Cosmic Magnetic Field:
From Planets, to Stars and Galaxies.
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Dead zone formation and non-steady hyperaccretion in collapsar disks

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Abstract. In ultra dense and hot region realized in stellar core-collapse, neutrino takes major role in energy and momentum transports. We investigate the growth of magnetorotational instability (MRI) in neutrino viscous matter by using linear theory. It is found from the local linear analysis that the neutrino viscosity can suppress the MRI in the regime of weak magnetic field ($B \ll 10^{14}$G). This suggest that MHD turbulence sustained by the MRI might not be driven efficiently in the neutrino viscous media. Applying this result to collapsar disk, which is known as the central engine of gamma-ray burst (GRB), we find that the MRI can be suppressed only in its inner region. Based on this finding, a new evolutionary scenario of collapsar disk, "Episodic Disk Accretion Model" are proposed.

Keywords. Gamma-rays: bursts – accretion disks – MHD

1. Introduction

Gamma-ray bursts (GRBs) are the most energetic event in the universe. GRBs are generally considered to be powered by hyperaccretion onto a stellar-mass black hole (Woosley 1993). The hyperaccretion rate is an order of $0.1 M_{\rm sun} s^{-1}$ and the release of gravitational energies powers the burst.

A key process for releasing the gravitational energy of disk systems is angular momentum transport. As in the case of the other disk systems, the MRI-driven turbulence is believed to play an essential role in the angular momentum transport of the hyperaccretion disk. Physical conditions of the disk are quite different from the others. Because it is ultra-dense and hot like supernova core, the energy and momentum are mainly transported by the neutrino in neutrino-opaque regions. Masada *et al.* (2007a) investigate the effect of neutrino transport on the MRI in the supernova core and show that the neutrino viscosity can suppress the MRI in weak magnetized conditions. We can thus apply these results to the hyperaccretion disk here.

The growth time of the MRI in the absence of viscosity is given by λ / v_A, where λ is the wavelength of a perturbation and $v_A = B/(4\pi\rho)^{1/2}$ is the Alfvén speed. The MRI is suppressed dramatically if the growth time is longer than the viscous damping time $\sim \lambda^2/\nu$, where ν is the kinematic viscosity. Then a large enough viscosity can reduce the linear growth rate of the MRI. Since the typical wavelength of the MRI is $\lambda \sim v_A/\Omega$ with angular velocity Ω, the condition for the efficient growth of the MRI can be given as

$$R_{\rm MRI} \equiv LU/\nu = v_A^2/\nu\Omega \gtrsim 1 \ , \tag{1.1}$$

where $R_{\rm MRI}$ is the Reynolds number for MRI. We choose v_A/Ω as the typical length scale L and v_A as the velocity scale U. In the neutrino-opaque matter, the neutrino viscosity becomes quite large, so that the condition (1.1) would not be satisfied.

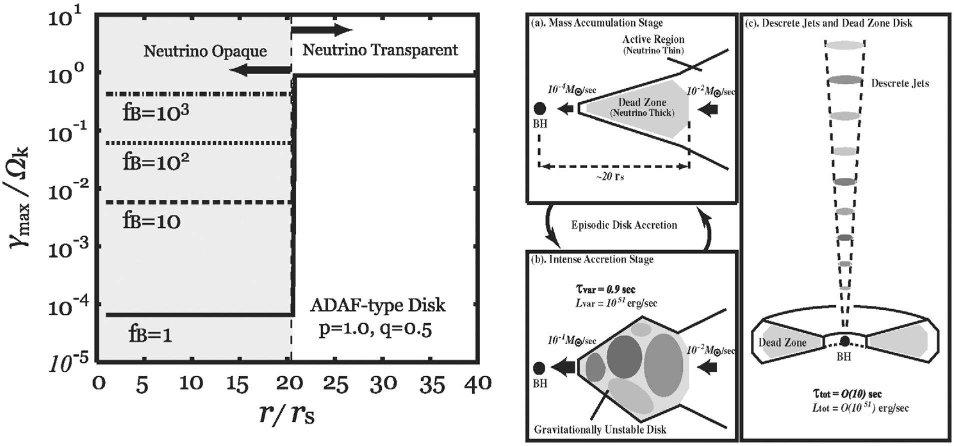

Figure 1. (a). The maximum growth rate of the MRI in ADAF-type collapsar disks as a function of disk radius. (b). Episodic Disk Accretion Model proposed in Masada *et al.* 2007b.

2. Episodic Disk Accretion Model

We investigate where the MRI operates in hyperaccreting collapsar disks focusing on the neutrino viscous effect. As the radial structure of the collapsar disk, we adopt the ADAF-type simple power law model with the surface density $\Sigma(r) = \Sigma_0 \hat{r}^{-0.5}$, the disk temperature $T(r) = T_0 \hat{r}^{-1}$ and magnetic field $B(r) = f_B B_0 \hat{r}^{-1}$, where $\hat{r}$ is the disk radius normalized by Schwarzschild one r_s, $\Sigma_0 = 10^{18}\mathrm{gcm}^{-2}$, $T_0 = 4 \times 10^{11}\mathrm{K}$, and $B_0 = 10^{11}\mathrm{G}$ (see Masada *et al.* 2007b for more details.).

Figure 1a shows the maximum growth rate of the MRI for the cases with different field parameter $f_B = 1$–10^3. The units of vertical and horizontal axes are the Keplerian velocity and Schwarzschild radius. The critical radius dividing the neutrino-thick and thin regions locates at $r_{\rm crit} \simeq 20 r_s$. Gray shaded area represents the neutrino opaque region. The strong field more than 10^{14}G is found to be necessary for the efficient growth of the MRI in collapsar disks. When the magnetic field is weaker than the critical value, the inner disk can be "dead zone" where the MRI is suppressed by the neutrino viscosity.

Finally, we consider a dead zone formed around the inner part of a collapsar disk. Then the angular momentum in the dead zone can be transported by the neutrino viscosity itself with the amplitude $\alpha_v \simeq 10^{-4}$. On the other hand, in the active region, the turbulent viscosity sustained by the MRI should take the angular momentum transport. Nonlinear studies tell us that the α-parameter of the MRI-driven turbulence would be $\alpha_t \simeq 10^{-2}$. The baryonic matter is thus expected to be accumulated into the dead zone from outer active region. If the mass accumulation continues, the inner dead zone becomes gravitationally unstable at some stage. Then the gravitational torque causes intermittent mass accretion and drives discrete jets, which are thought to be the origin of short-term variability in the prompt emission of GRBs. The prospective evolutionary scenario of collapsar disks "Episodic Disk Accretion Model" is depicted schematically in Figure 1b, and which can explain various observational features of GRBs qualitatively (see Masada *et al.* 2007b for more details).

References

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