Quiescent State Spectra of Neutron Star X-ray Binaries

Osamu Nagae[1], Hiromitsu Takahashi[1], Yasushi Fukazawa[1],
Tsunefumi Mizuno[1]

[1] Department of Physical Science, School of Science, Hiroshima University,
1-3-1 Kagamiyama, Higashi-hiroshima, Hiroshima 739-8526
E-mail(ON): nagae@hep01.hepl.hiroshima-u.ac.jp

Abstract

Spectra and accretion picture of X-ray binaries in quiescent state (QS) have not been understood well. Thus, we performed detailed spectral analyzes of neutron star X-ray binaries (NS-XRBs), 4U 1700+24 and IGR J16194-2810 in their quiescence. The continuum spectra of both objects can be represented by two Comptonized radiations.

Key words: quiescent state — stars:binaries: close — X-ray: binaries

1. Introduction

X-ray spectra of NS XRB exhibit several spectral states which depend on their luminosity. When their luminosities are 10^{-2}–10^{-3} $L_{\rm Edd}$ and below 10^{-4} $L_{\rm Edd}$ where $L_{\rm Edd}$ is Eddington luminosity, they are classified as low/hard state (LHS) and QS, respectively. Although their accretion pictures have been understood well above 10^{-3} $L_{\rm Edd}$, that of the QS has not been understood. The purpose of this work is to learn the spectra and accretion picture of QS.

Here we focus on 4U 1700+24 and IGR J16194-2810. These two objects are NS-XRBs containing M-type giant star. The X-ray luminosity normalized by $L_{\rm Edd}$ of 4U 1700+24 is 10^{-4}–10^{-6} $L_{\rm Edd}$ and that of IGR J16194-2810 is 10−3 $L_{\rm Edd}$, respectively. In this paper, we present spectral analyzes of Suzaku datasets of 4U 1700+24 and IGR J16194-2810 and XMM-Newton archive data of 4U 1700+24.

2. Observation

2.1. Suzaku observation

We observed 4U 1700+24 and IGR J16194-2810 with Suzaku on 2007 August 22 and 2009 February 5, respectively. The data were acquired with the X-ray Imaging Spectrometer (XIS) and the Hard X-ray Detector (HXD). For the data analyzes of both objects, we used cleaned events of the XIS and the PIN distributed by Suzaku team. The non X-ray background (NXB) event ("LCFITDT" version "2.0pre0804"; Fukazawa et al. 2009) of the PIN datasets are distributed by HXD team. In addition to the NXB, we have to consider the contribution of the cosmic X-ray background (CXB). The CXB was estimated with PIN response for point source observed at the HXD nominal position as $8.0 \times 10^{-4} \times (E/1\ {\rm keV})^{-1.29} \times \exp(-E/40\ {\rm keV})$ photons/cm^2/s/deg^2/keV, where E is photon energy.

2.2. XMM-Newton observation

There are four archival data of 4U 1700+24 observed on 2002 August 11, 2003 March 7,9, and August 13. We analyze three datasets (Newton A, Newton B, and Newton C, in the ascending order of the observational dates.) without 2003 March 7 dataset. The datasets of the MOS are affected by heavy pile-up, and we use PN and RGS datasets. In this paper, we show analysis results of PN only (Nagae et al. 2009 shows also RGS analysis results).

3. Results

We analyze the time averaged spectrum over each observation to examine spectral variability over the three orders of luminosity. For 4U 1700+24, we fix the interstellar absorption to be $N_{\rm H} = 4 \times 10^{20}$ cm^{-2} (Dickey & Lockman 1990). On the other hand, the value of N_H of IGR J16194-2810 is free in our analyzes.

At first we start the analyzes using a black body (BB) which is thought to be arisen from the NS surface. The BB is unacceptable due to large hard and soft residuals for both objects (See both second panels of Figure 1). The LHS spectra above ∼ 1 keV of NS-XRBs are represented by a Comptonized BB radiation fixed with the comptonizing electron temperature, ∼ 100 keV (e.g., Barret et al. 2000). Thus, we try to represent the spectra above ∼ 1 keV using the CompPS model (Poutanen & Svensson 1996). Hereafter, this model is denoted as CompPS-BB. The third panels of Figure 1 show the residuals with respect to the CompPS-BB. For below ∼ 1 keV, we test several spectral models, thermal bremsstrahlung, disk black body (DBB), BB, CompPS-BB, and Comptonized DBB to provide physical expla-

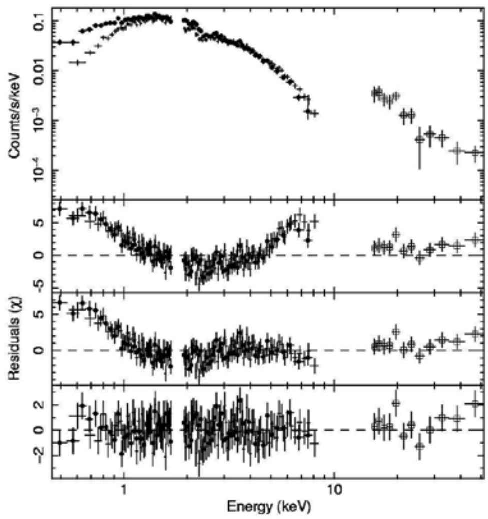

Fig. 1. Top panel shows the spectrum of 4U 1700+24 observed with Suzaku. The PIN spectrum is not subtracted the CXB. The other panels second to bottom show the residuals with respect to the BB, CompPS-BB, and CompPS-DBB + CompPS-BB.

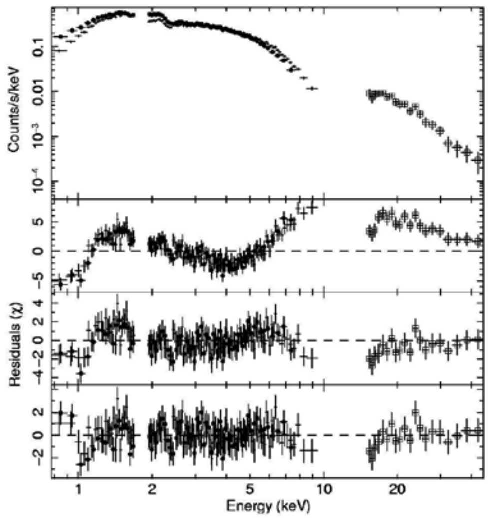

Fig. 2. IGR J16194-2810 spectrum observed with Suzaku and the residuals with respect to the each models in the same manner of Figure 1. Although the third panel indicates the CompPS-BB is marginally acceptable, there is wavy residuals are remained.

nation. We also use the CompPS model for the Comptonized DBB (hereafter CompPS-DBB) with fixing electron temperature 100 keV. We find that the spectra can be represented by PL, CompPS-BB, or CompPS-DBB (bottom panels of Figure 1). The candidates of the PL type emission are thought to be the Synchrotron radiation, the SSC. From our spectral fitting, however, we cannot constrain which model is plausible. We discuss the radiation mechanism of the continuum spectra below ~ 1 keV in §4.

4. Discussion

We first exam whether the Synchrotron radiation. When we assume the typical magnetic field around NS, $B = 10^8$ Gauss and the electron temperature, 100 keV, the calculated energy of the Synchrotron photon is ~ 2 eV which is much lower than ~ 1 keV. Second, we calculated the Inverse Comptonized photon energy by SSC. Assuming the Comptonizing electron temperature is also 100 keV, the Comptonized photon energy is estimated only $\sim 2\ E_{\rm sync}$ where $E_{\rm sync}$ is the energy of the radiated seed photon. In the case of these candidates, the MeV order electron energy is needed. Therefore, the PL modeling (the Synchrotron and the SSC) is not plausible origin of below 1 keV spectra. Third, we discuss the CompPS-BB model, where the seed photon BB is assumed to be arisen from the cooler region of the NS surface. The obtained temperature of the seed photon is $T_{\rm BB} \sim 0.05$ keV (See Nagae et al. 2009 in detail), which is much lower than those observed in isolated NSs (~ 0.3 keV; e.g., Wijnands et al. 2003). Since the temperature of the NS surface increases through the mass accretion onto the NS, the CompPS-BB modeling is again unlikely origin. Finally, we discuss the CompPS-DBB. For the DBB, the inner disk temperature, $T_{\rm DBB}$ is proportional to $L_{\rm disk}^{1/4}$ where $L_{\rm disk}$ is accretion disk luminosity. Generally, $T_{\rm DBB}$ is about 1 keV when the NS-XRBs luminosities are close to $\sim L_{\rm Edd}$ so that $T_{\rm DBB}$ of both objects (10^{-3}–$10^{-6}\ L_{\rm Edd}$) is expected to be ~ 0.1 keV order or less, which is consistent with the obtained $T_{\rm DBB}$ of both objects (See Table 1).

References

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Wijnands et al. 2003 ApJ., 618, 883

Table 1. Best fit parameters of continuum spectra of both objects.

Object	$T_{\rm BB}$ / $T_{\rm DBB}$	${\rm Norm_{BB}}$ / ${\rm Norm_{DBB}}$	$\tau_{\rm BB}$ / $\tau_{\rm DBB}$	χ^2 / dof
IGR	1.03 ± 0.01	3.46 ± 0.35	0.61 ± 0.05	195
J16194	< 0.12	$> 1.0\times10^4$	< 0.34	210
4U 1700	1.10 ± 0.01	$45.2\ ^{+1.1}_{-0.5}$	2.02 ± 0.02	1633
Newton A	0.09 ± 0.01	$2.06^{+0.08}_{-0.15}\times10^4$	$0.83\ ^{+0.02}_{-0.01}$	1298
4U 1700	$1.05\ ^{+0.03}_{-0.04}$	$8.53\ ^{+1.17}_{-1.21}$ 0.07	$1.17\ ^{+0.09}_{-0.11}$	538
Newton B	$0.09^{+0.02}_{-0.01}$	$0.50^{+0.40}_{-0.24}\ \times10^4$	$1.10^{+0.18}_{-0.14}$	517
4U 1700	$1.03^{+0.01}_{-0.02}$	$12.2^{+1.0}_{-0.4}$	$1.40^{+0.04}_{-0.04}$	1024
Newton C	0.09 ± 0.01	$0.88^{+0.03}_{-0.04}\times10^4$	$0.79^{+0.02}_{-0.01}$	930
4U 1700	0.76 ± 0.01	1.16 ± 0.10	0.33 ± 0.05	180
Suzaku	< 0.05	$> 2.40\times10^4$	< 0.35	190