Binary Paths to Type Ia Supernovae Explosions
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Light Curve Models for SN 2009dc

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Abstract. Simplified explosion models of super-Chandrasekhar-mass C-O white dwarfs (WDs) are constructed with parameters such as WD mass and ^{56}Ni mass. Their light curves are obtained by solving one-dimensional equations of radiation hydrodynamics, and compared with the observations of SN 2009dc, one of the overluminous Type Ia supernovae, to estimate its properties. As a result, the progenitor of SN 2009dc is suggested to be a 2.2–2.4-$M_\odot$ C-O WD with 1.2–1.4 $M_\odot$ of ^{56}Ni, if the extinction by its host galaxy is negligible.

Keywords. supernovae: individual (SN 2009dc) — radiative transfer — white dwarfs

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SN 2009dc is one of the overluminous Type Ia supernovae (SNe Ia) and is estimated to have $\geqslant$1.2 $M_\odot$ of ^{56}Ni (e.g., Yamanaka *et al.* 2009). To explain the production of such a large mass of ^{56}Ni, its progenitor is proposed to be a super-Chandrasekhar-mass (super-Ch-mass) C-O white dwarf (WD). An asymmetric explosion of a Ch-mass C-O WD could also explain the high luminosity of SN 2009dc (Hillebrandt *et al.* 2007), but is unlikely because of the observed small polarization for SN 2009dc (Tanaka *et al.* 2010).

To study the properties of SN 2009dc from its light curves (LCs), simplified explosion models of super-Ch-mass C-O WDs are constructed in a manner similar to Maeda & Iwamoto (2009). A model is parameterized by its masses of WD, electron-captured (stable Fe-peak) elements (ECEs; Fe, Co, and ^{58}Ni), ^{56}Ni, intermediate-mass elements (IMEs; Si, S, Ca), and C and O ($M_{\rm WD}$, $M_{\rm ECE}$, $M_{\rm Ni}$, $M_{\rm IME}$, and $M_{\rm CO}$, respectably). Once the above parameters are set, its kinetic energy ($E_{\rm kin}$) is calculated, assuming that the central density is 3×10^9 g cm^{-3}. Then the density and velocity structures are obtained by scaling those of W7 (Nomoto *et al.* 1984, Thielemann *et al.* 1986) with $M_{\rm WD}$ and $E_{\rm kin}$. For its abundance distribution, the model consists of ECEs, ^{56}Ni, IMEs, and C-O layers, from the center to the surface. However, mixing is assumed for a certain region due to the observed slow Si II line velocity (Yamanaka *et al.* 2009). The parameter ranges in this study are $M_{\rm WD}/M_\odot = 1.8, 2.0, \ldots, 2.8$; $M_{\rm Ni}/M_\odot = 1.2, 1.4, 1.6, 1.8$; $M_{\rm ECE}/M_{\rm WD} = 0.1, 0.2, \ldots$; and $M_{\rm CO}/M_{\rm WD} = 0.1, 0.2, \ldots$. With the relation, $M_{\rm WD} = M_{\rm ECE} + M_{\rm Ni} + M_{\rm IME} + M_{\rm CO}$, $M_{\rm IME}$ is hereafter not indicated. Any model whose $E_{\rm kin}$ is not positive is excluded.

The STELLA code is used to calculate the LCs, which solves one-dimensional equations of radiation hydrodynamics (e.g., Blinnikov *et al.* 1998). In this study, multi-band (U-, B-, V-, R-, and I-band) LCs are obtained, as well as bolometric ones. The "bolometric" LCs in the observations are not truly bolometric, but cover *uvoir*. For SN 2009dc, the observed *uvoir* luminosity is assumed to be ~1.6 the integrated $BVRI$ one (Yamanaka *et al.* 2009), which is common for normal SNe Ia (Wang *et al.* 2009). Since it is still unknown whether this assumption is true for overluminous SNe Ia, $BVRI$ LCs are compared in the following.

The resultant $BVRI$ LCs of the models show a similar tendency to that in Maeda & Iwamoto (2009); a massive WD model has a wider $BVRI$ LC and vice versa. Since SN

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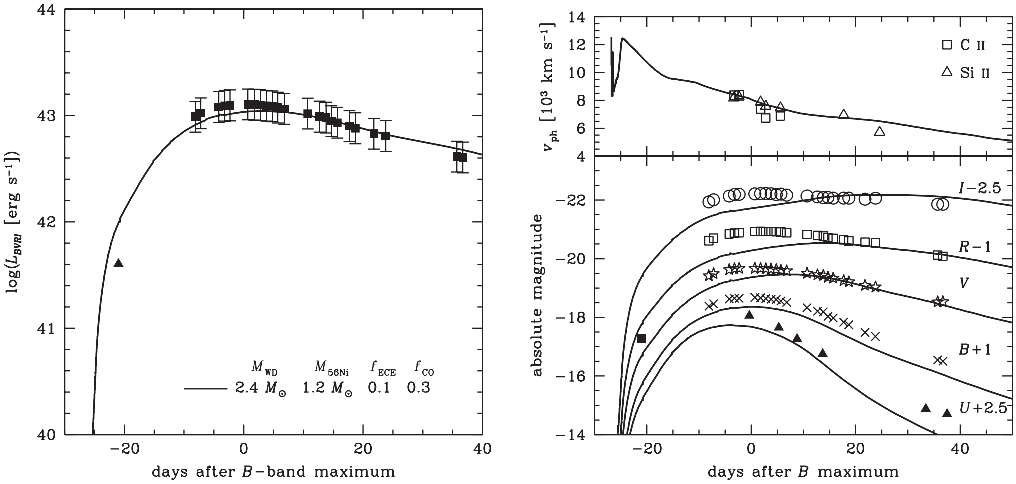

Figure 1. Comparison of the most preferred model with SN 2009dc. The model parameters are indicated in the left panel. The observational data are taken from Yamanaka *et al.* (2009), except for the early detection (triangle in the left panel, filled square in the right-bottom), estimated from Silverman *et al.* (2011). Note that the extinction by the host galaxy is neglected.

2009dc shows a wide $BVRI$ LC, lighter WD models such as $M_{\rm WD} = 1.8\ M_\odot$ can be excluded. Many models have much larger photospheric velocity ($v_{\rm ph}$) than the observed line velocity. To make a further comparison between the $BVRI$ LCs of the models and the observations without the host-galaxy extinction, χ^2 is calculated for the models with smaller $v_{\rm ph}$. Among them, the models with $M_{\rm WD}$ = 2.2–2.4 $M_\odot$, $M_{\rm Ni}$ = 1.2–1.4 $M_\odot$, $M_{\rm ECE} = 0.1 M_{\rm WD}$, and $M_{\rm CO} = 0.3 M_{\rm WD}$ show relatively small χ^2, being well fitted to the observation (Figure 1). These models indicate that the progenitor of SN 2009dc should have a relatively massive C-O layer, which results in smaller $E_{\rm kin}$ and thus $v_{\rm ph}$.

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