DYNAMICAL EVOLUTION OF ACCRETION FLOW ONTO A BLACK HOLE

M. YOKOSAWA
Department of Physics
Ibaraki University, Mito, Japan

1. Introduction

Active galactic nuclei(AGN) produce many type of active phenomena, powerful X-ray emission, UV hump, narrow beam ejection, gamma-ray emission. Energy of these phenomena is thought to be brought out binding energy between a black hole and surrounding matter. What condition around a black hole produces many type of active phenomena ? We investigated dynamical evolution of accretion flow onto a black hole by using a general-relativistic, hydrodynamic code which contains a viscosity based on the alpha-model. We find three types of flow's pattern, depending on thickness of accretion disk. In a case of the thin disk with a thickness less than the radius of the event horizon at the vicinity of a marginally stable orbit, the accreting flow through a surface of the marginally stable orbit becomes thinner due to additional cooling caused by a general-relativistic Roche-lobe overflow and horizontal advection of heat. An accretion disk with a middle thickness, $2r_{\rm h} \leq h \leq 3r_{\rm h}$, divides into two flows: the upper region of the accreting flow expands into the atmosphere of the black hole, and the inner region of the flow becomes thinner, smoothly accreting onto the black hole. The expansion of the flow generates a dynamically violent structure around the event horizon. The kinetic energy of the violent motion becomes equivalent to the thermal energy of the accreting disk. The shock heating due to violent motion produces a thermally driven wind which flows through the atmosphere above the accretion disk. A very thick disk, $4r_{\rm h} \leq h$, forms a narrow beam whose energy is largely supplied from hot region generated by shock wave. The accretion flowing through the thick disk, $h \geq 2r_{\rm h}$, cannot only form a single, laminar flow falling into the black hole, but also produces turbulent-like structure above the event horizon. The middle disk may possibly emit the X-ray radiation observed in active galactic nuclei.

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The thin disk may produce UV hump of Seyfert galaxy. Thick disk may produce a jet observed in radio galaxy. The thickness of the disk is determined by accretion rate, such as $h \approx \kappa_{\rm es}/c\dot{M}f(r) \approx 10r_h\dot{m}f(r)$, at the inner region of the disk where the radiation pressure dominates over the gas pressure. Here, $\dot{M}$ is the accretion rate and $\dot{m}$ is the normarized one by the critical-mass flux of the Eddington limit. $\kappa_{\rm es}$ and c are the opacity by electron scattering and the velocity of light. $f(r)$ is a function with a value of unity far from the hole.

2. Numerical Calculation of an Accretion Disk in Curved Spacetime

We consider the structure and evolution of the innermost parts of the accretion disk based on a numerical simulation. We used a numerical technique of flux-corrected transport, which was developed from numerical codes used for special relativistic hydrodynamics and for general-relativistically magnetohydrodynamic accretion. In order to examine a standard accretion disk, we include the viscosity in the transport of angular momentum and in the heat equation. The heat generated by viscosity, $-t_{\alpha\beta}\sigma^{\alpha\beta}$, is transported by the radiation. The transport of radiation was solved by the diffusion approximation.

In the case of a thin disk, $h_0 = 0.1 - 1r_{\rm h}$, the accreting fluid is smoothly swallowed by a hole. Within the critical surface, $r = r_{\rm ms}$ the fluid rapidly falls, and then the gradient of the velocity becomes very large. This causes an additional cooling due to general-relativistic Roche lobe overflow and horizontal advection of heat. The rate of work due to the pressure force in the radial direction, $\dot{E}_{P\nabla V_r} = -P/\sqrt{\gamma}\ \partial_r(W\sqrt{\gamma}v^r)$, is negative there. On the other hand, its rate becomes positive in the vicinity of the horizon. Its sign is determined by the divergent $\dot{E}_{P\nabla V_r} \propto -\partial_r(W\sqrt{\gamma}v^r) = -\partial_r(\sqrt{g}u^r) \propto -\partial_r(r^2u^r)$. When $\partial_r(u^r)/u^r < -2/r$, then $\dot{E}_{P\nabla V_r} < 0$. If the fluid freely falls into a hole, $u^r = -\sqrt{2/r}$, then $\dot{E}_{P\nabla V_r} > 0$. The rapidly falling fluid through the critical surface enters a state of free fall near to the horizon.

In the case of the medium thickness of the disk, $h_0 = 2 - 3r_{\rm h}$, some portion of the fluid in the disk can not be swallowed by a hole, and then begins to blow out into the atmosphere. The initial density at the vicinity of the critical surface, $r = r_{\rm ms}$ distributes along the lines of iso-density, $z(r)_\rho \propto r^n$, $n > 1$. These lines bend strongly at $r \approx r_{\rm ms}$. The fluid in the neighbourhood of the equatorial plane is attracted by the hole and cooled by the horizontal advection of heat. Although the upper part of the disk is also attracted by a hole, its direction of force is radial. Then, the advection of heat, $-P/\sqrt{\gamma}\partial_r(W\sqrt{\gamma}v^r)$, becomes positive. Work due to movement of fluid heats the flow, thus causes an expansion of the flow.