Three spectral states of the disk X-ray emission of the black-hole candidate 4U1630-47

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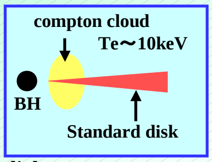
Recent RXTE observations of black-hole candidates reveal several phenomena, so-called very high state, that do not follow the standard accretion disk model. By analyzing GRO J1655-40 and XTE J1550-564, Kubota et al.(2001,2003) found that these phenomena can be explained by the inverse Compton scattering and slim disk emission. This idea is important to consider the unified view of disk emission around the black-hole, but the sample is still poor. In addition, it is not confirmed that the idea remains successful about black-hole binaries which repeat outbursts. Therefore, we analyzed black-hole candidate 4U1630-47, which is known to exhibit X-ray outburst in a period of about 650 days, and found to be in very high state in RXTE observations. We also found an additional different state in other outburst. By considering the inverse Compton scattering and slim disk, we found these two very high states can be explained as Kubota et al.. The state is different in outburst by outburst, although we find that all the outburst follows the same Lx-kT relation, indicating that all the outburst can be treated by the one basic physical picture. 4U1630-47 is the third to exhibit the three states, and they are thought to be common in the black-hole binaries.

1. Three States of Accretion Disk (Kubota et al.)

(1) Standard regime
The standard disk by Shakura & Sunyaev. X-ray spectrum is reproduced by sum of blackbody at each radius and power-law, and Rin is constant.

(2) Anomalous regime
A fraction of the disk emission are converted into hard X-rays through inverse Compton scattering. The spectrum is hard and inner radius appears to change.



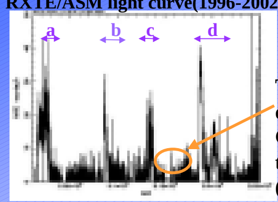
(3) Apparently standard regime
Luminosity is saturated and Rin is slightly small. The radial temperature gradient in the disk become flatter than (1). The disk must be the optically-thick and advection-dominant slim disk.

In very high luminosity, the solution of standard accretion disk becomes instability because of more dominant radiative pressure than gas pressure. When the disk temperature reaches a critical value Tin ～ 1.2 keV, the disk turns from (1) to (2) or (3).

2. Black-hole Candidate 4U1630-47

We analyzed RXTE data for 4 outbursts(a-d). From past observation, outburst (b) has been found variability of Rin (Oosterbroek et al.1998) and QPO(Tomsick et al.). This variability was explained as anomalous regime by Kasama.

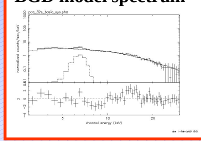
RXTE/ASM light curve(1996-2002)



The companion star has been found
→ the black-hole mass is not identified

This period is observed only diffuse emission from the Galactic plane. We modeled these data as background (BGD) and added in fitting model.

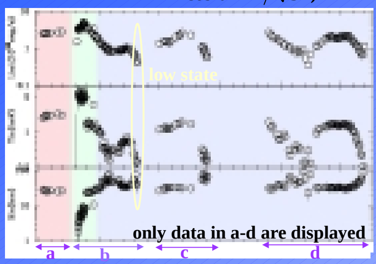
BGD model spectrum



(model : bremss + gaussian as Fe-line)

3. Fitting Results in Standard Model

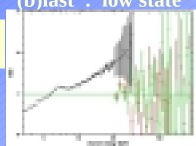
(assuming a distance of 10 kpc, a inclination of $\cos\theta = 1/\sqrt{3}$)



We first fitted data in standard model(diskbb + power-law), the spectra show 4 distinct states. In high state(lower 3 spectra), above 3 regimes are indicated.

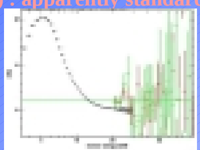
ratio of power-law(α =2)

(b)last : low state

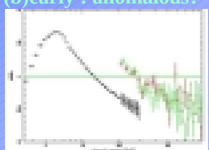


only power-law component

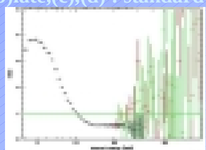
(a) : apparently standard? (b)early : anomalous? (b)late,(c),(d) : standard



Luminosity is high and constant. very soft spectrum



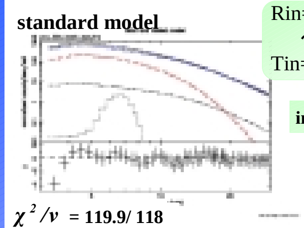
Tin is high
Rin is very small.



Rin is constant

4. Results in considering the inverse Compton scattering

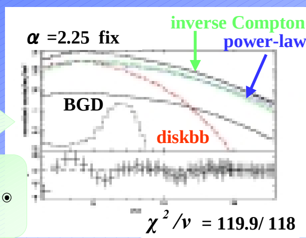
In early of (b), we refitted data in a model concluding the inverse compton scattering. ($N_H=9.5\times10^{22}cm^{-2}$ fix)



Rin=5.8km
～0.64M⊙
Tin=2.0keV

inverse Compton

Rin=29.8km
～3.3M⊙
Tin=1.2keV

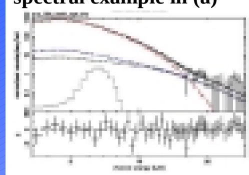


In standard model, Rin is very small and Tin is high compared to standard regime (～3M⊙). By considering the inverse Compton scattering, Rin and Tin are consistent with standard regime, respectively.
Accordingly, early (b) is explained by the inverse Compton scattering .
(This is consistent with the results by Kasama)

5. Probability of Slim Disk

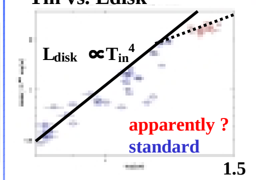
The spectral shape in (a) resembles that in the standard regime, but the fitting parameters are different from standard regime.

spectral example in (a)



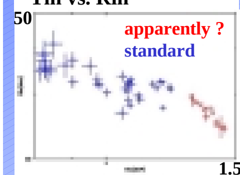
The spectrum is very soft

Tin vs. Ldisk



The gradient is smaller than standard regime

Tin vs. Rin



tendency of $R_{in} \propto T_{in}^{-1}$

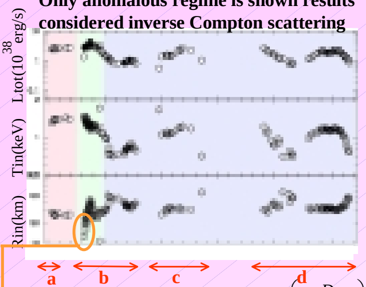
➡ Radiation efficiency is low in inner disk

These properties fit theoretical slim disk reported in Watarai et al.(2000).

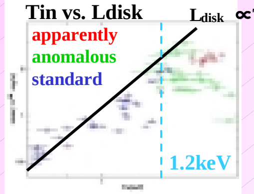
➡ (a) may be in slim disk

6. Results by considering the inverse Compton scattering and slim disk

Only anomalous regime is shown results considered inverse Compton scattering



Tin vs. Ldisk



➡ The critical value Tin ～ 1.2keV for 4U1630-47

Rin is almost constant	$30\text{-}50\left(\frac{D}{10\ kpc}\right)\left(\frac{\cos\theta}{3^{-1/2}}\right)^{-1/2}$ km	dependence on distance D, inclination θ
black-hole mass	$3.4\text{-}5.6\left(\frac{D}{10\ kpc}\right)\left(\frac{\cos\theta}{3^{-1/2}}\right)^{-1/2}$ M⊙	

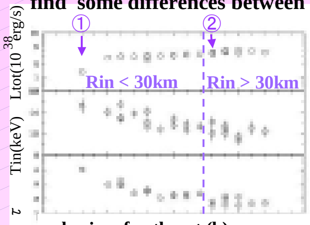
4U1630-47 also exhibits three states in the high state.

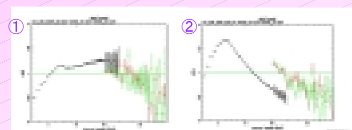
(b), (c) were observed from rise of each outburst.
rise of c ⇒ standard regime
rise of b ⇒ Rin is still small, although it is considered the inverse Compton scattering

➡ Attention to the rise of outburst (b)

7. Rise of outburst b(anomalous regime)

For the rise and late of anomalous regime, we compared each spectrum to find some differences between them.





① has more hard spectrum and τ is large.This is consistent, for larger τ , the inverse Compton scattering becomes strong.

In rise of anomalous regime, Compton cloud is more optically-thick and slowly becomes thin.

8. Conclusion

This is the first time that several outbursts were analyzed by such a method, and the state is different in outburst by outburst dependently on its inner temperature of accretion disk. Observed 2 rises of outburst show the standard regime and the anomalous regime, respectively. That is, when outburst occurs, accretion disk is not always a specified state. After this, we will analyzed QPO and more samples.