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Probing accretion flow structure of the HMXB Centaurus X-3 through X-ray spectral variability

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Abstract. We analyzed 39 ks NuSTAR data of Cen X-3 through both orbital- and pulse-phase resolved spectroscopy. Orbital-phase resolved spectra show extrinsic fluctuations due to absorption by surrounding plasma, as the spectral fluctuation mainly emerges below 10 keV. Pulse-phase resolved spectra, on the other hand, show intrinsic fluctuations depending on effectiveness of Comptonization, since the spectrum becomes hard above 10 keV at the pulse peak.

Keywords. accretion, accretion disks, stars: neutron, X-rays: individual (Cen X-3)

1. Introduction

High mass X-ray binaries (HMXBs) accompanied by a strongly magnetized neutron star (NS) with $B \sim 10^{12}$ G provide us with ideal and unique laboratories to investigate physical conditions under such strong magnetic fields. They are considered to form the "accretion columns" on their magnetic poles (Becker & Wolff 2005, 2007), because the strong magnetic fields prevent accretion flows from directly falling onto the neutron star. The X-ray spectra of these systems are consequences of Comptonization by optically thick plasma inside the accretion columns, usually providing energy for seed photons from neutron star surface.

The X-ray spectra of HMXBs are generally expressed by phenomenological models, far from interpretation based on physical processes. One of the difficulties is their time variability. Many of observed HMXBs exhibit fluctuations of spectral shape and flux depending on their orbital phase and spin phase. The spectral fluctuations are due to various factors such as changes of accretion rates, pulsar rotation, and absorption by surrounding photo-ionized plasma. In order to estimate contribution of each factor, one needs to investigate highly time-resolved observation data.

Cen X-3 is one of the most luminous NS HMXBs in our galaxy with an orbital period of 2.1 days and spin period of 4.8 s. It is one of the best targets to study physical processes around the accretion column because of its high luminosity of $\sim 5.0 \times 10^{37}$ erg s^{-1} (Suchy *et al.* 2008) and strong magnetic field of $\sim 3 \times 10^{12}$ G (Santangelo *et al.* 1998). In

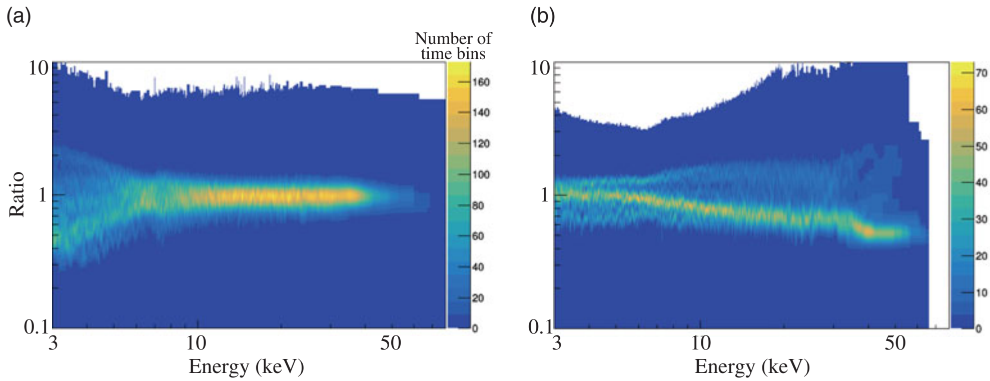

Figure 1. Collections of ratio spectra for (a) orbital-phase resolved spectra and (b) spin-phase resolved spectra. The color bars denote the number of time bins at each grid.

this work, we present detailed time-resolved spectral analysis for X-ray observation data of Cen X-3.

2. Observation and Methods

We analyzed 39 ks *NuSTAR* data observed in 2015 November, which provide us with wide coverage of energy band (3–78 keV) and good timing resolution (2 μs). The observation data cover orbital phase of $\phi = 0.20$–0.41. In order to study both orbital- and spin-phase variability, the whole observation data were divided into small pieces with respect to both orbital and spin phase. We first divided the whole observation data into 78 bins for orbital-phase resolved analysis with each bin covering every 500 s. At the same time, we generated 20 sets of observation data for spin-phase resolved analysis with each bin covering 0.05 phase of the spin period. The X-ray spectrum generated from each interval is compared to the average spectrum by "count ratio spectrum" $R(E)$, which is defined by

$$R(E) = \frac{C_1(E)A_{\text{ave}}(E)}{C_{\text{ave}}(E)A_1(E)}, \tag{2.1}$$

where $C_1(E)$, $C_{\text{ave}}(E)$, and $A(E)$ denote the count spectrum of specific time bin, the average count spectrum, and the effective area, respectively.

3. Results

Figure 1 shows 2-dimensional profiles of ratio spectra both for orbital- and spin-phase resolved spectroscopy. They show how each spectrum changes compared to the average. When there is no fluctuation, all of the data should be plotted on $y = 1$. The results extracted from all of the time bins are plotted together. The spectral fluctuations along with the orbital phase (Figure 1a) are mainly originated from low energy photons below ~ 10 keV, which suggests that the absorption by surrounding plasma is responsible for the fluctuations. The spin-phase fluctuations (Figure 1b) shows rather different properties, in which high energy photons above ~ 10 keV fluctuate a lot. We also confirmed that spectra above 10 keV get harder at the pulse peak and softer at the pulse minimum. These results could be due to differences of effectiveness of Comptonization, as we observe different angles of the accretion column at different spin phase. Thus, we can conclude that the orbital- and spin-phase fluctuations are originated from totally different factors; the former is due to extrinsic factors outside the neutron star while the latter is due to intrinsic factors close to the neutron star.

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References

Becker, P. A., & Wolff, M. T. 2005, *ApJL*, 621, L45
Becker, P. A., & Wolff, M. T. 2007, *ApJ*, 654, 435
Santangelo, A., del Sordo, S., Segreto, A., *et al.* 1998, A&A, 340, L55
Suchy, S., Pottschmidt, K., Wilms, J., *et al.* 2008, *ApJ*, 675, 1487

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