Three-dimensional simulations of double detonations in double-degenerate systems for type Ia supernovae

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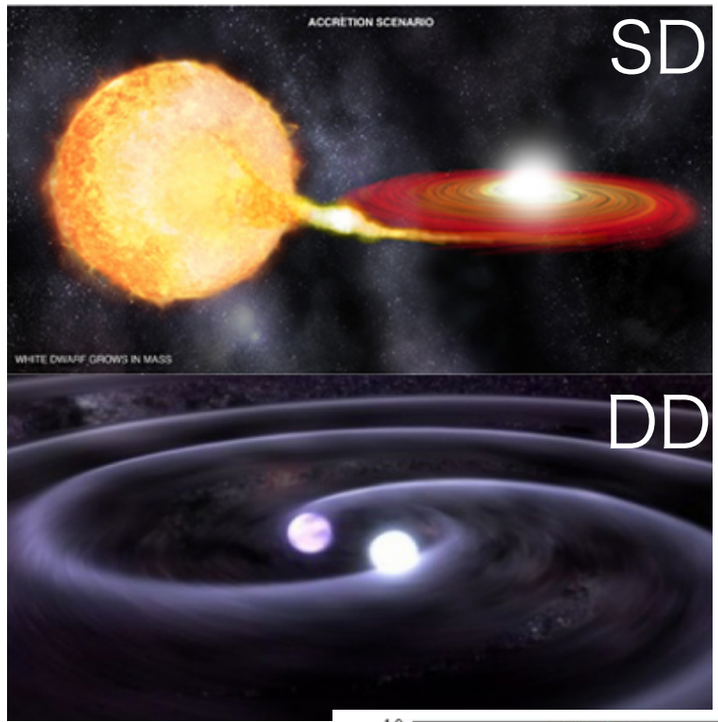
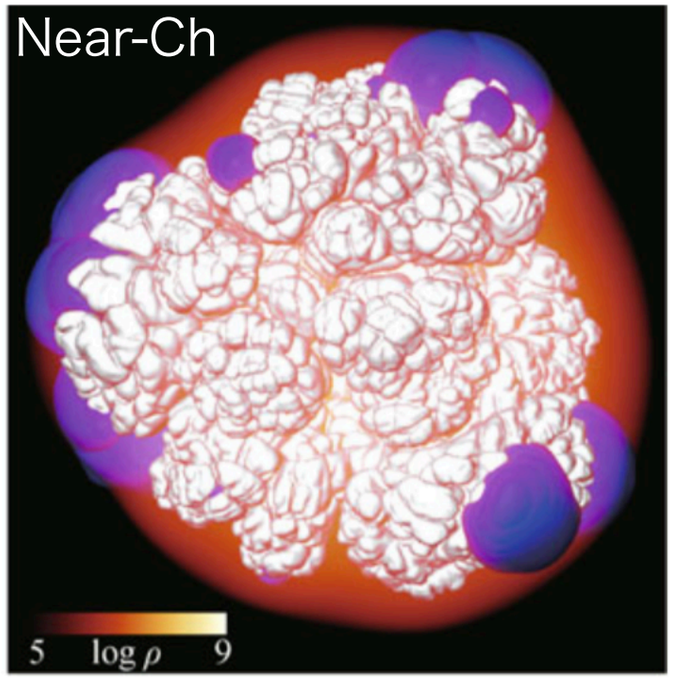
The Beginnings and Ends of Double White Dwarfs
Copenhagen, July 4th 2019

Tanikawa, Nomoto, Nakasato (2018, ApJ, 868, 90)
Tanikawa, Nomoto, Nakasato, Maeda (submitted)

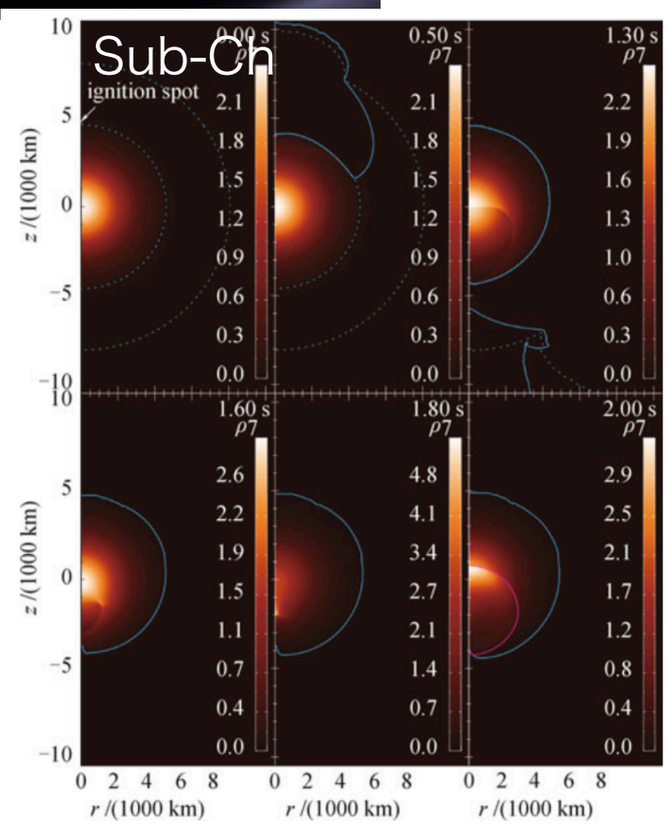
Type Ia supernovae

- One of the brightest and most common objects in the universe
- A cosmic distance indicator
- The origin of iron peak elements
- Thermonuclear explosions of white dwarfs (WDs) in binary systems
- Open questions
  - Single Degenerate (SD) or Double Degenerate (DD)
  - Near-Chandrasekhar mass (Near-Ch) or sub-Chandrasekhar (sub-Ch) mass





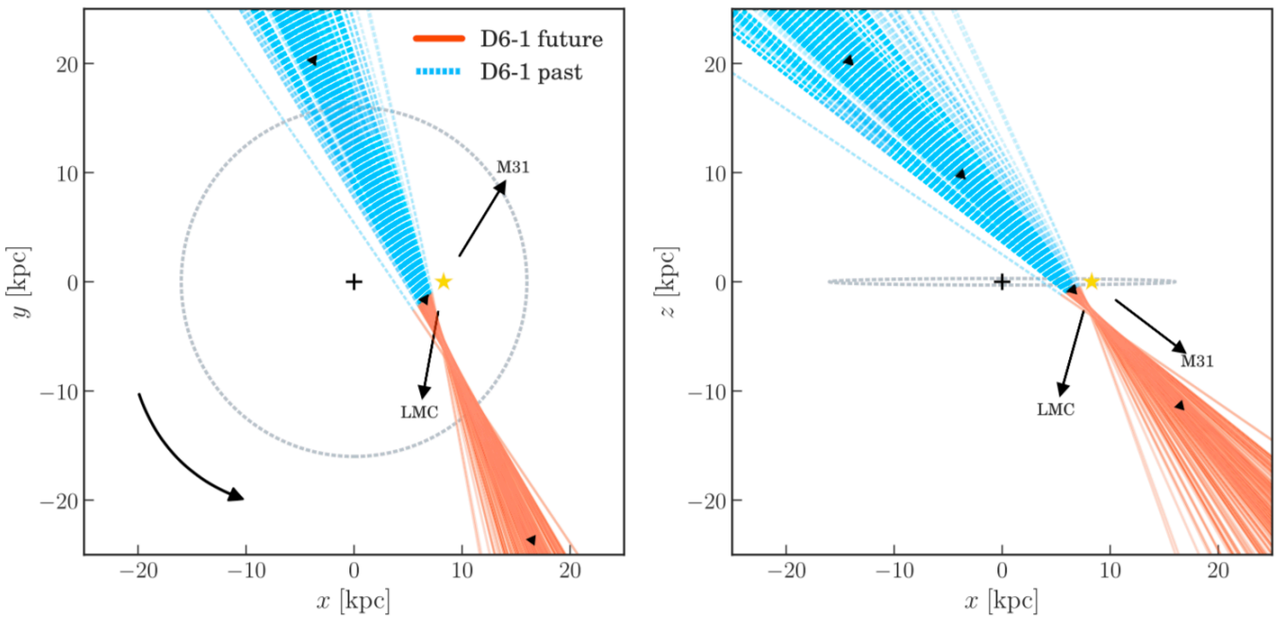
Seitenzahl et al. (2013)



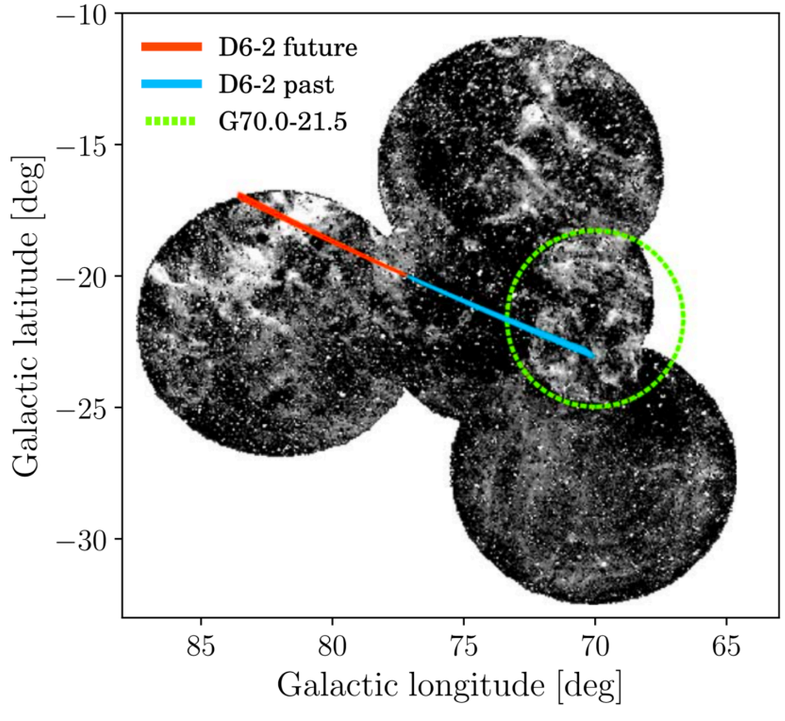
Fink et al. (2010)

Hypervelocity WDs

- Several hypervelocity WDs have been discovered from the Gaia's database (Shen+ 18).

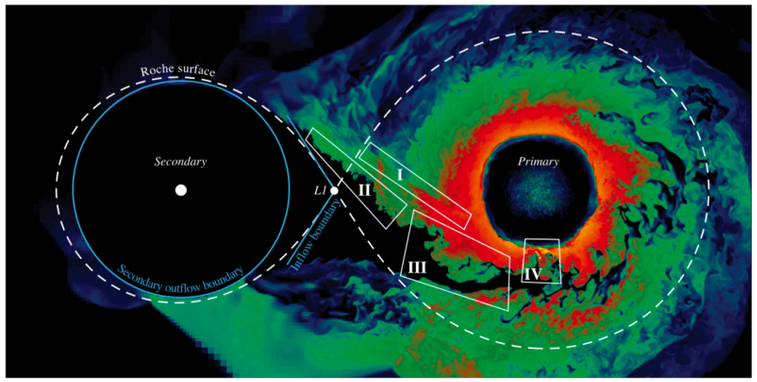


- Their start points are NOT the Galactic center.
- One of them may start from a SNR.
- The D^6 model is supported.

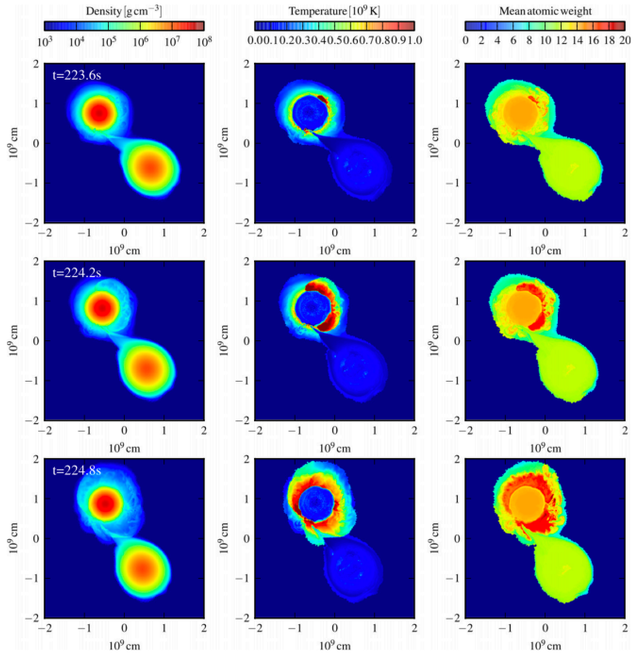


Previous and this studies

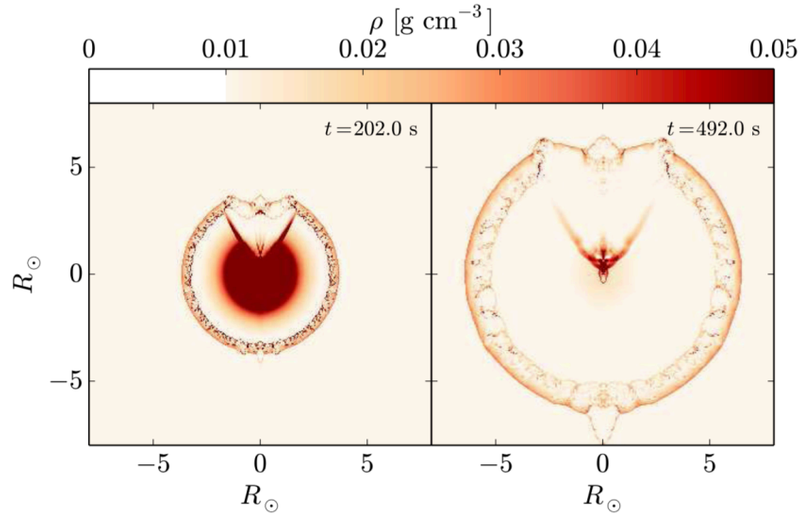
- Previous studies investigated a part of the D^6 processes.
  - Guillochon+10 and Pakmor+13 does not follow the explosions of the heavier WDs.
  - Papish+15 followed the processes of interactions between the SN ejecta and companion WD.
- This study
  - We reproduce the D^6 explosion for SN Ia observations, and explore signatures of these explosions.
  - We test another explosion mode.



Guillochon et al. (2010)



Pakmor et al. (2013)



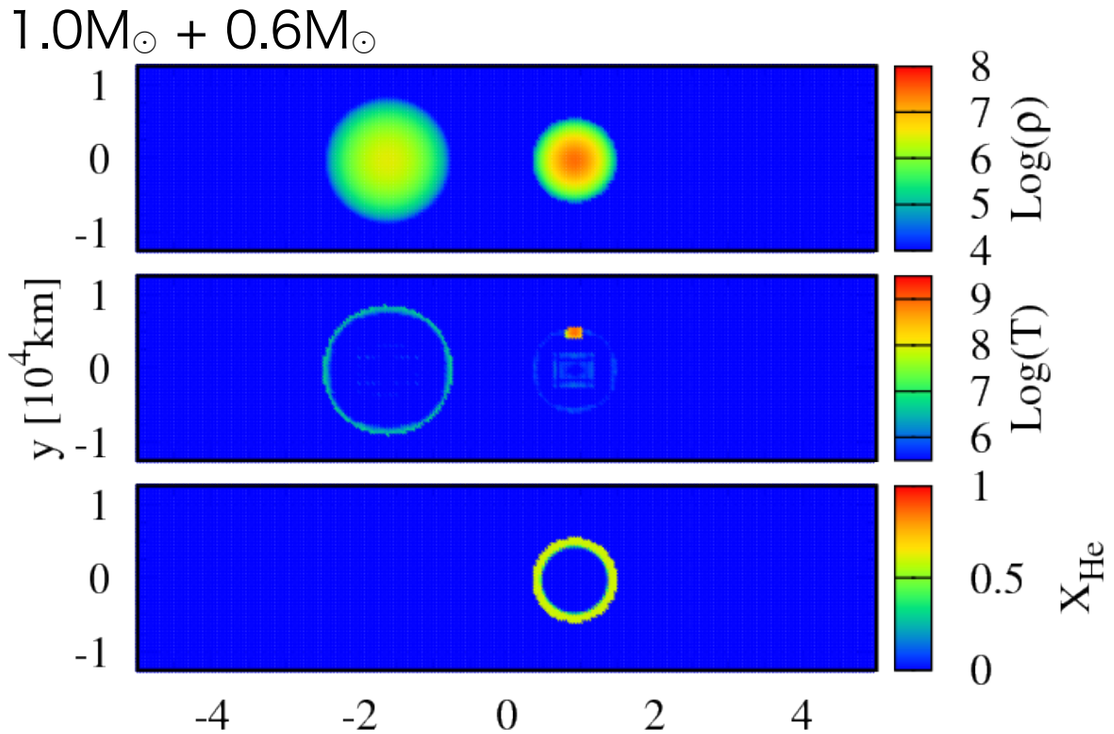
Papish et al. (2015)

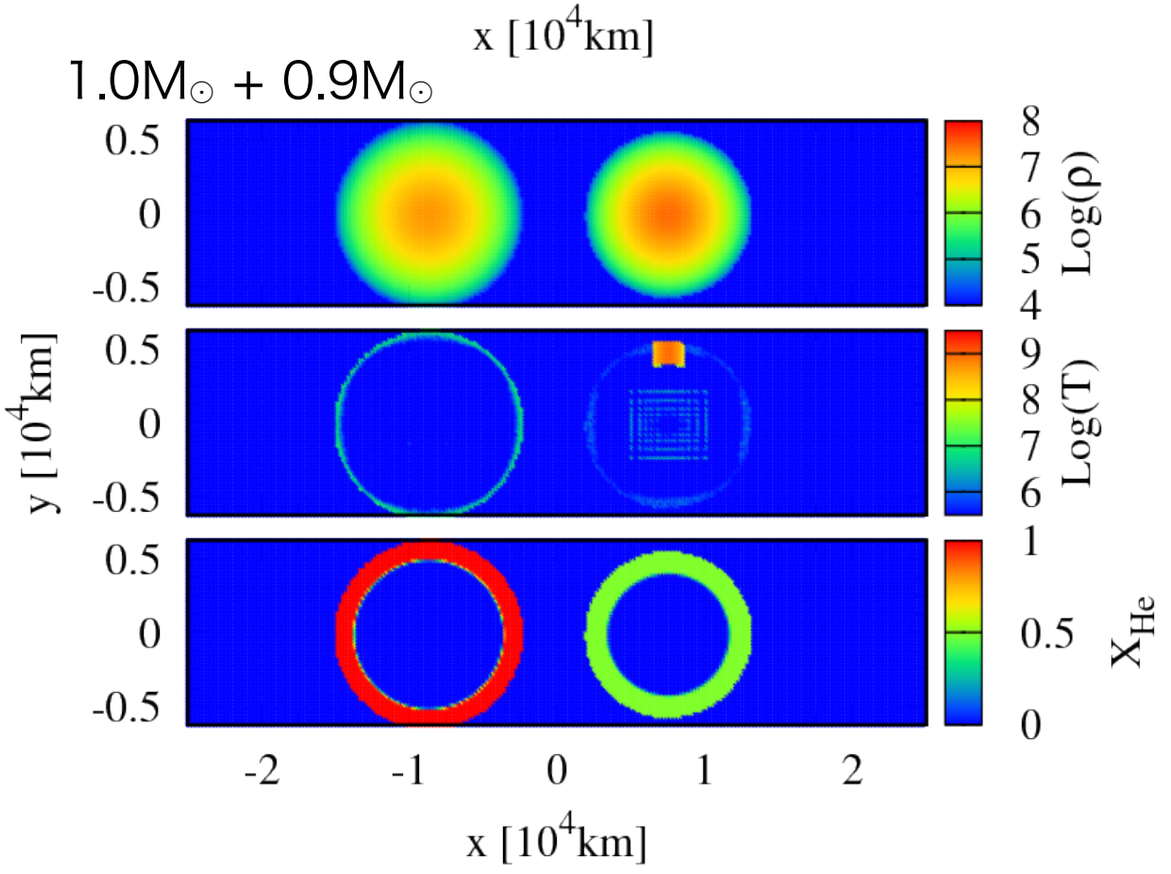
Method

- 3D SPH method
  - Monaghan's artificial viscosity with Balsara switch (similar to GADGET)
  - Parallelized by FDPS (Iwasawa, AT+ 2016)
    - Vectorized by SIMD (e.g. AT+ 2012; 2013)
    - The number of SPH particles is 4 millions per $0.1M_{\odot}$.
- Helmholtz EoS (Timmes, Swesty 2000)
- Aprox13 nuclear reaction networks (Timmes et al. 2000)

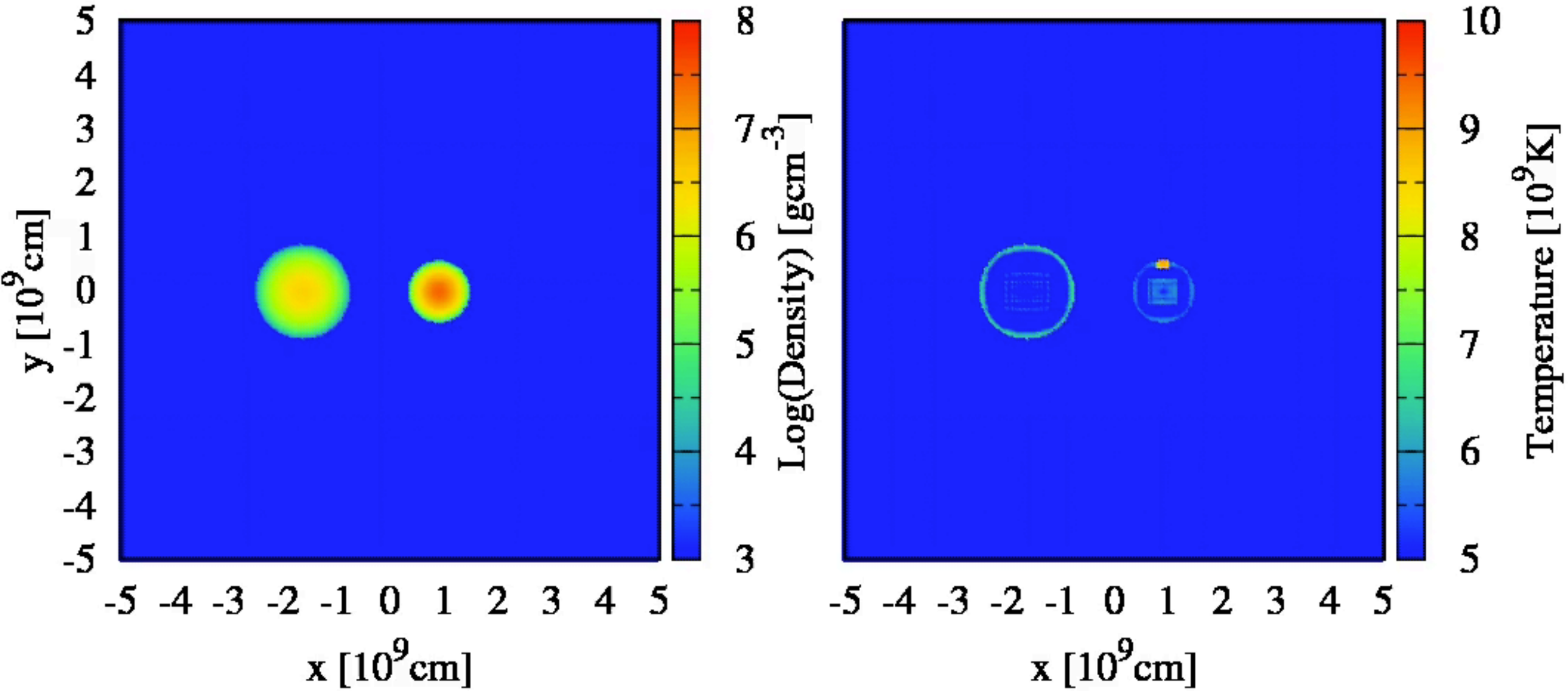
Two initial conditions

- 1.0$M_\odot$ + 0.6$M_\odot$ COWDs
  - No He shell on the companion WD
  - D^6 explosion
- 1.0$M_\odot$ + 0.9$M_\odot$ COWDs
  - Thick He shell on the companion WD (~0.054$M_\odot$)
  - Induced explosion of the companion WD
  - Quadruple Detonation (QD) explosion
- Two WDs so close that mass transfer occurs
- He shells on the primary WDs
- Hotspots in the He shells



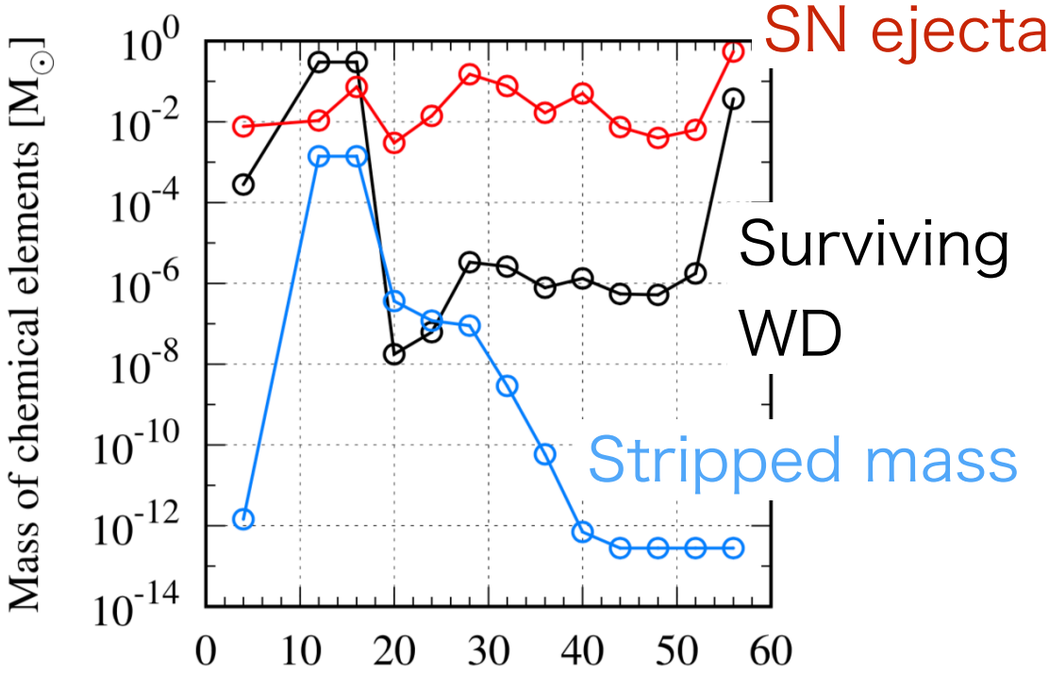


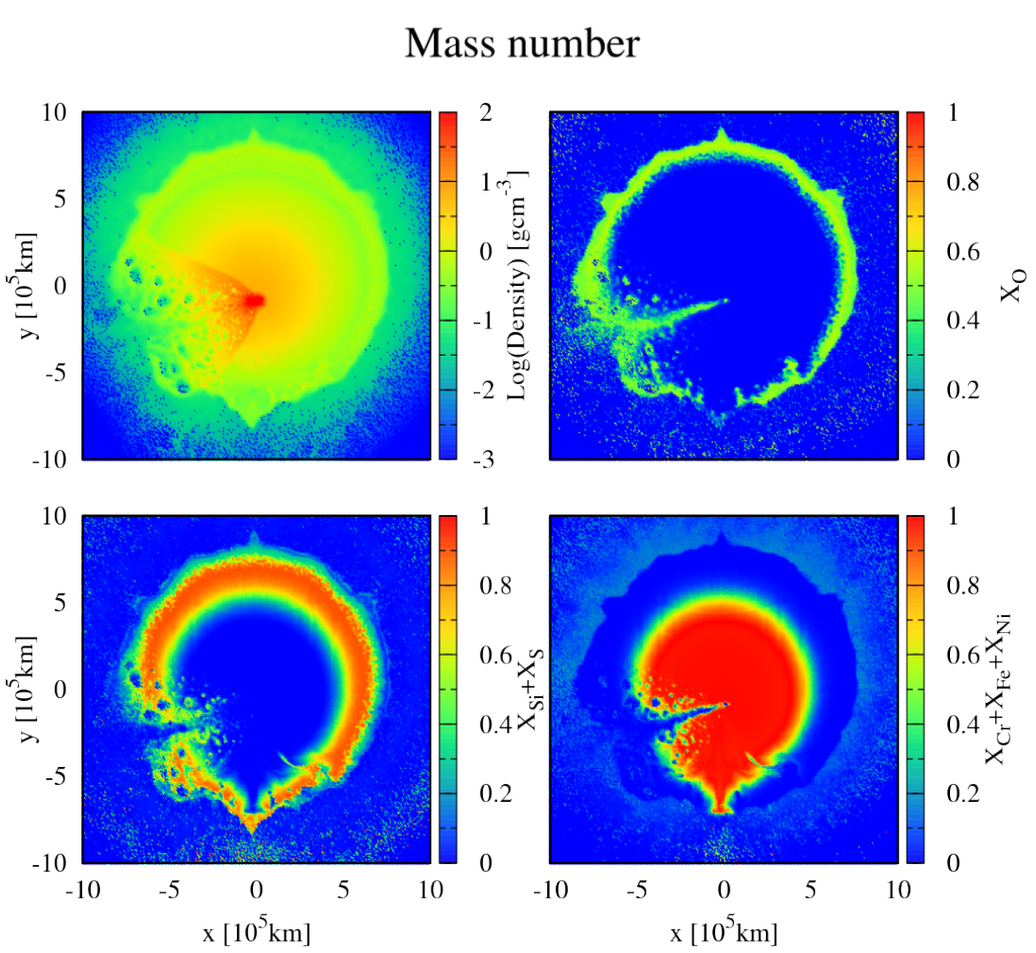
The first DD system



Supernova ejecta

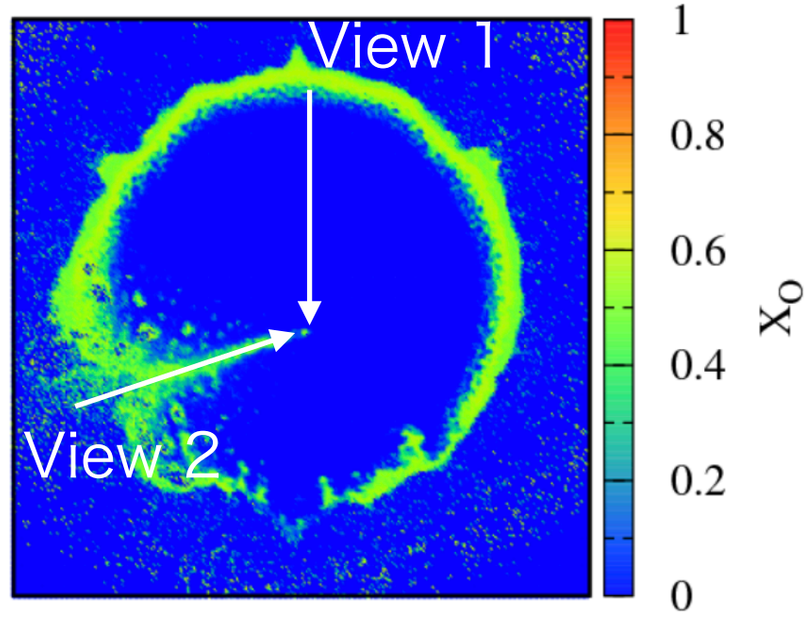
- ^{56}Ni mass is ~ 0.6 $M_\odot$
- Mass of materials stripped from the companion WD is ~ 0.003 $M_\odot$
- The stripped materials consist of carbon and oxygen.
- Supernova ejecta have a shadow (Papish et al. 2015).
- Supernova ejecta have a stream consisting of the stripped materials (companion-origin stream).



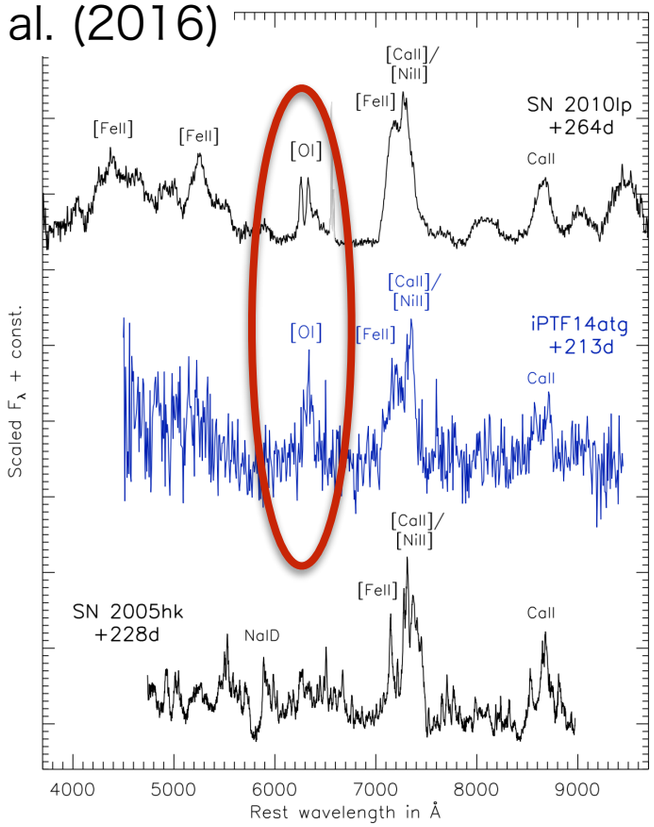


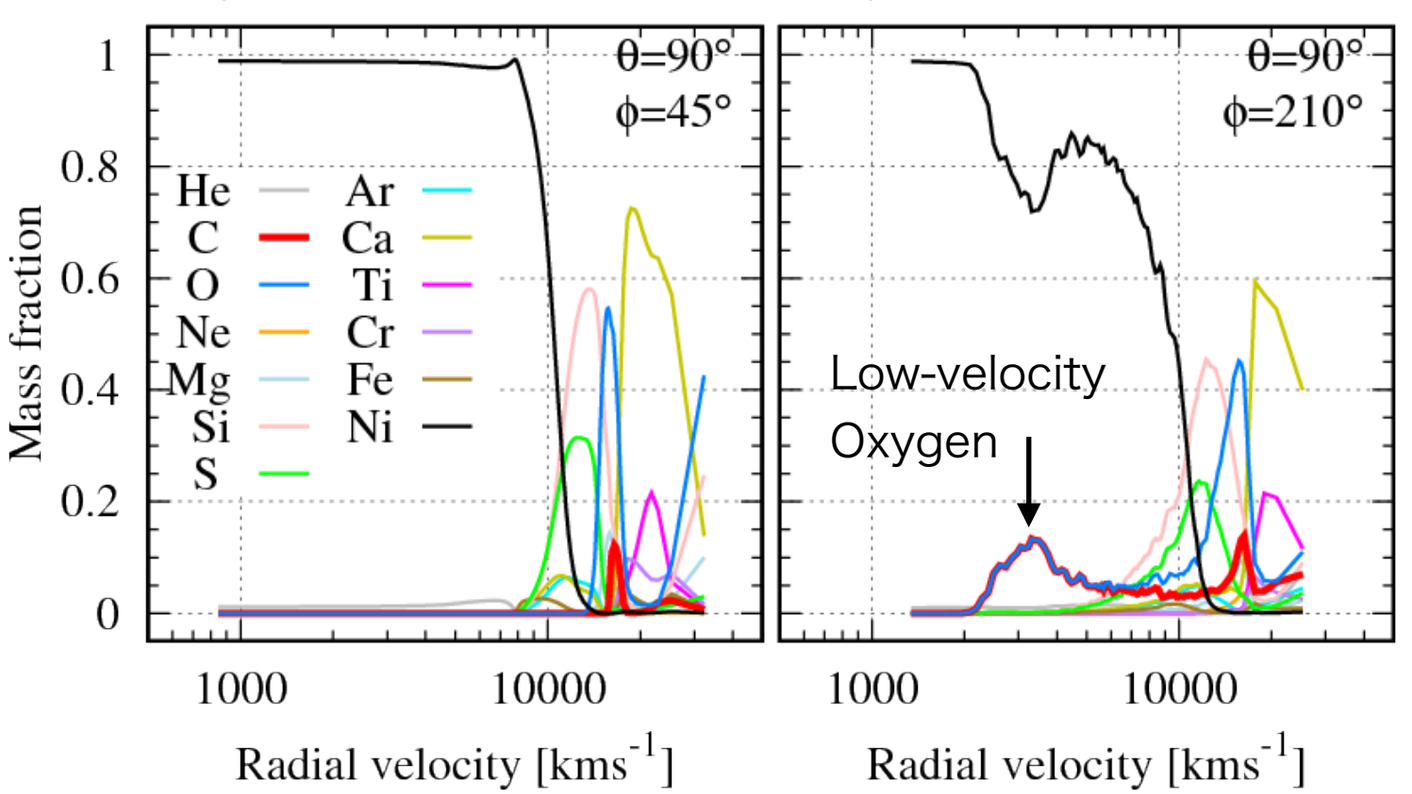
Low-velocity oxygen

- The companion-origin stream could be a key of D^6 explosions..
- D^6 explosions have low-velocity oxygen (~1000km/s) originating from the companion-origin stream.
- Such low-velocity oxygen can explain nebular-phase spectra of some of sub-luminous SNe Ia.
- We will investigate nebular phase spectra of D^6 explosion by radiative transfer calculation in near fugure.

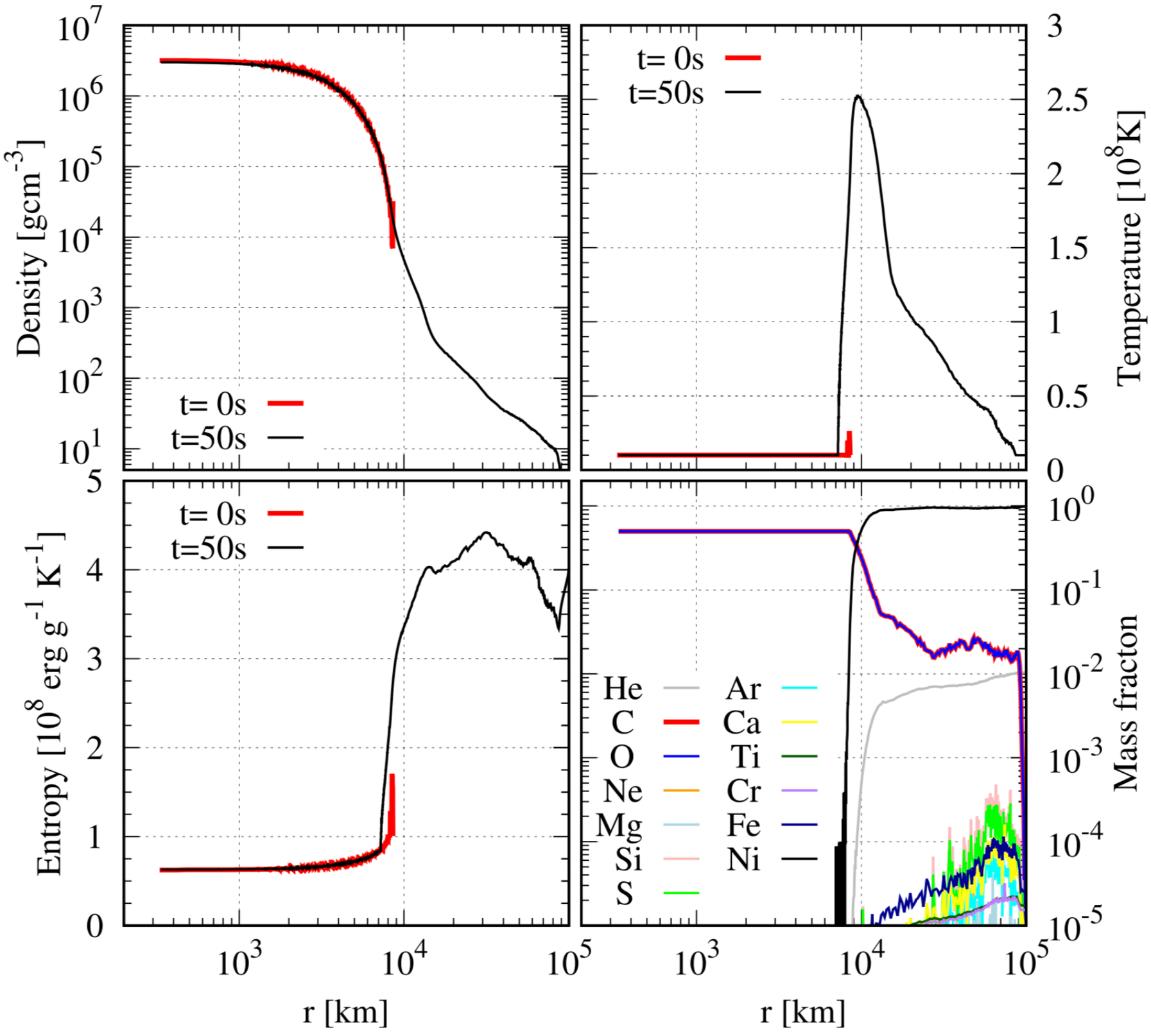


Kromer et al. (2016)

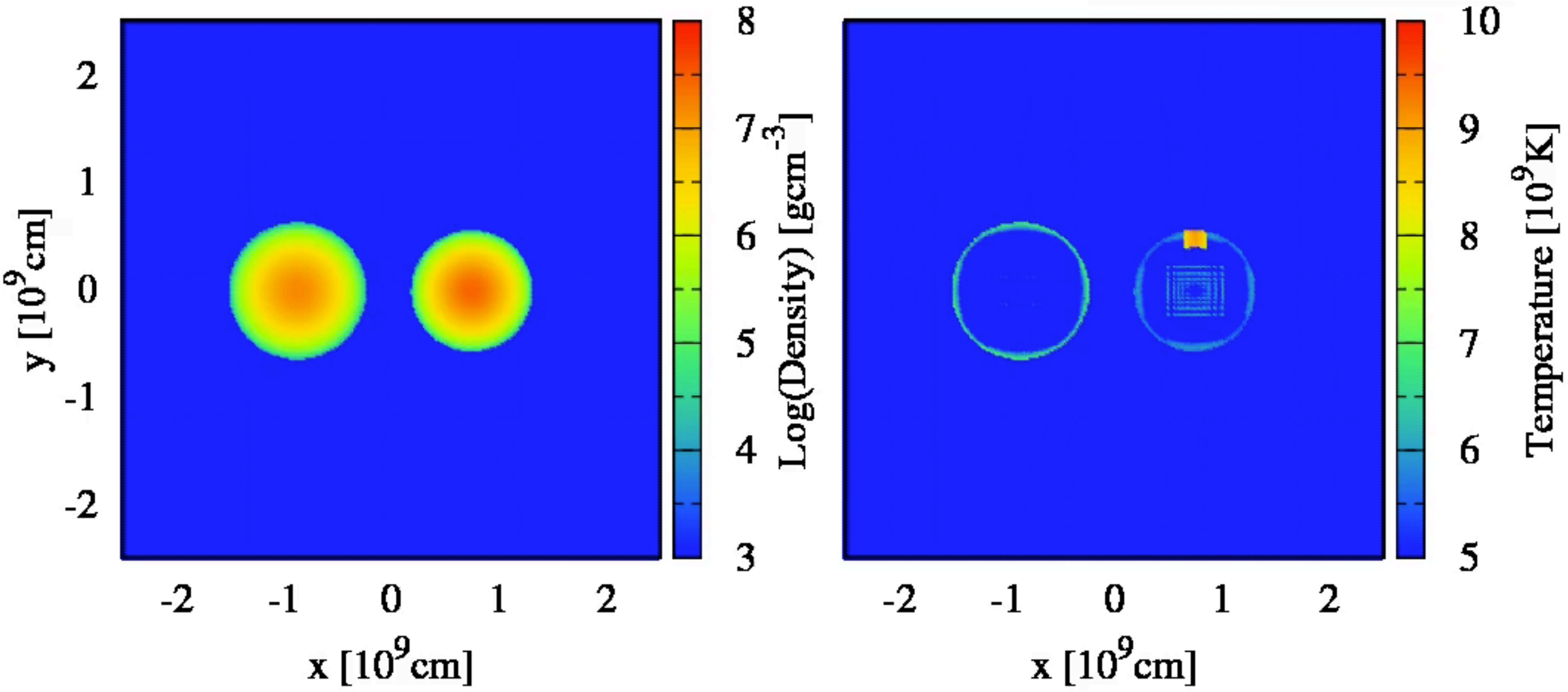




Surviving WD

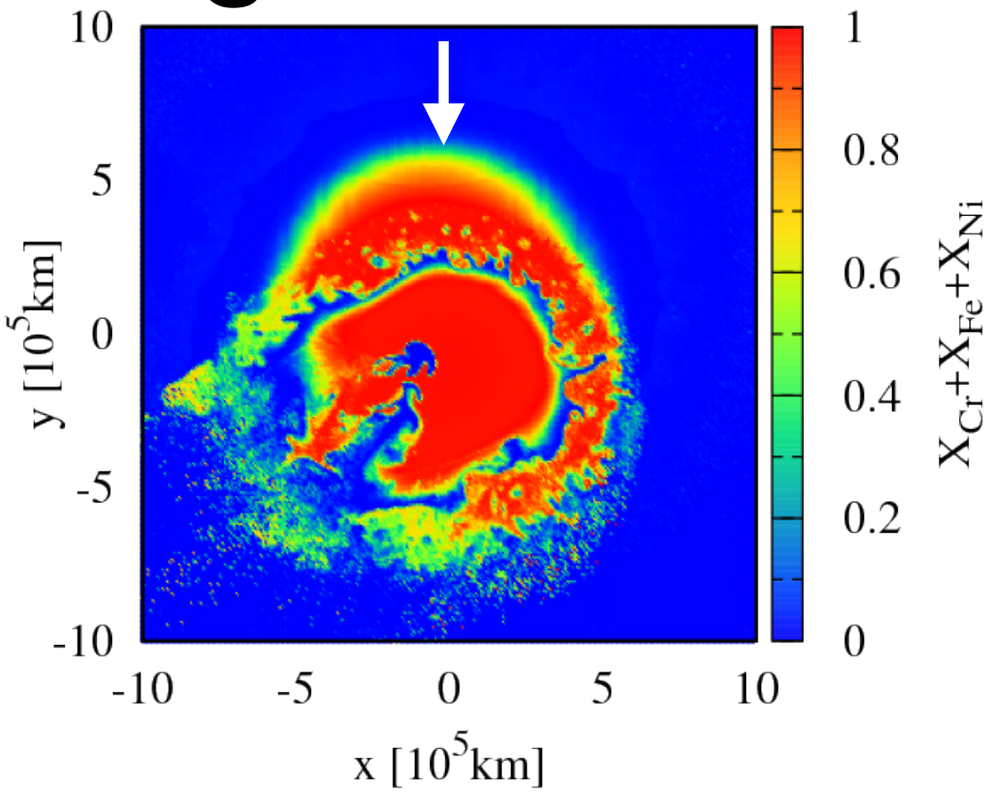


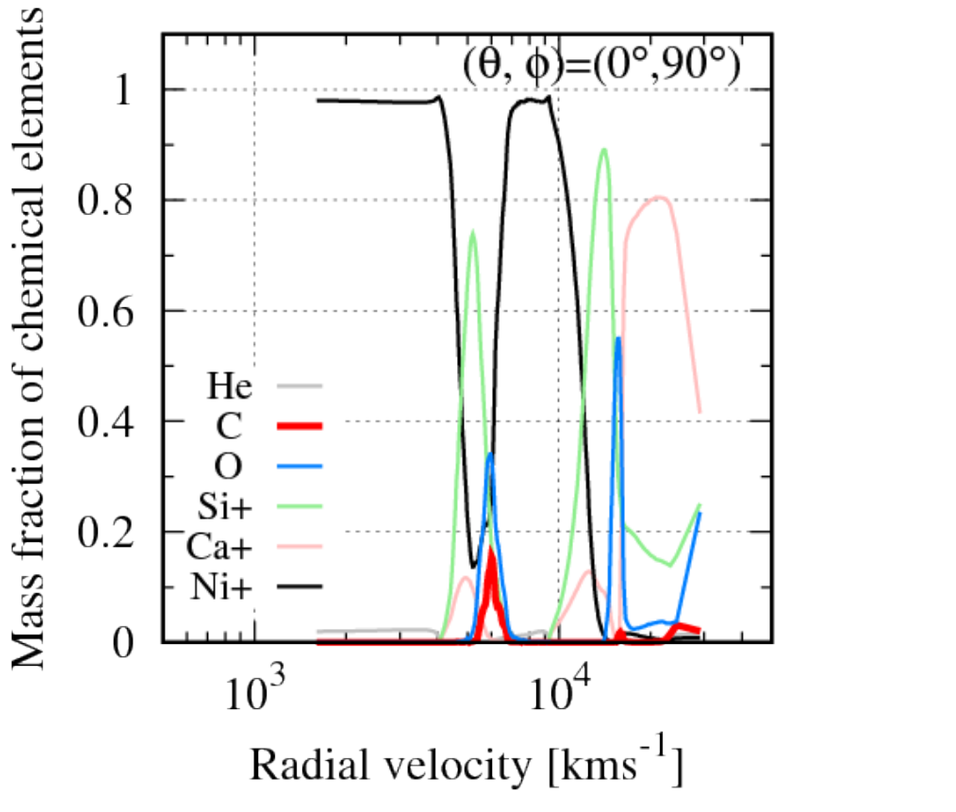
The QD explosion



Supernova ejecta

- Large ^{56}Ni mass, ~1.0$M_{\odot}$
- Luminous SNe Ia?
  - Early emissions of luminous SNe Ia could result from He-detonation products (Maeda et al. 2018).
- Super-Chandrasekhar SNe Ia have massive CSMs (Yamanaka et al. 2016), which is inconsistent with DD systems.





Summary

- We have performed 3D simulations of double-detonation explosions in DD systems.
- D^6 explosions can contain materials stripped from companion WDs.
- The stripped materials can contribute to low-velocity oxygen (and carbon).
- Primary explosions can induce companion explosions, if the companions have thick He shells (QD explosions).
- The QD explosion can yield large ^{56}Ni, ~ $1.0M_{\odot}$.