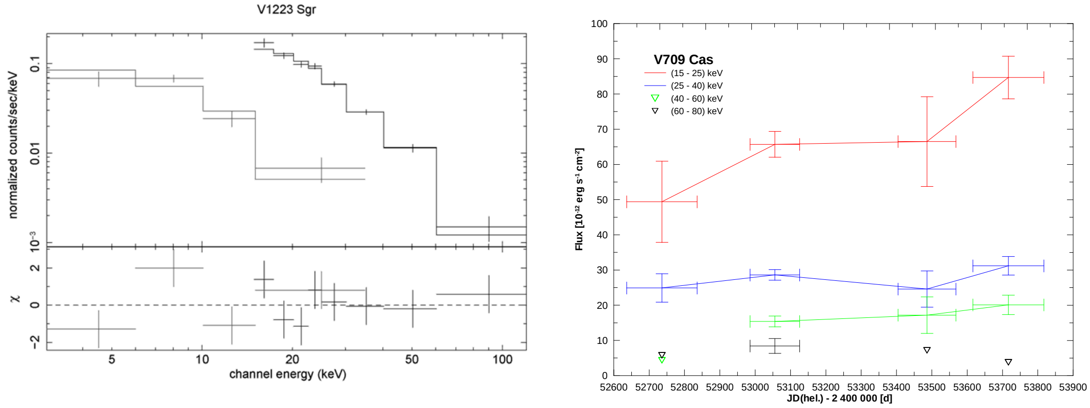

Figure 3: Left: The IBIS and JEM-X spectra for V1223 Sgr fitted by a thermal bremsstrahlung model. Right: The gamma–ray light curve for V709 Cas. The IBIS data were used.

V1432 Aql. This is an example of a asynchronous polar (Patterson et al. 1995) seen by the INTEGRAL IBIS telescope. The orbital period (3.37 hr) differs from the rotational period of the WD by ∼0.3 percent. The flux in the 15–40 keV IBIS passband is $(8.8 \pm 0.9) \times 10^{-4}$ photon cm^{-2} s^{-1}. The corresponding luminosity is L(15–40 keV) = 1.4×10^{32} erg s^{-1}.

V2400 Oph. Example of a diskless intermediate polar detected by the INTEGRAL IBIS gamma-ray telescope. Orbital period: Porb = 3.4 hr, rotational period of the WD: Prot = 927 sec, beat period: Pbeat = 1003 sec.

GK Per. This IP (e.g. Watson et al. 1985) exploded as a classical nova in 1901. Fluctuations by ∼1 mag and later dwarf nova-type outbursts appeared after its return to quiescence (e.g. Hudec 1981). These outbursts are accompanied by an increase of the X-ray luminosity (e.g. King et al. 1979). The interval between the two outbursts when the INTEGRAL observation was performed was 973 days. The IBIS observation started at ∼42 percent of the interval between consecutive outbursts (measured since the previous outburst). The measured flux in the 15–40 keV passband is $(2.7 \pm 1.2) \times 10^{-4}$ photon cm^{-2} s^{-1}. The corresponding luminosity is L(15–40 keV) = 4.6×10^{32} erg s^{-1}. This is similar to the value obtained by Ishida et al. (1992) and can suggest that the amount of matter arriving to the WD and the parameters of the X-ray emitting region on the white dwarf remained almost the same during similar phases of the quiescent intervals.

V834 Cen. The optical light curve of V834 Cen during the lifetime of INTEGRAL shows active and inactive states (Fig. 4). 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.

Symbiotic stars. Three symbiotic systems have been detected by INTEGRAL in hard X-rays. This is another valuable and unexpected outcome from INTEGRAL. 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.

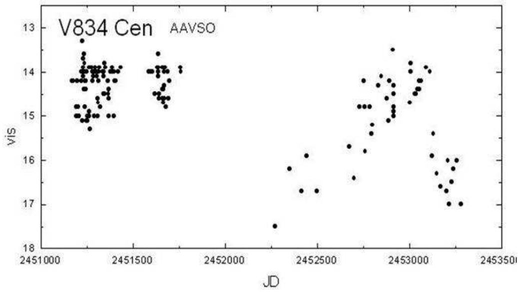

Figure 4: The AAVSO light curve for V834, a cataclysmic gamma-ray loud variable detected by the ESA INTEGRAL satellite. The active state around JD 2453000 represents the time period when the source was detected in gamma-rays, while it remained undetected at times when the source was in the inactive state.

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

Figure 5: Cataclysmic Variables detected in hard X-rays by INTEGRAL IBIS (ISGRI).The newly detected objects are emphasized.

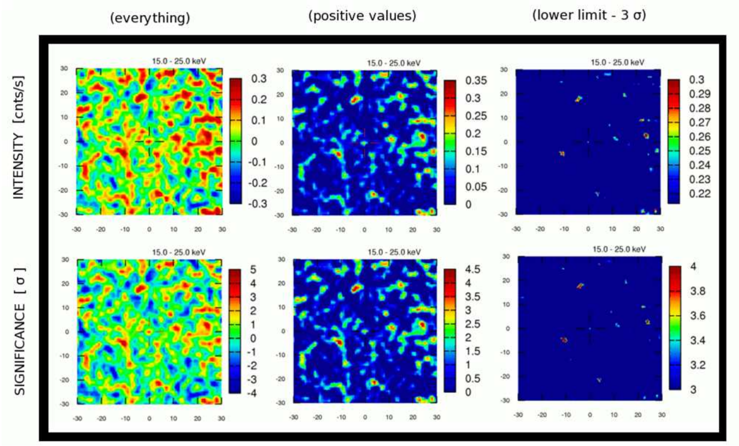

Figure 6: XY Ari (IP, example of a new detection). Comparison of the visualization methods Ű- noise reduction.

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).

4. Conclusions

INTEGRAL is an effective tool to study CVs and symbiotics stars in hard X–rays: 32 CVs and 3 symbiotics were detected so far by the IBIS gamma–ray imager. These results also indicate that more CVs (and in harder passband) will be detectable with increasing integration time. 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 symbiotics stars can provide valuable inputs for better understanding of involved physical processes.

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