Effects of companion white dwarfs in D6 explosions for modeling type Ia supernovae

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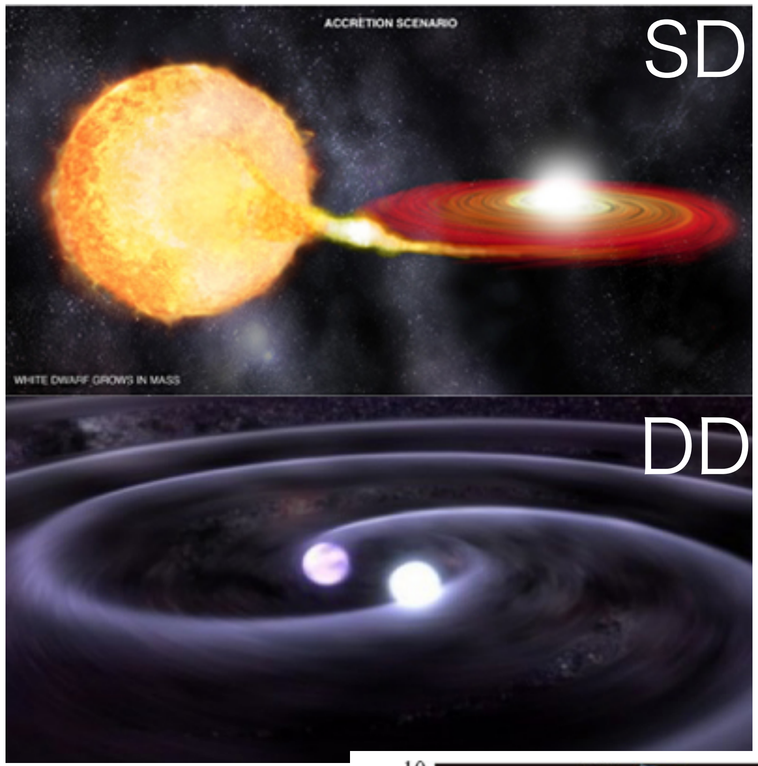
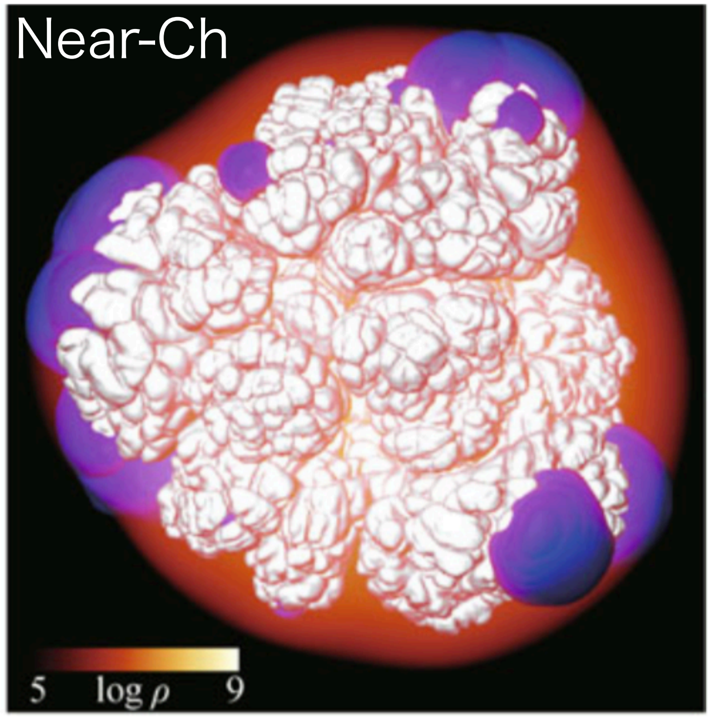
Tanikawa, Nomoto, Nakasato (2018, ApJ, 868, 90)

Tanikawa, Nomoto, Nakasato, Maeda (2019, ApJ, 885, 103)

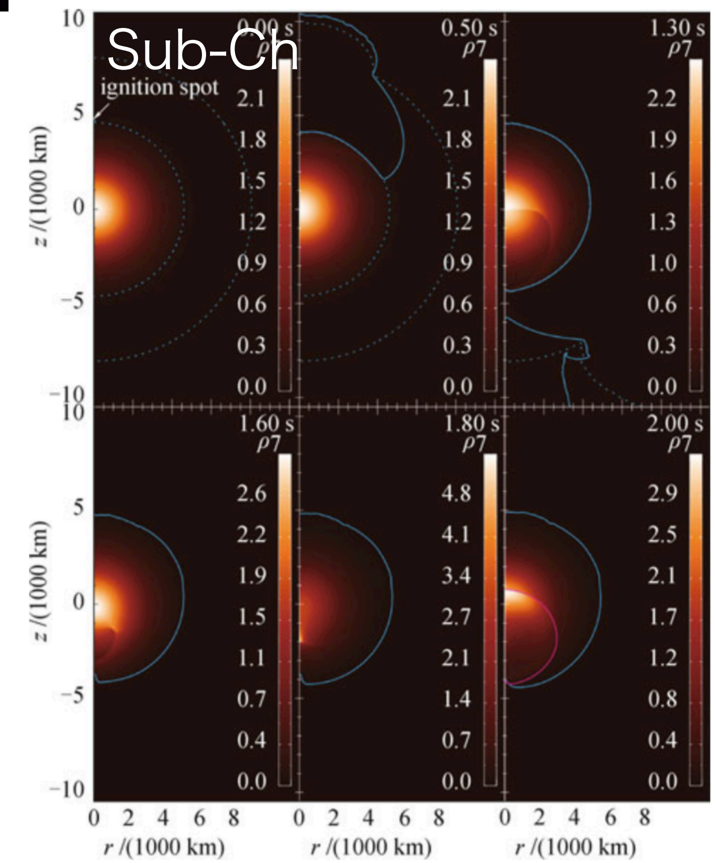
Type Ia supernovae

- 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





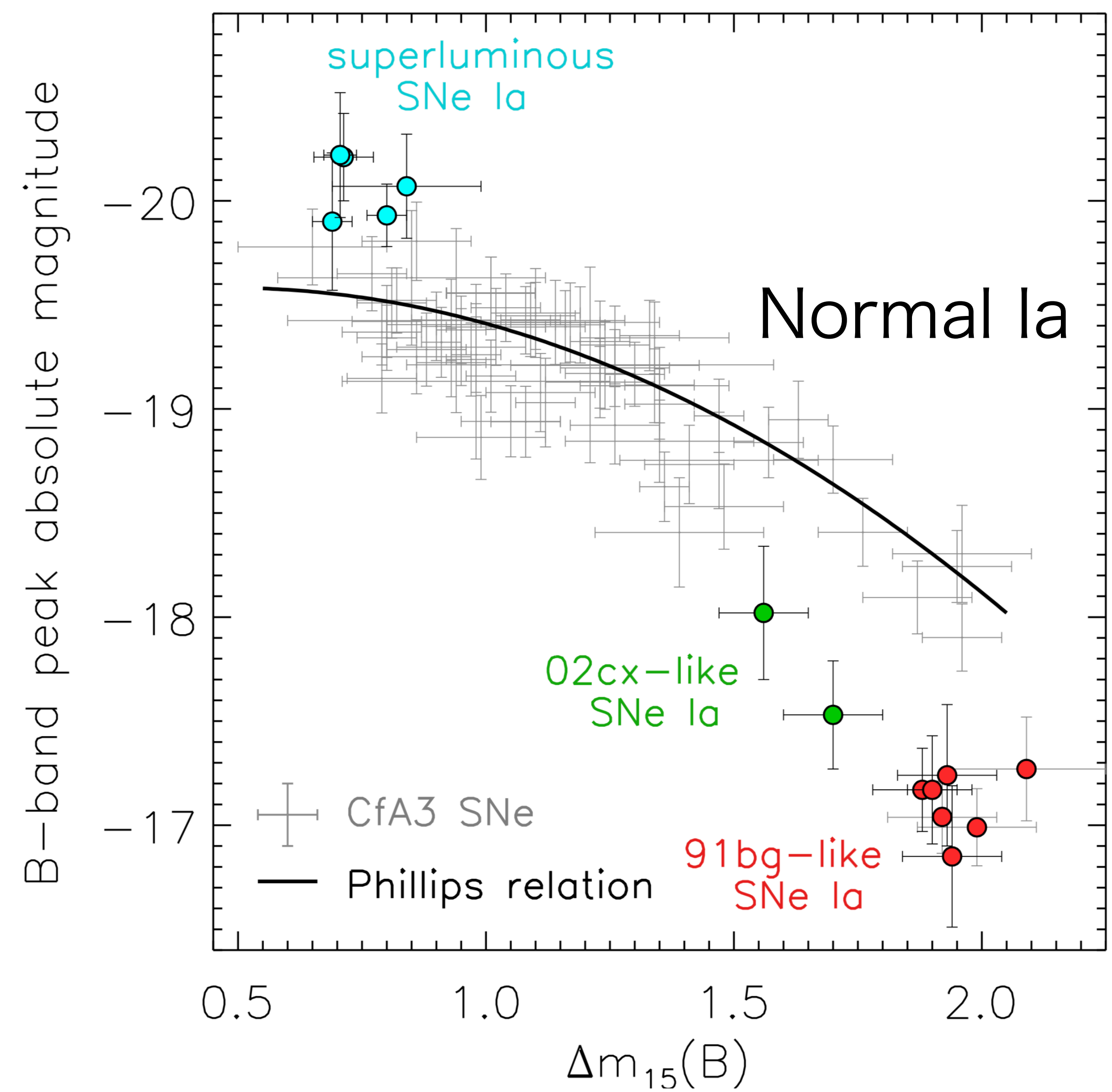
Seitenzahl et al. (2013)



Fink et al. (2010)

Normal & Peculiar SNe Ia

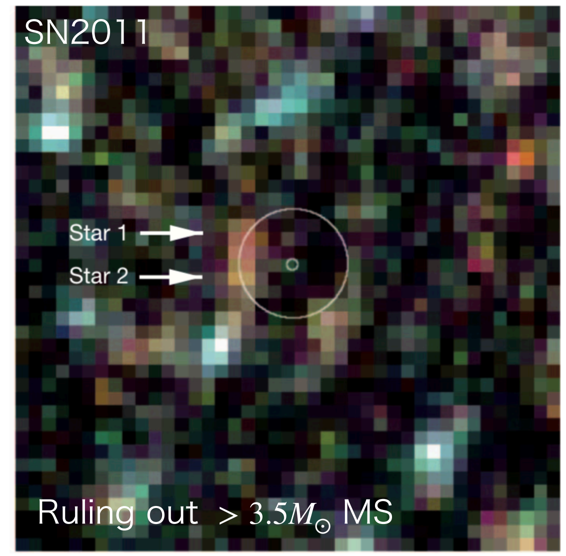
- Normal Ia
  - Standard candle
  - Dominant population (~50%)
- Peculiar SNe Ia
  - Sub-luminous Ia (e.g. 91bg-likes)
  - Type Iax, or 02cx-like
  - Over-luminous Ia (e.g. 91T-likes and 99aa-likes)
  - Super-Chandrasekhar Ia
- Discussion about the normal Ia



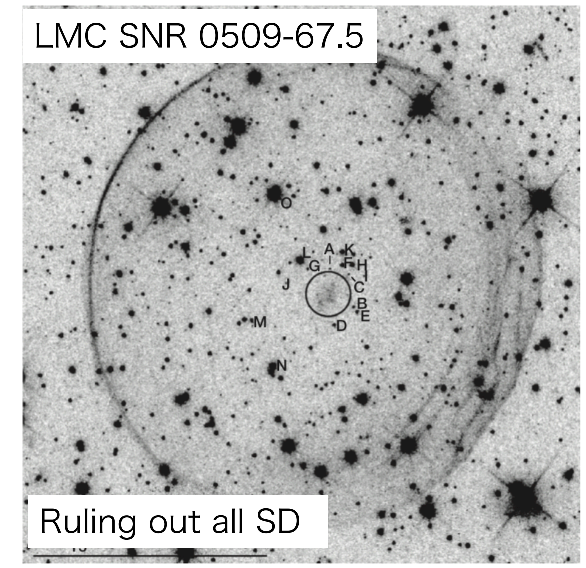
Hillebrandt+ (2013)

Non-degenerate companion

- There are several problems in the near SD scenarios.
- Nearby SNe Ia have
    - No companion stars (Li+2011; Schaefer+12)
    - No circumstellar matter (CSM) (Maugutti+12; 14)
    - No hydrogen stripped from companion stars (Shappee+ 13)
- Some SNe Ia indicate the presence of non-degenerate stars, but
    - PTF11kx could be over-luminous (Dilday+12).
    - iPTF14atg is sub-luminous (Cao+15).

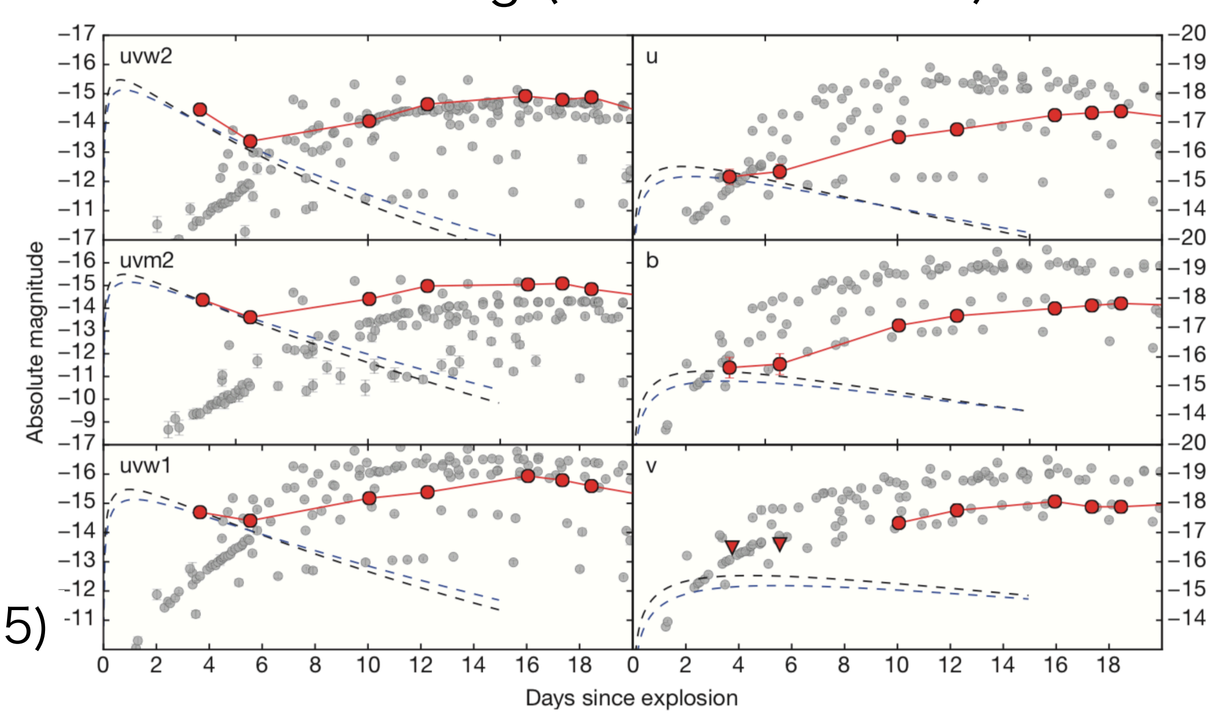


Li+ (2011)



Schaefer+ (2012)

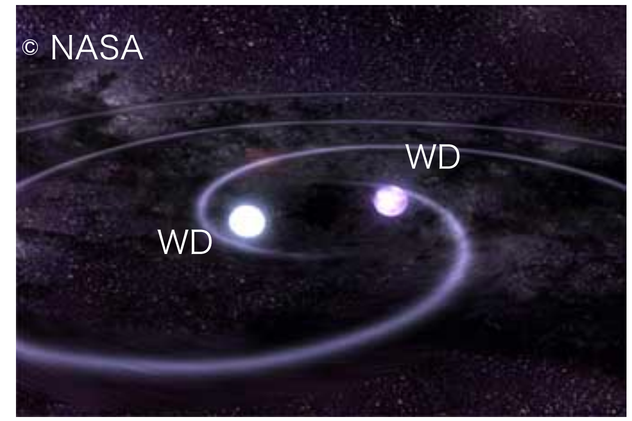
iPTF14atg (sub-luminous Ia)

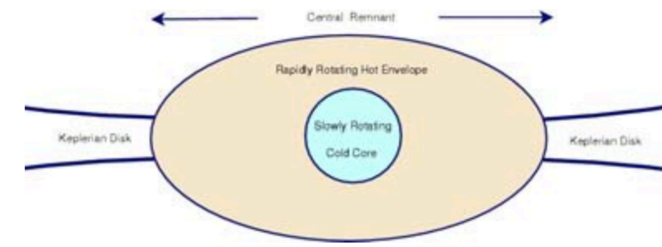


Cao et al. (2015)

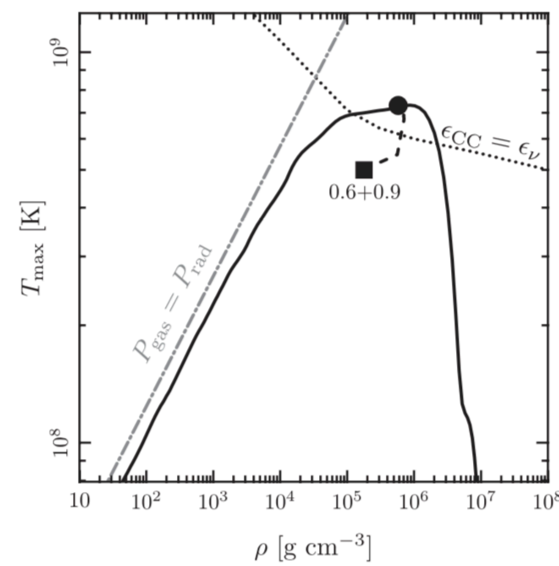
Near-Ch DD scenario

- Evolution of the near-Ch DD system
  - WD-WD merger
  - Merger remnant
    - Cold core (originally the heavier WD)
    - Debris (originally the lighter WD)
  - Rapid accretion of the debris due to magnetic viscosity
  - Ignition of slow (not explosive) C+C reactions
  - Conversion of the merger remnant from CO to ONeMg
  - Gravitational collapse to NS/BH
- A WD-WD merger ends with gravitational collapse unless some mechanism works before they completely merge.

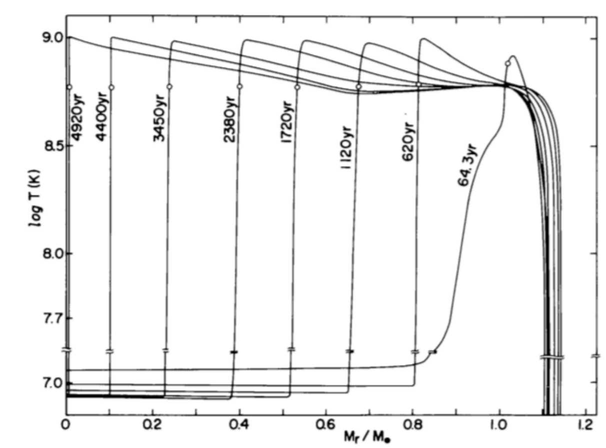




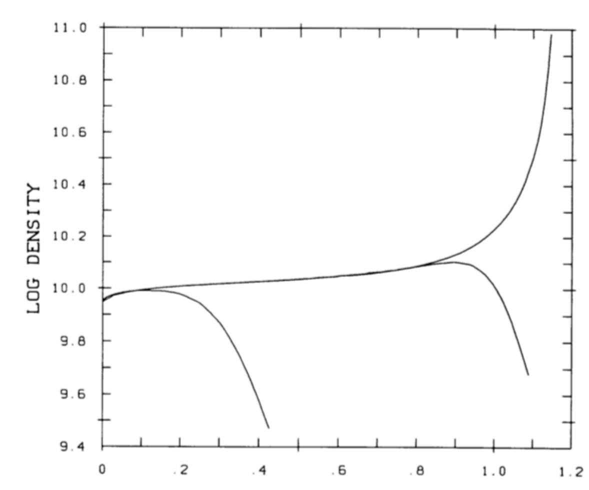
Yoon et al. (2007)



Schwab et al. (2012)

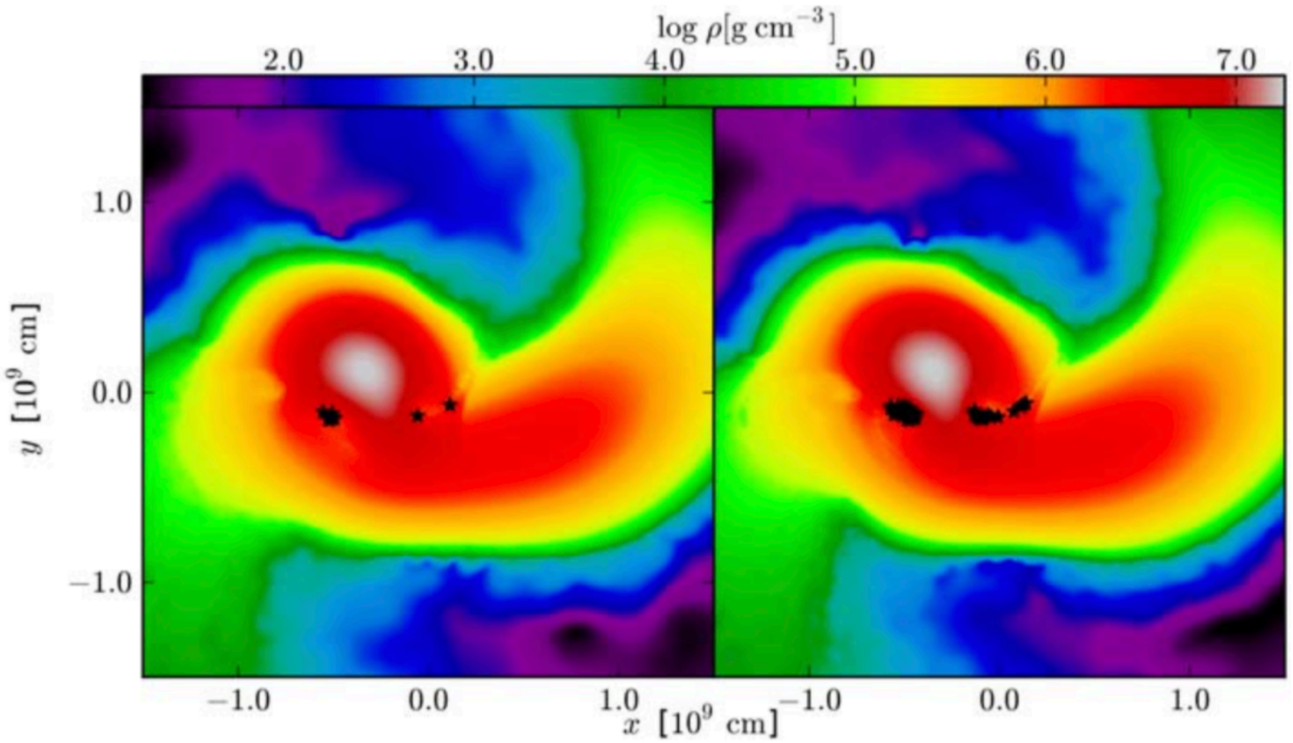


Saio, Nomoto (1985)

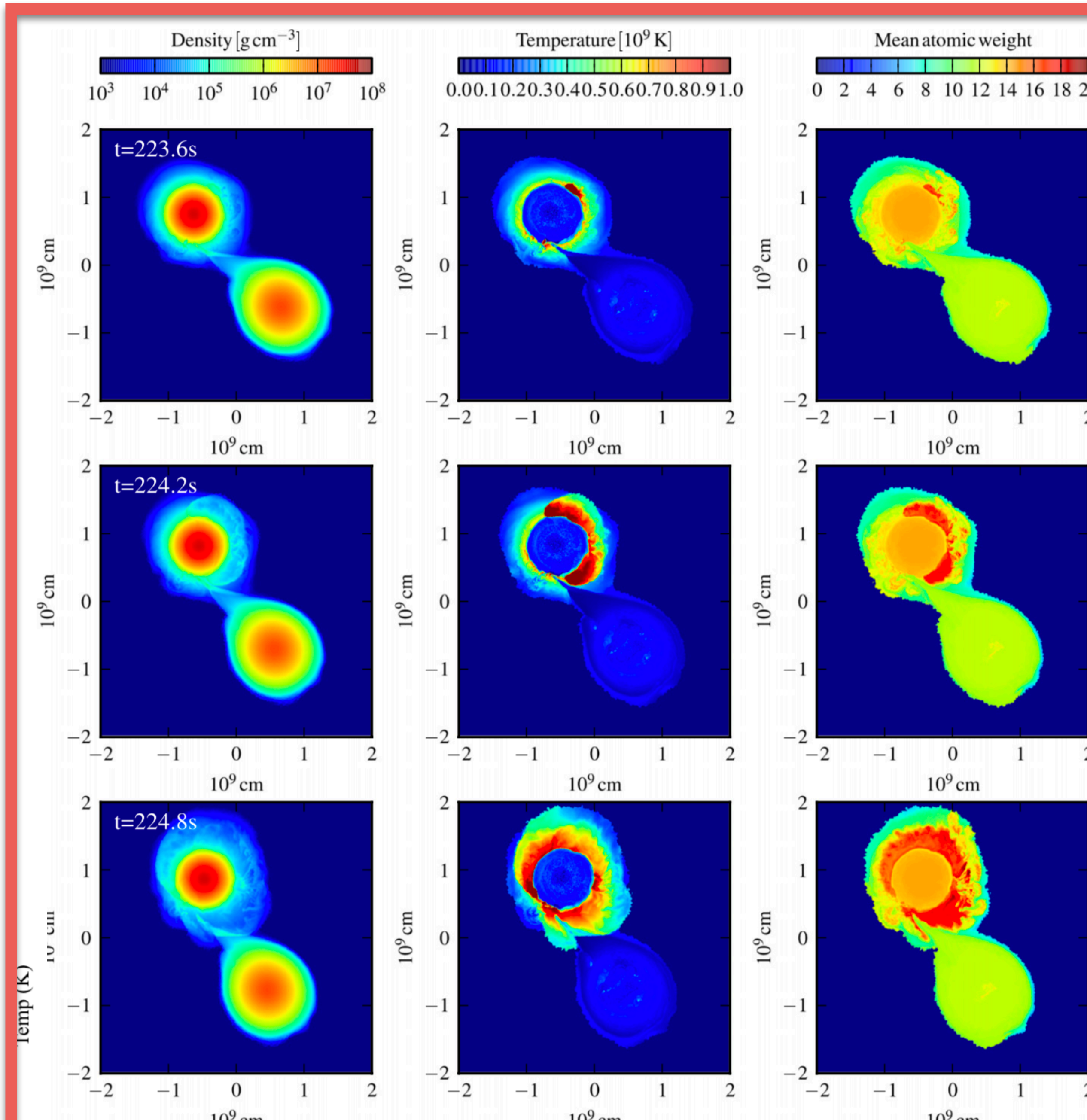


Nomoto, Kondo (1991)

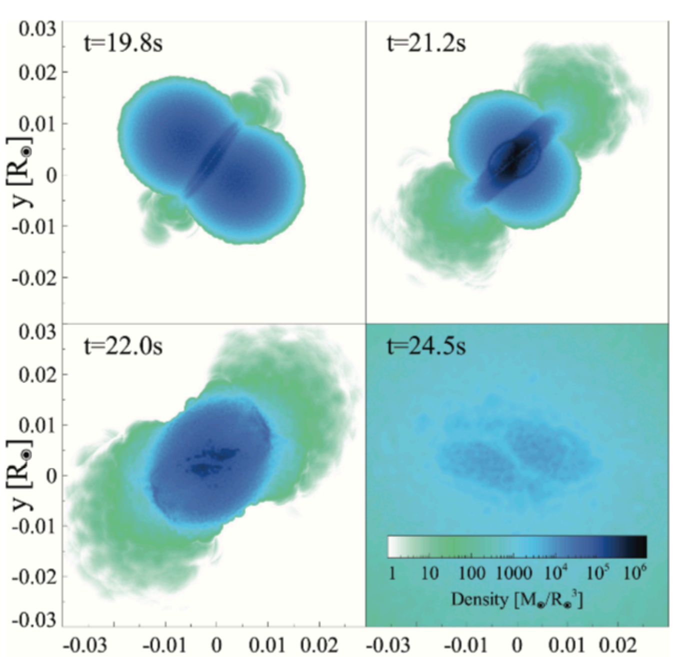
Sub-Ch DD Scenarios



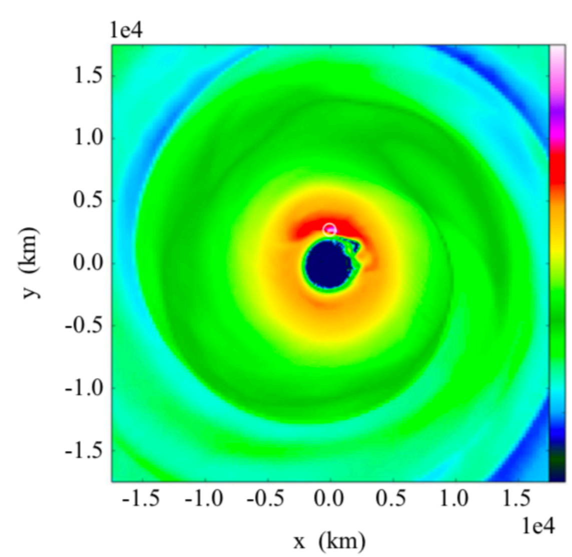
Violent merger (Pakmor+10; 11; 12; see also Tanikawa+15; Sato+15;16)



Helium-ignited violent merger or Dynamically-Driven Double-Degenerate Double-Detonation (D6) model(Guillochon+10; Pakmor+13)

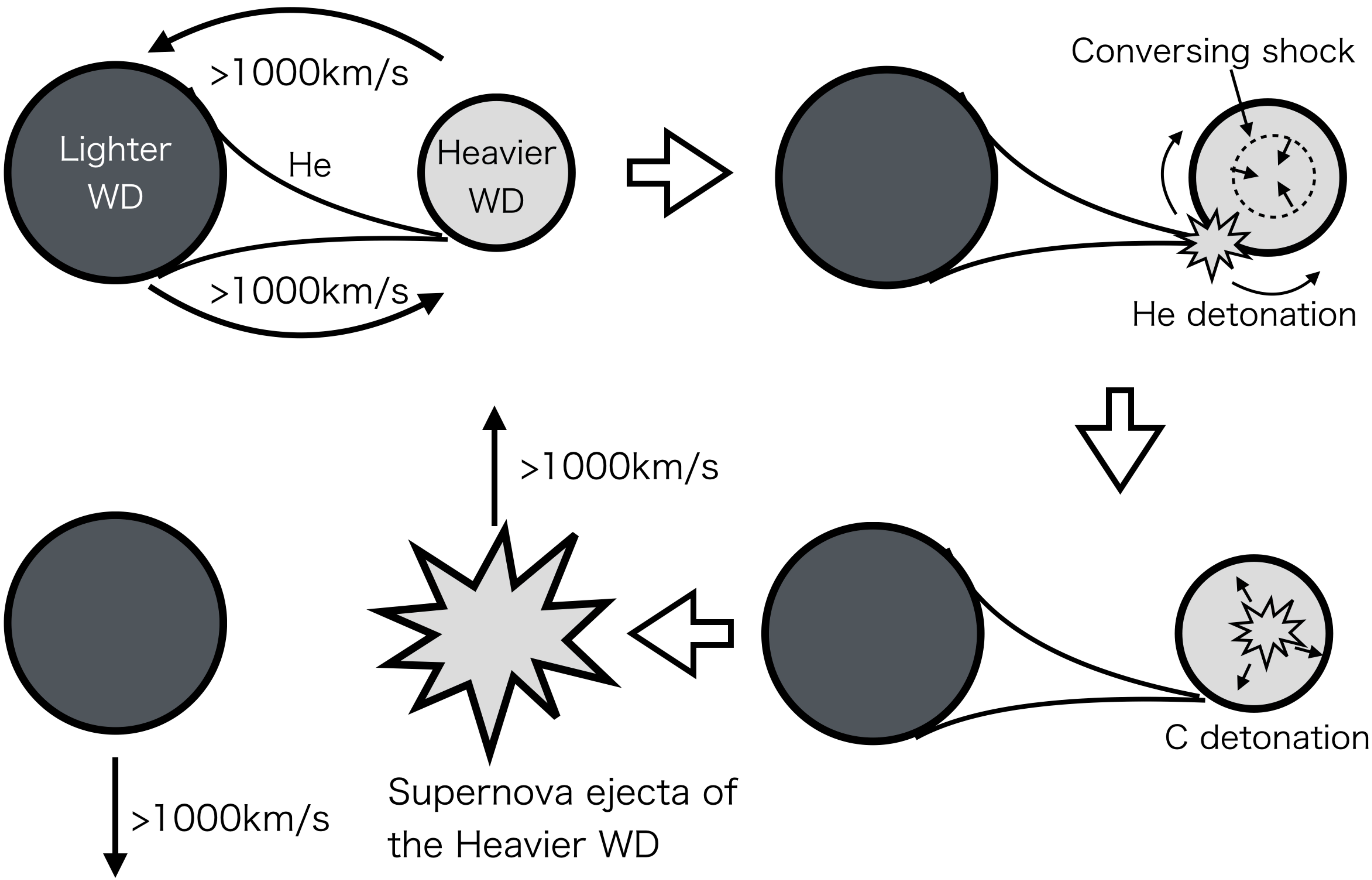


Collisional scenario (Raskin+09; Rosswog+09; Loren-Aguilar+10; Dong+15; Isern's talk)



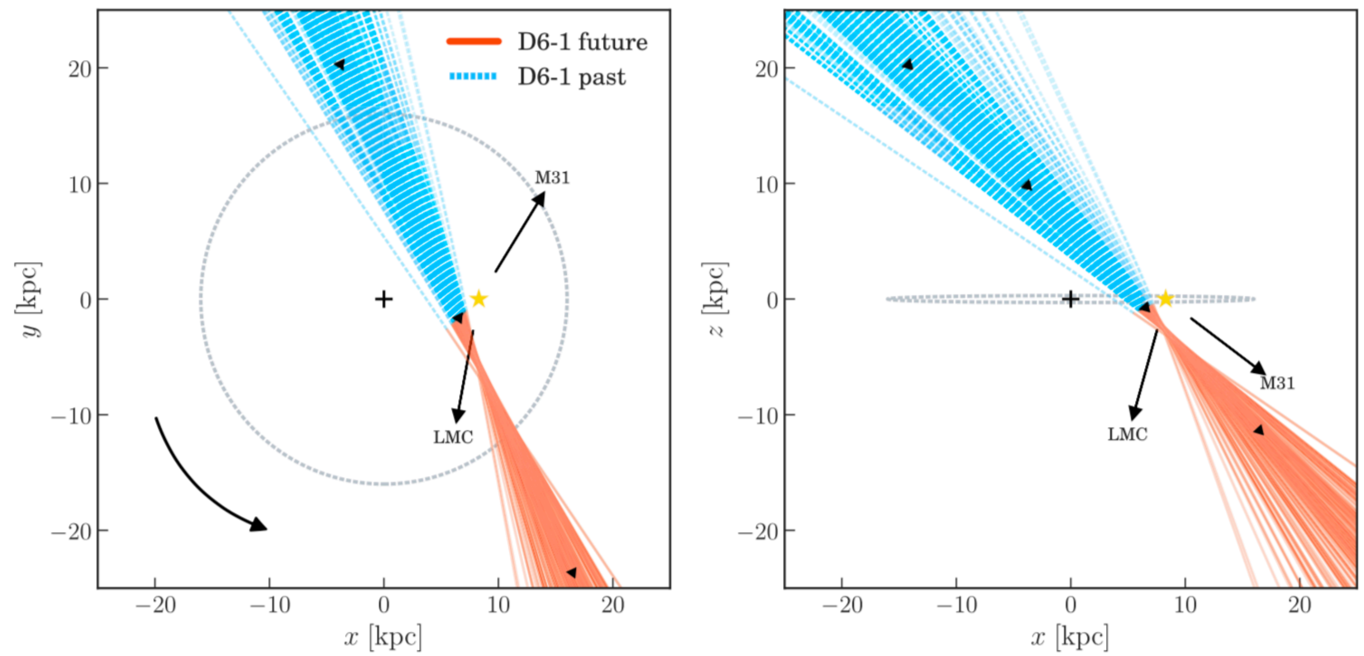
Spiral instability (Kashyap+15;17)

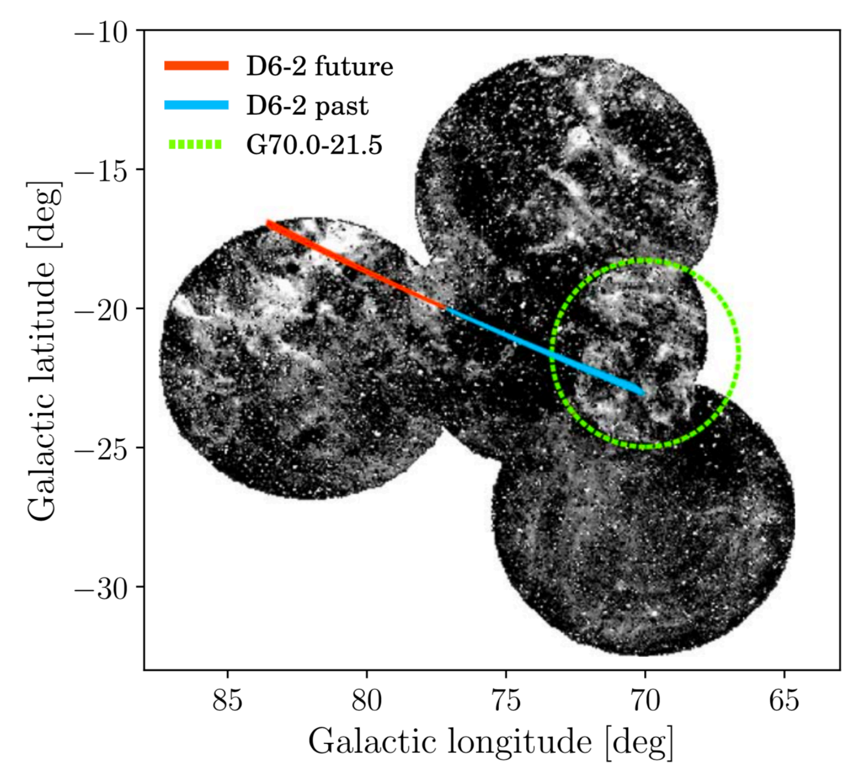
The D6 processes



Hypervelocity WDs

- Several hypervelocity WDs (>1000km/s) 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 D6 model is supported.
- Hypervelocity WDs are also formed from SNe Iax (e.g. Raddi et al. 2019)





Our study

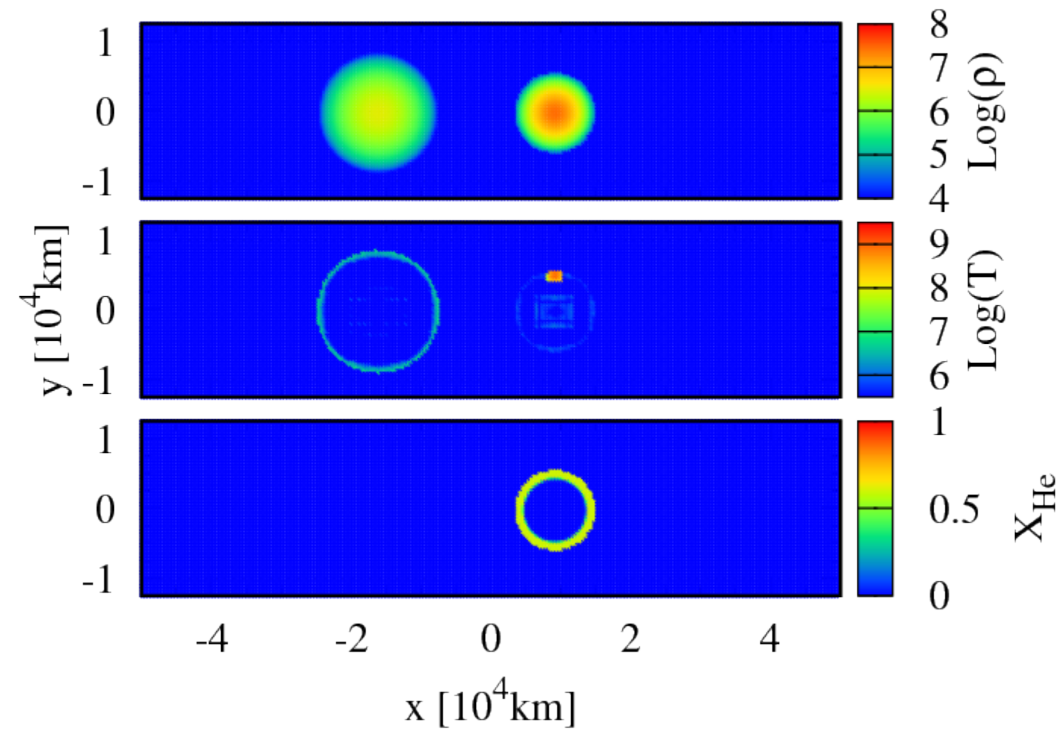
- The D6 model could be promising.
- However, it is unclear whether the hypervelocity WDs are products of normal Ia, or peculiar Ia.
- We reproduce D6 explosions, and investigate their features to assess whether they are consistent with normal Ia or peculiar Ia.
- We perform two simulations.
    - In the first case, the system experiences D6 explosion as predicted.
    - In the second case, the system indicates another explosion mode.

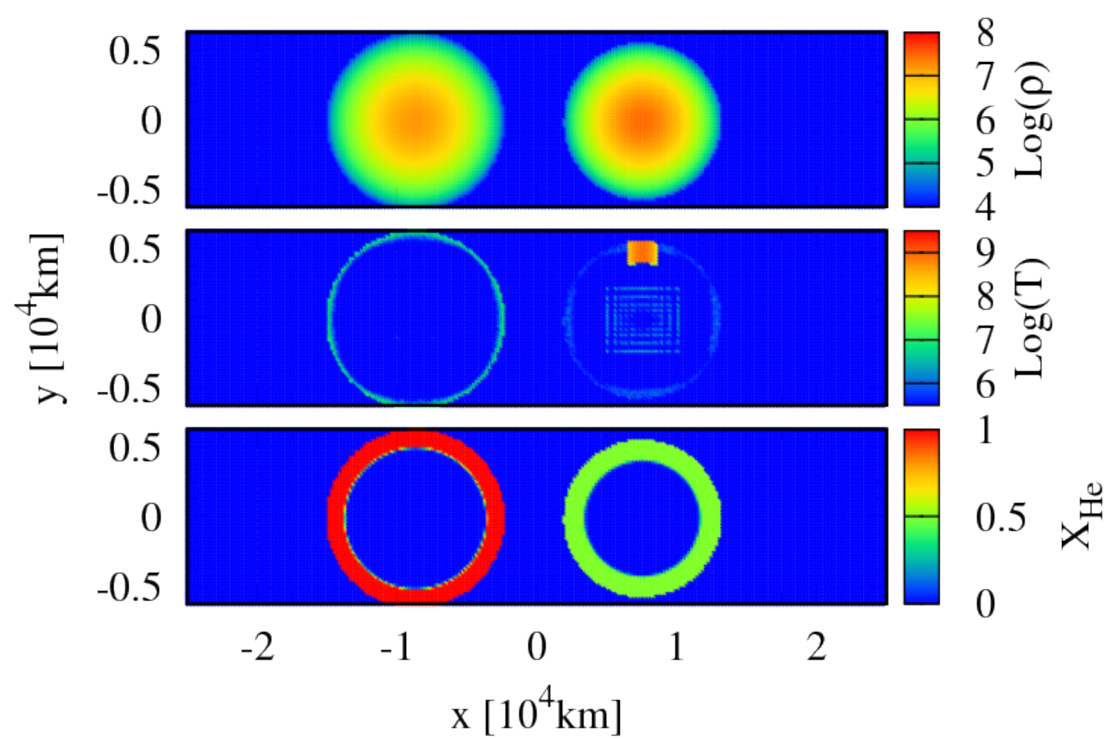
Simulation method

- 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)

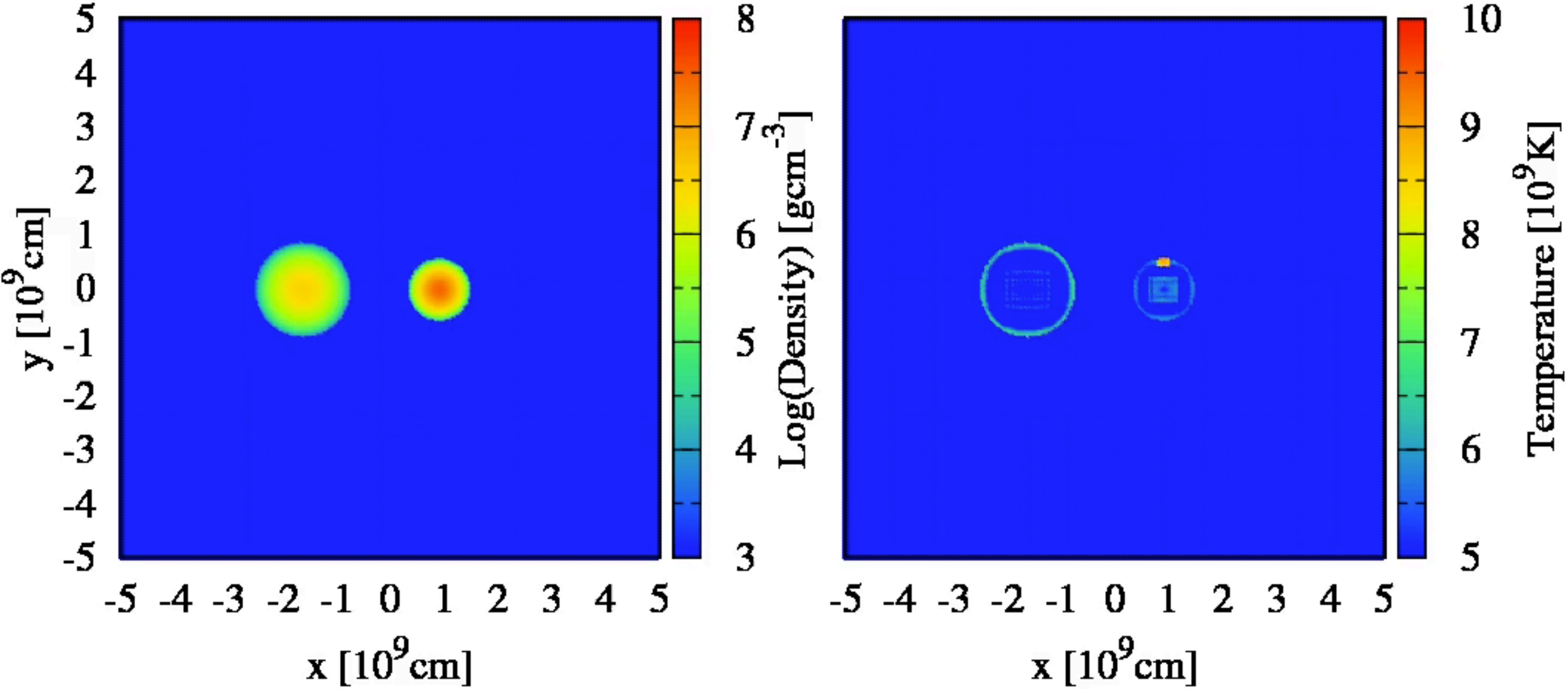
Initial conditions

- The first case
  - $1.0M_{\odot}$ COWD + $0.6M_{\odot}$ COWD
  - He outer shell on the heavier WD
  - No He outer shell on the lighter WD
- The second case
  - $1.0M_{\odot}$ COWD + $0.9M_{\odot}$ COWD
  - He outer shells on the heavier WD
  - Massive He outer shell on the lighter WD





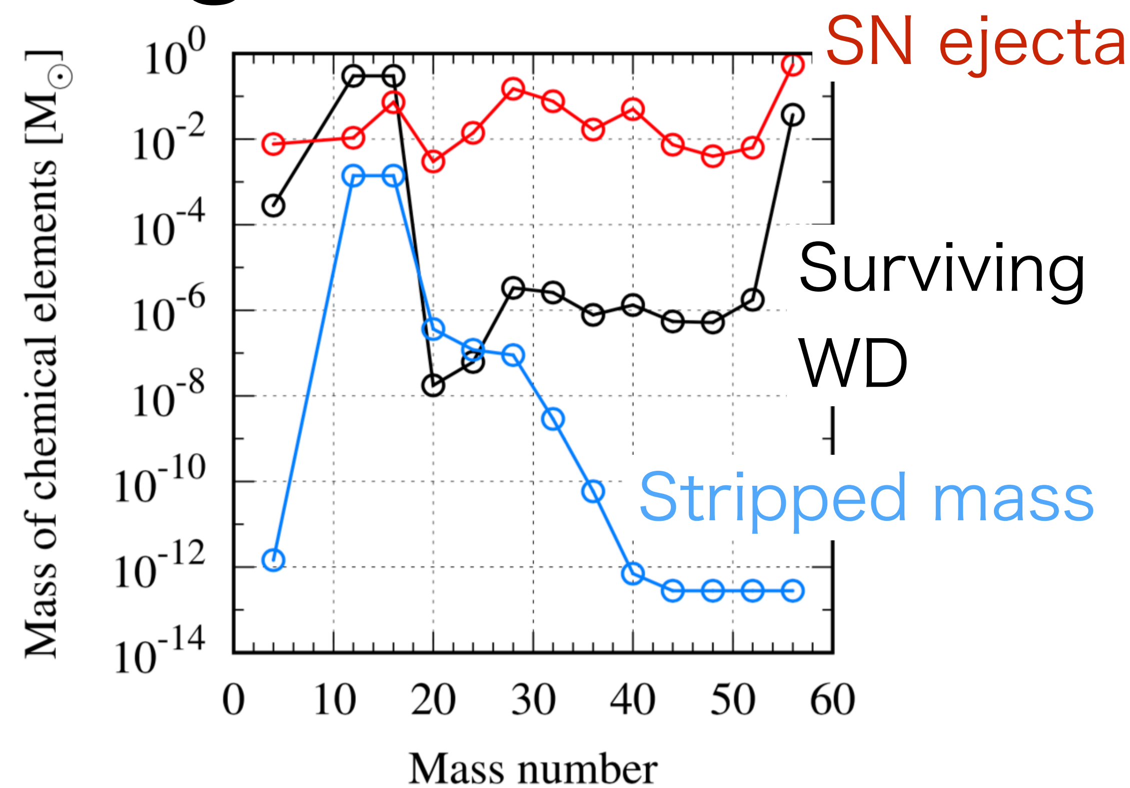
The first case

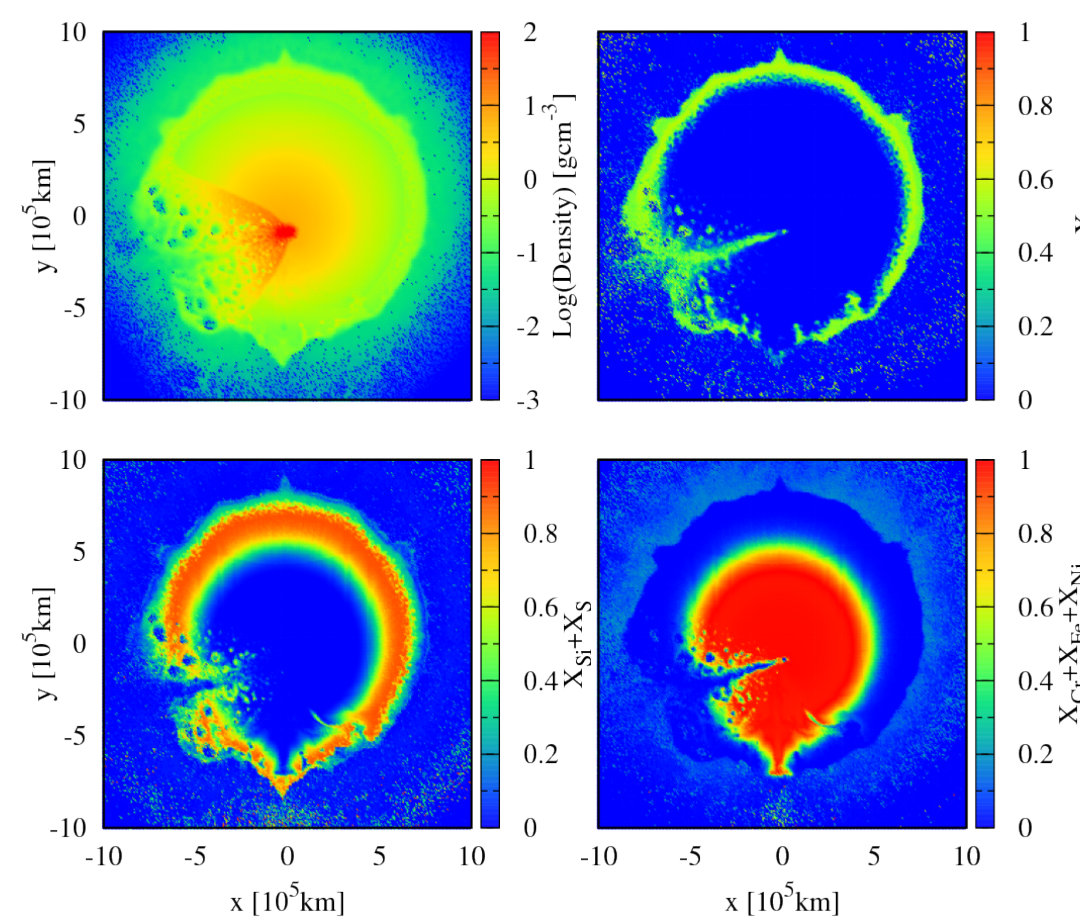


Tanikawa et al. (2018, ApJ, 868, 90)

Supernova ejecta

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

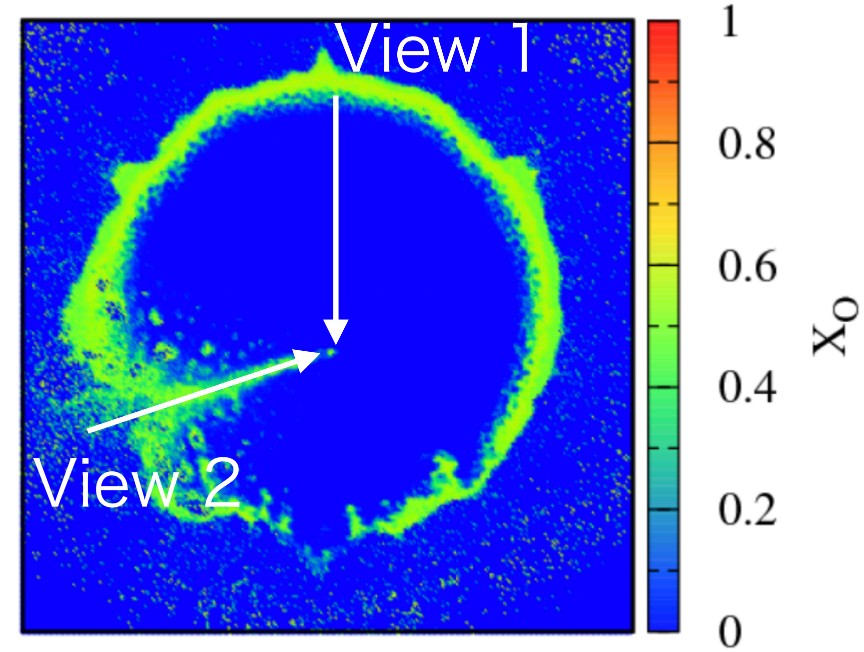




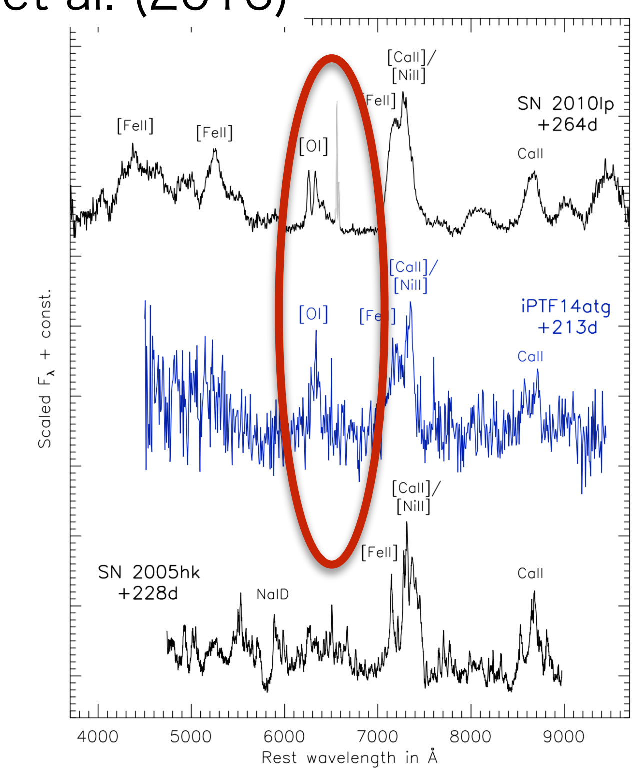
Tanikawa et al. (2018, ApJ, 868, 90)

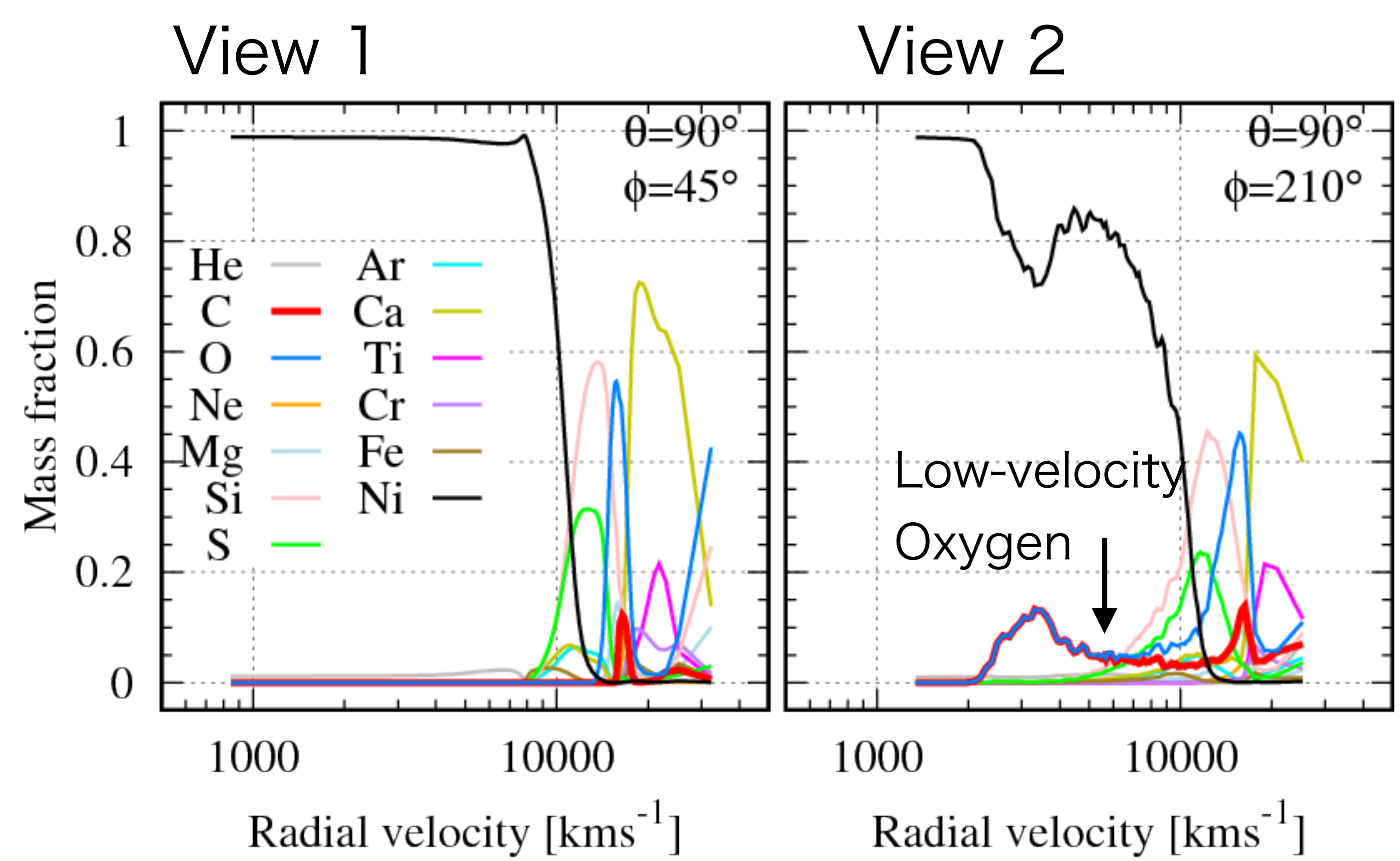
Low-velocity oxygen

- The companion-origin stream could be a key to identify D6 explosions.
- D6 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 D6 explosion by radiative transfer calculation in near future.



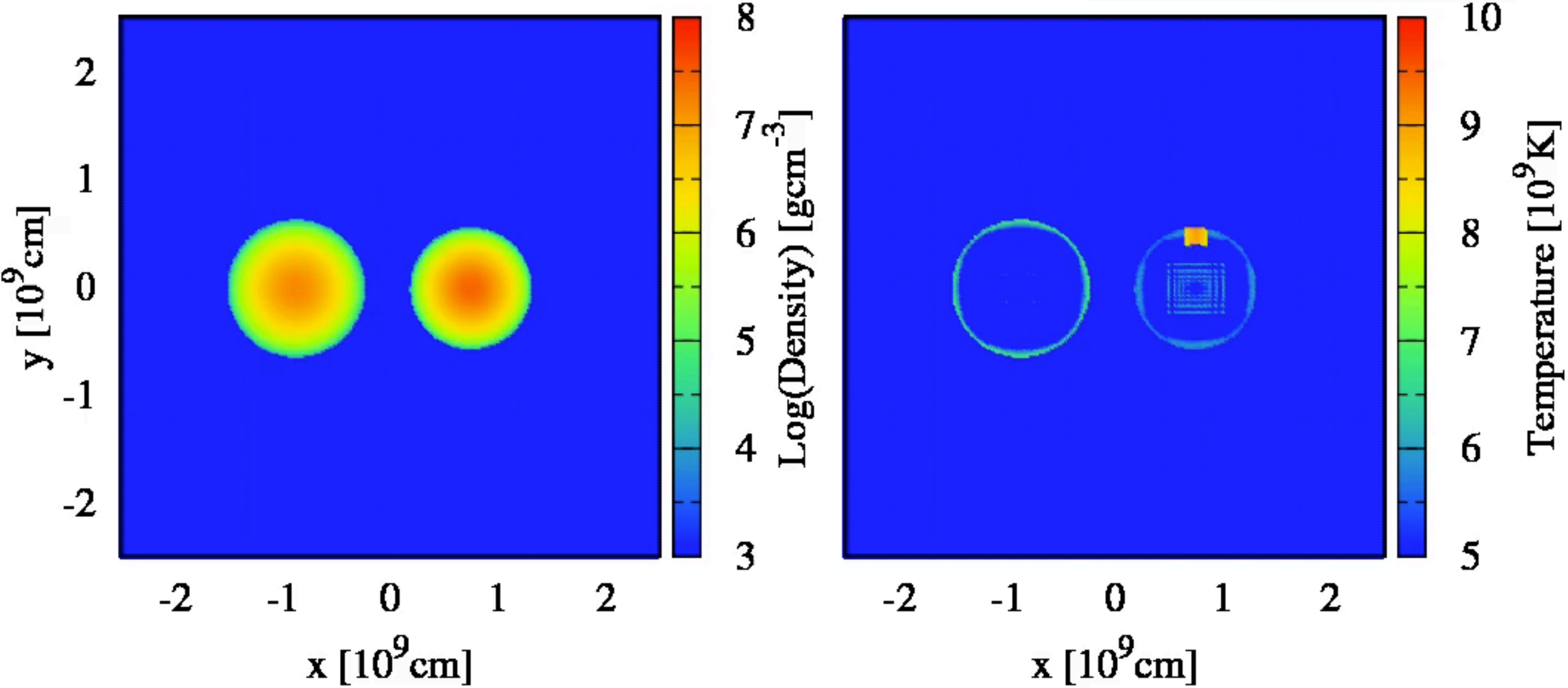
Kromer et al. (2016)





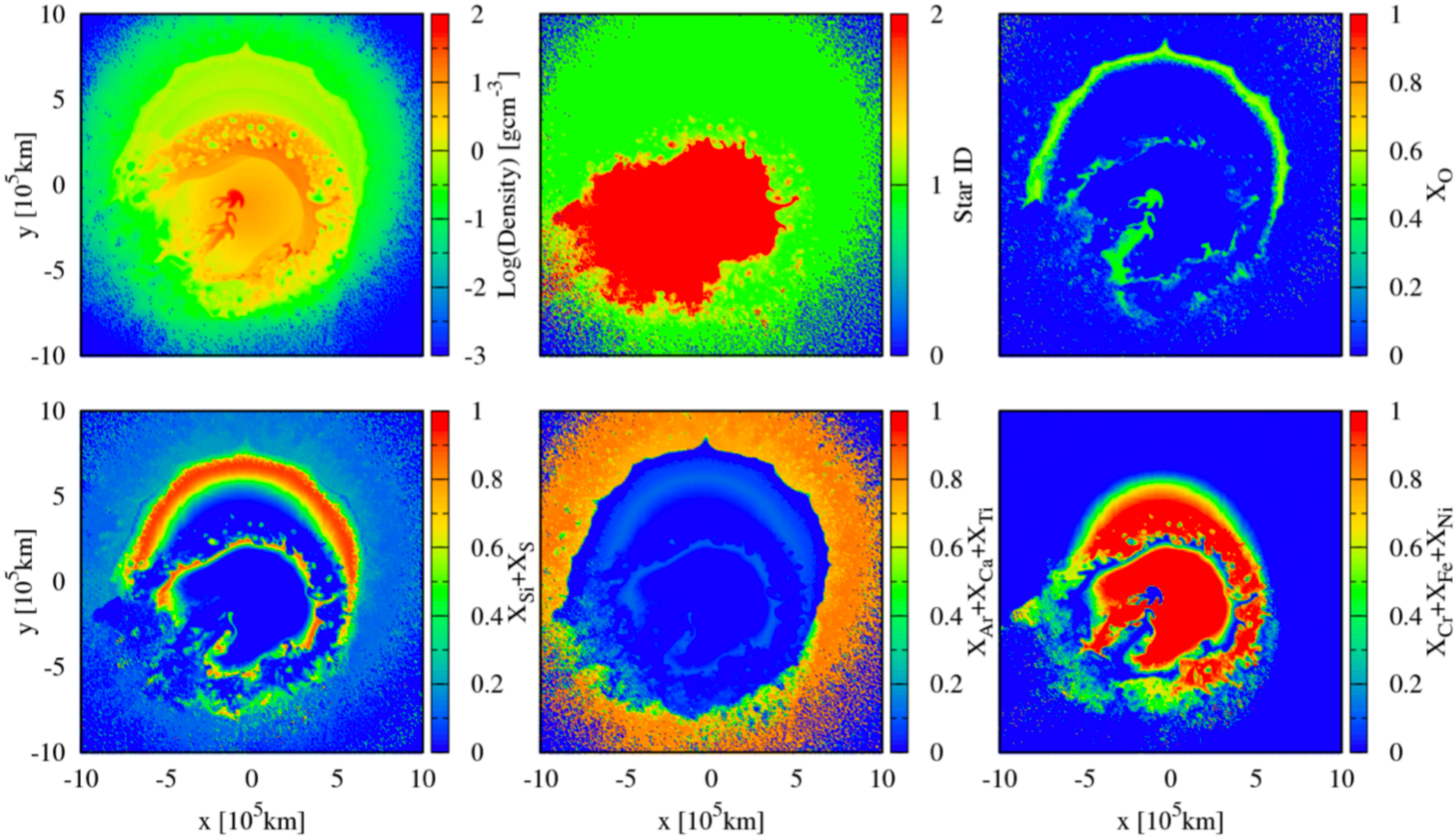
Tanikawa et al. (2018, ApJ, 868, 90)

The second case



Tanikawa et al. (2019, ApJ, 885, 103)

Chemical abundance



- ^{56}Ni mass is ~1.0Msun.

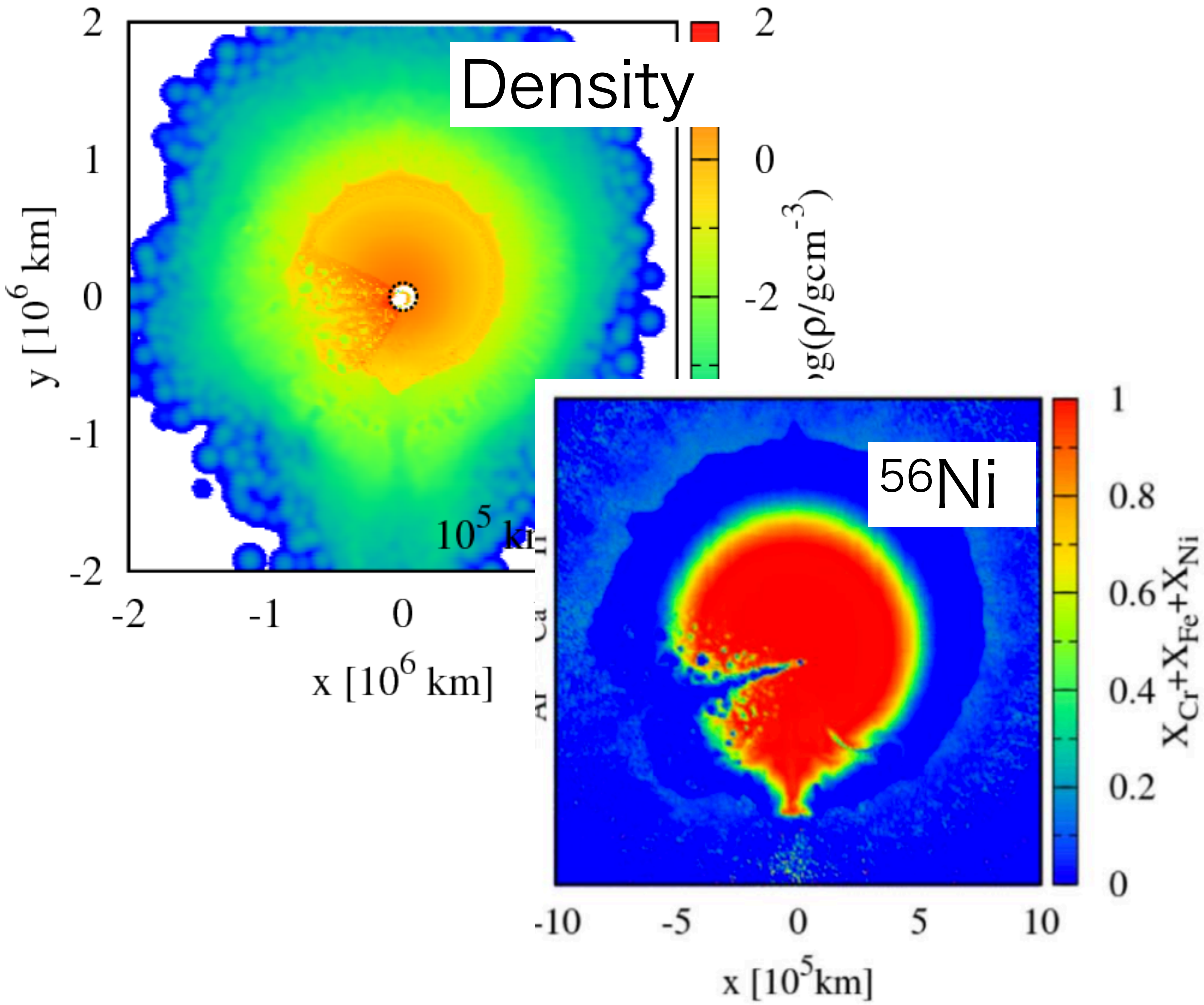
Tanikawa et al. (2019, ApJ, 885, 103)

Luminous SNe Ia?

- QD explosions have early emissions because of He detonation products.
- The colors of the early emissions may be consistent with those of Luminous SNe Ia, such as SN1991T and SN1999aa (Maeda et al. 2018).
- The colors of early emissions through interactions with non-degenerate companions and CSMs may be too blue (Hosseinzadeh et al. 2017; Maeda et al. 2018).
- Super-Chandrasekhar SNe Ia cannot be explained by QD explosions, since they have massive CSMs (Yamanaka et al. 2016).

Tanikawa et al. (2019, ApJ, 885, 103)

Future plans



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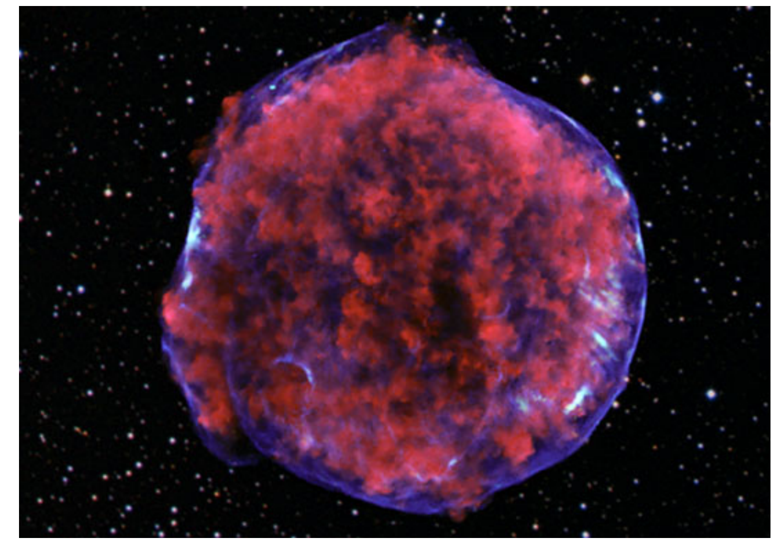
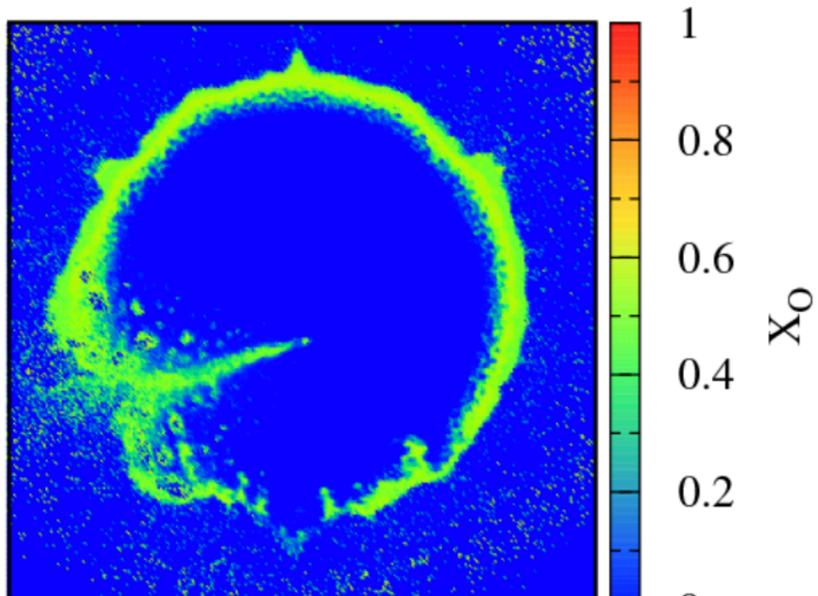


Collaboration with
G. Ferrand

Companion-
origin stream



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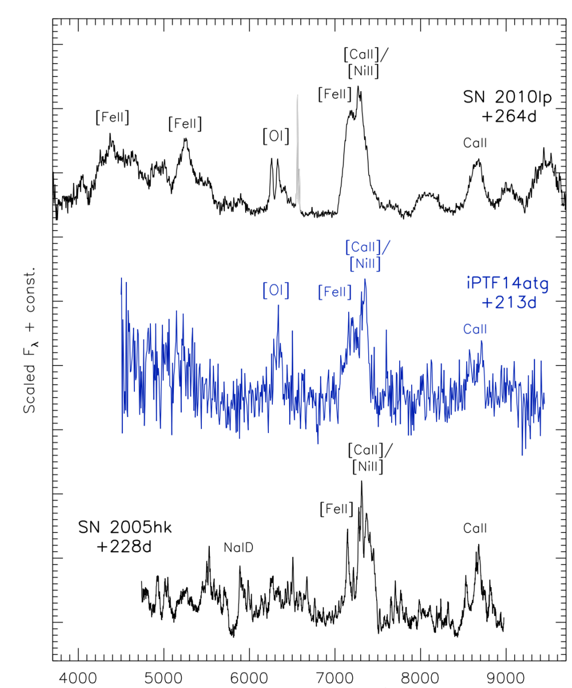

Kromer et al. (2016)

Summary

- SNe Ia can need the near-Ch SD and sub-Ch DD scenarios.
- We have assessed one of sub-Ch DD scenarios, the D6 model.
- The D6 model indicates several asymmetric features, such as the ejecta shadow, and companion-origin stream.
- The companion-origin stream can contribute to oxygen emissions in nebular phase spectra found in peculiar Ia.
- We will compare these asymmetric features with observations by detail calculations in the near future.