Properties of Magnetars Mimicking ⁵⁶Ni

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Recent large-scale transient surveys revealed the existence of extremely luminous supernovae (SNe) that are called superluminous SNe. The luminosities of canonical SNe can be explained by the energy provided by the nuclear decay of ⁵⁶Ni that is synthesized during the SN explosions. However, while the required amount of ⁵⁶Ni to explain the luminosities of canonical SNe is of the order of $0.1 \,\mathrm{M_{\odot}}$ at most, superluminous SNe require more than $5 \, M_{\odot}$ of 56 Ni to account for their luminosities. It is difficult to synthesize this amount of ⁵⁶Ni during the SN explosions. Thus, to replace the ⁵⁶Ni heating mechanism, an alternative scenario to explain the huge luminosities of superluminous SNe, i.e., the formation of the rapidly-rotating strongly-magnetized neutron stars (magnetars) that can release their huge rotational energy through the radiation caused by the strong magnetic fields and efficiently thermalize the radiation is suggested. On the other hand, if we look into the light curves (LCs) of superluminous SNe, it is known that the decline rates of their LCs are often consistent with that is expected from the nuclear decay of ⁵⁶Co made by the nuclear decay of ⁵⁶Ni. Thus, if magnetars are actually the major heating source to make superluminous SNe bright, magnetars should be able to reproduce the LC decline rates that are consistent with those of ⁵⁶Co. In this study, we investigated the conditions for magnetars to reproduce SN LCs that look as if they are powered by ⁵⁶Ni [1]. As a result, it is found that magnetars need to emit their radiation almost by the pure dipole radiation to mimic ⁵⁶Ni. In addition, it is found that, for magnetars that release their rotational energy through dipole radiation to mimic a LC powered by a certain amount of ⁵⁶Ni, only their dipole magnetic fields need to be in a certain range and the condition does not depend on their initial rotational periods. In Fig. 1, we present the require magnetic field strength to mimic a given amount of ⁵⁶Ni. For example, a typical amount of ⁵⁶Ni required to explain the peak luminosities of superluminous SNe are about $10 \, M_{\odot}$ and it can be found that about $10^{14} \, G$ is required for magnetars to mimic LCs powered by this amount of ⁵⁶Ni. Interestingly, the required magnetic field strengths for magnetars to explain the early LCs of superluminous SNe are also about 10¹⁴ G. Fig. 2 shows rise times and peak luminosities of SN LCs that can be powered by magnetars as if ⁵⁶Ni is powering them. The gray region indicates all the LC properties that magnetars can mimic ⁵⁶Ni. However, if a LC requires more ⁵⁶Ni than ejecta, for example, we can clearly say that the LC is not powered by ⁵⁶Ni. If we exclude this kind of region, the black region remains. In other words, the SN LCs that fall into

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the black region may actually be powered by magnetars even if they look as if they are powered by ${}^{56}Ni$. The dots in Fig. 2 are LC properties of superluminous SNe and they locate in the region where magnetars can mimic ${}^{56}Ni$.



Figure 1: Dipole magnetic fields that magnetars require to mimic given amounts of ⁵⁶Ni.



Figure 2: SN LC properties for which magnetars can power like ⁵⁶Ni.

Reference

[1] Moriya, T. J., Chen, T.-W., Langer, N.: 2017, ApJ, 835, 177.