Study of shock propagation velocity and accretion flow dynamics around the black hole candidate H1743-322

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The inner region of a transient source is cooled down by the inverse Comptonization of soft photons from the Keplerian disk component. The reduction of pressure forces the outer boundary of the Compton cloud, namely, the centrifugal pressure supported shock to move inward slowly in order to satisfy Rankine-Hugoniot conditions. We consider the transient source H1743-322 to study this movement of the shock. The presence of cooling changes the geometry of the Compton cloud gradually. We also see how the flow parameters of this source change day by day during a complete outburst. As the shock-oscillation could also modulate harder X-rays, we want to resolve the question: are QPOs originated from shock oscillations and can the time variation of the QPO frequency be explained by this slow propagation of the shock? For that we solve the Rankine-Hugoniot conditions and derive the condition of shock formation in presence of Compton cooling. We also compute inward velocity of the shock Compton cloud to be a few meters per second, which agrees well with earlier observational results.

Keywords: X-Rays:binaries; stars:individual:H7143-322; black holes; shock waves; accretion; accretion disks; radiation:dynamics.

1. Introduction

Observational evidences of black holes mainly come from the dynamical studies and gravitational influences on neighboring stars and gas clouds. A few properties characterize black holes candidates: strongly variable power-law X-rays, powerful collimated jets and low frequency quasi-periodic oscillations (QPOs). These are correlated by physical processes[7, 9] inside the disk. Formation of the shocks[1] close to the black hole and cooling of the post-shock region[3, 21] are some of the very important processes in black hole accretion. There are many models in the literature, which explains origin of QPOs. They include global disk oscillation[26], oscillation of warped disk[25], accretion ejection instability at the inner radius of a Keplerian disk[24]. Chakrabarti and his collaborators[17] showed that the oscillations of the accretion shocks[2] could cause low frequency QPOs. According to two-component advective flow (TCAF) model[3] the post-shock region itself is the Compton cloud. Because the shock is formed due to centrifugal force, where energy is dissipated and angular momentum is redistributed, post-shock region is also known as the CENtrifugal pressure supported BOundary Layer (or, CENBOL) of the black hole. The post-shock region CENBOL not only produces observed hard X-rays[3], it also supplies matter for the jet and the outflow[4]. The inverse Compton process mainly removes thermal energy of the inflow. As the radiative loss decreases thermal pressure, it not only reduces the CENBOL size, it also reduces the outflow rate. Due to the dissipation of energy by the up scattering of the soft-photons from the Keplerian disk, size of the CENBOL decreases. As a result, the shock moves towards the black holes[18]. Using the Propagating Oscillatory Shock (POS) model by Chakrabarti and his collaborators[6, 11, 23] one can satisfactorily explain monotonically increasing frequency using the movement of the shock with time during the rising phase of the outburst. Exactly opposite scenario is observed during declining phase. Recently,[19, 13, 15, 16] also showed physical reason behind spectral state transitions from spectral model fitted parameters of TCAF model for two different Galactic BHCs H1743-322, GX 339-4 and MAXI J1659-152 during their outbursts. QPOs frequencies are then obtained from shock locations which are obtained from the TCAF fitting. Thus, TCAF solution is capable of unifying spectral and timing properties through the shock location. The *paper* is organized in the following way: in the next Section, we discuss the equation of shock invariant quantity in presence of Compton cooling and the methodology obtained for the solution. In §3, we briefly discuss our results and make our concluding remarks.

2. Methodology of Solution and Analysis Procedure

In TCAF, CENBOL is a hot, and puffed up region, which loses energy due to inverse Compton scattering with softer photons. As a result, Rankine-Hugoniot (R-H) shock condition modifies. The modified R-H shock condition is given below[18],

$$\frac{[M_+(3\gamma-1)+(\frac{2}{M_+})]^2}{2+(\gamma-1)M_+^2}=\frac{[M_-(3\gamma-1)+(\frac{2}{M_-})]^2}{2+(\gamma-1)M_-^2-\xi}, \tag{1}$$

where, M, v and γ are the Mach number, radial velocity and adiabatic index of flow respectively, $\xi=\frac{2\Delta\varepsilon(\gamma-1)}{a_-^2}$. Here, a is the adiabatic sound speed. We follow the same mathematical procedure and methodology as in[18], to find shock location when cooling is included. We analyze archival data of RXTE/PCA instrument starting from 2010 August 9 (Modified Julian Day, i.e., MJD = 55417.2) to 2010 August 16 (MJD = 55424.1), selected from rising phase of 2010 outburst of H 1743-322. We carry out data analysis using FTOOLS software package HeaSoft version HEADAS 6.14 and XSPEC version 12.8. For generation of source and background '.pha' files and spectral fitting (in 2.5 − 25 keV energy range) using combined disk blackbody and power-law models, we use same analysis procedure as described in[12, 19]. After achieving best fit based on reduced chi-square value ($\chi^2_{red}\sim 1$), we integrate only power-law component of the spectrum. This can be written as[20],

$$\sum_{i=E_{min}}^{E_{max}} E_i F_{Comp}(i),$$

where, E_{min} and E_{max} are minimum and maximum energy range. Cooling of the Compton cloud (CENBOL) is calculated from the observed spectrum. For distance correction we multiply the integrated spectrum by the model normalization value

($norm$) of $\frac{4\pi D^2}{cos(i)}$, and absorption correction[22], where 'D' is source distance in 10 kpc unit and 'i' is the disk inclination angle.

3. Results and Discussions

In this work, we study movements of the shock due to Compton cooling at the time of outburst of H1743-322. In Fig. 1a, we show the variation of cooling rate with time. Amount of cooling increases as the system goes from hard to soft states[21]. Earlier it was demonstrated that shock moves inwards due in presence of cooling[18]. Here we show the shock movement from hydrodynamical solution using the observational data. In Fig. 1b, we show time variation of the shock location variation. It is seen that at the beginning of the outburst, the shock was at $\sim 360 r_g$ and at the end of the rising phase it reaches $\sim 65 r_g$ in ~ 8 days. Most of this results are in[21]. Depending on the energy dissipation of the flow, the shock conditions are satisfied at a particular location and the flow jumps from supersonic to sub-sonic branch. As the location of the shock moves in with increasing cooling and the same shock produces the QPO frequencies, we can conclude that the Compton cooling is mainly responsible for the origin of QPOs.[9] also showed using rigorous means that when cooling time scale roughly matches with the infall time scale, resonance condition occurs and QPOs originate, as already suspected earlier from numerical simulations (e.g.,[17]). We compute the velocity of the movement of shock location. This is found

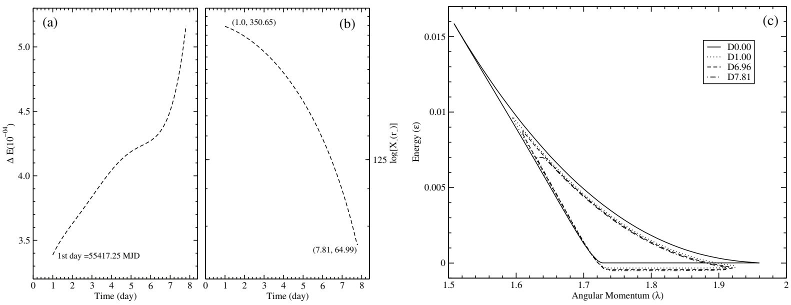

Fig. 1. Variation of (a) cooling rate in successive days of H 1743-322 during its 2010 outburst. In (b), movement of the shock location with time (in day), and (c) variation of parameter space for different cooling rates.

to be a few meters per second. Our result agrees well with the previous results[5,12] obtained using POS model. In Fig. 1c, we show how the parameters shift day by day due to the increase in cooling. The solid curve shows the parameter space for non-dissipative flow. The dotted, dash-dotted and dot-dashed curves show parameter spaces for 1^{st}, 7^{th} and 8^{th} day of the outburst. Our present paper considers the cooling from observed fitted spectrum to study the flow dynamics therefore our result is complementary in nature.

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