

Late-Phase Observations of a Super-Chandrasekhar SN Ia

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Abstract. A super-Chandrasekhar (SC) supernova (SN) has an extremely high luminosity and a slow decline rate of the light curve in the early-phase. We present late-phase observations of the SC SN 2009dc. We find that the optical luminosity a year after maximum is much fainter than that expected from its early luminosity. We attempt to fit the analytic light curve model to the observations using Arnett's rule. The model successfully explains the light curves until 120 days. This suggests that the extremely high luminosity originates from the ⁵⁶Ni decay. We suggest that the late-phase decline would be caused by dust formation. The existence of strong carbon features in early-phase spectra would support this scenario. We also find a blend of [Ca II] and [Ni II] in its late-phase spectrum. This indicates that the calcium is distributed in the inner layer along with nickel and iron. We conclude that the mixing may occur in the inner parts of the ejecta.

Keywords. supernovae: individual (SN 2009dc)

1. Introduction

SN 2009dc exhibits an extremely high luminosity ($M_V = -20.3$) and a very slow decline rate ($\Delta m_{15}(B) = 0.65$) in its early-phase (Yamanaka *et al.* 2009, Silverman *et al.* 2011, Taubenberger *et al.* 2011). Spectra show the deep C II $\lambda 6580$ absorption line, which is not seen in typical SNe Ia. The line velocity of Si II and C II is estimated to be 8,000 km s⁻¹, which is slower than the 12,000 km s⁻¹ of typical SNe Ia. The observational properties of SN 2009dc are similar to those of SN 2006gz. The ⁵⁶Ni mass is calculated to be 1.8 M_⊙ from the peak quasi-bolometric luminosity, assuming that the extinction is $A_V = 0.43$ and the rise time is 20 days (Yamanaka *et al.* 2009). The presence of large amounts of carbon supports that the total ejected mass is even more. Low polarization of the continuum also support this (Tanaka *et al.* 2010). From these observational facts, Yamanaka *et al.* 2009 conclude that SN 2009dc is a super-Chandrasekhar SN Ia (see also Silverman *et al.* 2011, Taubenberger *et al.* 2011).

2. Late-Phase Observations

A late-phase spectrum is a useful tool to understand the inner structure of SN ejecta. As an SN expands, the ejecta become optically thin. Thus, late-phase observations of an

SN inform us of the inner structure of the ejecta. We performed optical photometric and spectroscopic observations using the 8.2m Subaru telescope with FOCAS (Kashikawa *et al.* 2002) on May 13, 2010 (383 days after B -band maximum). For photometry, we used B , V , R_C and I_C filters. For spectroscopy, the spectral coverage is 3800–10200Å and the resolution is $R \sim 500$.

3. Results

We constructed the quasi-bolometric light curves using B , V , R_C and I_C -band light curves (Figure 1). The early-phase light curves are from Yamanaka *et al.* 2009. The quasi-bolometric light curves indicate that the late-phase luminosity is fainter than that expected from the early-phase luminosity. We attempt to fit to the light curve using Arnett's rule (Arnett *et al.* 1982). The analytic model successfully explains the light curves until 120 days after B -band maximum. Thus, we conclude that the early-phase luminosity originates from ^{56}Ni decay. We suggest that the late-phase luminosity is decreased by dust formation. The presence of carbon supports this scenario. The much redder color than a typical SN Ia at late-phase also supports it. In Figure 2, we consider the possible identification of $[\text{Ca II}]\lambda 7299$ in the late-phase spectrum, by comparing the spectrum of SN 2009dc with a typical SN Ia, SC SN 2006gz (Maeda *et al.* 2009) and with a core-collapse SN 1993J. This calcium line shows a redshift of 300 km s^{-1} , while the nickel and iron emission lines are blueshifted by 600 km s^{-1} . This indicates that the calcium is distributed in a layer interior to that of the iron-group elements. This situation could be produced by the mixing in the ejecta.

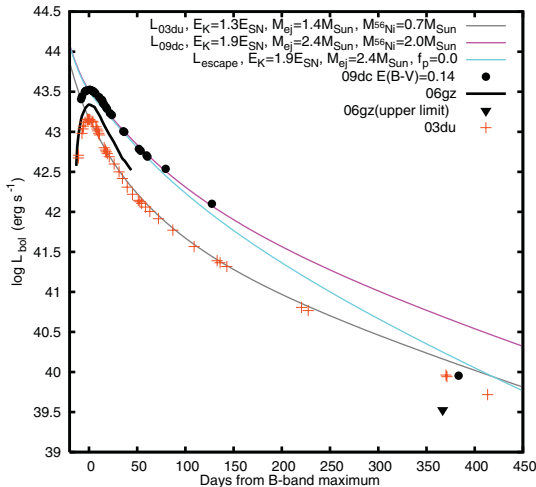


Figure 1. The quasi-bolometric light curve of SN 2009dc compared with those of a typical SN Ia 20003du and another SC SN 2006gz. Analytic light curves are constructed based on Arnett's rule (Arnett *et al.* 1982) for the total ejected mass of $2.4M_{\odot}$ and kinetic energy of 1.9×10^{51} erg, denoted as the pink line.

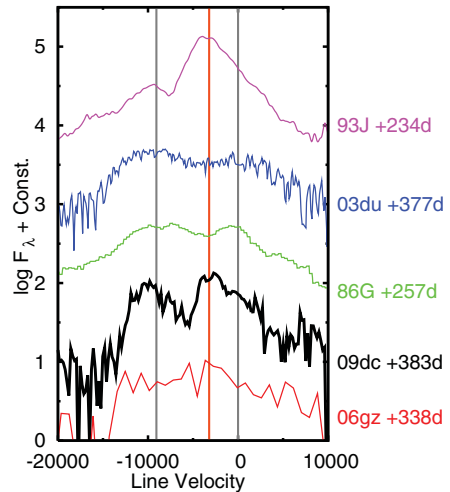


Figure 2. Emission lines of SC SN 2009dc compared with another SC SN 2006gz (Maeda *et al.* 2009), typical SN Ia 2003du (Stanishev *et al.* 2007), sub-luminous SN 1986G and core-collapse Type IIb SN 1993J. The two vertical gray lines denote the rest frame velocity of $[\text{Fe II}]\lambda 7155$ and $[\text{Ni II}]\lambda 7379$. On the other hand, the vertical red line denotes that of $[\text{Ca II}]\lambda 7299$.

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