Iron Lines and Precession Variability of the Unique Microquazar GRS1915+105

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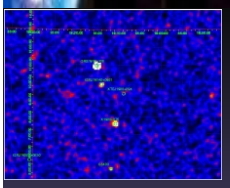

Fig.1. The image of the sky region near object GRS1915+105, observed with ISGRI/IBIS detector in 25-50 keV energy range with exposition of ~ 20 ks.

Abstract.

Based on INTEGRAL (2003-2007) and RXTE (1996-2008) data we studied X-ray variability of GRS1915+105 in the $10^{-3} - 10$ Hz frequency range, aiming to detect features in their power density spectra associated with the long term periodicity. The 300-days piriodicity was detected for thehard X-ray component of the GRS1915+105 flux (ISGRI/IBIS). Analyzis oflow-ionized iron line evolution in the specrum of GRS1915+105 is presented for different observations (XMM-Newton, Chandra, ASCA, BeppoSAX) carried out during 1994-2004. For allobservations we fond tight correlation between the value of equivalent wigthand the precession phase. The long-term behaviour of the source togetherwith variation of K_alpha iron line flux tends to indicate a precessionalnature of this variability and could shed light on the nature of thispecular microquazar. The future prospects are connected with a hight resolutuin X-ray spectroscopy (XMM-Newton, XEUS) of GRS1915+105. The investigation of K_alpha iron line profile in course of precession motion will offer the best opportunity to provide verification of origin of iron K emission in the spectrum of puzzling object GRS1915+105.

1. Introduction

The galactic X-ray binary system GRS1915+105 is the most prominent microquazar showing extreme variability in its light curve (Greiner et al., 1996), quasi-periodic oscillations, and X-ray/radio correllation behaviour. In 1992, the WATCH all-sky monitor onboard GRANAT discovered the X-ray source GRS1915+105 as a bright transient (Castro-Tirado et al., 1992). Mirabel & Rodriguez (1994) reported the observation of radio relativistic expansion interpreted in terms of collimated emission of matter, which made GRS1915+105 the first galactic "microquazar" with superluminal jets. No optical counterpart of GRS1515+105 was found because of the high Galactic extinction and only a IR counterpart was detected (Mirabel et al., 1994). GRS1915+105 is the most energetic object known in our galaxy with a luminosity of $\sim 5\cdot10^{39}$ erg/s in the high state and $\sim 10^{38}$ erg/s in the low state. The binary system, located at a distance of ~12 kpc, consist a $0.81+/-0.53\ M_{\odot}$ late type giant (Greiner et al., 2001a) in a 33.5 days orbit around a $14+/-4\ M_{\odot}$ black hole (Greiner et al., 2001b). The numerous observations of GRS1915+105 made with the instrument on board the RXTE satellite show an extremely complex variability in the X-ray band, which Belloni et al. (1997a, 1997b) interpreted as an oscillation of the inner region of the accretion disc caused by a thermal-viscous instability. Belloni et al. (2000) introduced a model-independent classification of the different types of X-ray variability in three basic spectral states high/soft, low/hard and intermediate state. The transitions between these states and a link between an accretion and ejection processes is, however, far from beeing understood. Last time, GRS1915+105 is being observed with INTEGRAL (2003-2007). We show that the source demonstrates precessional variability during this observational set in hard X-ray.

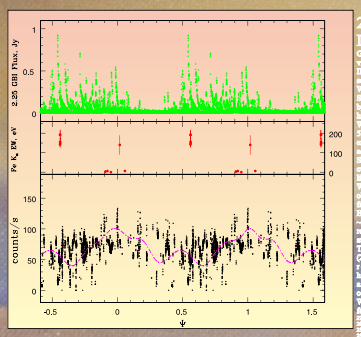

Fig.2. X-ray/radio data of GRS1915+105 object as a function of ~300-days precession periodicity: (lower panel) ISGRI/IBIS/INTEGRAL light curve in 13-250 keV (2003-2007); dot-dashed line indicates the mean light curve derived with sliding average method; (middle panel) EW of K iron line (6.4 keV) based on XMM-Newton, Chandra, ASCA and BeppoSAX observations (1994-2007); (upper panel) Green Bank – Interferometer radio flux on the frequency 2.25 GHz. The "zero-point" is ID=2452841 - the maximum of X-ray.

2. Observation and Data Aanalysis

GRS1915+105 was many times in the field of view of the IBIS/ISGRI detector onboard INTEGRAL during the routine Galactic plane scan and pointed observations (2003-2007). We have used the version 6.0 of the Offline Science Analysis (OSA) software distributed by INTEGRAL Science Data Center (ISDC, http://isdc.unige.ch) (Courvoisier et al., 2003). We studied all public data obtained until MJD 53339 in the 20-250 keV energy range. A total exposure of all public data ~2.2 Ms was accumulated. We built mosaic images for each ISW (Science Window) and accreted the light curve. Typical net exposures for one mosaic light curve point of 2 ks.

We used data of the ASM instrument of RXTE observatory (Twenk, 1999), covering the period from 1996-2008 in the 2-12 keV energy range. Each five measurement (dwell) last duration of ~90 s. The dwell-by-dwell light curves were retrieved from the public RXTE/ASM archive at HHEASARC(http://heasarc.nasa.gov/FTP/xte/data/ASM_lc/).

The radio data of the Green Bank Interferometer (2.25 Ghz) and Ryle Telescope (15 GHz) were retrieved from public archives http://www.gb.nrao.edu/fghigh/glist.html and http://www.mrao.cam.ac.uk/~guy/, correspondingly.

We used ASCA GIS-2 spectra and light curves for 10 observations:

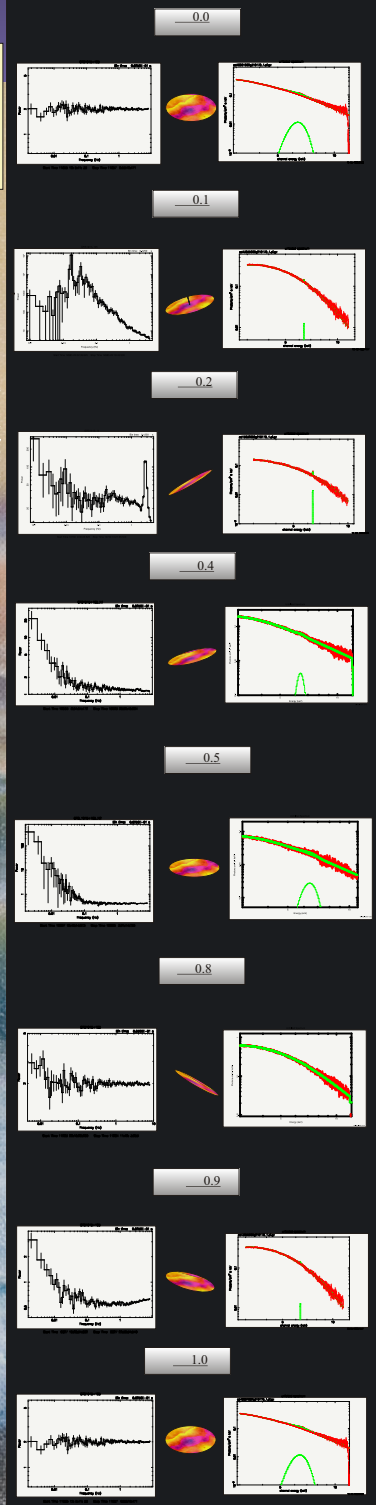

Fig. 5. PDSs (left panel) and photon spectra (right panel) of GRS1915+105, produsedwith the PCA/RXTE and GIS/ASCA data in course of precession motion.

3. Precession variability of Hard X-Ray

The analysis of the 2003-2007 ISGRI/IBIS 20-250 keV data set revealed long term X-ray variability of GRS1915+105. INTEGRAL data show (Fig.2,3,4) the long term behavior is indicative of 150 to 300 days recurrence in the GRS1915+105 flux. The results of this analysis lead us to suggest that the high level of the hadr X-ray interval of GRS1915+105 is due to periodical tilting of the accretion disc to the observer. In order to compare the results of INTEGRAL observations with archived observations of GRS1915+105 we also present in Fig.6 simultaneous ASM/RXTE 2-12 keV light curve. It is significant that the soft X-ray component did not show any periodicity. The analysis of the spectral index of hard X-ray flux for all INTEGRAL observations of GRS1915+105 reveals a remarkably periodic behaviour. It shows a nearly sinusoidal variation (Fig.1) on a time scale of ~ 300 days. For the determination of a cycle duration an analysis of variance for several model parameters and X-ray and radio fluxes was performed using the Abbe-Lafler-Kimmann distribution function (Fig.3). The results for 15-250 keV X-ray IBIS/ISGRI/INTEGRAL flux and the 2.25 GHz flux are given in the Fig.2. The amplitude of this long term variability has a local maximum in the 23-40 keV energy range.

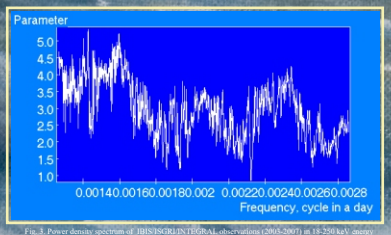

Fig. 3. Power density spectrum of IBIS/ISGRI/INTEGRAL observations (2003-2007) in 18-250 keV energy range.

4. Iron Lines

At the first time the emission line of low-ionized iron (6.4 keV) was detected in ASCA observation on September 1994 (Kotani et al., 2000) in a low-hard state. The iron K_alpha emission line in the GRS1915+105 is usually not very intensive. Lee et al. (2001) reported that neutral Fe K_alpha emission is present in the high-resolution data of a low-hard state, collected with Chandra HETGS, together with Fe photoelectric edges and absorption lines due to highly ionized matter. During the several observational campaigns performed by BeppoSAX, the Fe K_alpha line was almost invariably rather weak, with Equivalent Widths (EW) of a few tens of eV at most. Only in the observation of April 19, 1998, the line was strong enough (EW~200 eV). Also broad emission iron K_alpha line was registered in next ASCA observations of April 21, 2000 (Miller et al., 2004) with EW~140 eV. High resolution XMM-Newton (17.21 April, 2004) observations marginally found a 6.4 keV iron emission line with EW~6 eV (Tabl.1).

Photon spectrum is fitted by model of attenuated BMC and Gaussian line. In Fig.3 (right hand panels) the resulting spectra are shown by red curve. Analyzis of low-ionized iron line evolution in the specrum of GRS1915+105 is presented for different observations (XMM-Newton, Chandra, ASCA, BeppoSAX) carried out during 1994-2004. For all observations we fond tight correlation between the value of equivalent wigth and the precession phase. The long-term behaviour of the source together with variation of K_alpha iron line flux tends to indicate a precessional nature of this variability.

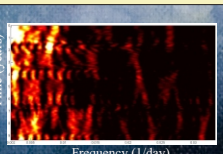

Table 1

JD	Int	Equivalent Width	error	Satellite
2449468.8	6.397	107	20	ASCA(1)
2451915.2	6.393	21.4	5.5	Chandra(1,2)
2451915.1	6.693	20.29	8	Chandra(1,2)
2451917.1	6.691	20.83	8	Chandra(1,2)
2451917.1	6.693	20.83	8	Chandra(1,2)
2449468.8	6.404	5.689	1900. 300.	Beppo(SAX)(3)
2449468.8	6.404	5.689	1900. 300.	Beppo(SAX)(3)
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2449468.8	6.404	5.689	1900. 300.	Beppo(SAX)(3)
2449468.8	6.397	107	20	ASCA(1)
2449468.8	6.397	19	99.8	ASCA(1)

(1) Chandra HETGS observation of Nova Sco 1994
(2) Chandra HETGS observation of Nova Sco 1994
(3) Beppo(SAX) observation of Nova Sco 1994

Fig. 4. Dynamical power spectrum of IBIS/ISGRI/INTEGRAL observations (2003-2007) in 18-250 keV energy range.

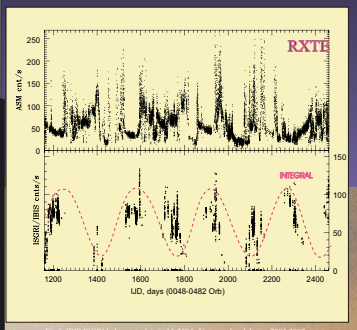

Fig.6. IBIS/ISGRI light curve data in 15-250 keV energy band during 2003-2007 observation run (bottom), simultaneous ASM/RXTE data (top) in the 2-12 keV

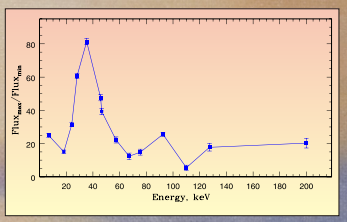

Fig.7. The amplitude of long-term variability of GRS1915+105 in different spectral range based on RXTE, BATSE and INTEGRAL data.

5. Power Dencity Spectra

Detailed timing analysis of the RXTE data (Morgan et al., 1997) reveals three types of QPO: a 1-10 Hz QPO with variable centroid frequency, two quasi-stable QPOs with centroid frequencies ~40 and ~67 Hz (Strohmayer et al., 2001), and variable low frequency QPOs (10^{-2} - 1 Hz), which can be identified with transitions between the states of Belloni et al. (2000). To produce the PDS, for RXTE and ASCA observation we use data in 2-13 keV range. For RXTE data we divided each observation interval in intervals 16 s long and produced an average PDS per observation summing the PDS of the individual segments. Power density spectra were computed in the 2-12 keV (PCA/RXTE) and 3-12 keV (GIS/ASCA) energy range. The PDS of the source were analysed with powerspec task from FTOOLS 5.1. The power spectra are shown in left panel of Fig.5. For reference, we plot in each panel correspondence photon spectrum on the right. We investigate the evolution of PDS with precession period and fond the remarkably corellation with the shape of PDS and EW of iron K line (also Fig.1,5). Interpretation for the QPO based on the pulsation modes of the corona (Shaposhnikov & Titarchuk 2006).

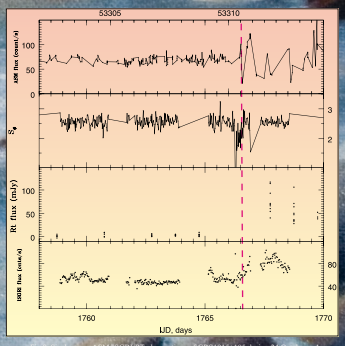

Fig.8. Simultaneous ASM/ISGRI/RT observations of GRS1915+105 during 24 October - 4 November 2004 (precession phase 0.97-1.0).

6. Discrepancy of X-ray/Radio Flash Episodes

We detected an unusual correlation between radio and high-energy hardness during 24 October-8 November 2004. As shown in Fig.7, during the INTEGRAL observations (MJD=53311) the 0.3-10 keV ASM powers count rate increased from 20 to 150 counts/s on 1.5 days. The derived IBIS/ISGRI 13-250 keV light curve and hardness ratio are shown in Fig.7. From 53311 to 53312.5, while the ASM powers count rate increased, the ISGRI/IBIS high energy hardness decreased from Γ=2.5 to Γ=1.5 before peak. This unusual probably indicated a state transitions (or flash?) as also suggested by the following decrease in the IBIS hard ratio, occured again during next monents. Radio flux has a simultaneous peak with maximum the hard X-ray. Similar transition, with the changes in the ASM light curve and an evolution IBIS/ISGRI hardness ratio, can be understood in a model involving Comptonization (Titarchuk 1994).

8. Conclusions

We report results obtained with INTEGRAL, Rossi-XTE, ASCA, XMM-Newton, Candra and BeppoSAX for microquazar GRS1915+105:

- detected the precession variability of hard X-ray [15-250 keV] with INTEGRAL/IBIS/ISGRI detector;
- we detected correlation between the value of equivalent width K Fe line and the precession phase;
- we detected correlation between the shape of value of PDS and the precession phase;
- detected an unusual correlation between radio data and high-energy hardness;
- the maximum of the precession variability was observed at 23-40 keV based on INTEGRAL, BATSE, Rossi-XTE data.

The future prospects are connected with a hight resolutuin X-ray spectroscopy (XMM-Newton, XEUS) of GRS1915+105.

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