INTEGRAL broadband X-ray spectra of the selected intermediate polars

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Abstract

In total, 21 cataclysmic variables (CVs) were detected by *INTEGRAL* satellite in hard X-ray/soft gamma ray. Intermediate polars (IPs) dominate the group of CVs seen by IBIS/ISGRI. We processed all available observational data from *INTEGRAL/IBIS* and *INTEGRAL/JEM-X* for selected IPs and we constructed and analysed the composite spectra (3 - 100 KeV). These broad-band spectra can be well fitted by a thermal bremsstrahlung model ($kT \approx 20$ - 25 keV), with reflection from an optically thick cold medium (the surface of the white dwarf) in some cases.

Introduction

CVs are close binary systems consisting of a white dwarf (WD) and red MS star, which fills the volume of its inner Roche lobe and transfers matter to the vicinity of the WD. According to strength of WD magnetic field this matter is creating an accretion disc or follows magnetic field lines and falls to the surface of the WD. In IPs, the WD magnetic field ($10^6 - 10^7$ G) is not generally strong enough to disrupt the disc entirely (as in polar systems) and simply truncates the inner part of the disc, resulting in an accretion flow that is channelled down towards the magnetic poles and onto the WD surface.

In a simple model of a column of gas impacting the atmosphere of the WD, a shock will form (Aizu 1973) and hard X-ray/soft gamma-ray emission will result from thermal bremsstrahlung cooling by free electrons in the hot post-shock region (PSR) with $kT \approx 10$s of keV (King &Lasota 1979). Reflection of the bremsstrahlung photons at the WD surface also contributes to the hard X-ray spectrum (van Teeseling, Kaastra & Heise 1996). The recent investigations by Canalle et al. (2005) and Saxton et al. (2007) have studied the role of the two-temperature plasma and considered the dipole magnetic funneling. Suleimanov et al. (2008) showed that the influence of Compton scattering on the broad-band X-ray spectra of IPs is significant only at high accretion rates and large WD masses. The plasma temperature in the PSR depends on the free-fall velocity at the WD surface and, therefore, the X-ray spectra of IPs can be used to determine the WD mass (Rothschild et al. 1981, Suleimanov et al. 2008).

Observations and analysis

We used all available observational data from *INTEGRAL/JEM-X* and *INTEGRAL/IBIS* detectors to study broadband spectra (3 - 100) keV of the following IPs: V 709 Cas, GK Per, IGR J16167-4957, V 1223 Sgr and V 2400 Oph. To process the data, we created mosaic images of the corresponding regions to extract the list of all detected sources, and then we extracted the spectra using INTEGRAL's standard OSA 7.0 software. Spectral analysis was performed with the XSPEC (Arnaud 1996) version 11.3.2.

V 709 Cas

This X-ray source was recognized as an IP following its detection in the ROSAT All Sky Survey as RX J0028.8+5917 and was identified with a 14th magnitude blue star, V709 Cas. Suleimanov et al. (2008) fitted the broad-band spectrum (3 – 100) keV of this object by bremsstrahlung model with temperature $kT = 29.6 \pm 2.5$ keV., the covering factor $C_f = 0.31 \pm 0.04$, the column density $n_H = (58 \pm 15)\times10^{22}$ cm^{-2} and the iron line energy 6.5 ± 0.2 keV. They showed that accounting for Compton scattering does not change significantly the obtained mass of the WD ($M_{WD} \approx 0.9\ M_\odot$) in the case of V 709 Cas.

Our analysis of all available observational data of V709 Cas showed that this source is detectable up to 100 keV. The hard X-ray / soft gamma ray fluxes are not persistent and the light curves indicate that the brightness of this IP increased by a factor ≈2 from MJD 52700 to MJD 53700 in (15 - 25) keV energy band. Our broad-band spectrum (Figure 1 - left panel) was well fitted by a thermal bremsstrahlung model with post-shock temperature of $kT = 24.4^{+1.5}_{-1.4}$keV (χ^2/d.o.f = 14.9/10). Total flux in (20 - 60) keV band was 3.8×10^{-11} erg cm^{-2} s^{-1}.

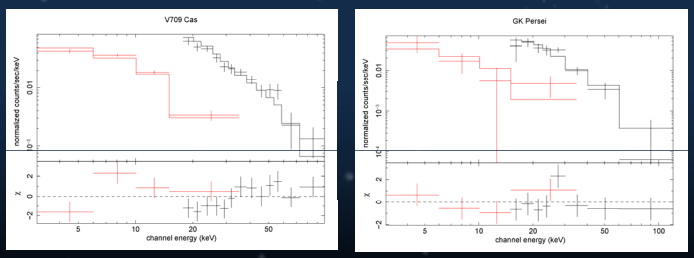

Figure 1. *INTEGRAL/JEM-X + IBIS* broadband spectra of V709 Cas (left panel) and GK Per (right panel) fitted by a thermal bremsstrahlung models.

GK Per

GK Per is a classical nova system with the longest known orbital period 1.996803 days, which shows erratic optical maxima reminiscent of dwarf nova outbursts with recurrence times between 880 days and 1240 days (Kim et al., 1992). The system consists of the WD with mass about (0.7-0.8)$M_\odot$ and an evolved K2 sub-giant with mass 0.25$M_\odot$ (Cherepashchuk et al., 1996). The rotation of WD is asynchronous with the spin period of WD equals to 351 s. *INTEGRAL/IBIS* (20 - 100) kev spectrum was fitted by Barlow et al. (2006) by a thermal bremsstrahlung model with temperature $kT = 28.7 \pm 15.6$ keV.

We processed all available observational data for GK Per from *INTEGRAL*/IBIS and I*NTEGRAL*/JEM-X with total exposure time 500 and 66 ksec, respectively. The source is detectable up to (30-50) keV with ~7σ significance. The (3-100) keV spectrum (Figure 1 – right panel) we fitted by a thermal bremsstrahlung model with post-shock temperature of $kT = 22.5^{+4.5}_{-3.4}$keV (χ^2/d.o.f = 9.9/10). Total flux in (20-60) keV band was 2.3×10^{-11} erg cm^{-2} s^{-1}. Significant excess around 28 keV can be related with reflection from an optically thick cold medium (the surface of the WD).

IGR J16167-4957

The source IGR J16167-4957 was discovered in all-sky *INTEGRAL/IBIS* mosaics (Walter et al. 2004). Object was identified as IP through the appearance of its optical spectra with Balmer emissions up to at least H_δ, as well as several He I and He II lines in emission. All of the detected lines are consistent with being at z = 0, indicating that this object belong to our Galaxy.

Total exposure time of the observational data for IGR J16167-4957 from *INTEGRAL*/IBIS and I*NTEGRAL*/JEM-X was 2.5 and 0.9 Msec, respectively. Our best fitting bremsstrahlung temperature in the (3 – 100) keV energy band was $kT = 19.5^{+2.0}_{-1.7}$keV (χ^2/d.o.f = 7.7/8). Total flux in (20-60) keV band was 1.7×10^{-11} erg cm^{-2} s^{-1}. *INTEGRAL/JEM-X + IBIS* broadband spectrum of IGR J16167-4957 fitted by a thermal bremsstrahlung model is plotted in Figure 2 - left panel.

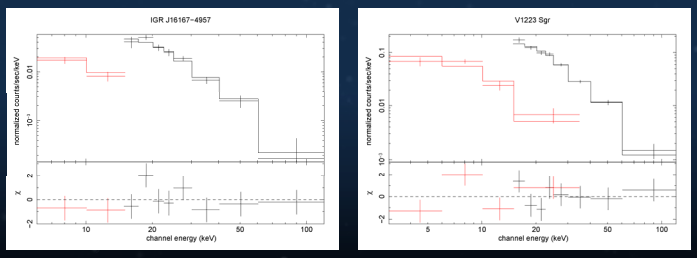

Figure 2. *INTEGRAL/JEM-X + IBIS* broadband spectra of IGR J16167-4957 (left panel) and V1223 Sgr (right panel) fitted by a thermal bremsstrahlung models.

V 1223 Sgr

The IP V1223 Sgr (4U 1849–31) is the most significantly detected CV by *INTEGRAL/IBIS*. The broad-band spectrum (3 – 100 keV) provides an estimate of the post-shock temperature of $kT = 29 \pm 2$ keV when fit with a thermal bremsstrahlung model with reflection from an optically thick cold medium plus neutral absorption ($n_H = 3.3\times10^{22}$ cm^{-2}) and an iron line at ≈6.5 keV (Revnivtsev et al. 2004). Unusual high energy flare was observed by *INTEGRAL/IBIS* in MJD 52743 (Barlow et al. 2006). The best fitting bremsstrahlung temperature of the burst in the (20 – 100) keV energy band is slightly softer compared to the average spectrum (13.78 ± 2.50 keV and 18.77 ± 1.20 keV, respectively).

In our spectral analysis we used data with total exposure time 1.1 Msec (*IBIS*) and 83 ksec (*JEM-X*). V 1223 Sgr was detectable up to (50 - 100) keV energy band with ~5σ significance. Our broad-band spectrum (Figure 2 – right panel) was very well fitted by a bremsstrahlung model with the temperature of $kT = 23.7^{-1.4}_{-1.3}$keV (χ^2/d.o.f = 12.4/10). Total flux in (20-60) keV band was 6.4×10^{-11} erg cm^{-2} s^{-1}.

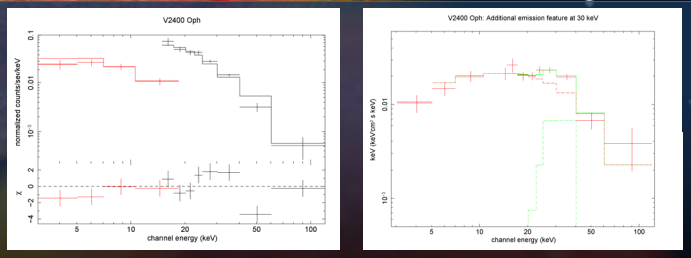

Figure 3. *INTEGRAL/JEM-X + IBIS* spectrum of V2400 Oph fitted by a thermal bremsstrahlung model (left panel) and by a thermal bremsstrahlung model with absorption and reflection components (right panel).

V 2400 Oph

V2400 Oph is a unique CV system because it shows evidence of an IP (the spin period of the WD is much shorter than the orbital period), but there is ample evidence that the system has no accretion disk, which is typical for polars. The X-ray emission produced by the optically thin radiation of a shock-heated hot plasma near the surface of the WD pulsates with a period ≈1003 s which is the beat period between the orbital period (≈3.42 h) and the WD spin period (≈927 s). The reason is that the matter out-flowing through the inner Lagrangian point accretes alternately on one and the other magnetic poles of the WD.

We processed all available observational data for V2400 Oph from *INTEGRAL/IBIS* and *INTEGRAL/JEM-X* with total exposure time 3 Msec and 250 ksec, respectively. The fit of composite spectrum (3-100 keV) by only a thermal bremsstrahlung model with temperature $kT = (21 \pm 1.6)$ keV (Figure 3 – left panel) is not sufficient to completely describe the data (χ^2/d.o.f = 29/10). Significant excess around ≈ 30 keV can be connected with reflection from the surface of the WD. If we take into account the absorption ($n_H = 5\times10^{22}$ cm^{-2}) and we fit the ≈ 30 keV excess by Gaussian profile (Figure 3 –right panel), the spectrum is well described with χ^2/d.o.f = 6/8. Total flux in (20-60) keV band was 2.9×10^{-11}erg cm^{-2} s^{-1}.

Conclusion

We analysed the spectra of selected IPs constructed using all available observational data from *INTEGRAL/IBIS* and *INTEGRAL/JEM-X*. Our analysis showed that the studied broad-band spectra (3 -100 keV) can be well fitted by a thermal bremsstrahlung model with the temperature of post-shock region kT ≈ 20 - 25 keV. In the case of GK Per and V2400 Oph there are strong evidences for emission excess around 30 keV, which can be caused by reflection of X-ray from an optically thick cold medium (the surface of the WD).

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