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Geometry variation of accretion disks of compact objects

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Abstract. The Temporal and Spectral variations of black hole candidates during outbursts have been reported in several publications. It is well known that during an outburst, the source becomes soft in the first few days, and then returns to the hard state after a few weeks or months. In the present paper, we show the variation of Comptonization Efficiency (CE), obtained from the ratio of the black body photon number to the power-law photon number, as a function of time in several outbursts. Since the power-law photons are generated through inverse-Comptonization of the intercepted soft photons, the CE is a measure of the geometry of the Compton cloud. Our investigation indicated that all the outbursts starts with a large CE and becomes very small after a few days, when the Compton cloud becomes very small to intercept any significant number of soft photons. CE returns back to a larger value at the end of the outburst.

Keywords : black holes physics – accretion, accretion discs – radiation mechanisms: general

1. Introduction

It is well known that the black hole accretion flows in a compact binary system typically consist of a Keplerian disk which emits soft or low energy photons and a hot Compton cloud which inverse Comptonizes the soft photons into high energy photons. When the black hole spectral state changes from the hard state to the soft state and vice versa (Chakrabarti & Titarchuk 1995) the Compton cloud must change its shape and temperature: In the soft state when the accretion rate in the Keplerian disk is high, the Compton cloud is smaller and cooler, while in the hard state, when mass accretion rate via Keplerian disk is very low, the Compton cloud is larger and hotter. There are various models of the Compton cloud in the literature, ranging from the hot Corona, to post-shock region of an accreting low angular momentum flow.

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Outburst sources are ideal candidates to study the changes in the size of the Compton cloud. This is because, the object is known to be in the hard state at the beginning of the outburst, but in a matter of few days to a few weeks, it changes its states to other states, thereby giving us a unique opportunity to study the size of the Compton cloud very well. Fig. 1 shows the cartoon diagram of variation of CENBOL geometry during outburst of XTE J1550-564 (Chakrabarti et al. 2009). From the spectral analysis, it appears that the following sequence is typically followed by most, if not all, the outburst sources: hard → hard-intermediate → soft-intermediate → soft → soft-intermediate → hard-intermediate → hard) (Chakrabarti et al. 2008, 2009). Recently, Pal et al. (2011, 2013) showed that the Compton cloud in the variable source GRS 1915+105 changes its size as it transits from one variability class to another. We computed a quantity called the Comptonizing Efficiency (CE) which is the ratio of the power-law photons to the blackbody photons in the spectrum at a given instant. We show that CE is very small in softer classes and larger for the harder classes. Within some of the classes, there are evidences of rise and fall of the count rates and the spectral slopes in a matter of a few seconds. Since the number of hard photons depends on the the optical depth of the Compton cloud, we clearly see the change in the optical depth of the Compton cloud in that time scale.

In the present paper, we analyze RXTE data to study the variation of the size of the Compton cloud during the outbursts of several black hole candidates. We clearly show that the outburst starts with a large Comptonization efficiency, i.e., a large sized Compton cloud with a poor soft photon source. In the rising phase, the cloud becomes smaller and smaller on a daily basis till it became minimum when the object went to a soft state. In the declining phase of the outburst, the trend is reversed. The black hole candidates we analyzed are GRO J1655-40 and XTE J1550-564.

2. The efficiency of comptonization

In order to obtain the correct number of soft photons, we first correct for the energy dependent absorption by the hydrogen column. We compute the photon numbers emitted in the power-law (N_{PL}) and the multi-color blackbody components (N_{BB}). The ratio N_{PL}/N_{BB} will be the Comptonization Efficiency (CE). This is similar to a ‘Hardness ratio’ but the ranges of the hard and the soft photons are automatically selected by the fitting process. The number of black body photons are obtained following Makishima et al. (1986) within the energy range 0.1 keV to the best fitted energy range obtained from spectral fitting. The best fitted energy range is obtained by fitting the spectrum with diskbb model and the higher range of the spectrum is obtained from the consideration that the reduced χ^2 value from the resultant fit must be ~ 1.0. This higher energy range of diskbb component varies for different data sets. Comptonized photons N_{PL} are calculated by using the power-law equation given by $P(E) = N(E)^{-\alpha}$, where, α is the power-law index and N is the total photons/s/keV at 1 keV. The power-law is integrated from $3 \times T_{in}$ to 40 keV to calculate the number of Comptonized photons (photons/s). The ratio of the calculated power-law photons and

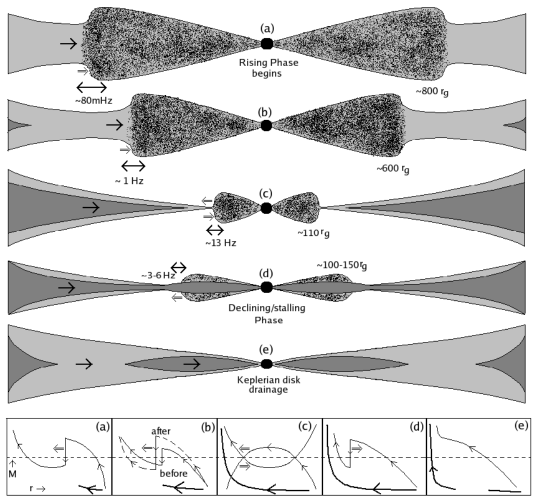

Figure 1. Cartoon diagram of CENBOL geometry variation during outburst of XTE J1550-564.

diskbb photons will give the parameter CE. This CE represents the geometrical size of CENBOL/ hot electron cloud (Pal et al. 2011, 2013).

3. Results

GRO J1655-40: The RXTE data during 2005 outburst of GRO J1655-40 is analyzed here and shown in Fig. 2(a). The compact object is analyzed from MJD 53435 (06/03/20 05) to MJD 53632 (19/09/2005). During this outburst CE was varying between 2% and 0.1%. The QPO variation is already reported in Chakrabarti et al. (2008).

XTE J1550-564: The RXTE data during 2000 outburst of the XTE J1550-564 is analyzed from MJD 51644 (10/04/2000) to MJD 51690 (26/05/2000). The result is shown in Fig. 2(b). During this outburst, the CE is varying initially between 1.0−1.5% but after MJD 51660, the CE is reduced to less than 0.5%. This indicates that the oscillating shock was still present. After a few days, the CE again increased to $\sim$ 1.5% before settling to a $\sim$ 1%. As the shock recedes from the black hole, the optical depth initially rises, but then goes down as the CENBOL density drops. This may be the cause for *CE* to rise first and then to come down at $\sim$ 1% in the outburst.

4. Discussions and conclusions

In this paper, we can come to a conclusion that generally speaking, all the outbursts start and end with a high Compton cloud size, though not necessarily the highest optical depth. As the outburst progresses, the CE becomes smaller at the peak of the

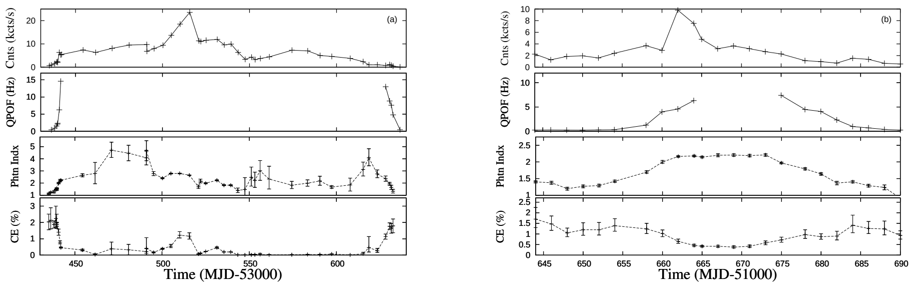

Figure 2. Simultaneous variation of 2.0 – 40.0 keV counts in kcts/s (upper panel), QPO frequency in Hz (second panel), spectral slope (third panel) and the CE (lower panel) of (a) GRO J1655-40 during its 2005 outburst and (b) XTE J1550-564 during its 2000 outburst.

outburst CE has the minimum value, i.e., the size of the CENBOL is very small. Since CE is a concept where the hardness ratio is determined from ratio of the dynamically obtained black body and power-law photons, it is insensitive to the mass of the black hole. This is unlike the usual hardness ratio, where photons in each energy band could be a mixture of the black body and power-law photons. We find that CE in outbursts sources may vary from almost $\sim$ 0.0 to $\sim$ 3. In contrast, the variable source GRS 1915+105 shows CE between 0.005 to 0.8 and has relatively high luminosity (even after factoring out the effect of the mass of the black hole), suggesting that it is in the soft-intermediate and hard-intermediate states just after the peak of a possible outburst (Pal et al. 2013). If so, in future, this source may slow down its activities when the viscosity in the system is reduced. From Pal & Chakrabarti (2012), we see that the range of CE is different for different objects. The duration of the outbursts, the QPO frequency range etc. are also found to be different. There is also a considerable scatter in CE which may be triggered by outflows from the CENBOL. All these require a more thorough analysis for a unifying understanding of the outbursts. This will be addressed in our future publications.

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