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ORIGINAL ARTICLE

Magnetic field decay of magnetars in supernova remnants

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Abstract In this paper, we modify our previous research carefully, and derive a new expression of electron energy density in superhigh magnetic fields. Based on our improved model, we re-compute the electron capture rates and the magnetic fields' evolutionary timescales t of magnetars. According to the calculated results, the superhigh magnetic fields may evolve on timescales $\sim(10^6{-}10^7)$ yrs for common magnetars, and the maximum timescale of the field decay, $t \approx 2.9507 \times 10^6$ yrs, corresponding to an initial internal magnetic field $B_0 = 3.0 \times 10^{15}$ G and an initial inner temperature $T_0 = 2.6 \times 10^8$ K. Motivated by the results of the neutron star-supernova remnant (SNR) association of Zhang and Xie (2011), we calculate the maximum B_0 of magnetar progenitors, $B_{\max} \sim (2.0 \times 10^{14}{-}2.93 \times 10^{15})$ G when $T_0 = 2.6 \times 10^8$ K. When $T_0 \sim 2.75 \times 10^8{-}1.75 \times 10^8$ K, the maximum B_0 will also be in the range of $\sim 10^{14}{-}10^{15}$ G, not exceeding the upper limit of magnetic field of a magnetar under our magnetar model. We also investigate the relationship between the spin-down ages of magnetars and the ages of their SNRs, and explain why all AXPs associated with SNRs look older than their real ages, whereas all SGRs associated with SNRs appear younger than they are.

Keywords Magnetar · Electron capture rate · Supernova remnant · Superhigh magnetic field

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1 Introduction

Recent developments have shown that a substantial fraction of newly born stars have magnetic field strengths in excess of the quantum critical value, $B_{\rm cr} = 4.414 \times 10^{13}$ G, above which the effect of Landau quantization on the transverse electron motion becomes considerable (Ternov et al. 1965). We divide them into two glasses—Soft Gamma-ray Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs) through the studies of their emission mechanisms. The SGRs and AXPs are currently considered to be 'magnetars', powered by extremely strong magnetic fields, rather than by their spin-down energy loss, as is the case for common radio pulsars (Duncan and Thompson 1992; Thompson and Duncan 1993, 1996).

A supernova remnant (SNR) is an expanding diffuse gaseous nebula that results from the explosion of a massive star. To date, there are 23 detected magnetar candidates: 11 SGRs (7 confirmed), and 12 AXPs (9 confirmed). Of the magnetar candidates, 4 SGRs and 5 AXPs (more than a third) are associated with the known SNRs, suggestive of an origin in massive star explosions (Gaensler et al. 2001; Marsden et al. 2001; Allen and Horvath 2004; Mereghetti 2008). Estimations indicate that about 10 % of supernova explosions may lead to a magnetar (Kouveliotou et al. 1994).