INTEGRAL/IBIS observations of a hard X-ray outburst in high mass X-ray binary 4U 2206+54

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ABSTRACT

Aims. 4U 2206+54 is a wind-fed high mass X-ray binary with a main-sequence donor star. The nature of its compact object was recently identified as a slow-pulsation magnetized neutron star.

Methods. INTEGRAL/IBIS observations have a long-term hard X-ray monitoring of 4U 2206+54 and detected a hard X-ray outburst around 15 December 2005 combined with the RXTE/ASM data.

Results. The hard X-ray outburst had a double-flare feature with a duration of \( \sim 2 \) days. The first flare showed a fast rise and long time decaying light curve about 15 hours with a peak luminosity of \( \sim 4 \times 10^{36} \) erg s\(^{-1}\) from 1.5 – 12 keV and a hard spectrum (only significantly seen above 5 keV). The second one had the mean hard X-ray luminosity of \( 1.3 \times 10^{36} \) erg s\(^{-1}\) from 20 – 150 keV with a modulation period at \( \sim 5550 \) s which is the pulse period of the neutron star in 4U 2206+54; its hard X-ray spectrum from 20 – 300 keV can be fitted with a broken power-law model with the photon indexes \( \Gamma_1 \sim 2.3, \Gamma_2 \sim 3.3 \), and the break energy is \( E_b \sim 31 \) keV or a bremsstrahlung model of \( kT \sim 23 \) keV.

Conclusions. We suggest that the hard X-ray flare could be induced by suddenly enhanced accretion dense materials from stellar winds hitting the polar cap region of the neutron star. This hard X-ray outburst may be a link to supergiant fast X-ray transients though 4U 2206+54 has a different type of companion.

Key words. stars: individual (4U 2206+54) — stars: neutron — X-rays: binaries — X-rays: bursts

1. Introduction

Massive X-ray binary 4U 2206+54 was discovered by the Uhuru satellite (Giacconi et al. 1972). The optical counterpart was identified as an O9.5V star with a high He abundance and has a distance of \( \sim 2.6 \) kpc (Blay et al. 2006). Without a circumstellar disk around the donor, the material for accretion and production of high energy emission must come from stellar wind (Negueruela & Reig 2001). The wind terminal velocity of 4U2206+54 has a low value of \( \sim 350 \) km s\(^{-1}\) (Ribo et al. 2006), so assuming an eccentric orbit and using the Bondi-Hoyle formalism wind-fed accretion could produce X-ray luminosity and variability \( (L_x \sim 10^{33} – 10^{36} \) erg s\(^{-1}\)) as seen by RXTE, BepposAX, Swift and INTEGRAL (Torrejon et al. 2004; Masetti et al. 2004; Blay et al. 2005; Corbet et al. 2007; Wang 2009).

X-ray monitoring of 4U 2206+54 by RXTE suggested a modulation period of 9.6 days (Corbet & Peele 2001) which may be an orbit period. Recent SWIFT/BAT observations (Corbet et al. 2007) and RXTE/ASM data (Wang 2009) found a modulation of \( \sim 19.12 \) days consistent with twice the 9.6-day period.

The nature of the compact object in 4U 2206+54 has been in dispute for a long time (Negueruela & Reig 2001; Corbet & Peele 2001). Recent reports on the detection of cyclotron resonant absorption line at \( \sim 30 \) keV and 60 keV suggested a magnetized neutron star with a magnetic field of \( \sim 3.3 \times 10^{12} \) G by INTEGRAL observations (Wang 2009; Blay et al. 2005). The reports of possible 5500 s pulsations in light curves of 4U 2206+54 from RXTE, INTEGRAL and Suzaku observations suggested that it would be a X-ray pulsar (Reig et al. 2009; Wang 2009; Finger et al. 2009).

In this work, we will report a long duration hard X-ray flare in 4U 2206+54 discovered by INTEGRAL/IBIS and RXTE/ASM observations. We first introduce the observations of INTEGRAL/IBIS and RXTE/ASM telescopes in §2. The main features of the hard X-ray flare in 4U 2206+54 are described in §3. The summary and discussions on the possible origins of this hard X-ray flare will be delineated in §4.

2. Observations

2.1. INTEGRAL/IBIS

The hard X-ray source 4U 2206+54 was observed during the INTEGRAL pointed observations of the Cassiopeia region around December 2005. The hard X-ray flare were captured by the low-energy detector (called ISGRI) of the Imager (IBIS, Lebrun et al. 2003) aboard INTEGRAL. The IBIS-ISGRI scientific data analysis was carried out using the Off-line Scientific Analysis (OSA) software version 7.0 (Goldwurm et al. 2003) provided by the INTEGRAL Science Data Center (ISDC). Individual pointings in each satellite revolution (3 days) processed with OSA 7.0 (Goldwurm et al. 2003) aboard INTEGRAL. The IBIS-ISGRI scientific data analysis was carried out using the Off-line Scientific Analysis (OSA) software version 7.0 (Goldwurm et al. 2003) provided by the INTEGRAL Science Data Center (ISDC). Individual pointings in each satellite revolution (3 days) processed with OSA 7.0. We have used the 20 – 40 keV band for source detection and to quote fluxes (Table 1). For Rev 387, 4U 2206+54 has a detection significance level of \( \sim 45\sigma \) with an average IBIS/ISGRI count rate up to \( \sim 11.9 \) cts/s in the energy band of 20 – 40 keV. 4U 2206+54 appeared in the outburst state around Dec 15 2005 in the hard X-ray bands.

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We derived the hard X-ray light curve of 4U 2206+54 in the band of 20 – 40 keV from 2005 Dec 11 to Dec 19 (see Fig. 1). 4U 2206+54 was unfortunately outside the field of view (FOV) of IBIS sometimes, and the data were also screened for solar-flare events and erratic count fluctuations due to passages through the Earth’s radiation belts, so several data gaps appeared in the light curve of 4U 2206+54 (Fig. 1). From the available IBIS data, a strong hard X-ray outburst was still detected around Dec 15 – 16, 2005, which lasted \( \sim 10^4 \) s.

### 2.2. RXTE/ASM

RXTE had no pointed observations on the source 4U 2206+54 during December 2005. Fortunately the source was regularly monitored by the All Sky Monitor (ASM) onboard RXTE. The ASM consists of three Scanning Shadow Cameras (SSCs) mounted on a rotating drive assembly, each camera having a field of view of \( 6^\circ \times 90^\circ \). The assembly "dwells" at a fixed position for \( \sim 90 \) s, followed by a rotation of \( 6^\circ \). Each camera has a position sensitive proportional counter, and the data is analyzed to give not only the total source intensity in the 1.5 – 12 keV band, but also the intensity in each of 3 energy bands: 1.5 – 3 keV, 3 – 5 keV and 5 – 12 keV. The ASM data are available in two forms: count rates from individual 90-s dwells, and one-day averaged count rates from individual 90-s dwells, and one-day average for a source.

From the archival dataset provided by the surveys of the All-Sky Monitor (ASM) on board RXTE, we obtained the dwell-by-dwell light curve (1.5 – 12 keV) of 4U 2206+54 during the hard X-ray outburst (Fig. 1). ASM data filled up the data gap before the hard X-ray burst obtained from the IBIS data. Therefore, the complete observed features of the super-long duration hard X-ray outburst in 4U 2206+54 were derived by using both ASM and IBIS observations.

### 3. Results

The hard X-ray outburst occurred at UT 2005 Dec 15.1085 and lasted over 2 days. This peculiar flare showed a double-flare feature in the light curve. We will present the properties of the first and second flares separately in the following.

#### 3.1. The first flare

The first flare was only captured by the ASM data and had a peak flux of \( \sim 100 \) mCrab and decayed to \( \sim 20 \) mCrab. This flare appeared to have a sharp rise peak and then the flux decayed with a long time of \( \sim 15 \) hours. The peak flux in the energy range of 1.5 – 12 keV is \( (3.3 \pm 0.9) \times 10^{-9} \) erg cm\(^{-2}\) s\(^{-1}\), and a total fluence \( \sim 5.3 \times 10^{-5} \) erg cm\(^{-2}\). For a distance of 2.6 kpc (Blay et al. 2006), the peak luminosity at the first flare reached \( 3.6 \times 10^{36} \) erg s\(^{-1}\), and total energy release during the first flare is \( \sim 6 \times 10^{40} \) ergs in the energy range of 1.5 – 12 keV. The hardness ratio analysis from ASM data implied a hard spectrum in the first flare: this X-ray flare cannot be significantly detected below 5 keV (Fig. 2).

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1. [http://xte.mit.edu/asmlc/ASM.html](http://xte.mit.edu/asmlc/ASM.html)
Table 1. INTEGRAL/IBIS observations of the field around 4U 2206+54 from 2005 Dec to 2006 Jan. The time intervals of observations in the revolution number and the corresponding dates, the corrected on-source exposure time are listed. Mean count rate and the detection significance level value in the energy range of 20 – 40 keV were also shown.

| Rev. Num. | Date          | On-source time (ks) | Mean count rate s$^{-1}$ | Detection level |
|----------|---------------|---------------------|--------------------------|-----------------|
| 384      | 2005 Dec 05 – 07 | 118                | 2.86 ± 0.24              | 15σ             |
| 385      | 2005 Dec 08 – 10 | 132                | 2.01 ± 0.20              | 11σ             |
| 386      | 2005 Dec 11 – 13 | 121                | 1.66 ± 0.19              | 10σ             |
| 387      | 2005 Dec 14 – 16 | 98                 | 11.9 ± 0.25              | 45σ             |
| 388      | 2005 Dec 17 – 19 | 103                | 2.38 ± 0.21              | 14σ             |
| 389      | 2005 Dec 20 – 22 | 110                | 1.38 ± 0.30              | 6σ              |
| 390      | 2005 Dec 23 – 25 | 102                | 0.66 ± 0.25              | 4.9σ            |
| 391      | 2005 Dec 26 – 28 | 113                | 1.78 ± 0.21              | 9σ              |
| 392      | 2005 Dec 29 – 31 | 110                | 2.58 ± 0.22              | 14σ             |
| 393      | 2006 Jan 01 – 03 | 118                | 0.77 ± 0.21              | 5.5σ            |
| 394      | 2006 Jan 04 – 06 | 115                | 1.68 ± 0.20              | 10σ             |
| 395      | 2006 Jan 07 – 09 | 124                | 1.61 ± 0.21              | 9σ              |

Fig. 2. The ASM lightcurves of the X-ray binary 4U 2206+54 in two energy bands: 1.5–5 keV; 5 – 12 keV. The X-ray flare cannot be significantly detected below 5 keV.

4. Summary and discussion

In this paper we reported the INTEGRAL/IBIS and RXTE/ASM observations of a 2-day long-duration hard X-ray outburst in 4U 2206+54 which harbors a highly magnetized neutron star (Wang 2009). This outburst is peculiar in the following ways: (1) a double-flare feature: the second flare occurred about 15 hours after the first one; the first flare had a temporal profile of fast rise and exponential like decay, the second one had a modulation period of 5550 s which is the pulsation period of the neutron star; (2) the flare had a hard spectrum: the first flare was only seen above 5 keV from RXTE/ASM data; for the second flare, the 18 – 250 keV spectrum was fitted by a thermal bremsstrahlung model with $kT \sim 23.4$ keV or a broken power-law model with the photon indexes $\Gamma_1 \sim 2.3$, $\Gamma_2 \sim 3.3$, and break energy $E_b \sim 31$ keV. No cyclotron absorption line during the outburst was detected. The long-duration flare has a mean X-ray luminosity of $\sim 1.3 \times 10^{36}$ erg s$^{-1}$ and a total released energy higher than $10^{41}$ ergs in the range of 20 – 100 keV.

The sudden strong X-ray flares have been detected in some other high mass X-ray binaries (e.g., GX 301-2, see Haberl 1991, Leahy 1991, Koh et al. 1997; XTE J0052-723 Laycock et al 2003). In these systems, the X-ray flares occur always before periastron passages of the neutron star.

Fig. 3. Top The light curve of the second flare of the hard X-ray outburst by INTEGRAL/IBIS. Bottom The power spectrum of the INTEGRAL/IBIS light curve of 4U 2206+54 during the second flare. A significant period at 5550 ± 50 s is detected in the light curve.

Fig. 4. The IBIS/ISGRI background subtracted light curve (20 – 40 keV) of 4U 2206+54 during the second flare folded at a pulsation period (5550 s). The pulse profile is repeated once for clarity.
Therefore, the flares show the recurrence of orbital periodicity, and have the following characteristics: (1) duration of \(\sim 0.1\) orbital phase, roughly several days (Leahy 2002; Laycock et al. 2003); (2) strong photoelectric absorption, which makes the flares events absent at low energies (< 5 keV, see Leahy 2002); (3) the spectrum can be described by a cut-off power-law model (Laycock et al. 2003). Recently, the X-ray outburst of a Be/X-ray pulsars A 0535+26 was detected with a double-feature (Caballero et al. 2010). This outburst also showed the orbital modulations with a duration of more than ten days (orbital period \(\sim 111\) days, Finger et al. 2006). In addition the cyclotron absorption features were detected during the outburst, suggesting that the transient circumstellar-disk accretion near the neutron power the outburst of A 0535+26 (Caballero et al. 2010).

Since these X-ray flares occurred with orbital periodicity, we can check this possible modulation in X-ray light curve of 4U 2206+54. If we assume the detected X-ray flare occur around the periastron passage of the neutron star, then the X-ray flares would be recurrent with the recurrence time of \(\sim 19\) day. In Table 1, we presented the hard X-ray light curves (20–40 keV) of 4U 2206+54 observed by IBIS-ISGRI covering two orbital periods, but only one flare was detected and no orbital modulation was found. Then the X-ray flare in 4U 2206+54 was different from the outbursts near the periastrons in other sources because the detected hard X-ray flare would not be repeated just due to orbital modulation. Thus the hard X-ray flare in 4U 2206+54 may have other origins.

Recently, some soft gamma-ray time-structured burst durations of several hours to about 1 day have been detected by INTEGRAL/IBIS observations in some supergiant high mass X-ray binaries which were called supergiant fast X-ray transients (SFXTs, see Sidoli et al. 2005; Negueruela et al. 2006; Sguera et al. 2007, 2008). The SFXTs also belong to the wind-fed systems. The physical origin of the fast outbursts displayed in SFXTs is still unknown. It was suggested that the presence of dense clumps in the wind of OB supergiant companions produces the accretion outbursts in SFXTs (in't Zand 2005; Walter & Zurita Heras 2007). It is believed that SFXTs should contain sporadically accreting neutron stars, and they would be similar to the system of 4U 2206+54. Some of SFXTs have been found to contain a neutron star with pulsation pe-}

**Fig. 5.** The average spectrum of 4U 2206+54 from the INTEGRAL/IBIS observations during the second flare of the X-ray burst. The spectrum was fitted by a thermal bremsstrahlung model with \(kT \sim 23.2\) keV.

**References**

Bird, A.J. et al. 2009, MNRAS, 393, L11

Blay, P. et al., 2005, A&A, 438, 963

Blay, P. et al., 2006, A&A, 466, 1095

Caballero, I. et al. 2010, arXiv:1003.2969

Corbet, R.H.D. & Peele, A.G., 2001, ApJ, 562, 936

Corbet, R.H.D., Markwardt, C.B. & Taylor, J., 2007, ApJ, 655, 458

Finger, M.H. et al. 2006, BAAS, 38, 339

Finger, M.H. et al. 2009, arXiv:0908.3042

Giachon, R., et al., 1972, ApJ, 178, 281

Goldwurm, A. et al., 2003, A&A, 411, L223 490, 491

Haberl, F. 1991, ApJ, 376, 245

In’t Zand, J.J.M. 2005, A&A, 441, L1

Jain, C., Paul, B. & Dutta, A. et al. 2009, MNRAS, 397, L11

Karasev, D.I., Tsygankov, S.S. & Lutovinov, A.A. 2008, MNRAS, 386, L10

Koh, D.T. et al. 1997, ApJ, 479, 933

Laycock, S. et al. MNRAS, 339, 345

Leahy, D.A. 1991, MNRAS, 250, 310

Leahy, D.A. 2002, A&A, 391, 219

Lebrun, F. et al., 2003, A&A, 411, L141

Massetti, N. et al., 2004, A&A, 431, 313

Negueruela, I. & Reig, P., 2001, A&A, 371, 1056

Negueruela, I. et al., 2006, ESA SP-604, 165

Prinja, R.K., Massa, D. & Searle, S.C. 2005, A&A, 430, L41

Reig, P. et al., 2009, A&A, 494, 1070

Ribó, M. et al., 2006, A&A, 449, 687

Sguera, V. et al., 2006, ApJ, 646, 452

Sguera, V. et al., 2007, A&A, 467, 249

Sguera, V. et al., 2008, A&A, 487, 619

Sidoli, L. et al. 2005, A&A, 429, L47

Torrejón, J.M. et al., 2004, A&A, 423, 301

Walter, R. & Zurita Heras, J.A. 2007, A&A, 476, 335

Wang, W. 2009, MNRAS, 398, 1428

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