Long-time Three-dimensional Core-Collapse Supernova Simulations

Annop Wongwathanarat

Ewald Müller

Hans-Thomas Janka

Victor Utrobin

Michael Gabler

The Progenitor-Supernova-Remnant Connection

Max-Planck-Institut für Astrophysik

Astrophysical Big Bang Laboratory

RIKEN

Introduction

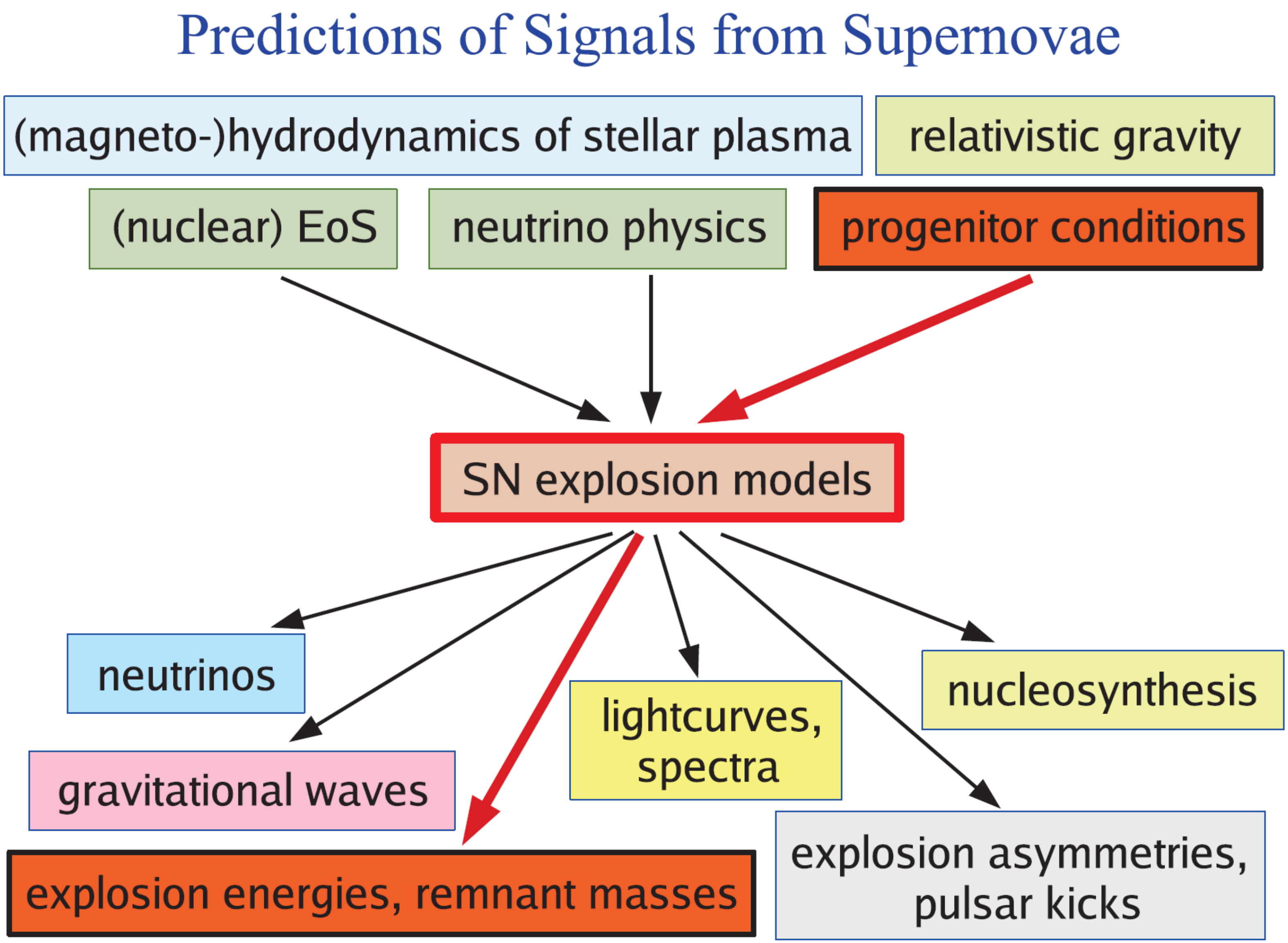


Figure from Janka et al. (2012)

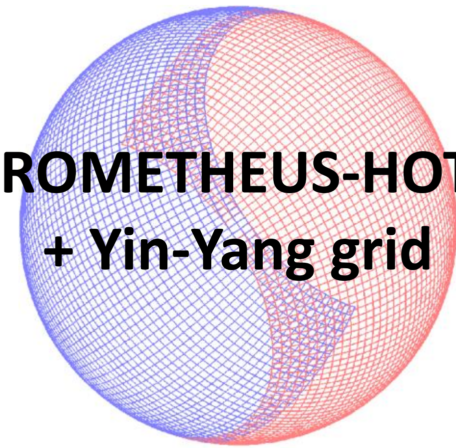
Simulation flow chart

Stellar evolution model

1D

PROMETHEUS-VERTEX

core-collapse and bounce



PROMETHEUS-HOTB + Yin-Yang grid

3D

Explosion >>> 1.3 s post bounce

>10 years after explosions ???

1.25 day after explosions

See Michael Gabler’s talk on Friday

1D

Light curves calculations

See Victor Utrobin’s talk later

Numerics

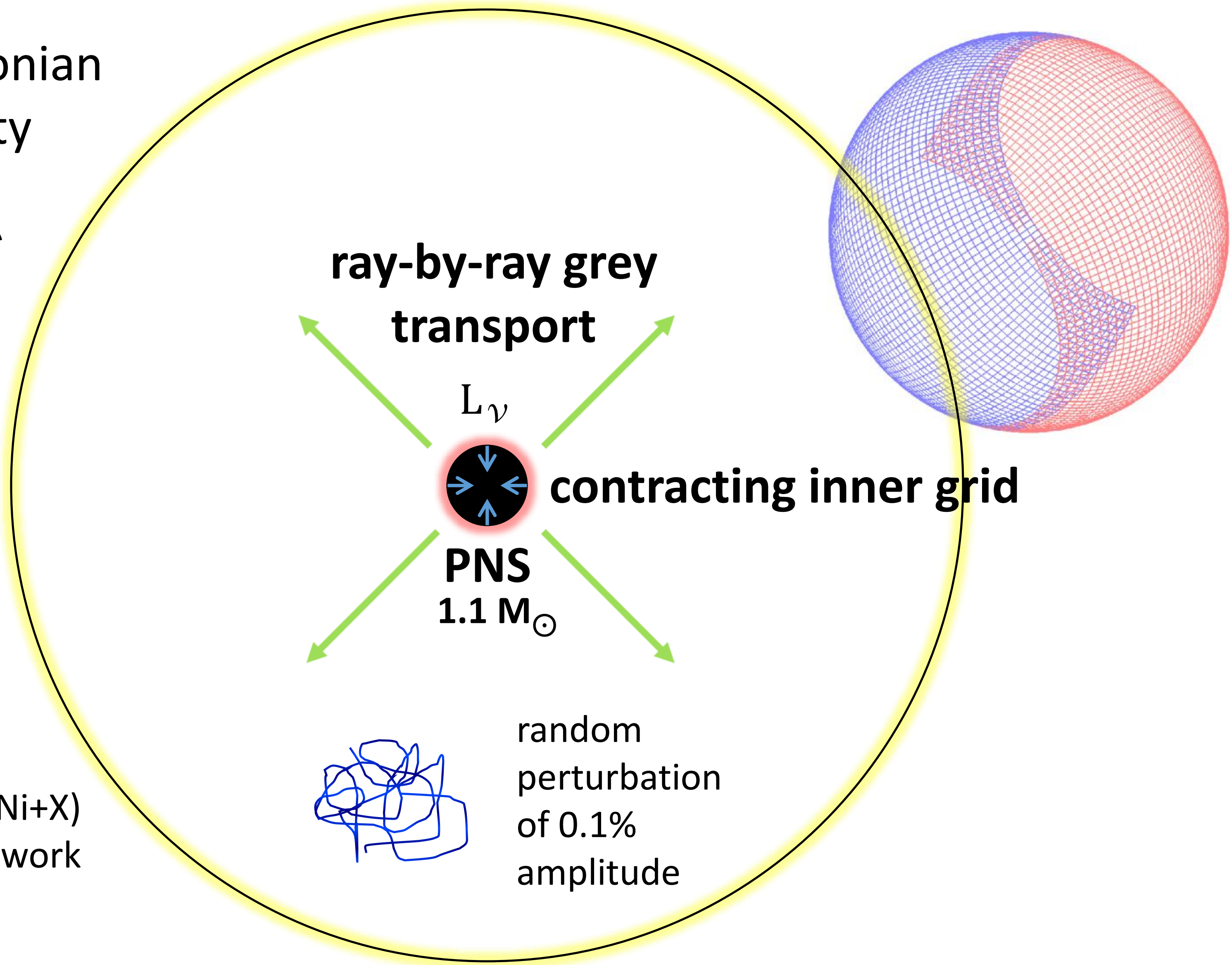
3D Newtonian self-gravity

monopole GR correction

tabulated EOS by Janka & Müller (1996)

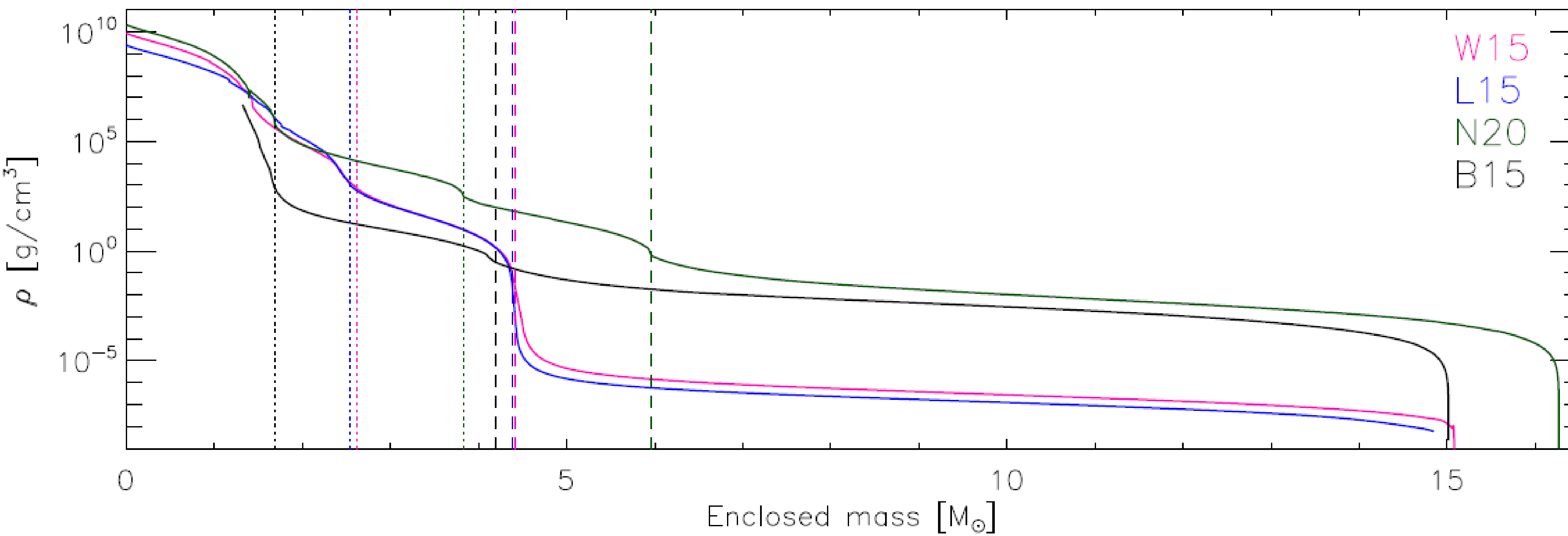
4 nuclear species in NSE (n, p, ^{4}He, ^{54}Mn)

14 species (^{4}He- ^{56}Ni+X) alpha-reactions network



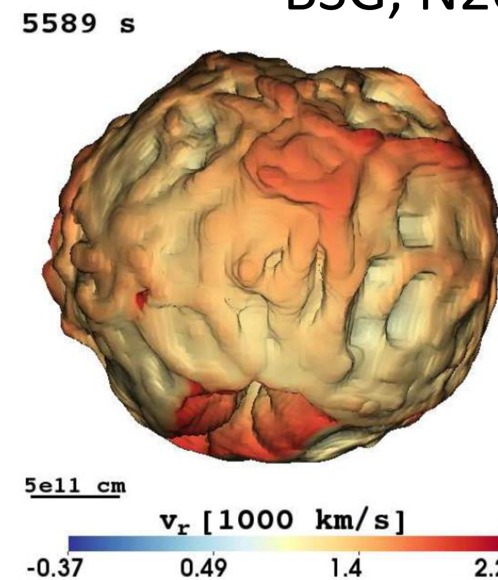
Explore several progenitors, varying expl. energies

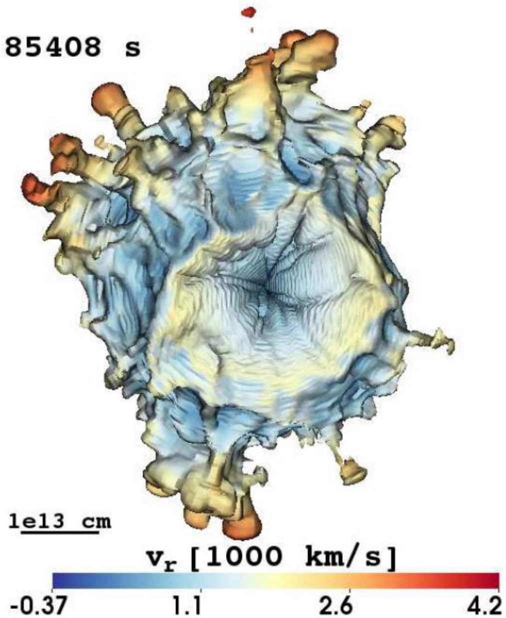
progenitor type	3D model	explosion model	time [s]	E_{exp} [B]	$\mathrm{avg}_{(\mathrm{min})}^{(\mathrm{max})}\ R_s$ [10^6 km]	M_{Ni} (M_{Ni+X}) [$M_\odot$]	v_{max}(Ni) [10^3 km s^{-1}]	$< v >_{1\%}$ (Ni) [10^3 km s^{-1}]
RSG	W15-1-cw	W15-1	84974	1.48	$389_{(355)}^{(443)}$	0.05 (0.13)	5.29	3.72
	W15-2-cw	W15-2	85408	1.47	$393_{(349)}^{(458)}$	0.05 (0.14)	4.20	3.47
	L15-1-cw	L15-1	95659	1.75	$478_{(448)}^{(530)}$	0.03 (0.15)	4.78	3.90
	L15-2-cw	L15-2	76915	2.75	$475_{(458)}^{(500)}$	0.04 (0.21)	5.01	4.51
BSG	N20-4-cw	N20-4	5589	1.65	$39.7_{(35.6)}^{(43.6)}$	0.04 (0.12)	2.23	1.95
	B15-1-cw	B15-1	5372	2.56	$41.5_{(39.5)}^{(43.6)}$	0.05 (0.11)	6.25	5.01
	B15-1-pw	B15-1	7258	1.39	$42.7_{(40.0)}^{(45.7)}$	0.03 (0.09)	3.34	3.17
	B15-3-pw	B15-3	8202	1.14	$48.1_{(44.7)}^{(51.1)}$	0.03 (0.08)	3.18	2.95



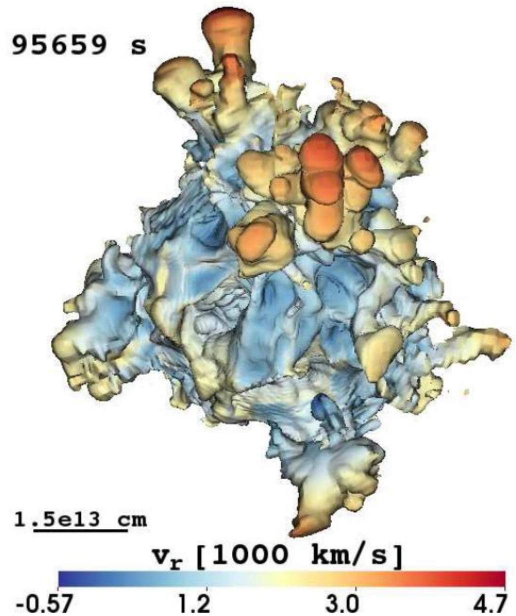
Results

Shigeyama&Nomoto (1990)
BSG, N20



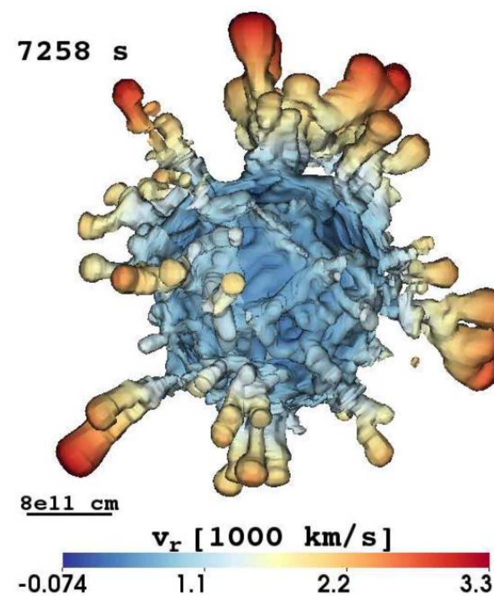


Woosley&Weaver (1995)
RSG, W15



Limongi+ (2000)
RSG, L15

Nickel-rich ejecta at shock breakout

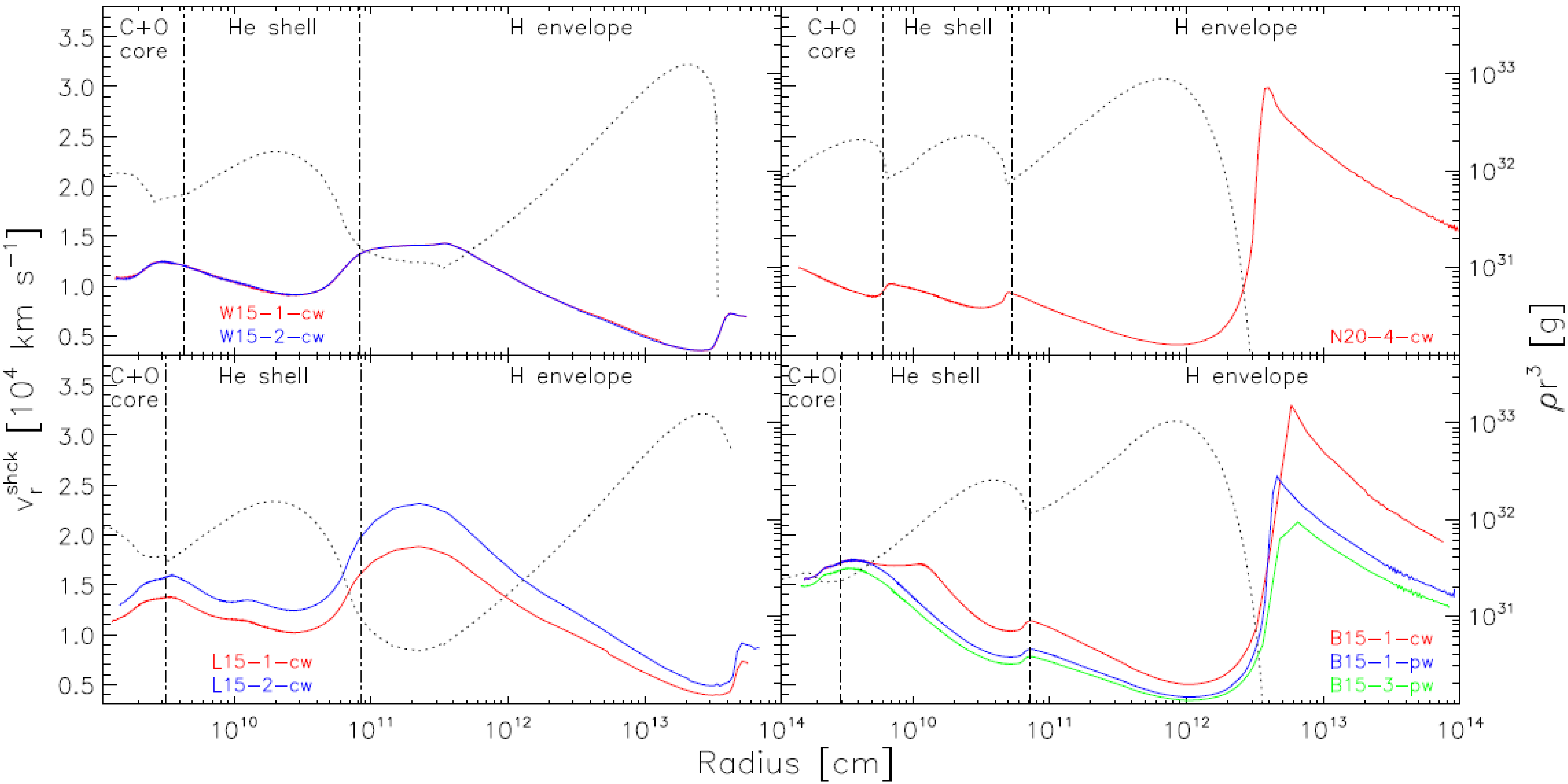


Woosley+ (1988) BSG, B15

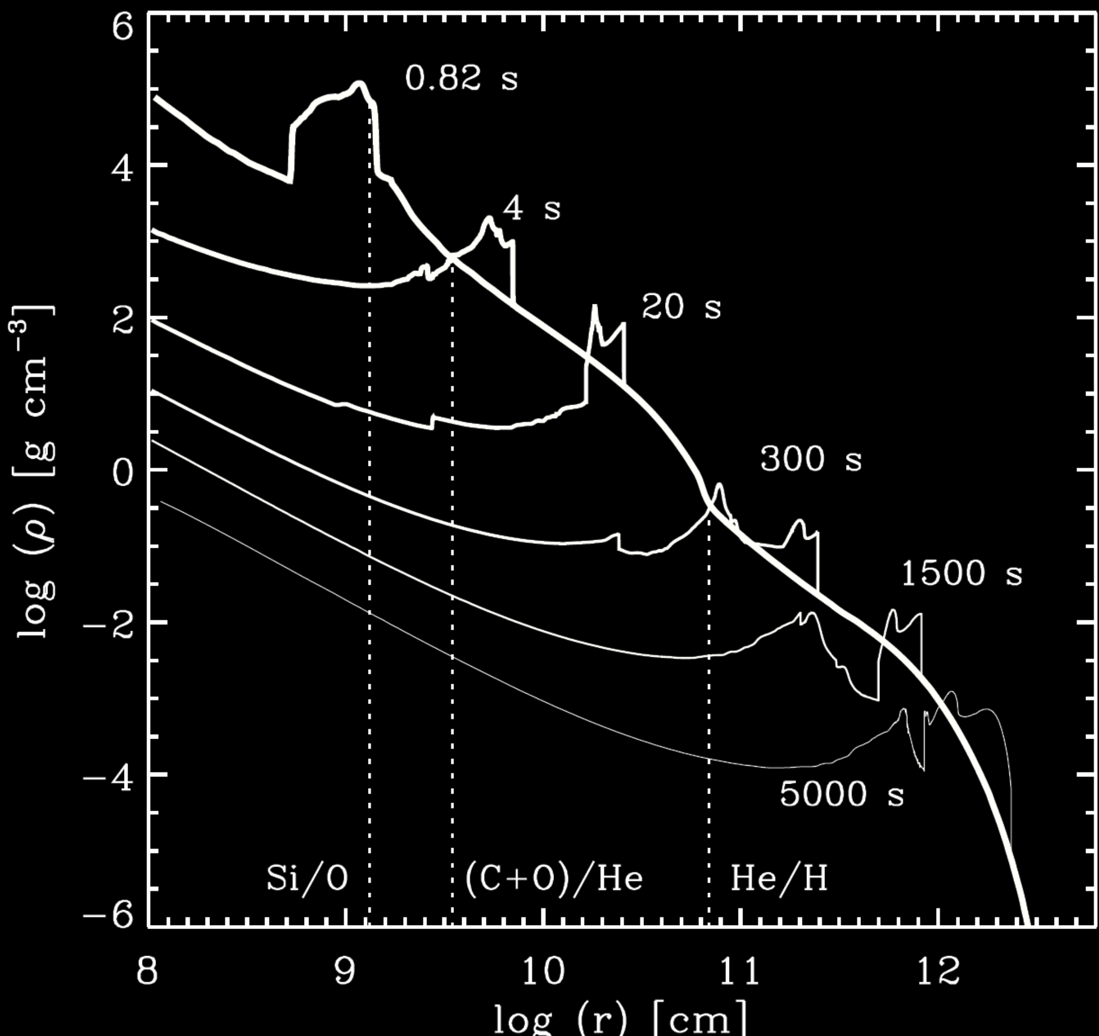
Shock dynamics

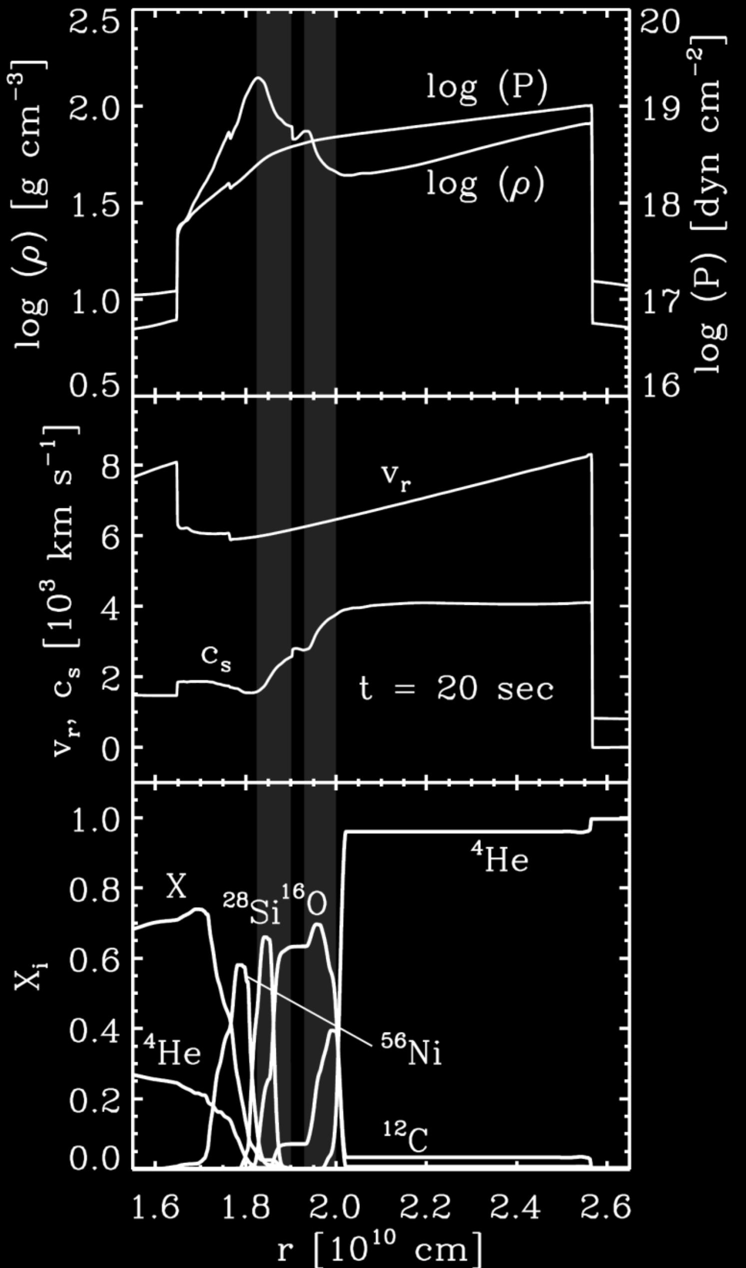
shock propagates according to blast wave solution (Sedov, 1959)

accelerates when ρr³ decreases, and vice versa



Rayleigh-Taylor instabilities induce mixing





Kifonidis+ 2003

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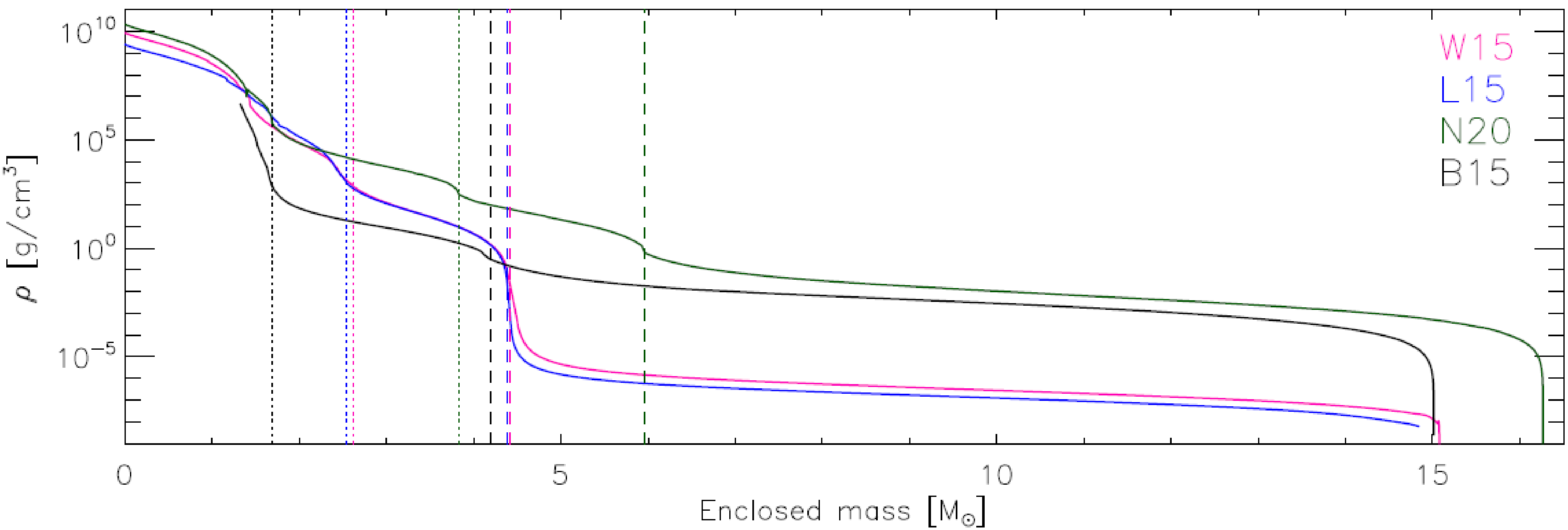

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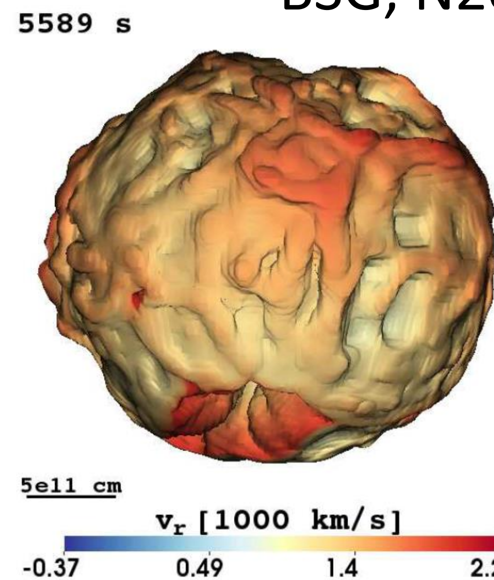

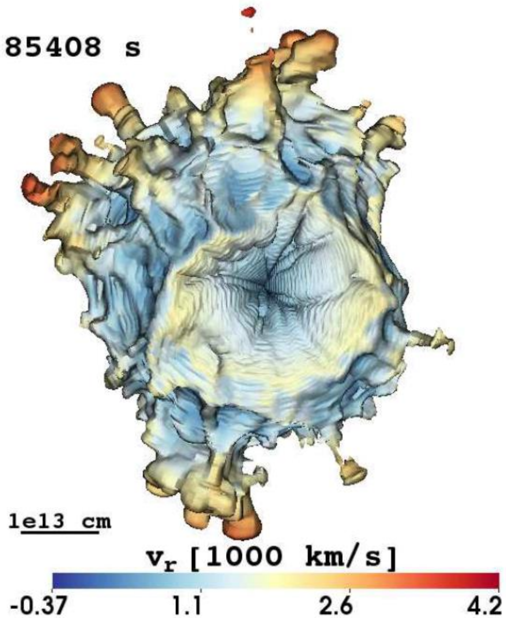

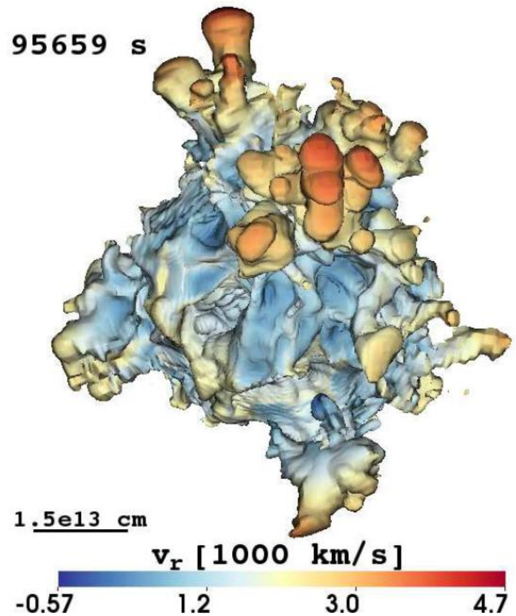

Woosley&Weaver (1995)
RSG, W15

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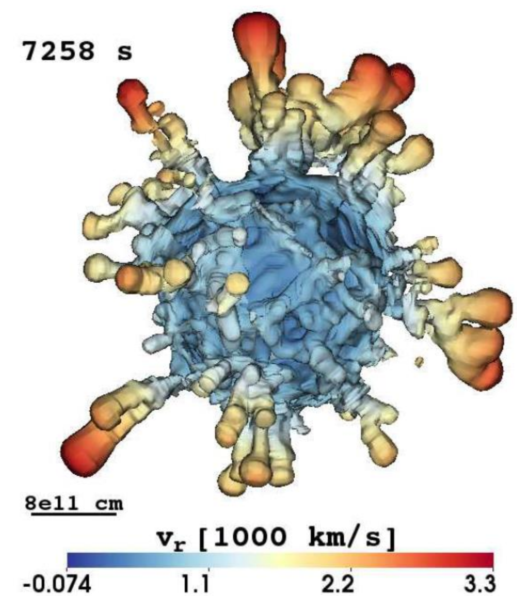
RSG, L15



Nickel-rich ejecta at shock breakout

Woosley+ (1988) BSG, B15

SN1987A

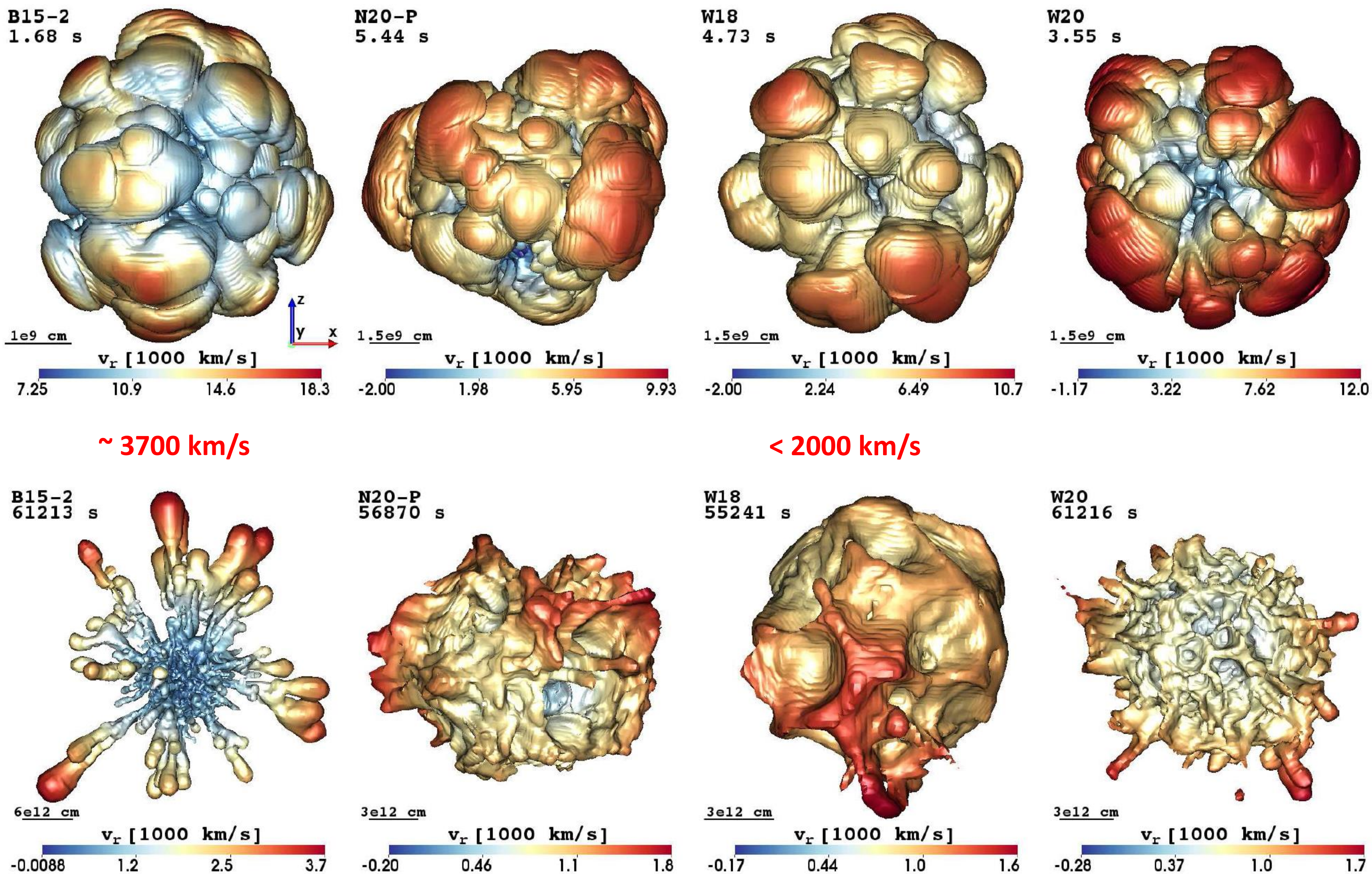
3 more progenitors coming soon

Woosley et al. (1988)

Woosley (2007)

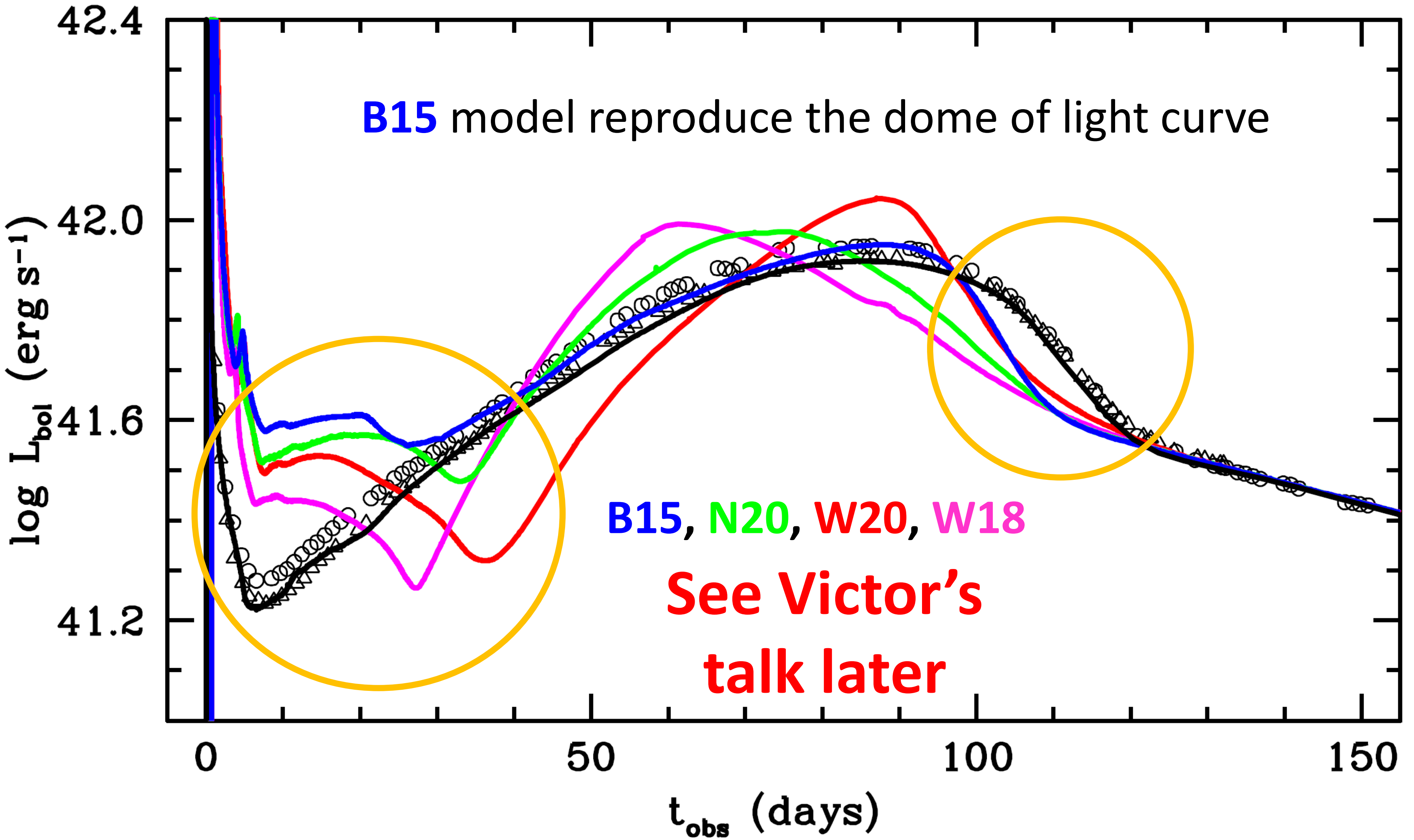
Shigeyama & Nomoto (1990)

Woosley et al. (1997)



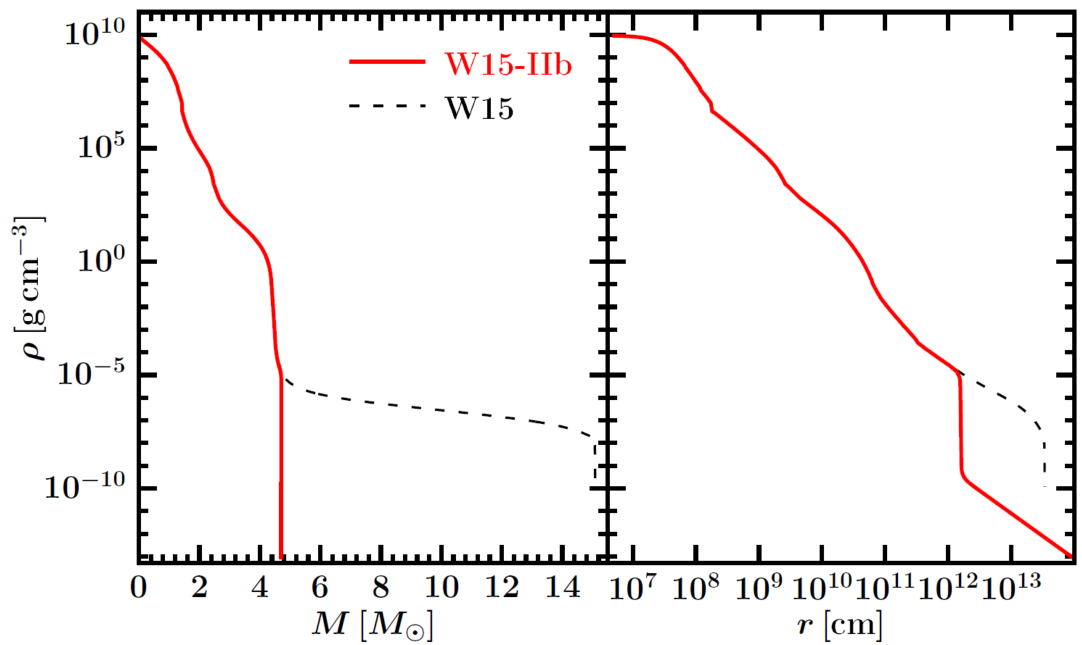
Light Curves of SN1987A

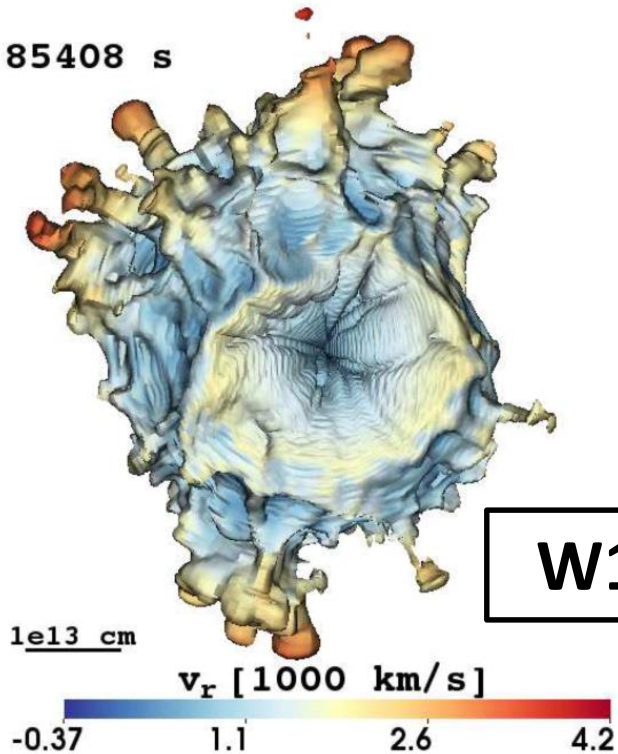
Utrobin et al. (2015)



Type IIb model

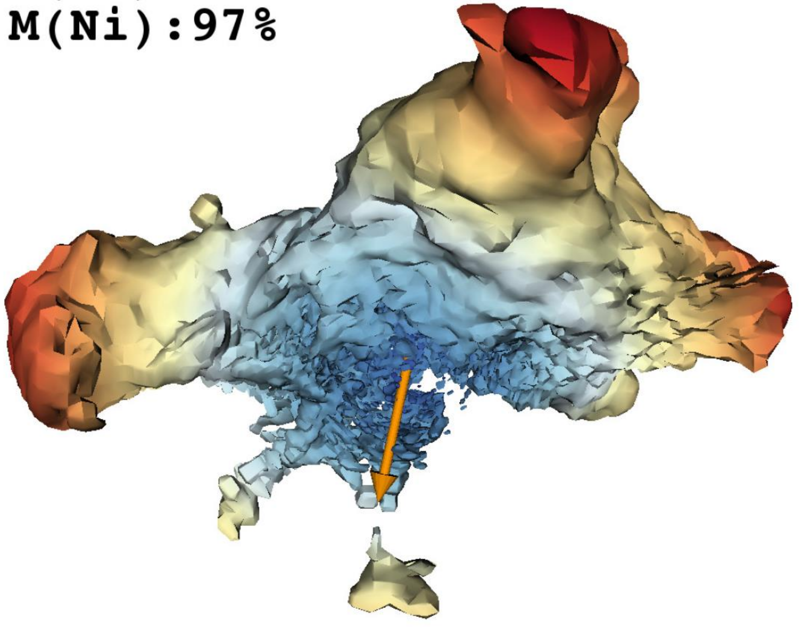
Without thick H-envelope we retain larger scale asymmetries from the explosion





W15-2

X(Ni)=0.13
M(Ni):97%



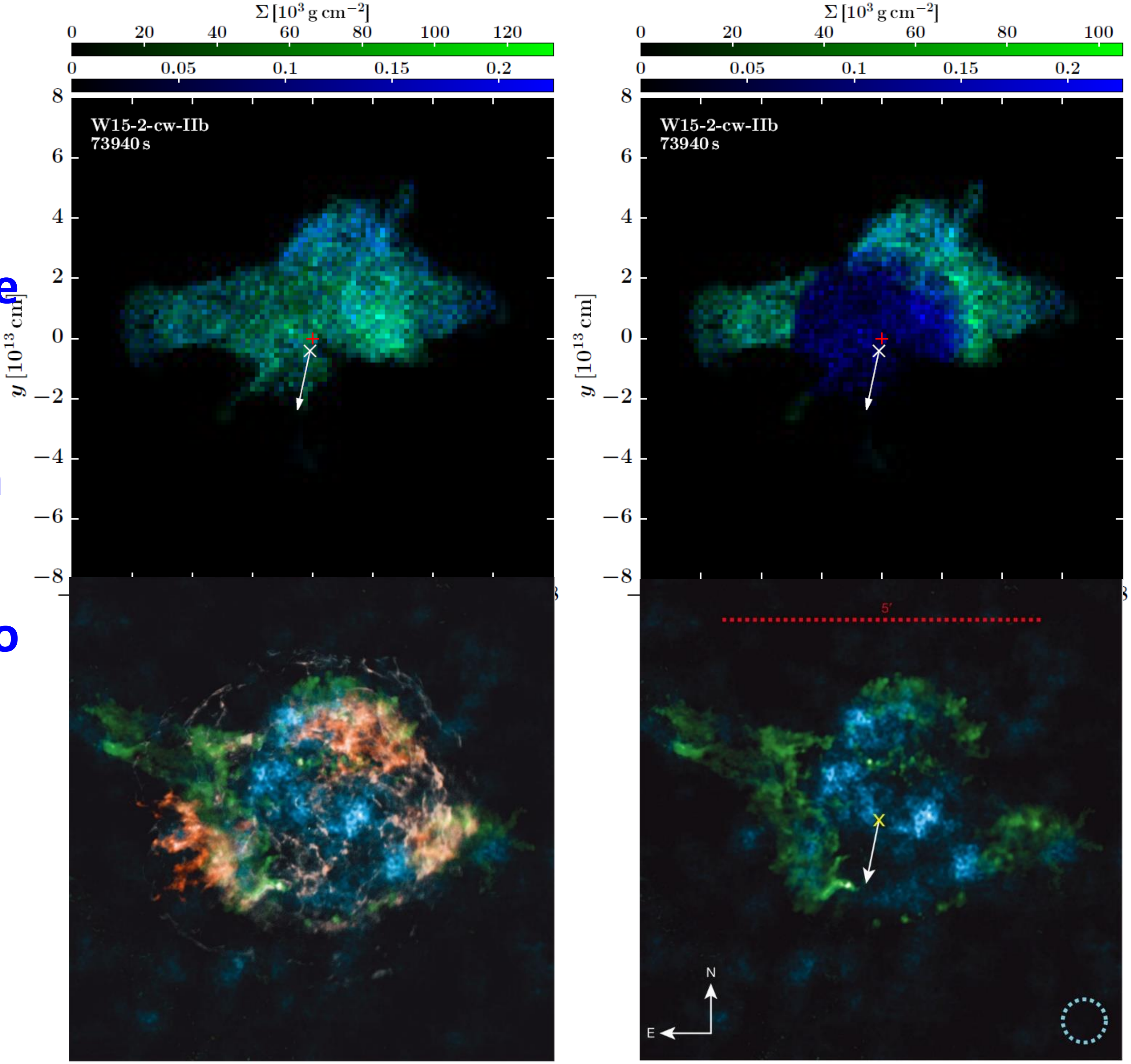
W15-IIb

Type IIb model

W15-IIb

Similarities in orientation of three large Fe plumes in our model and observations from Cas A

More Fe opposite to NS kick

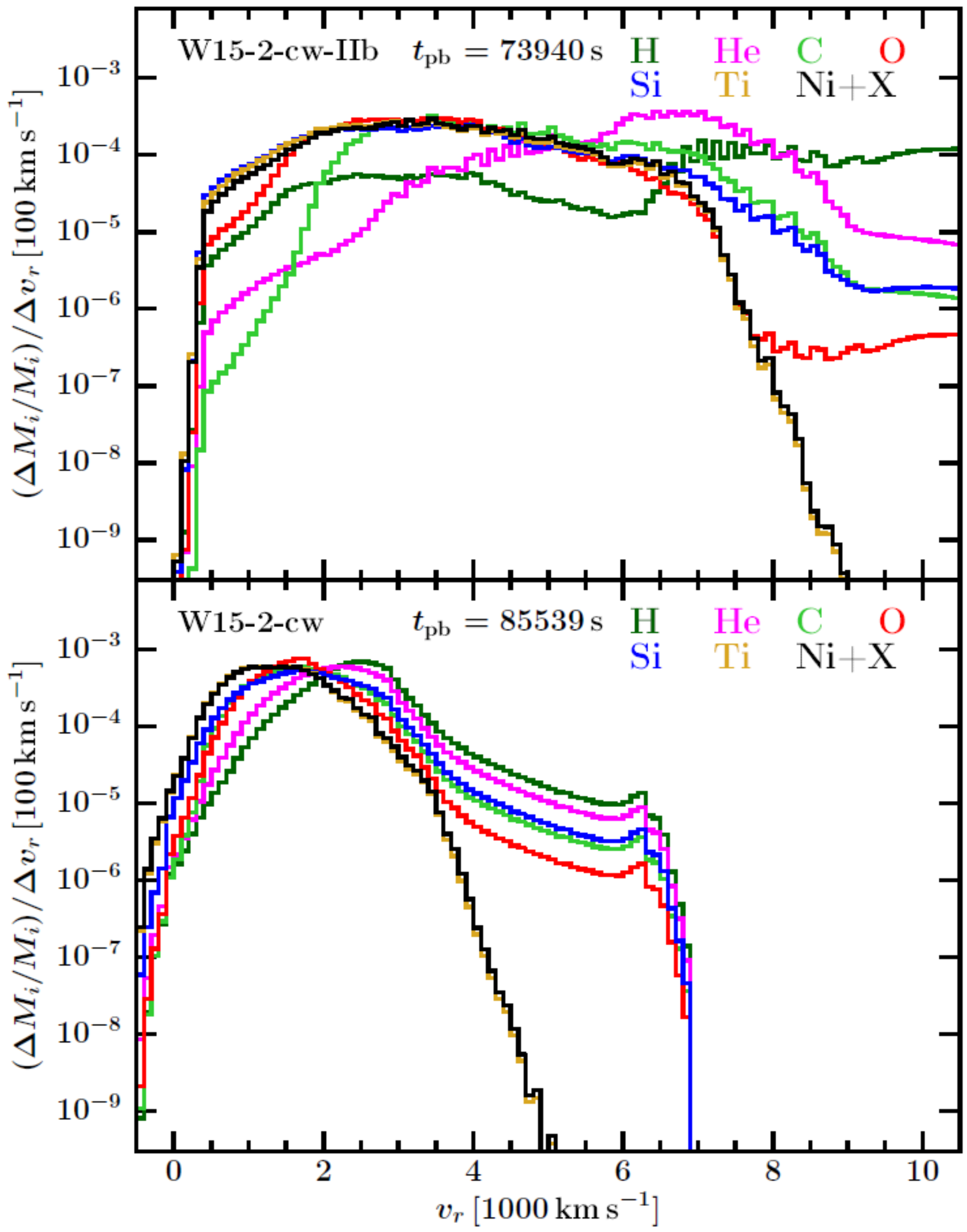


Grefenstette et al. (2014)

Type IIb model

W15-IIb

W15-2

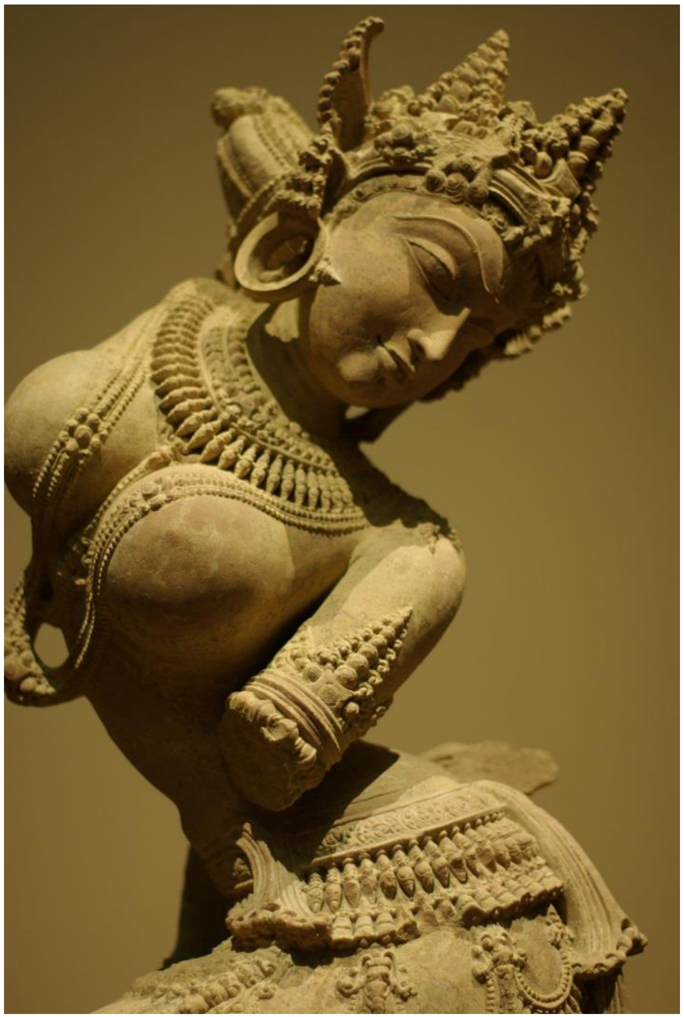


3D interactive visualization

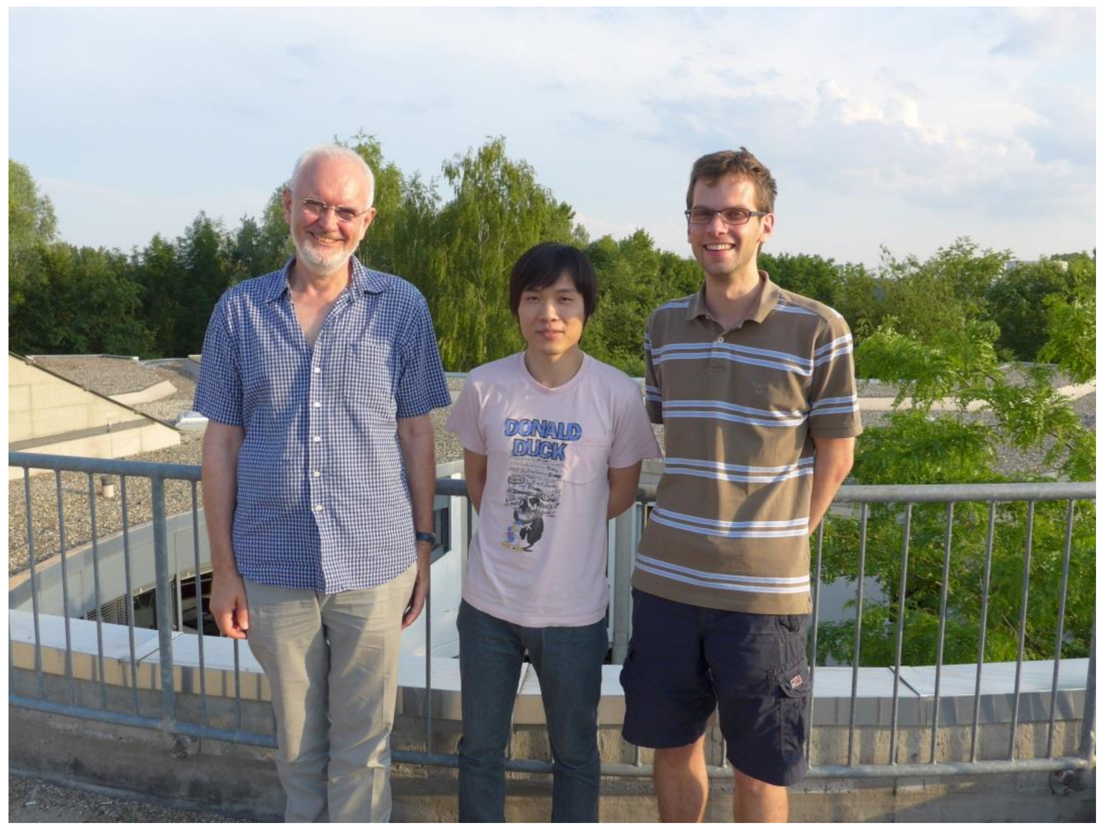
Apsara: A multidimensional unsplit fourth-order explicit Eulerian hydrodynamics code for arbitrary curvilinear grids

A. Wongwathanarat, H. Grimm-Strele, and E. Müller

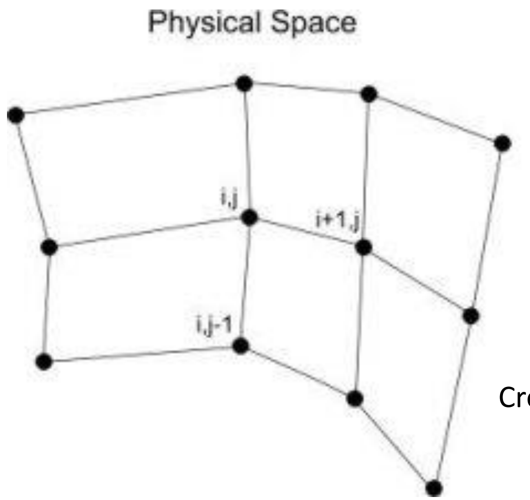
(figure from wikipedia)

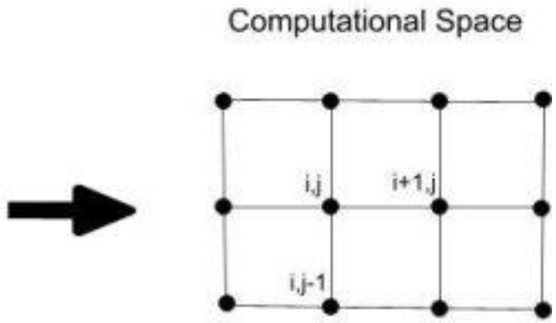


An Apsara is a female spirit of the clouds and water in Hindu mythology.
Apsaras are said to be able to change their shape at will.



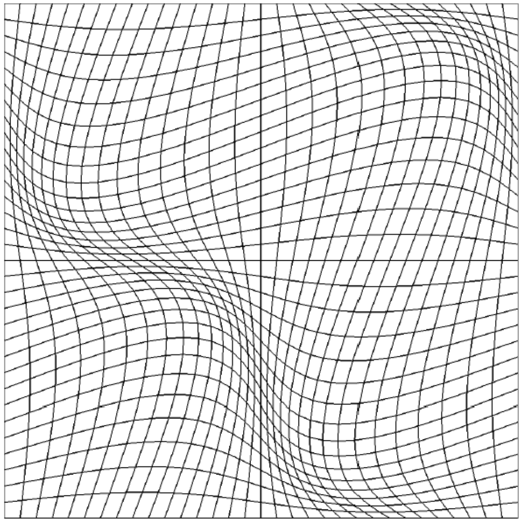
Mapped grid technique

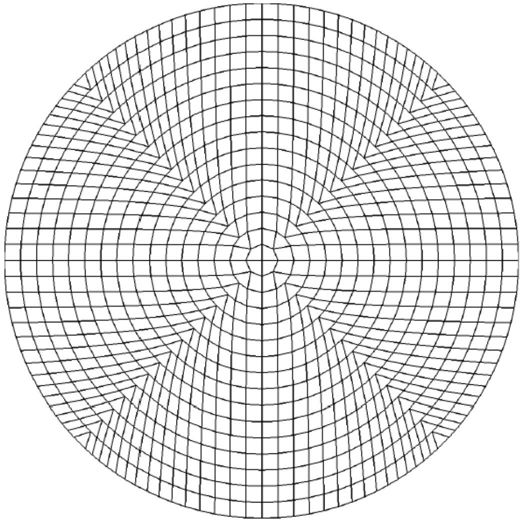




Credit: http://www.innovative-cfd.com/cfd-grid.html

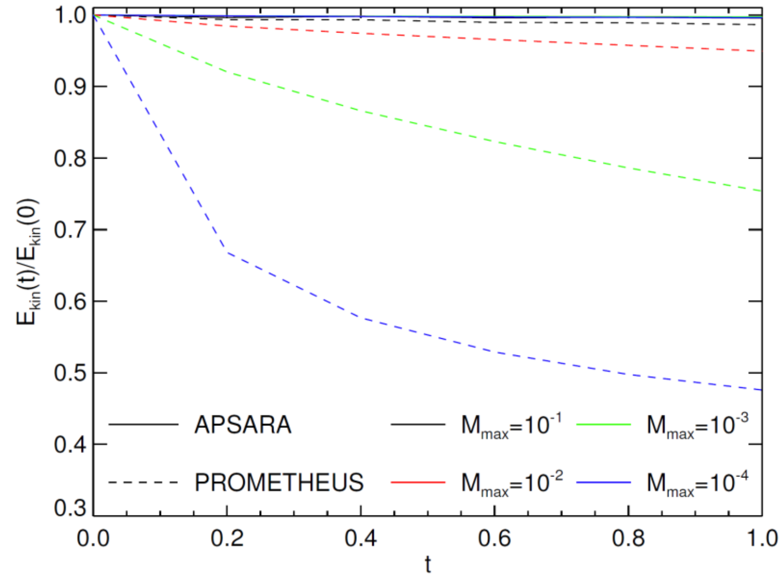
Non-uniform grid in physical space is mapped to equidistant Cartesian grid in computational space

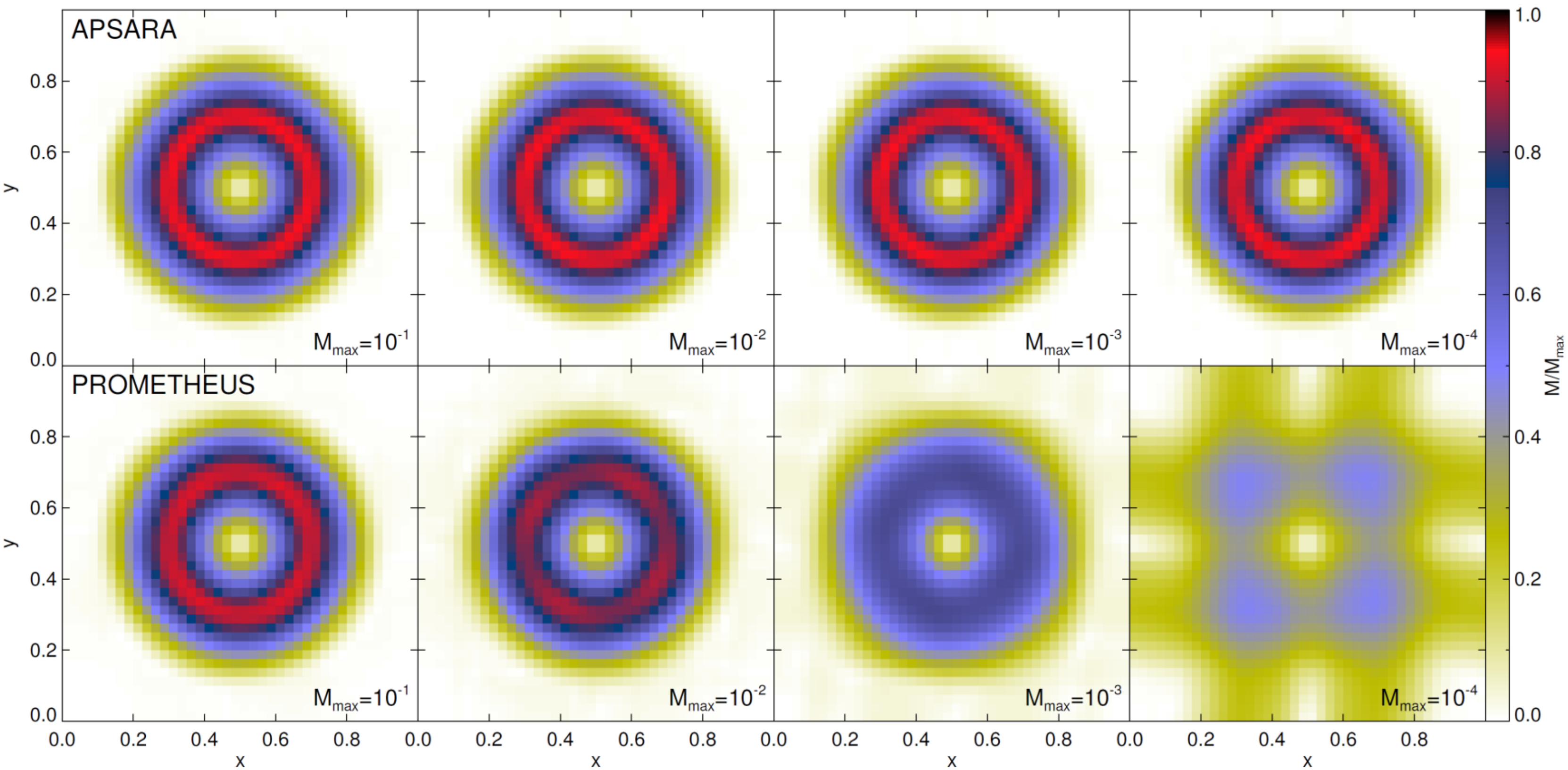




Gresho vortex

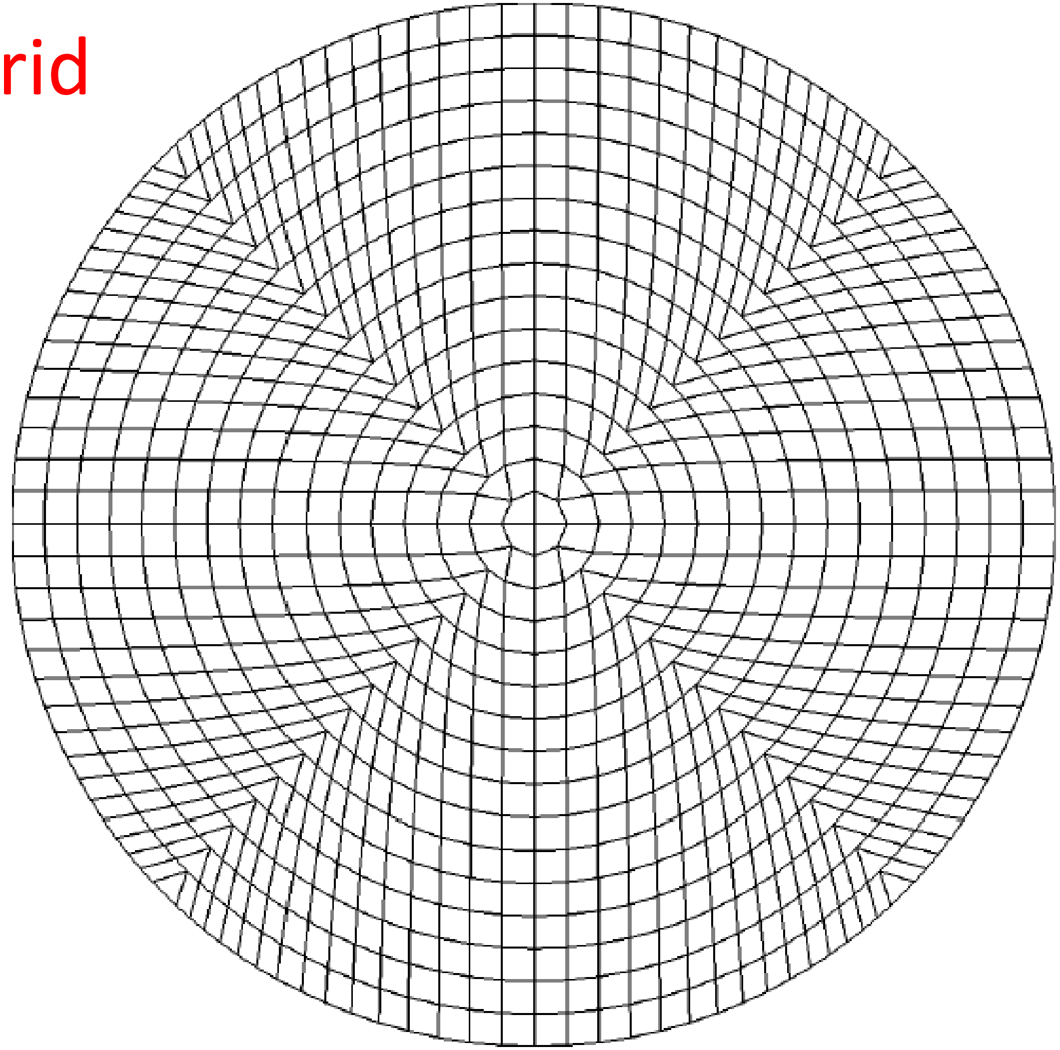
APSARA can capture low-mach number flows better



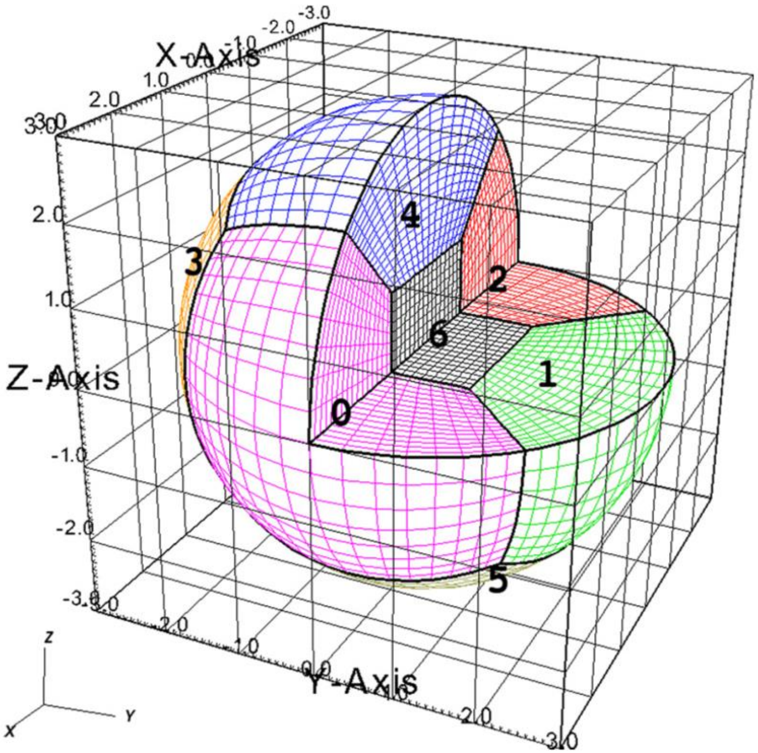


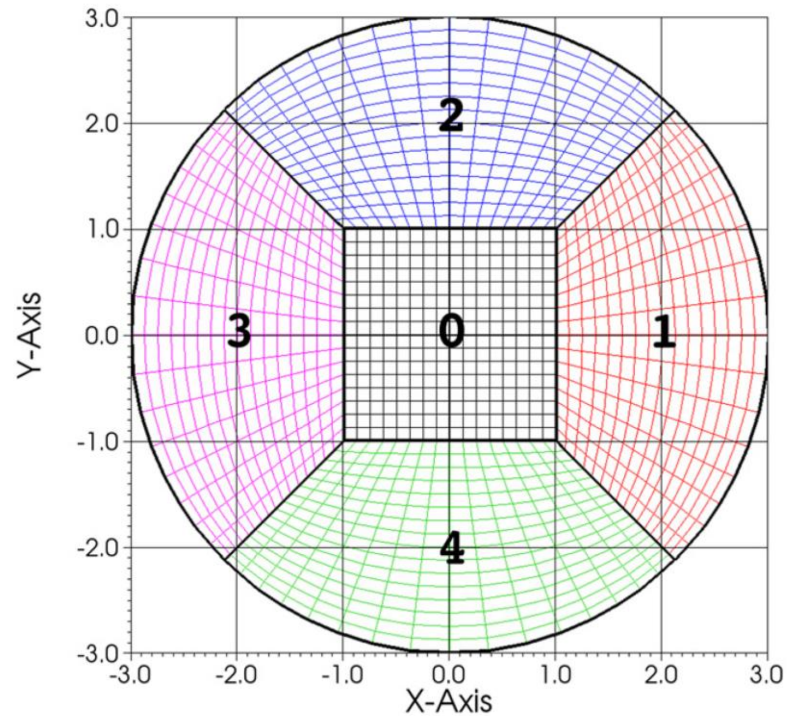
Single block circular domain

Low quality grid cells along diagonals



Mapped multi-block grid





High-order finite-volume methods for hyperbolic conservation laws on mapped multiblock grids

P. McCorquodale [a,*], M.R. Dorr [b], J.A.F. Hittinger [b], P. Colella [a]

[a] Computational Research Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Mail Stop 50A1148, Berkeley, CA 94720, USA

[b] Center for Applied Scientific Computing, Lawrence Livermore National Laboratory, P.O. Box 808, L-561, Livermore, CA 94551-0808, USA

Conclusion

- 3D models from explosion to shock breakout now feasible

- evolution of early-time asymmetries associated with explosion mechanism depends on complex interplays between the asymmetries and the SN shock

- SN shock dynamics connects to the density structure of the progenitor star

- Density structure of He shell and He/H interface are very important in determining the fate of heavy clumps

How apsaras were born ??

Ceremony to obtain
the nectar of immortality

Suvarnabhumi international airport, Bangkok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ห้ามจับ
PLEASE DO NOT TOUCH


CHANEL