JETS FROM TIME-DEPENDENT ACCRETION FLOWS ONTO A BLACK HOLE

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1. Introduction

It is widely believed that accretion onto a black hole is the origin of X- and γ-ray emission and jets emerging from AGNs. Since the X- and γ-rays are highly variable, the accretion is also expected to be variable. We investigate highly variable hydrodynamical accretion with numerical simulations.

Numerical simulation of hydrodynamical accretion onto a black hole was studied by Hawley et al. (1984), Molteni et al. (1994), and others. In these simulations jets were not clearly formed, while our numerical simulations show semi-relativistic bipolar jets.

2. Models

We investigate axisymmetric accretion onto a black hole having the mass of $10^7 M_\odot$. For simplicity the gravity of the black hole is approximated by the pseudo-Newtonian potential. We assume that the flow consists of the ideal gas and black body radiation. The computational domain covers from $r = 2r_g$ to $104r_g$.

In most models one or two dense cool gas tori are superimposed on a hot steady flow. The gas tori are in the pressure balance with the surrounding flow at the initial stage. The hot steady flow is characterized by P/ρ evaluated at the outer boundary. It is set to be $0.001c^2$ in most models.

3. Results

Figure 1 shows the evolution of a typical example of our models. At the initial stage two dense gas tori are superimposed at $r = 20$ and $30r_g$. Each torus has the mass of 6×10^{28} g and the specific angular momentum of

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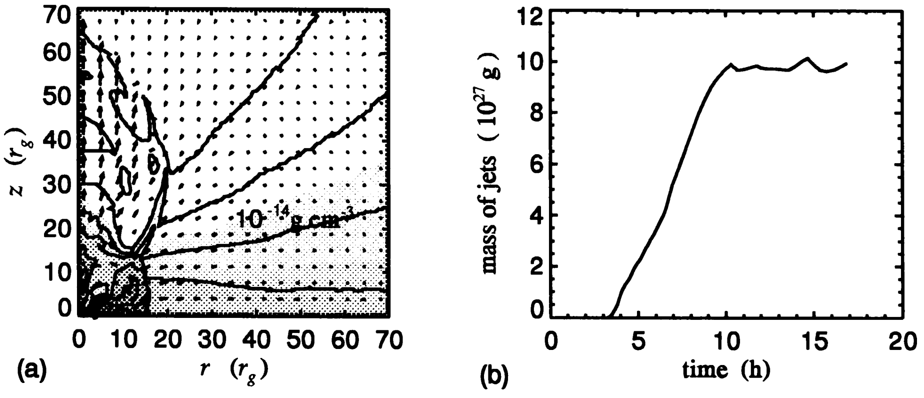

Figure 1. (a) The density distribution at $t = 7.3$ hr. The contour levels are spaced with an interval of $\Delta(\log_{10} \rho) = 0.5$. The head of the jet reaches $z = 65r_g$ at this stage. (b) The jet mass as a function of the time.

$\ell = 2.1cr_g$. The gas tori infall and are stretched in the r-direction. At $t =$ 2.0 hr, a part of the inner gas torus moves outwards. This is the collision and the bounce of the tori with the centrifugal barrier which locates at $r = 2.8r_g$. Shock waves are formed at the head of the tori. At the shock front the gas is heated up from 10^5 K to 3×10^5 K. At $t = 3.1$ hr the high pressure pushes gas to outflow along the rotation axis. The outflowing gas evolves into bipolar semi-relativistic jets.

The results of our models are summarized as,

(1) Bipolar jets emanate when the infalling gas blobs have high specific angular momentum ($\ell \geq 2cr_g$). The jet mass ejection is largest when the blobs with $\ell = 2.2cr_g$ infall.

(2) When gas blobs have low specific angular momentum ($\ell < 2cr_g$), shock waves and jets are not formed. The blobs accrete smoothly onto a hole.

(3) Jets are more massive when the blobs are more massive. There is a critical mass of the blobs, $\sim 10^{28}$ g, to emanate jets, when the average accretion rate is $0.11 M_\odot$ yr^{-1}.

(4) The efficiency of the energy gain of the jets is $3 \sim 11\%$. It is larger when the blobs have higher specific angular momentum or larger mass.

(5) When the steady ambient gas is colder, the jets are better collimated. See Nobuta & Hanawa (1997).

References

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