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Intermediate region of BH X-ray binary formed by disk gas evaporation

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We study the state transition from the hard state to the soft state of black hole X-ray binaries. Previous studies have shown that the radiative cooling instability causes the low-density, high-temperature accretion flow to contract toward the equatorial plane and transition into a low-temperature accretion disk and a high-temperature halo surrounding it.[1], [2], [3] This was revealed by the results of magnetohydrodynamic or hydrodynamic numerical simulations. Considering the temperature difference between the formed low-temperature accretion disk and the high-temperature halo surrounding it, we are conducting an axisymmetric 2.5-dimensional magnetohydrodynamic numerical simulation that considers the anisotropic heat conduction, regarding the state transition from the hard state to the soft state.[4] We set the mass of the black hole to be 10 times the mass of the sun, set the bremsstrahlung as radiative cooling, and use the Spitzer type coefficient for heat conduction. Also, the anomalous resistivity is taken into consideration.

We performed a numerical simulation including heat conduction and found that when the accretion flow reaches a steady state after the state transition, there is an intermediate region between the high-temperature outflow from the accretion flow near the black hole and the low-temperature accretion disk at the equatorial plane. The temperature and density of this intermediate region have values between the cold accretion disk and the hot outflow. Active evaporation of gas from the surface of the accretion disk to the intermediate region was observed, forming a transition layer where the heating by heat conduction and the cooling by evaporation of disk gas are balanced (Figure 1 (a)~(c)).

In the intermediate region formed by the rise of evaporated gas, a rough estimate shows that the heat conduction flux and the enthalpy flux can be balanced between r_s and $4r_s$ (Figure 1 (d)). Here, $r_s=3\times10^6$cm is the Schwarzschild radius. Referring to research on solar chromosphere evaporation due to the energy release by magnetic reconnection, we set up an approximated formula that sets the sum of heat conduction flux and enthalpy flux to zero.[5], [6] This formula is simplified under reasonable assumptions based on the results of numerical experiments. As a result, we were able to obtain two scaling laws regarding the column density and emission measure of the intermediate region, which are expressed using the temperatures of the high temperature region and the low temperature region as representative parameters.

We present an example of evaluations using respective scaling laws for the column density and the emission measure of the intermediate region. At radius $r=6r_s$, if we adopt $T_L=10^8$ K as the temperature of the low-temperature disk and $T_H=10^{11}$ K as the temperature of the high-temperature outflow, the column density of the intermediate region is 3×10^{24}cm^{-2}, emission measure is evaluated as 10^{57}cm^{-3}. We will compare the observation results regarding the accretion disk corona with our results as a future work.

References
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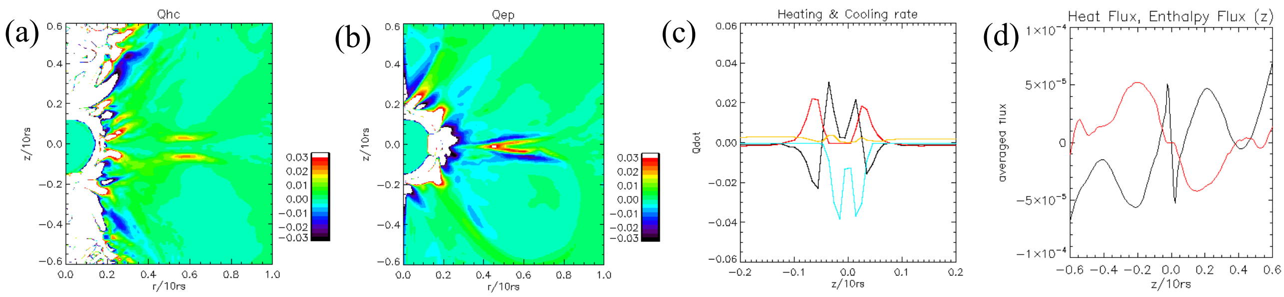

Figure 1 (a) Time average of the heating rate of heat conduction between 30 and 40 rotation periods at $10r_s$. The horizontal axis is r. The vertical axis is z. (b) Time average of the divergence of enthalpy flux for same time interval as (a). (c) Time average of heating or cooling rates at $6r_s$ for same time interval as (a). Red line, black line, yellow line and blue lines represent the heating rates of the heat conduction, divergence of the enthalpy flux, the Joule heating and the radiative cooling, respectively. The horizontal axis is z. (d) Time average of fluxes at $6r_s$ for same time interval as (a). Red and black lines represent the heat flux and the enthalpy flux, respectively. The horizontal axis is z.