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Unstable mass-loss from a geometrically thick accretion disc around black holes

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Abstract. We investigate the possible origin of the unstable mass-outflows from a low angular momentum thick accretion flow around stationary black hole using 2D time-dependent hydrodynamical simulation. When the flow is advection dominated, a torus disc is formed in the vicinity of the black hole. At the inner edge of the torus, a series of hot blobs is intermittently developed which grow up along the outer surface of the torus and eventually causes the irregular modulation of luminosity and the mass-outflow rate. We point out that the unstable behavior of the mass-outflow perhaps results due to the existence of Kelvin-Helmholtz instability in the inner region of the flow.

Keywords : black hole physics – accretion, accretion disc – methods: numerical

1. Introduction

Understanding the physical mechanisms that produce the mass-outflows from the vicinity of the black holes draws significant attention in recent days. Often, the mass-outflows are seen to be unstable in nature and also correlated with the emergent radiations that modulate quasi periodically. Several models including the advection-dominated accretion disc model (Narayan and Yi 1994) and the low angular momentum disc model (Chakrabarti 1989, 1996; Das 2007) were proposed in order to examine the properties of geometrically thin accretion disc around stationary black holes. Recently, Das et al. (2014) showed that origin of the periodic mass-loss from the geometrically thin accretion disc seems to be attributed when the viscosity is chosen to its

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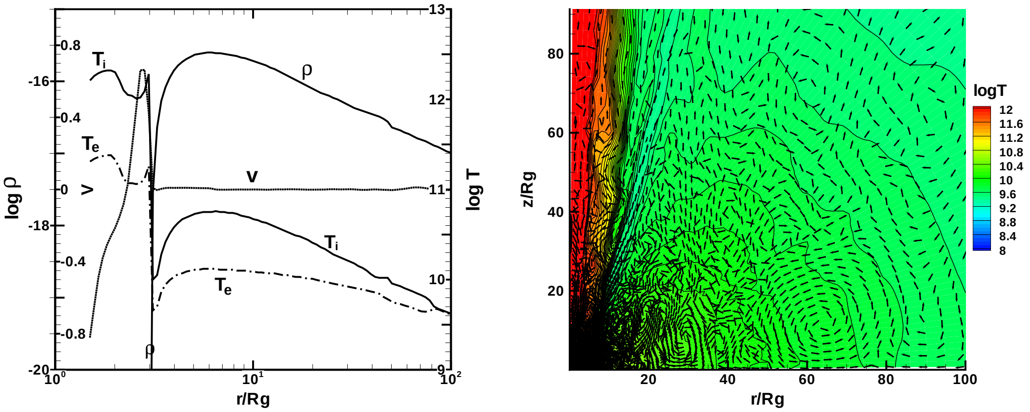

Figure 1. *Left:* Variations of density ρ (g cm^{-3}), ion temperature $T_{\rm i}$, electron temperature $T_{\rm e}$ and radial velocity v on the disc equatorial plane. *Right:* Contours of ion temperature $T_{\rm i}$ with unit velocity vectors at $t = 5.0 \times 10^6$ s, where convective cells are found in the inner region.

critical value. Meanwhile, Okuda and Molteni (2012) and (Okuda 2014) reported that the thick accretion flows with low angular momentum also exhibits unstable eruptive mass ejections. Very recently, Okuda and Das (2015) pointed out that the origin of such intrinsic unstable behavior is possibly due to the presence of Kelvin-Helmholtz instability active in the inner part of the disc. In this work, we extend this study and examine the properties of the advection-dominated thick accretion disc around a stationary black hole using 2D hydrodynamical simulation.

2. Results and Discussion

We begin with a geometrically thick and optically thin accretion flow, where the space-time geometry around the black hole is approximated adopting the pseudo-Newtonian potential introduced by Paczyński and Wiita (1980). Here, we use geometric unit as $G = M_{BH} = c = 1$, where, G, M_{BH} and c are the gravitational constant, mass of the black hole and speed of light, respectively. In this unit system, distance, velocity and time are expressed in units of $r_g = 2GM_{BH}/c^2$, c and r_g/c, respectively. We consider a supermassive black hole with mass $M_{BH} = 4 \times 10^6 M_\odot$ which is same as the mass of Sgr A*. The flow parameters are chosen as follows: injection radius $r_{\rm out} = 200$, angular momentum $\lambda_{\rm out} = 4.13$, radial velocity $v_{\rm out} = -0.0026$, density $\rho_{\rm out} = 4.14 \times 10^{-18}$, ion temperature $T_{i,{\rm out}} = 2.082 \times 10^9$K, adiabatic index of ion $\gamma_i = 1.6$, relative disc thickness $(h/r)_{\rm out} = 0.5$, viscosity parameter $\alpha = 0.1$, ratio of the magnetic energy density to the thermal energy density $\beta_{\rm out} = 10^{-3}$ and accretion rate $\dot{M} = 1.5 \times 10^{-6} M_\odot$ yr^{-1}, respectively. We separate the outer boundary in two parts. In the first part, matter continuously enters from the outer boundary with a

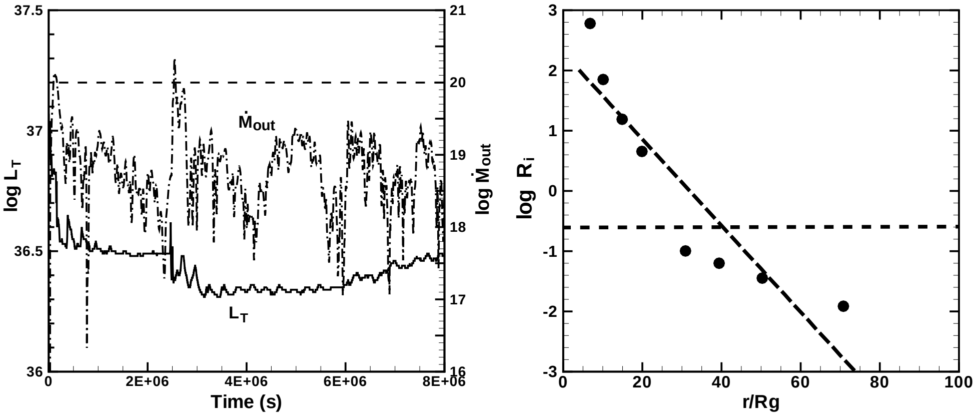

Figure 2. *Left:* Variations of total luminosity $L_{\rm T}$ (erg s^{-1}) and mass-outflow rate $\dot{M}_{\rm out}$ with time. Here, the dashed horizontal line denotes the input accretion rate. *Right:* Distribution of Richardson number $R_{\rm i}$ with radial coordinate on the shock surface. Filled circles are the representative points and the solid line represents the best fit. Dashed horizontal line denotes the critical value of $R_{\rm i}^{cr}$ to establish the Kelvin-Helmholtz instability.

constant accretion rate $\dot{M}$ and the other part is the outer boundary region above the accretion disc from where matter is allowed to eject in the form of outflow only with positive radial velocity. In addition, we impose the condition that all the flow variables remain constant always at the outer boundary of the disc.

In the left panel of Fig. 1, we present how the density ρ, ion temperature $T_{\rm i}$, electron temperature $T_{\rm e}$ and radial velocity v at the equatorial plane varies with radial coordinate. We find that the density and temperatures of the flow attain its maximum value around $r \sim 6R_{\rm g}$ and sharply decreases as the flow proceeds towards the black hole. Around $r \sim 3R_{\rm g}$, the discontinuous raise of temperatures is observed although density continues to decrease even further. We depict the contours of ion temperature in the right panel of Fig. 1 at time $t = 5.0 \times 10^6$ sec. In the plot, the velocity vectors are illustrated by unit vectors. Here, the flow is unstable and number of convective cells are seen at the inner part of the disk. We also observe that a torus is formed with having a concentric center at $r \sim 6R_{\rm g}$.

We calculate the total luminosity in the computational domain V as $L_T = \int (q_{\rm br} + q_{\rm syn}) dV$ where, $q_{\rm br}$ and $q_{\rm syn}$ are the bremsstrahlung and synchrotron emissivities, respectively and the mass-outflow rate at the outer boundary S is obtained as $\dot{M}_{\rm out} = \int \rho_{\rm out} v_{\rm out} dS$. We present the variation of $L_{\rm T}$ and the $\dot{M}_{\rm out}$ with time in the left panel of Fig. 2. The flow ejected from the region with polar angle $\zeta \geq 60°$ having positive radial velocities is considered as outflowing matter. We denote the inflow accretion rate $\dot{M}_{\rm in} \sim 10^{20}$ g s^{-1} by the dashed horizontal line. $\dot{M}_{\rm out}$ attains 10% of $\dot{M}_{\rm in}$ and varies by a factor of 10 and L_{T} is modulated only by a very small factor. The large mass-outflow activity occurs in the form of intermittent ejection of hot blob roughly in the intervals of few days.

In order to understand the intrinsic origin of the unstable nature of the outflow, we study the Kelvin-Helmholtz instability that generally occur when there is a velocity difference across the interface between two fluids. In the present scenario, the hot blobs are located along the interface between the outflow and the outer surface of the torus disc (i.e. at the shock boundary) and hence the Kelvin-Helmholtz instability is developed there. Following Okuda and Das (2015), we estimated the Richardson number (R_i) (Chandrasekhar 1961). When $R_i < 0.25$, the growth of Kelvin-Helmholtz instability is established. In the right panel of Fig. 2, we show the variation of R_i with radial coordinate along the shock surface and observe that Kelvin-Helmholtz instability are seen away from the equator. This gives an indication that the Kelvin-Helmholtz instability possibly triggers the origin of the unstable mass-outflow from the vicinity of the black holes.

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