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Magnetic field amplification in chiral magnetohydrodynamic simulation

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One remarkable phenomenon in a system where the chirality imbalance is induced by some processes is the generation of an electric current along the magnetic field, known as the chiral magnetic effect (CME). The importance of the CME has been paid great attention in astrophysical contexts, particularly high-temperature plasmas in the early Universe[1] and core-collapse supernovae[2,3]. In the chiral magnetohydrodynamics (MHD), the amplification of the magnetic field due to the chiral plasma instability (CPI) is a natural outcome of the CME. We have performed three-dimensional (3D) chiral MHD simulations to investigate the properties of CPI in the context of core-collapse supernovae.

We confirm that the magnetic amplification due to the CPI occurs in a wide range of the chiral magnetic conductivity which relates to the current induced by the chirality imbalance. Figure 1 shows 3D configuration of magnetic field lines and the comparison of the magnetic field strength between the linear (panel a) and nonlinear (panel b) phases in our fiducial model. Red and blue tones represent the positive and negative values of the magnetic field, respectively.

In the panel (a), the CPI with the typical wavelength determined by the initial value of the chiral magnetic conductivity for the fiducial model is developed. In addition to the magnetic amplification, the inverse cascade of the magnetic energy is observed in the nonlinear phase (panel b), consistent with previous studies[1,2]. We find the physical origin of the inverse cascade of the magnetic field in chiral MHD simulations. In the linear phase, the chiral magnetic conductivity is independent of time. On the other hand, it decreases in the nonlinear phase. That results in a longer wavelength of the fastest-growing mode derived from the linear theory of the CPI where the typical wavelength of the CPI is inversely proportional to the chiral magnetic conductivity. This is the origin of the inverse cascade of the magnetic energy in chiral MHD simulations.

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References

[1] A. Brandenburg et al., ApJL, 2017, **845**, L21
[2] Y. Masada et al., Phys. Rev. D, 2018, **98**, 083018
[3] J. Matsumoto et al., Phys. Rev. D, 2022, **105**, 123029

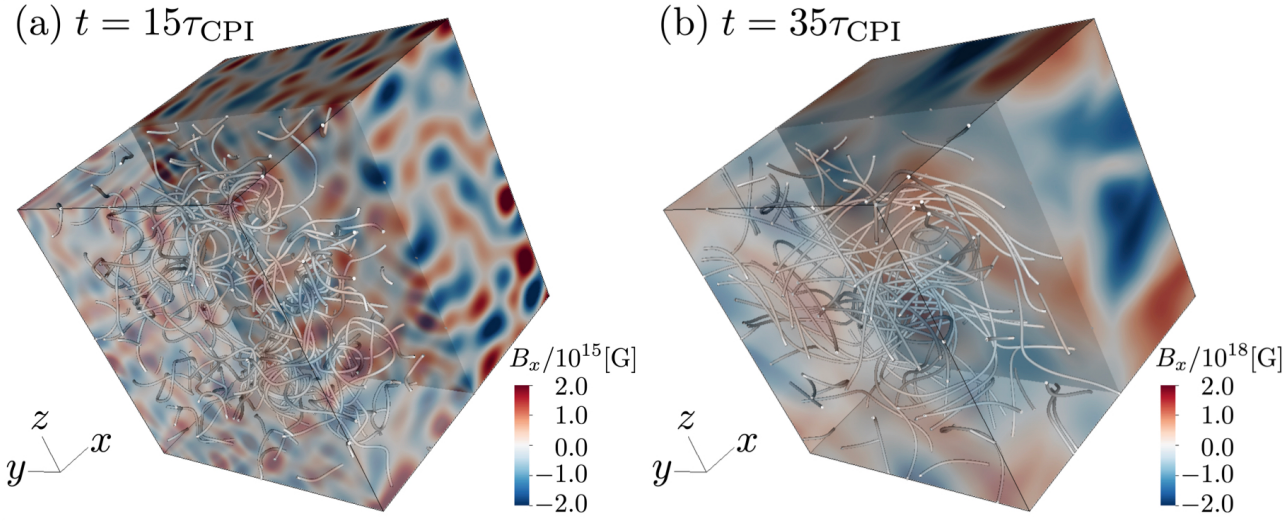

Figure 1. Snapshots of 3D configuration of magnetic field lines and x-component of the magnetic field strength in our fiducial model for the chiral MHD simulation. Red and blue tones represent the positive and negative values of the magnetic field, respectively.