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Magnetic field configurations of magnetars

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Abstract. We evaluated ambipolar diffusion velocity in a magnetar. Previous studies concerning ambipolar diffusion ignored the presence of the crust, although a magnetar has both core and crust. We considered both core and crust and examined the influence of the crust in this study. We found that the crustal magnetic field can accelerate the ambipolar diffusion in its core.

Keywords. stars: neutron, stars: magnetic fields

1. Introduction

A magnetar has strong dipole magnetic field whose value reaches 10^{15} G at its surfaces. Since the magnetar displays both intense persistent emission and dynamical flares releasing the magnetic energy, its magnetic field might be decaying as it ages. Low field magnetars (e.g. Rea *et al.* 2010) are considered as old magnetars whose magnetic fields have decayed. Both Hall effect within the crust (Goldreich & Reisenegger 1992; Naito & Kojima 1994; Kojima & Kisaka 2012; Gourgouliatos *et al.* 2013; Viganò *et al.* 2013) and ambipolar diffusion in the core (Goldreich & Reisenegger 1992; Hoyos *et al.* 2008; Passamonti *et al.* 2017; Castillo *et al.* 2017; Gusakov *et al.* 2017) are important physical process for decaying of magnetic fields. Previous studies concerning ambipolar diffusion, however, considered only its core and ignored the presence of the crust. In this study, we consider both core and crustal magnetic field and examine the influence of the crust.

2. Numerical models and result

We use a npe 3 species core EOS (Glendenning & Moszkowski 1991) and a crust EOS (Douchin & Haensel 2001) to obtain a magnetar model. We assume that the core temperature is 2×10^8 K and isothermal. Previous studies used an analytical core magnetic field model derived by Akgün *et al.* (2013), but we adopt magnetar models with MHD core and Hall equilibrium crust obtained by Fujisawa & Kisaka (2014). Figure 1 displays three magnetic field configurations of our magnetar models. Although the strength of the surface magnetic fields of these models are same ($B \sim 5.0 \times 10^{14}$G), the internal magnetic fields are different due to the presence of the crustal magnetic field (Fujisawa & Kisaka 2014). Model (a) has only poloidal magnetic field, but model (b) and (c) have both poloidal and toroidal magnetic fields. Model (b) has locally strong toroidal magnetic field and model (c) has globally strong toroidal magnetic field. In order to calculate ambipolar diffusion velocity, we use Gusakov *et al.* (2017)'s formulation in this study.

Figure 2 shows ambipolar diffusion velocity in each model. Typical velocities are of 1-10 km Myr^{-1} but the velocity patterns are different from each other. The presence of the crust can accelerate the ambipolar diffusion in the core. Crustal magnetic field and core-crust boundary are important to consider ambipolar diffusion in the magnetar core.

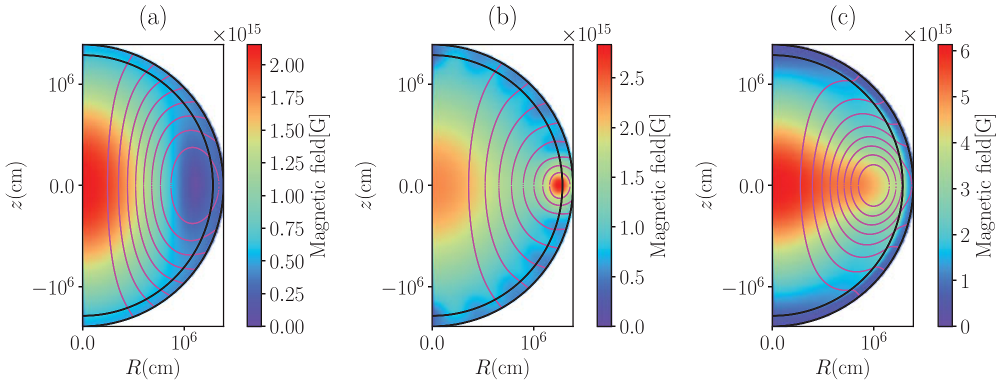

Figure 1. Magnetic field configurations. The color represents the strength of the magnetic field. The solid line is poloidal magnetic field line and the solid curve denotes the core-crust boundary.

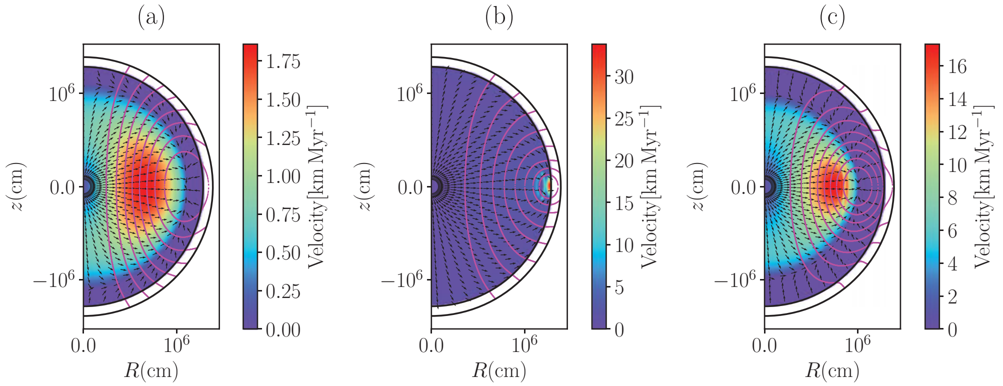

Figure 2. Magnetic field configurations and ambipolar diffusion velocity. The color represents the velocity of the ambipolar diffusion and the arrow denotes the direction of the velocity vector. The length of the arrow is normalized. The solid line is poloidal magnetic field line and the solid curve denotes the core-crust boundary and the stellar surface respectively.

References

Akgün T., Reisenegger A., Mastrano A., & Marchant P., 2013, *MNRAS*, 433, 2445
Castillo F., Reisenegger A., & Valdivia J. A., 2017, *MNRAS*, 471, 507
Douchin F. & Haensel P., 2001, *A&A*, 380, 151
Fujisawa K. & Kisaka S., 2014, *MNRAS*, 445, 2777
Glendenning N. K. & Moszkowski S. A., 1991, *Phys. Rev. Letters*, 67, 2414
Goldreich P. & Reisenegger A., 1992, *ApJ*, 395, 250
Gourgouliatos K. N., *et al.*, 2013, *MNRAS* 434, 2480
Gusakov M. E., Kantor E. M., & Ofengeim D. D., 2017, preprint, arXiv 1705.00508
Hoyos J., Reisenegger A., & Valdivia J. A., 2008, *A&A*,487, 789
Kojima Y. & Kisaka S., 2012, *MNRSA*, 421, 2722
Naito T. & Kojima Y., 1994, *MNRAS*,266, 597
Passamonti A., *et al.*, 2017, 465, 3416
Rea N., *et al.*, 2010, *Science*, 330, 944
Viganò D., *et al.* 2013, *MNRAS*, 434, 123