General Relativistic MHD Simulations of the Gravitational Collapse of a Rotating Star with Magnetic Field as a Model of Gamma-Ray Bursts

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We have performed 2.5-dimensional general relativistic magnetohydrodynamic (MHD) simulations of collapsars as a model of gamma ray bursts (GRBs). This simulation showed the formation of a disk-like structure and the generation of a mildly relativistic jet ($\sim$ 0.3 c). We have found the jet is accelerated by the magnetic pressure and the centrifugal force and is collimated by the pinching force of the toroidal magnetic field amplified by the rotation.

§1. Introduction

GRBs and the afterglows are well described by the fireball model, in which a relativistic outflow is generated from a compact central engine. Rapid temporal decay of several afterglows is consistent with the evolution of a highly relativistic jet with bulk Lorentz factors $\sim 10^2 - 10^3$. The formation of relativistic jets from a compact central engine remains one of the major unsolved problems in GRB models. From recent observations, some evidence was found for a connection between GRBs and the death of massive stars.[1)–4)] It is thus probable that a major subclass of GRBs is a consequence of the collapse of a massive star.

In this study, we perform 2.5-dimensional general relativistic MHD simulations of the gravitational collapse of a rotating star with magnetic field as a model for a collapsar.

§2. Initial condition

In order to study the formation of relativistic jets from a collapsar we use a 2.5-dimensional general relativistic magnetohydrodynamics (GRMHD) code.[5)] We consider a non-rotating black hole as the central black hole. We employ 1-dimensional supernova simulation data of Bruenn (1992)[6)] to obtain the initial density, pressure and radial velocity distribution. We add the effect of stellar rotation and intrinsic magnetic field. See Mizuno et al. (2004)[7)] for details.

§3. Results

The stellar matter falls onto the central black hole at first. This collapse is anisotropic due to the effects of rotation and magnetic field. The matter piles up on

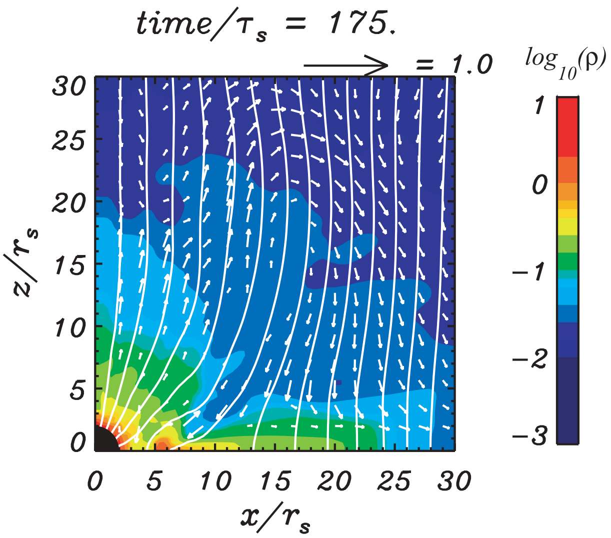

Fig. 1. The snapshot of density at $t/\tau_s = 175$ ($\tau_s \equiv r_s/c$). Accreting matter forms a disk-like structure. The jet-like outflow is ejected.

the equatorial plane, and a disk-like structure is formed near the central black hole. Since the magnetic field is frozen into the plasma, it is dragged by the accreting matter and amplified. The amplified magnetic field expands outwards as Alfvén waves. The jet-like outflow is generated into the expanding magnetic field. The jet-like outflow formed in the simulation is magnetically driven. The jet has a mildly relativistic velocity, ~ 0.3 c (the poloidal velocity is ~ 0.1 c). It exceeds the escape velocity. Thus, the jet is likely to get out of the stellar remnant. The magnetic field plays an important role in the collimation.

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