# INTEGRAL OBSERVATIONS OF X-RAY TRANSIENT GS1843+009 DURING 2003–2005 ACTIVITY EVENTS

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## ABSTRACT

We report the detection of a new hard X-ray outbursts of the transient X-ray binary pulsar GS1843+009 with IBIS/ISGRI detector aboard INTEGRAL. The source was detected during November 10–22, 2003; May 1–13, 2004, September 2–11, 2004; October 26–Novenber 2, 2004 with mean flux 12, 10, 7 and 7.2 mCrab respectively in the 20–50 keV energy range at a S/N ratio 7, 7, 5, 6 respectively. These source outbursts were much weaker than the four known ones (1988, 1977, May 2003, 2005). We report here the analysis of INTEGRAL observations at different epochs. The long-term behaviour of the source tends to indicate 180-days periodical outbursts in the high mass X-ray binary system with Be companion. We explain the origin of GS1843+009 X-ray outbursts in terms of the model of colliding winds at the periastron. Physical parameters of the model have been evaluated.

Key words: X-ray; Pulsars; Transients.

## 1. INTRODUCTION

Transient X-ray binary pulsar GS 1843+009 was discovered on 1988 April 3 during plane scan observations by GINGA satellite [12, 13]. The LAC [18] on board GINGA [11] detected this object at a position of $\alpha$=18$^h$45$^m\pm$1$^m$, $\delta$=0°51'47.5". Coherent pulsations with a period P=29.5056 $\pm$ 0.0002 s were discovered in its X-ray flux [7, 8]. The source was detected again during an outburst on 1997 March 3 by Burst and Transient Experiment (BATSE) on board CGRO [19]. A new measurement of the pulse period, P=29.5631$\pm$0.0003 s, allowed the period derivative to be inferred, $\dot{P}$=-(3.65$\pm$0.11)10$^{-8}$ s/s, that could be due to a Doppler effect of orbital motion [6, 15]. Based on spectral and photometric observations Israel et al. [5] reported on the identification of GS 1843+009 optical/IR counterpart as B0-B2IV-Ve spectral type star located at a distance $\geq$ 10 kpc [5].

## 2. OBSERVATIONS AND DATA ANALYSIS

GS 1843+009 was many times in the field of view of the IBIS/ISGRI detector onboard INTEGRAL during the routine Galactic plane scan and pointed observations (2003–2005). I have used the version 5.1 of the Offline Science Analysis (OSA) software distributed by INTEGRAL Science Data Center (ISDC, *http://isdc.unige.ch*) [3]. A total exposure of all public data $\sim$2.2 Gs was accumulated. We built mosaic images for each 10 ScW (Science Window) and extracted the light curve. Typical net exposures for one result light curve point of 20 ks.

## 3. DIAGNOSTIC OF FLARING ACTIVITY WITH INTEGRAL

The reduction of the mosaic image of the source generated for March 2003-November 2004 data yielded an average 20-50 keV flux of 6.4 mCrab at a signal to noise ratio of 7. During this time the source displaed five outbursts with long periods of quiescence, when no X-ray flux was detected (see Fig.1) . First X-ray outburst of this source registered with INTEGRAL was detected during the May 1–11, 2003 observing run at a S/N ratio $\sim$20 in the 18–100 keV energy range [4]. The source was detected again during new outbursts on November 10-22, 2003; May 1–13, 2004; September 2–11, 2004 and October 26–November 2, 2004 by the INTEGRAL with mean flux of 10.2 mCrab in the 20-50 keV energy range at a S/N ratio of 6 (Table 1). These four GS1843+009 outbursts were much weaker than the three previous ones (1988, 1997, May 2003). In particular the flux of the last (2004) outburst measured with INTEGRAL was 2.5 times lower than that measured with INTEGRAL during the May 2003 outburst and 6.5 times lower than that measured in the same 20–50 keV energy range with BATSE/CGRO during the 1997 outburst.

Surprisingly, after $\sim$180 days GS 1843+009 was detected again during the X-ray outburst in April 23–29, 2005 which was brighter than the five previous outbursts recorded with INTEGRAL. The source has been observed during ISWT observations of the Scutum Arm region with INTEGRAL and was first detected on 23

*Table 1. The calendar of GS1843+009 outbursts.*

| Data | Energy range, keV | Mean flux, mCrab |
|---|---|---|
| 3 April 1988 | 2–37[1] | 50 |
| 3-23 March 1997 | 20–50[2] | 37 |
| 1-11 May 2003 | 20–50[3] | 18 |
| 10-22 November 2003 | 20–50[3] | 12 |
| 1-13 May 2004 | 20–50[3] | 10 |
| 2-11 September 2004 | 20–50[3] | 8 |
| 26 October-2 November 2004 | 20–50[3] | 7 |
| 23-29 October 2005 | 20–60[4] | 40 |

[1] – GINGA [13], [2] – BATSE [19]
[3] – INTEGRAL (this work), [4] – INTEGRAL [10]

*Table 2. Best-fit parameters of the GS1843+009 spectrum approximation. ISGRI/IBIS data (15–150 keV).*

| | |
|---|---|
| Power law $dN/dE \sim E^{-\Gamma}$ | |
| Photon index, $\Gamma$ | 2.37±0.08 |
| Flux 15-150 keV, $10^{-10}$ erg/cm$^2$/s | 3.4 |
| $\chi^2$ (d.o.f) | 1.82 (15) |
| Power law with high energy cutoff $dN/dE \sim E^{-\Gamma} exp(-(E-E_{cut})/E_{fold})$ | |
| Photon index,$\Gamma$ | 0.82±0.09 |
| $E_{cut}$, keV | 7.8±0.4 |
| $E_{fold}$, keV | 26±0.9 |
| Flux 15-150 keV, $10^{-10}$ erg/cm$^2$/s | 2.8 |
| $\chi^2$ (d.o.f) | 0.66 (13) |

April 2005 with a 20–60 keV mean flux ∼20 mCrab, S/N=10 [10]. Over the following 5 days, the source appeared to have slowly doubled in brightness, to its current level of 40 mCrab. On October 29, 2005 the corresponding 20–60 keV ISGRI flux was ∼30 mCrab [10]. This suggests possible variability of the amplitude of the outbursts in reccurent transient pulsar GS1843+009.

## 4. ANALYSIS OF THE LIGHT CURVE

An analysis of the 2003–2005 ISGRI/IBIS 20–50 keV data set revealed long term X-ray variability of GS1843+009. INTEGRAL data show the minimal interval between hard X-ray outburst for this peculiar object to be ∼50 days. The long term behavior is indicative of 50 to 180 days recurrence in the GS1843+009 flux changes and allows us to classify this system as HMXBs periodic transient with Type I outbursts [16, 14]. The results of this analysis lead us to suggest that the outburst periodicity of GS1843+009 is due to periodical shortening of the distance between binary components at the periastron in at eccentric orbit.

In order to compare the results of INTEGRAL observations with archived observations of GS 1843+009 we also present in Fig. 1 simultaneous ASM/RXTE 2-12 keV light curve. Peak fluxes can be seen to correlate with RXTE data.

## 5. SPECTRAL ANALYSIS

The spectral analysis was done with NASA/GSFC XSPEC software package. The source shows a very hard spectrum during the outburst of May 1–11, 2003. We build mosaic image by coadding 0067, 0068, 0069, 0070 Orbits (May 1–11, 2003) and extracted the spectrum (Fig. 2). We used two simple models - a power law ($dN/dE \sim E^{-\Gamma}$) and a power law with high energy cutoff ($dN/dE \sim E^{-\Gamma} exp(-(E-E_{cut})/E_{fold})$) to fit the source spectrum. The latter model was successfully used for describing the source spectrum in the wide energy range obtained during GS1843+009 outburst in 1997 [15]. Best-fit parameters (with the allowance for 10% systematic errors) of the source spectrum are presented in Table 2. Figure 2 shows the spectrum together with the best fit model.

## 6. POSSIBLE INTERPRETATION OF THE PULSE-PERIOD CHANGE IN GS1843+009

The monitoring of GS 1843+009 obtained by combining BATSE, RXTE/PCA and BeppoSAX data during March-April 1997 confirmed the presence of a high intrinsic spin up rate [15]. Real change of the pulse period was higher and the Doppler effect [6, 15] may exceeds intrinsic spin up rate. Morover, Piraino et al. [15] assumed that the Be transient system having an orbital period between 50 and 60 days, inferred from the pulse-orbital periods relation of Corbet [2], to estimated the upper limit of pulse period change for circular orbit. In this way we investigate the behaviour of pulse period for ellipical orbit.

The orbital phase ($\varphi$) dependance of change of pulse period $\Delta P$ due to orbital motion has the form:

$$\frac{\Delta P}{P} = \frac{\sin i(1+e\cos\varphi)}{c\sqrt{1-e^2}} \left(\frac{2\pi G}{P_{orb}}(m_s+m_{ns})\right)^{1/3}$$

where $P$ is the pulse period; $i$, orbital plane inclanation to line of sight; $e$, eccentricity of orbit; $c$, the speed of light; $G$, the gravitational constant and $m_{ns}$, $m_s$ are the mass of Be and neutron stars, respectively.

The pulse period approximation for the GS1843+008 outburst between March 3–23, 1997 based on

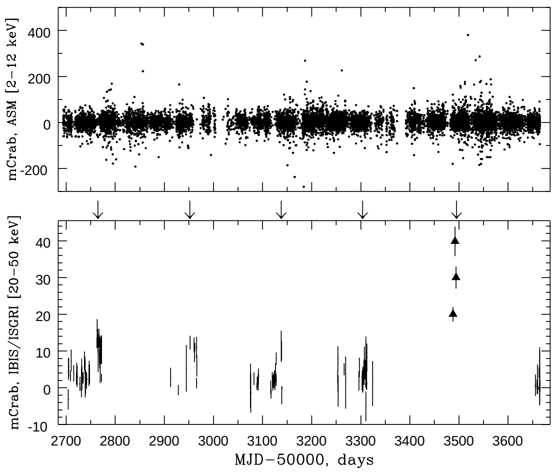


*Figure 1. IBIS/ISGRI light curve data in 20–50 keV energy band during 2003–2005 (filled triangles: data April 23–29, 2005 taken from [10]) observation run (bottom), simultaneous ASM/RXTE data (top) in 2–12 keV energy range. The arrows mark the moments of significant GS 1843+009 outbursts according to Table 1.*

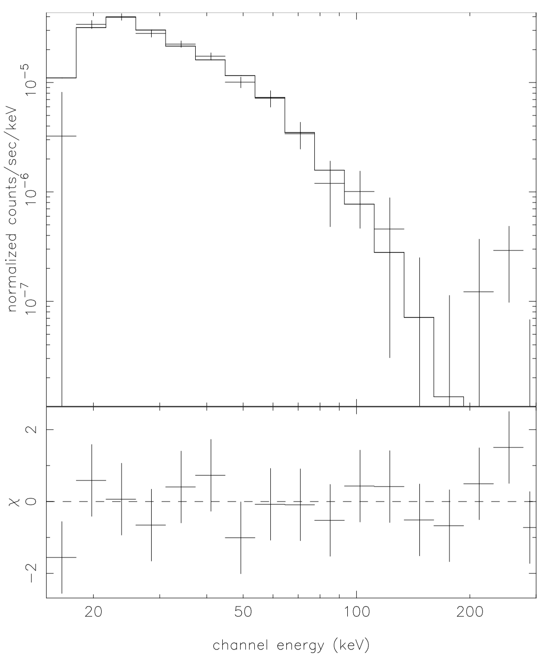


*Figure 2. ISGRI (15-150 keV) spectra of GS1843+009 during 1-11 May 2003 outburst fitted with model power law with high energy cutoff.*

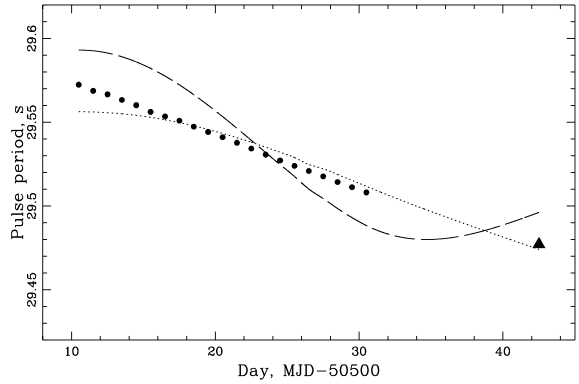


*Figure 3. The pulse period approximation for GS1843+009 outburst between 3-23 March 1997 obtained from BATSE and 4 April 1997 with BeppoSAX (triangle) for two critical orbital periods 50 (stippled line) and 180 (dotted line) days.*

*Table 3. Best-fit parameters of the GS1843+009 pulse period change according to approximation BATSE/CGRO data of March 3–20, 1997.*

| Parameters | |
|---|---|
| Orbital inclination, $i$ | 40° - 70° |
| Orbital eccentricity, $e$ | 0.5 - 0.99 |
| Orbital period, $P_{orb}$ | 180 days |
| Mass of Be star, $M_{Be}$ | 15 $M_{\odot}$ (fixed) |
| Mass of neutron star, $M_{ns}$ | 1.4 $M_{\odot}$ (fixed) |
| Pulse period, $P$ | 29.47 s (fixed) |

BATSE data and April 4, 1997 with BeppoSAX (*http://f64.nsstc.nasa.gov/batse/pulsars/sources*) for two marginal orbital periods (see Fig. 3) give us the reasons to choose orbital periods larger than 60 days. For $P_{orb}$=180 days period, inferred from INTEGRAL data analysis, we have a good agreement with BATSE&BeppoSAX observations for binary parameters listed in Table 3 .

## 7. MODEL ANALYSIS

We study the variation of the X-ray radiation from the shock due to wind-wind collision and interpret the X-ray outburst in GS1843+009. In this model a binary system consists of a Be and neutron star in an eccentric orbit. Be-star has non-relativistic stellar wind with an asymmetrical velocity $u_s = u_0 exp(-(\varphi - \varphi_0)^2/\Delta\epsilon^2)$ and mass loss rate $\dot{M}_s$. It is stopped by the relativistic MHD wind of the pulsar with a Lorentz factor of $\gamma_p$ and spin-down lu-

*Table 4. Best-fit parameters of the GS1843+009 light curve approximation IBIS/ISGRI data May 1–11, 2003.*

| Model parameters | |
|---|---|
| Equatorial Be wind velocity, $u_s$ | (1–2) $10^{8}$ cm/s |
| Mass loss via Be wind, $\dot{M}_s$ | (1–5)$10^{-8}$ $M_\odot$/year |
| Angle width of Be disk, $\Delta\epsilon$ | 20–21° |
| Lorenz factor of pulsar wind, $\gamma_p$ | 10 (fixed) |
| Distance from theEarth, $d$ | 10–15 kpc |

minosity of $L_p$. In the region of wind-wind collision, an extended zone of X-ray forms. This model suggests that the expansion time of the gas heated at the front exceeds the cooling time. The calculation become very simple in this approximation and we can write definite integrals instead of differential equations [9]

$$L = \int_S F(T_{fr}, n) dS.$$

Here $F$ is the radiative flux from the surface boundary element. The element $dS$ is crossed by the stationary flow with particle number density $n$ and shock temperature $T_{fr}$. The shape of the contact surface $S$ between the two winds can be described by the differential equation published by Stevens et al. [17]. Detailed calculation of the X-ray luminosity and X-ray spectrum from the shock due to wind-wind collision was by Cherepashchuk et al. (1995) [1]. We performed detailed calculations of the 20–50 keV light curve of GS1843+009 to compare the theoretical model with the observations. In this model interpretation of the shape X-ray outburst in GS1843+009 well described for a wide of binary parameter values listed in table 4.

## 8. CONCLUSIONS

We report the detection of hard X-ray outburst of GS1843+009 with IBIS/ISGRI detector aboard INTEGRAL during 10-22 November 2003, 1-13 May 2004, 2-11 September 2004 and 27 October-2 November 2004 observation runs. Our analysis showed the source to be detected by IBIS telescope up to energies 100 keV and to exhibit flaring activity. The spectrum of the pulsar in the energy range 15-150 keV can be described either by the simple power law with photon index ∼2.3 or by a power law model with high energy cutoff. We explain the origin of GS1843+009 X-ray in terms of the colliding wind model and reconstruct the light curve of the source. We show that the source 20–50 keV flux is variable and could be caused by a binary orbital motion with the period ∼180 days. The maximum of detected hard X-ray flux (20-50 keV) occurs nearly at the periastron passage. We point out that GS 1843+009 exhibits periodical outbursts with variable amplitude: high flux (∼40 mCrab) outbust alternates with long interval of relatively low (∼10 mCrab) outbursts. This variability of the outburst amplitude possible due to variations of inner binary parameters. In order to cover more complete orbital cycles and to determine the orbital parameters more precisely, new and more extensive observations are required.

## ACKNOWLEDGMENTS

Research has made use of data obtained through the INTEGRAL Science Data Center (ISDC), Versoix, Switzerland. Author is thankful to the group of INTEGRAL Science Data Center for their hospitality and computing resources. This work partially supported by grant of the European Cosmic Agency and by grant of Science Informatical Center ”Basis” of Russian Education Department ”Physics of close binary: The determination of fundamental characteristics of stars and relativistic objects”.

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