PROCEEDINGS OF SCIENCE

Concluding Remarks - II

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Type Ia supernovae (SNe Ia) play important roles in astronomy and astrophysics. Nevertheless, their progenitors have been controversial. Recently, the observations of a nearby SN Ia put strong constraints on the SN Ia progenitor models. We summarize what progenitor models survive still, and what progenitor models will be constrained next.

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Type Ia supernovae (SNe Ia) have several important roles in astronomy and astrophysics. They are one of the brightest and most common astronomical transients in the universe, are utilized as a cosmic distance indicator, and should be a main source of iron group elements. It has been widely accepted that SNe Ia are the outcome of thermonuclear explosion of carbon-oxygen (CO) white dwarfs (WDs) in binary systems [1]. Nevertheless, the nature of WD companion stars has been under debate. It can be non-degenerate stars, such as red-giant and main-sequence stars (SD scenario) [2, 3], degenerate stars, in other words another WDs, (DD scenario) [4, 5], or stellar cores of giant stars (CD scenario) [6].

Many studies have attempted to constrain the nature of WD companion stars. The statistical properties of SNe Ia, such as their delay time distribution, can be explained by both the SD and DD scenarios. Binary population synthesis models [7–9] have suggested that the DD scenario can successfully reproduce the power law index of the delay time distribution of SNe Ia (~ -1) [10]. On the other hand, this is also true for the SD scenario [11]. A sort of golden events may determine the progenitors of SNe Ia. If a nearby recurrent nova, such as M31N 2008-12a [12], will explode as a normal SN Ia, it will exclusively concludes that the SD scenario is correct. However, such a golden event is unpredictable. It can happen tomorrow, or a few 100 years later. It is unclear if such a golden event will be the deciding factor for the progenitors of SNe Ia.

The observations of SNe Ia located $\lesssim 10$ Mpc away may strongly constrain the progenitors of the SNe Ia. They are not extremely rare (one per a few 10 years), and are observed well. Several strong constraints have been put on the SD scenario mainly due to the observations of SN2011fe, a normal SN Ia, located ~ 6.7 Mpc away. There is no red-giant star in the pre-explosion image [13]. There is no evidence of the presence of helium star nor main-sequence star 11.5 years after the explosion [14]. The SD scenario has been largely constrained, while it has not yet been completely ruled out. Moreover, even if the SD scenario will be ruled out, the positive evidence of the DD scenario should be needed. We use this opportunity to make clear what progenitor models have not yet been constrained, and will be constrained most easily in the near future.

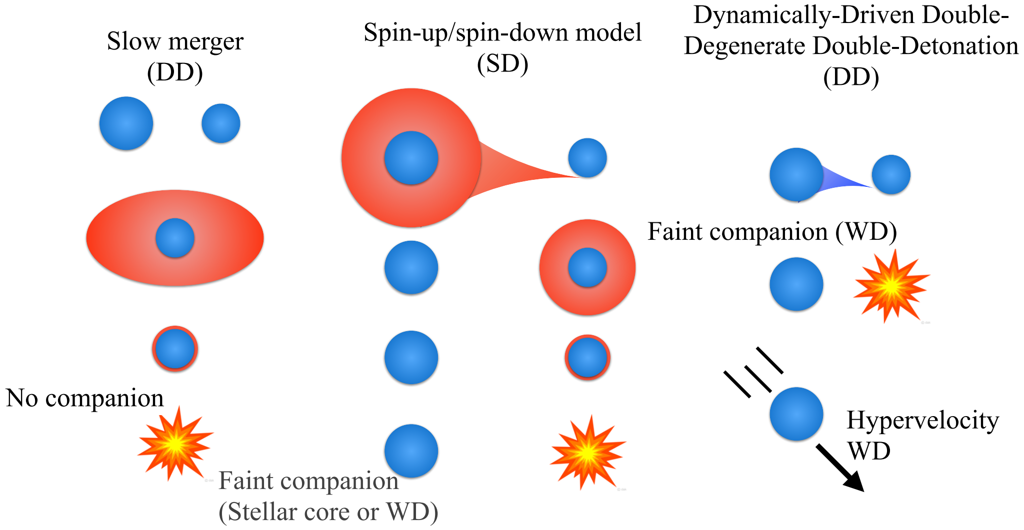

Figure 1: SN Ia progenitor models not yet constrained by the observations of SN2011fe.

In Figure 1, we show SN Ia progenitor models not yet constrained by the observations of SN2011fe. The slow merger model [15], the conventional DD scenario, is drawn in the left side. In this model, the exploding WD does not have any companion star at the explosion moment. It is difficult to constrain the slow merger model. The spin-up/spin-down model [16–19], the SD scenario, is illustrated in the middle.. In this model, the exploding WD has a stellar core or another WD $\gtrsim$ 1 au (or the size of a red-giant star) away. Since it explodes effectively as a single WD, it is also difficult to constrain the spin-up/spin-down model. In the right side, we draw the Dynamically-Driven Double-Degenerate Double-Detonation (D^6) model [20]. The exploding WD has a close WD companion $0.1R_\odot$ away, since the explosion is triggered by mass accretion from the WD companion. The presence of the close WD companion may leave imprints on the observational features of SNe Ia and their remnant. The D^6 model should be easiest to constrain among the three models drawn in Figure 1.

There are several possibilities of the imprints. The most prominent one is hypervelocity WDs [20, 21]. On the other hand, it is pointed out that a hypervelocity WD is too fast to be the remnant of the D^6 explosion [22]. The presence of hypervelocity WDs can affect the light curves of SNe Ia, while SN2011fe does not show such features [23]. Close WD companions can act as obstacles of SN Ia ejecta, and SN Ia ejecta should have non-spherical shapes [24–26]. Such non-spherical shapes survive a few thousand year [27], and leave imprints on SN Ia remnants. Hypervelocity WDs are inflated for an unknown reason [28]. The reason should be an important if the origin of hypervelocity WDs is the D^6 explosion or not. Although the D^6 model is not fully supported or rejected, it should be clear in the near future if the D^6 model is correct or not.

We summarize this paper. Recently, the observations of a nearby SN Ia (SN2011fe) put strong constraints on the SD scenario. We draw three surviving models of SNe Ia in Figure 1. Among them, the D^6 model will be constrained easiest by several types of observations. In the near future, it should be clear if the D^6 model is correct or not.

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