Hard X-ray study of low mass X-ray binary Sco X-1 with Suzaku

Chiho Okada[1], Hiromitsu Takahashi[1], Tatsuya Nakaoka[1], Takao Kitaguchi[1], Yasushi Fukazawa[1], Tadayasu Dotani[2], Yoshitomo Maeda[2], Satoru Katsuda[2], Hideyuki Mori[3], Murakami Hiroshi[4]

[1] Hiroshima University
[2]ISAS
[3]UMBC
[4]Tohoku Gakuin University
E-mail (CO): okada@astro.hiroshima-u.ac.jp

ABSTRACT

Low-mass X-ray binaries with neutron stars, whose luminosity are close to the Eddington limit (10^{38} erg/s), are called as Z sources. It is known that Z sources transit among three states (branches) on their color-color diagrams (CCD); Horizontal branch (HB), Normal branch (NB), and Flaring branch (FB). Apart from the thermal emission, the hard X-ray tail above 50 keV from Sco X-1 has been reported by RXTE and INTEGRAL satellites. However, detection of the hard emission relies on the time variability and instrument calibration uncertainties, and thus the characteristics of the hard tail are not understood well. We think that clarifying this phenomenon leads to understanding a physical picture around the neutron star and their neighboring accretion disk. Since Sco X-1 is the most brightest object in the X-ray band, it is suitable to examine time variation of the hard tail with three state transitions. Therefore, we performed an observation of Sco X-1 by Suzaku on March 9-12, 2015. We detected that Sco X-1 transited among three states (HB, NB, FB) of Z sources during the observation by making the CCD of XIS and HXD-PIN data. We also found that inverse Compton scattering of black-body seed photons from the neutron star surface can reproduce the observed spectrum only less than 35 keV. The hard tail was needed to exist above 50 keV with the flux of ~ 4×10^{-10} erg/cm2/s in 20-200 keV at average.

KEY WORDS: X-ray binaries

1. Introduction

From Sco X-1, emission of hard X-ray tail above 50 keV has been reported by RXTE, INTEGRAL satellites. Many of these results show that the hard X-ray flux has decreasing trend from HB, NB to FB (e.g., [1]). There is also a report that some RXTE observations of Sco X-1 showed the state of top FB, which has the very hard component of the power-law index of ~1.4 [2].

Therefore, we analyzed Suzaku data of Sco X-1, and investigated the relationship between state transition and hard tail.

2. Observation and Result

Reproducibility of the PIN background model is not good in 2015, because the background observation was limited due to the electricity shortage of Suzaku. Therefore, we corrected the background model carefully to reproduce earth-occultation data within 1% level, using GK Per (previous observation) and Sco X-1. Then, the systematic uncertainty of the background is added in the following analysis, PIN : 3~4 % in 35-70 keV and GSO : 1% in 50~500 keV.

2.1. Spectral fitting of average spectrum

We first fit the average spectrum of HXD (PIN+GSO) data. The net exposure time is 30 ks and the systematic error of 0.3% is added for fitting models.

The result shows the high energy region above 35 keV cannot be reproduced by only the single inverse Compton emission (compTT model) with $\chi2$/d.o.f = 87.1/65, and requires the additional power-law component ($\chi2$/d.o.f = 65.52/63). The null hypothesis not to exist the power-law emission is 0.01% by F test. Figure 1 and Table 1 show the fitting results of compTT+power-law model.

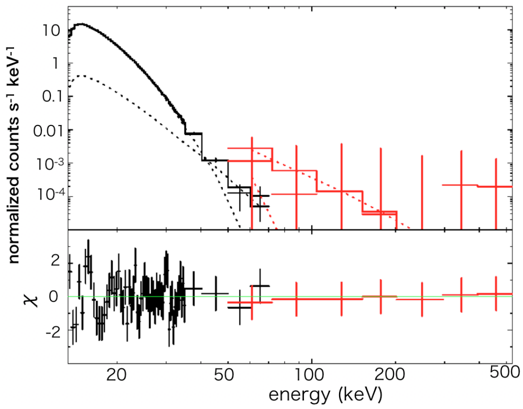

Figure 1. fitting with compTT + power-law model

compTT	Temperature (keV) (Seed photon)	$1.7^{+0.2}_{-0.1}$
	Temperature (keV) (Scattering electron)	$3.0^{+0.2}_{-0.2}$
	Optical depth	$3.9^{+0.7}_{-0.5}$
	Flux (10^{-9} ergs/cm^2/s)	10^{+1}_{-3}
power-law	Photon Index Γ	4^{+1}_{-2}
	Flux (20-200 keV) (10^{-10} ergs/cm^2/s)	4^{+4}_{-2}

Table 1. best fit parameters with 90% errors

2.2. Time variability

We plot the light curve and CCD of Suzaku data with 128-s binning for three energy ranges of 0-2, 4-8, and 15-20 keV, to examine the time variability of the hard tail (Figure 2 and 3). This shows that Sco X-1 was highly variable during Suzaku observation. In 15-20 keV, the average rate is ~30 counts/s, but it reaches ~80 counts/s at the maximum. CCD shows the three states of HB, NB and FB in "ν" shape.

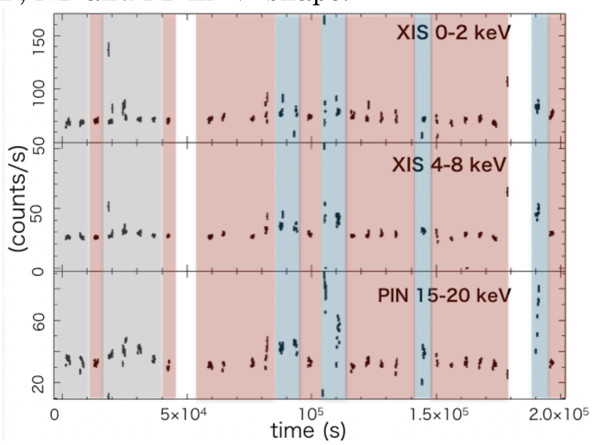

Figure 2. light curve

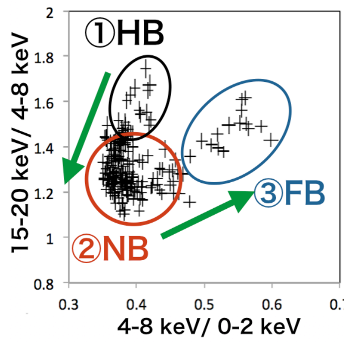

Figure 3. color-color diagram

2.3. Spectrum fittng of each state

We obtain the PIN spectra at each state and every 96 minutes (= 1 satellite orbit), and fitted with compTT + power-law model. Figure 4 shows the obtained 20-200 keV power-law flux (red: each state, blue: 96 minutes from HB, NB to FB shown in the green arrow of Figure 3.). This result confirms that the flux of the hard tail decreases toward FB. The very hard emission reported in top FB was not observed in the PIN+GSO spectrum of FB (Γ=1.4 fixed). The upper limit of the 20-200 keV flux is 6 ×10^{-10} erg/cm^2/s, which is a half of the value in [2].

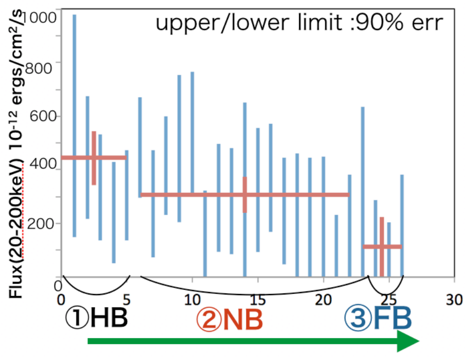

Figure 4. flux of power-law model (Γ=2.7 fixed)

3. Discussion

We observed that Sco X-1 exhibited the three states of Z sources during the Suzaku observation, and the flux of the hard tail changed and decreased from HB, NB to FB. The hard X-ray tail above 50 keV is interpreted as the inverse Compton scattering of high energy electrons. Such electron clouds seem to exist only in HB and NB, and disappear in FB.

References

[1] T. Di Salvo, et al. 2006, ApJ, 649, L91-L94
[2] L. Titarchuk, et al. 2014, ApJ, 789, 98