White dwarf merger by SPH simulation

Ataru Tanikawa (University of Tokyo)
Collaborators
Y. Sato, N. Nakasato, K. Nomoto, K. Maeda, I. Hachisu

Tanikawa+Nomoto+ (2015, ApJ, 807, 40)
Sato+Tanikawa, Nomoto+ (2015, ApJ, 807, 105)
Sato+Tanikawa, Nomoto+ (2016, ApJ, 821, 67)

Contents of this talk

- Detail investigation of massive carbon-oxygen (CO) white dwarf (WD) merger
  - Tanikawa et al. (2015)
- Parameter survey of CO WD mergers with various mass combination
  - Sato et al. (2015; 2016)

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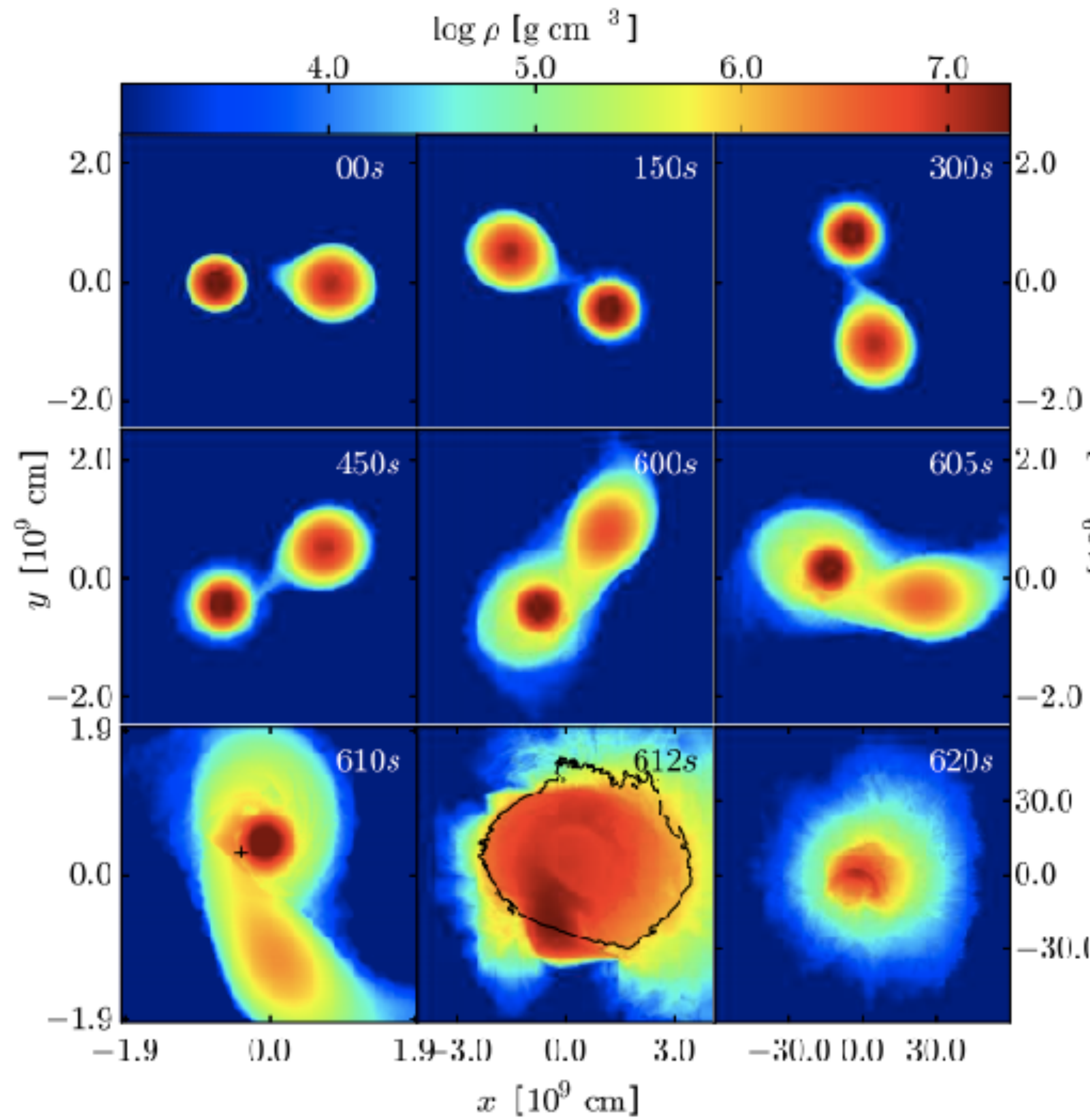
Violent merger explosion

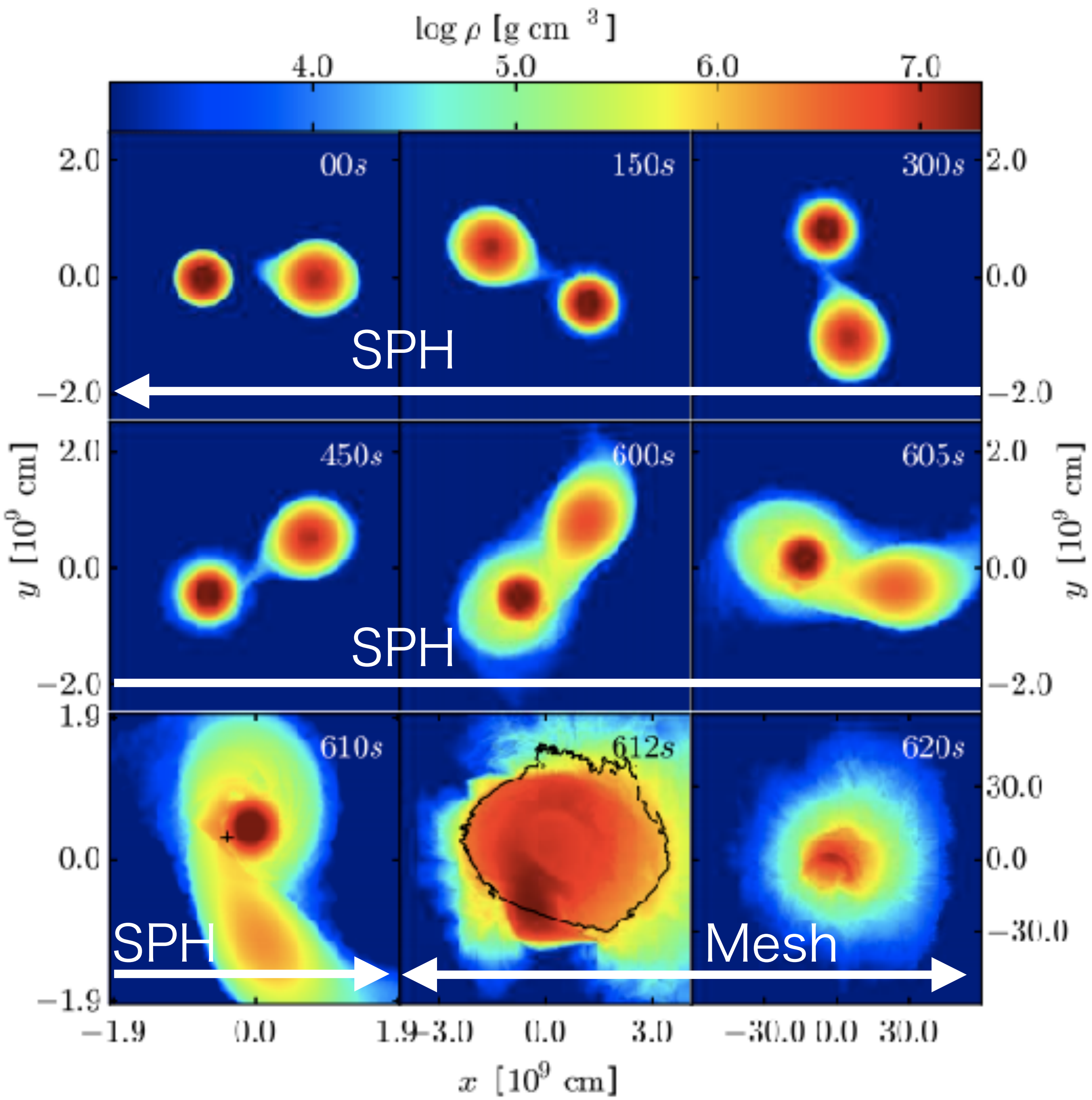
- Carbon is ignited by hydrodynamical effect.
- Sub-Chandrasekhar mass explosion
- Possible counterparts to sub-luminous SNe Ia



Pakmor et al. (2012)

Uncertainty in the beginning time of explosion

- Violent merger explosion does not occur self-consistently in SPH simulation.
- The explosion artificially starts after a “hotspot” appears in SPH simulation.
- The “hotspot” can be defined in various ways (the next slide).
- The explosion does not necessarily start when they considered.



Pakmor et al. (2012)

Various definitions of temperature in SPH

- Whether a hotspot appears or not depends on the definition of temperature.
- Two definitions of temperature in SPH simulation
  - Raw temperature
  - Smoothed temperature $T_{s,i} = \sum_{j}^{N} T_{r,j} \frac{m_j}{\rho_j} W\left(\left|\boldsymbol{r}_j - \boldsymbol{r}_i\right|, h_j\right)$,
- The success and time of the violent merger explosion can depend on the definitions of temperature.

Our study

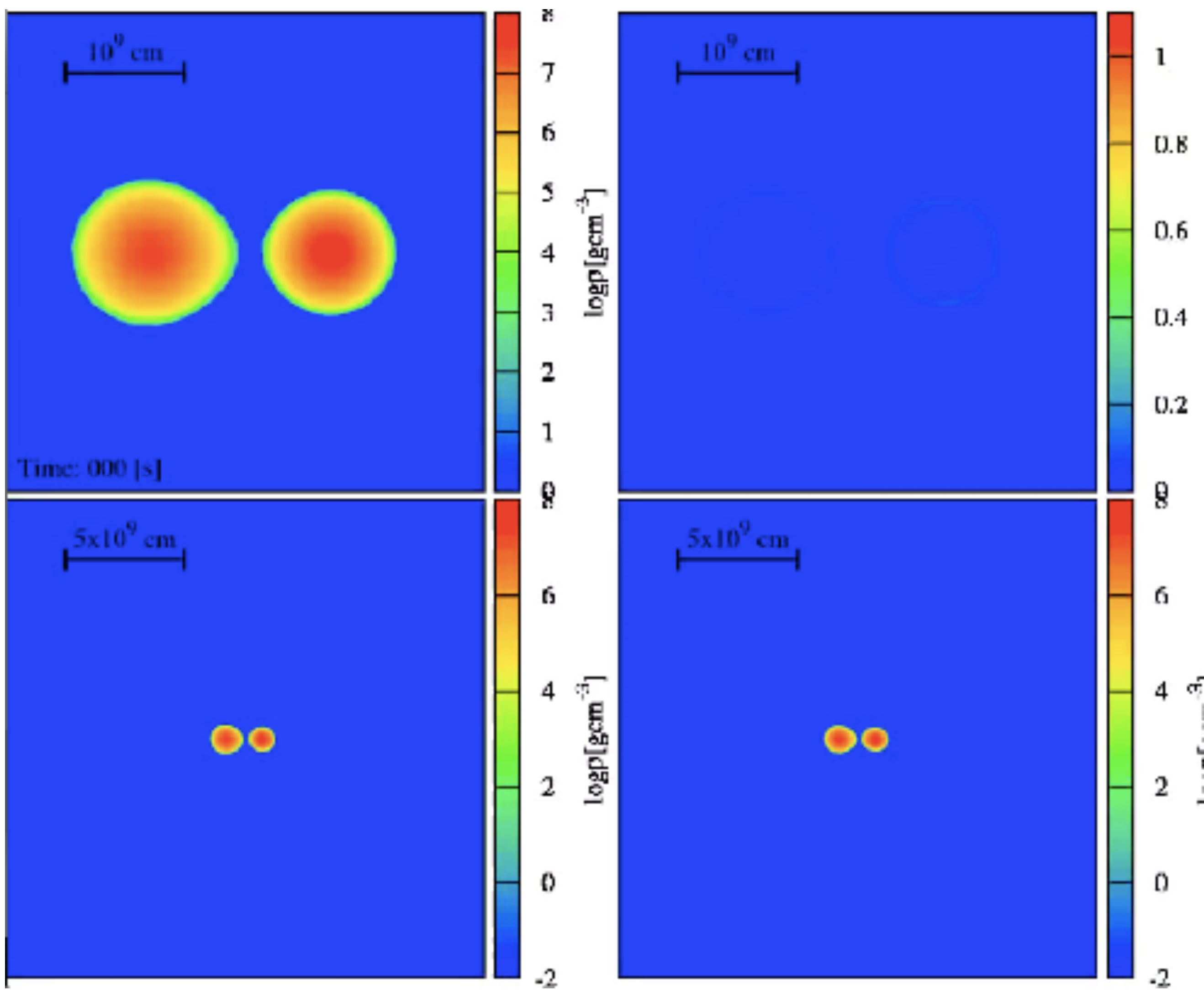
- High-resolution SPH simulation of massive CO WD merger ($N \sim 10^7$)
- The two definitions of temperature
- Expected nucleosynthesis
- Structure of circumstellar materials

SPH simulation

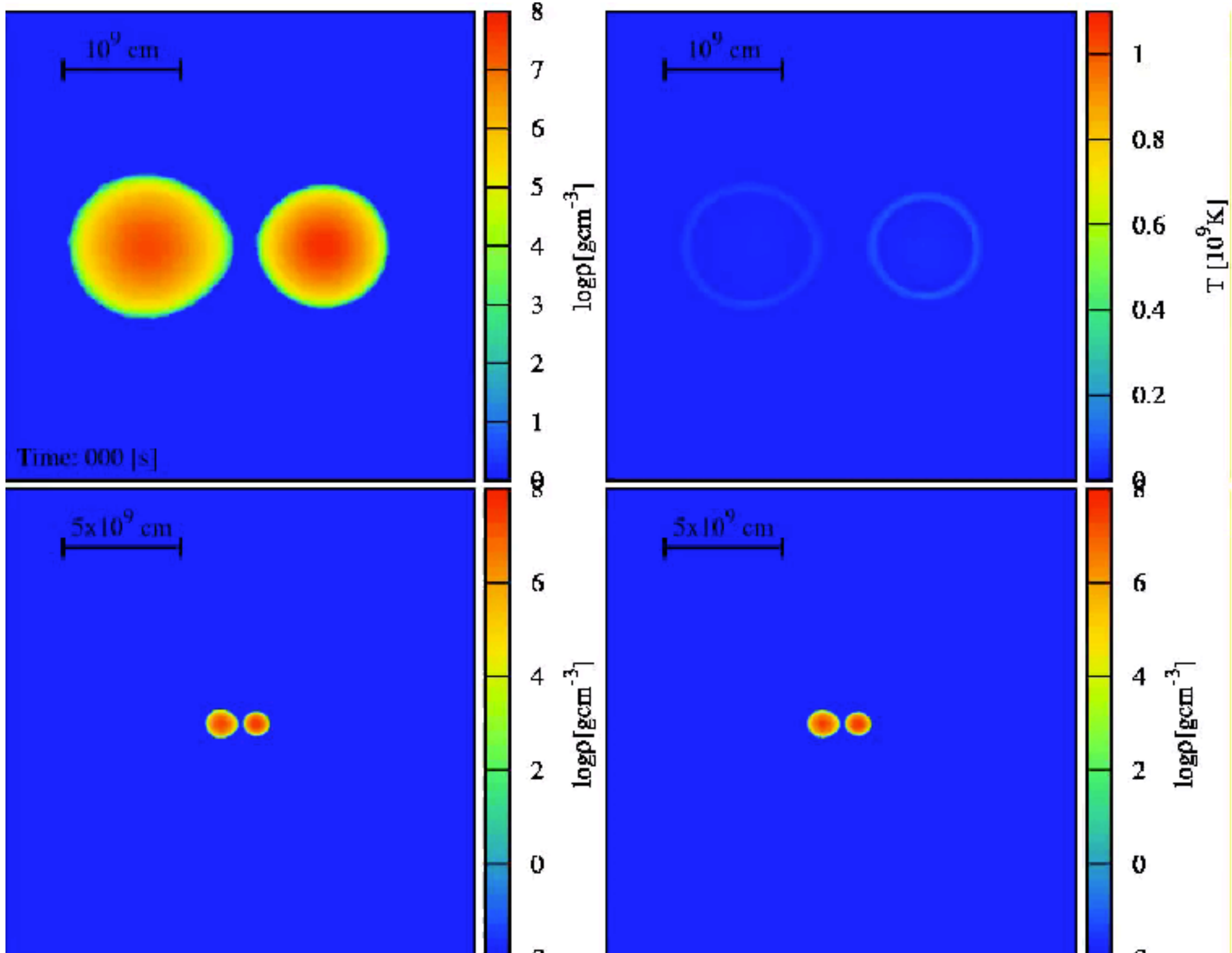
- Conventional artificial viscosity
  - Time-dependent artificial viscosity (Morris, Monaghan 1997)
  - Balsara’s switch (Balsara 1995)
- Equation of state: Helmholtz EoS (Timmes, Swesty 2000)
- No nuclear reaction
- Supercomputer HA-PACS (4 GPUs NVIDIA Tesla M2090)

Initial conditions

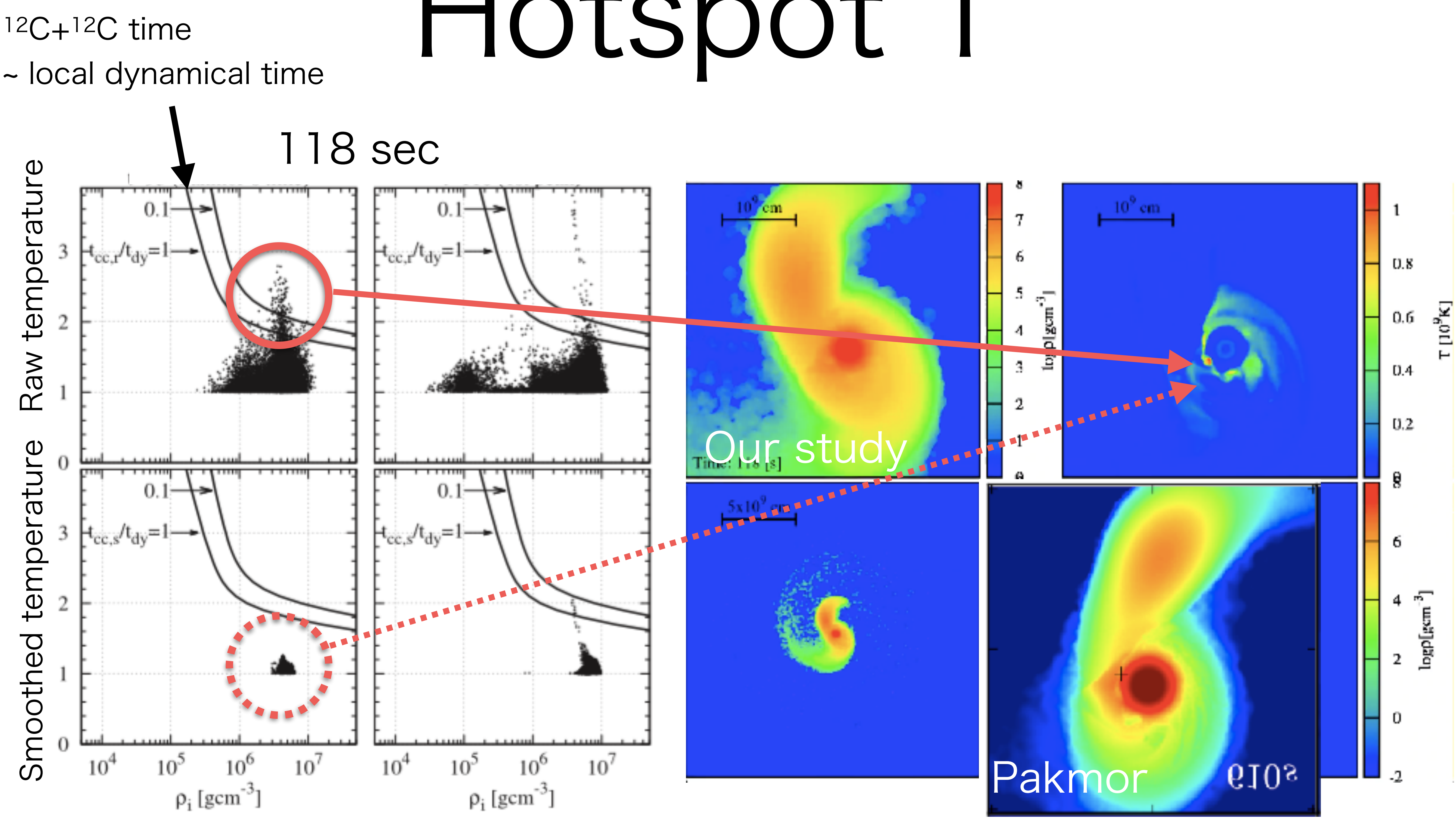
- 1.1M⊙-1.0M⊙ CO WD
- Composition: carbon 50%, oxygen 50%
- The number of SPH paritcles: 1.1×10^7
- Relaxation scheme (see also Dan et al. 2011)



1.1-1.0M$_\odot$ COWD merger

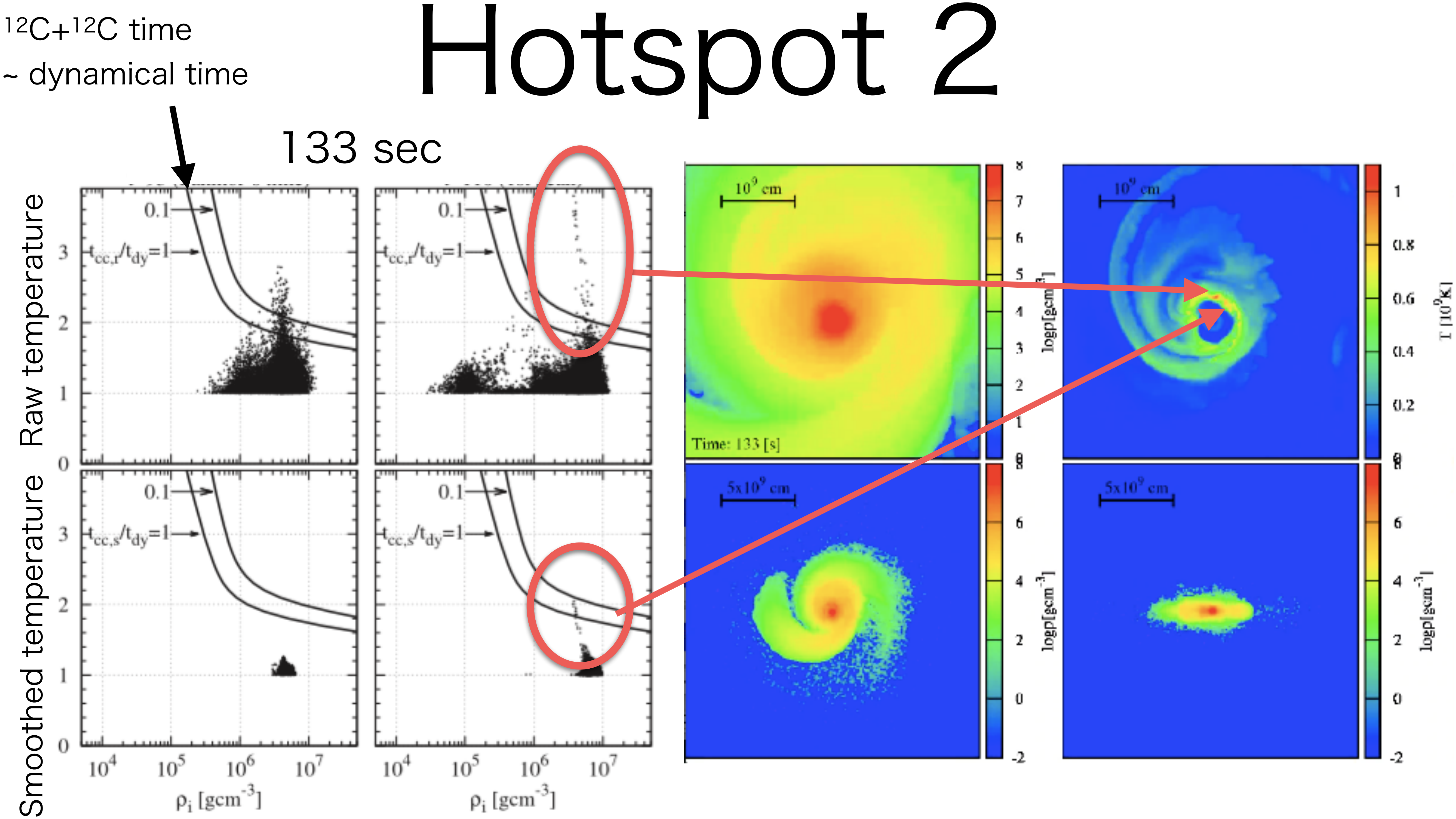


Hotspot 1



- A hotspot appears from the view point of raw temperature.
- The morphology is quite similar to Pakmor's one.
- The explosion may fail from the view point of smoothed temperature.

Hotspot 2



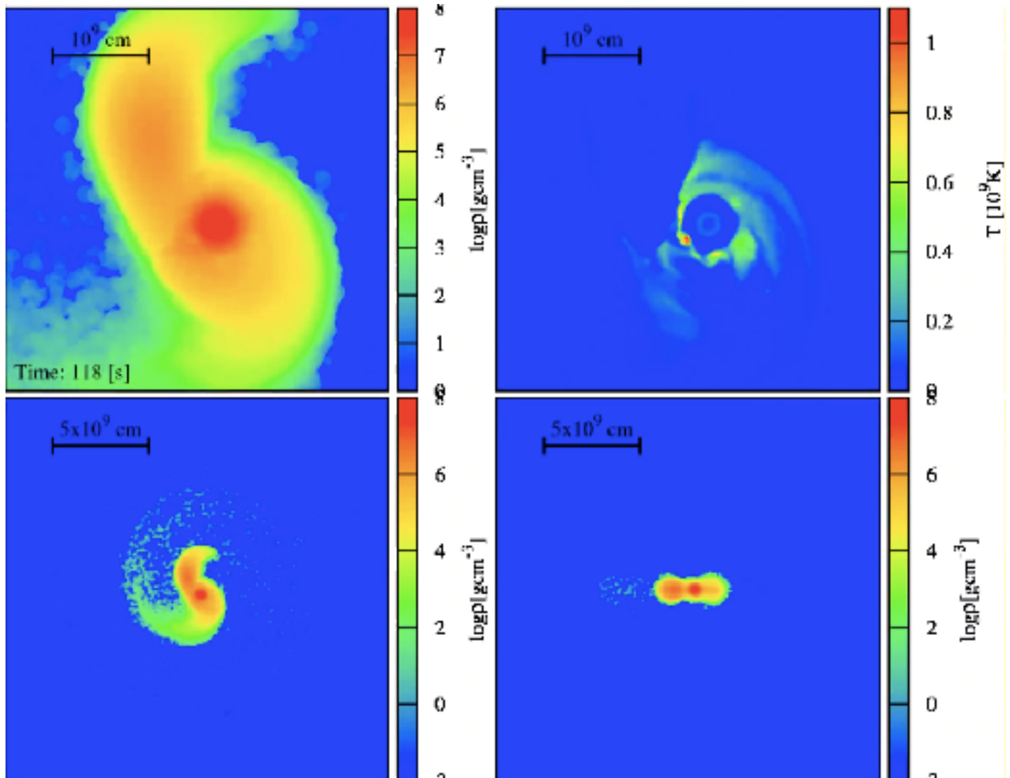
- A hotspot appears from the view point of both raw and smoothed temperature.
- The explosion may begin at this time.

Hotspot structure

- ホットスポットの大きさはSPHカーネルの大きさよりも小さいことを図示する
- エネルギー保存も調べる

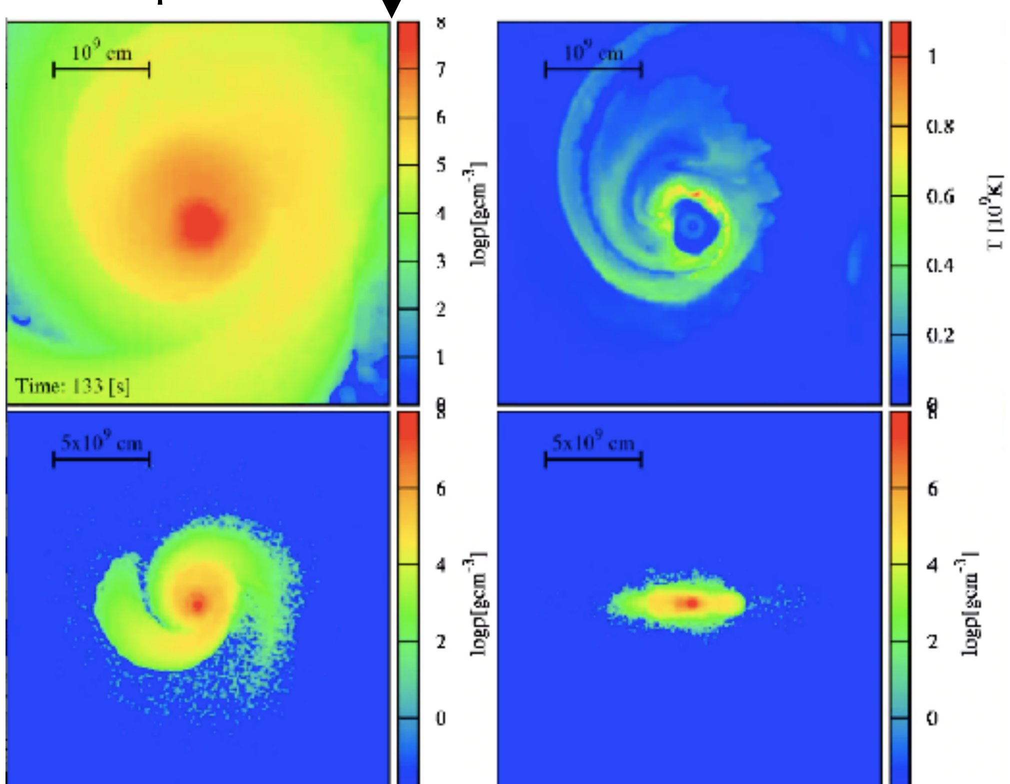
Expected nucleosynthesis

Hotspot 1

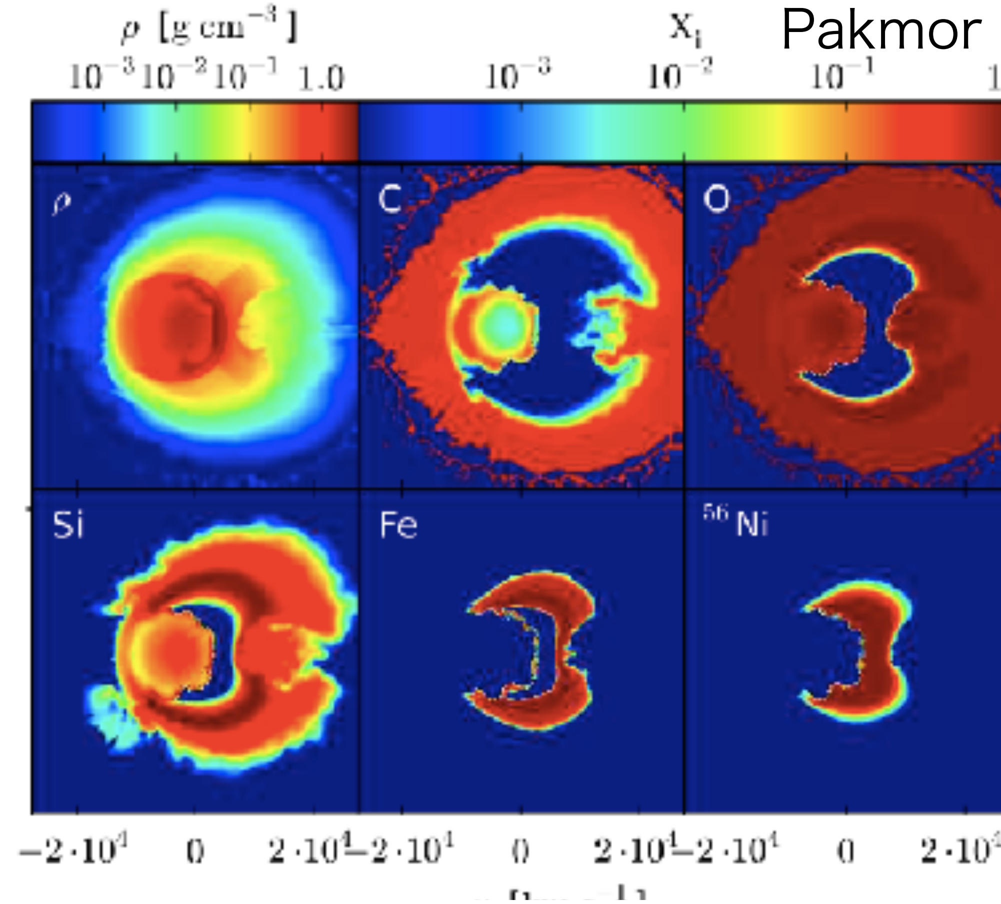


15sec (< orbital time)

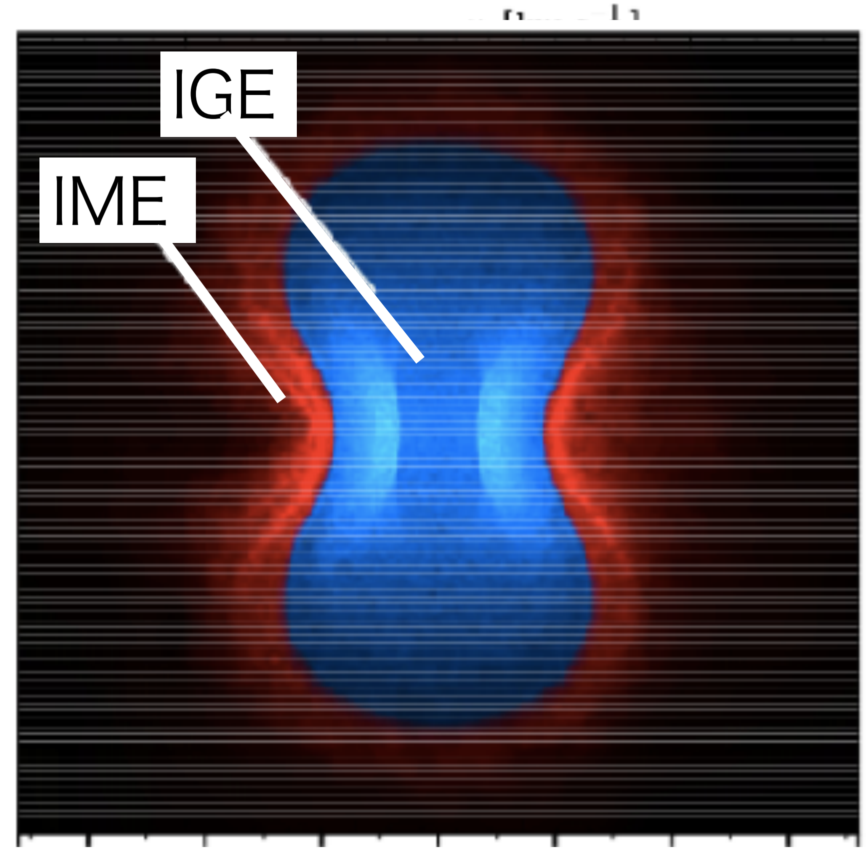
Hotspot 2



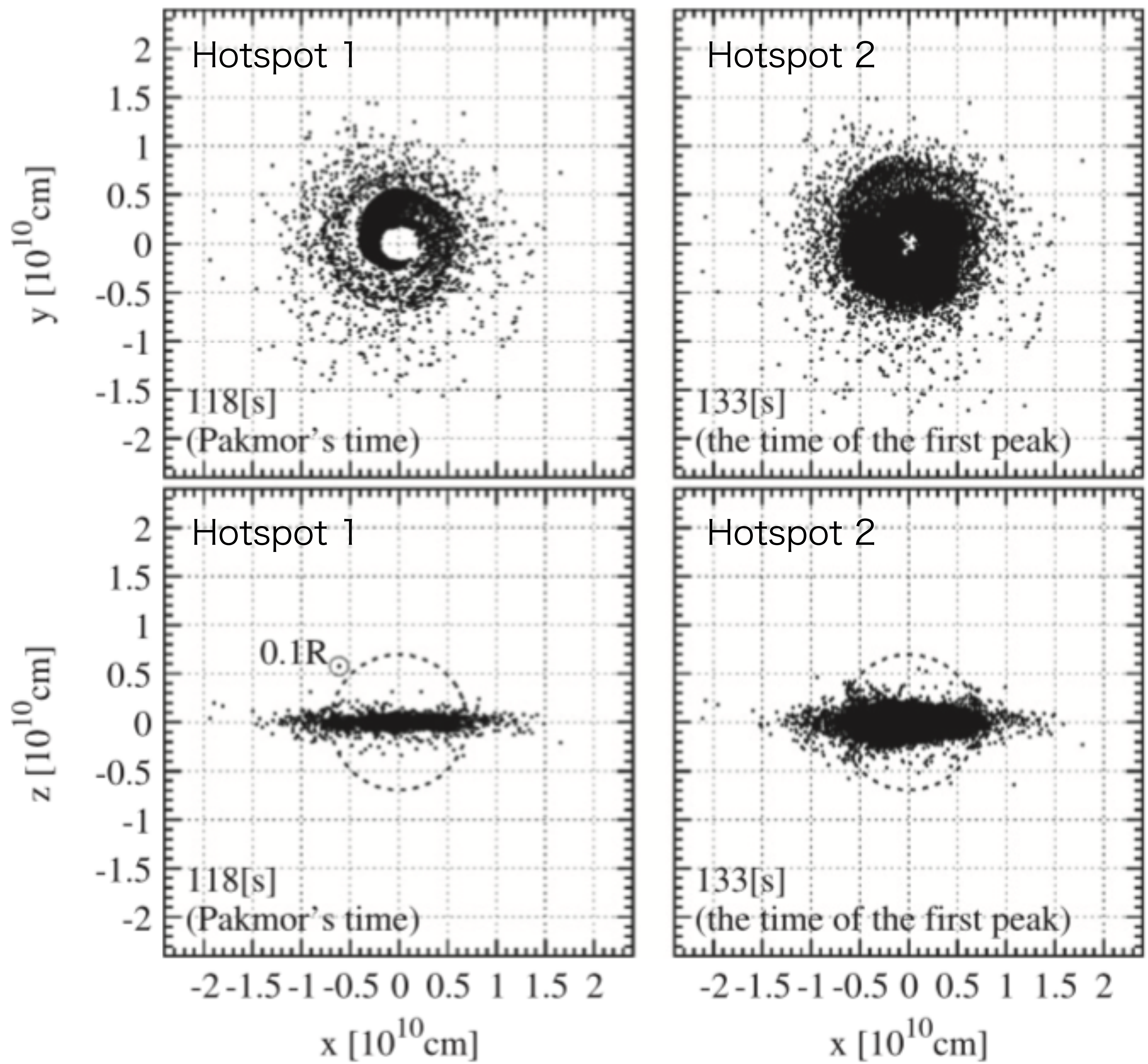
Pakmor et al. (2012)



Raskin et al. (2014)



Circumstellar materials



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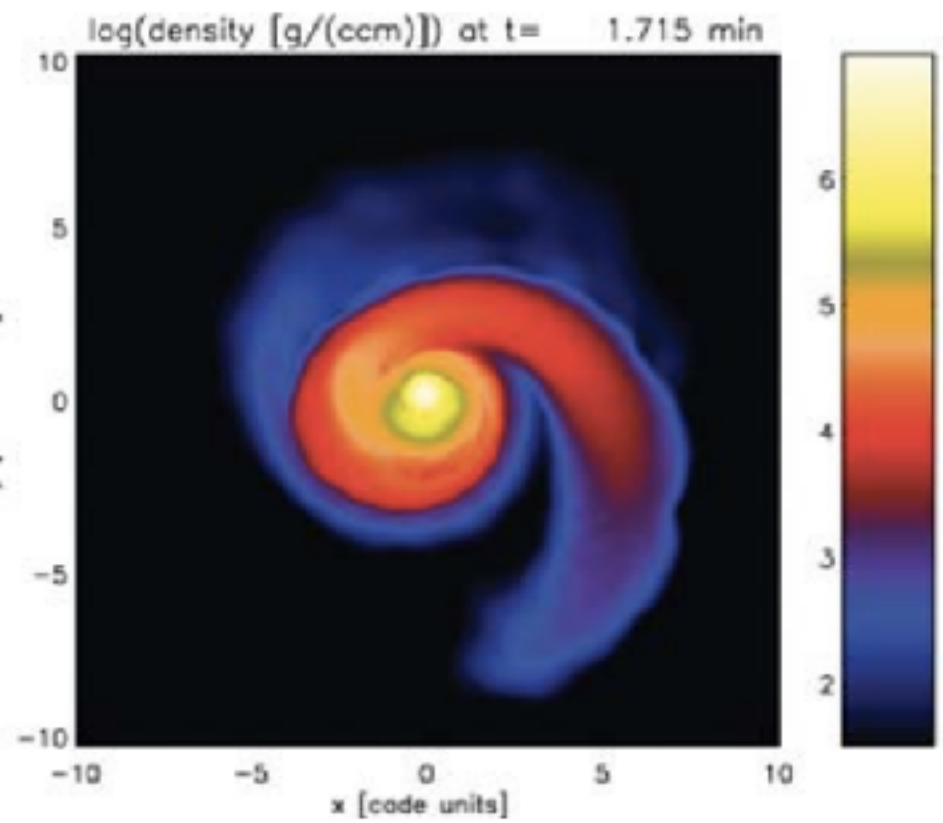
Fate of white dwarf merger

- Thermonuclear explosion
  - Sub-Chandrasekhar mass explosion
    - He-ignited violent merger (Pakmor et al. 2013)
    - C-ignited violent merger (Pakmor et al. 2010)
    - Spiral-induced explosion (Kashyap et al. 2015)
    - Magnet-induced explosion (Schwab et al. 2012)
  - Chandrasekhar mass explosion
    - accretion-induced explosion (AIE)
- No explosion
  - Massive white dwarf
  - Accretion-induced collapse (AIC)

chronological order

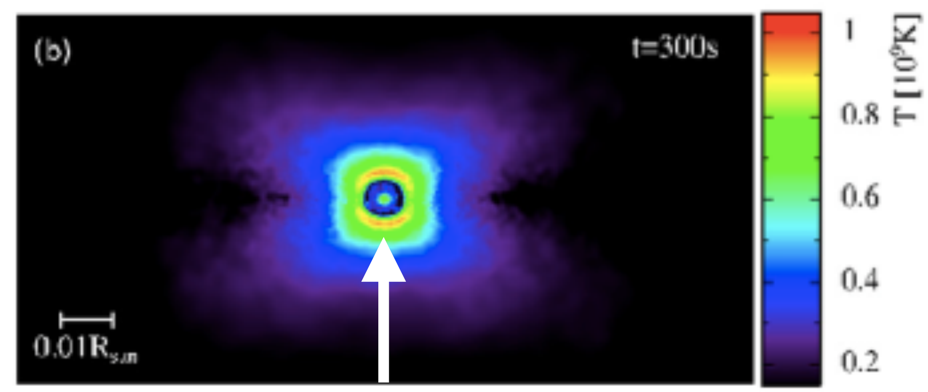
AIE or AIC

- Chandrasekhar explosion (AIE)
- Long time after merger



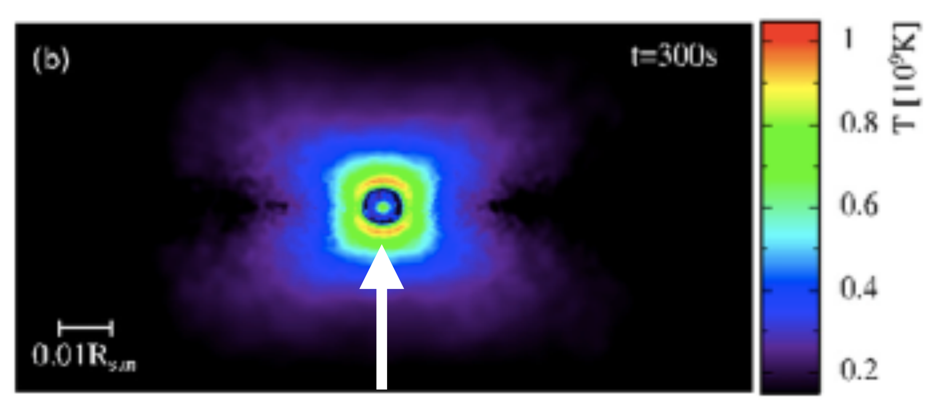
Yoon et al. (2007)

Sato et al. (2015)



C heating > neutrino cooling

→ ONeMg WD/NS (AIC)



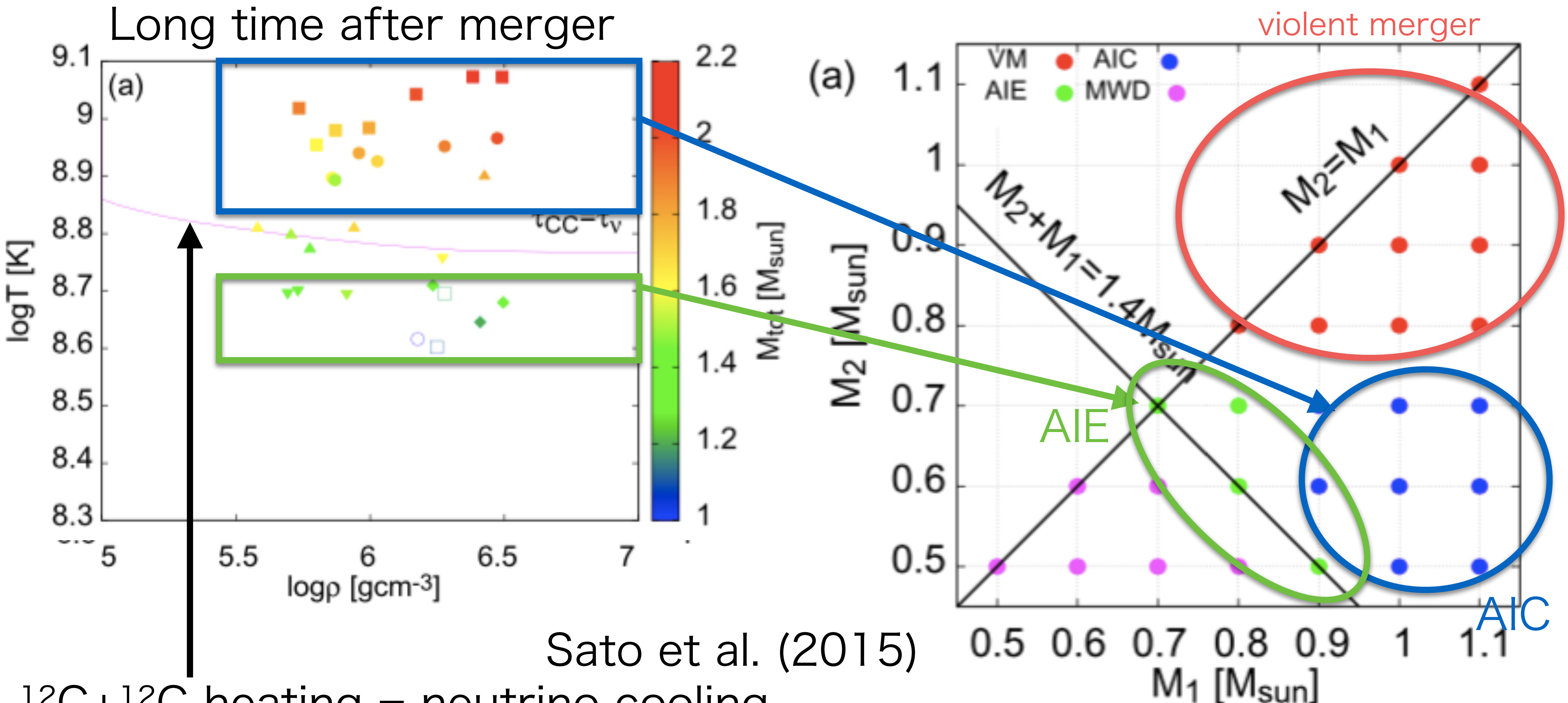
C heating < neutrino cooling

→ SN Ia (AIE)

Our study

- Various mass combination of two COWDs by high-resolution SPH simulations
- Fate of white dwarf merger
  - e.g. Dan et al. (2012; 2014), Zhu et al. (2013)
- Criterion of violent merger
  - High-resolution SPH simulation is required (Pakmor et al. 2012)

Mass combination



Sato et al. (2015)

$^{12}C+^{12}C$ heating = neutrino cooling

- If the secondar mass is larger than 0.8 $M_\odot$, violent merger explosion occurs
- The rate of violent merger explosion is 2% of Galactic SN Ia rate.
- The rate of AIE is 7% of Galactic SN Ia rate.

Summary

- Detail investigate of violent merger explosion
  - There can be various explosion times for violent merger explosion.
  - The nuclear structure is very sensitive to the explosion time.
- Parameter survey of fates of various mass combinations