BLACK HOLE DISK ACCRETION IN SUPERNOVAE

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1. Introduction

Massive stars in a certain mass range $(20-40M_{\odot})$ may form low mass black holes after supernova explosions. In such massive stars, fall back of $\sim 0.1M_{\odot}$ materials onto a black hole is expected due to a deep gravitational potential or a reverse shock propagating back from the outer composition interface. We study hydrodynamical disk accretion onto a new-born low mass black hole in a supernova using the SPH (Smoothed Particle Hydrodynamics) method.

2. Results and Discussions

As for particular case, we apply the quantities of SN1987A; that is, the mass of the central object, $M_0 = 1.4M_{\odot}$, the mass of the fallback matter, $M_{\rm fb} = 0.1M_{\odot}$, the place where a reverse shock appears, $r_0 = 5\times10^{10}$cm, the sound velocity, $c_s = 3.45 \times 10^7$cm s^{-1}, the angular frequency, $\Omega = 10^{-3}$rad s^{-1} (for comparison, we also simulate cases with $\Omega = 0.0$), and the specific heat ratio $\gamma = 4/3$.

When the ambient gas has no angular momentum, it accretes toward the center with a free-fall velocity, whereas if the gas has a certain angular momentum, it first falls onto the equatorial plane, forming a rotating gas disk, and then accretes inward via viscosity (Figure 1).

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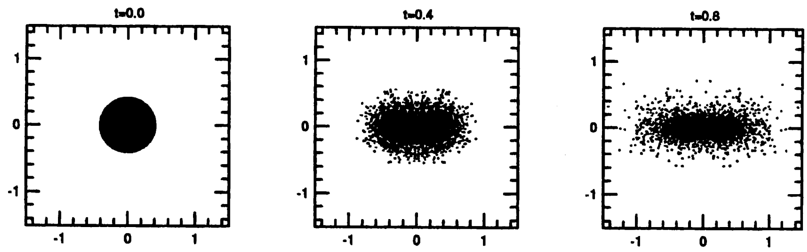

Figure 1. **The time evolution of SPH particle distributions with the initial angular momentum. The length scale is normalized by $[L] = 1.22 \times 10^{11}$cm and the times are in the unit of $[T] = 3.14 \times 10^3$s.**

Numerically derived mass accretion rate is roughly,

$$\dot{m} \sim 1.0 \times 10^5 (\alpha t/\mathrm{yr})^{-1.35}$$

where $\dot{m} \equiv \dot{M}/\dot{M}_{\rm crit}$, $\dot{M}_{\rm crit} \equiv L_E/c^2$, L_E is the Eddington luminosity,and α is the viscous parameter.

The results thus indicate a hypercritical disk accretion. When $\dot{M}$ exceeds the critical rate, a disk becomes advection dominated and optically thick (so-called the slim disk), as long as shear-viscous tensor does depend on the radiation pressure.

This suggests the view on following two topics.

1. The luminosity of SN 1987A

The observed bolometric luminosity of SN 1987A is $\sim 10^{36}$ erg s^{-1},which can be explained by the energy deposition from the ^{44}Ti decay. If standard disk accretion occurs, the disk luminosity should be, at least, of the order of the Eddington luminosity ($\sim 10^{38}$erg s^{-1}), contrary to the observations. But in the advection-dominated, hypercritial accretion disk, that discrepancy is avoided due to advection of the radiation energy and photon trapping at the hottest part of the disk. (The photon trapping occurs inside the radius $\sim 10^{11}$cm for $\dot{M}/\dot{M}_{\rm crit} \sim 10^6$.)

2. Possible nucleosynthesis

The slim disk is hot and dense; for $\dot{M}/\dot{M}_{\rm crit} \sim 10^6$, $T \sim 10^9(\alpha/0.01)^{-1/4}$K and $\rho \sim 10^3(\alpha/0.01)^{-1}$g cm^{-3}. If some hydrogen and helium have been mixed down to deeper layers and accreted, interesting nucleosynthesis processes via rapid proton and alpha captures on heavy elements would take place. The elements produced in this way might be advected inward and swallowed by the central black hole, but some of them could be ejected in a disk wind or a jet.

References

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