Radiation Drag Effects in Black Hole Outflows from Super-critical Accretion Disks via Special Relativistic Radiation Magnetohydrodynamics Simulations

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A black hole accretion disk system is one of the most energetic phenomena in the universe. A mass accretion onto the black holes results in efficient gravitational energy release. According to the mass accretion rate, three accretion modes, i.e., standard disk model, radiatively inefficient accretion flow model, and slim disk model have been proposed. Whereas these three models are established by one-dimensional approach, multi-dimensional effects are also very important because jets and outflows are observed in black hole accretion disk system. Also the relativistic effects should be taken into account since the jet velocity is close to the light speed. For the case of high accretion rate (slim disk), a radiation is an important ingredient for understanding disk and jet structures. The radiation pressure dominates the gas pressure, so that the most of energy is transported in the form of radiation. Such a large amount of radiation energy would form the radiatively driven jets or outflows. Thus, the relativistic radiation magnetohydrodynamic (RRMHD) simulations are required to study the radiatively-driven high-velocity outflows. In this paper, we performed RRMHD simulation to study the mechanisms of outflow acceleration and determine the outflow speed [1].

Figure 1 shows overall structure of the accretion disks. At this time ($t = 10$ s), the accretion rate onto the black hole is $\dot{M} \simeq 1000\, M_{\rm Edd}$. Here $\dot{M}_{\rm Edd}$ is the Eddington accretion rate $\dot{M}_{\rm Edd} \equiv 4\pi\, GM_{\rm BH}/c\kappa_{\rm es}$ = $1.4 \times 10^{18}\, (M_{\rm BH}/10\, M_\odot)$ g s^{-1}, where G is the gravitational constant, c is the light speed, $M_{\rm BH} = 10\, M_\odot$ is the black hole mass, and $\kappa_{\rm es}$ is the opacity for electron scattering. Thus the super-critical accretion is stably realized. Besides the accretion flow, a fast relativistic outflow is observed just above the accretion disks (arrows in the right panel). The direction of velocity vector almost coincides with the radiation flux vector (arrows in the left panel), indicating that the relativistic flow is accelerated by the radiation force. The gas is accelerated at the small altitudes, and its velocity finally saturates at the outer region ($z \gtrsim 100\, r_{\rm S}$, where $r_{\rm S}$ is the Schwarzschild radius). The terminal outflow velocity is about $0.3–0.4\, c$, which nicely agrees with the jets speed ($0.26\, c$) observed in SS433. Considering the outflow acceleration, a balance between two forces determines the terminal velocity. First one is the radiation flux force, which pushes the gas away from the accretion disks. Then the gas is accelerated upward. The accelerated gas is subjected to the radiation drag force, which prevents the outflow from further acceleration. By comparing these two forces, the outflow velocity is estimated at $0.3–0.4\, c$. We observed that these results are justified in the range of $10^2 \lesssim \dot{M}/\dot{M}_{\rm Edd} \lesssim 10^4$.

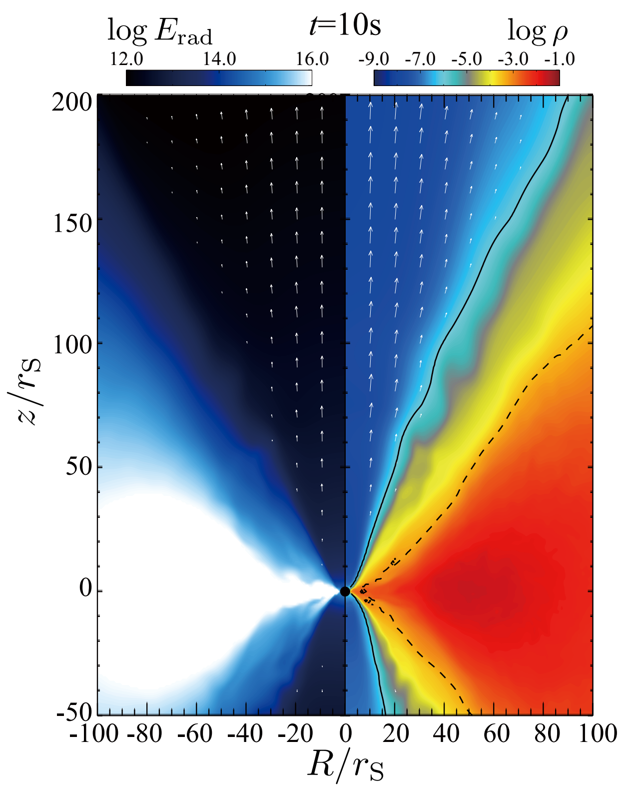

Figure 1: Overall structure of the super critical accretion disks. Left and right colors show the radiation energy density and gas density. The arrows show the radiation flux (left) and the velocity (right). Solid and dashed curves denotes where the total and effective optical depths become unity.

Reference

[1] Takahashi, H. R., Ohsuga, K.: 2015, *PASJ*, **67**, 60.