CATACLYSMIC VARIABLES AND RELATED OBJECTS OBSERVED WITH *INTEGRAL*

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ABSTRACT

The examples of the results of investigation of cataclysmic variables (CVs) and related objects with the ESA INTEGRAL satellite mostly within the Core Programme are presented and discussed. It is evident that INTEGRAL satellite serves as an efficient tool to study these objects and that not only the onboard high-energy telescopes but also the small optical camera OMC provide valuable scientific information.

INTRODUCTION

There are four co-aligned instruments onboard the INTEGRAL (The 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) [1]. 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 CV in each scan or field, assuming that the object is inside the FOV. The basic codes of observations are as follows: (a) Regular (weekly) Galactic Plane Scans (GPS) ($-14^o<b$II$<+14^o$), (b) Pointed observations (AO), (c) Targets of oportunity (ToO).

1. PRODUCTION OF GAMMA-RAYS IN CVS

Acceleration of particles by the rotating magnetic field of the WD in intermediate polars in the propeller regime – as observed in AE Aqr – detected by ground-based Cherenkov telescopes in the TeV passband [2] can result in very high energies of generated photons. TeV emission from another object, polar AM Her was detected by ground-based Cherenkov telescopes [3]. Detection in the keV – MeV passbands by *INTEGRAL* represent an important suplement to the science of CVs, since before, there was an observational energy gap between the region of soft X-rays covered by X-ray satellites and by ground-based Cherenkov teleskopes working in the TeV region. As shown in this contribution, observation in the energy band sof the INTEGRAL instruments provide important addition for the physics of CVs and related objects.

2. SYMBIOTIC SYSTEMS

In addition to CVs, some symbiotic stars have been also detected by INTEGRAL. The symbiotic variable stars represent a heterogeneous group – they are often represented by late-type giant transferring mass onto a compact object (a WD or a neutron star) via a strong stellar wind or in some cases via Roche lobe overflow (more than 100 symbiotics known). Most symbiotics are the long-period causins 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 Murset et al. [4] is as follows: group a: supersoft X-ray spectra (hot white dwarfs?), group b: harder X-ray spectra (colliding winds?), group c: relatively hard X-ray sources (neutron star instead of a WD?).

3. CVS, SYMBIOTICS, AND INTEGRAL:

In total, ~ 335 CVs brighter than 17.5 mag (*V*) at least during maxima of their long-term activity and located within $-14^o < b$II $<+14^o$ are contained in *The Catalog and Atlas of CVs* [5] (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 the 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 object. 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. Observation of the extreme (hardest) part of the bremsstrahlung spectrum (most sensitive to the temperature variations) represent important input for the physical analyses of the objects.
INTEGRAL is suitable for: (a) detection of the populations of CVs and symbiotics with the hardest X-

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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 science window (OMC observations also for systems bellow the detection limit in hard X-rays).

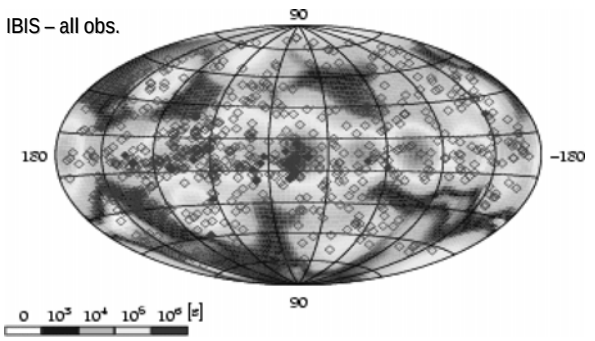

Fig. 1. Known CVs from Catalog and Atlas of Cataclysmic Variables [5] shown on the map of exposure of INTEGRAL -IBIS gamma-ray telescope

4. V1223 SGR

This is the brightest CV seen by INTEGRAL so far. The object belongs to intermediate polars with accretion via disk. It is bright X-ray source (4U 1849–31). Orbital period: *P*orb = 3.37 h, rotational period of the white dwarf: *P*rot = 746 sec. Beat period (combined effect of *P*orb and *P*rot): *P*beat = 794.3 sec. Prominent long-term brightness variations are as follows: (a) outburst with a duration of ~6 hr and amplitude >1 mag [6], (b) episodes of deep low state (decrease by several magnitudes) [7].

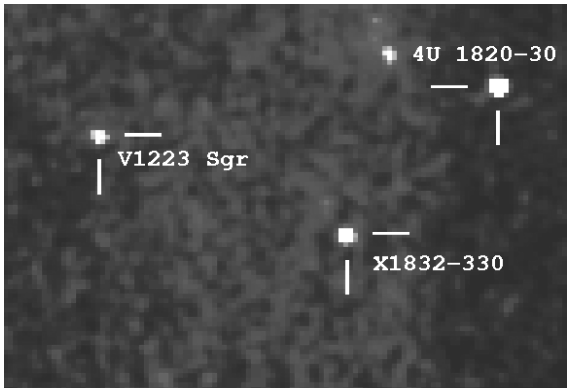

Fig. 2. Field of the intermediate polar V1223 Sgr on co-added frames from IBIS (25-40 keV). Start exposure JD 2452730.17, integration time: 66 700 sec. Size of the field: 9.1°x7.1°. North is up, East to the left.

5. V 1432 AQL

This is an example of desynchronized polar seen by the INTEGRAL IBIS telescope. The orbital period (3.37 hr) and the rotational period of the WD differ by ~0.3 percent in this system. The estimated flux (15 – 40 keV) = (8.8 +/- 0.9) x 10^{-4} photon/cm2/s and *L* (15 – 40 keV) = 1.4 x 10^{32} erg/s.

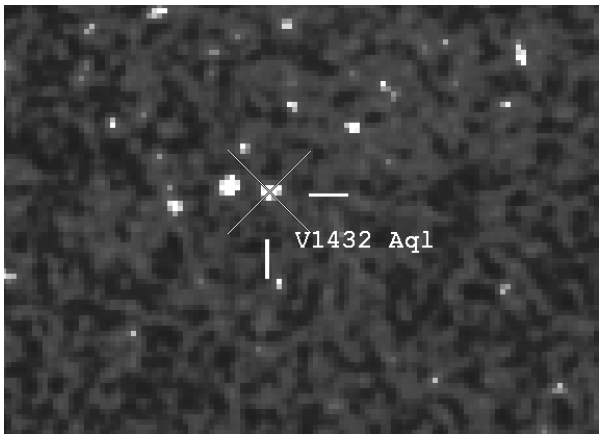

Fig. 3. Field of V1432 Aql. Co-added fully coded images from IBIS: JD 2 452 756. Integration time 37 160 sec, size of the field: 9°x7°. North is up, East left.

6. V2400 OPH

Example of a diskless intermediate polar detected by the INTEGRAL IBIS gamma-ray telescope. Orbital period: *P*orb = 3.4 hr, rotational period of the WD: *P*rot = 927 sec, beat period: *P*beat = 1003 sec.

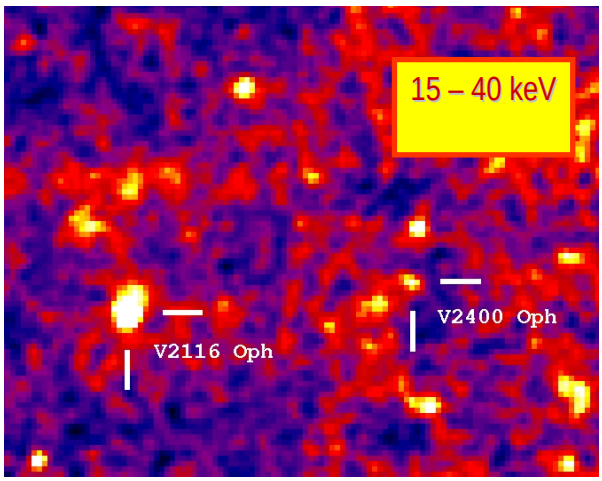

Fig. 4. IBIS image of the field of the intermediate polar V2400 Oph and the symbiotic (neutron star) system V2116 Oph. Co-added fully coded images from IBIS: JD 2452733 + JD 2452920 + JD 2453054. Integration time: 53 760 sec. Size of field: 9.1°x7.1°. North is up, East to the left.

7. GK PER

Example of intermediate polar, with very long *P*orb=1.99 days. Spin period of the white dwarf is *P*spin=351 sec .The star exploded as a classical nova in 1901 with fluctuations by ~1 mag after return to quiescence, later they developed into infrequent dwarf nova-type outbursts [8][9]. The observed X-ray (2.5 – 11 keV) spin modulation is 351 s (*EXOSAT*) during optical outburst [10]. The X-ray start can precede the optical start by up to 40 days [9]. The Interval between the two outbursts when the INTEGRAL observation was performed was 973 days. The IBIS observation started at ~42 percent of this interval (measured since the previous outburst). Amount of matter arriving to the WD and the parameters of the X-ray emitting region on the WD remained almost the same during these phases of the quiescent intervals.

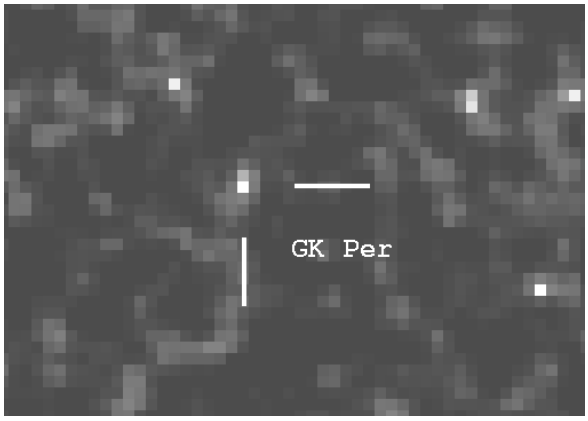

Fig.5. IBIS (25–40 keV) image of GK Per (Integr. time: 79 980 sec Co-added images: 19 March 2003, 27 – 29 July 2003. Size of field: 4.1°x3.0°. North is up, East to the left.

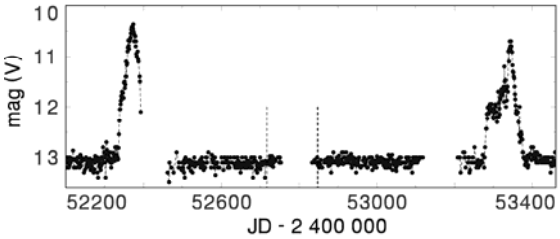

Fig. 6. The position of INTEGRAL observation described in this paper between the two optical outbursts of GK Per.

The measured flux (15 – 40 keV) = (2.7 +/- 1.2) x 10^{-4} photon/cm2/s *L* (15 – 40 keV) = 4.6 x 10^{32} erg/s. Quiescent X-ray spectrum with parameters from Ishida et al. (1992): (*kT* = 32 keV, *N*H = 1022 cm^{-2}, norm. factor: 0.0039+/-0.0002 photon/cm2/s1/keV).

8. IX VEL

This is an example of the CV not detected in gamma-rays by IBIS, but with important information gained by the onboard OMC camera.

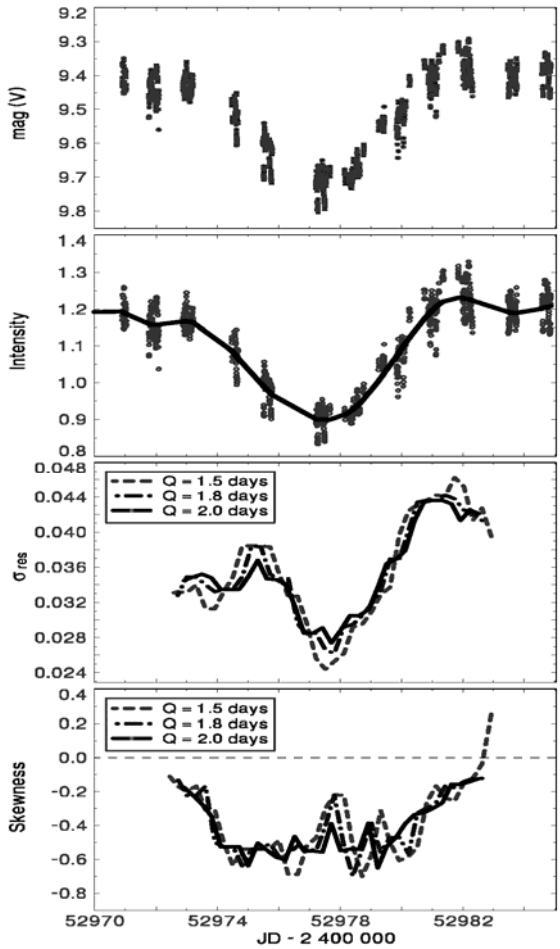

Fig. 7. Examples of OMC light curves for IX Vel.

The Fig. 7 shows the evolution of various parameters of the light curve through the short-lived episode of the shallow low state. The amplitude of the rapid variations (mostly flickering) depends on the level of the current level of intensity. The amplitude of the rapid changes was lower before the episode of the low state than after it.

9. RS OPH

This is an example of relatively bright symbiotic system observed by OMC but invisible in IBIS so far. The orbital period is *P*orb=460 days, the inclination angle 30 – 40 deg, with giant component underfilling its lobe RS Oph is a system with white dwarf (WD) and recurrent nova (five observed explosions) [11].

The quiescent optical brightness exhibit fluctuations (months and years) between magnitudes 11 – 12 mag (*V*), sometimes even 10 mag (*V*). The rapid optical variations with time scale of tens of minutes, similar to those often seen in short-period CVs have been also observed.

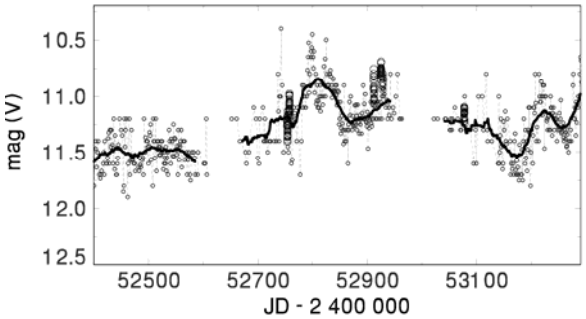

Fig. 8 Optical light curve of RS Oph.

The OMC observations were performed in various orbital phases; Sets 1, 3 in orbital phase 0.9848 – 0.9935. RS Oph was observed with OMC at various levels of brightness (lower value ~11.35 mag(*V*)). Rapid variations of brightness have been detected: The largest peak-to-peak amplitude amounts to ~0.3 mag(*V*). The amplitude of flickering tends to increase with increasing mean level of intensity – this is origin of both flickering and "constant" optical luminosity from the same source. The WWZ method was used for detection of typical frequency of flickering for each set. Typical frequency found is 30 – 50 cycles/day. There is complicated relation between amplitude of flare in flickering and its duration inside a given science window. In set 3 the amplitude decreases with the decrease of cycle-length (and hence duration of flare). The observed short time scale of flickering indicates that the most probable location is in close vicinity of the WD (supported also by rapid variations of He II 4686 emission). All this contradicts the origin of flickering from rotation of magnetized white dwarf – typical periods of flickering. The results found here are quite discordant with period of 81+/-2 min [12].

10. RESULTS FOR CV OBSERVATIONS WITH *INTEGRAL* AND FURTHER PERSPECTIVES

The successful observations of CVs by INTEGRAL provide a proof that CVs can be successfully detected and observed in far X-rays with *INTEGRAL* (for most CVs 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 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. The long-term variability of CVs can be monitored – it will be increasingly even more valuable with increasing observing time. The INTEGRAL observations covers the gap between TeV energies (observed by Cherenkov telescopes) and X-rays observations by previous satellites. 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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