Copenhagen, 26.8.2009

Collisions of white dwarfs as a new progenitor channel for type Ia Supernovae

(Rosswog et al., arXiv0907.3196)

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Jacobs University Bremen

In collaboration with:

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- Raph Hix, Oakridge, USA
- Dan Kasen, UC Santa Cruz, USA
- Enrico Ramirez-Ruiz, UC Santa Cruz, USA
- Holger Baumgardt, Bonn
- Marius Dan, Bremen
- Glenn van de Ven, Heidelberg

Punchline:

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There are several ways to explode WDs, examples include:

- WDs tidally pinched by black holes
- collisions of WDs
- ...

Crowded places

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Globular clusters

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- ~10^6 stars
- 10^2 - 10^4 per galaxy
- typical velocity dispersions σ ~ 5 km/s
- central densities up to
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- large, central number densities, ~ 10^8 stars/pc^3
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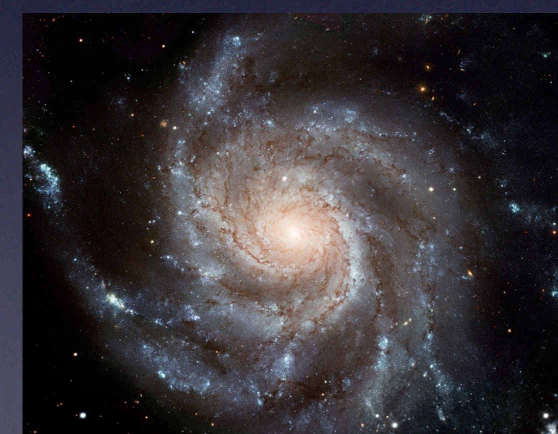

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→ frequent close encounters/collisions

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entirely dominated by gravitational focussing!

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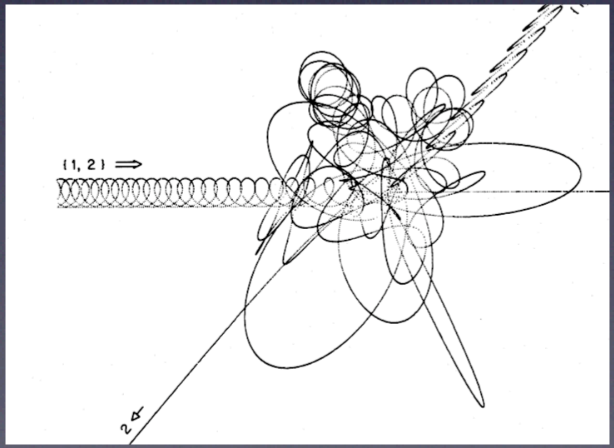
(Hut & Bahcall 1983)

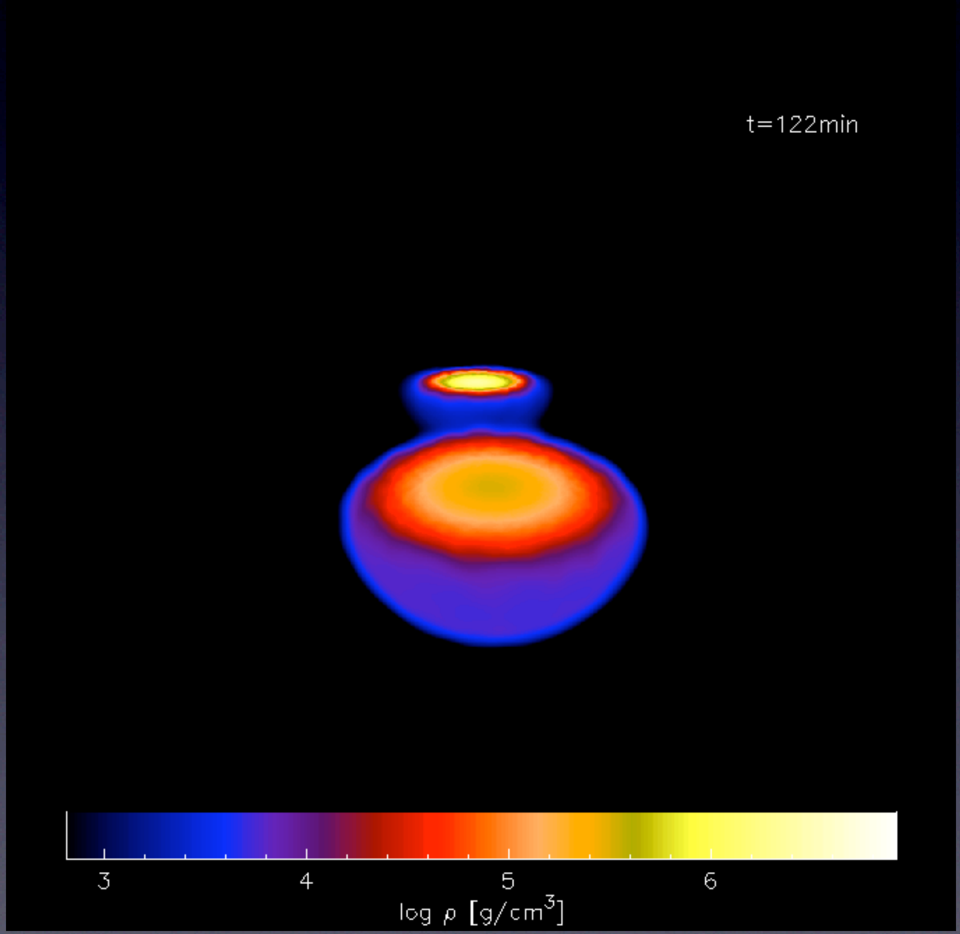


- possibly further enhanced by
  - binary fraction in cluster
  - contrib. galactic centres, ultra-compact dwarf galaxies etc ...

- distinguish:

merger of WD binary

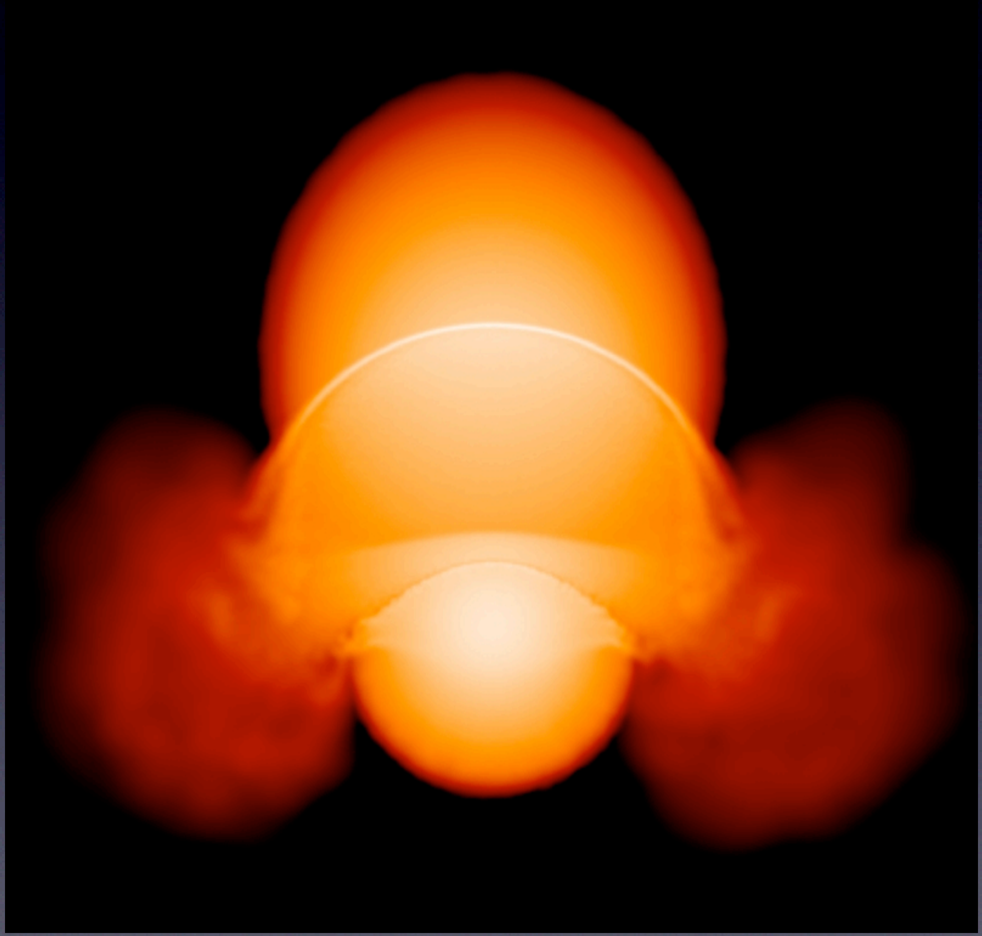
0.3 & 0.6 M_{sol}



Dan et al. in prep.

collision of two WDs

0.6 & 0.9 M_{sol}



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Modeling of WD-WD collisions

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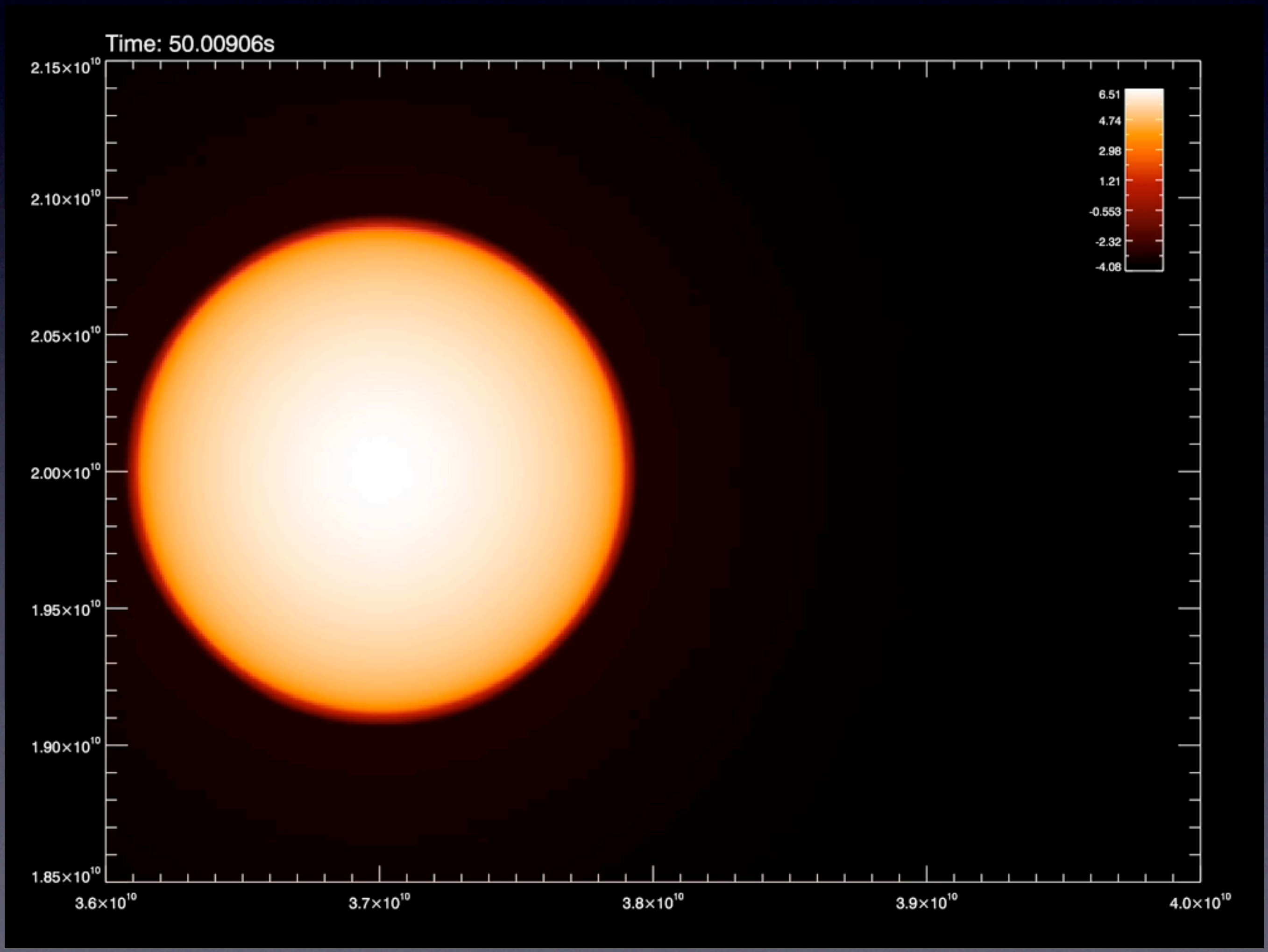
- Equation of state: Helmholtz-EOS (Timmes & Swesty 2000)
  - completely general e^+e^- treatment
  - therm. consistent interpolation
  - free specification of composition

- Artifacts in non-Galilean invariant methods:

  example: advecting a white dwarf across the grid



Adaptive mesh refinement code FLASH

- nuclear burning: 7-species, QSE-reduced alpha
  (Hix et al. 1998)
  - tuned for correct energy production
  - coupled directly with hydrodynamics (implicit/explicit time integration)
  - post-processing by 19-isotope network

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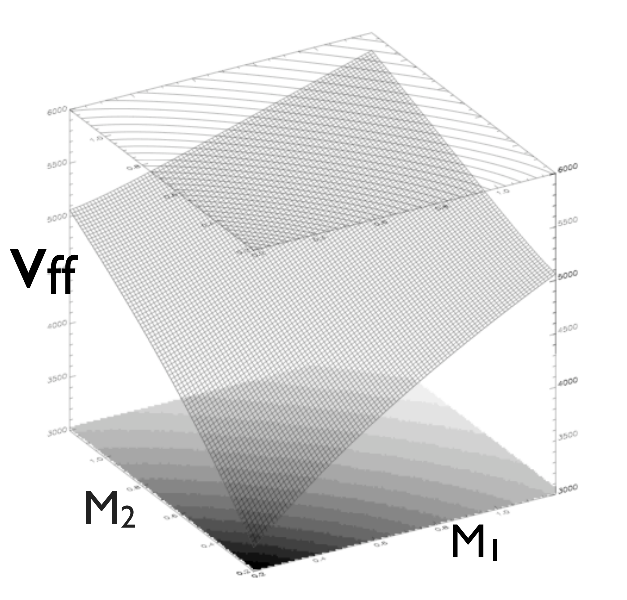
- complementary approach: FLASH
  - 19-isotope network
  - Helmholtz-EOS

Simulations:



- relative velocities at impact entirely dominated by mutual gravity:

$$v_{\rm rel} = 4000 \text{ km/s} \left(\frac{M_{\rm tot}}{1.2 \ M_\odot} \frac{2 \times 10^9 \text{cm}}{R_1 + R_2} \right)^{1/2} > c_{\rm s} >> \sigma_G C$$

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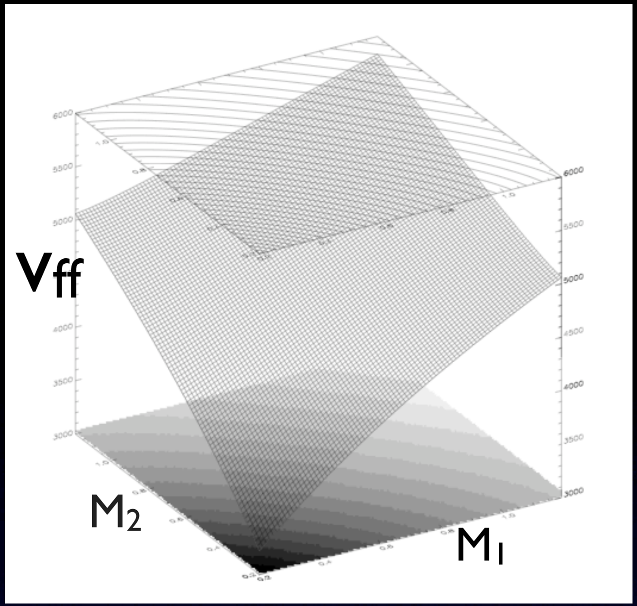

- initial orbits: parabolae

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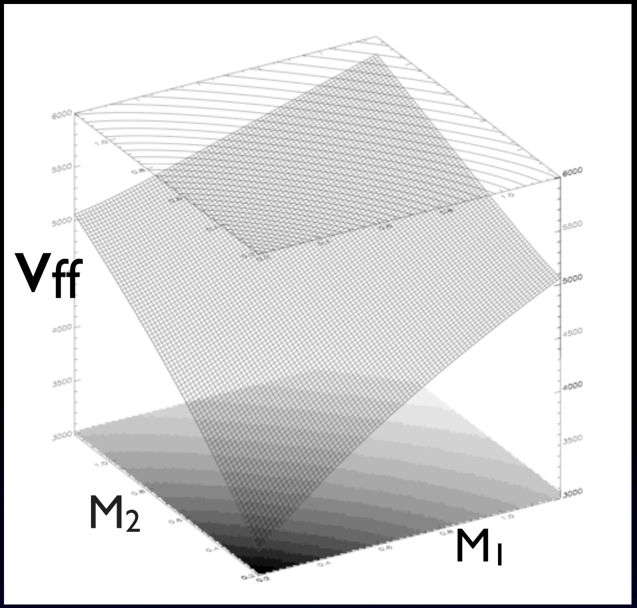

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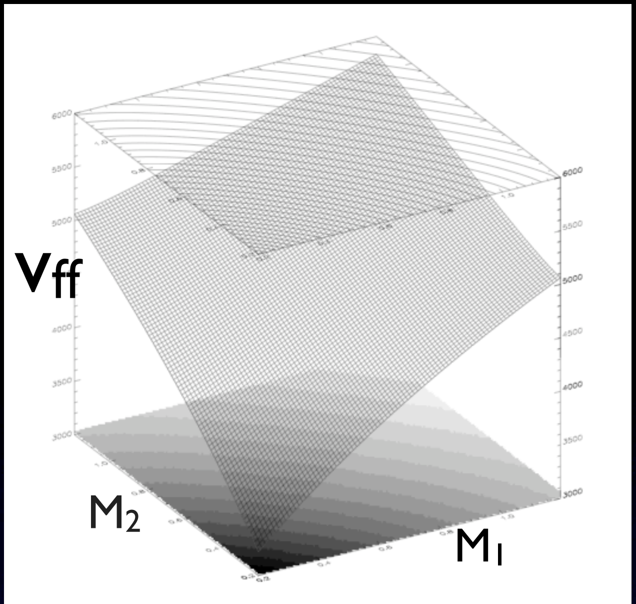

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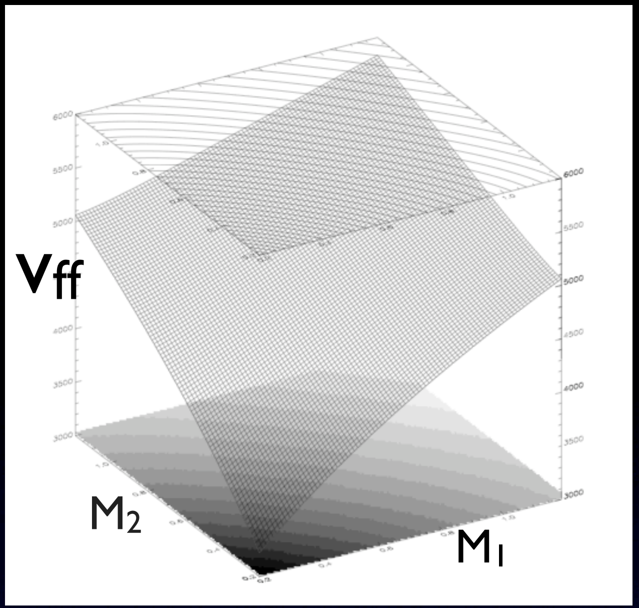

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- 15 simulations, betw. 500 000 & 3 000 000 SPH particles

- example: off-centre collision

$$M_1 = 0.6\ M_\odot, \quad M_2 = 0.9\ M_\odot, \quad \beta = 1, \quad \beta \equiv \frac{R_1 + R_2}{R_{\rm per}}$$

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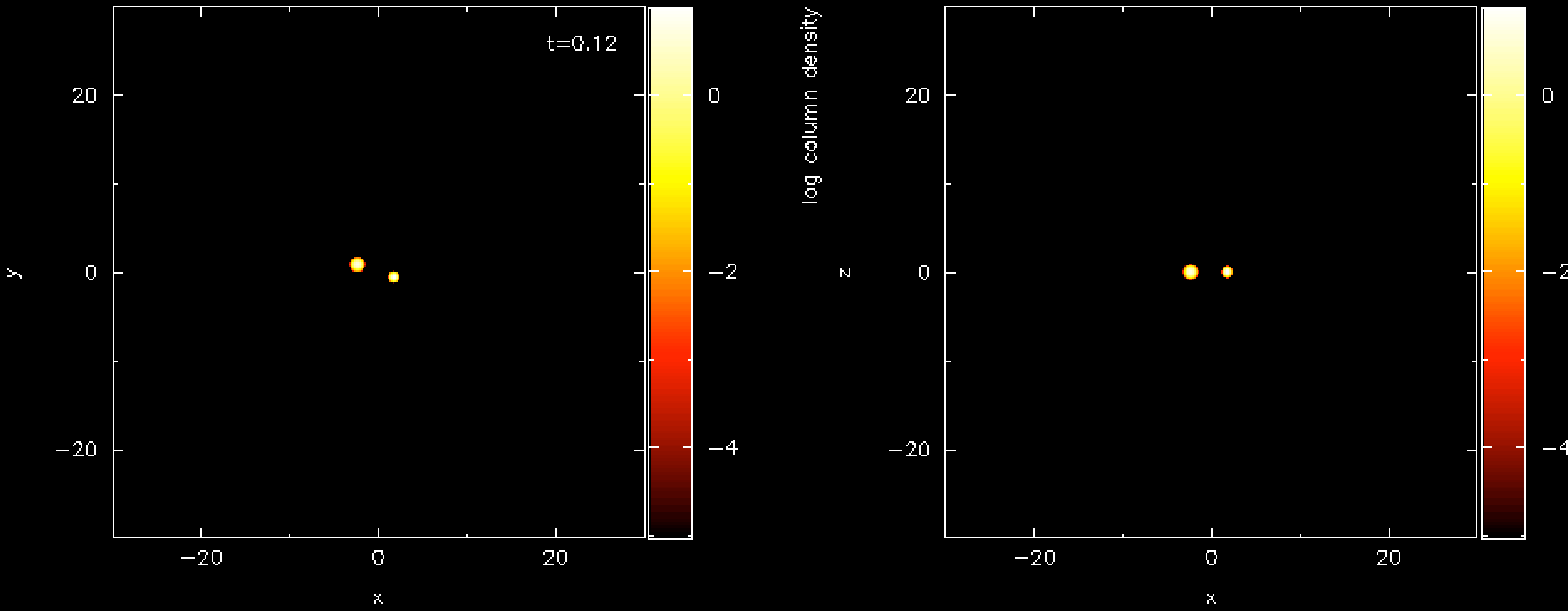
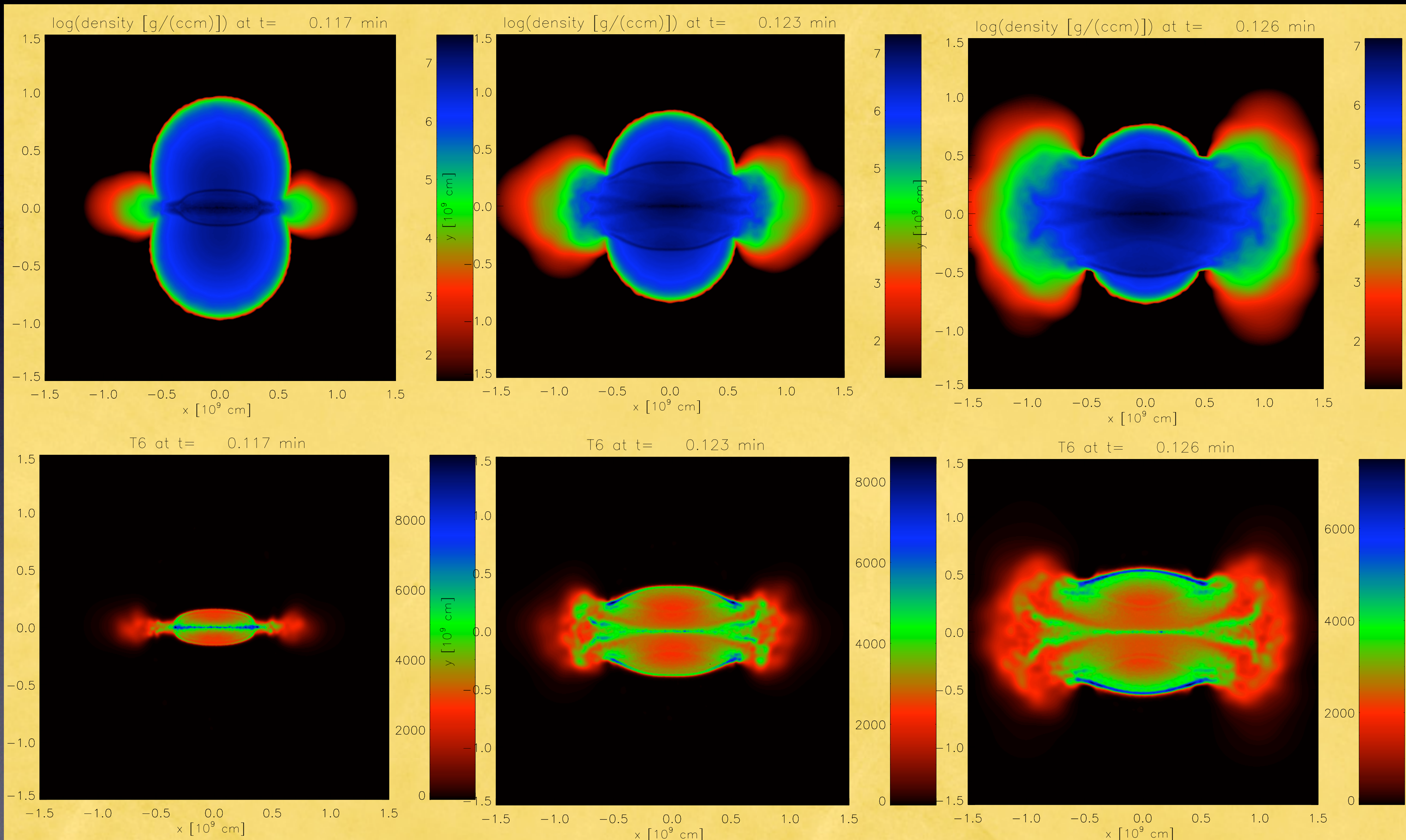


what about more central collisions?

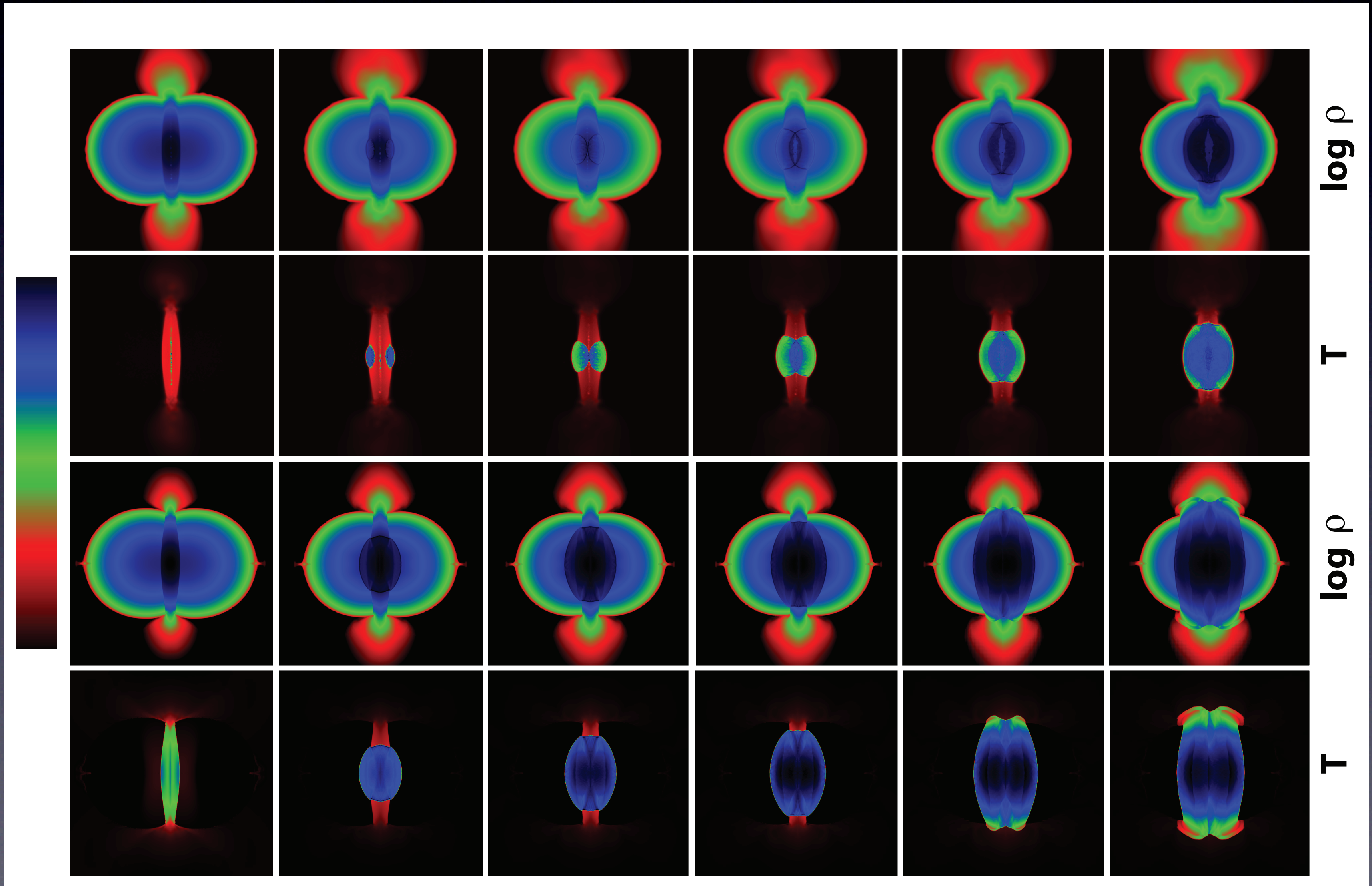
$$M_1 = 0.9\ M_\odot, \quad M_2 = 0.9\ M_\odot, \quad \text{headon}$$



ρ

T_6

code comparison: SPH & FLASH, 2 x 0.6 M_{sol}



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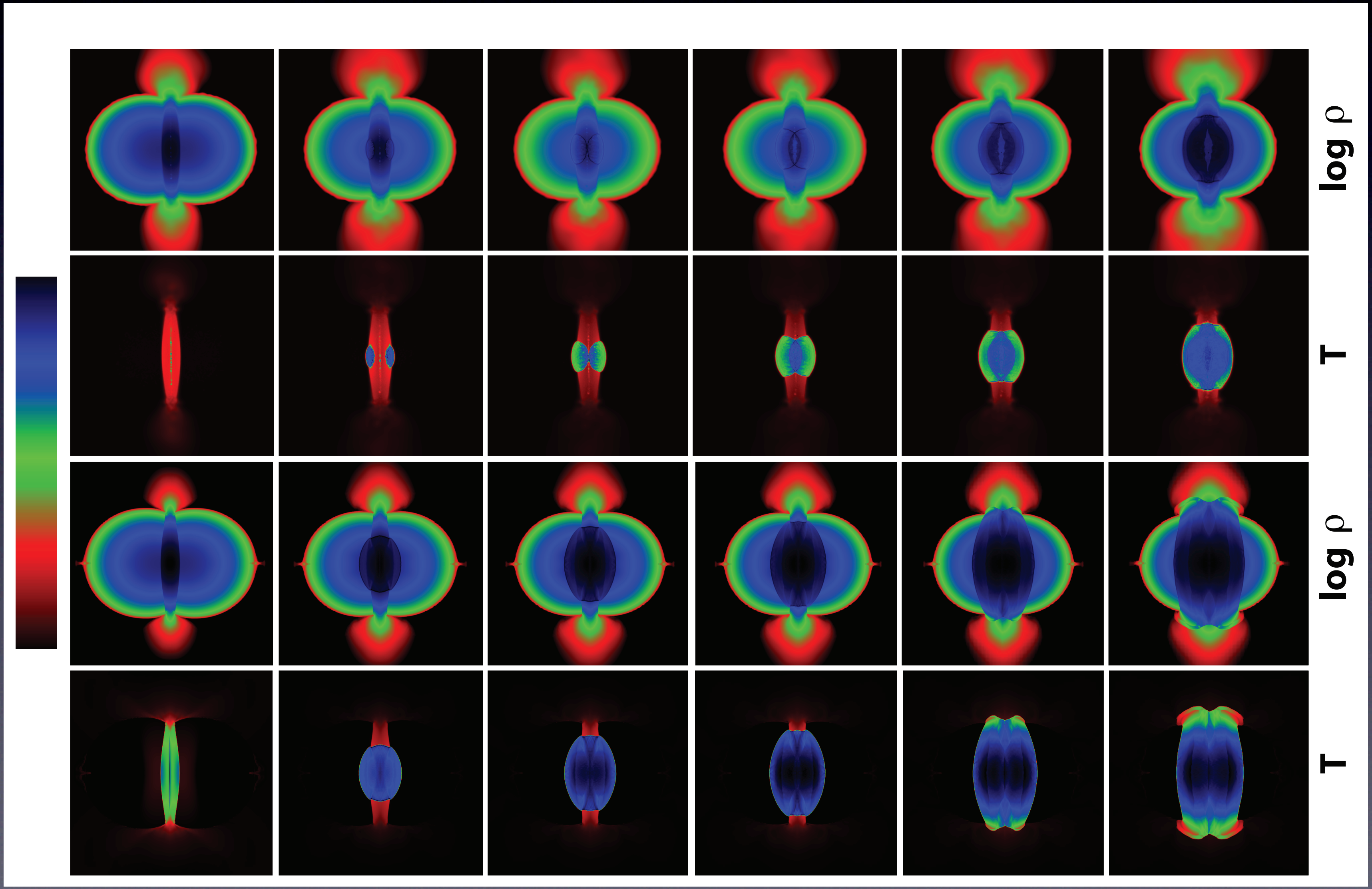

SPH

FLASH

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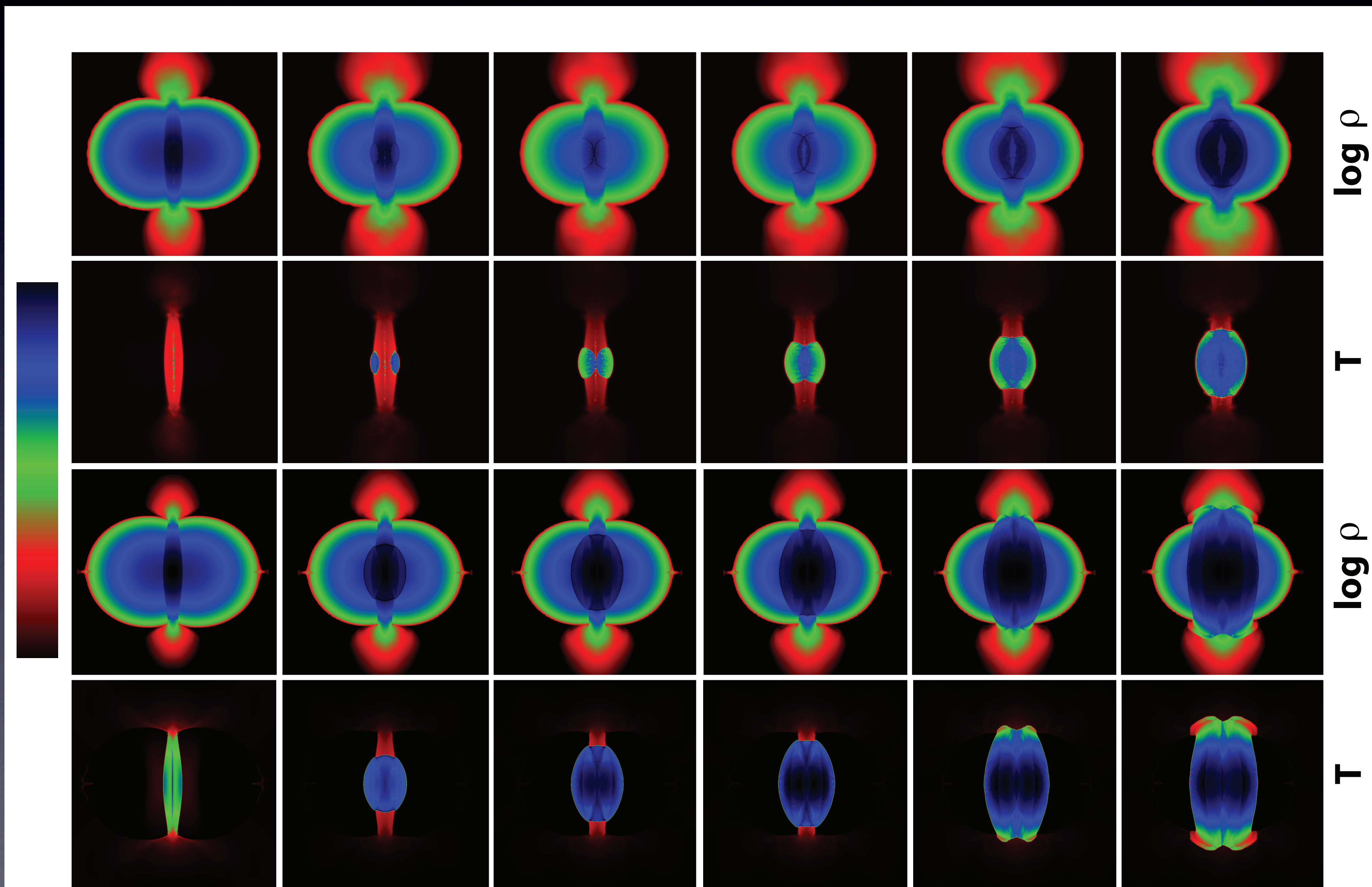
produced nuclear energy: SPH: $10^{51.21}$ erg
FLASH: $10^{51.11}$ erg



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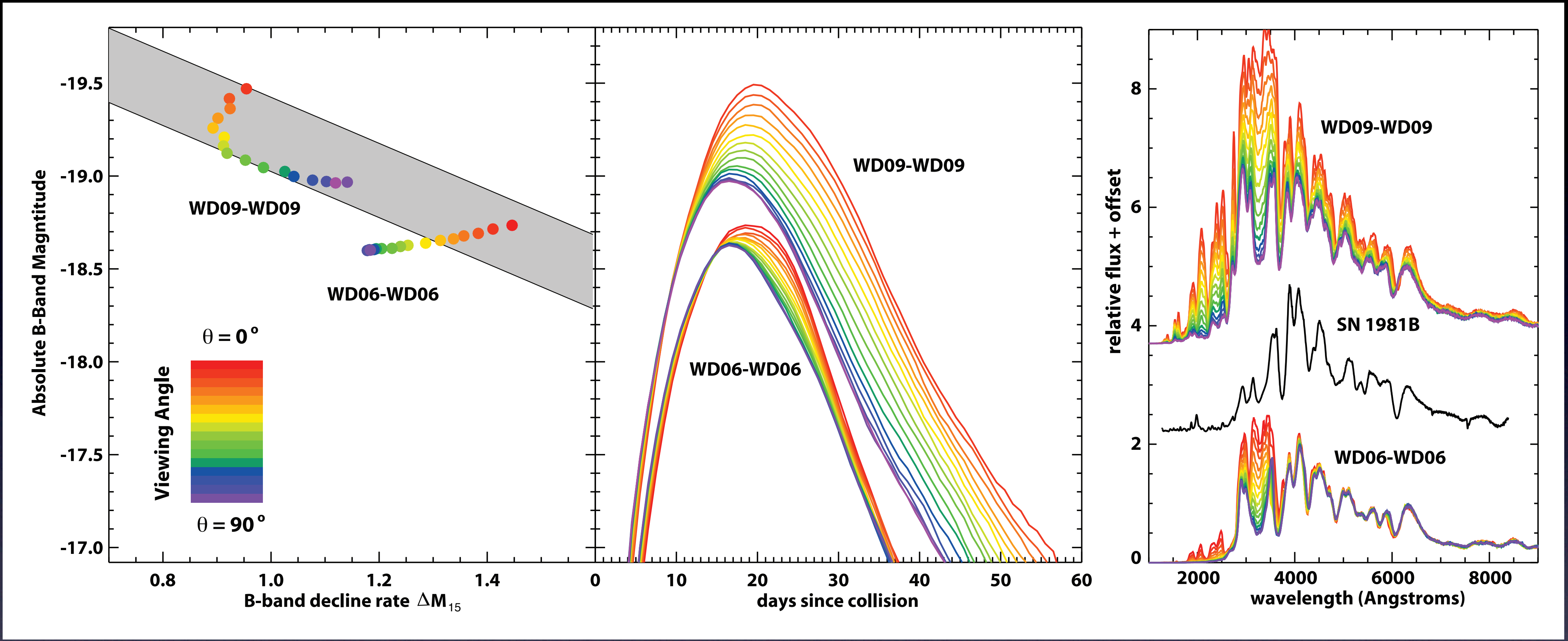

ΔM_{15} : decline in B − band 15 days after maximum

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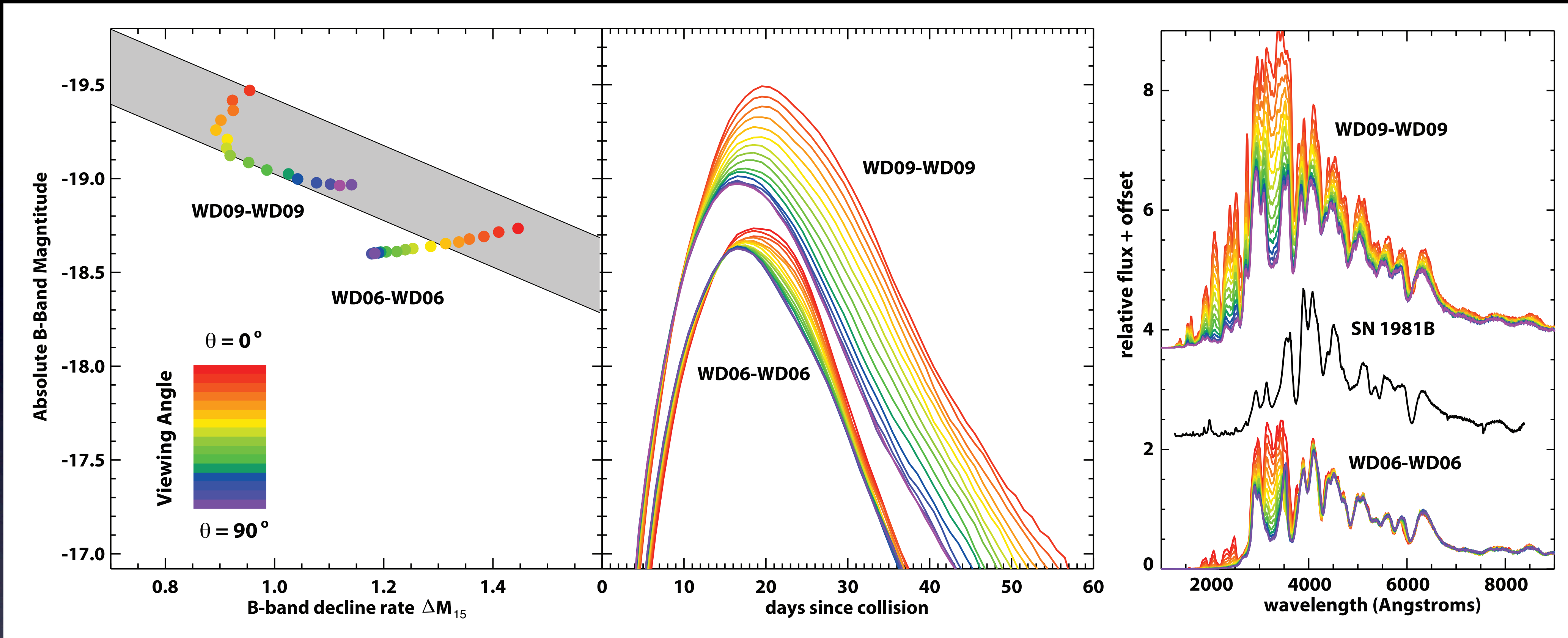

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- 56 Ni-masses: 0.32 M_{sol} (WD06-WD06) & 0.66 M_{sol} (WD09-WD09)
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- both (!) are broadly consistent with Phillips relation

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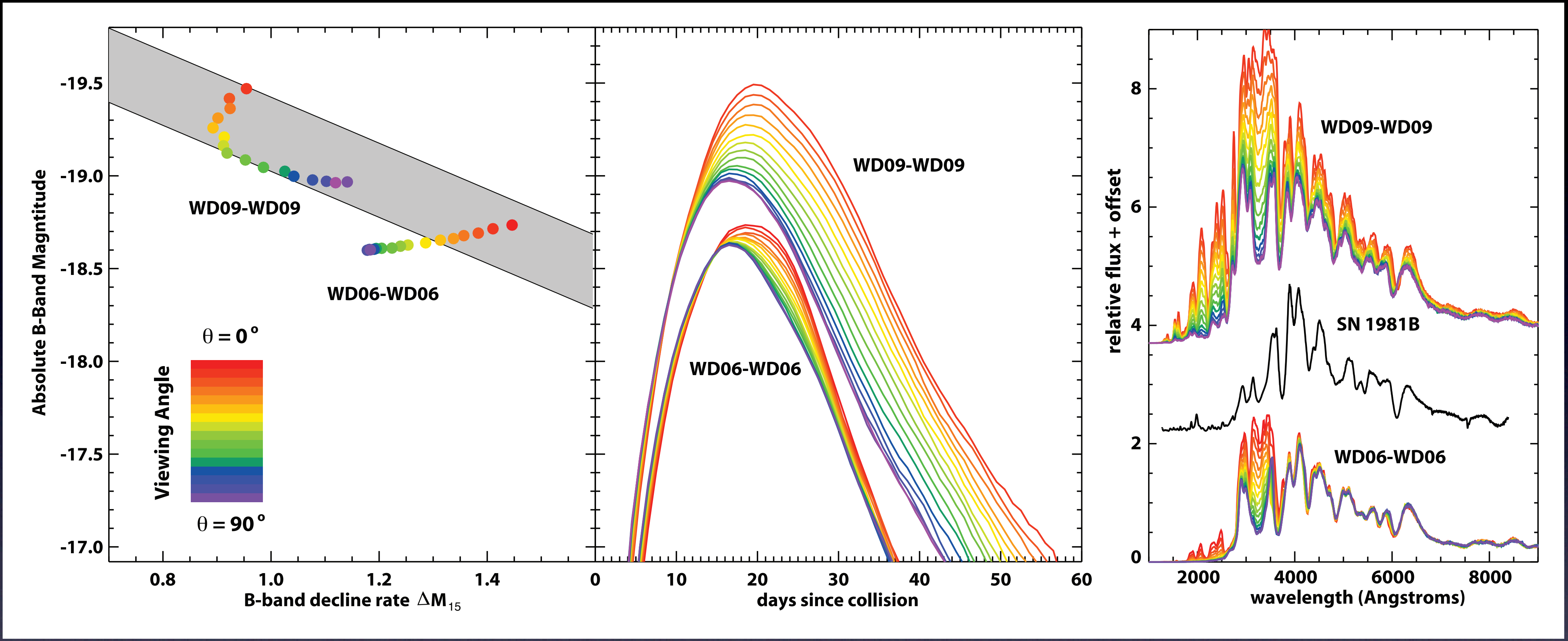

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very similar to "normal" SN Ia

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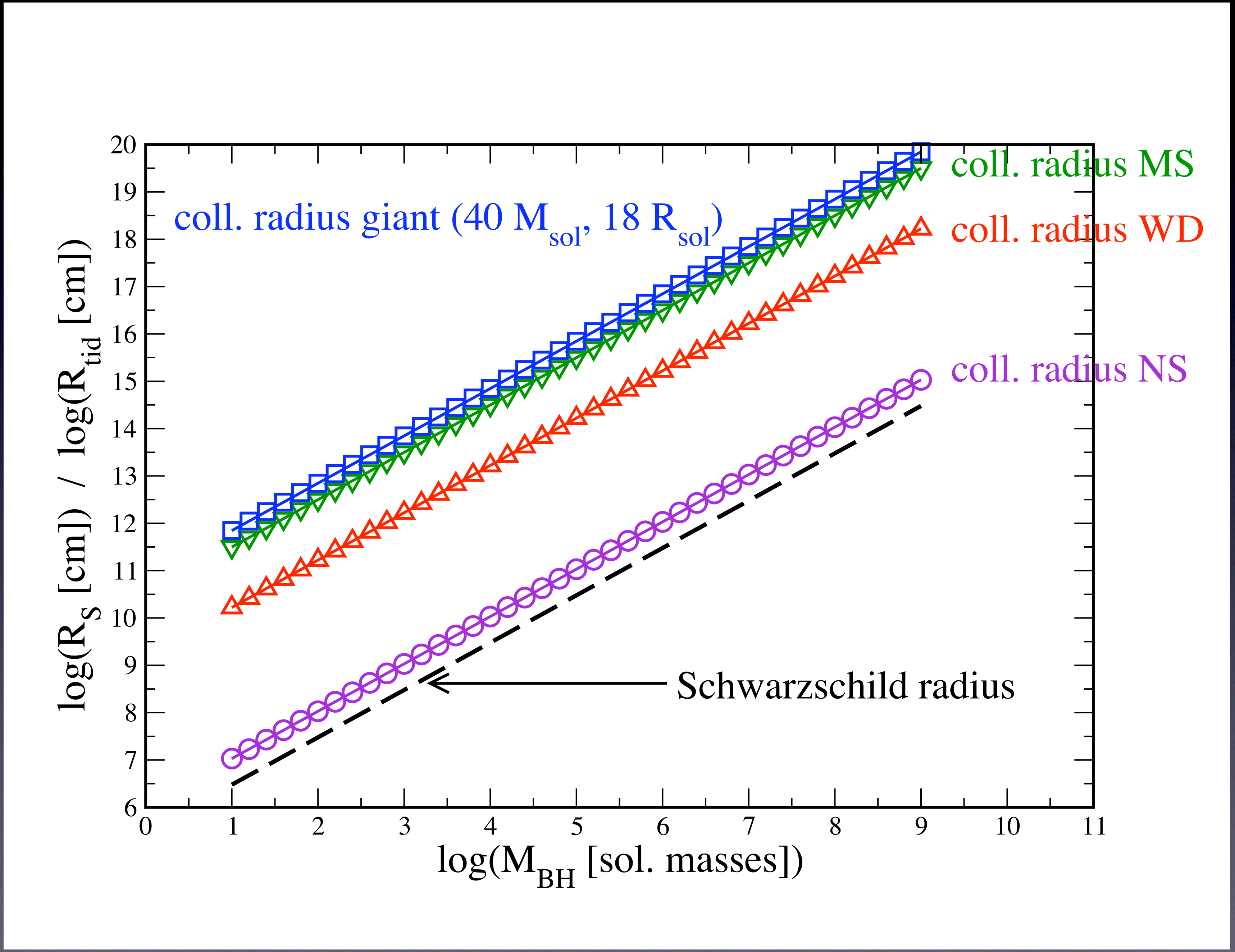
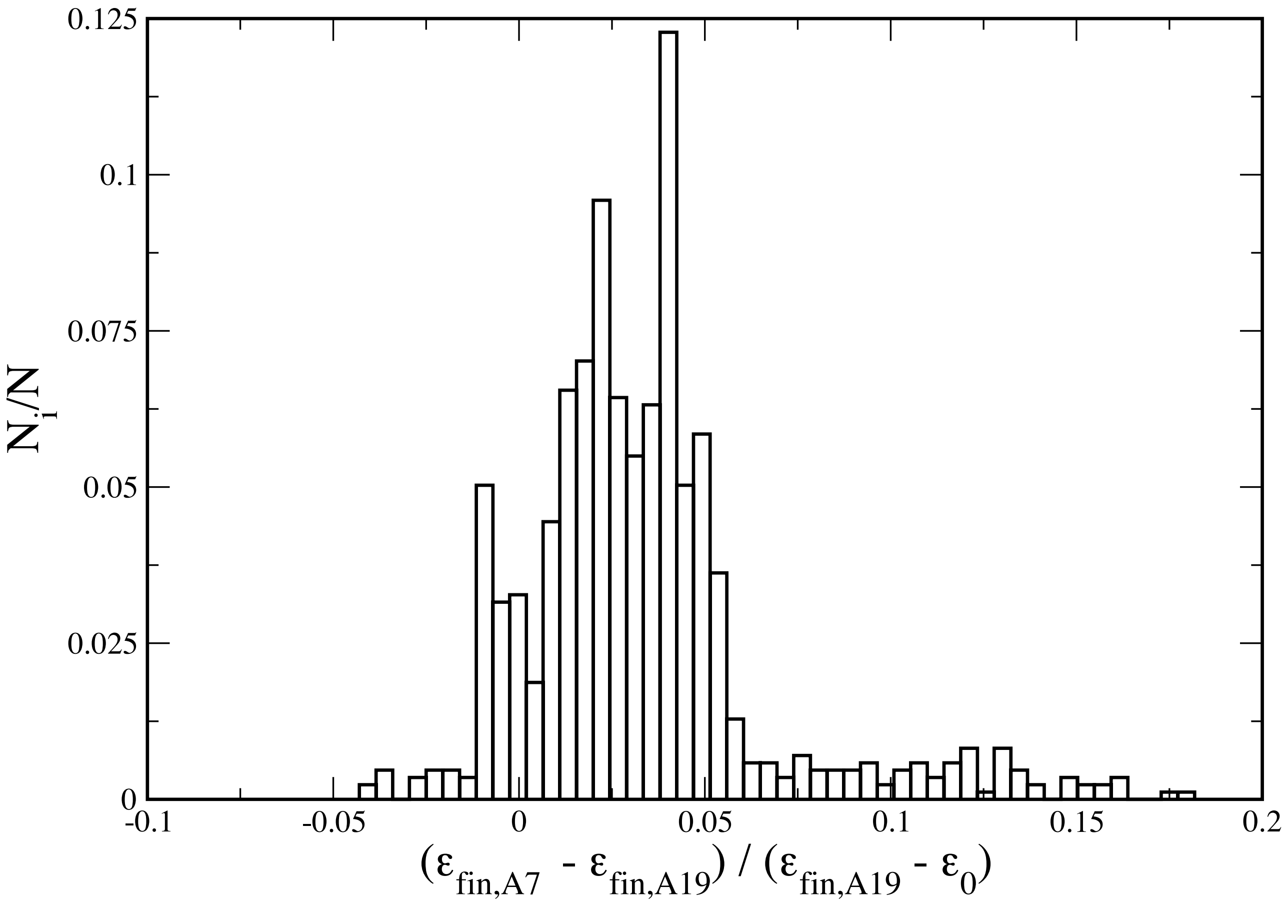
→ promise detection of several 10^5 supernovae per year

collision radii



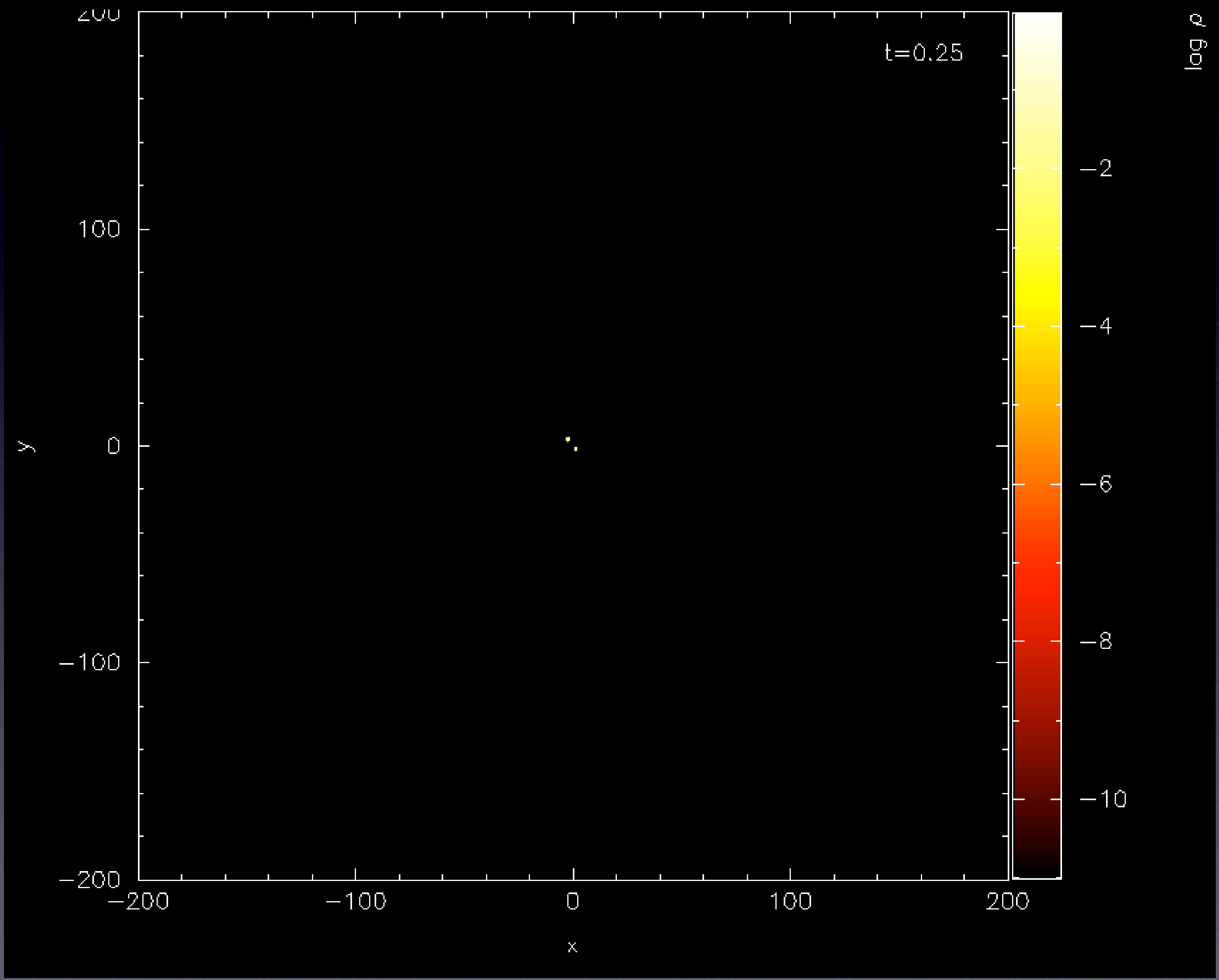
accuracy of A7- vs. A19-network



for most trajectories better than 5 %

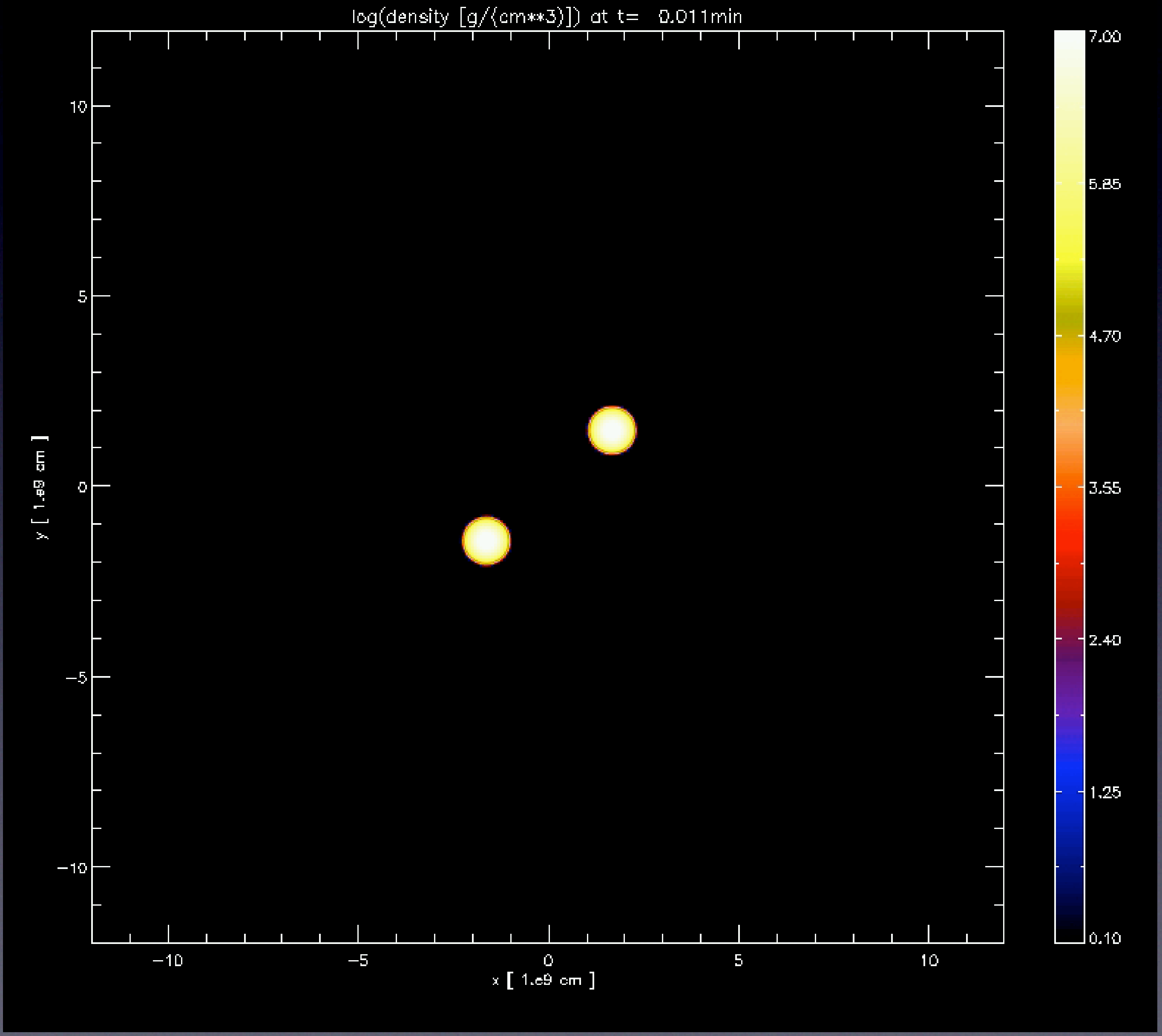
further collisions

$$M_1 = 0.4\ M_\odot, \quad 0.7\ M_\odot, \quad \beta = 3$$

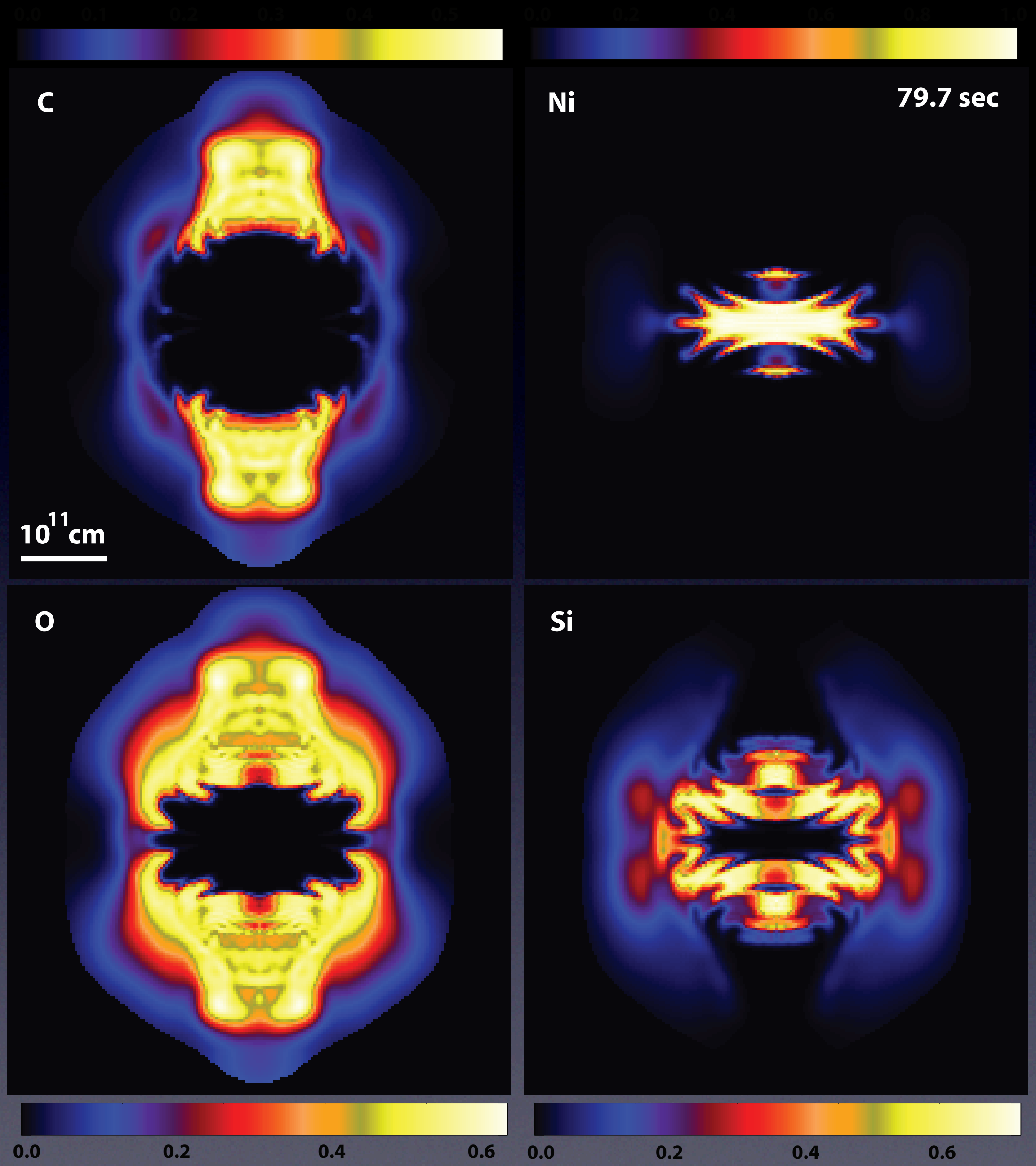


further collisions

$$M_1 = 0.9\ M_\odot, \quad M_2 = 0.9\ M_\odot$$



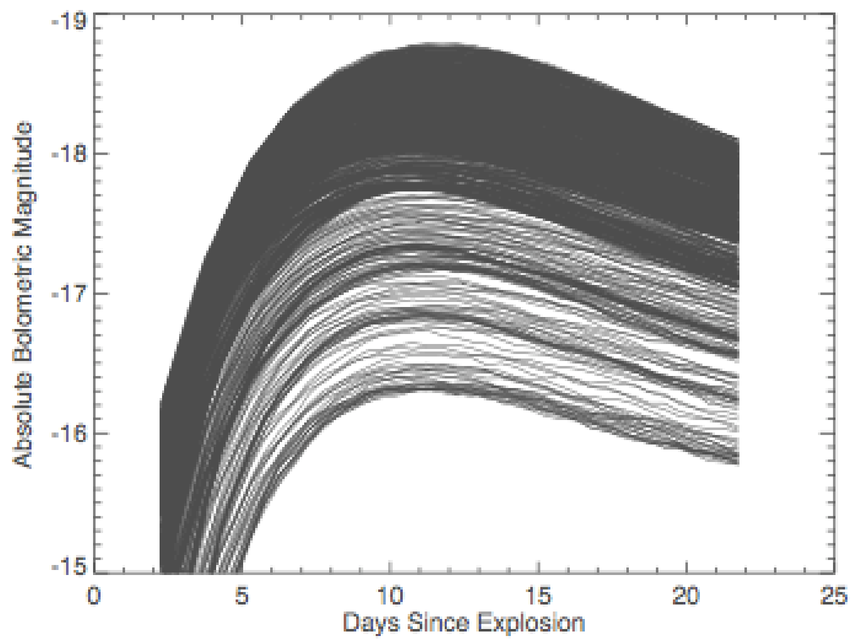
- distribution of species:

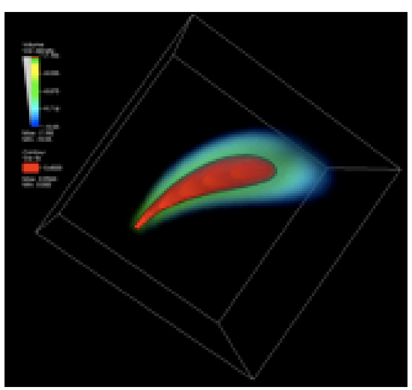


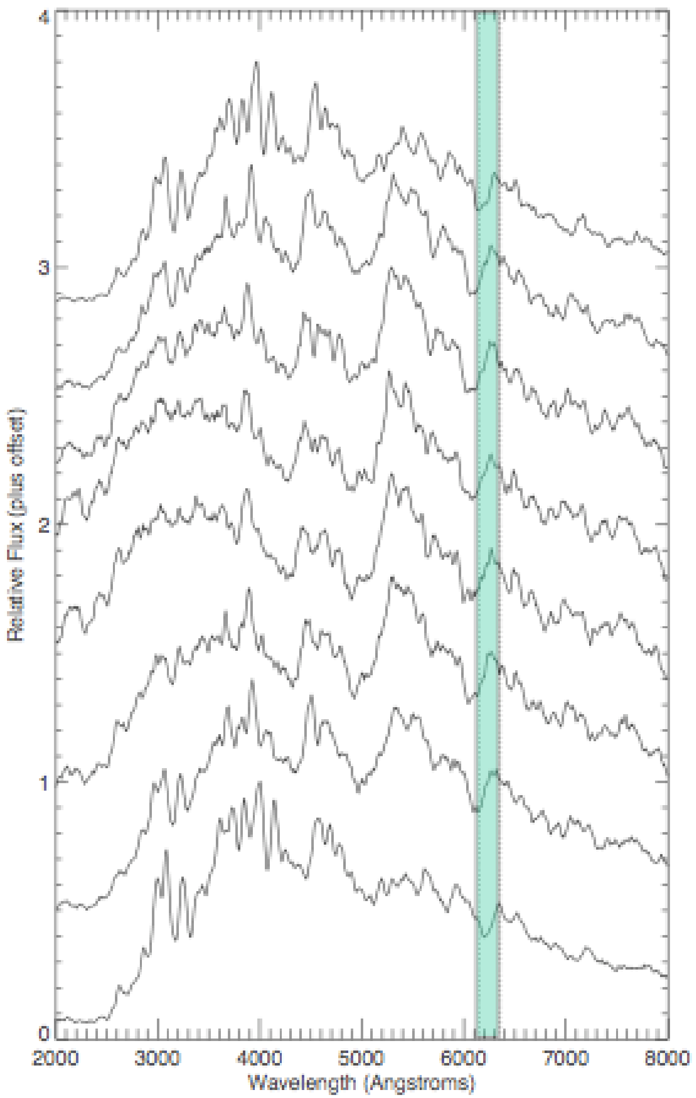
result of 19-isotope network

$$M_{\rm BH} = 1000\ {\rm M}_\odot, M_{\rm WD} = 0.2\ {\rm M}_\odot, \beta = 12$$

The Importance of Orientation







Post-processed mass fractions (Approx19 network)

2 x 0.6 (sol. masses)

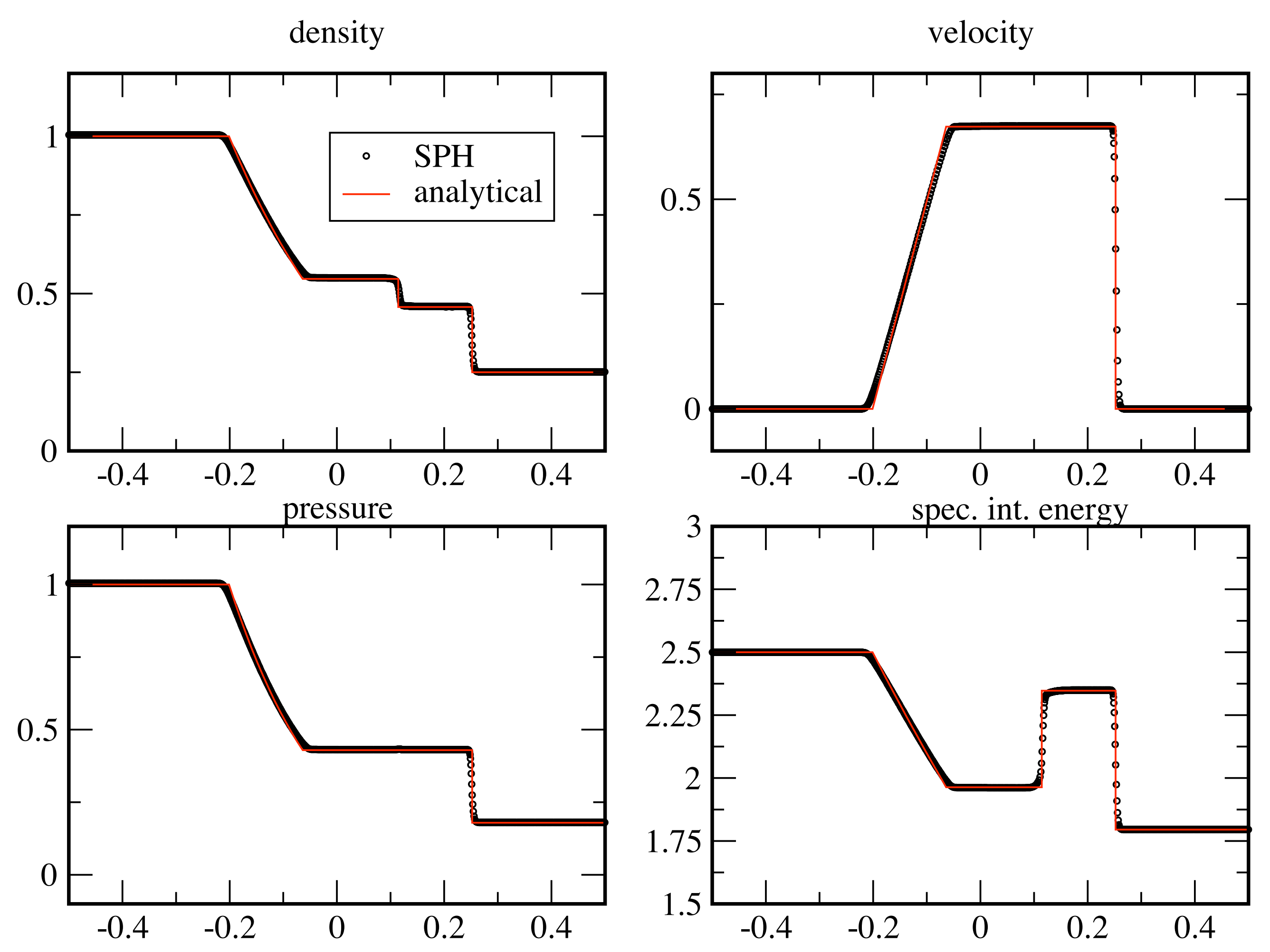
H1:	1.217106446584991E-030
He3:	3.594750358430493E-030
He4:	4.189043739183151E-003
C12:	2.495319687911574E-002
N14:	1.088185063636891E-02
O16:	0.170741773936532
Ne20:	7.141123691408813E-003
Mg24:	5.057439531547831E-002
Si28:	0.401987526550706
S32:	0.165240570241805
Ar36:	2.791319887545398E-002
Ca40:	2.435697639993441E-002
Ti44:	2.373173078559460E-005
Cr48:	2.760904614731734E-004
Fe52:	5.274240424876457E-003
Fe54:	1.572144622878850E-004
Ni56:	0.317170878739039
neut:	1.214341784544193E-016
prot:	2.099807811748382E-008

2 x 0.9 (sol. masses)

H1:	1.807451942143835E-030
He3:	5.396365023403411E-030
He4:	3.145408433755613E-003
C12:	2.141777908098629E-002
N14:	1.156883143104618E-025
O16:	0.198799495867811
Ne20:	8.051318839390595E-003
Mg24:	6.355383568977493E-002
Si28:	0.528208291808507
S32:	0.223095866689290
Ar36:	3.957642941078928E-002
Ca40:	3.694688547903079E-002
Ti44:	2.218725646853336E-005
Cr48:	5.049289284105797E-004
Fe52:	1.169269997771984E-002
Fe54:	5.935557993597524E-004
Ni56:	0.664391266963926
neut:	1.272072363488627E-016
prot:	1.474595322761357E-008

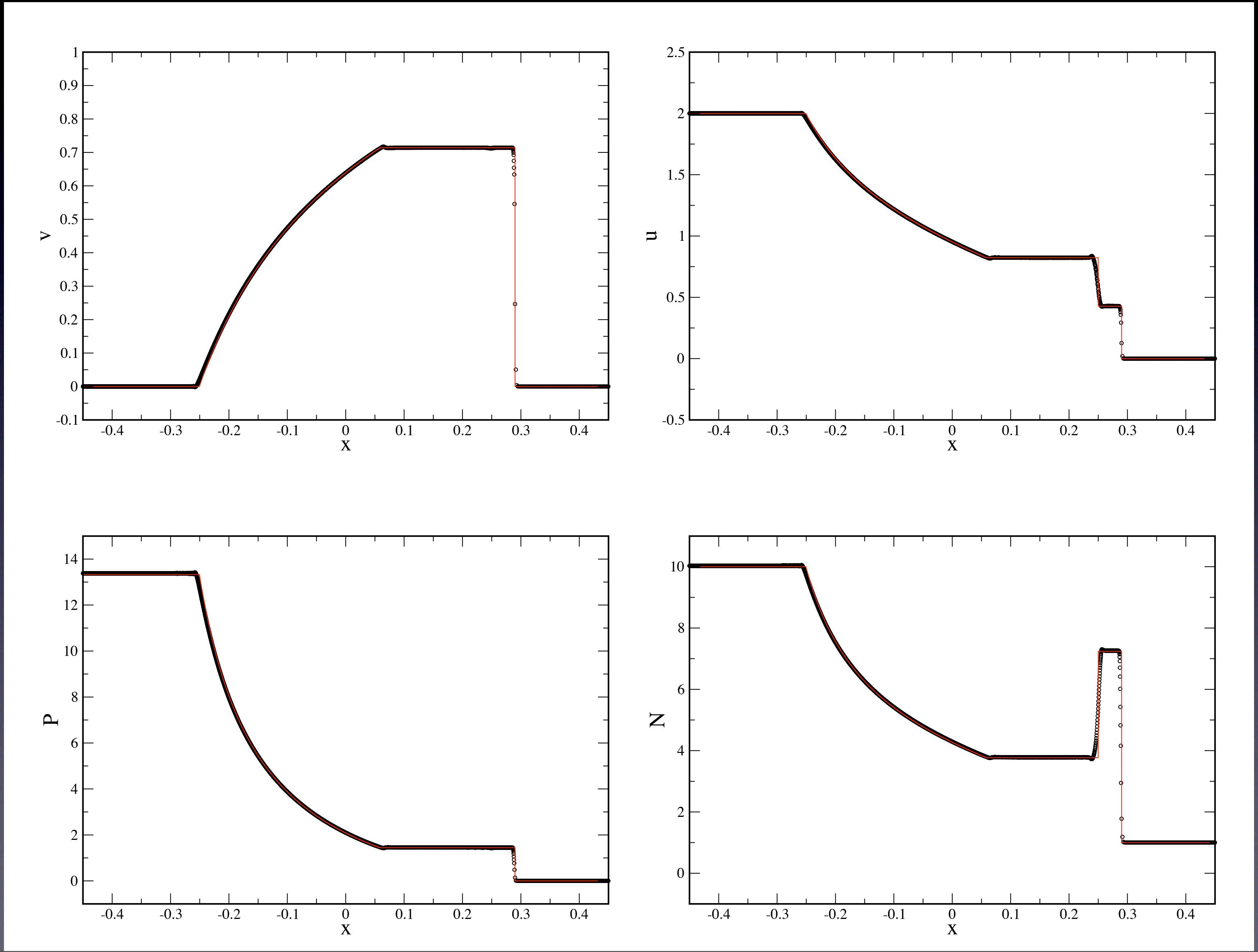
"SPH can't do shocks"

standard, Newtonian, "Sod"- shock tube



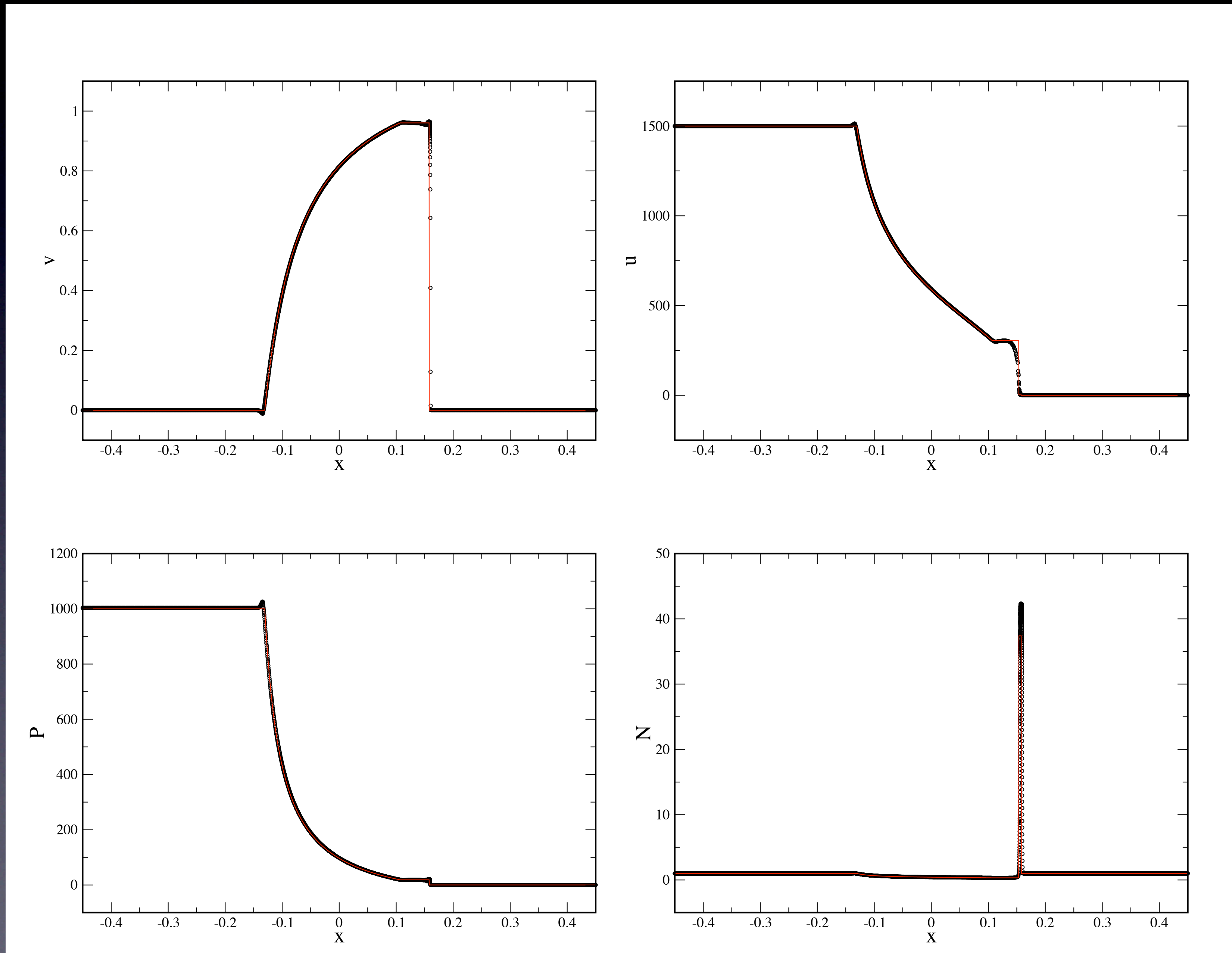
"SPH can't do shocks II"

mildly relativistic shock tube (Lorentz factor=1.4)



"SPH can't do shocks III"

strong, relativistic blast wave (Lorentz factor= 6.0)



“SPH can’t do shocks IV”

super-ultra-hyper-relativistic wall shock

$$\gamma = 50\,000, \quad v = 0.9999999998c$$