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# New Results on Cataclysmic Variables Observed by INTEGRAL

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**Abstract** The results of investigations of cataclysmic variables and related objects with the ESA INTEGRAL satellite mostly within the Core Programme are presented and discussed. It is evident that the INTEGRAL satellite serves as an efficient tool to study some of these objects, especially those containing a magnetic white dwarf.

**Key words:** cataclysmic variables, symbiotic stars, INTEGRAL

## 1 INTRODUCTION

There are four co-aligned instruments onboard the INTEGRAL (International Gamma-Ray Astrophysics Laboratory) satellite: (1) gamma-ray imager IBIS (15 keV–10 MeV, field 9 deg, 12 arc min 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 cataclysmic variable (CV) in each scan or field, assuming that the object is inside the field of view. The basic codes of observations are as follows: (a) Regular (weekly) Galactic Plane Scans (GPS) ($-14$ deg $< b_{\rm II} < +14$ deg), (b) Pointed observations (AO), (c) Targets of opportunity (ToO).

## 2 PRODUCTION OF GAMMA-RAYS IN CATACLYSMIC VARIABLES

Acceleration of particles by the rotating magnetic field of the white dwarf (WD) in intermediate polars (IPs) in the propeller regime, as observed in AE Aqr, detected by ground-based Cherenkov telescopes in the TeV passband (Meintjes et al. 1992) can result in very high energies of generated photons. 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 working in the TeV region. As shown in this contribution, observation in the energy band of the INTEGRAL instruments provides an important addition to the physics of CVs and related objects.

## 3 CVS, SYMBIOTICS, AND INTEGRAL

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 $< b_{\rm II} < +14$ 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 $b_{\rm II}$ 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

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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 extreme (hardest) 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 hardest 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 (the OMC observations can be used also for the systems below the detection limit in hard X-rays).

## 4 THE CV OBSERVATIONS BY INTEGRAL DURING THE FIRST 4 YEARS

In total, 21 CVs have been detected by the INTEGRAL IBIS gamma-ray telescope so far (surprisingly, this is more than expected before launch, and represents almost 10 percent of the INTEGRAL detections). 17 CVs were seen by IBIS and found by the IBIS survey team (Barlow et al. 2006; Bird et al. 2007), 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), i.e. new CVs, not in the Downes catalogue. They are mainly magnetic systems: 11 are confirmed or probable IPs, 4 probable magnetic CVs, 3 polars, 2 dwarf novae, 1 unknown. The vast majority have an orbital period $P_{\rm orb} > 3$ hr, i.e. above the period gap (only one has $P_{\rm orb} < 3$ hr), 5 objects are long-period systems with $P_{\rm orb} > 7$ hr.

The majority of CVs seems to display persistent 20–30 keV fluxes with the exception of V1223 Sgr and SS Cyg (but probably there are in fact more variable sources, see our recent detailed related efforts, e.g. Hudec et al. 2007).

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 $\sim$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. 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 ks of exposure time or more, but some of them remained invisible even after 500 ks. This can be however, at least in some cases, related to the activity state of the sources – the hard X-ray activity may be temporary or highly variable.

There is an indication for a far X-ray flare in a CV system, namely V1223 Sgr, seen by IBIS (a flare lasting for $\sim$3.5 hr during revolution 61 (MJD 52743), with the peak flux $\sim$ 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 instrument onboard INTEGRAL: 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. The physics behind the outbursts in IPs is either the disk instability or an increase in the mass transfer from the secondary.

## 5 SELECTED TARGETS

### 5.1 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 $\sim$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.

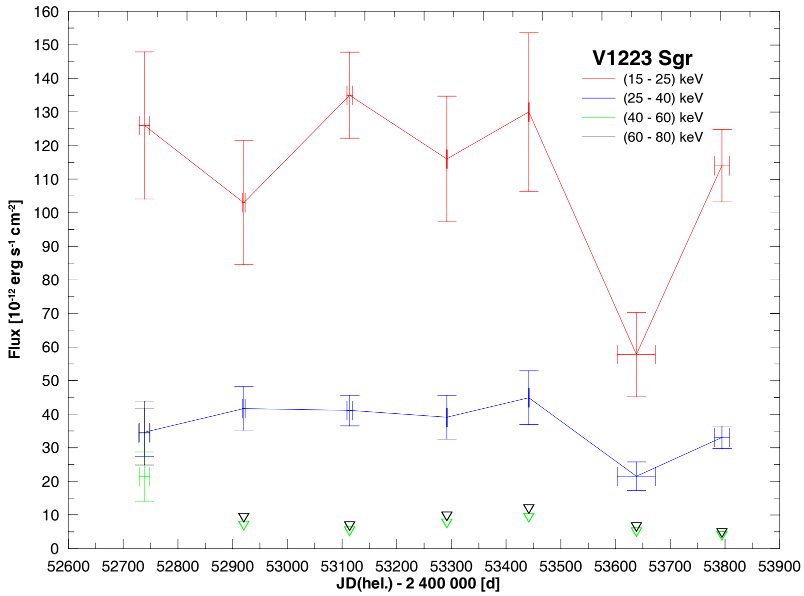


**Fig. 1** The IBIS gamma–ray light curve for V1223 Sgr.

### 5.2 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 ks 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 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. 2). 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).

The analysis is complicated by the vicinity of a pulsar in outburst IGR J00291+5934, newly discovered by INTEGRAL, only 20 arcmin apart (approximately 4 pixels). According to Falanga et al. (2005), who have performed more proper analysis by fitting two gaussian profiles, the pulsar, in average 8 times more significant than the CV, is decreasing in intensity during the period of observation, while V709 Cyg remains stable.

### 5.3 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) = $1.4 \times 10^{32}$ erg s$^{-1}$.

### 5.4 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

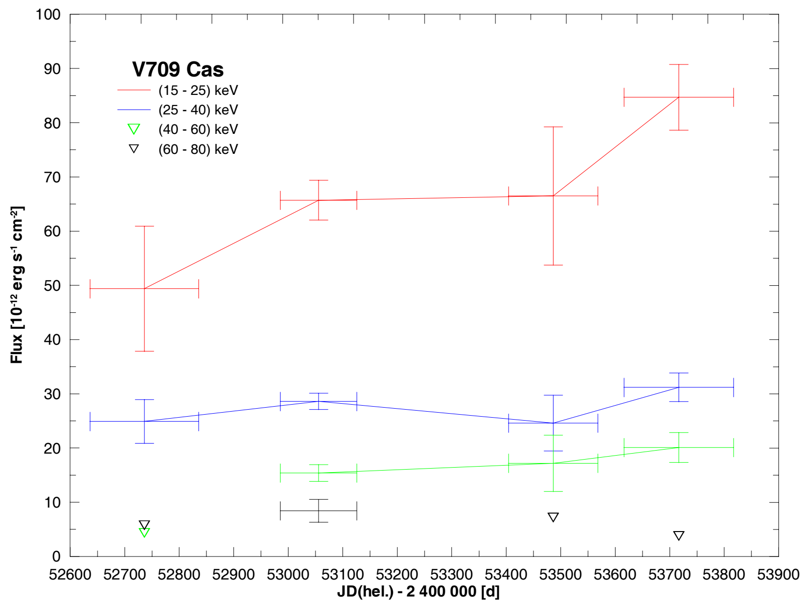


**Fig. 2** The gamma–ray light curve for V709 Cas.

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) = $4.6 \times 10^{32}$ 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.

## 6 SYMBIOTIC SYSTEMS AS HARD X–RAY SOURCES

In addition to CVs, some symbiotic systems have been detected by INTEGRAL in hard X-rays. This is another valuable 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. Dramatic variability on a large range of time scales (from less than a minute to years and decades) has been detected in these systems. Classification of symbiotics suggested by Mürset et al. (1996) is as follows: a) supersoft X-ray spectra (hot white dwarfs?), b) harder X-ray spectra (colliding winds?), c) relatively hard X-ray sources (neutron star instead of a white dwarf?).

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, Fig. 3). 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).

An interesting feature of symbiotic recurrent novae (RNe) is rapid optical flickering, and at least one symbiotic RN (T CrB) has also produced very hard X-ray emission. RT Cru produces optical flickering, too, has an optical spectrum like that of T CrB, and has been detected by IBIS in X-rays out to ∼60 keV with the flux $\sim 1 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the 40–60 keV range. The soft X-ray observations of RT Cru from the Chandra and Swift satellites (Sokoloski et al. 2005) clearly shows both thermal and non-thermal

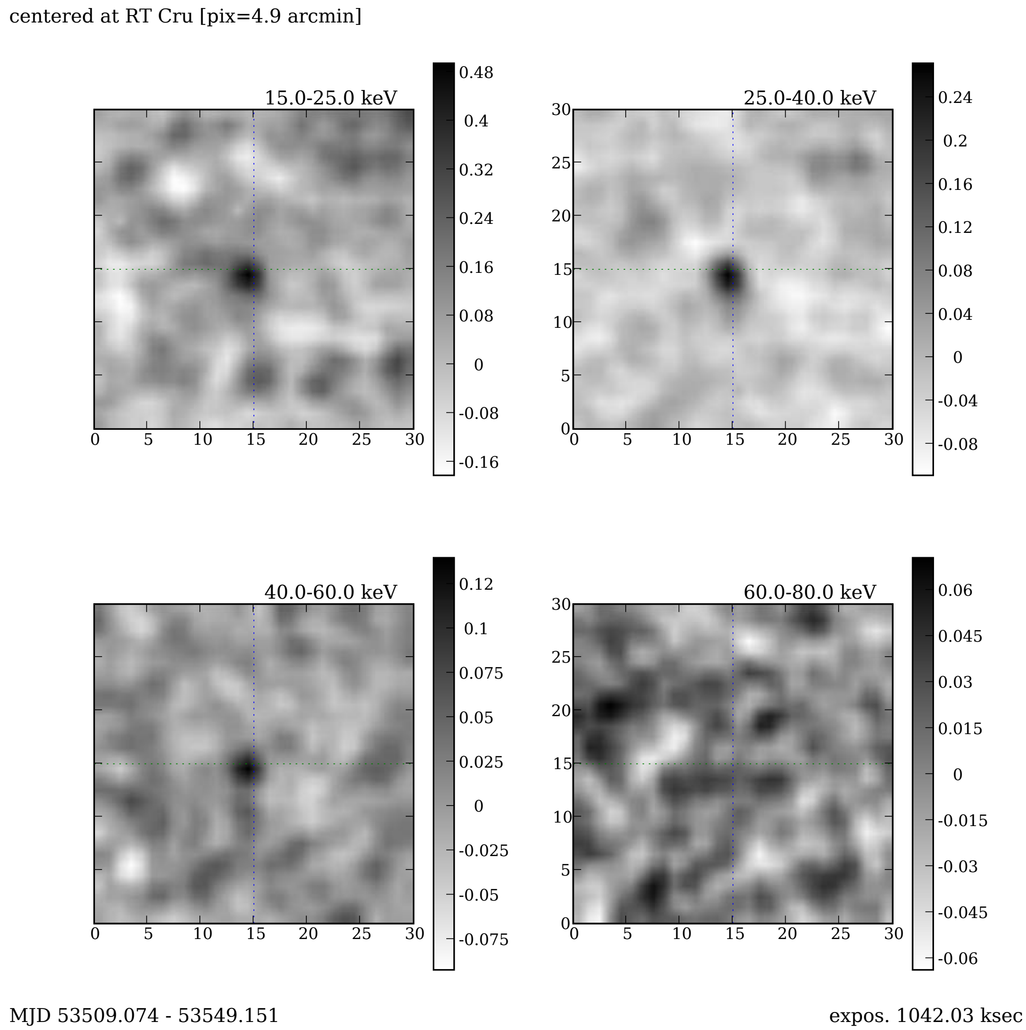


**Fig. 3** The IBIS co-added images of the symbiotic star RT Cru, representing in total about $10^6$ s of the exposure time. RT Cru is visible for $E < 60$ keV.

X-ray emission. Absorption of soft X-rays variable on a time scale of months may suggest occultation by the red giant. There are two possible models for RT Cru: a jet-producing system viewed nearly edge-on, or a magnetic white dwarf viewed pole-on.

## 7 CONCLUSIONS

INTEGRAL is an effective tool to analyze at least some CVs and symbiotics. 21 CVs and 3 symbiotics have been detected, with the number increasing with time. The successful observations of CVs by INTEGRAL provide a proof that CVs can be successfully detected and observed in hard X-rays with INTEGRAL (for most CVs this represents considerably harder passbands than possible previously). These results show that more CVs (and in harder passbands) will be detectable with increasing integration time. There is also an increasing probability of detecting the objects in outbursts, high and low states etc. The simultaneous hard

X-ray and optical monitoring of CVs (or at least suitable upper limits) can provide valuable inputs for better understanding of physical processes and evolution of CV systems as well as related objects. Long-term variability of CVs can be monitored. It will be even more valuable with increasing observing time. The INTEGRAL observations cover the gap between TeV energies (observed by Cherenkov telescopes) and X-ray observations by previous satellites (re-examination of the previously reported detections of some magnetic CVs by Cherenkov telescopes may be desirable). Valuable OMC observations have been provided even for those CVs below the detection limit of IBIS and SPI (deeper insight into the activity of various types of CVs).

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