Tidal detonation of a WD by IMBH

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'Using Tidal Disruption Events
to Study Super-Massive Black Holes'
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Contents

- Introduction
- Spurious heating in SPH simulation for WD TDEs (AT+ 17, ApJ, 839, 81)
- High resolution study of tidal detonation (AT 17a, arXiv: 1711.05451, ApJ submitted)
- Tidal double detonation (AT 17b, arXiv: 1711.07115, MNRAS Letters accepted)

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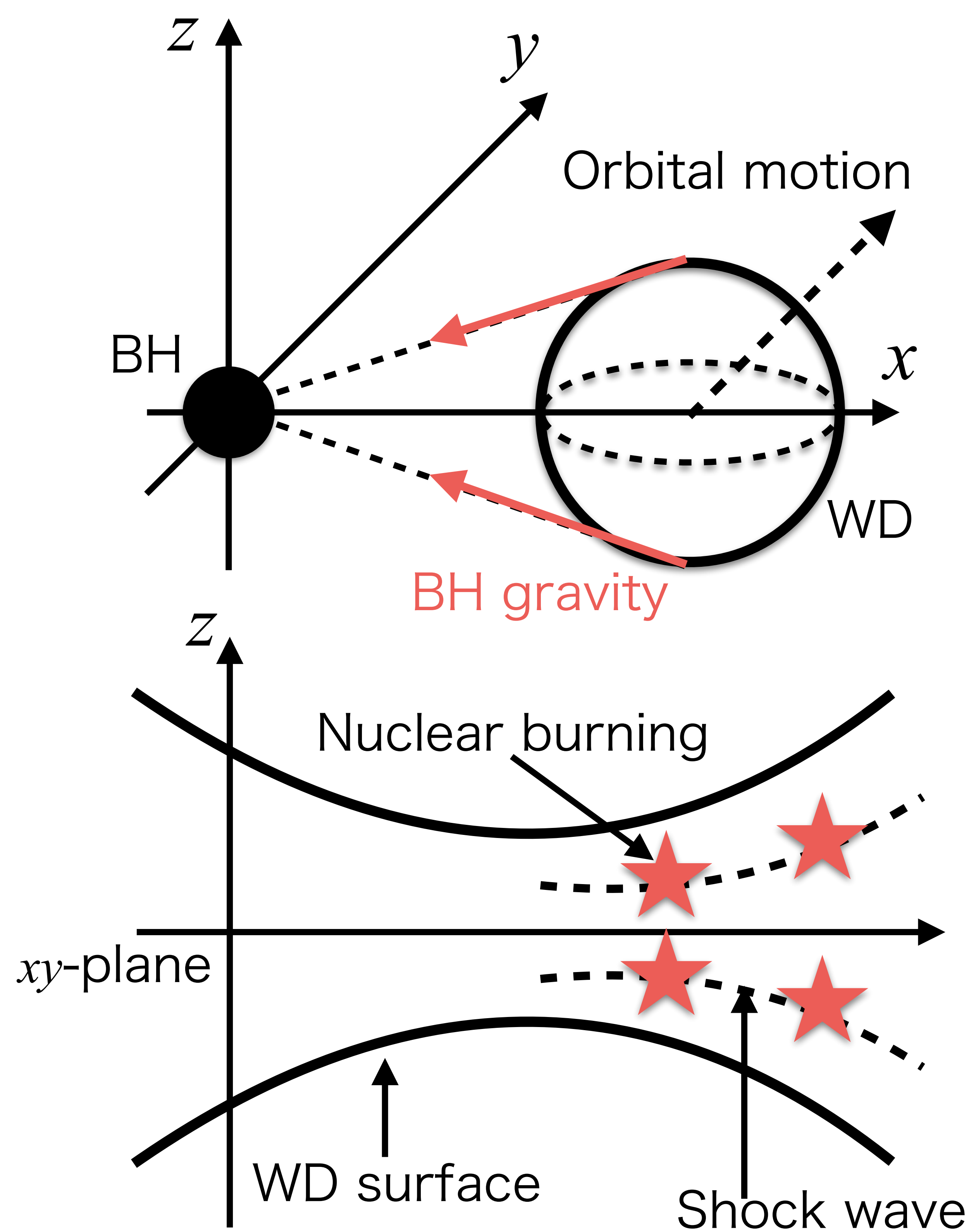
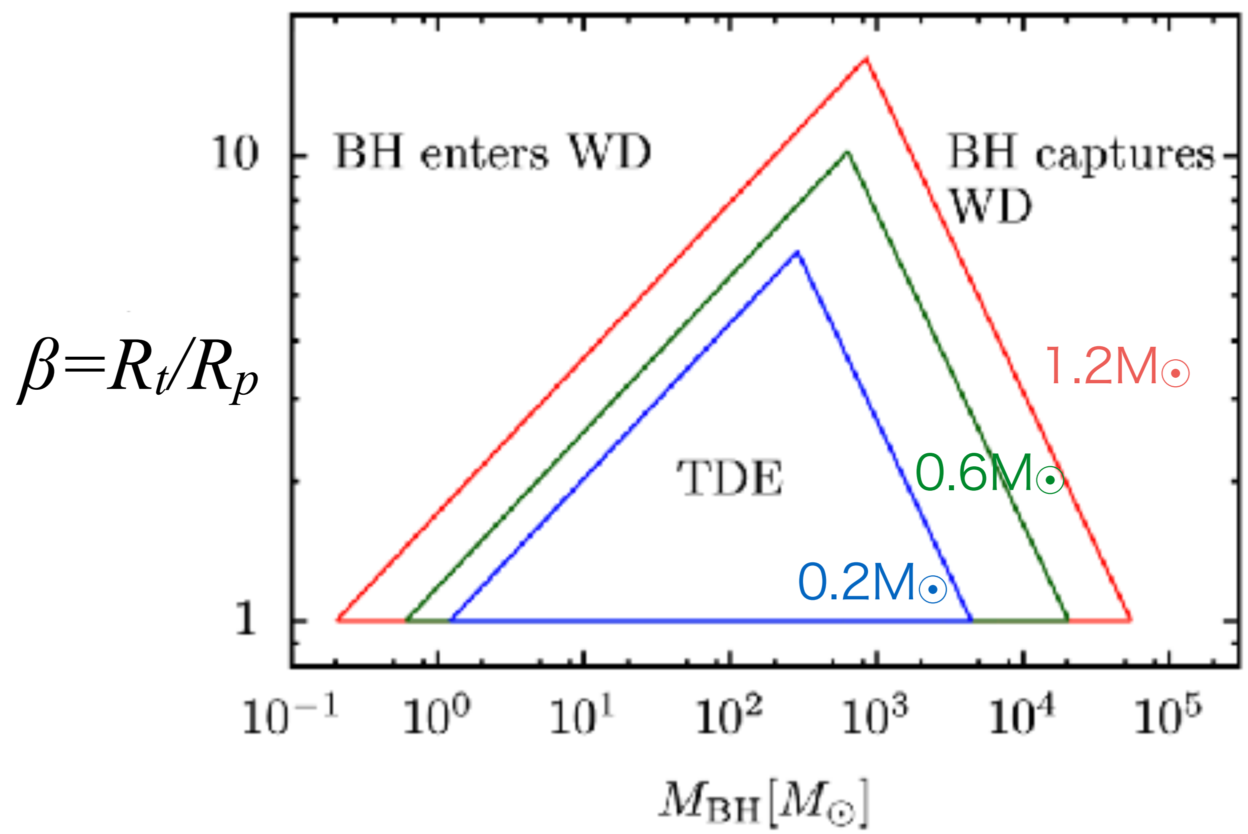
Tidal detonation

- Supersonic combustion induced by a tidal field of a BH
  - The WD is compressed in z-direction.
  - The compression induces a shock wave.
  - The shock wave triggers explosive nuclear reactions.
  - The nuclear reactions synthesize large amounts of ^{56}Ni.



Intermediate mass black hole

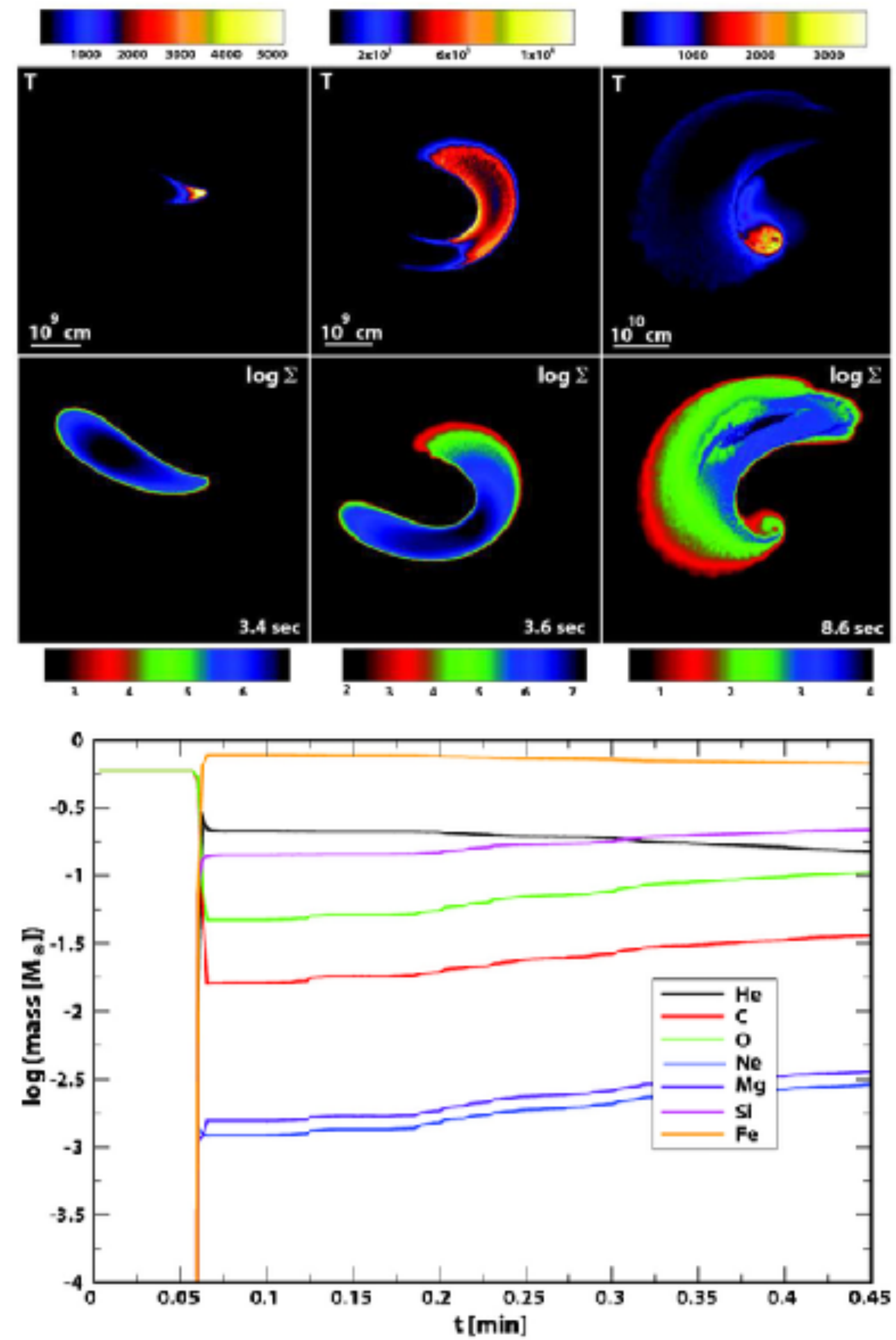
- For tidal detonation, a WD must approach to a BH so closely that the WD is tidally disrupted.
- A WD can be tidally disrupted only by an IMBH.
    - A WD swallows a stellar-mass BH before tidal disruption (but see Kojiro talk).
    - A WD is swallowed by a massive BH before tidal disruption.
- Tidal detonation will illuminate IMBHs by radioactive decay of ^{56}Ni synthesized.
- WD TDEs can be probes to search for IMBHs.



Kawana, AT+ 17 (see also Luminet, Pichon 1989 Rosswog et al. 2009; MacLeod et al. 2016)

Previous studies

- Rosswog et al. (2008; 2009) have performed SPH simulation for WD TDEs and tidal detonation.
- Large amounts of ^{56}Ni are synthesized in their simulation.
- WD TDEs can be observed as thermonuclear transients.
- But, they have not checked convergence of mass (or space) resolution in their simulation.



Rosswog et al. (2008; 2009)

Our studies

- We have performed SPH simulation, and have checked convergence of mass resolution.
- We have verified tidal detonation by high-resolution simulation, combining 1D mesh simulation with 3D SPH simulation in order to avoid the spurious heating.
- We have suggested tidal double detonation (TDD): a new explosion mechanism of a WD.

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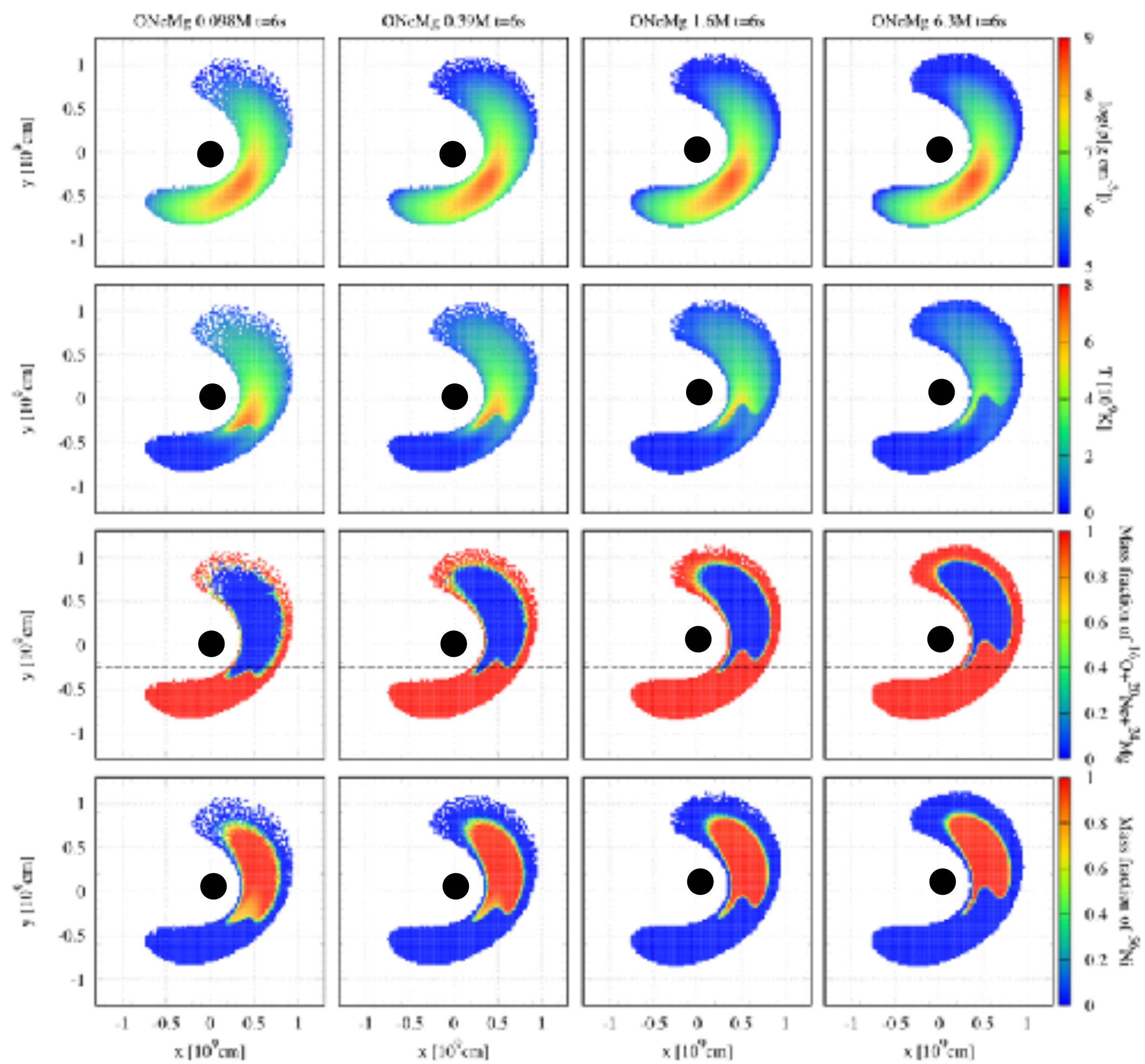
Simulation method

- 3D SPH simulation code
  - Parallelized by FDPS (Iwasawa, AT+ 16)
  - Optimized by AVX instruction set (AT+ 12ab)
- Helmholtz EoS (Timmes, Swesty 2000)
- Aprox13 nuclear reaction networks (Timmes et al. 2000)
- BH gravity
  - Newton potential
  - Paczyński-Wiita potential
  - Tejeda-Rosswog formulation (Tejeda, Rosswog 2013)

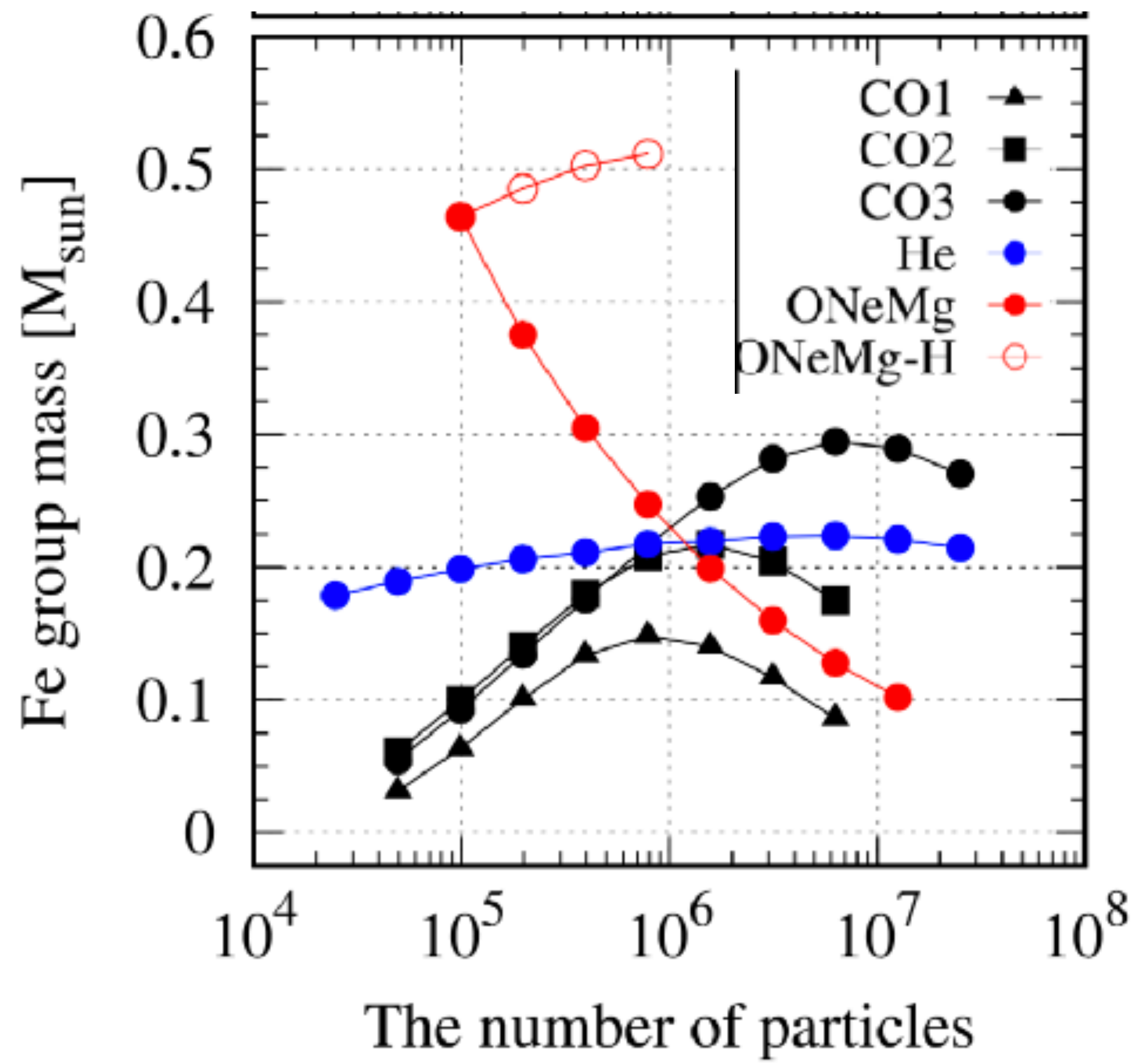


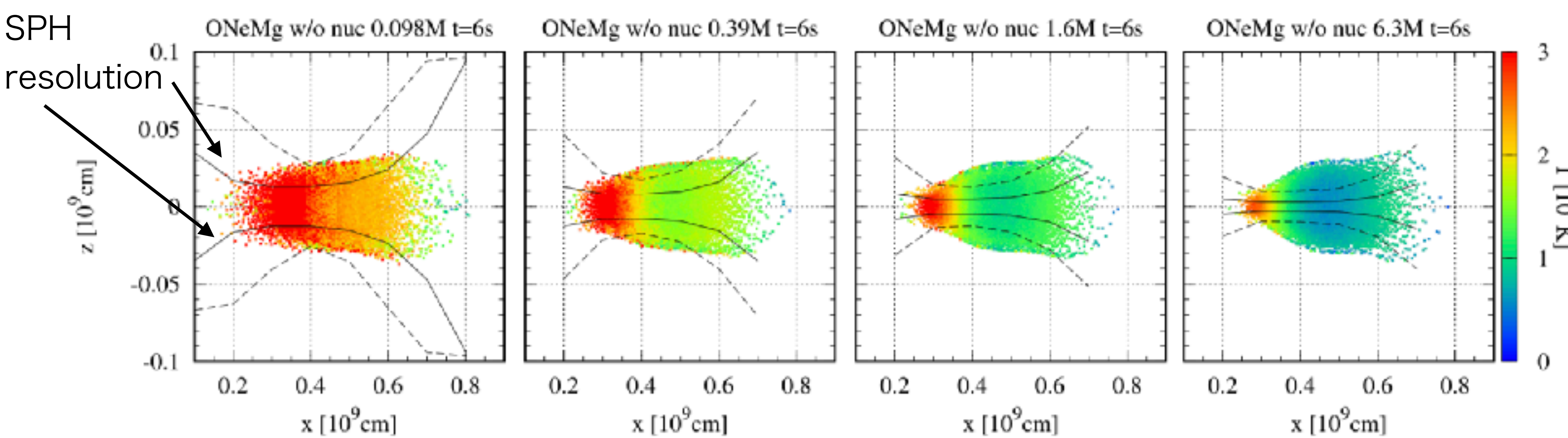
Initial conditions

- WD-IMBH systems
  - 0.3 $M_\odot$ He WD (β=5, 500$M_\odot$ IMBH)
  - 0.6 $M_\odot$ CO WD (β=5, 500$M_\odot$ IMBH)
  - 1.2 $M_\odot$ ONeMg WD (β=3, 100$M_\odot$ IMBH)
- 10^4 - 10^7 SPH particles (N) for a WD
- The WDs have parabolic orbits.
- The WDs and IMBHs have no spin.

Results

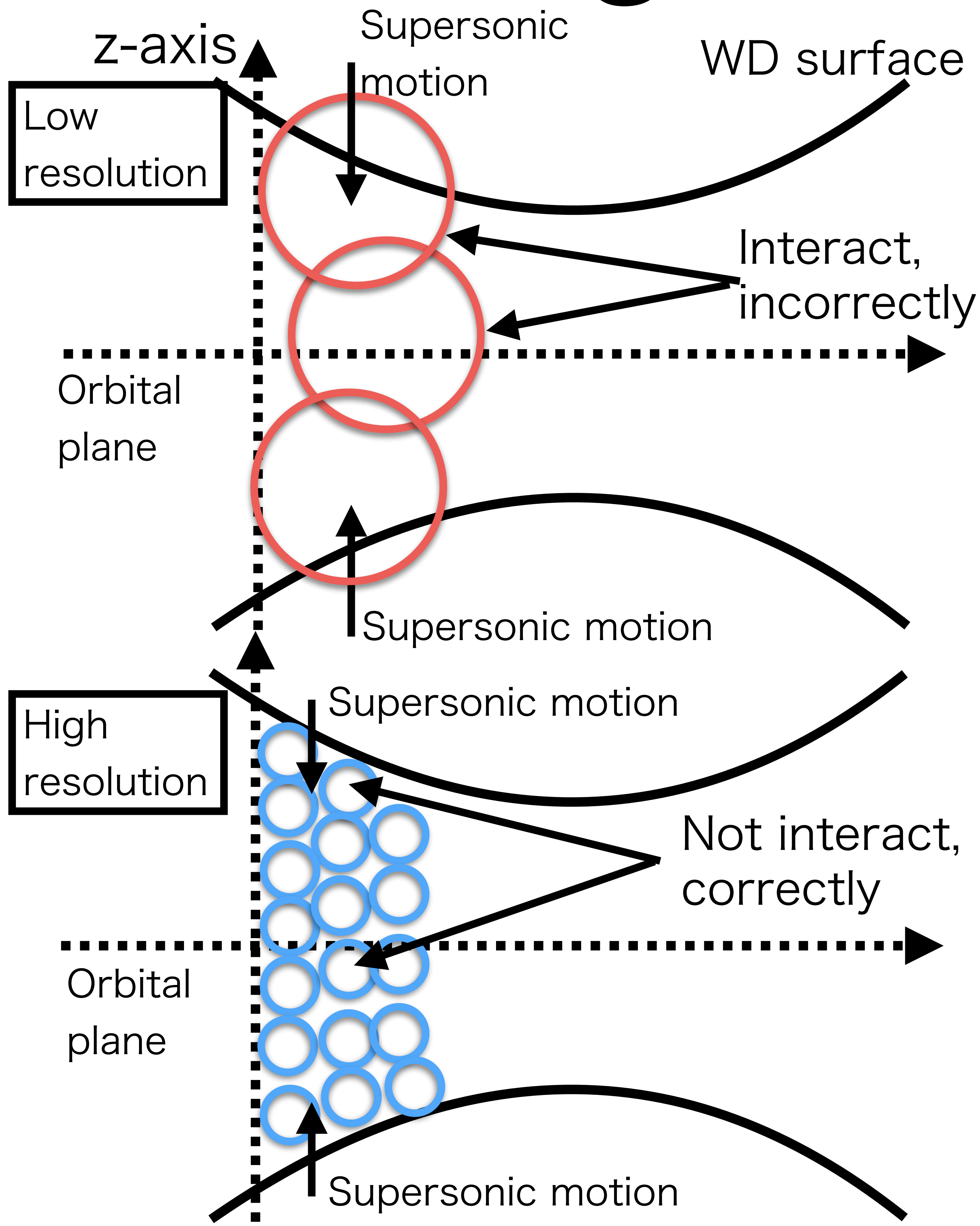
- Amounts of synthesized Fe group elements are not converged.
- These amounts become smaller with N increasing
- SPH simulations fail to resolve WD structure in z-direction.





Spurious heating

- Low resolution (small N)
  - There are few particles in z-direction.
  - Distant particles interact incorrectly.
  - Velocity gradient is overestimated.
  - Overestimated velocity gradient switches on artificial viscosity.
  - The artificial viscosity raises spurious heating and false nuclear reactions.
- High resolution (large N)
  - There are many particles in z-direction.
- Note that artificial viscosity is correct, but estimate of velocity gradient is wrong.



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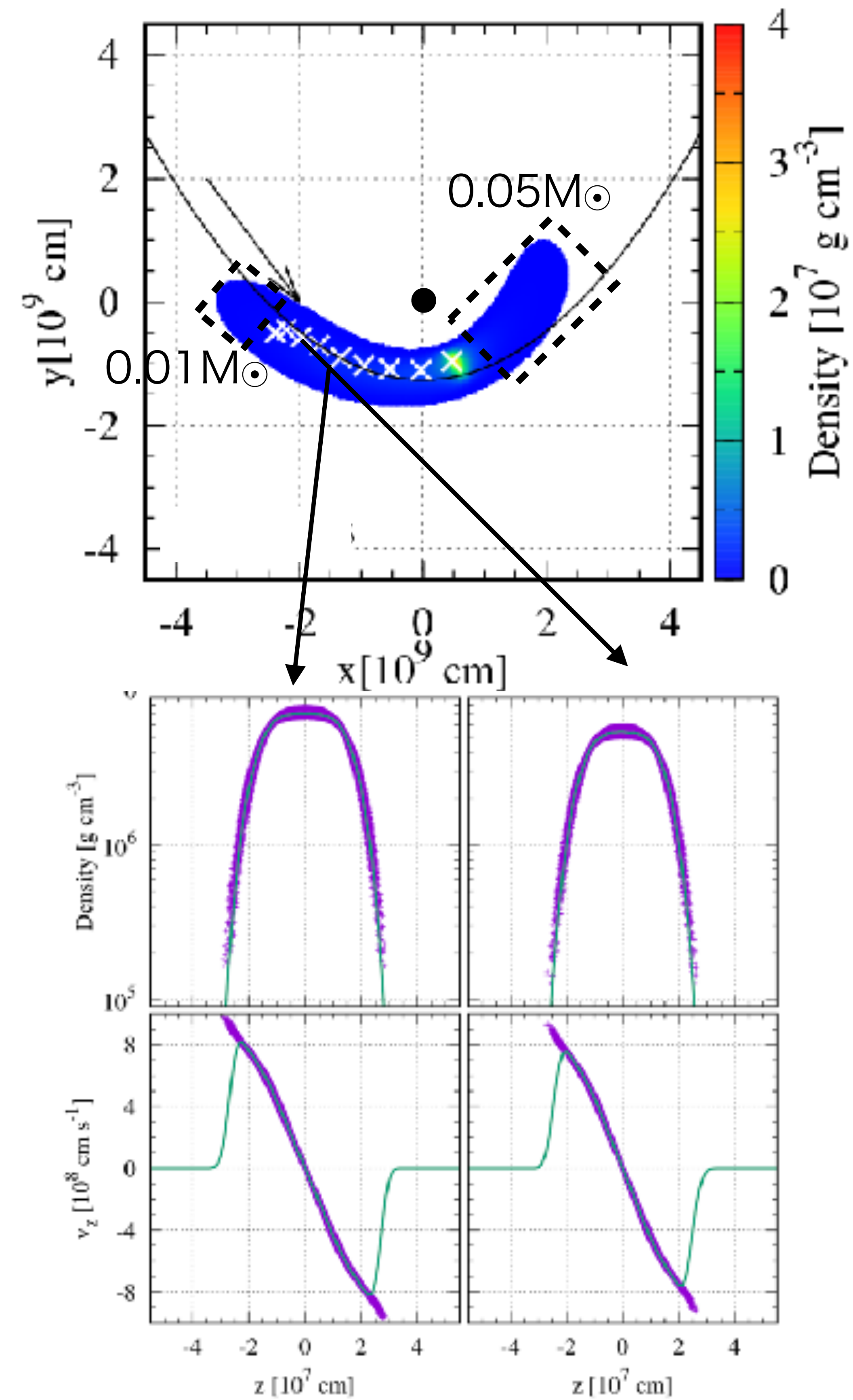
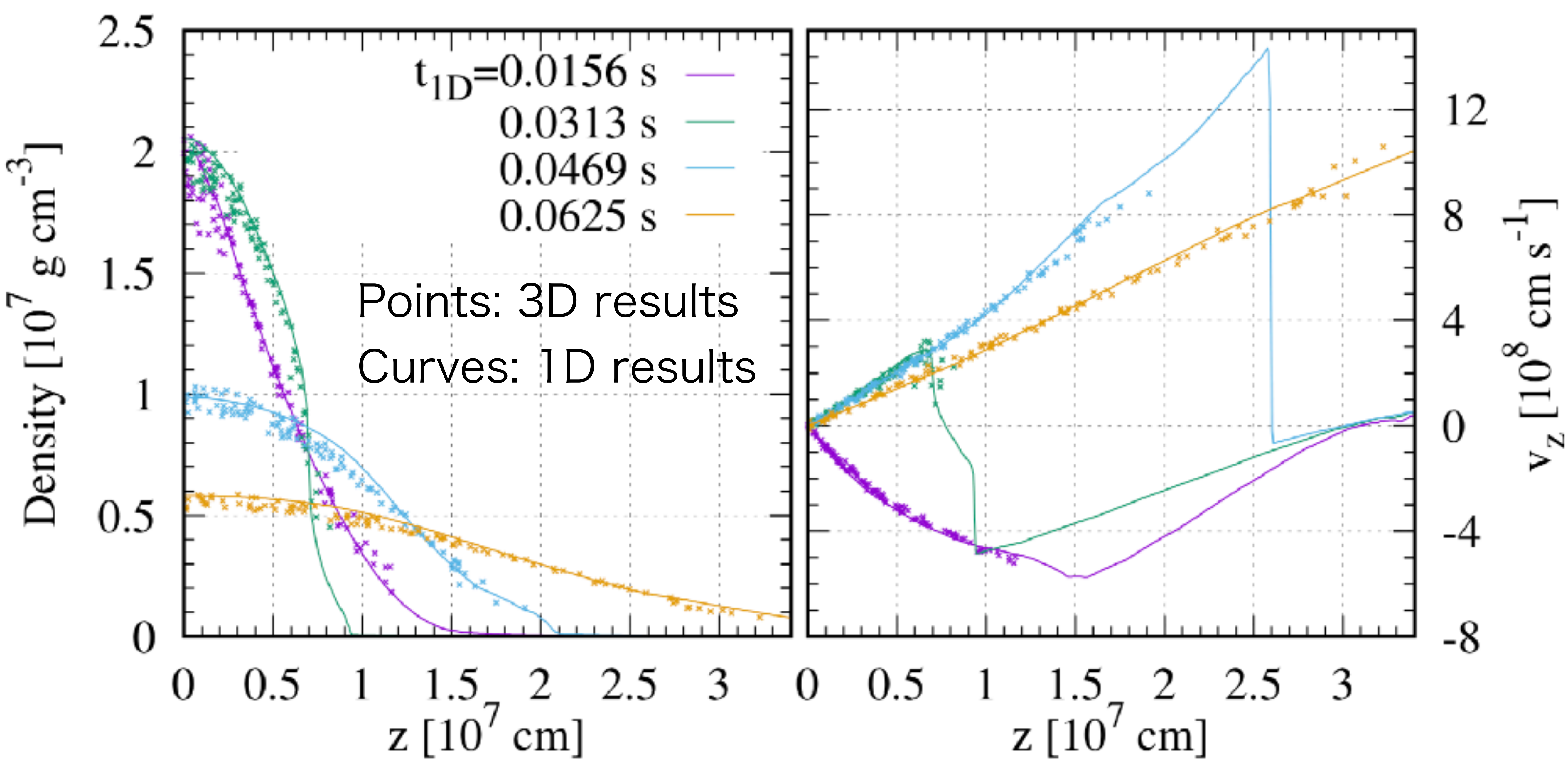
Simulation method

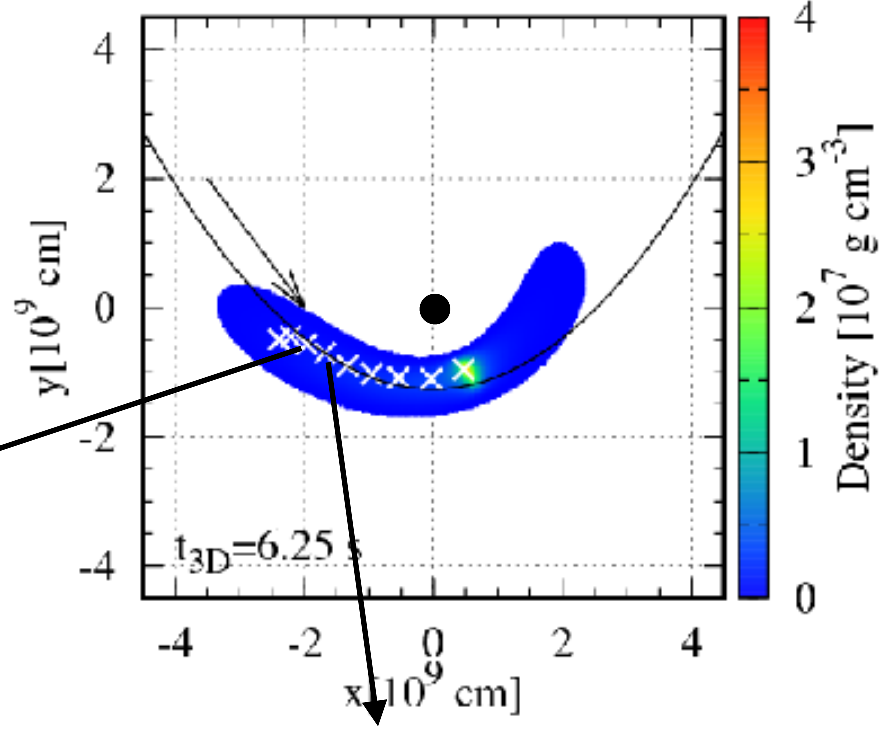
- Initial condition: 0.45M⊙ HeWD, 300M⊙ IMBH, β=7
- 3D SPH simulation without nuclear reaction network
  - N~300 millions per a WD
- Extract of z-columns from 3D structure as 1D initial conditions
- 1D mesh simulation by FLASH
  - Helmholtz EoS (Timmes, Swesty 2000)
  - Aprox13 (Timmes et al. 2000)
  - No gravity
    - Pressure gradient is much larger than self and IMBH gravity.

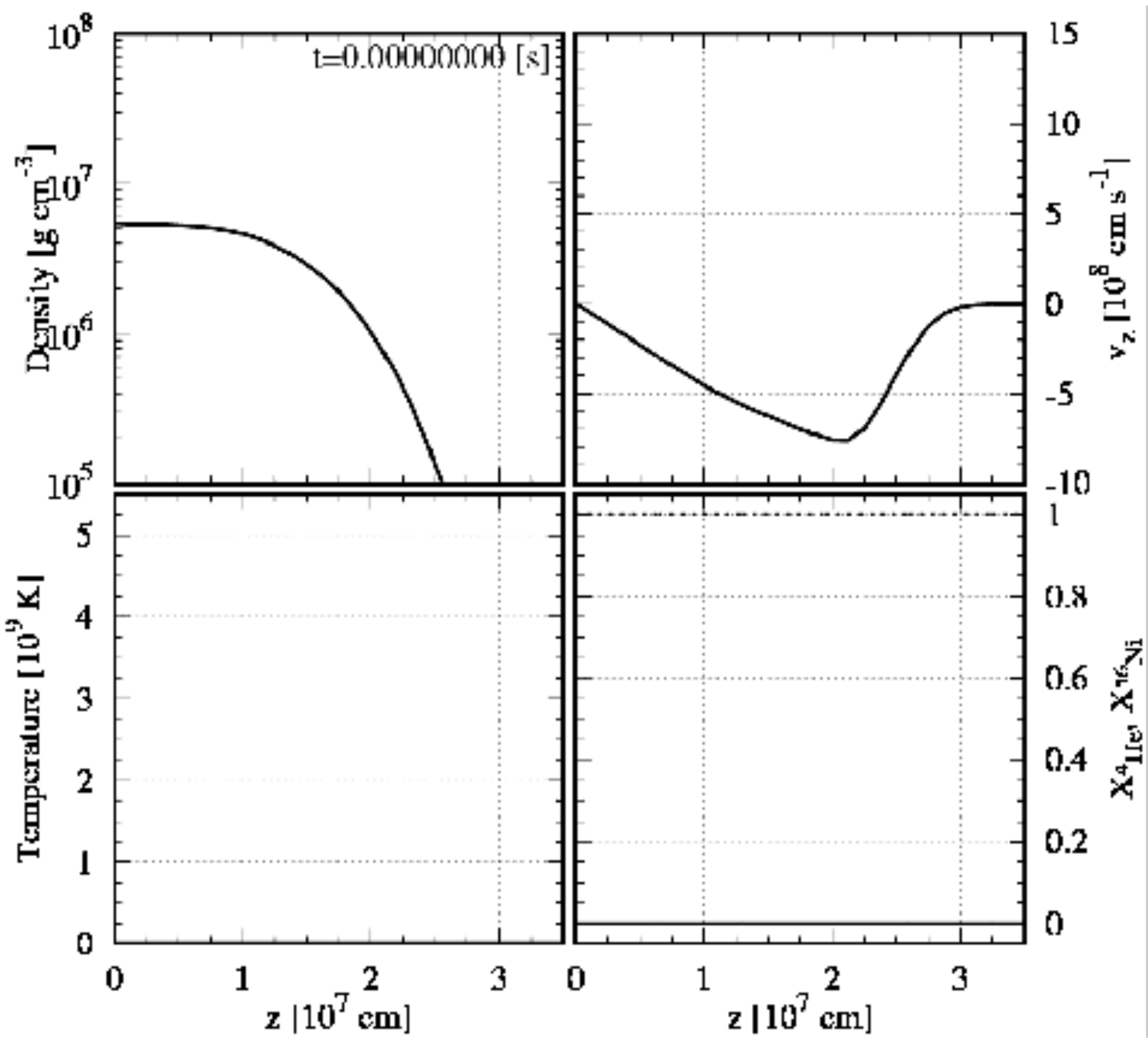


Comparison of 1D with 3D

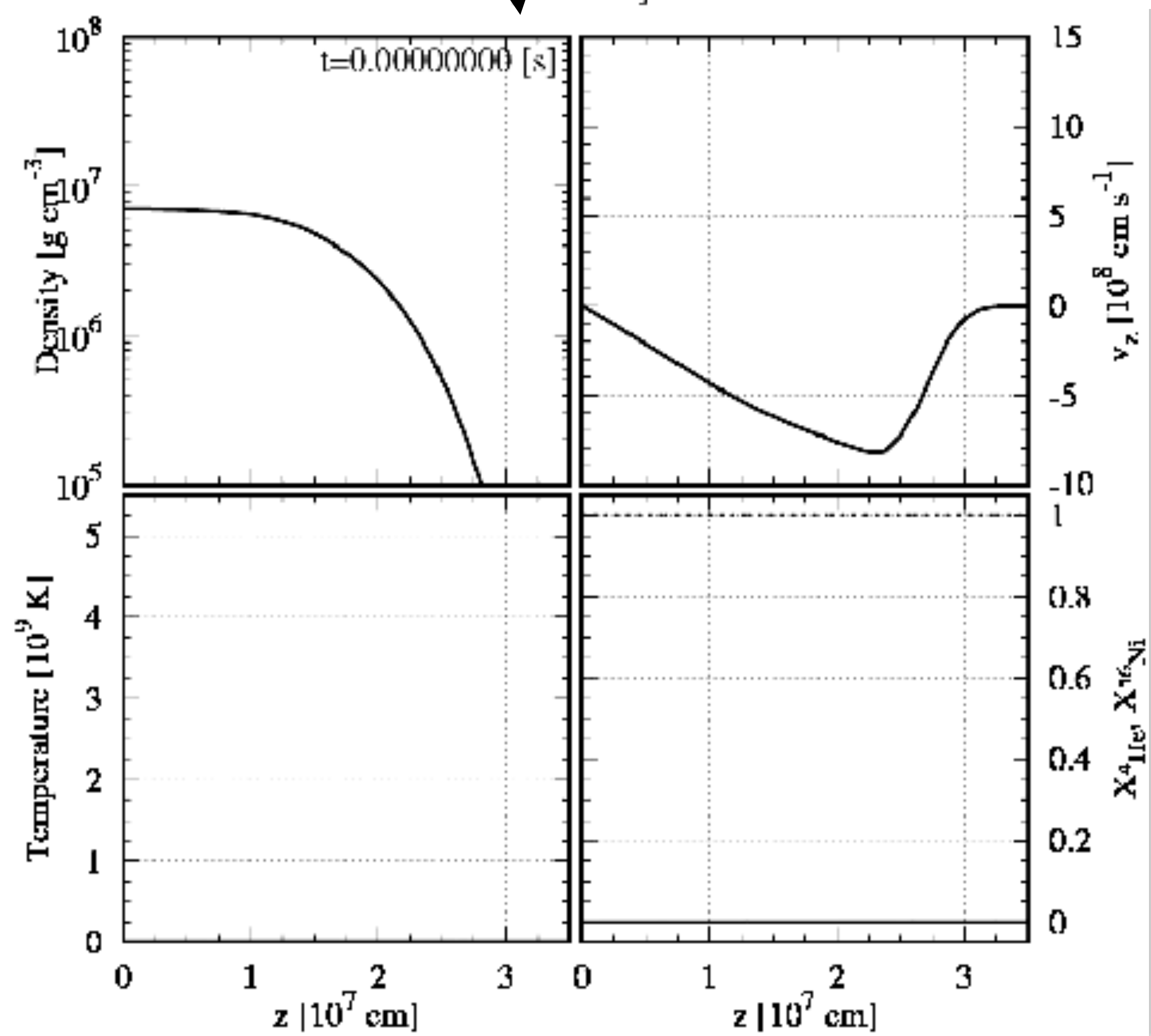


Animation



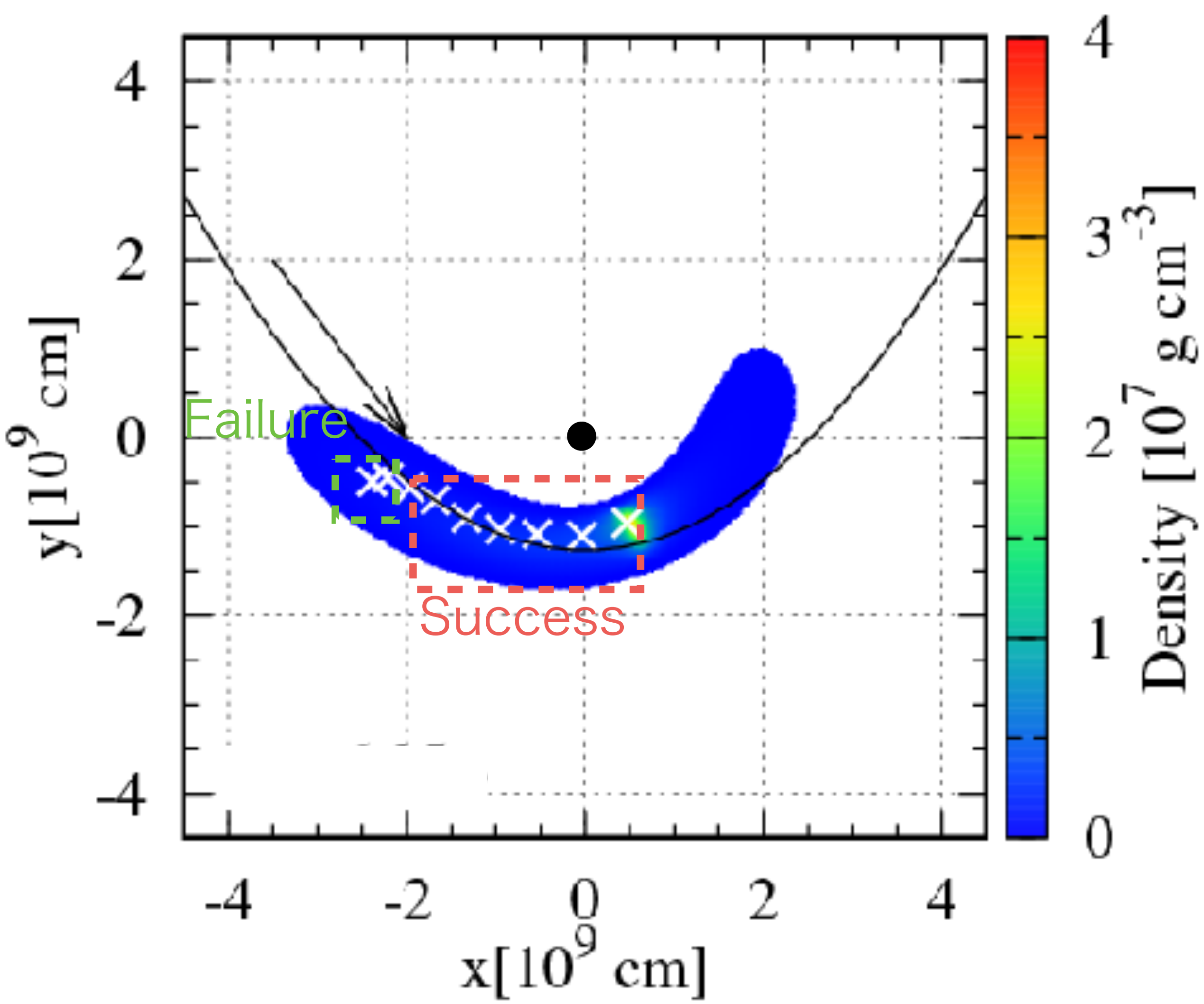


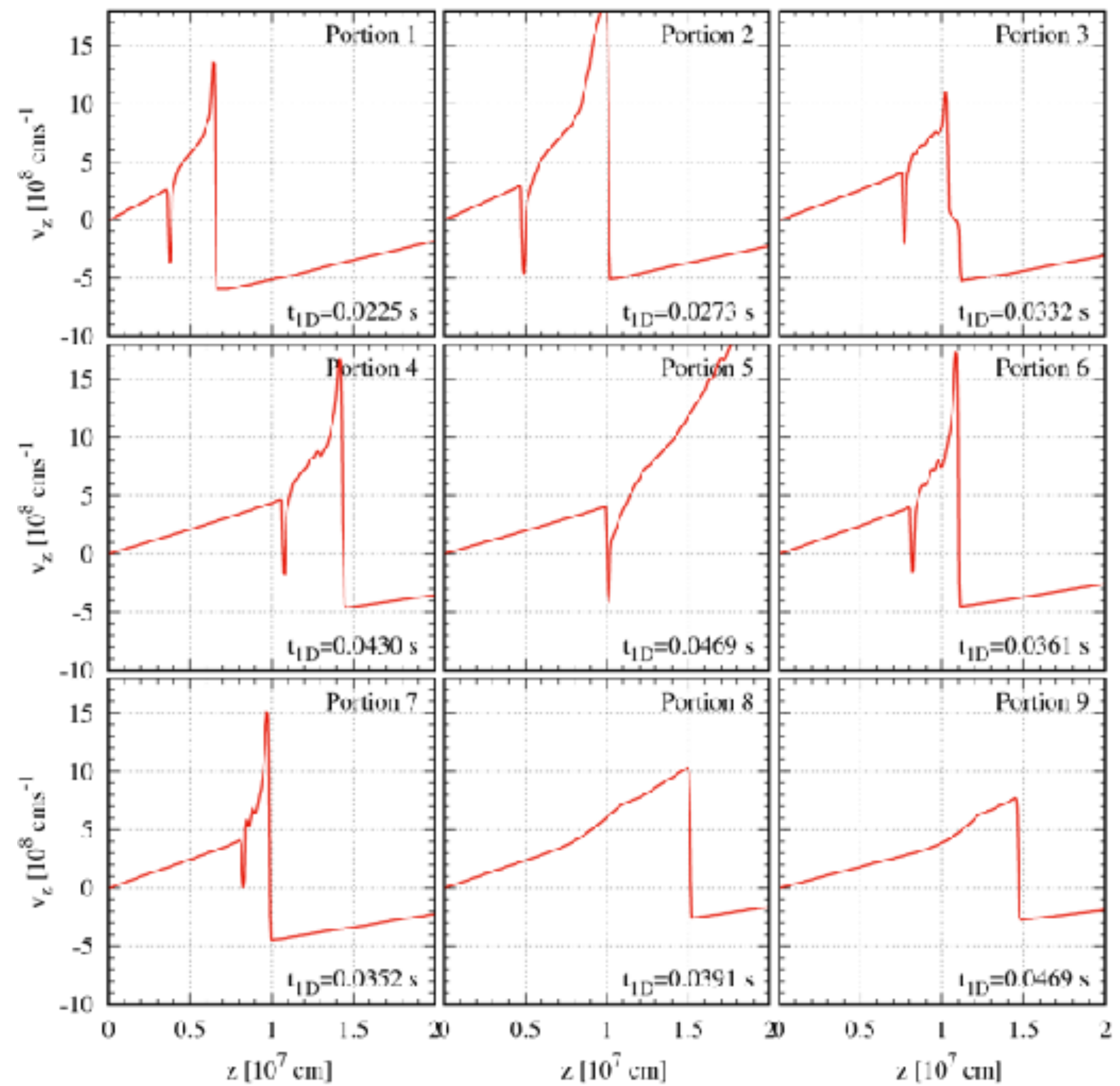
Failure case



Success case

Results



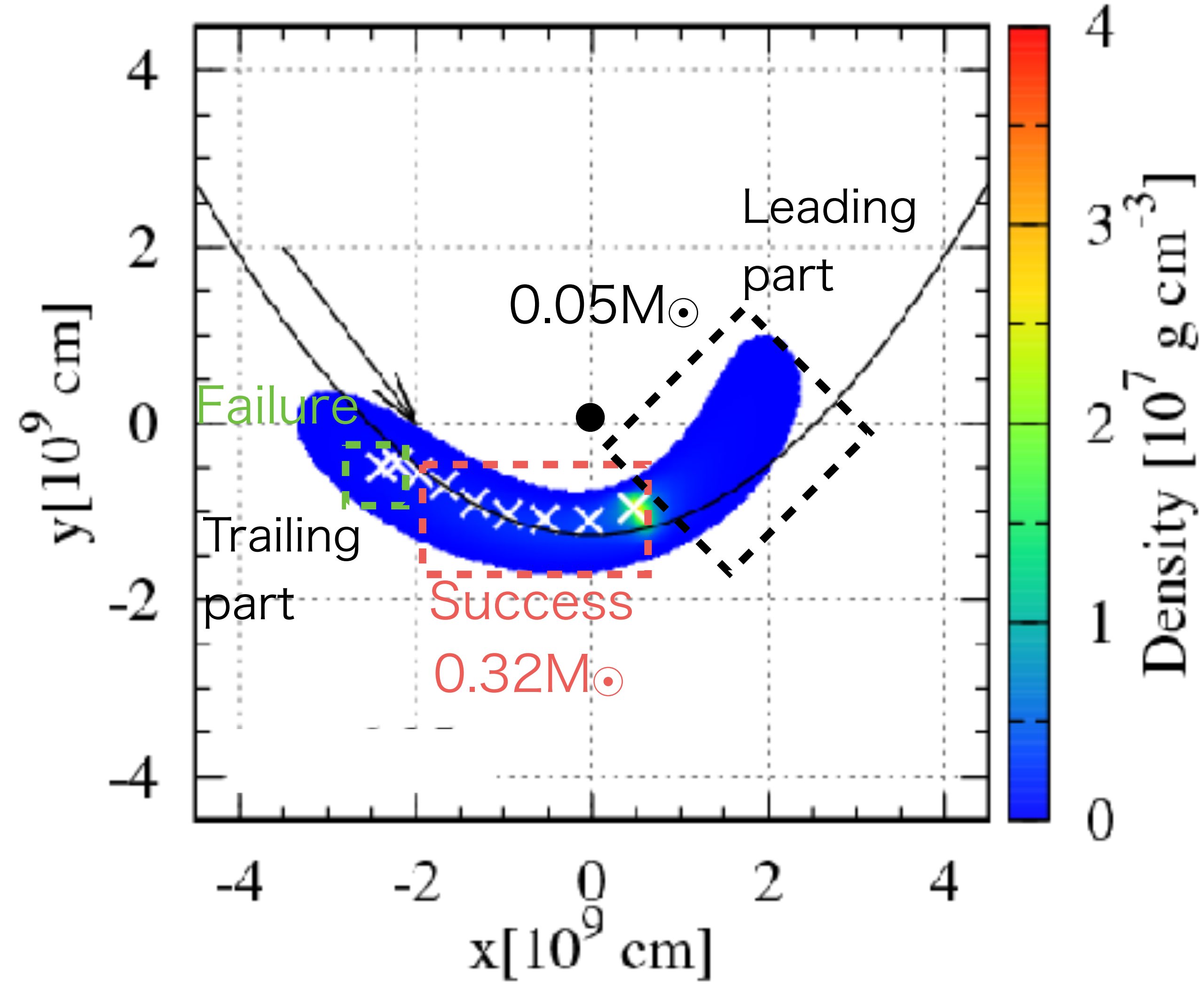


- Large parts of the WD are detonated.
- Small parts of the WD are undetonated.

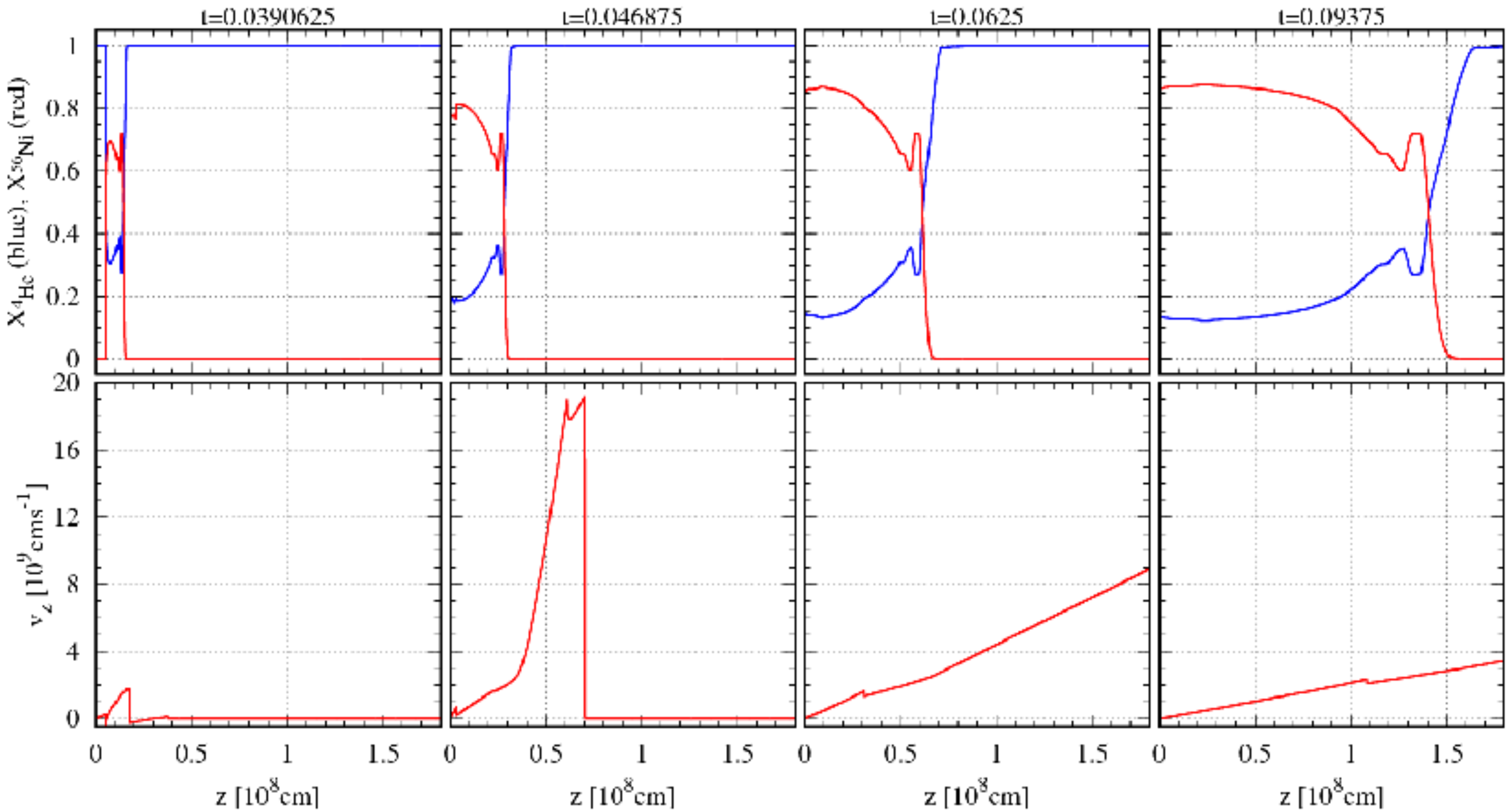
These results are converged in terms of 1D and 3D resolution.

Difference between success and failure cases

- The detonated columns precedes the undetonated columns.
- A leading part of a WD passes closer to an IMBH than a trailing part.
- The leading part is more compressed, and easier to be detonated.
- The detonated mass is at least 0.32M☉, and at most 0.37M☉.



Nucleosynthesis



- The detonation wave leaves 20% ^{4}He and 80% ^{56}Ni.
- The detonated region has high density (>10^{6} gcm^{-3}).
- The total ^{56}Ni mass is about 0.3$M_{\odot}$, comparable to SNeIa.

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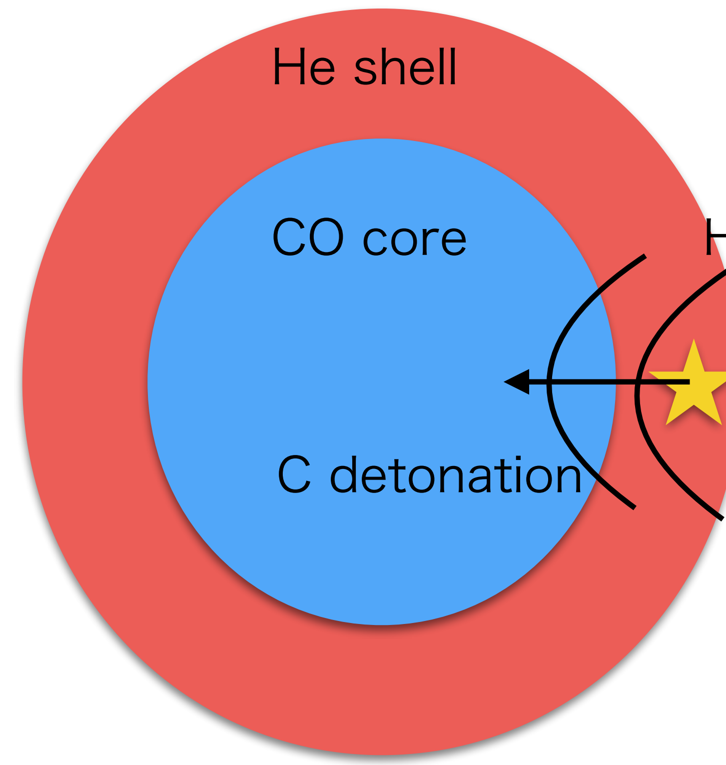
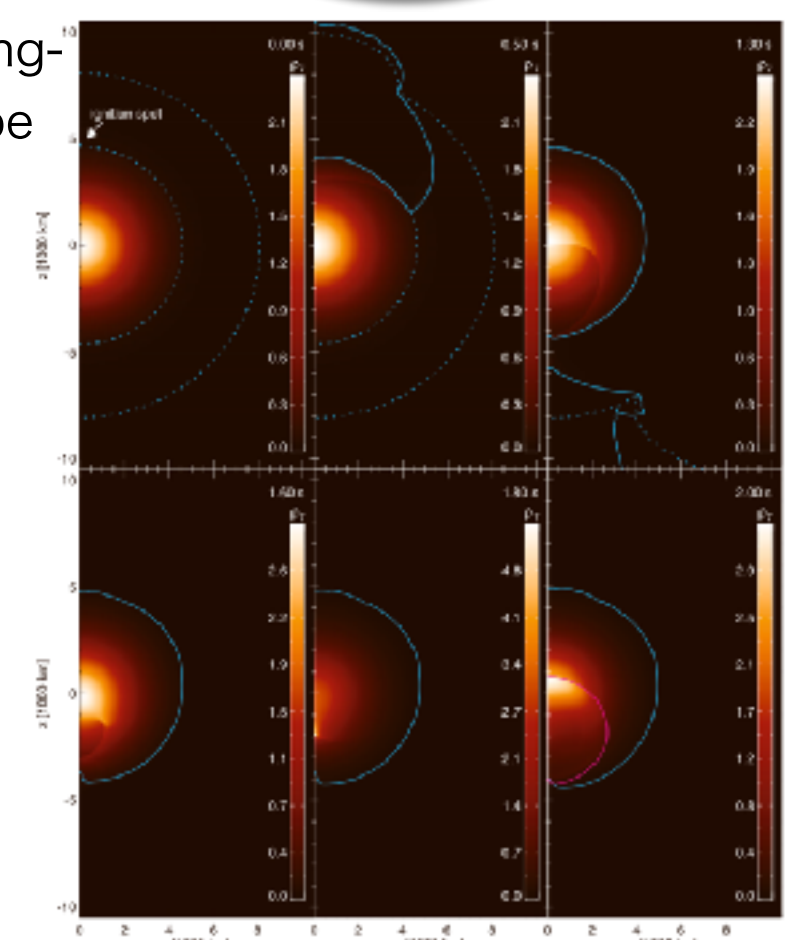
Double detonation

- One of explosion scenarios of SNeIa
- Explosion process
  - In a Helium shell, Helium detonation is ignited by mass accretion onto a WD from its companion star.
  - The Helium detonation drives Carbon detonation.
- Two types
  - Edge-lit type (Nomoto 1980; 1982; Woosley et al. 1980)
  - Converging-shock type (Livne 1990)



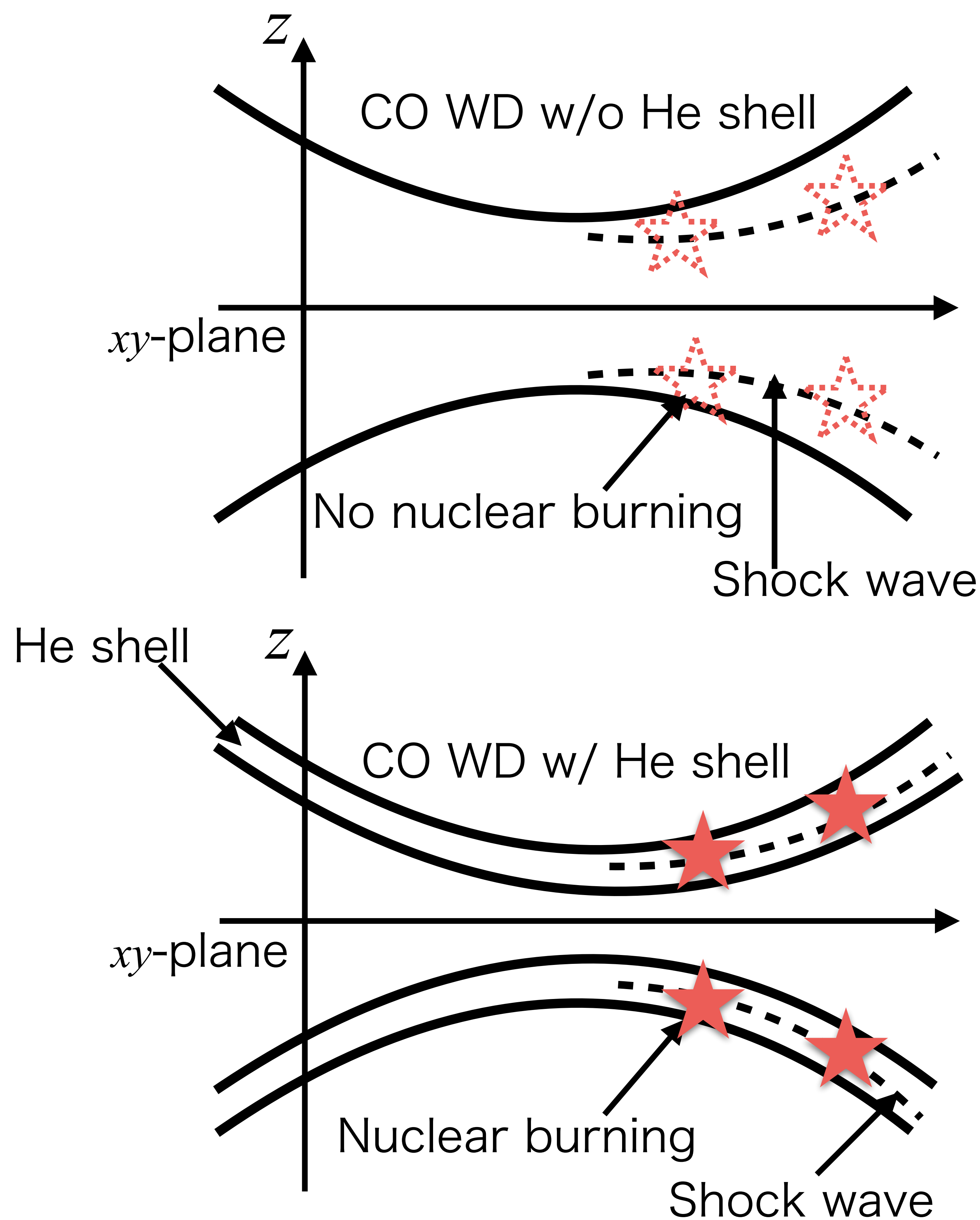
Converging-shock type



Fink et al. (2010)

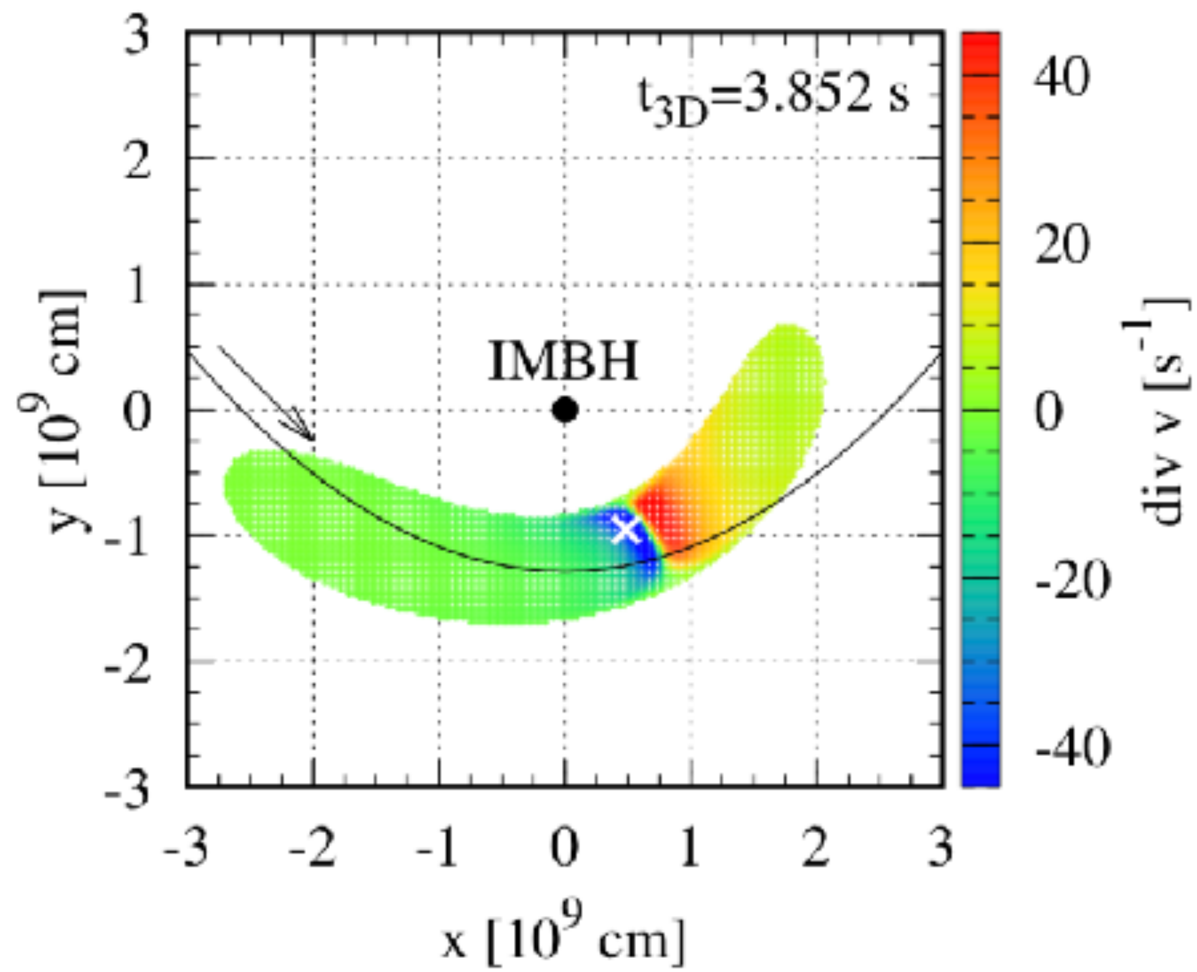
“Tidal” double detonation (TDD)

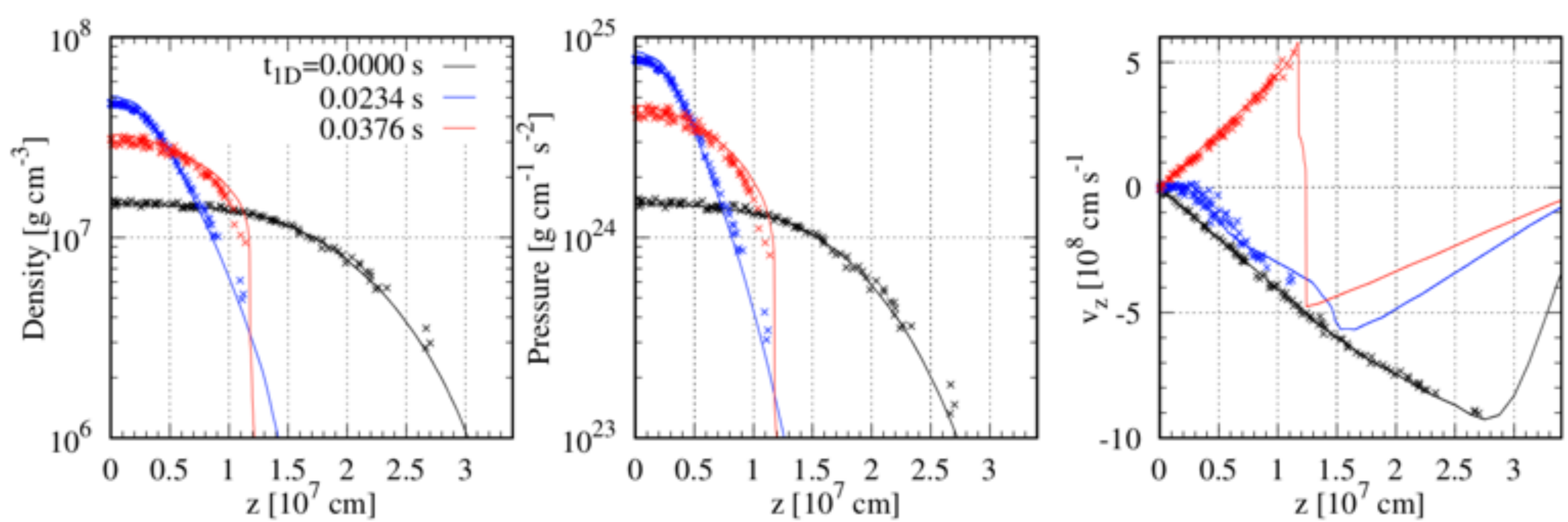
- A new explosion mechanism
- Helium detonation is ignited by tidal force, not by mass accretion.
- Tidal detonation is triggered by a shock wave in a He shell of a CO WD.
    - If there is no He shell, tidal detonation may not occur, since Carbon is harder to be ignited than Helium.
- TDD raises probability of illuminating IMBHs as thermonuclear transients.



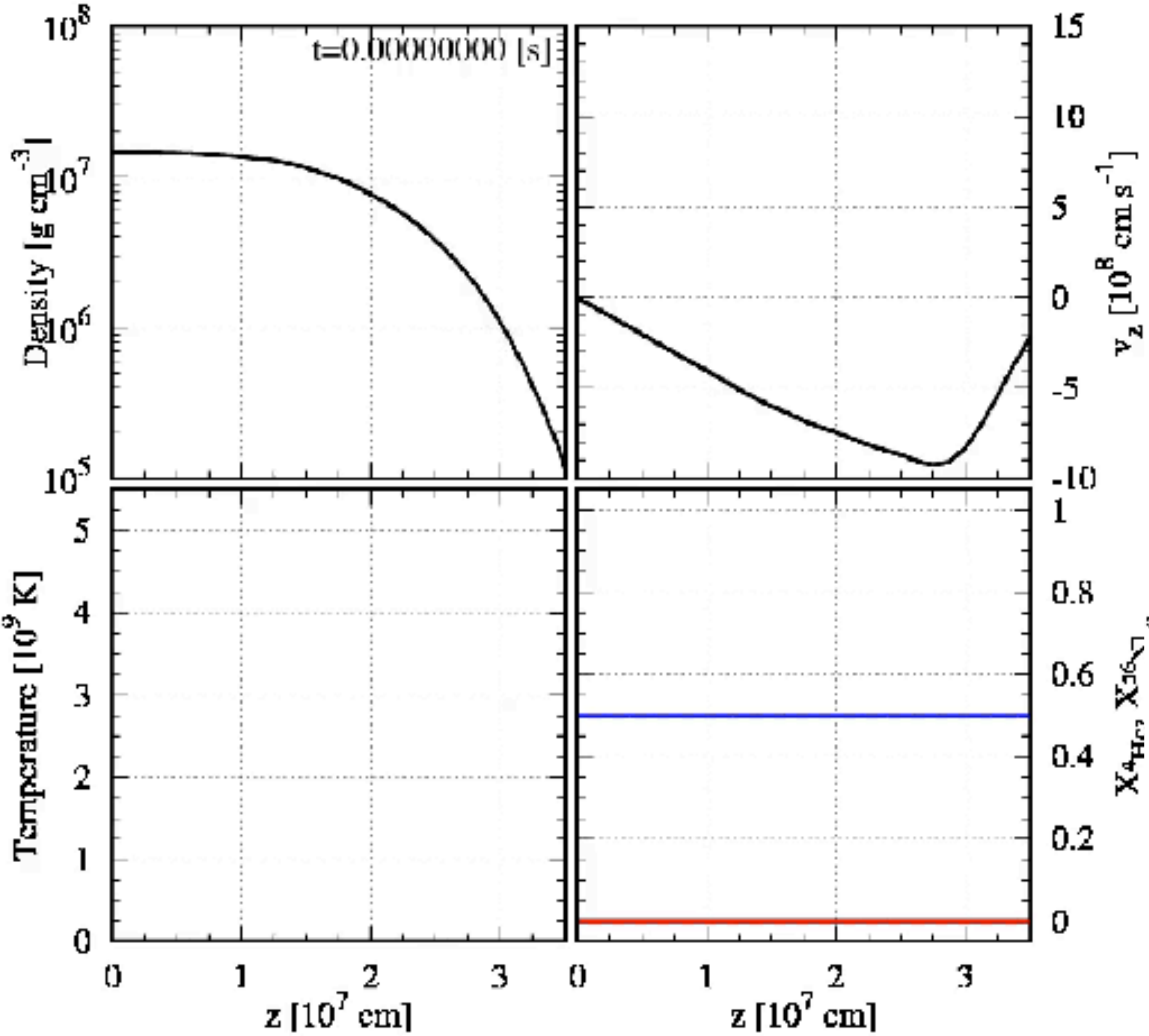
Initial conditions

- 0.6M☉ CO WD (N~100 millions)
  - w/o He shell
  - w/ He shell (5 and 10% of total mass)
- 300M☉ IMBH
- Parabolic orbit, β=5
- Simulation method is the same as the above.

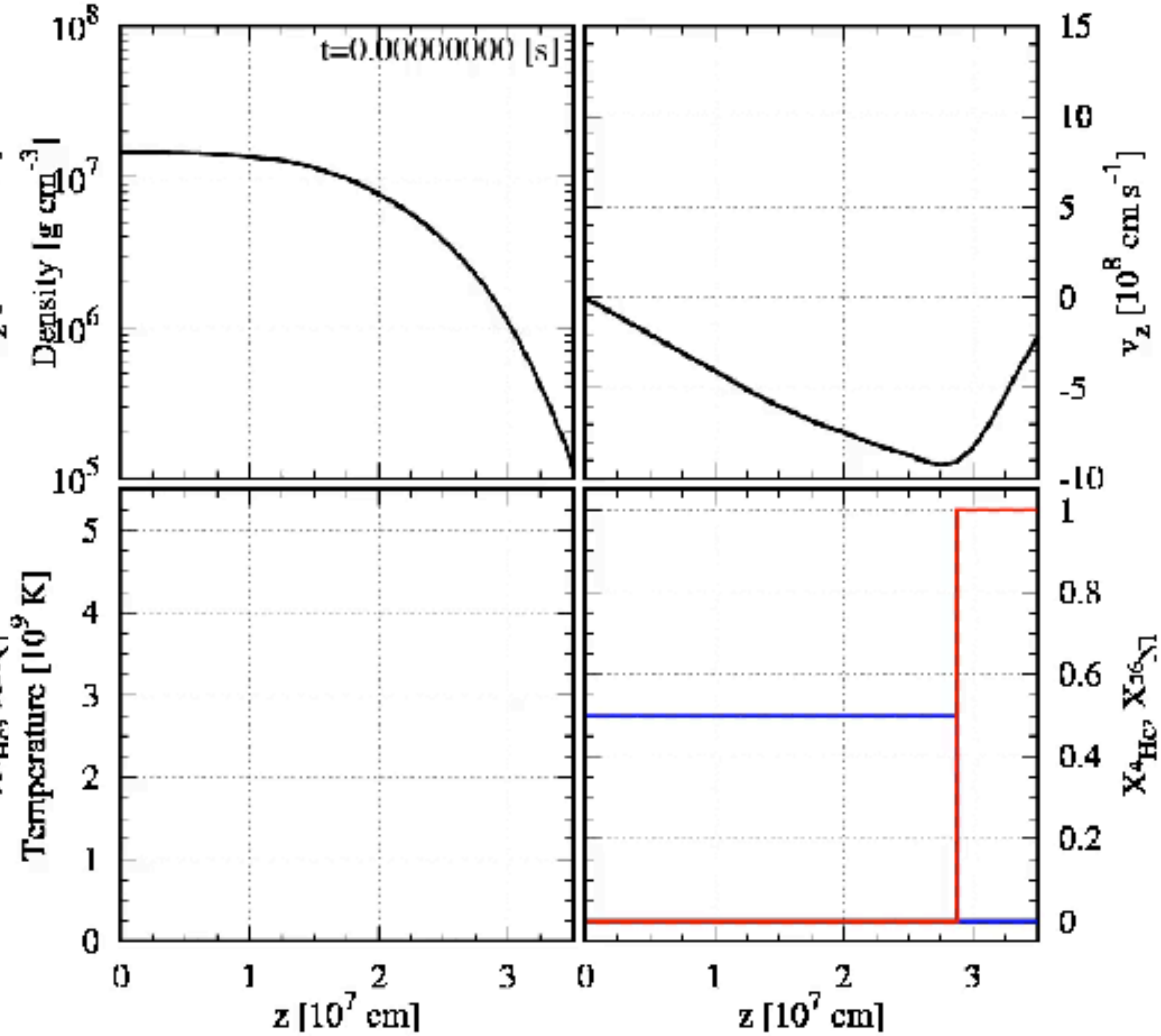




Results



w/o He shell



w/ 5% He shell

Summary

- We have studied tidal detonation of WDs.
- We should be careful of spurious heating in low-resolution SPH simulation.
- We have verified tidal detonation of WDs in the case of He WD with $0.45M_\odot$ in which large amount of ^{56}Ni ($\sim 0.3M_\odot$) is synthesized.
- We have suggested a new explosion mechanism of a WD: tidal double detonation (TDD).