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Understanding the behavior of high energy X-rays from the black hole candidate GRS 1915+105

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Abstract. Black Hole candidate GRS 1915+105 shows a very interesting behaviour at high energy X-rays. For instance, it shows Quasi-Periodic Oscillations (QPO) only at high energies. Also the spectral slopes at high energies vary and carry information about the winds and jets produced at the centrifugal barrier. We discuss these aspects of the observations with explanation from the present theoretical models.

Key words: X-rays: stars - accretion - outflows - black hole physics - GRS 1915+105

1. Introduction

The X-ray transient GRS 1915+105 (Castro-Tirado et al. 1994) is a X-ray binary ejecting plasma clouds at a speed of $\vartheta \approx 0.98c$ (Mirabel & Rodriguez 1994). Recently, the donor of this source is identified as a K-MIII star (Greiner et al. 2001). It exhibits very rich X-ray variablities and has become an astrophysical laboratory to test the theoretical models of Black Hole (BH) physics.

Most of the BH candidates have two canonical states: X-ray spectrum of more luminous state shows weak power law, without QPO in the X-ray variability and termed as High/Soft state; the less luminous one shows strong power law component with QPO and termed as Low/Hard state. Other than this two states, GRS 1915+105 has two more states termed as Off-state and On-state in which the Off-state is a little weaker than the Low/Hard state and the On-state is harder than the High/Soft state. The rapid spectral transition (i.e., Off/On transition) in a very small time scales (Yadav et al. 1999, Chakrabarti & Manickam 2000, hereafter CM00) is the special characteristics of GRS 1915+105.

Recently, two component advective flow (TCAF) model (Chakrabarti & Titarchuk, 1995) has been observed (Smith et al. 2001) and this model can explain most of the observational features observed in the BH candidates. In the two component flow, Keplerian flow supporting Shock Oscillation Model (MSC96). Figure 2 shows that QPO (location of peak in PDS) is absent in low energy (0 – 4 keV) and strong only in high energies.

Recently, we have calculated the outflow rate in terms of compression ratio of the shock. One example is shown in Fig. 3 where the maximum value is computed to be 2.6% of the inflow rate for an angular momentum (λ) = 1.73 (for details, see, Das et al. 2001). Here, outflow is assumed to be in a cone of half angle 10^o for concreteness.

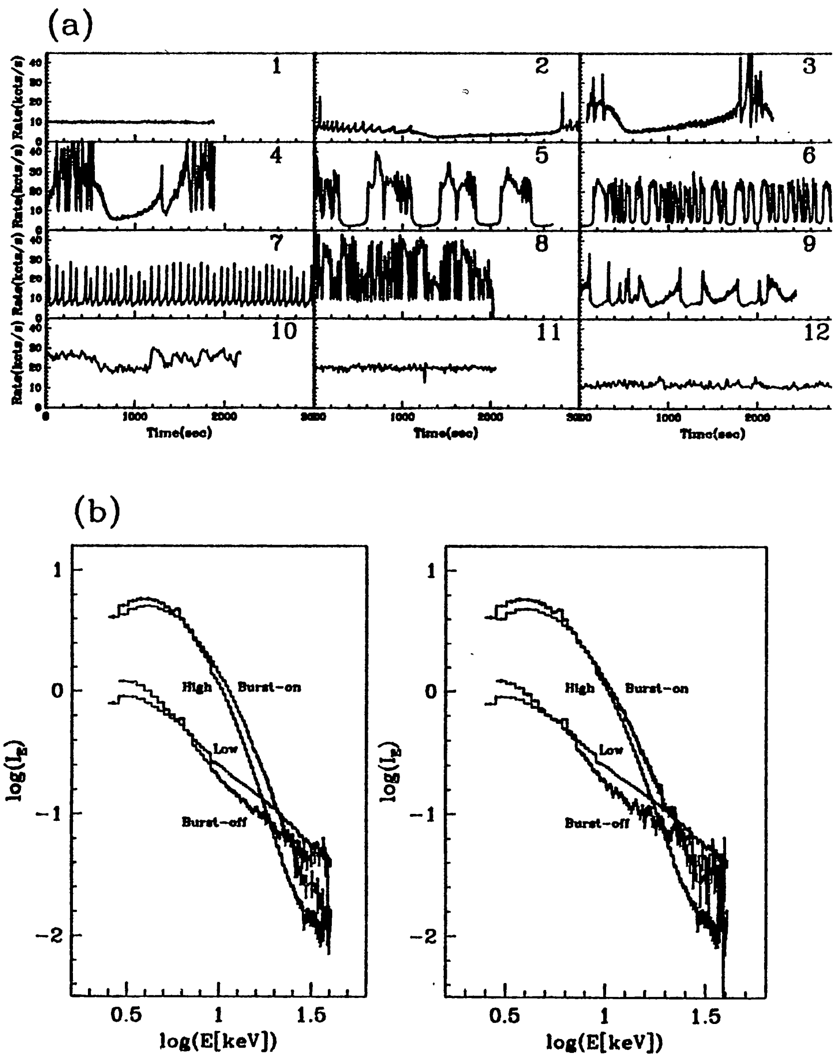


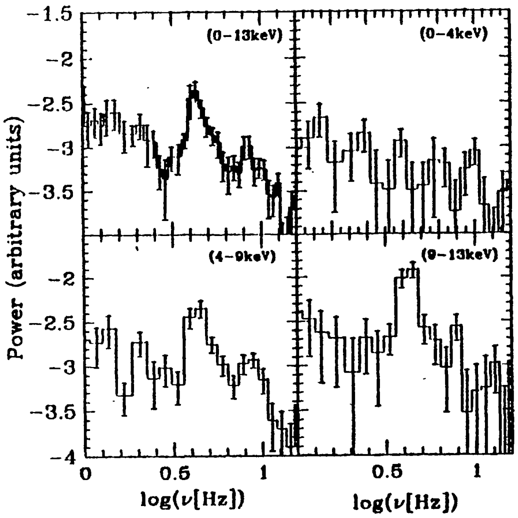
Figure 1: (a) All possible light curves of the black hole candidate GRS 1915+105. Along x-axis is time in seconds and along y-axis is photon counts in units of 10^3.
(b) RXTE-PCA spectra of GRS 1915+105 obtained during low/hard and high/soft states are compared with high-counts states (On-states) and low-counts states (Off-states).

resides in the equatorial plane (high viscosity region) whereas low viscous sub-Keplerian flow flanks the Keplerian component above and below the equatorial plane. The sub-Keplerian flow with positive specific energy may or may not form a shock. In this model, the Centrifugal barrier supported Boundary Layer (CENBOL) reprocesses the soft radiation coming out from the Keplerian disk and emits as hard X-ray radiation.
According to the Shock Oscillation Model (SOM) (Molteni, Sponholtz & Chakrabarti 1996, hereafter MSC96), due to oscillation of the shock, the post-shock region (CENBOL) fluctuates and as a result the flux of the hard X-rays will also oscillate. This is the basic cause of QPO in SOM model and this QPO is observed only in the Off-state. But in the On-state QPO is very weak as the shock is absent.
It is well known that the accretion and outflows/winds are common in most of the BH candidates. If we assume that the CENBOL is responsible for the outflows in GRS 1915+105, then the spectral slope variation at high energies is well understood. In presence of mass loss (i.e., outflows/winds) from the CENBOL its the electron density decreases and it becomes easier to cool down these electrons by the soft radiation and the spectra becomes softer. On the other hand, when the outflowing winds loss its outward driving force, some amount of matter will fall back in the and the spectra would be harder. Chakrabarti (1998) computed this two spectra and compared with the spectra of Soft and Hard states when outflow is assumed to be negligible. Because of this softening/hardening effect, the spectra intersects at much higher energies. Observations showing this effect would support models of wind creation from CENBOL.

2. Observational Result

We have analyzed the RXTE Proportional Counter Array (PCA) data using the FTOOLS and XSPEC software. Figure 1a shows all possible light-curves of the source GRS 1915+105 (see, also Belloni et al. 2000).
To study the spectral variations we select one observation each from the low/hard state and the high/soft state of the source GRS 1915+105. During the transition between these two states, the source exhibits various bursting behaviours. The regular variations in the light-curve (i.e. the Off state-On state transition) carries the information about the winds and jets at the CENBOL. CM00 explained the Off/On transitions in terms of repeated filling of the outflow region up to sonic sphere and its abrupt cooling due to inverse Comptonization by the soft photons.
The resultant unfolded spectra for the four states are shown in Fig. 1b. The power-law index in the low state (2.40 ± 0.01) is much flatter than the high state (3.61 ± 0.02) and the two spectra intersect at around 17 keV. More interestingly,the Off-state spectra has power-law index of 2.76 whereas On-state has 3.1 and it is clear that the Off-state spectrum is softer than the low state whereas the On-state spectrum is harder than the high state. As a result, the spectral pivoting point is shifted to higher energies ($\sim$ 25 keV.).

The Power Density Spectrum (PDS) of the low count states (Off-state) shows the QPO frequencies. Detailed analysis of the PDS gives a clear insight that the QPO is observed only at high energies and at low energy the QPO is completely disappeared thereby



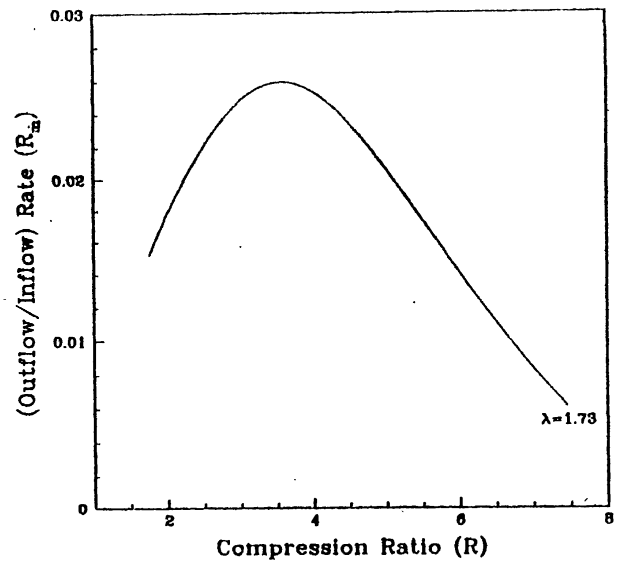


Figure 2 : Power density spectrum of an Off-states constructed from selected channel intervals of the binned RXTE-PCA data. QPO is seen only in high energies, strongly pointing to the Shock Oscillation Model.

Figure 3 : Variation of ratio of outflow to inflow rates $R_{\dot m}$ as a function of compression ratio for specific angular momentum ($\lambda = 1.73$). Outflow rate is maximum at some intermediate compression ratio.

3. Conclusion

High energy observations of GRS 1915+105 is satisfactorily explained by the TCAF model. In this model, we have established that CENBOL plays a crucial role for the production of hard X-rays as well as winds and outflows. We believe that this model would be valid for other Black Hole candidates as well.

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