

CSM formation via super-Eddington accretion in double WD system as Progenitors of Type Ia supernovae

Yusuke Inoue (Kyoto U.), Collaborator: Keiichi Maeda (Kyoto U.)

Abstract

✓**Background** The main progenitor channel of Type Ia SNe are unclear. Are they WD-MS (Single degenerate: SD) or WD-WD (Double degenerate: DD) binaries?

✓**Our study** We propose that Circumstellar matter (CSM) could be a tracer of the DD scenario.

✓**Results** ①DD system could form CSM which affects their light curves in early phase (~0.1-1.0 days).

②Our CSM model can explain the light curves of some over-luminous Ia (SNe 2020hvf, 2021zny and 2022ilv), which show an initial flash.

1. Background

- The main progenitor channel of Type Ia SNe is unclear. The DD system is one of the candidates [e.g., Sato+ 15].
- The DD system could produce various types of Ia SNe. For example,
 - Typical Ia SNe: e.g., $1.1 M_{\odot} + 0.9 M_{\odot}$ [Pakmor+ 12], = $1.4 M_{\odot}$ (total)
 - Over-luminous Ia: $> 1.4 M_{\odot}$ (total) [e.g., Howell+ 06]
 - Sub-luminous Ia: e.g., $0.9 M_{\odot} + 0.9 - 0.76 M_{\odot}$ [Pakmor+ 10, 12]

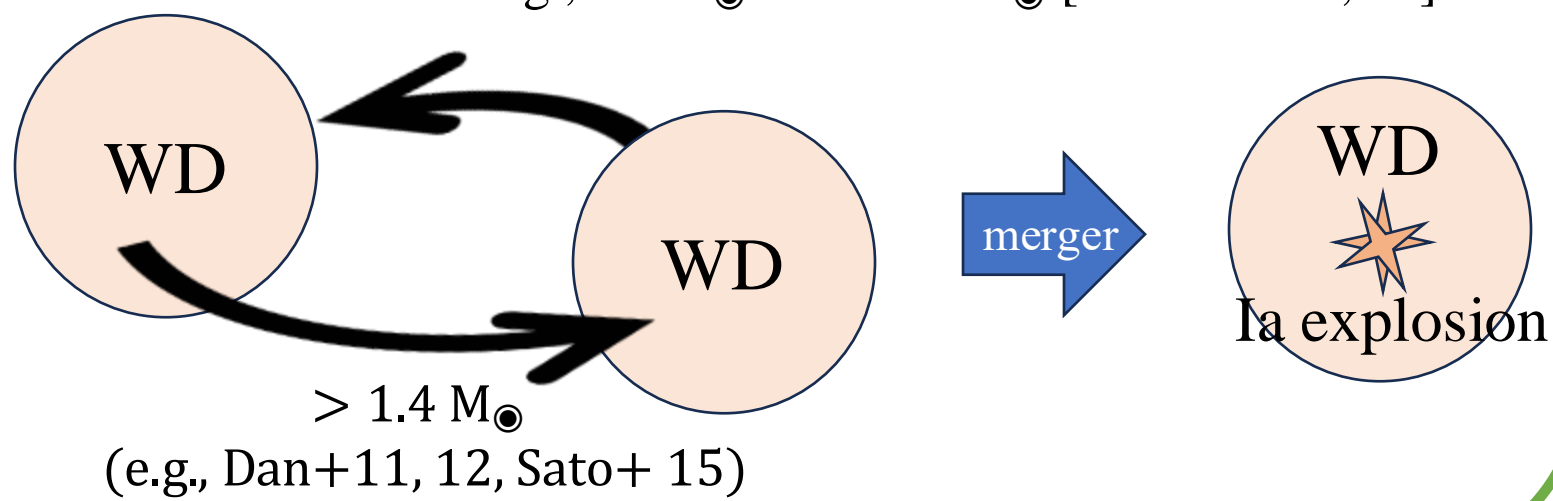


Fig. 1 The schematic picture of DD scenario

2. Our study

- We propose that Circumstellar matter (CSM) could be a tracer of the DD scenario.
- Mass transfer occurs just before the WD merger.
- CSM could be formed when the mass transfer rate exceeds the super-Eddington accretion rate.
- We model the CSM formation and discuss the observational signature of the CSM in optical light curves (LCs) of SNe Ia.

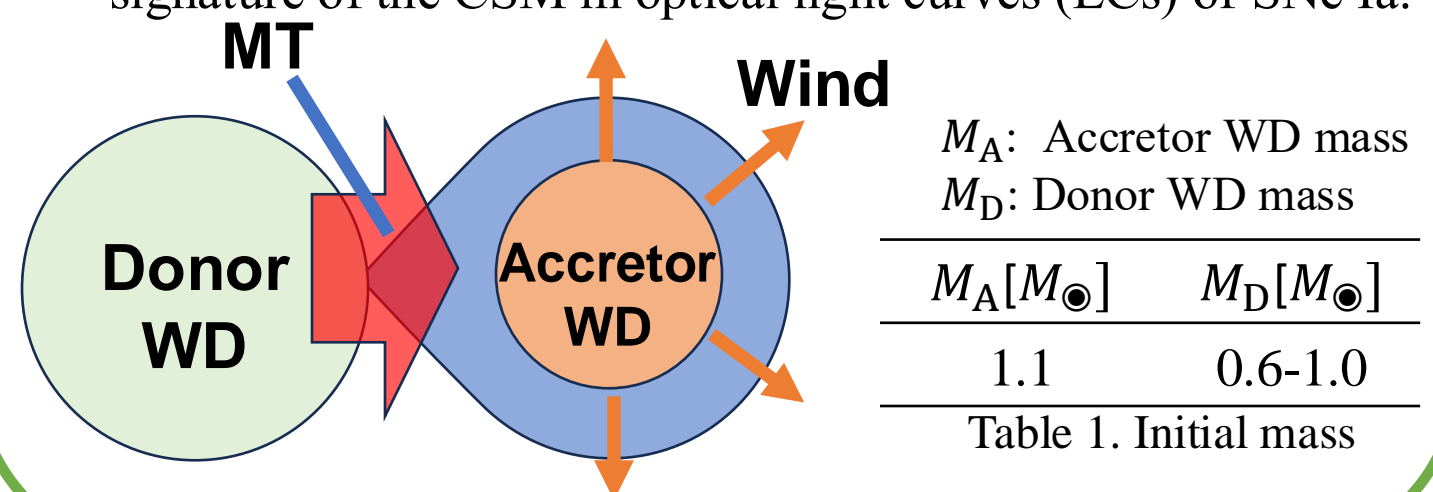


Fig. 2 Mass-transfer model in DD system

Mass transfer & CSM

※ Simulation: Start: $\dot{M}_D \lesssim \dot{M}_{\text{Edd}}$, Stop: $a \lesssim a_{\text{tidal disruption}} = 2(M_A/M_D)^{1/3} R_D$

3. Mass transfer & wind model [Hachisu+ 99, Nelemans+ 01, Marsh+ 04]

$$\frac{\dot{a}}{a} = -2 \frac{\dot{M}_A}{M_A} - 2 \frac{\dot{M}_D}{M_D} + \frac{\dot{M}_A + \dot{M}_D}{M_A + M_D} + 2 \frac{\dot{J}_{\text{orb}}}{J_{\text{orb}}} \quad \left(\frac{\dot{J}_{\text{orb}}}{J_{\text{orb}}} = \frac{\dot{J}_{\text{GR}}}{J_{\text{orb}}} + \frac{\dot{J}_{\text{MT}}}{J_{\text{orb}}} + \frac{\dot{J}_{\text{outflow}}}{J_{\text{orb}}} \right)$$

$$\frac{dM_D}{dt} = \dot{M}_D(R_D, R_L, P_{\text{orb}})$$

$$\frac{dM_A}{dt} = \dot{M}_D - \dot{M}_{\text{wind}}$$

$$\dot{M}_{\text{wind}} \sim f_{\text{loss}} \dot{M}_D \quad (\dot{M}_D > \dot{M}_{\text{Edd}})$$

($f_{\text{loss}} \approx 0.1 - 0.5$:
Optically thick wind model [Quataert+ 16])

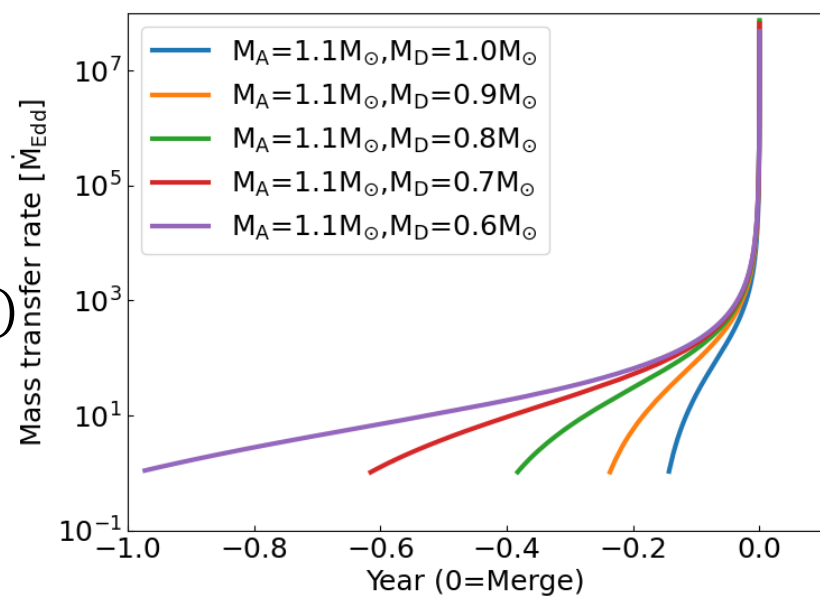


Fig. 3 The evolution of the mass transfer rate

Result:
Mass transfer time-scale
 $\tau_{\text{MT}} \sim 0.1 - 1.0$ yr
 $M_D/M_A \downarrow \Rightarrow \tau_{\text{MT}} \uparrow$

4. CSM formation

$\dot{M}_{\text{wind}} \Rightarrow$ CSM formation

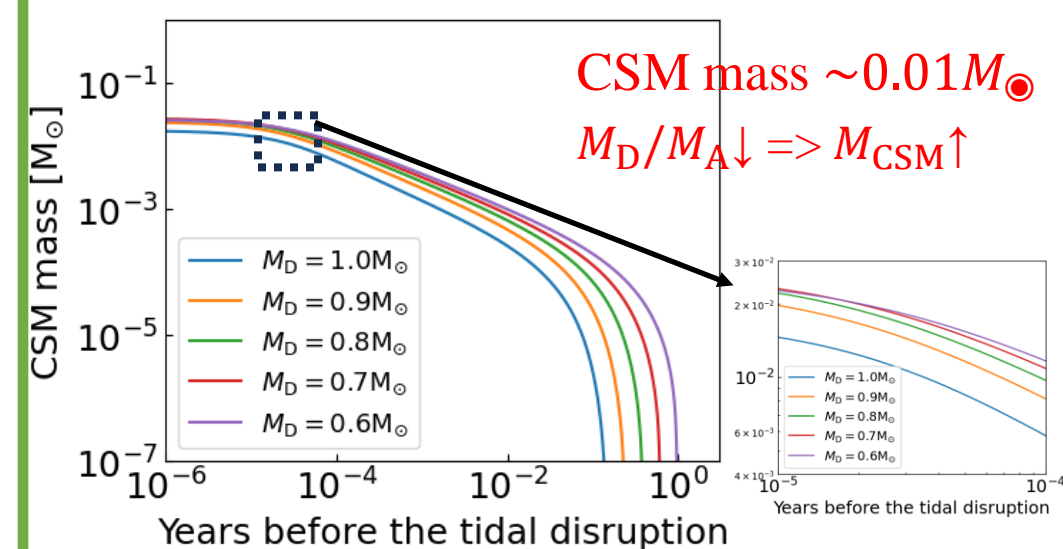


Fig. 4 CSM mass evolution

Light curve

※ Assumption:

The SNe Ia immediately occurs after the WD merger (Violent merger scenario; e.g., Dan+ 12).

5. LC synthesis setup: SN Ejecta + CSM

- We synthesize the LCs of SNe Ia with our CSM model using STELLA code [Blinnikov+ 98, 00, 06].
- We adopt the W7 model for the ejecta of SNe Ia [e.g., Nomoto+ 84].

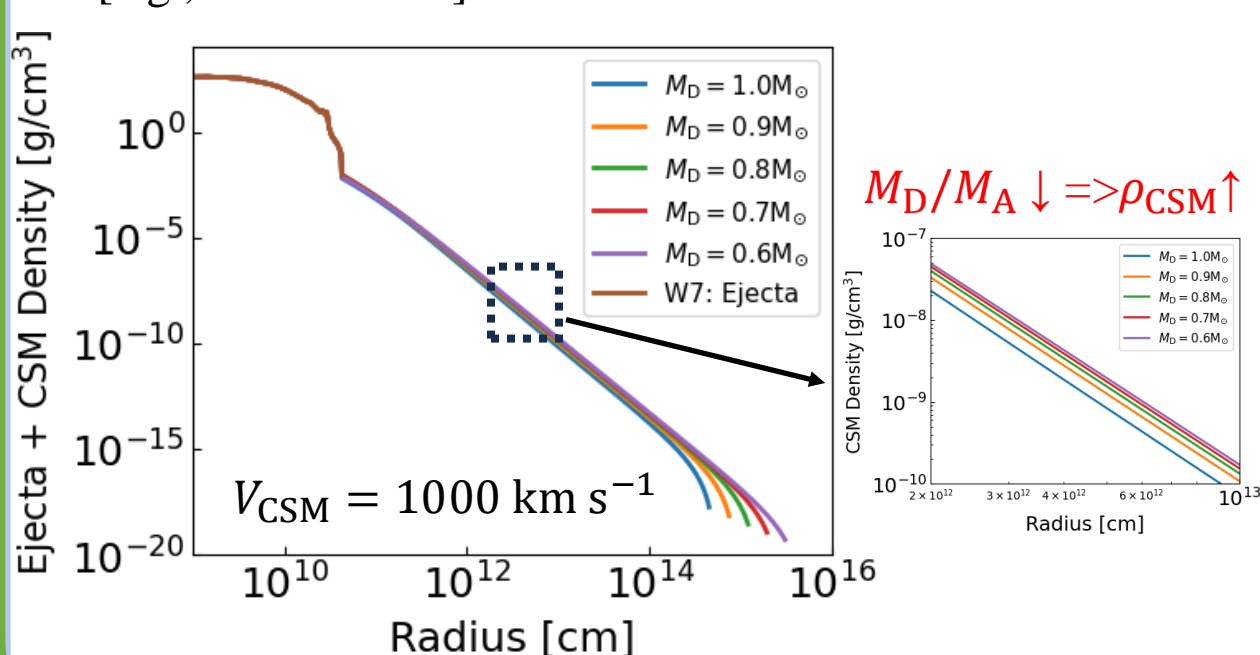


Fig. 5 Density distribution for LC simulations (V_{CSM} : Quataert+ 16)

6. Synthesized LCs & observations

possible DD candidate: over-luminous Ia SNe

- An initial flash (~0.1-1.0 days) appears in their LCs due to dissipation of the ejecta kinetic energy by the CSM.
- Some of our synthesized LCs match well with the observational data of some over-luminous Ia.

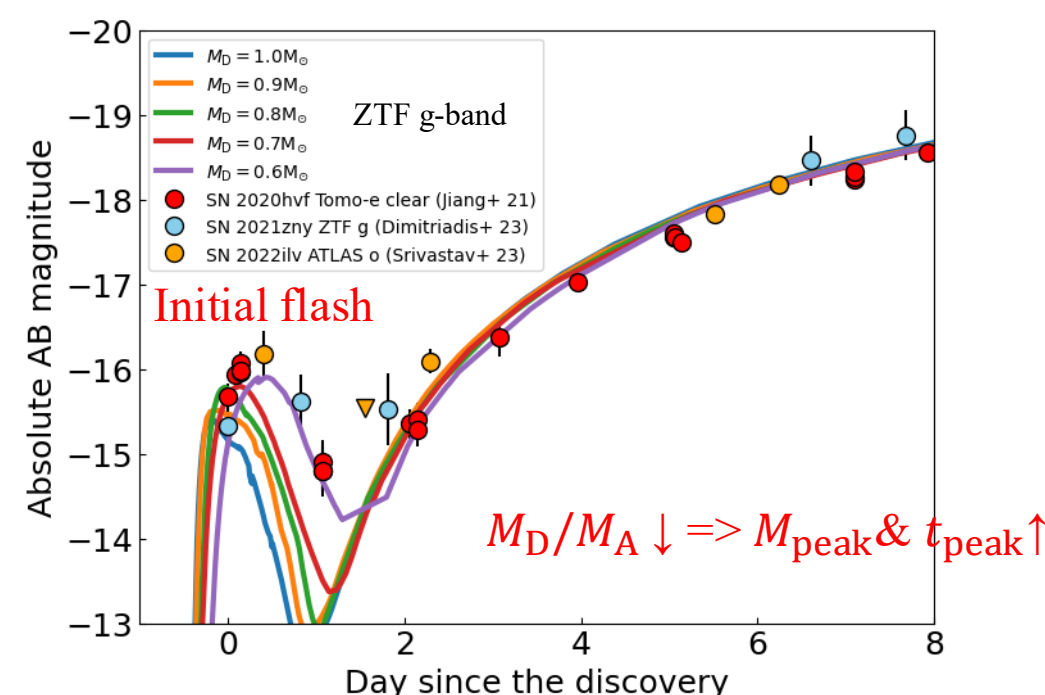


Fig. 6 Synthesized LCs and observational data

7. Summary of our results

- The lifetime of the DD system, after which the MT exceeds super-Eddington accretion rate, is $\sim 0.1 - 1.0$ yr.
- WD binary systems, which are candidate for progenitors of SNe Ia, could form CSM.

- The timescale of initial flash in the synthesized opt. LCs is $\sim 0.1 - 1.0$ days ($\approx V_{\text{CSM}} = 1000 \text{ km s}^{-1}$).

- The LCs of over-luminous Ia SNe 2020hvf, 2021zny and 2022ilv, with an initial flash in their LCs, can be explained by our CSM model.

\Rightarrow consistent with the DD & violent merger scenarios.