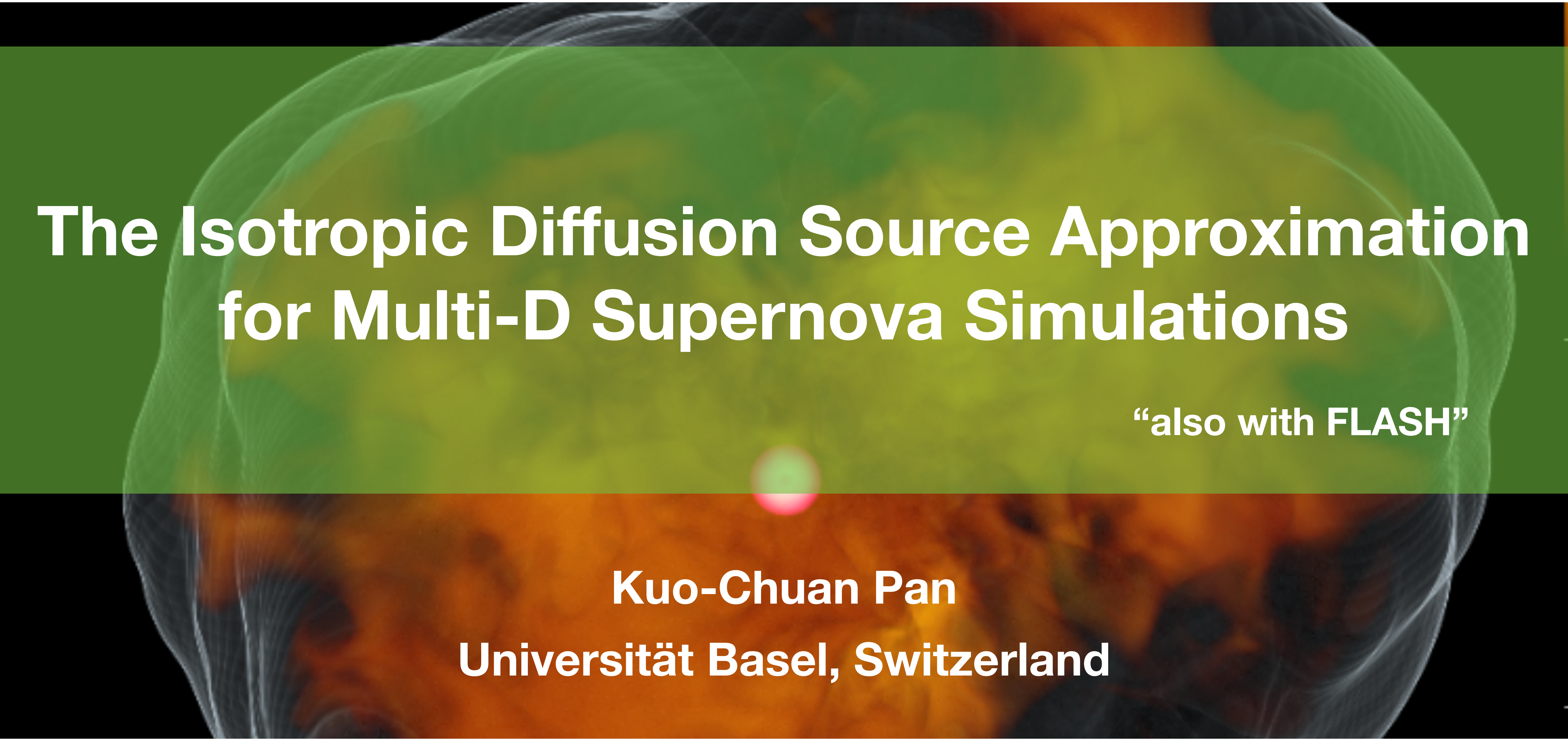

The Isotropic Diffusion Source Approximation for Multi-D Supernova Simulations

“also with FLASH”

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Friedrich-Karl Thielemann
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Andreas Lohs
Matthias Liebendörfer
Takami Kuroda
Rubén Cabezón
Kevin Ebinger

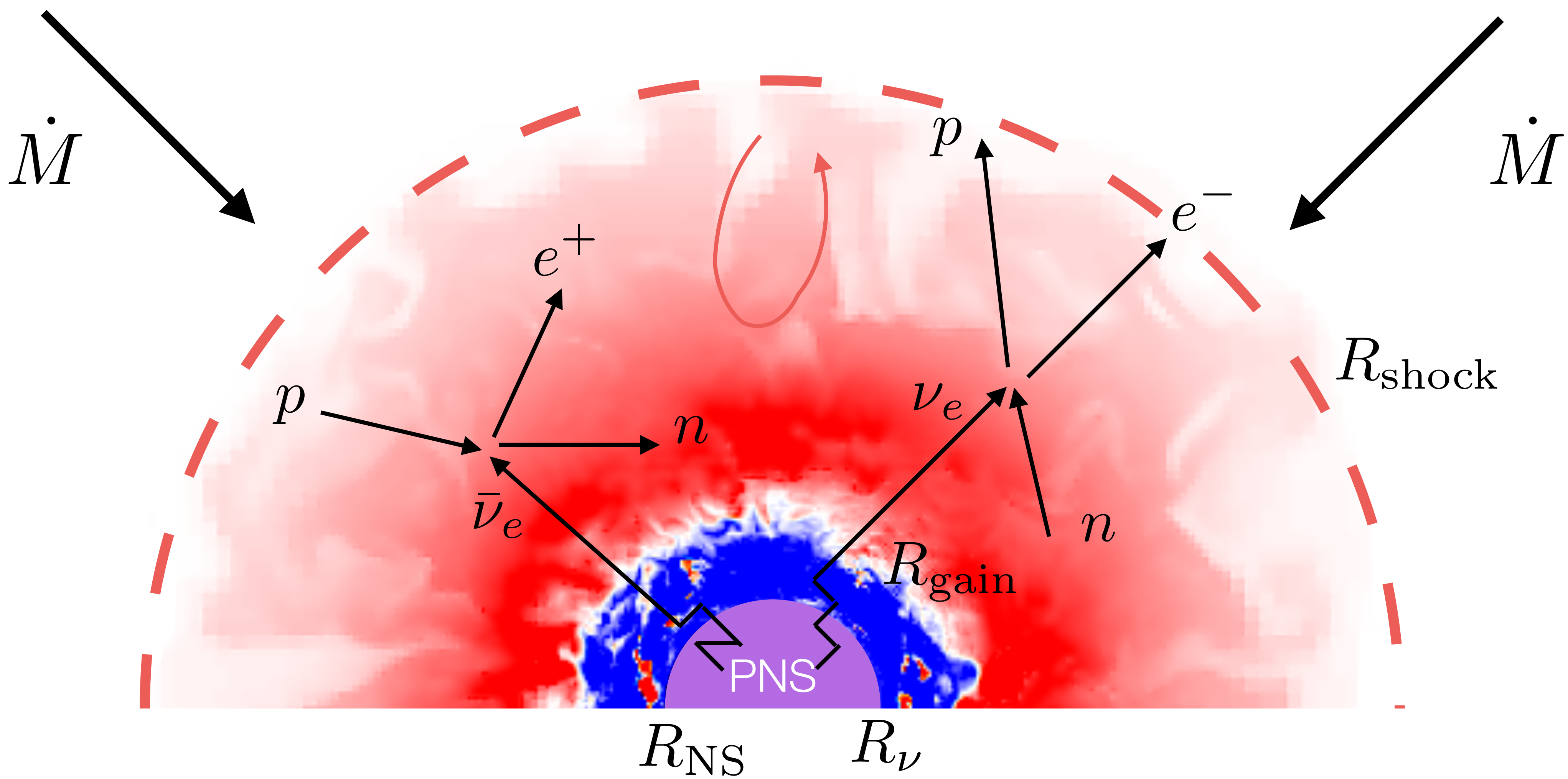
UNI BASEL

erc

CSCS

Basic Physics

- Direct hydrodynamics mechanism always fail!
- Neutrino-driven convection is the key



Adapted from Janka 01

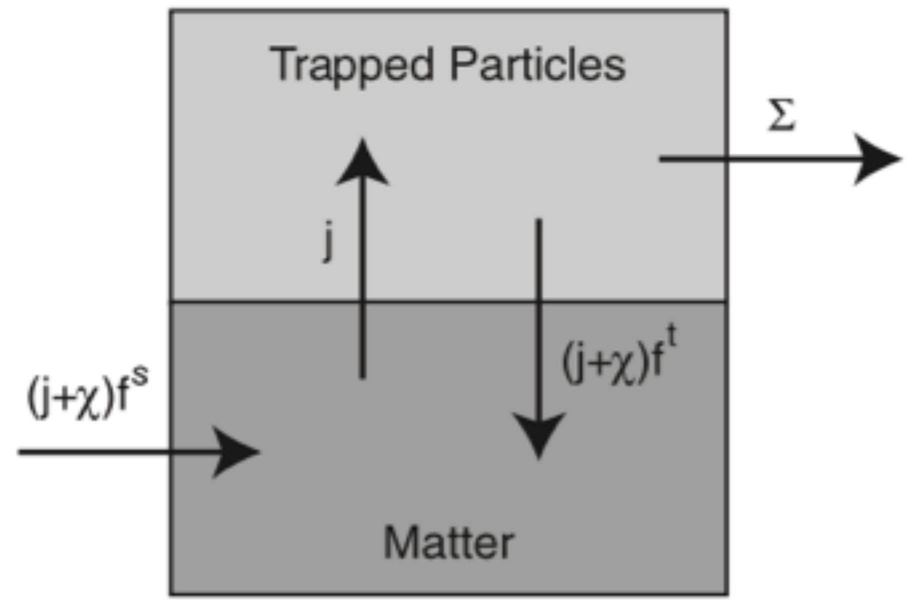
Isotropic Diffusion Source Approximation (IDSA)

IDSA (Liebendorfer+ 09)

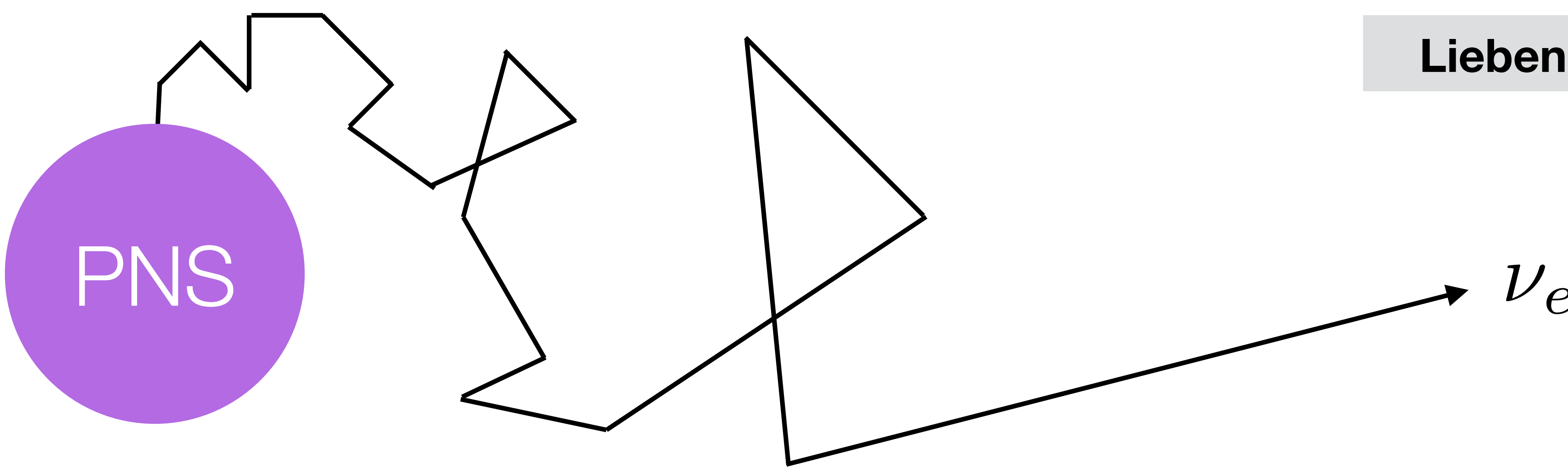
$$f_l = f_l^t + f_l^s$$

$$D(f_l^t) = C_l^t - \Sigma_l$$

$$D(f_l^s) = C_l^s + \Sigma_l$$



Liebendorfer+ 09

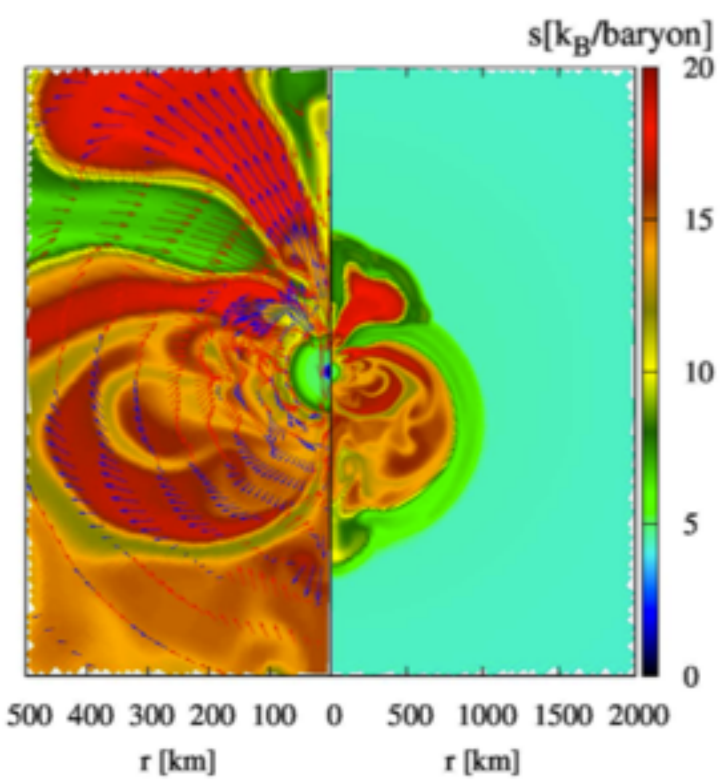


Opaque Semi-transparent Transparent

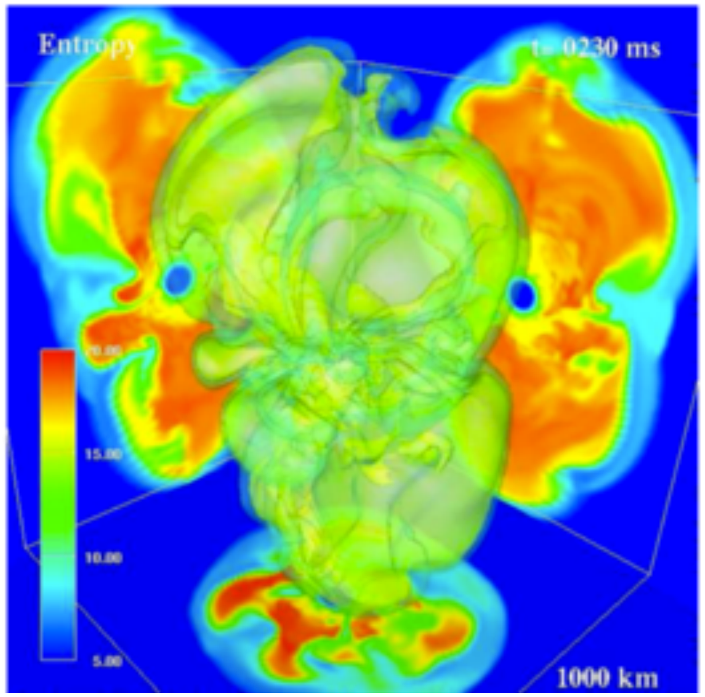
Multi-D Simulations with IDSA

- Multi-dimensional simulations with the IDSA have been studied by the Nippon groups
- ZEUS+IDSA in spherical coordinates with Ray-by-Ray approach

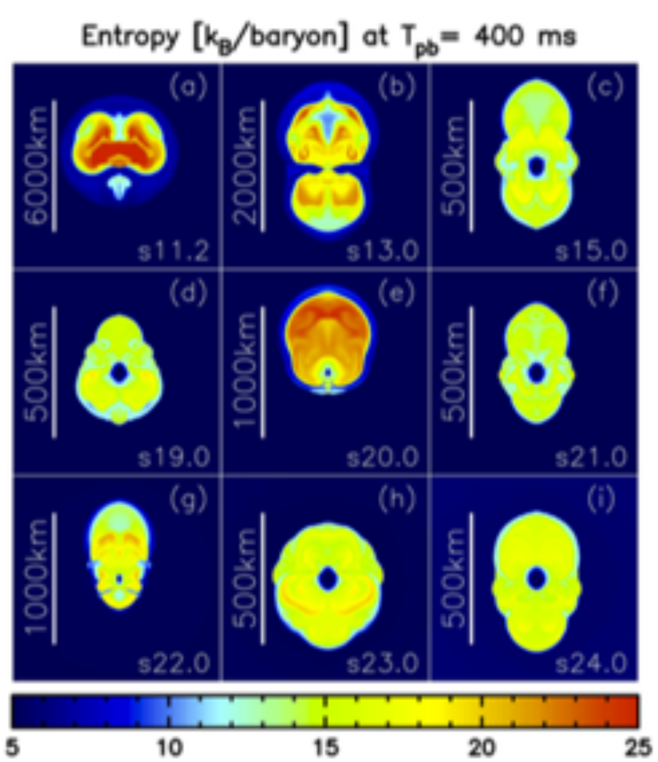
Suwa+ 13



Takiwaki+ 14



Nakamura+ 14



Multi-D IDSA with FLASH

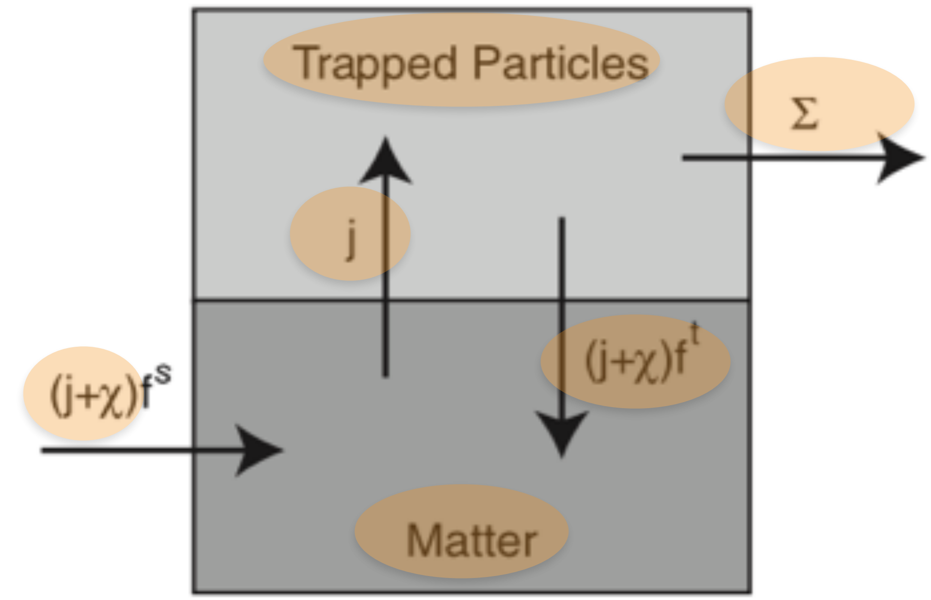
$$f_l = f_l^t + f_l^s$$

$$D(f_l^t) = C_l^t - \Sigma_l$$

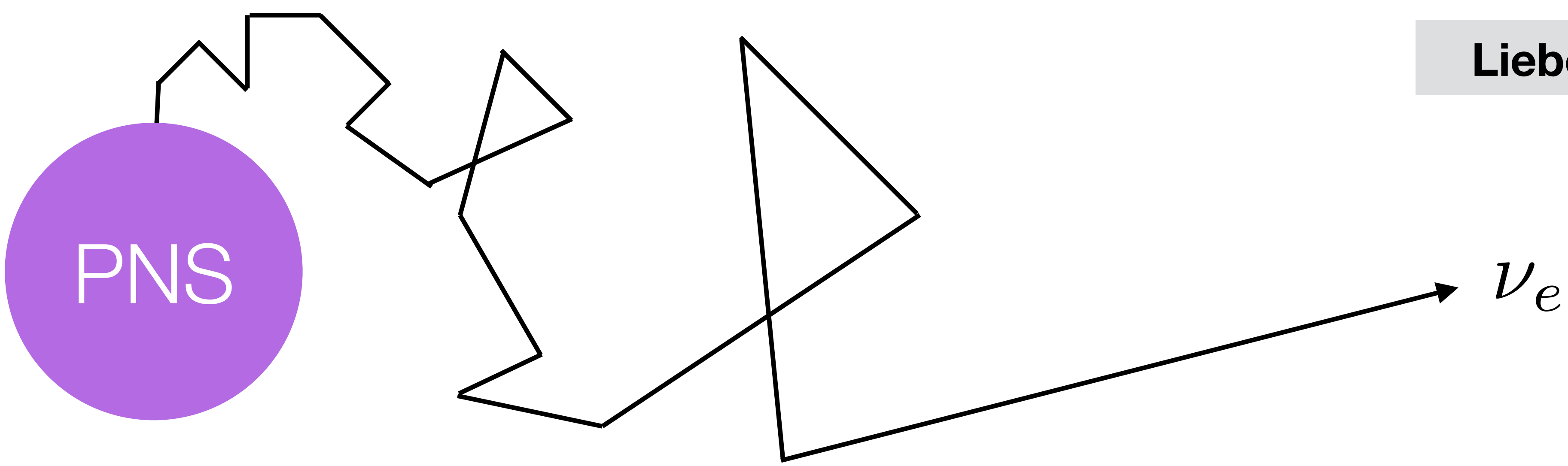
$$D(f_l^s) = C_l^s + \Sigma_l$$

Spherical Symmetry:

$$R_\nu(E, l)$$
$$f^s(E, l)$$



Liebendorfer+ 09

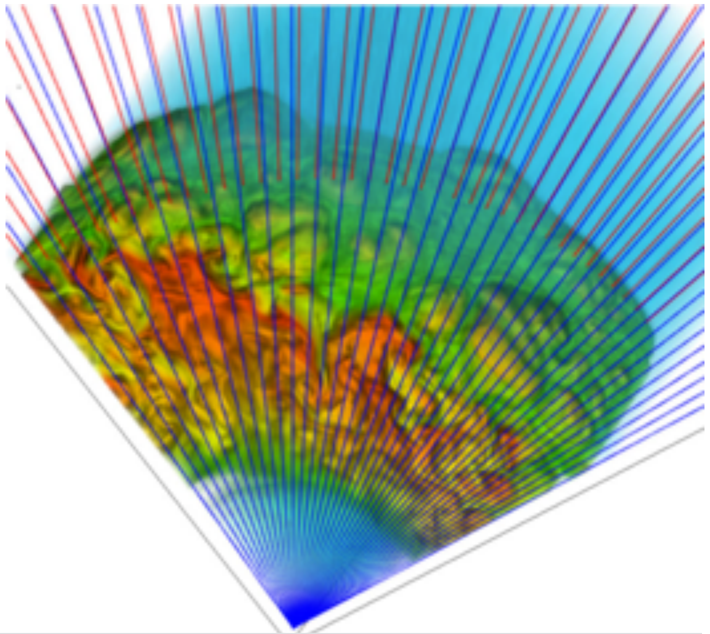


Opaque Semi-transparent Transparent

FLASH+IDSA

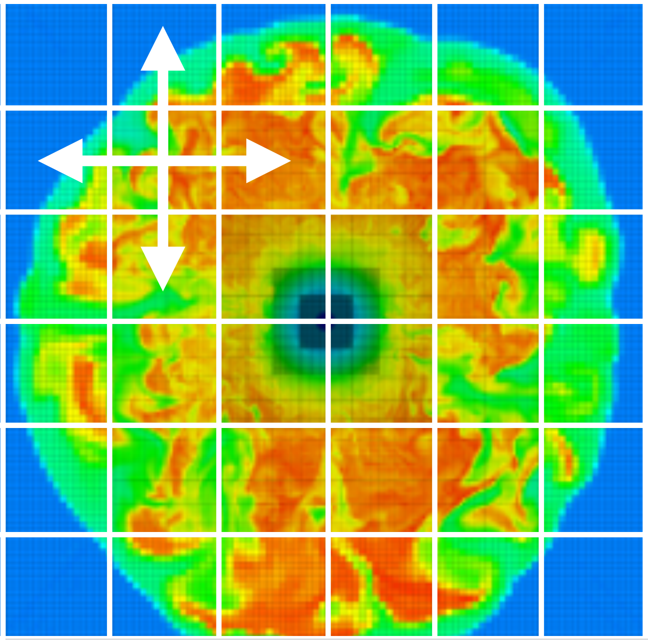
- 2D cylindrical and 3D Cartesian coordinates with AMR: better PNS but noisy
- Not "Ray-by-Ray" approach. We solve the diffusion source and trapped particle component in multi-dimensions, but keep the streaming component in spherical symmetry (Similar to the Elephant code)
- 20 energy bins from 3 MeV to 300 MeV
- Only for electron type neutrinos (Heavy neutrinos -> Leakage scheme)

Ray-by-Ray



Ott+ 12

Full 3D



This work

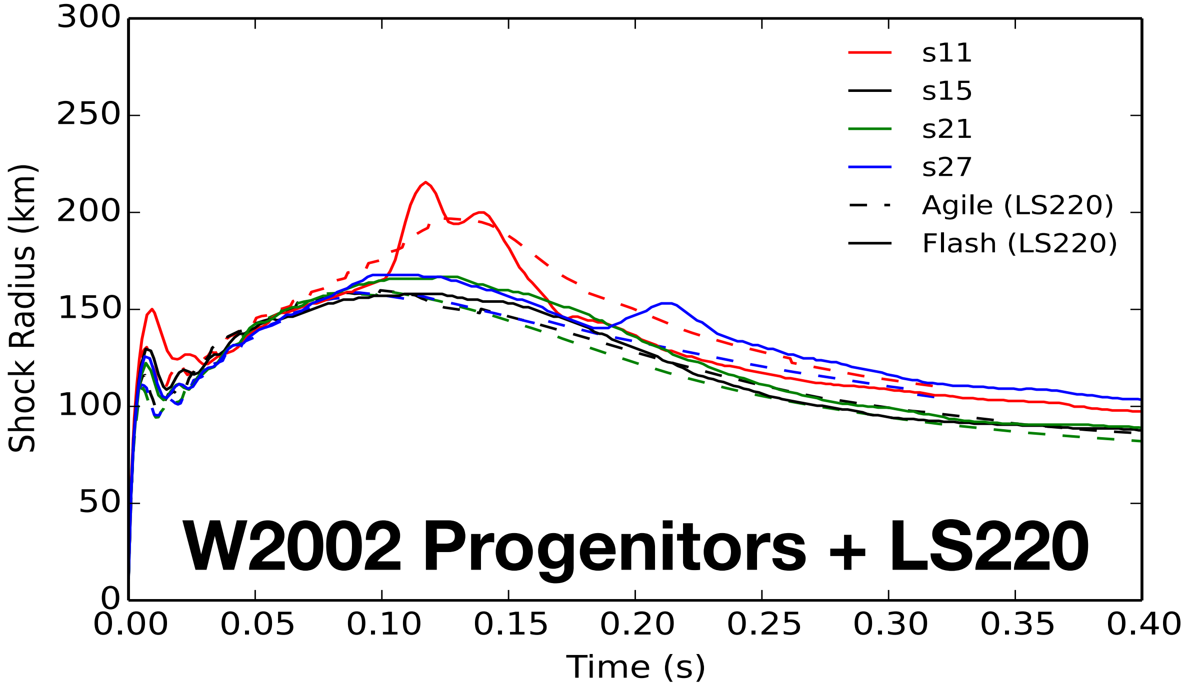
The FLASH code (v4.2.2)

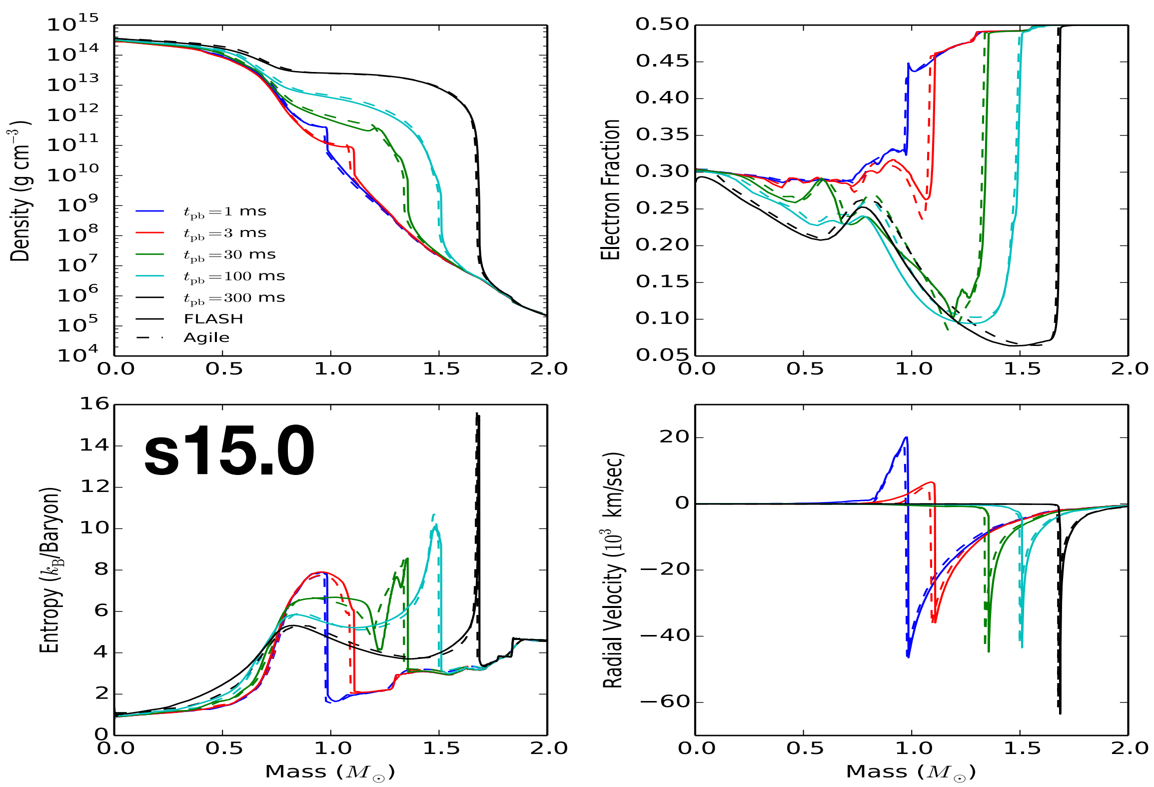
Code Status:

- Geometry: 1D spherical, 2D cylindrical, and 3D Cartesian (Similar to Couch+13)
- Hydrodynamics: 3rd PPM with HLLC Riemann solver with AMR
- Resolution: effective angular resolution (2D:~0.3-0.6^{0} ,3D:~1-2^{0})
- Simulation box: r= 0 to r= 10,000 km
- Gravity: The new improved multi-pole solver (Couch+13; Newtonian or eff. GR)
- EoS: Supernova EoS from http://stellarcollapse.org
- Neutrino transport: Isotropic Diffusion Source Approximation (IDSA)
  - Collapse: **IDSA** or parametrized deleptonization (**PD**; Liebendorfer+05)
  - Postbounce: IDSA (Liebendorfer+09)

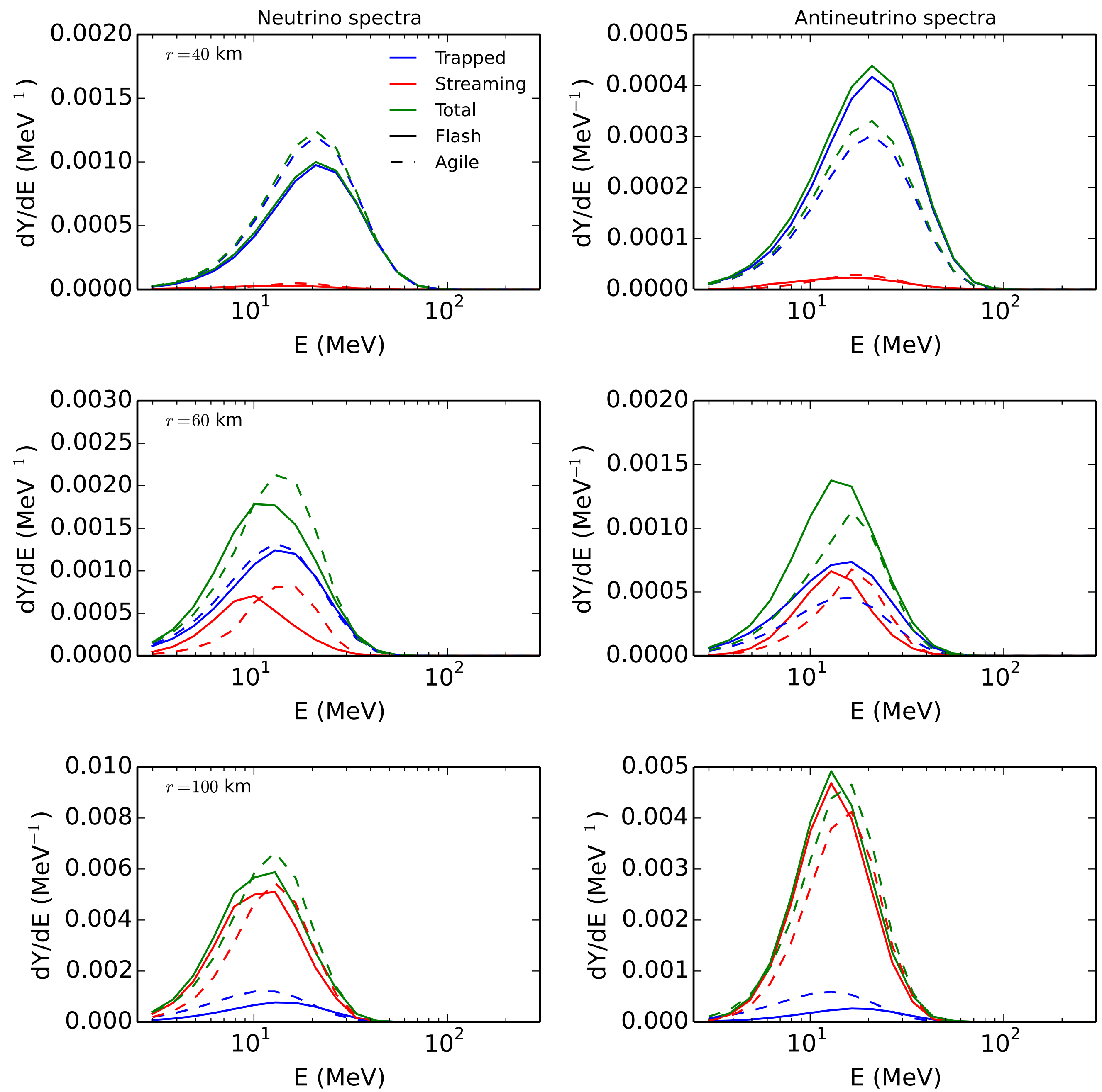
1D Code Comparison: FLASH v.s. AGILE

Shock Radius





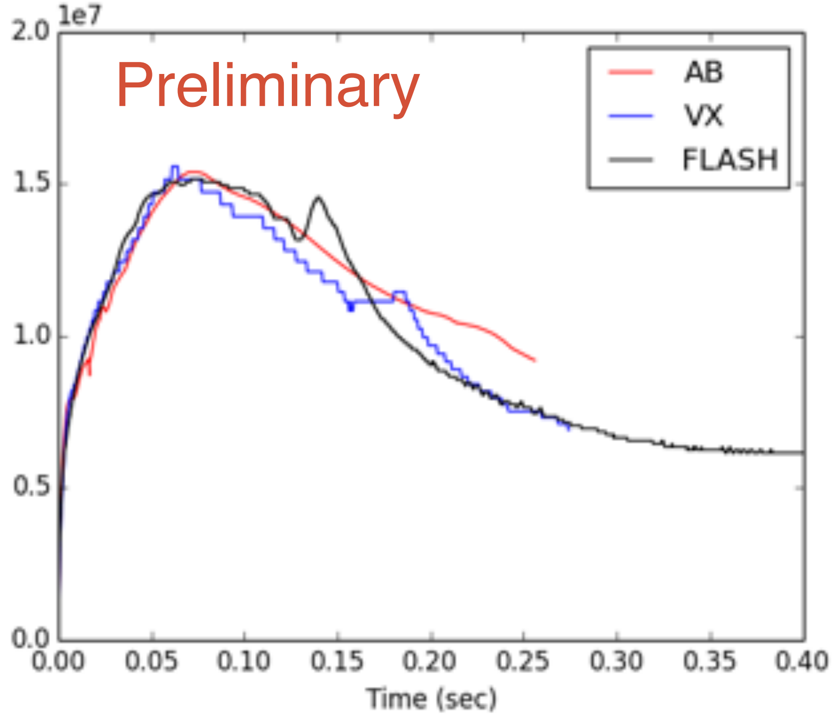
Neutrino Spectra



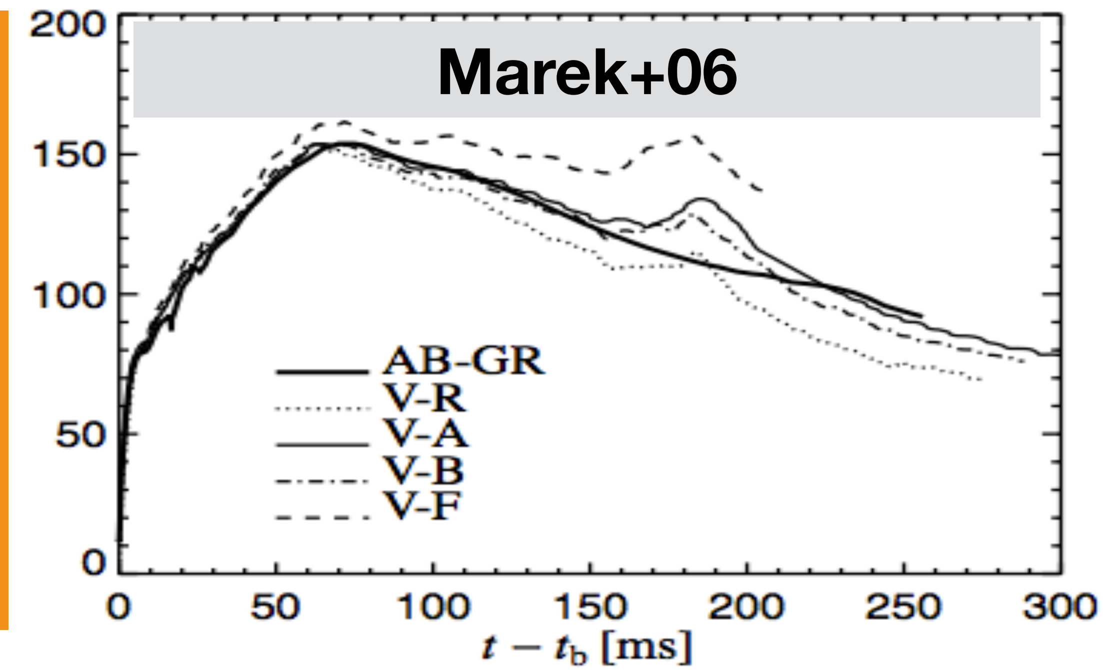
1D Code Comparison: Eff. GR

s15s7b2 (W1995) + LS180

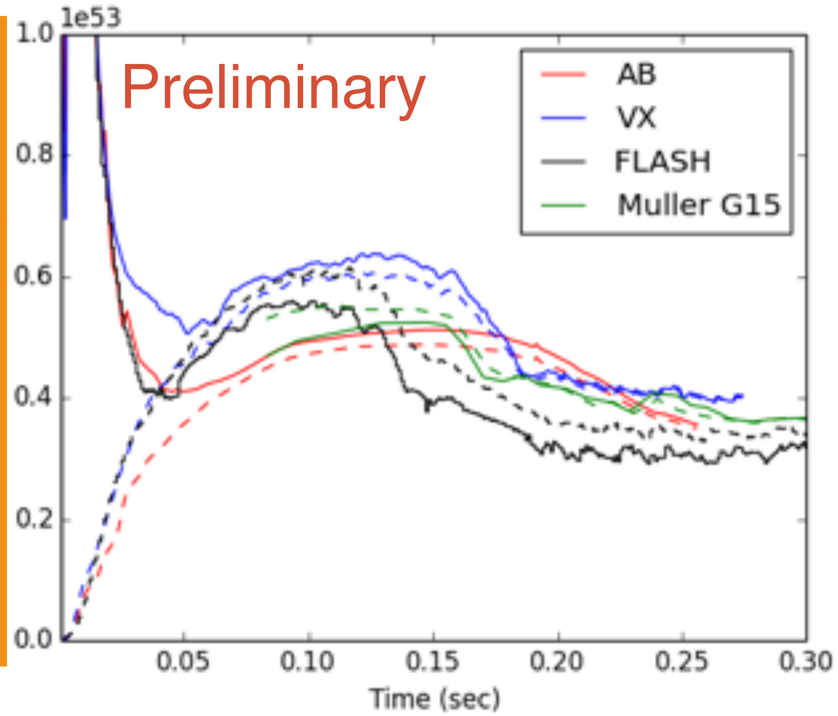
Shock Radius



Shock Radius

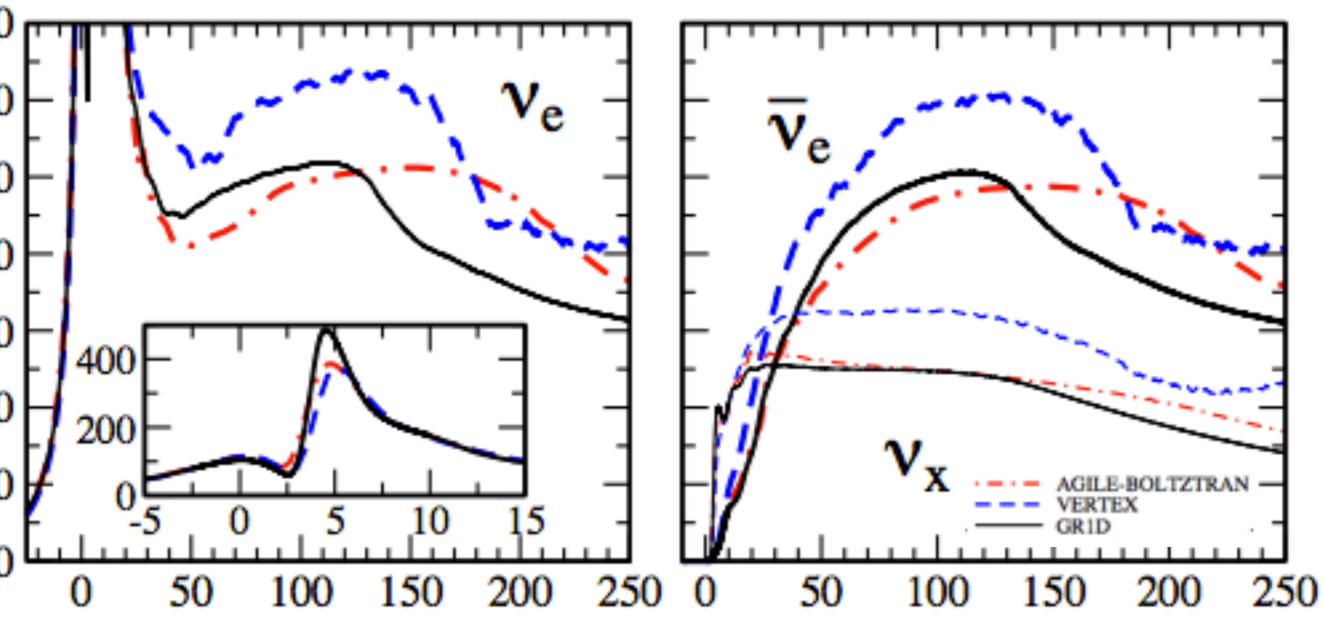


Neutrino Luminosity



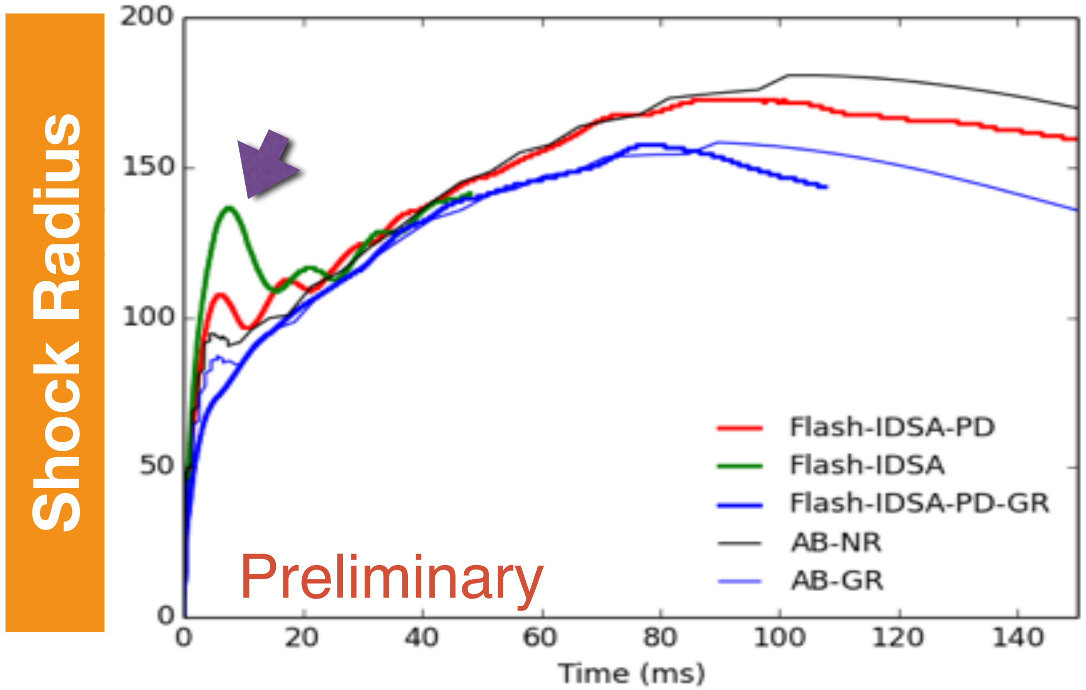
O'Connor+ 15

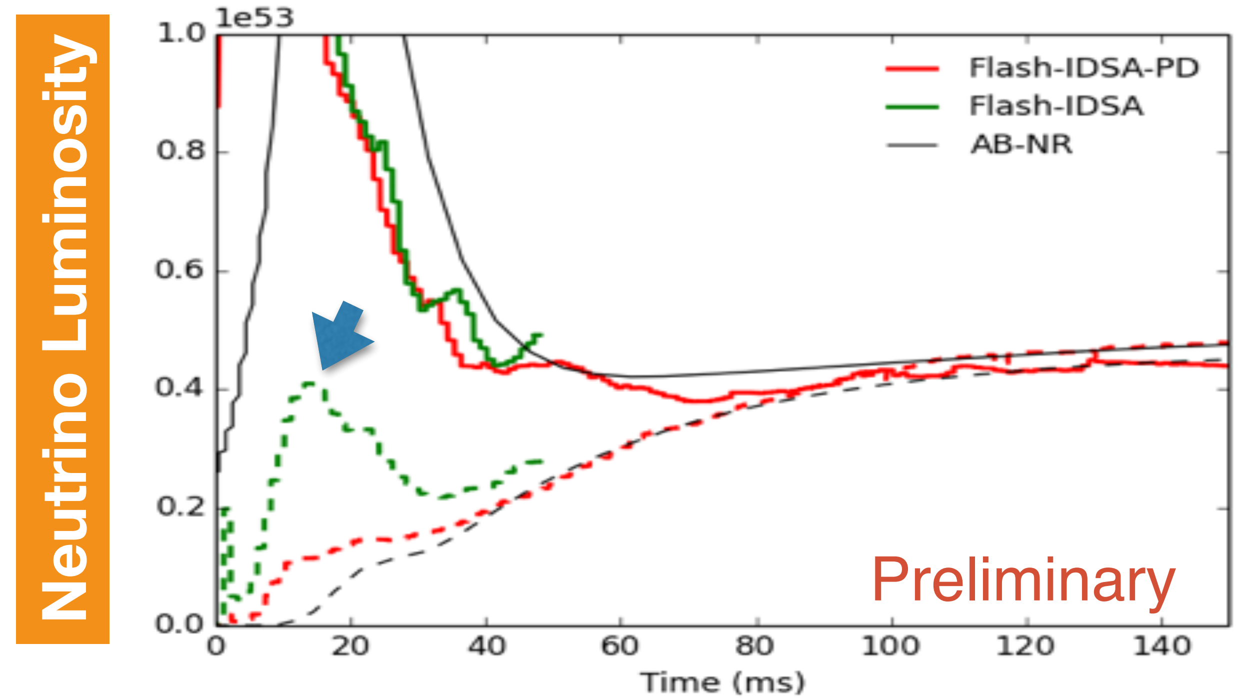
Neutrino Luminosity

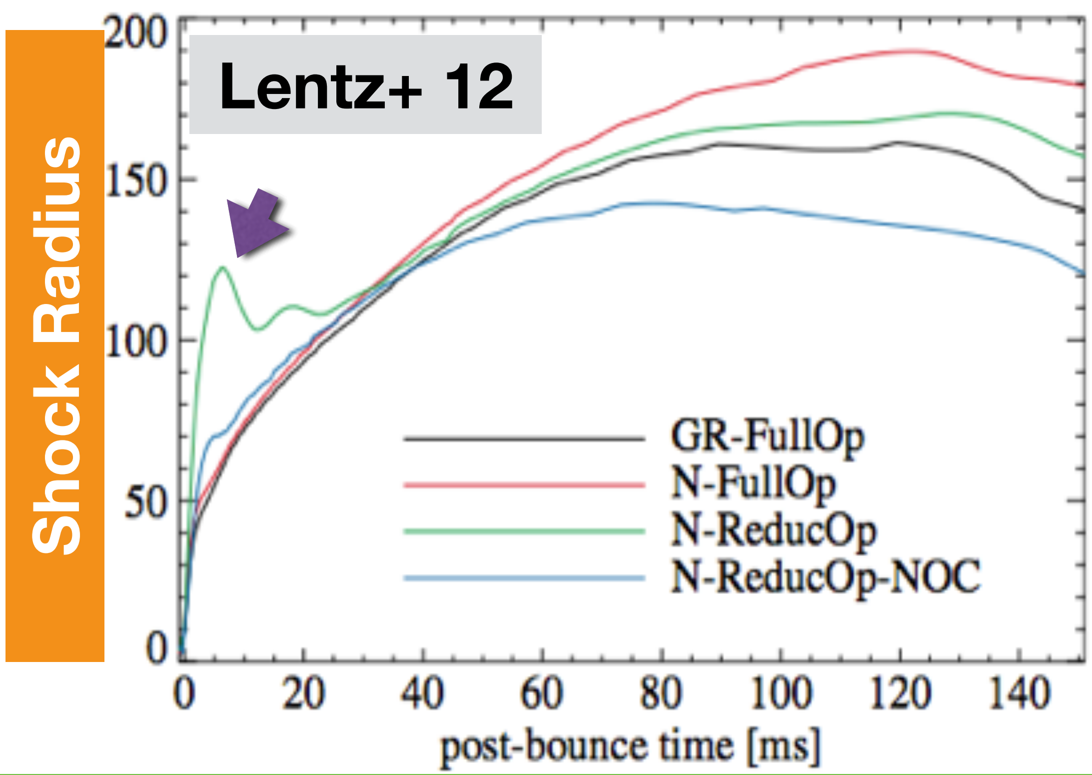


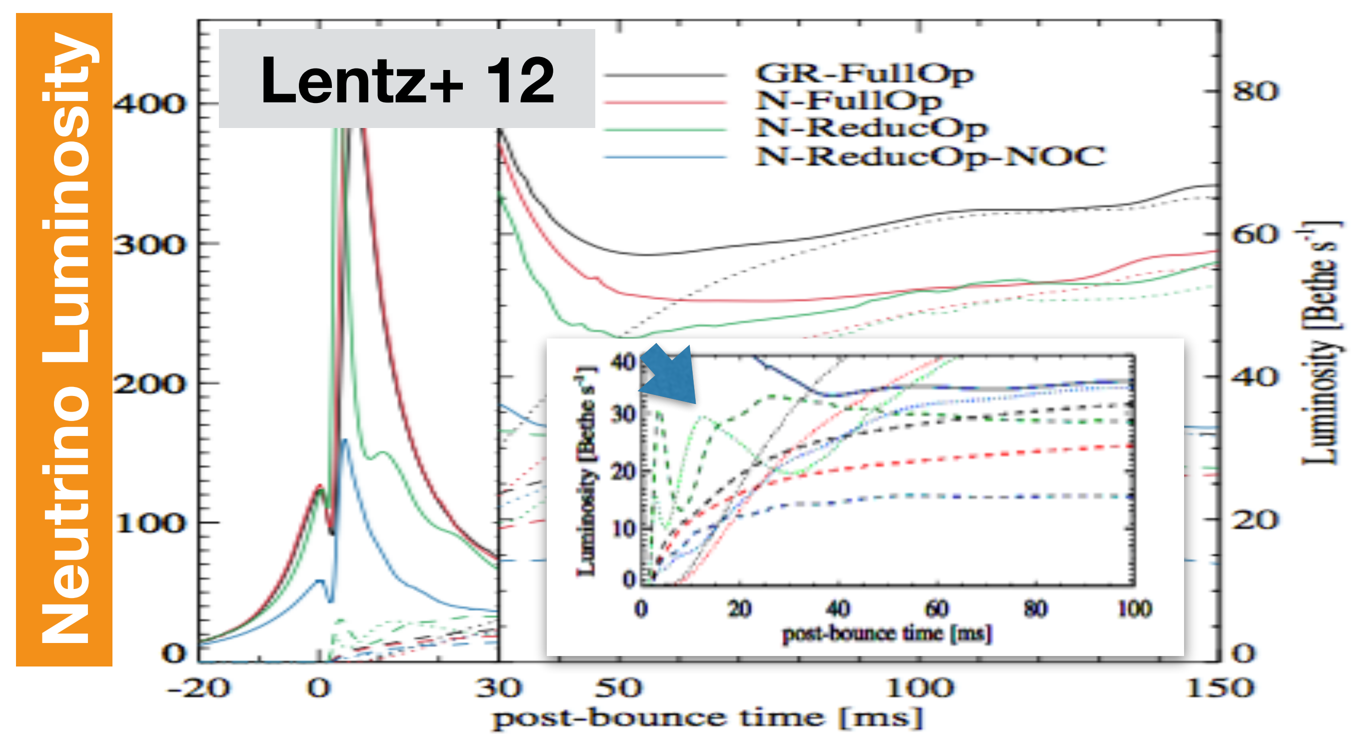
The Bruenn rates (1985) in IDSA

s15 (W2007) + LS220





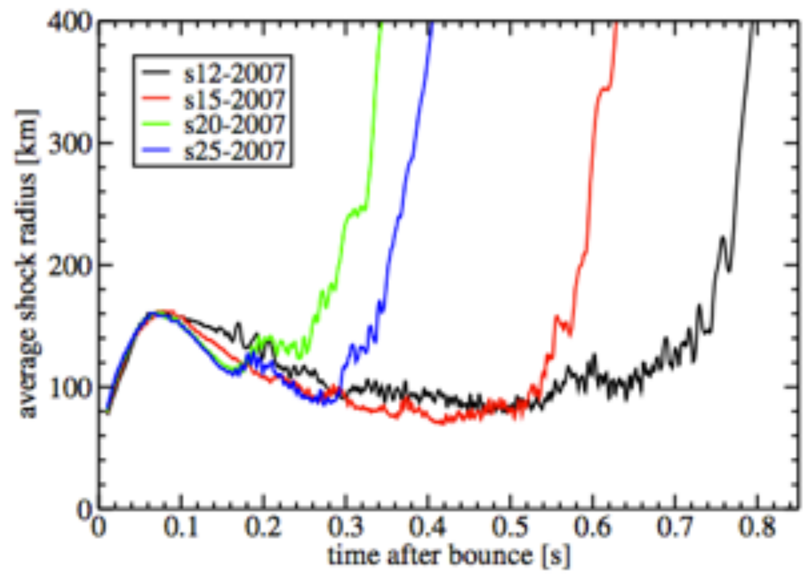




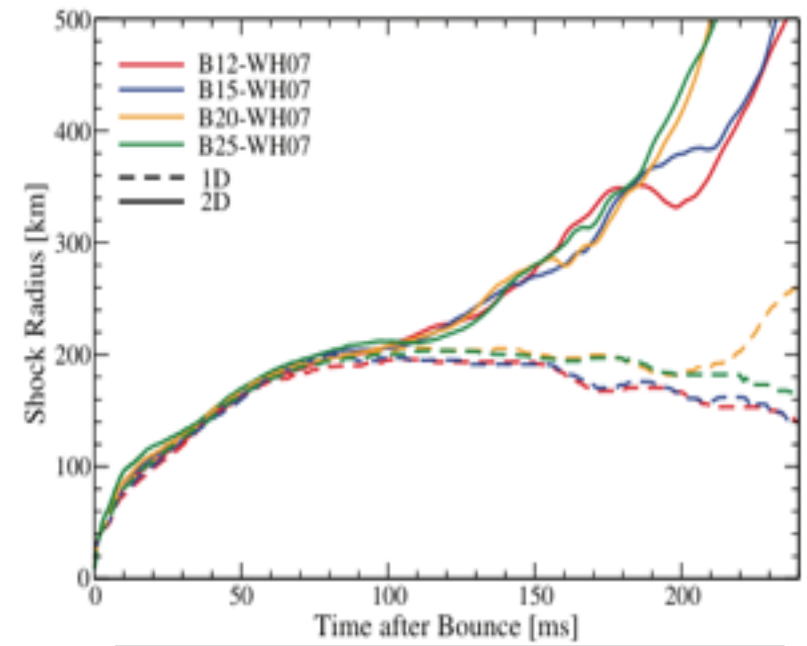
2D Code Comparison

The 2007 (WHW) Progenitors

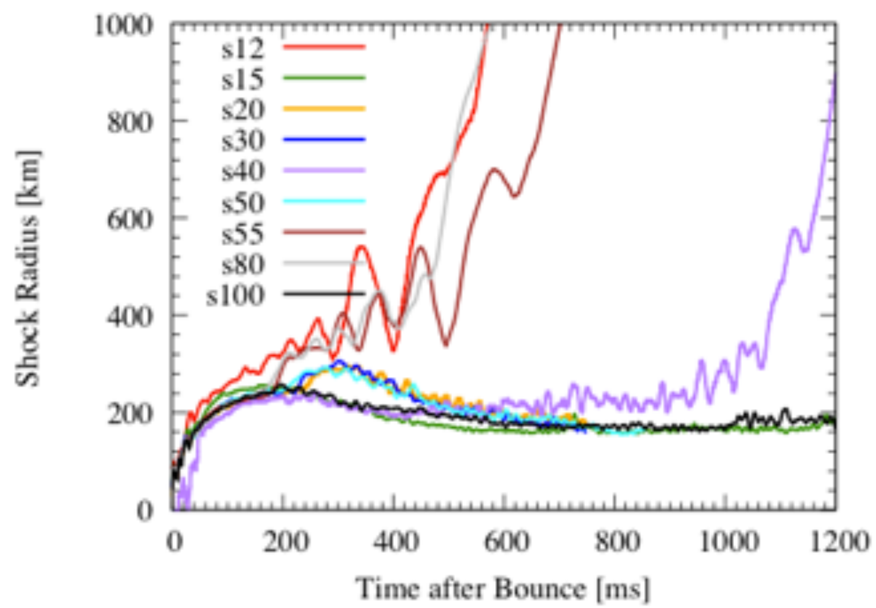
Hanke 14



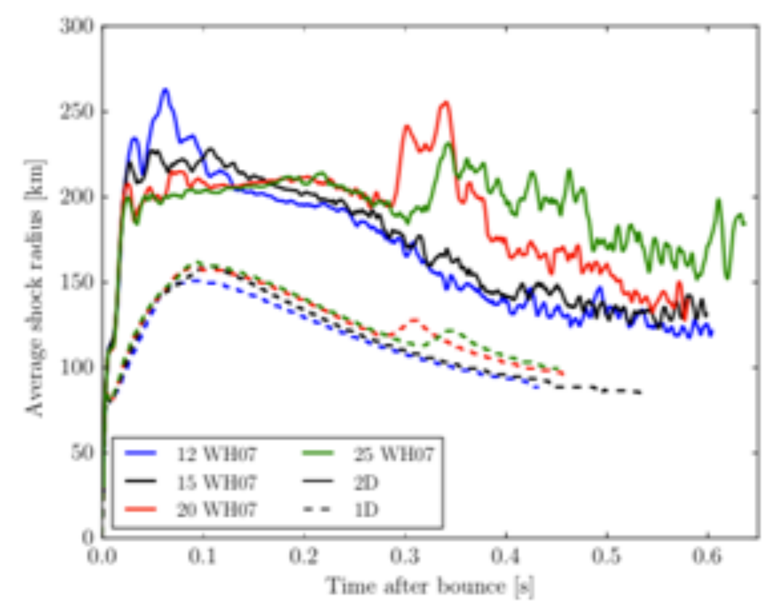
Bruenn +13



Suwa +14

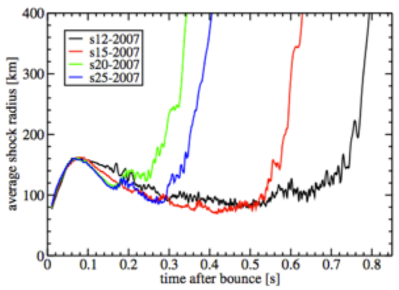


Dolence+15

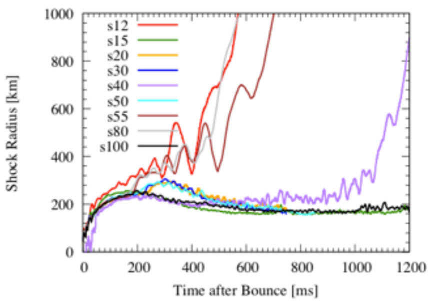


2D Code Comparison

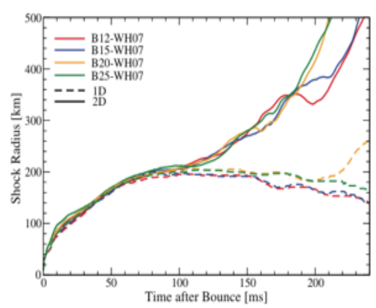
Hanke 14



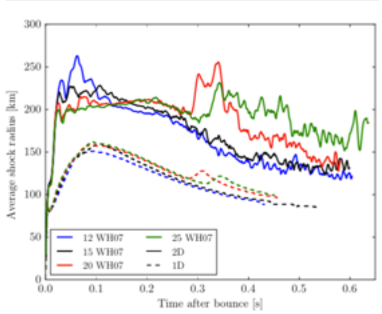
Suwa +14



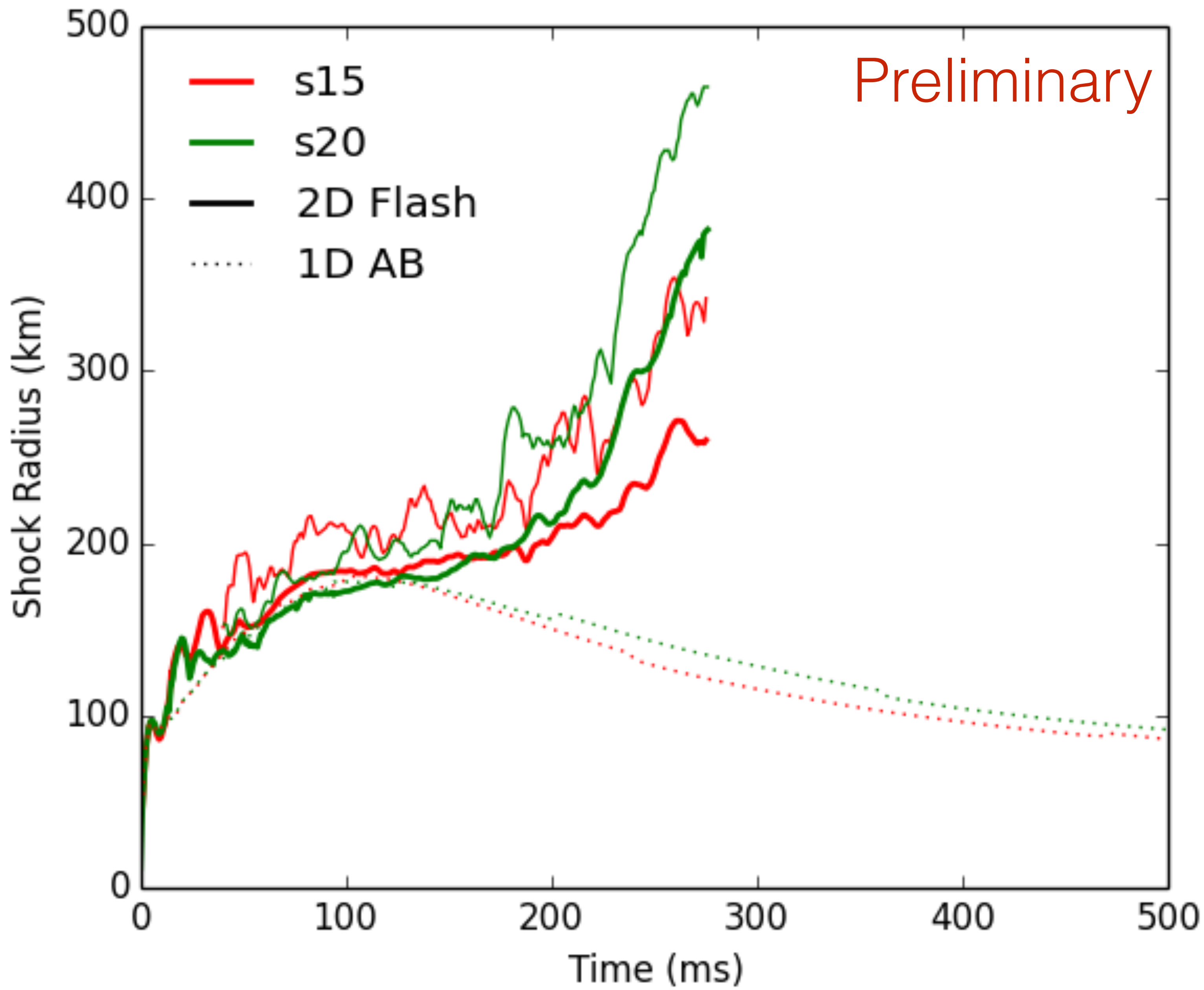
Bruenn +13



Dolence+15

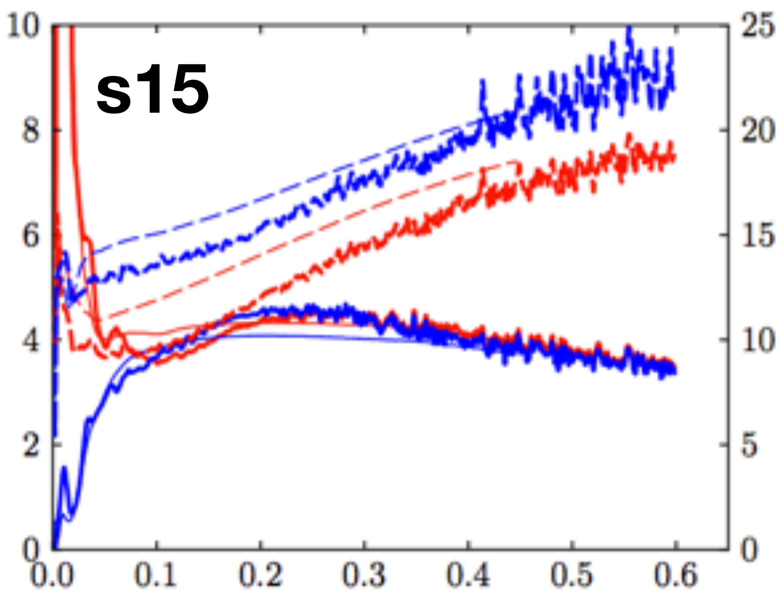


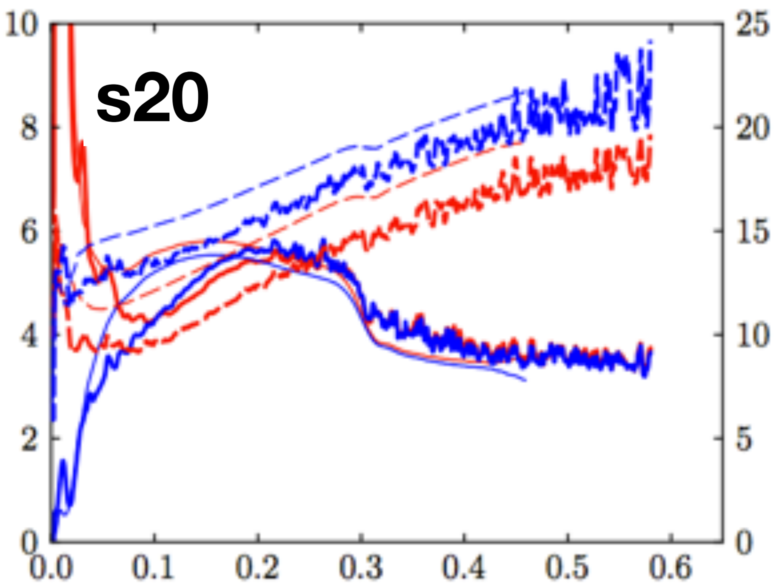
The 2007 (WHW) Progenitors



2D Code Comparison

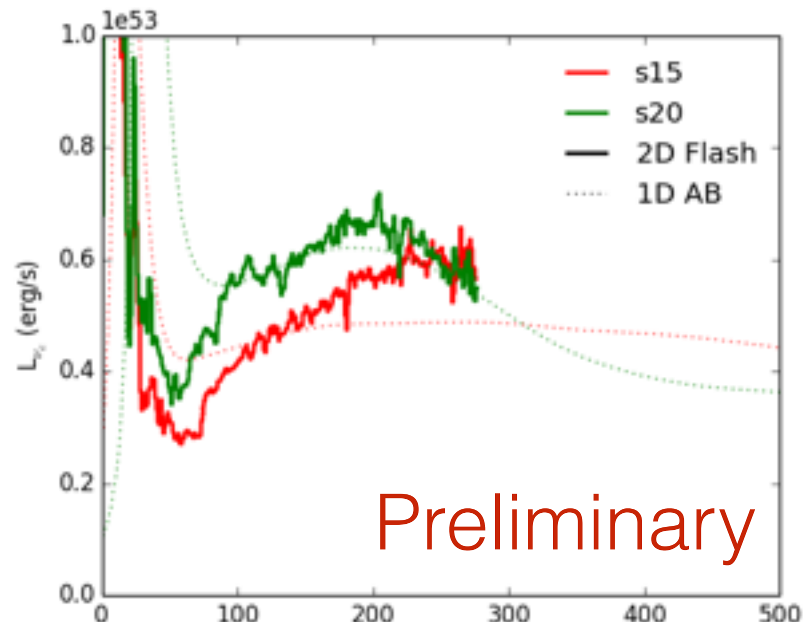
Dolence+15

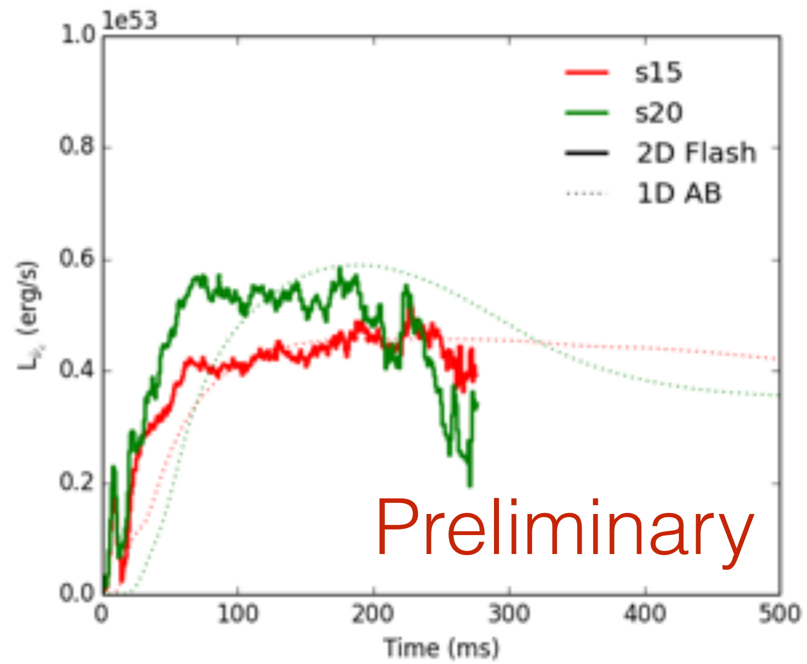




NR+ShenEoS

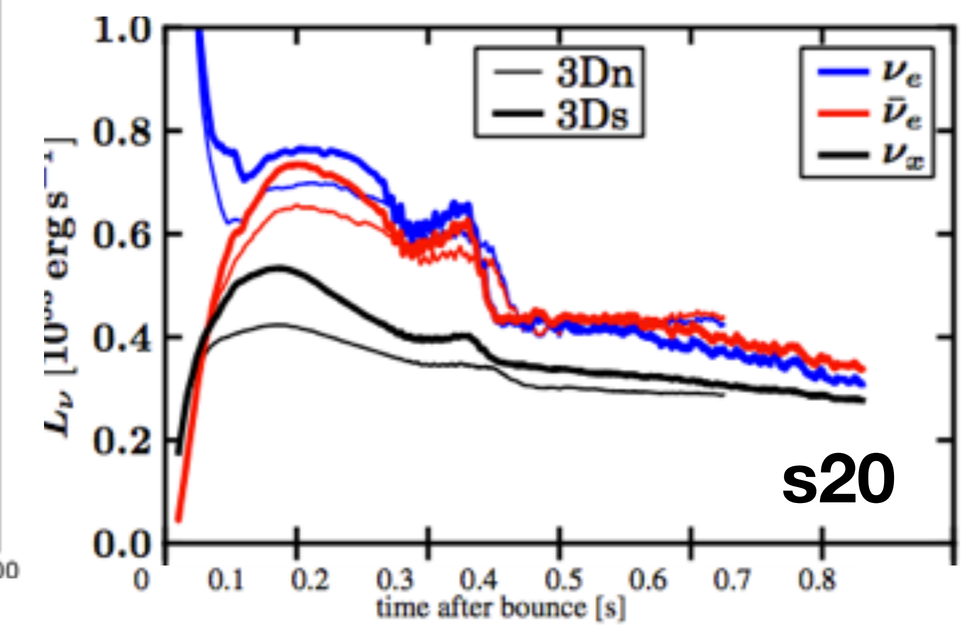
FLASH+IDSA

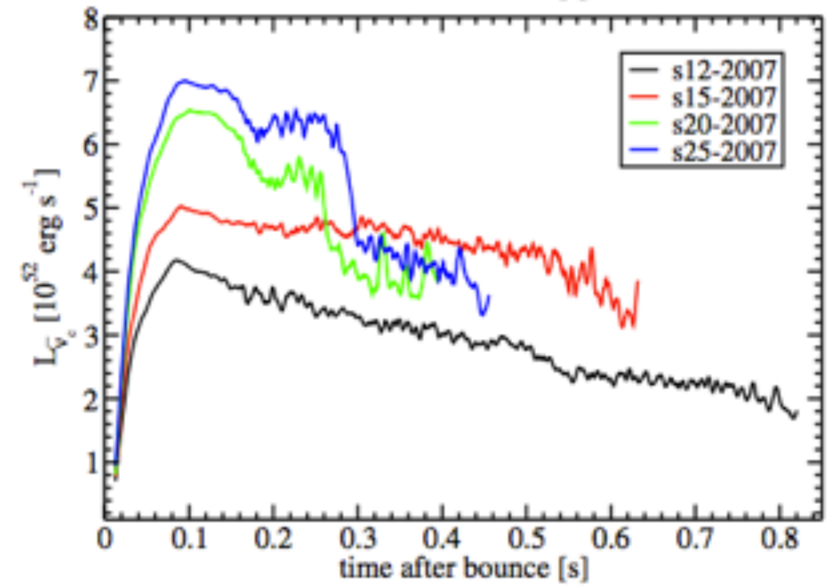




NR+LS220

Melson+15

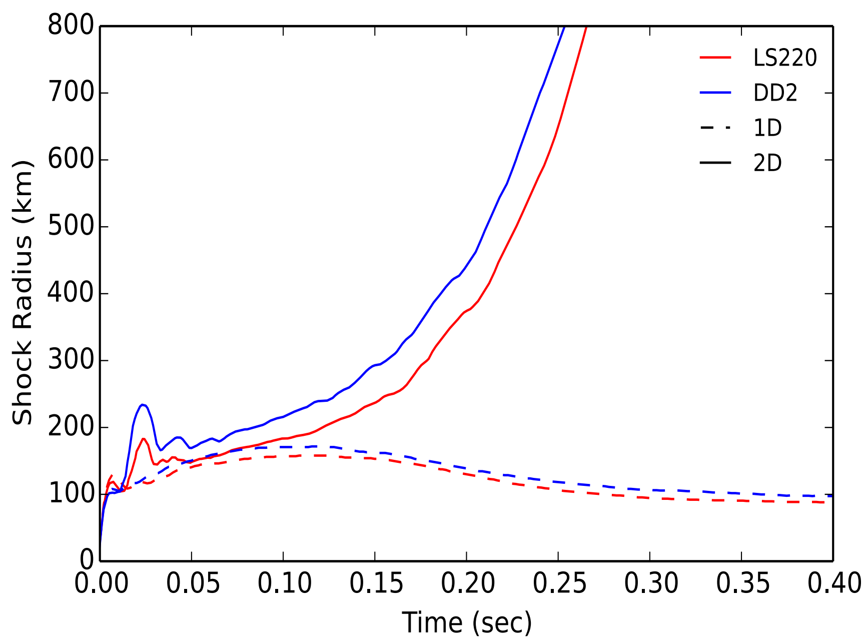




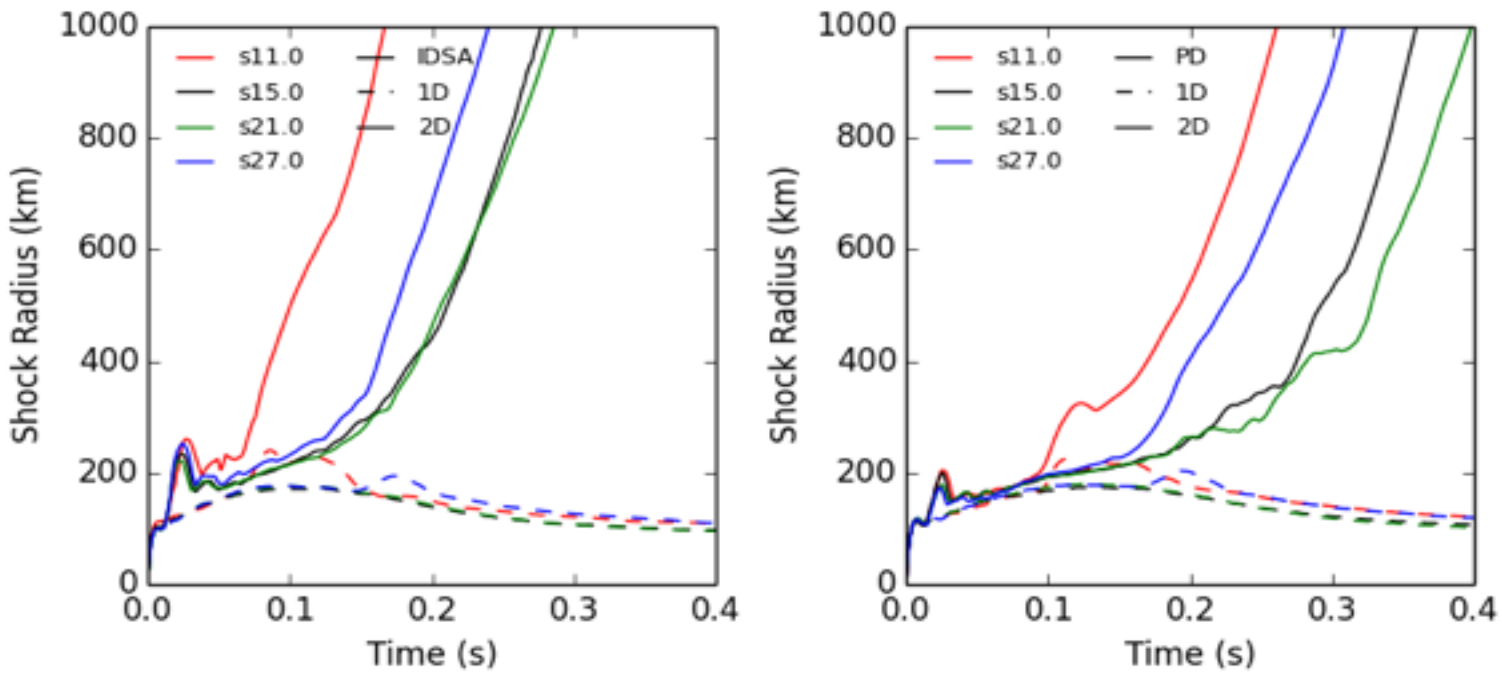
GR+LS220

2D: W2002 Progenitors

DD2 vs. LS220



FLASH+IDSA+DD2



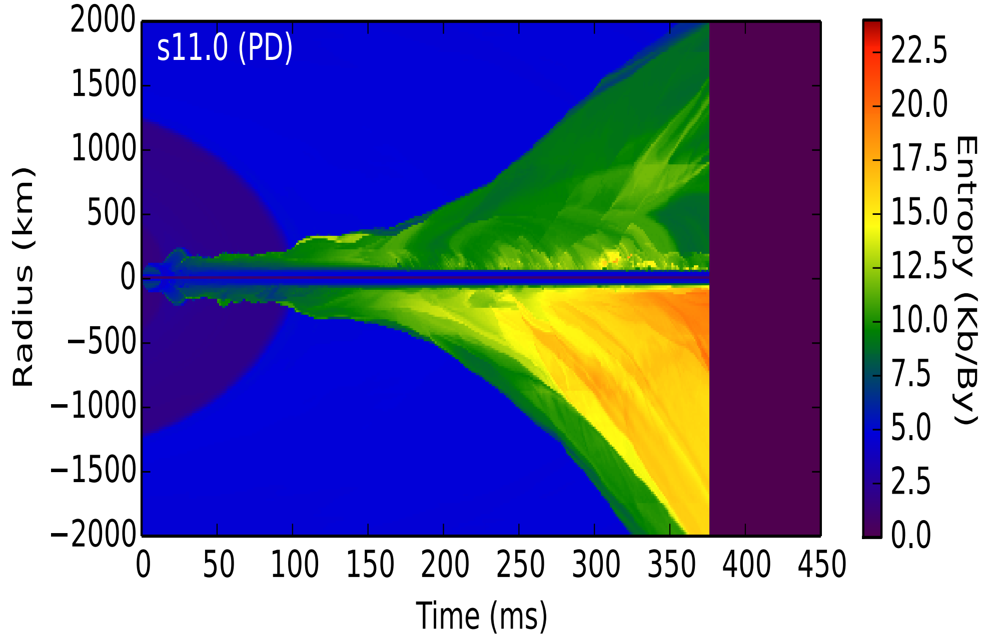
Pan+15

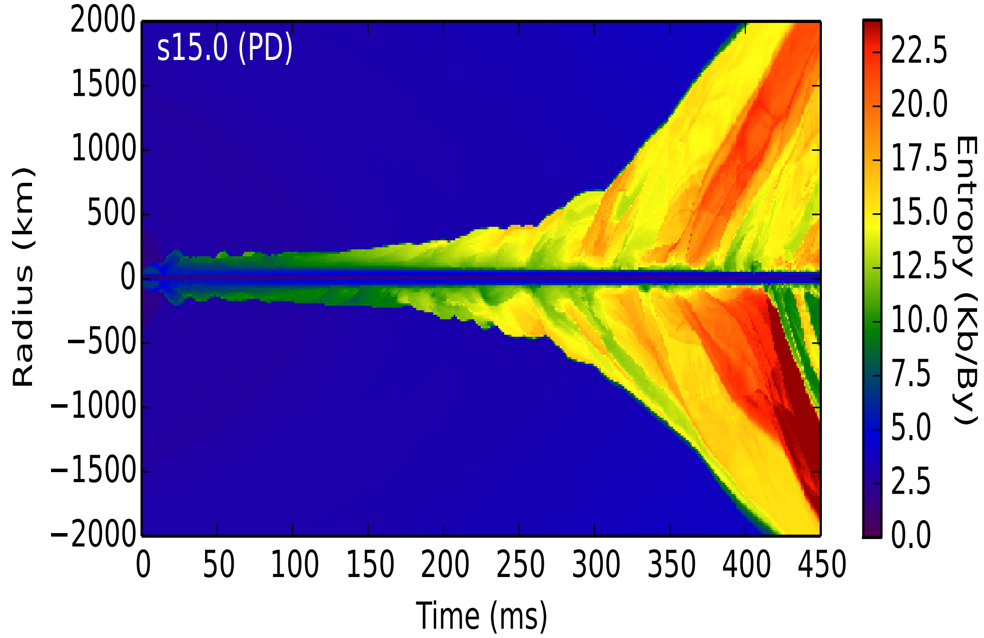
The HS(DD2) EoS

The new SN EoS HS (DD2) shows a better agreement with nuclear experiments (Kruger+13; Fischer+14; Hempel+15)

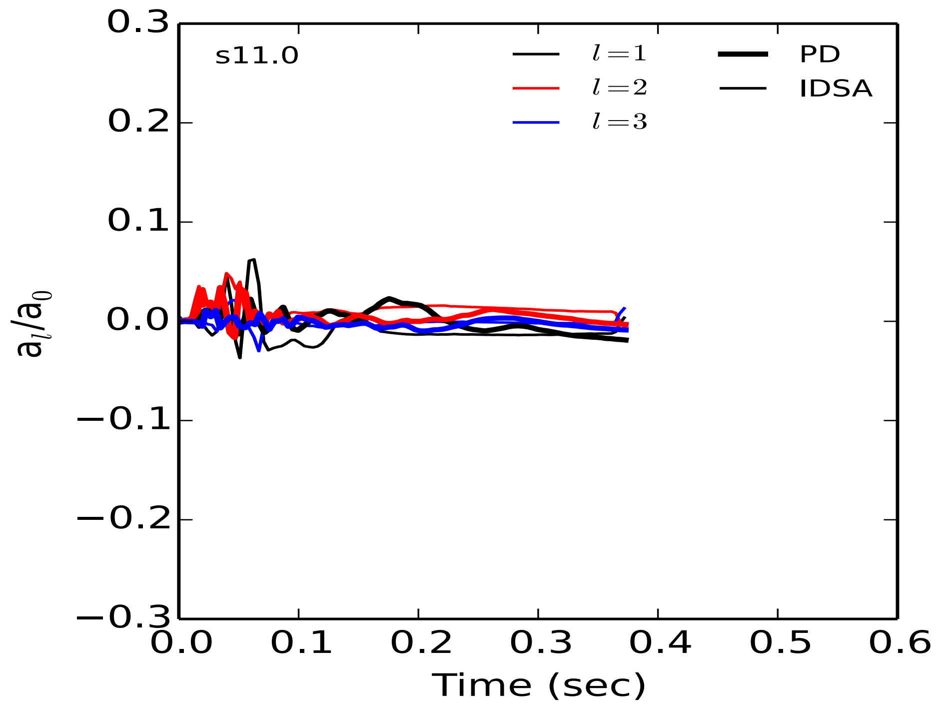
2D Results: SASI

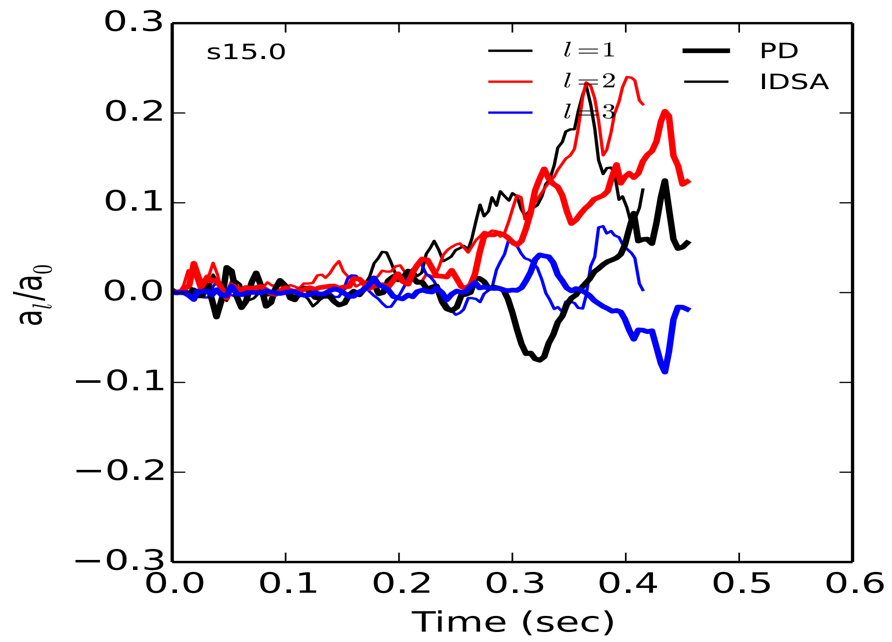
Pole Entropy





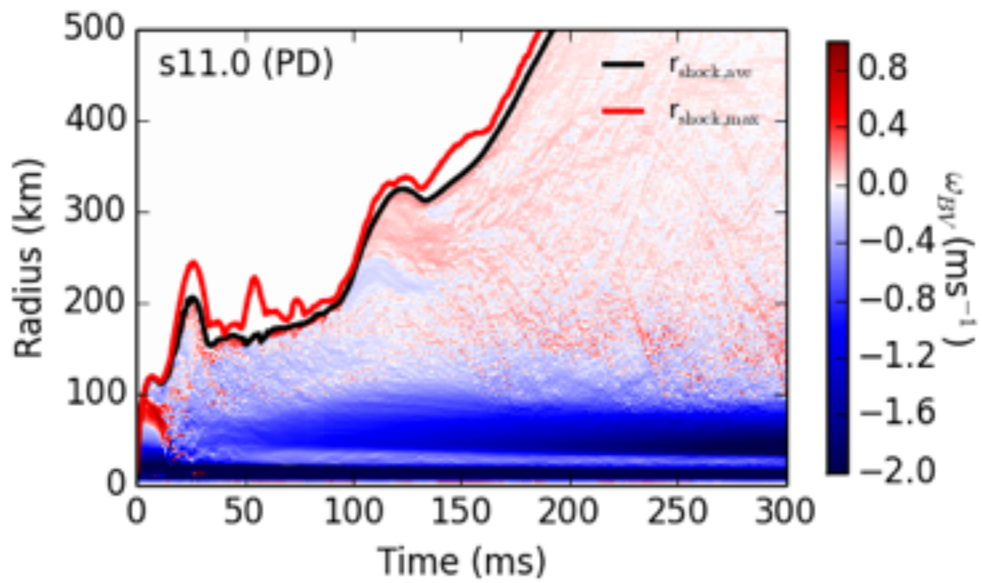
SASI Amplitude

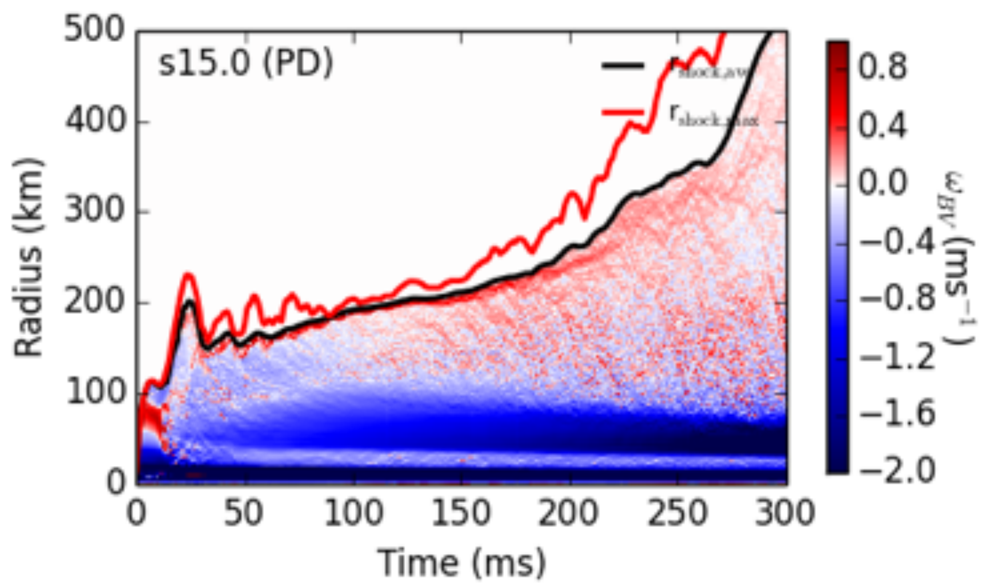




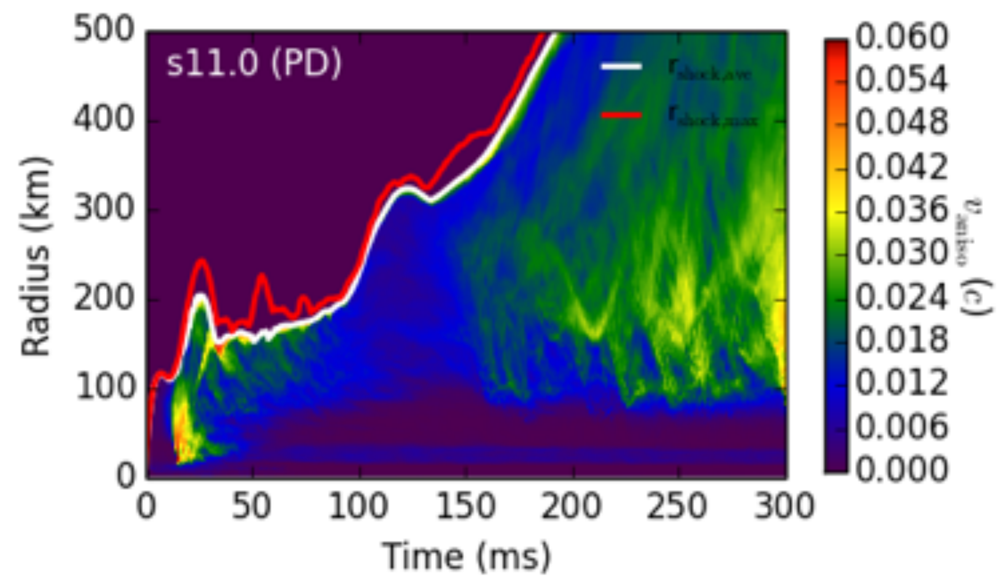
2D Results: Convection-Driven

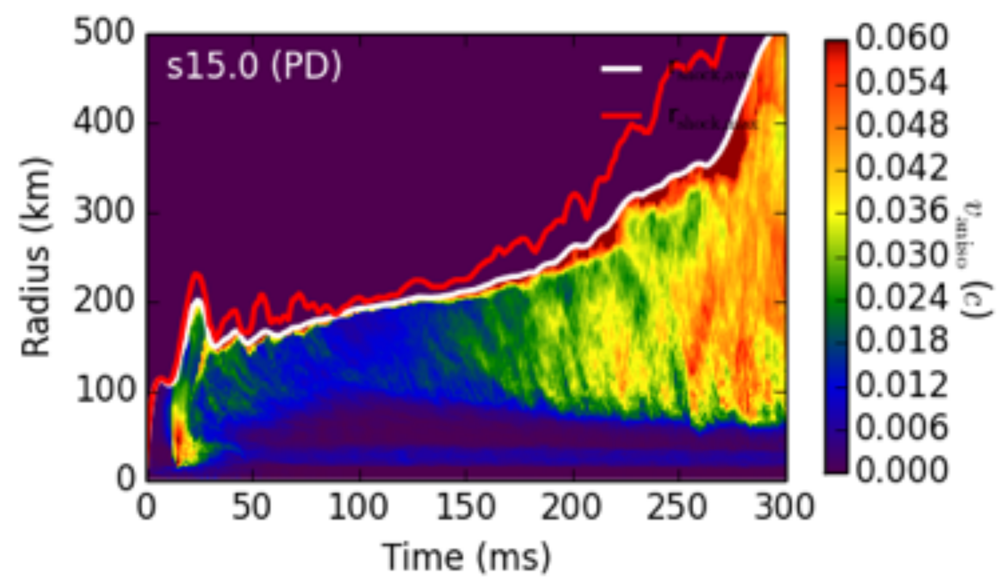
Brunt-Vaisala Frequenciy





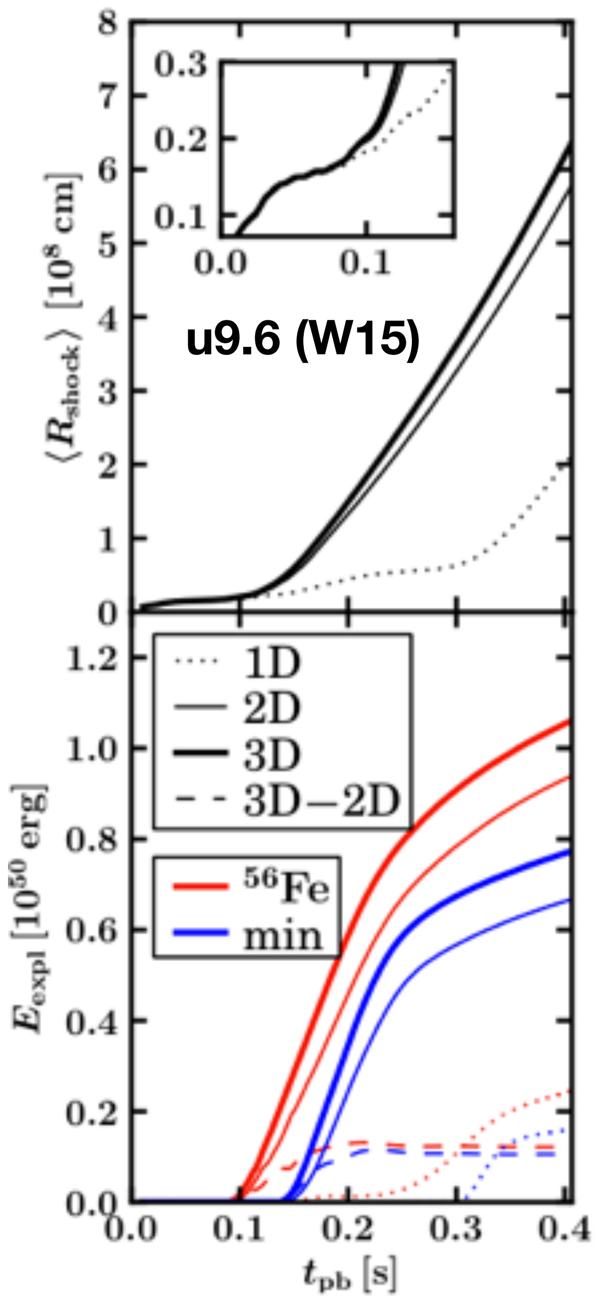
Anisotropic Velocity



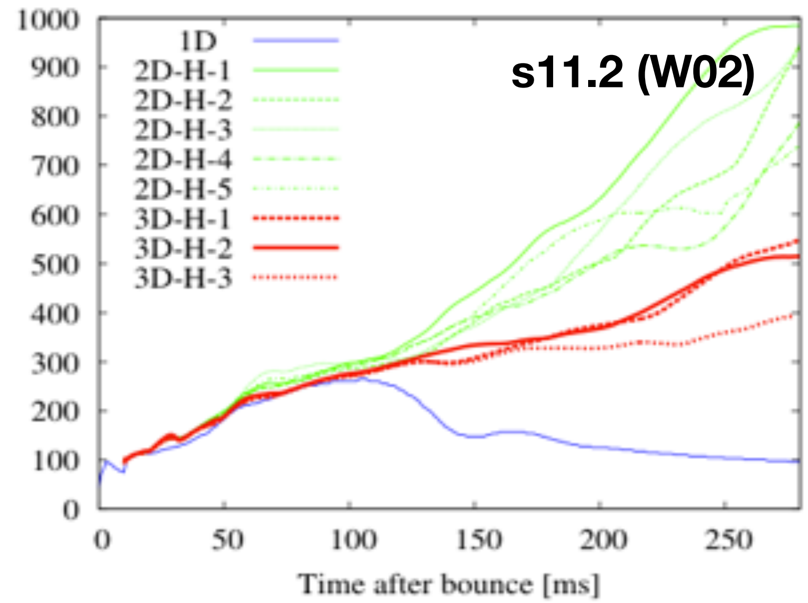


2D vs. 3D

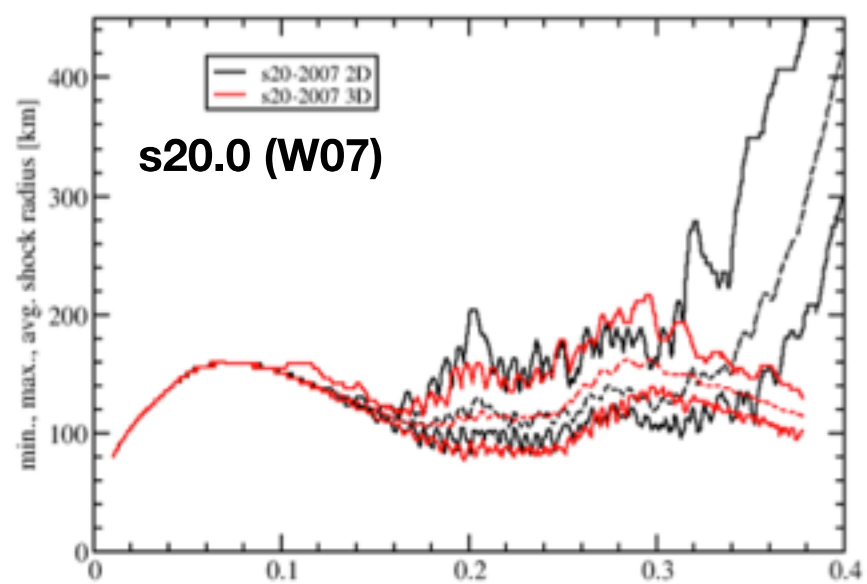
Melson+15



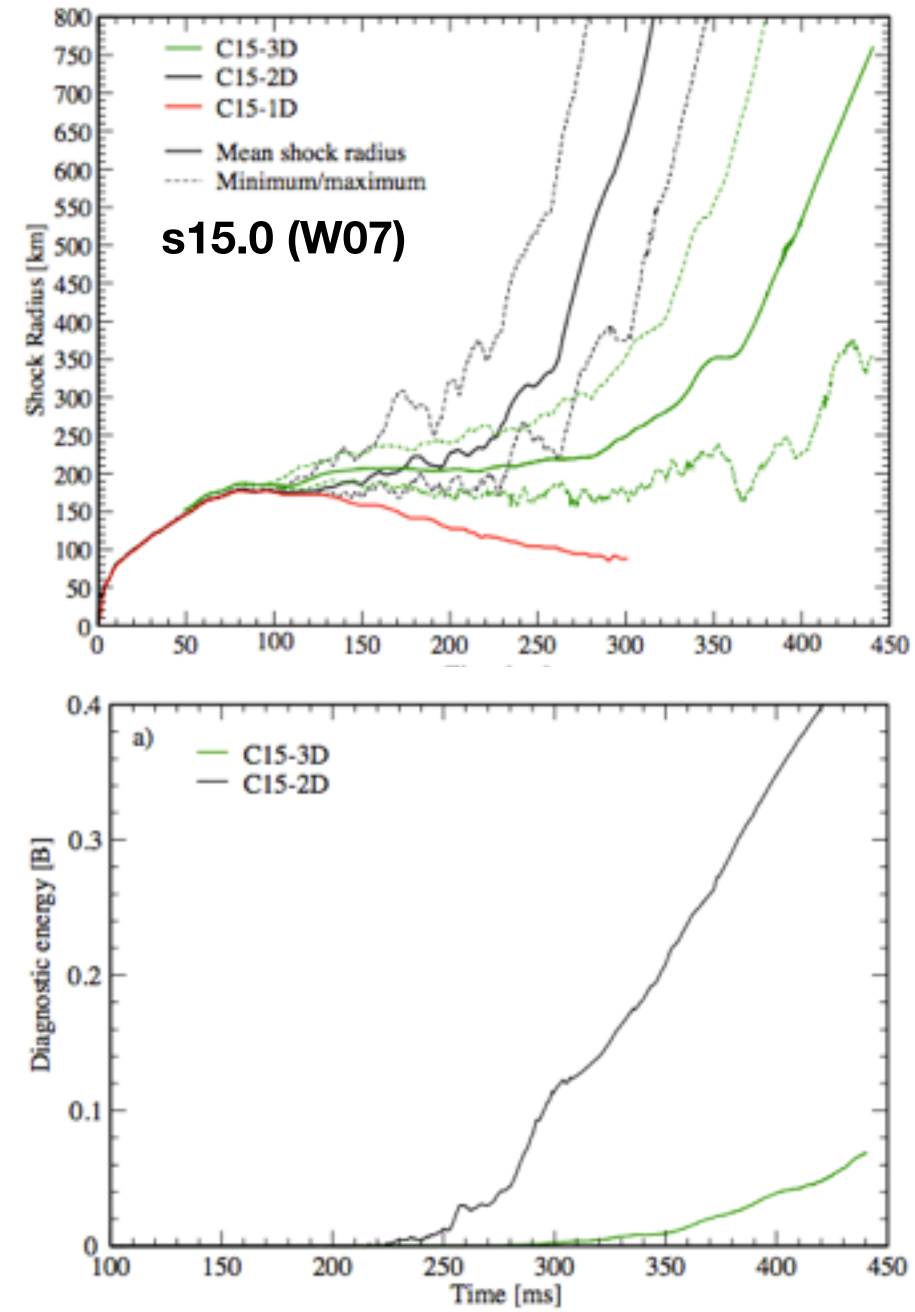
Takiwaki+14



Muller+13



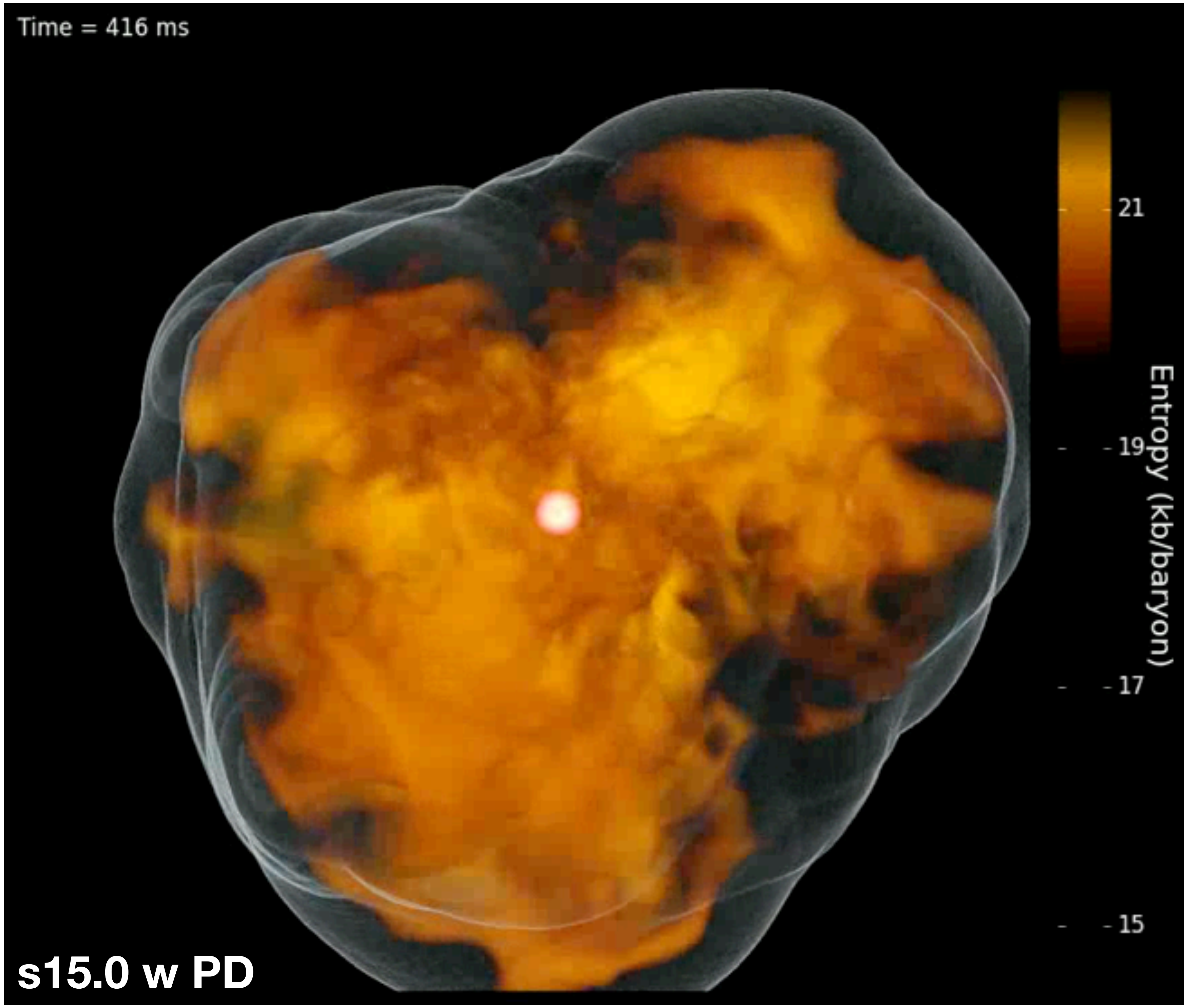
Lentz+15



3D FLASH-IDSA results

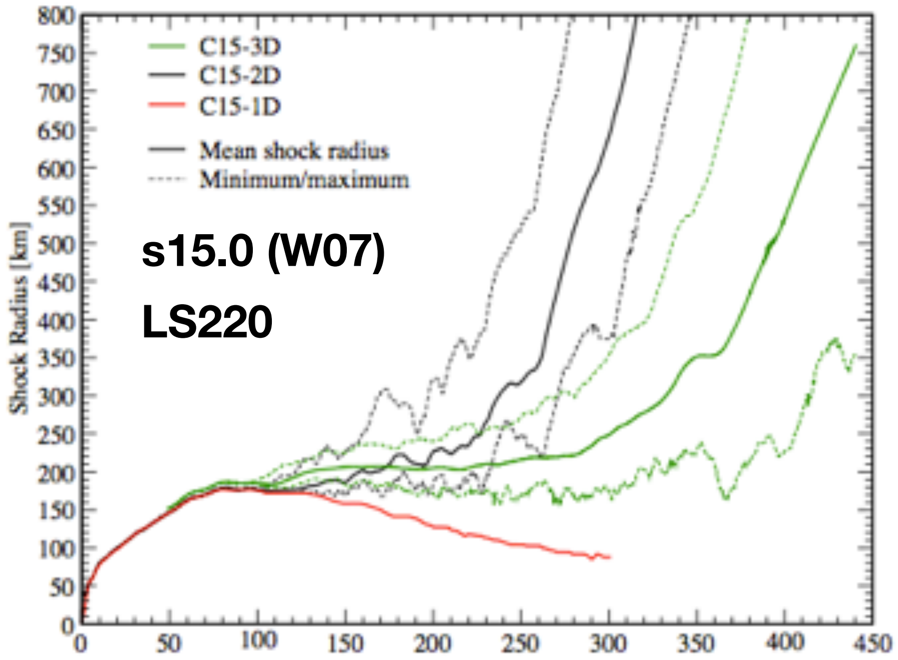
Pan+ in prep.

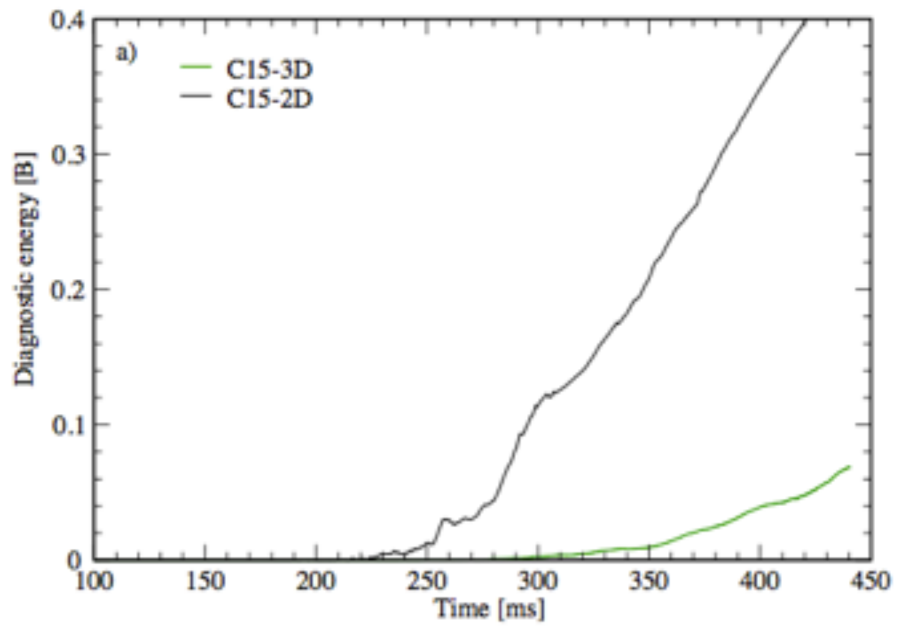
- 3D IDSA+PD
- 15M_{sun} (WHW+02)
- HS (DD2) EoS
- Newtonian
- Resolution: 1.8^0
- Only 0.5M cpu-hours



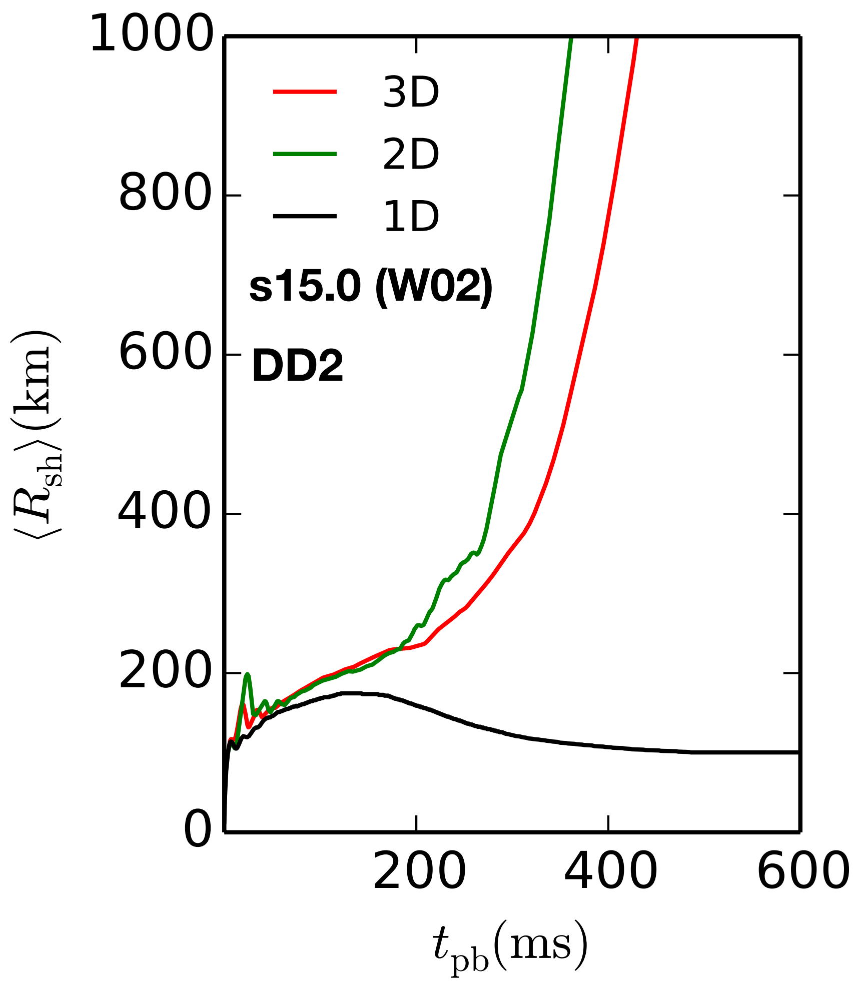
3D simulations with the 15.0 progenitor

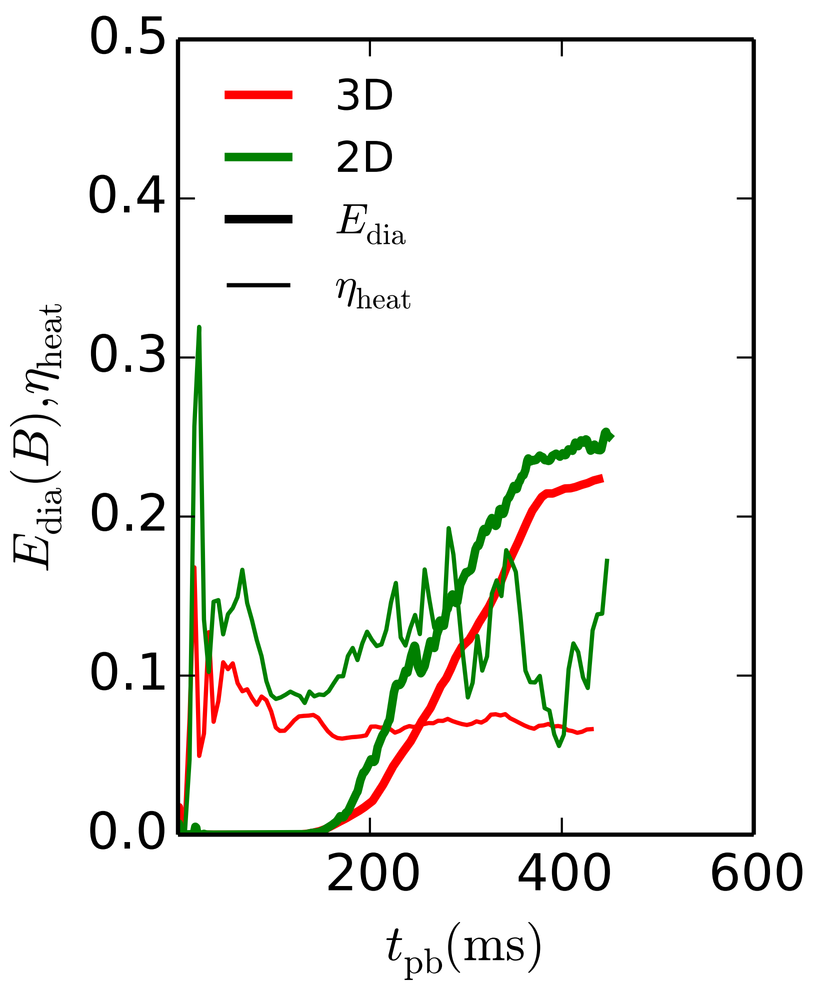
Lentz+15





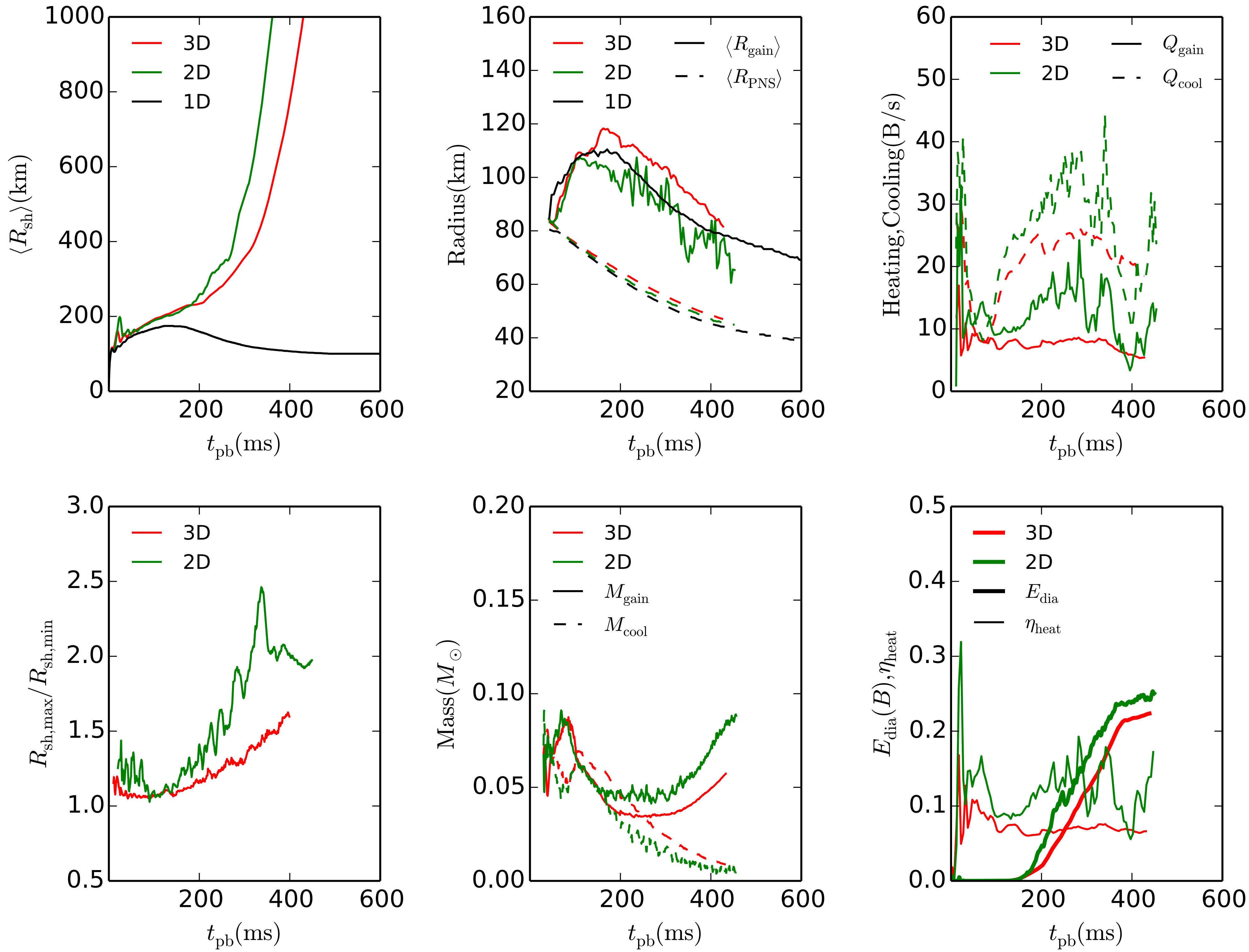
Pan+ in prep.





Note that the physics employed and the progenitors used are different

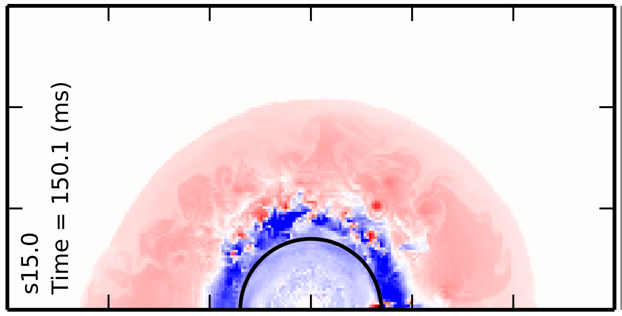
2D vs. 3D (conti.)



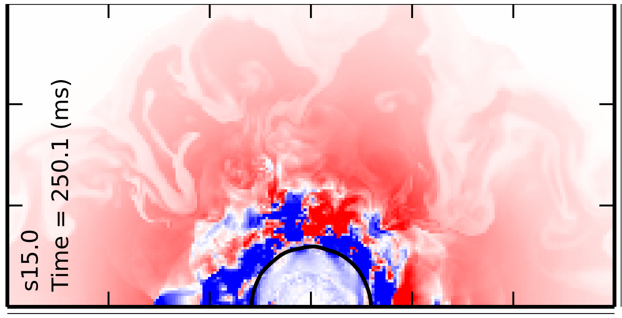
Neutrino Heating in 3D

2D

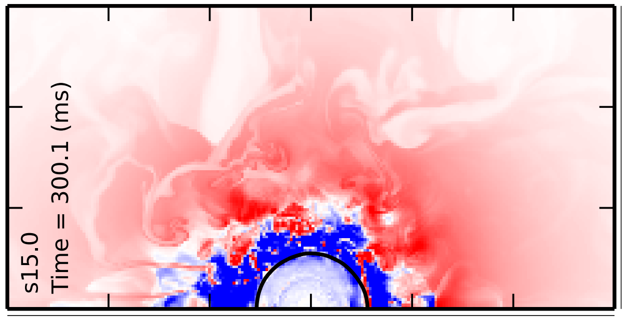
150 ms

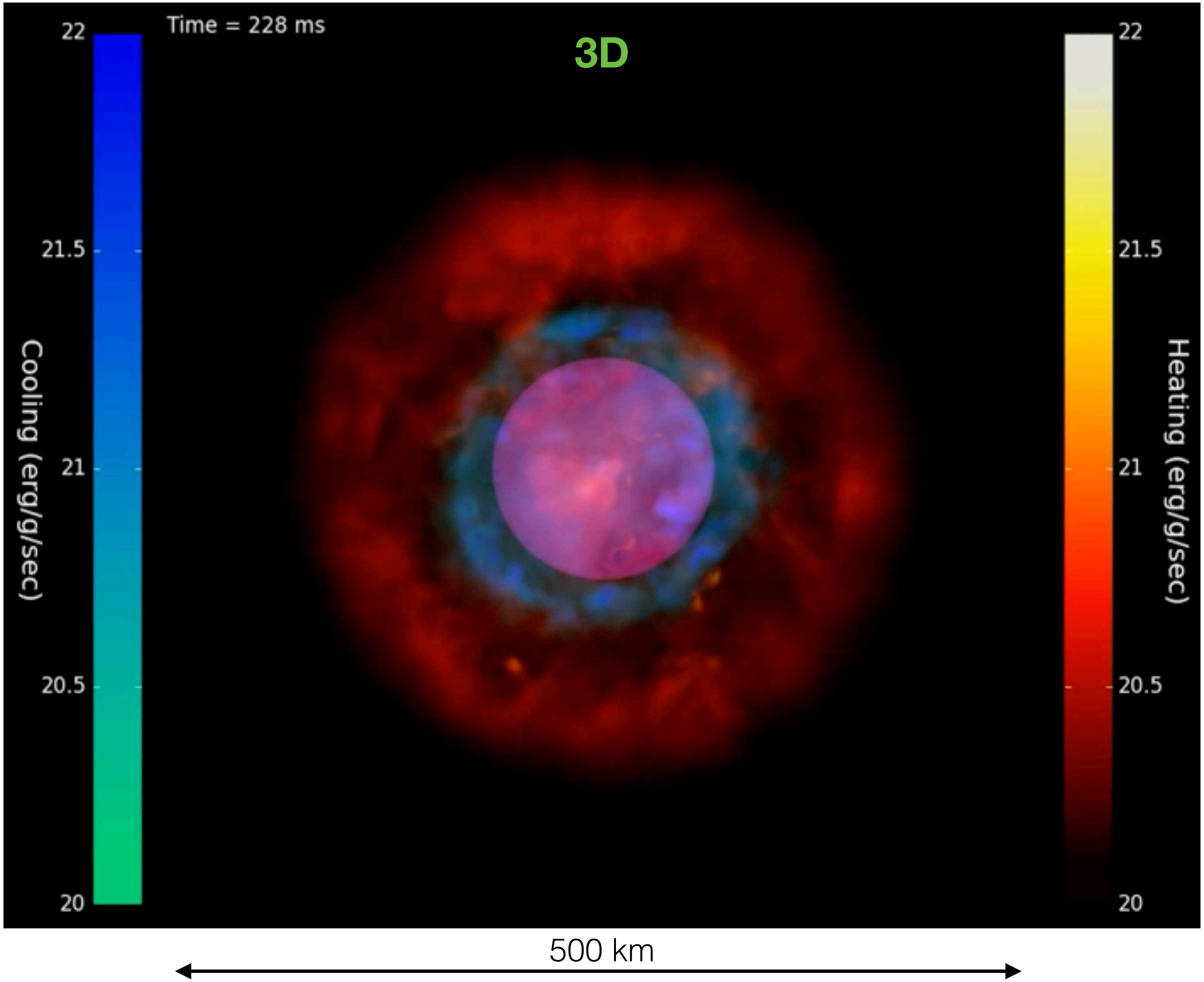


250 ms



300 ms





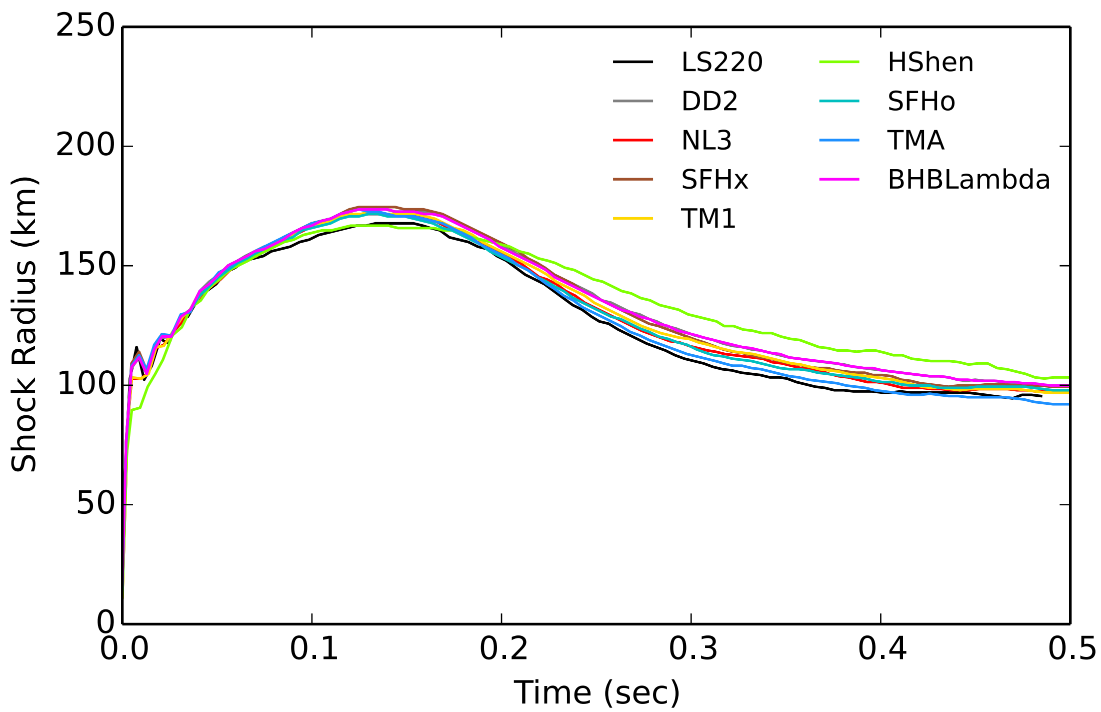
Conclusions

- Our IDSA implementation seems robust (or too optimistic; all 2D and 3D models exploded) with diagnostic explosion energies ~0.1-0.5 B (at ~400ms)
- Neutrino interactions (e.g. NES) during collapse are important in Multi-D
- Neutrino-driven convection with little SASI (W2002 Progenitors)
- DD2 is slightly easier to explode than LS220
- 3D seems harder to explode than 2D
- IDSA is promising to achieve high-resolution 3D simulations (good for progenitor studies, long-term evolutions and nuclear synthesis)

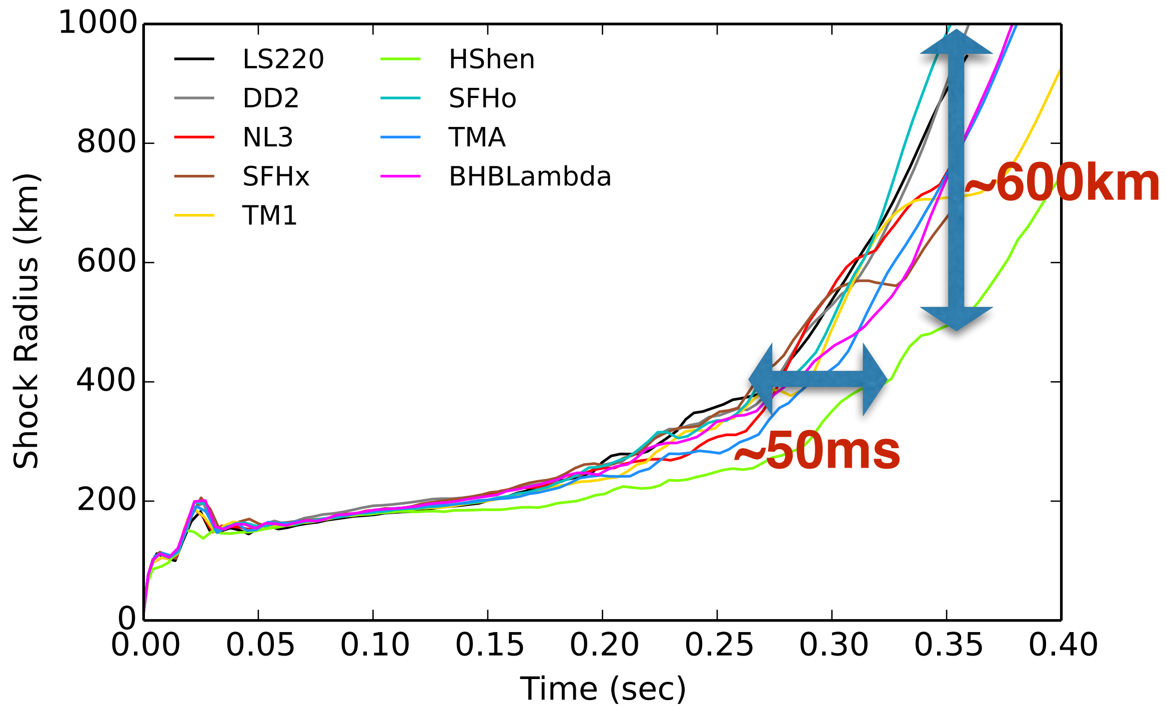
EoS Dependence

9 EoS from StellarCollapse with the s15.0 (W2002) progenitor

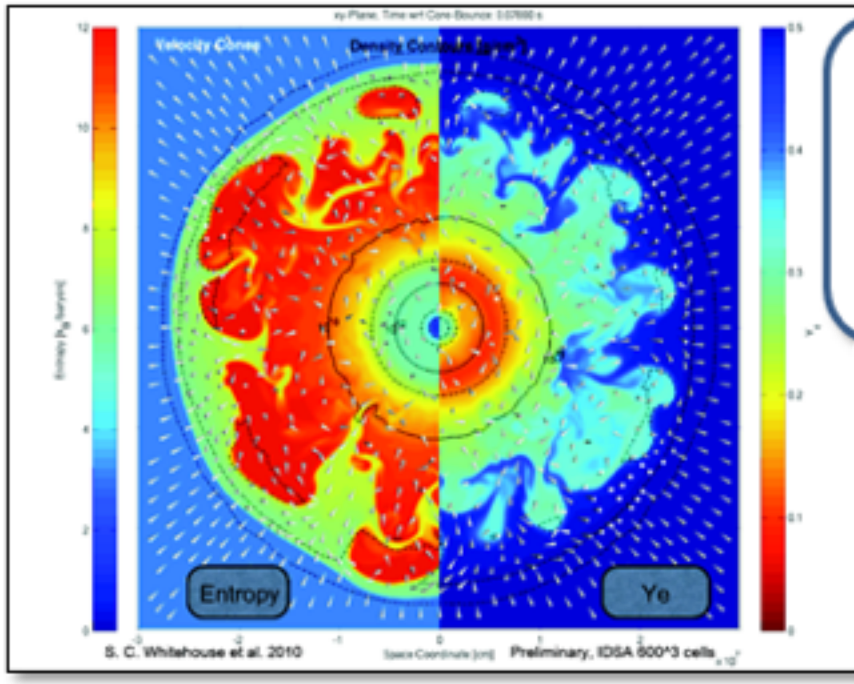
1D



2D

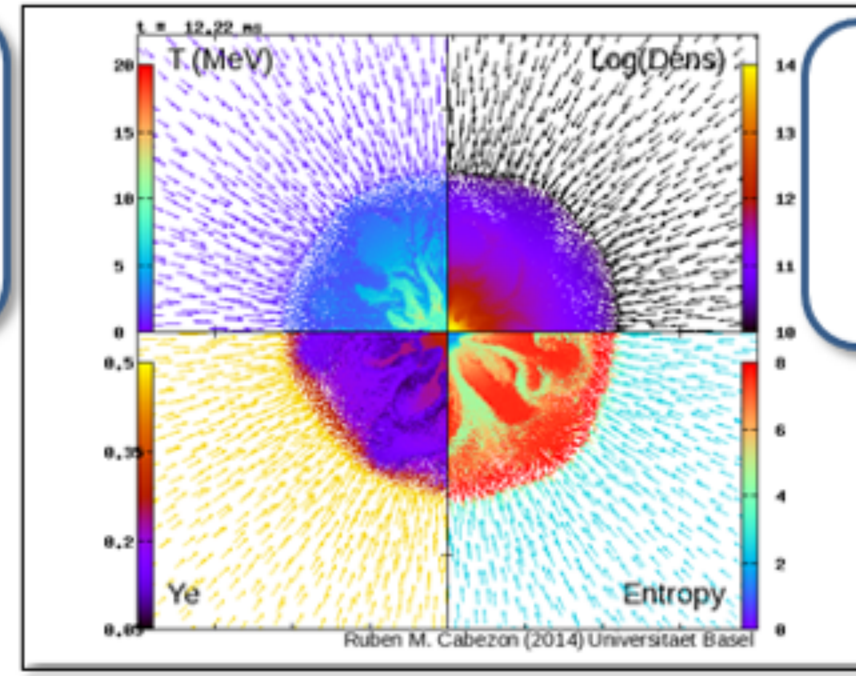


3D Code comparison



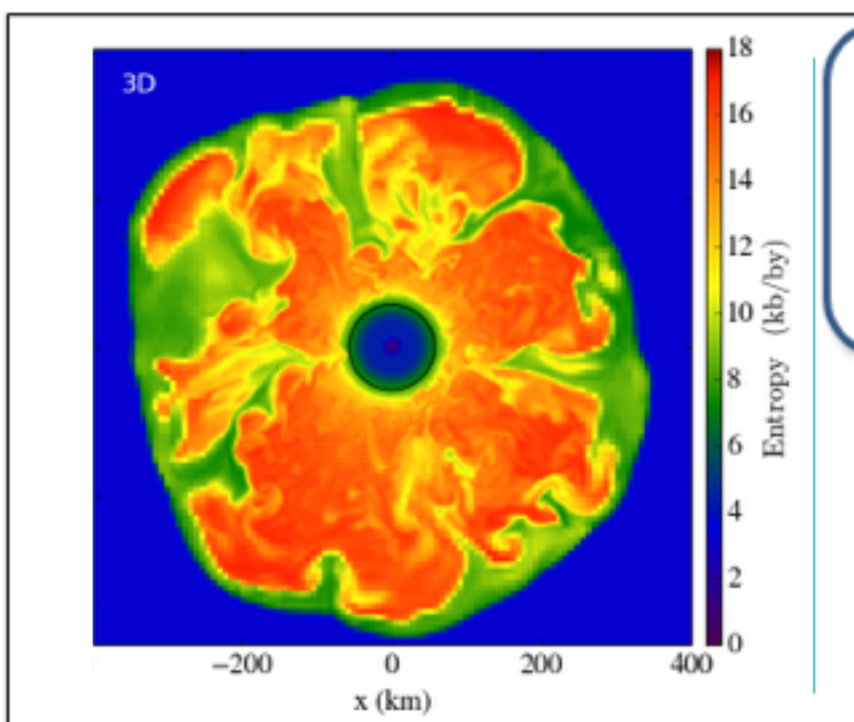
Elephant
3D IDSA
Cartesian mesh
NR/ eff. GR

M. Liebendörfer
S. C. Whitehouse
R. Käppeli



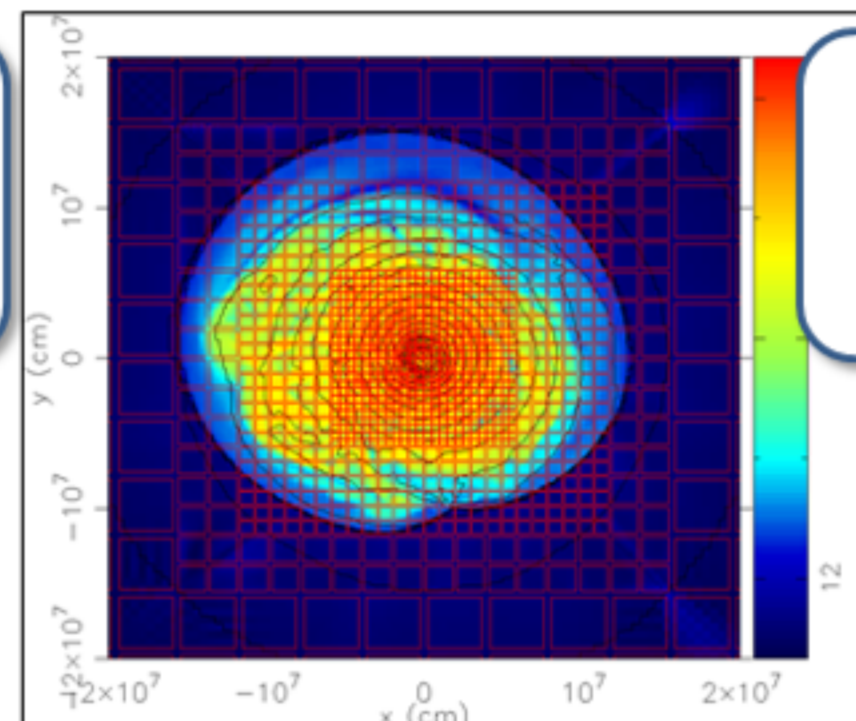
SPHYNX
ASL/IDSA
SPH
3D Newtonian

R. M. Cabezón



FLASH
1-3D IDSA
AMR
NR/eff. GR

K.-C. Pan



fGR_M1
M1
Nested meshes
3D full GR

T. Kuroda

2D vs. 3D

Time = 400 ms