Outburst of LS V+44 17 observed by MAXI and RXTE discovery of dip structure in pulse profile

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Abstract. We report the discovery of a dip structure in the pulse profile of Be/X-ray binary LS V +44 17 observed by RXTE during an outburst detected by MAXI. The outburst was first transient activity of LS V +44 17 since 1997 when the source was identified as a Be/X-ray binary. After the discovery with MAXI, the RXTE observations provided a pulse profile with a narrow dip structure in the soft X-ray band (3–10 keV). Our pulse-phase-resolved spectroscopy showed that the absorption column density at the dip phase is much higher than those at the other intervals. Thus we can conclude that the partial eclipse of the emission region by the accretion column of the neutron star causes the dip structure in the pulse profile of LS V +44 17 during the first outburst.

1. Introduction

The accreting pulsar LS V +44 17/RX J0440.9+4431 is one of Be/X-ray binaries consisting of a neutron star (a pulsar) and a Be companion star. Be/X-ray binaries typically show periodic and/or non-periodic outbursts which are thought due to a mass accretion from the companion star to the neutron star through the circumsteller disk of the Be star. LS V +44 17 was discovered during the ROSAT all-sky survey [1]. Reig and Roche [2] performed the RXTE observation and obtained the sinusoidal pulse profile with 202.5 ± 0.5 sec period. They classified LS V +44 17 into one of persistent Be/X-ray binaries which show no outburst and stay in low luminosity (≤10³⁴–³⁵ergs s⁻¹).

Monitor of All-sky X-ray Image (MAXI) [3] is a highly sensitive all-sky monitor mounted on the Exposed Facility of the Japanese Experimental Module ”Kibo” of the International Space Station. MAXI has two X-ray cameras, GSC (Gas Slit Camera) and SSC (Solid-state Slit Camera) and is monitoring the flux of more than two hundred sources. Fig. 1 shows the 2–20 keV light curve of LS V +44 17 obtained with GSC from 2009 August 15 to 2010 December 30. On 2010 March 31, MAXI detected an outburst of LS V +44 17 and reported it as the first transient activity for the source [4]. The X-ray flux has increased for a week and finally reached ~150 mCrab in the 2–20 keV band.

Following the detection with MAXI, RXTE confirmed the outburst on 2010 April 6 (see [5]) and carried out further observations on April 12 and 15 (the epochs of these observations, Obs.A, B and C, are shown in the small panel of Figure 1). We analyzed the RXTE data in the 2–60
keV band with Proportional Counter Array (PCA) and 15–250 keV with High-Energy X-ray Timing Experiment (HEXTE).

2. Analysis and Results

2.1. Timing Analysis

We estimated pulse periods from the RXTE/PCA light curves after applying the barycentric correction. Performing the epoch folding search, we obtained $\sim 205$ sec pulse periods of LS V +44 17 during the outburst. Considering a statistical error (almost several seconds) and a long-term spin period change, the estimated period is consistent with the past RXTE result. Folding the light curve with this period, we obtained energy-resolved pulse profile of the PCA observation as shown in Figure 2. Phase 0.0 was chosen at the minimum in the 3-20 keV PCA pulse profile for each observation. Notable point is that a narrow dip structure can be seen at phase 0.7 in Figure 2. The dip appeared only in the soft energy bands (3–6 and 6–10 keV), but not in the hard band (10–20 keV). Similar structure was reported for two Be/X-ray binaries (A0535+26 and RX J0812.4–3114) and can originate from a local absorption with higher density matter, such as an accretion stream on the neutron star.

2.2. Pulse-phase-average Spectroscopy

We carried out pulse-phase-averaged spectroscopy for the three RXTE observations. We used a power-law model with an exponential cut-off plus a blackbody and a Gaussian function corresponding to an Fe emission line (the width of this component is fixed to be 0.1 keV). The best fitting values are shown in Table 1, where the errors correspond to $1\sigma$.

Figure 1. MAXI/GSC light curve of LS V +44 17. The count rate corresponding to the flux of Crab pulsar is 2.5 count cm$^{-2}$ s$^{-1}$.

Figure 2. Pulse profiles of LS V +44 17 in the 3–6 and 6–10 keV bands in Obs.A (top and middle panel) and result of the phase-resolved spectroscopy (bottom panel). The unit of absorption column density $N_H$ is 10$^{22}$ cm$^{-2}$. 
Table 1. Pulse phase-averaged spectral fits results.

| Parameters                           | value       |
|--------------------------------------|-------------|
| \(N_H\) \(\times 10^{22}\) cm\(^{-2}\) | 3.3 ± 0.3   |
| \(\alpha\)                           | 1.15 ± 0.04 |
| cut-off energy \(E_{\text{fold}}\) (keV) | 26 ± 1      |
| blackbody temperature \(kT\) (keV)   | 2.17\(^{+0.06}_{-0.05}\) |
| Gaussian peak energy \(E_{\text{Fe}}\) (keV) | 6.44\(^{+0.10}_{-0.09}\) |
| Reduced chi-square / degree of freedom | 1.10/116    |

2.3. Pulse-phase-resolved Spectroscopy

To investigate a phase dependence of the absorption column density we performed pulse-phase-resolved spectral analysis for Obs.A. We used the same spectral model of the phase-average spectrum, where the photon index, the cut-off energy, the blackbody temperature and the peak energy of an iron line were fixed to the values obtained with the pulse-phase-averaged analysis. The ratio between the power-law and blackbody normalization was also fixed the phase-averaged value. Figure 2 shows the phase dependence of the absorption column density and the highest absorption density at the dip phase (phase \(\sim 0.7\)) is clearly seen. Further, we present a ratio between the phase-average and dip-phase spectra as Figure 3.

3. Discussion

According to Figure 2, the pulse profile obtained during Obs.A had the dip structure. Similar sharp dips have been seen in the pulse profiles of the some Be/X-ray binaries (e.g. A 0535+262 and RX J0812.4–3114). The origin of the dip has been considered as an accretion flow eclipses [6] [7]. In this picture the X-ray emission originating from the surface of the neutron star is reprocessed by the accretion flow when it passes through the line of sight as the stars revolve around each other. Čemeljić and Bulik [6] modeled the emission from a neutron star considering the accretion flow eclipse and reconstructed the pulse profiles of A0535+262. Galloway et al. [7] showed through pulse-phase-resolved spectroscopy that had the absorption column density took maxima at dip phases of GX 1+4 and RX J0812.4–3114 . They argued that the results confirmed the dip origin which was the partial eclipse by the accretion column. Our result
shows that the accretion column density is the highest at the dip phase and affects the dip-phase spectrum (Figure 2, 3). This result may be consistent with the model proposed for the three binary systems, indicating that the accretion column eclipse affects the pulse profile of LS V +44 17 and generates the dip structure. In figure 3, the residuals remaining below 5 keV can propose another low-temperature component. This component may be emitted from the accretion disk or the accretion column. We will report the analysis for the dip-phase spectrum in our PASJ paper soon.

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