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Possible Outflow Formation in the Central Engine of GRBs

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Abstract. We investigate the vertical structure of neutrino-dominated accretion flows in spherical coordinates. In our calculation, the empty funnel along the rotation axis can naturally explain the neutrino annihilable ejection. The outflow is possible due to the positive Bernoulli function, and the luminosity of neutrino annihilation is enhanced by one or two orders of magnitude.

Key words. Accretion: accretion disks—black hole physics—gamma rays: bursts.

1. Introduction

The model of neutrino dominated accretion flows (NDAFs) has been studied in our recent papers (Liu *et al*. 2007, 2008, 2010). In Liu *et al*. (2010), we investigated the vertical structure of NDAFs with detailed neutrino radiation by numerically solving the differential equations in the vertical direction. We stress that the flow should be geometrically thick when advection becomes dominant. In this paper, we discuss the enhanced neutrino annihilation luminosity and the possible formation of the accretion flow.

2. Results

Figure 1(a) shows that there exists a narrow empty funnel along the rotation axis. Thus the volume above the disk shrinks and the radiated neutrino density increases. The neutrino annihilation efficiency ($\eta \equiv L_{\nu\bar{\nu}}/L_{\nu}$, L_{ν} and $L_{\nu\bar{\nu}}$ are the neutrino luminosity and the neutrino annihilation luminosity, respectively) can be roughly estimated by $\eta \propto V_{\rm ann}^{-1}$ (e.g., Mochkovitch *et al*. 1993), where $V_{\rm ann}$ is the volume above the disk. $L_{\nu\bar{\nu}}$ can be enhanced by one or two orders of magnitude due to a significant decrease in the volume above the disk (e.g., Liu *et al*. 2010).

The Bernoulli function of the accreted matter is expressed as:

$$B = 4{c_{\rm s}}^2 + \frac{1}{2}({v_{\rm R}}^2 + \Omega^2 R^2) - \frac{GM}{R}, \tag{1}$$

where $c_{\rm s}$ is the sound speed, $v_{\rm R}$ is the radial velocity, Ω is the angular velocity of the disk, and M is the mass of the black hole (e.g., Kato *et al*. 2008). Figure 1(b) shows that Bernoulli function is positive in the region of the disk from $\sim 20R_g$ to

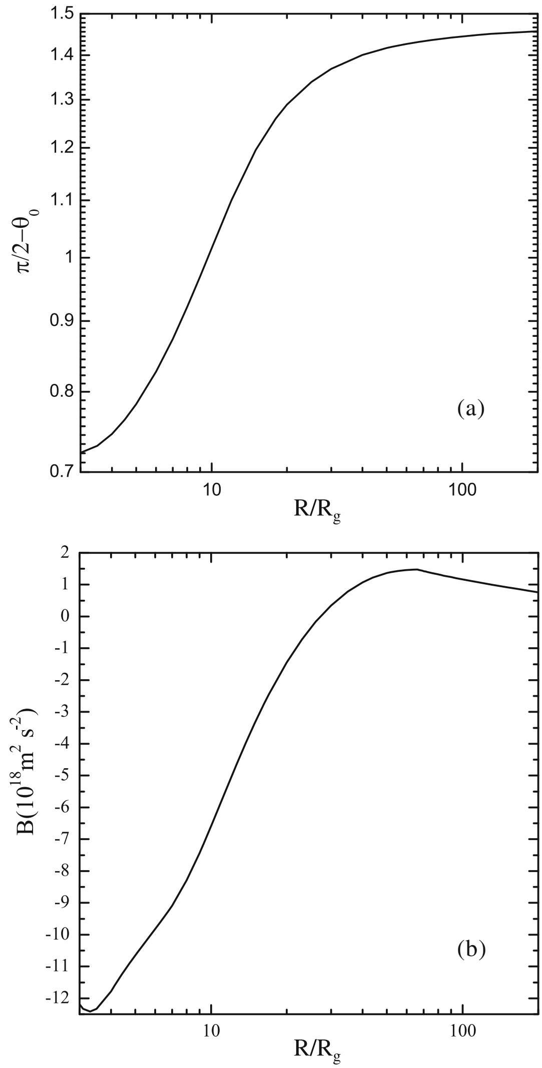

Figure 1. Variations of the half-opening angle of the disk ($\pi/2-\theta_0$) and Bernoulli function B with radius R, for which $M/M_\odot = 3$, the viscosity parameter $\alpha = 0.1$, and the mass accretion rate $\dot{M}/M_\odot\ \mathrm{s}^{-1} = 1$.

$\sim 100R_g$ (R_g is Schwarzschild radius of the black hole), which implies that outflow is possible. Neutrinos are annihilated in the empty funnel along the rotation axis to produce initial photons and most of the leptons in the fireball. On the other hand, the outflow may contribute to the initial baryons and partial leptons of the fireball.

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