7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Dependence of the magnetic field and rotation on the explosion mechanism of core-collapse supernovae

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Massive stars undergo explosive phenomena during the terminal stage of their lives. These explosions are called core-collapse supernovae (CCSNe) and manifest as exceptionally energetic and luminous occurrences in the Universe. An outwardly propagating shock wave is excited after the bounce of the core due to the gravitational collapse of the massive star. The explosion occurs when this shock wave reaches the surface of the massive star. However, its advancement is arrested within the Fe core because of the ram pressure exerted on the shock surface within the upstream region. Although the neutrino-heating mechanism is considered to be a key process in driving the explosion of massive stars, the CCSN explosion mechanism is not completely understood yet. Within this framework, neutrinos emitted by a protoneutron star, generated at the epicenter of the collapsing massive star, serve to thermally energize the matter behind the stalled shock wave. The turbulence behind the shock, resulting from convection arising due to negative entropy gradients and/or hydrodynamic instabilities, profoundly amplifies the efficacy of neutrino heating. This is because if the turbulence fully develops, the matter is effectively exposed by neutrinos and can gain substantial thermal energy to overcome the ram pressure due to the mass accretion.

The impact of the magnetic field on the explosion mechanism of CCSNe is a long-standing mystery. Recently, we have updated our neutrino-radiation-hydrodynamics supernova code (3DnSNe)[1] to include magnetohydrodynamics (MHD)[2]. Using this code, we have performed three-dimensional (3D) MHD simulations for the evolution of non- and slowly-rotating stellar cores[3,4]. Figure 1 shows 3D configuration of magnetic field lines and shock surface before/after the onset of the development of the turbulence for a slowly-rotating model. We find that the neutrino heating is the main driver for the explosion in our non-rotating model, whereas the drastic amplification of the magnetic field in a turbulent flow is responsible for the explosion in our rotating models.

This work was supported by JSPS KAKENHI Grant Number JP22H01223.

References

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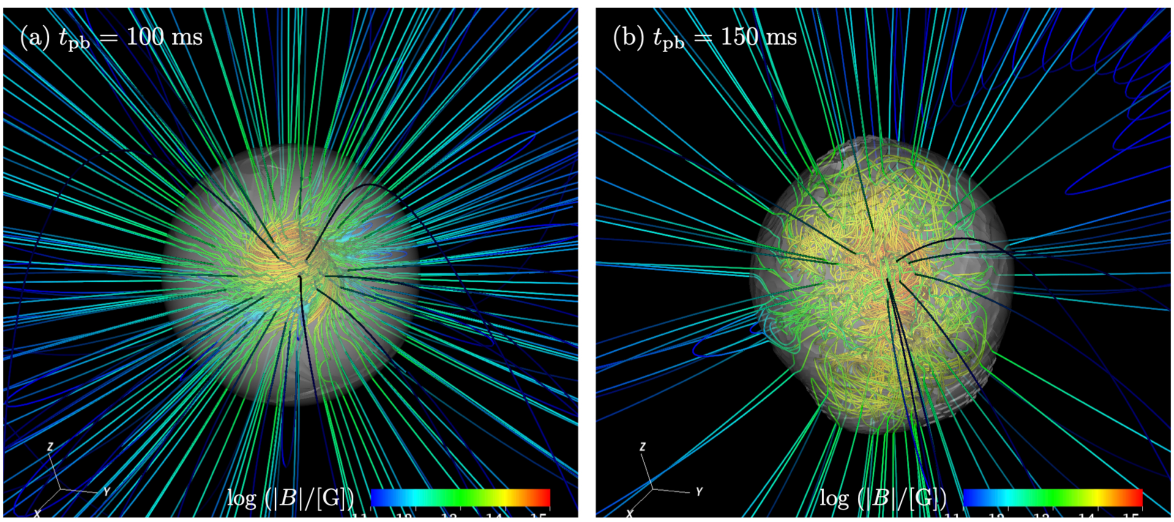

Figure 1. Snapshots of 3D configuration of magnetic field lines and the shock surface (whitish sphere) for a slowly-rotating model. The colors of magnetic field lines mean the absolute strength of the magnetic field. Panel (a) and (b) corresponds to the time t_{pb}=100 and 150 ms after bounce, respectively.