Supernovae Powered by Magnetars That Transform into Black Holes

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New kinds of supernovae (SNe) are starting to be discovered thanks to the recent large transient surveys. One of them is so-called superluminous SNe that are more than about 10 times brighter than normal SNe. The mechanism to make superluminous SNe so bright is not yet revealed. The most popular model is to make SNe superluminous with rapidly-rotating strongly-magnetized neutron stars (magnetars) that are formed during the SN explosions. If a magnetar that has a rotation period of less than a few ms and a dipole magnetic field of about 10^{14} G is formed during a SN explosion, the rotation energy of the magnetar (about 10^{52} erg) is released as a dipole radiation in a timescale of several days. It is known that observational properties of superluminous SNe can be explained if the magnetar can release its rotational energy and the released energy is efficiently thermalized.

Neutron stars have the maximum mass to support themselves and the neutron stars whose mass exceeds the maximum mass transform into black holes. The maximum mass depends on the rotation velocity of neutron stars. The maximum mass of non-rotating neutron stars is about 2.2 $M_\odot$ and that of rapidly-rotating neutron stars is about 2.7 $M_\odot$, depending on the equation of state. If a magnetar whose mass is between about 2.2 $M_\odot$ and about 2.7 $M_\odot$ is formed during a SN explosion, it can heat up the SN at first when it rotates rapidly. However, when it loses a lot of rotational energy and its rotational energy becomes less than that required to support itself, the magnetar transforms into a black hole and the SN suddenly loses its central heating source. In this study, we investigate observational properties of such SNe that are powered by magnetars that need rotational energy to support themselves and suddenly lose their central heating source due to the black-hole formation [1].

Fig. 1 presents how SN light curves (LCs) are affected by the transformation of magnetars into black holes. Because the black-hole formation leads to the sudden loss of the central heating sources, LCs become fainter when the black-hole formation occurs. In addition, if the black holes are formed shortly after the SN explosion, the shock breakout signals caused by the shock wave launched by the magnetar energy input can be clearly seen in the LCs.

Fig. 2 shows comparisons between LCs of the SNe powered by magnetars transforming into black holes and those of some observed SNe. SNe powered by magnetars that transform into black holes do not become as bright as superluminous SNe but their LCs are consistent with those of recently-found rapidly-evolving transients that have the peak luminosities between superluminous SNe and normal SNe.

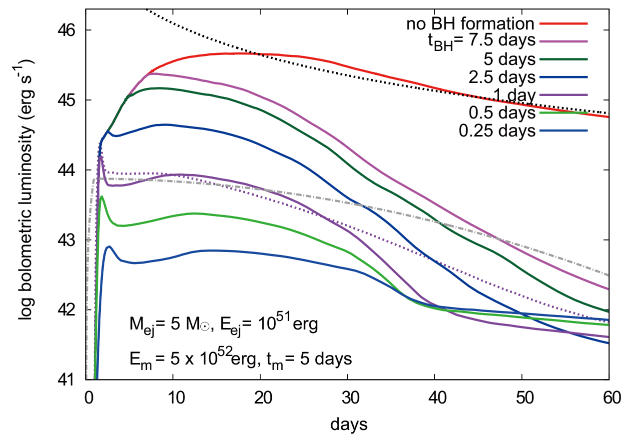

Figure 1: SN LCs in which magnetars powering the SNe transform into black holes. t_{BH} is the time when magnetars transform into black holes.

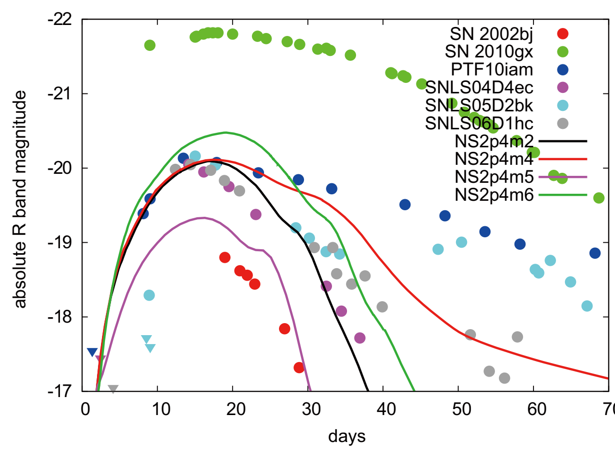

Figure 2: Comparison between model SN LCs in which magnetars powering the SNe transform into black holes and some observed SN LCs.

Reference

[1] Moriya, T. J., Metzger, B. D., Blinnikov, S. I.: 2016, *ApJ*, **833**, 64.