Linking 3D CCSN simulations with observations

Annop Wongwathanarat

Ewald Müller

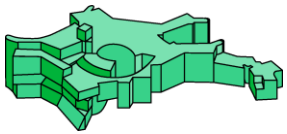
Hans-Thomas Janka

Victor Utrobin

Michael Gabler

IAUS 331 SN1987A, 30 years later, 20 Feb 2017

Max-Planck-Institut für Astrophysik



Astrophysical Big Bang Laboratory

RIKEN

Motivation

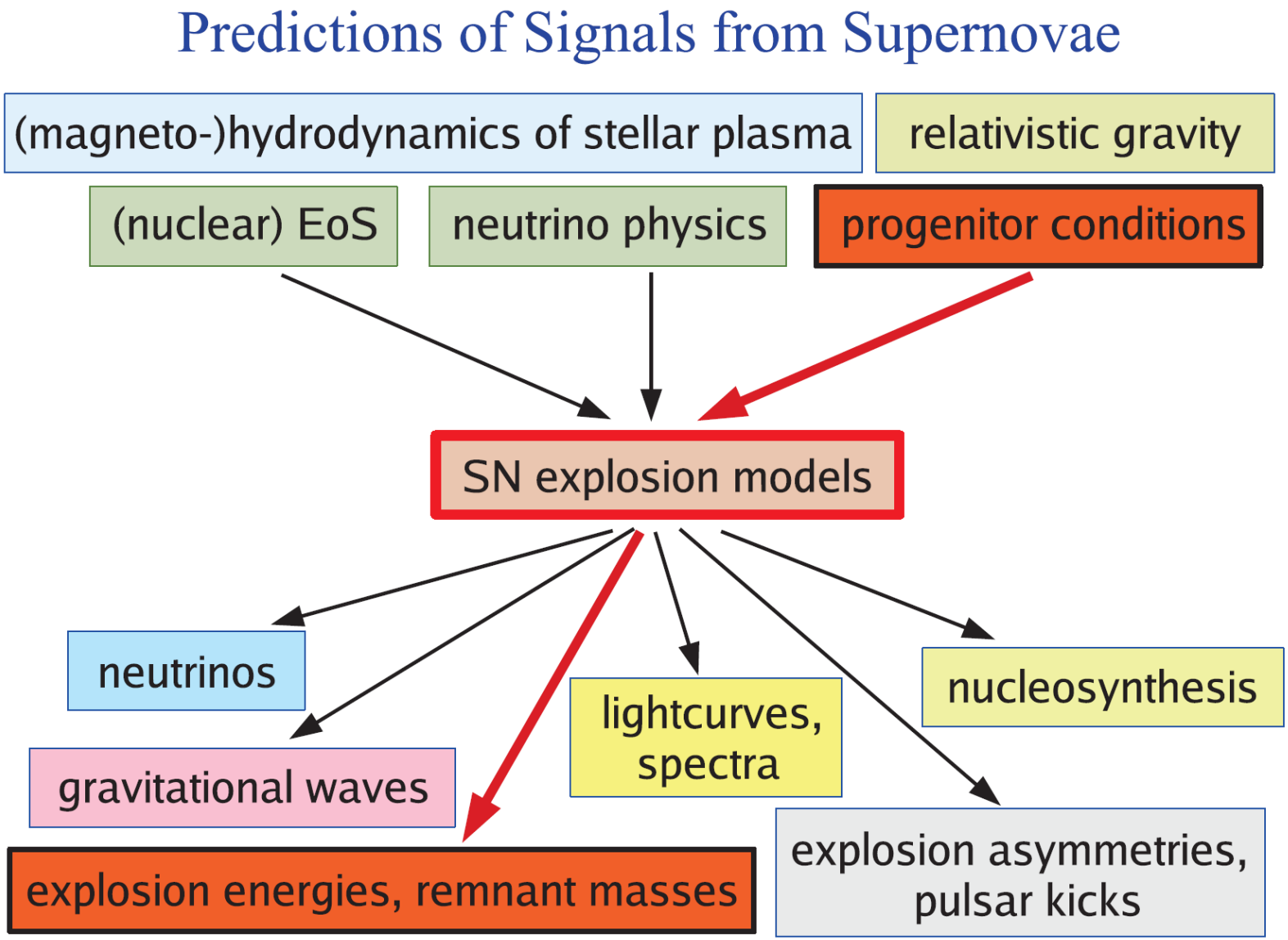
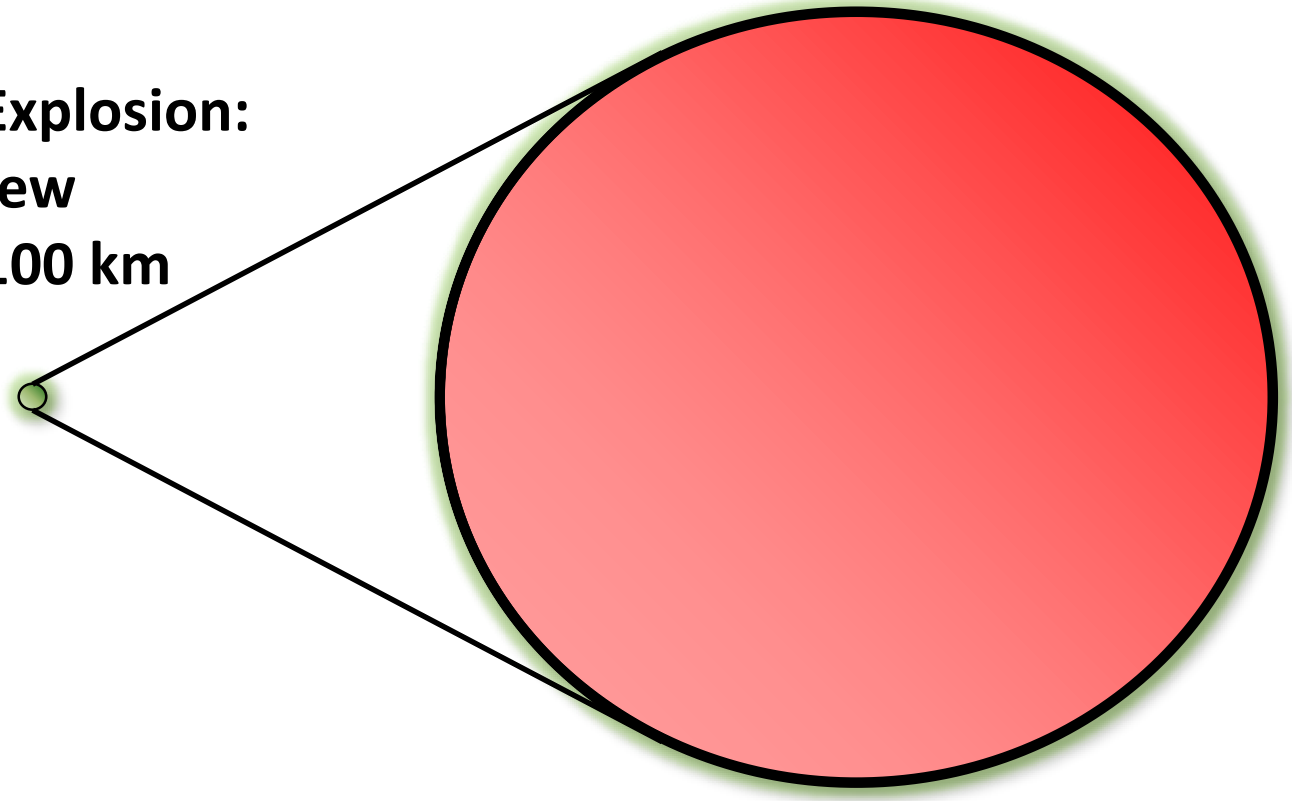


Figure from Janka et al. (2012)

Challenge

Star:
few 100
millions
km

Explosion:
few
100 km



Remnants:
few 10
trillions
km

Time scale: ms >>> hours, day >>>>>>>>>>>>>>>>>>>>>>>>> 100 years

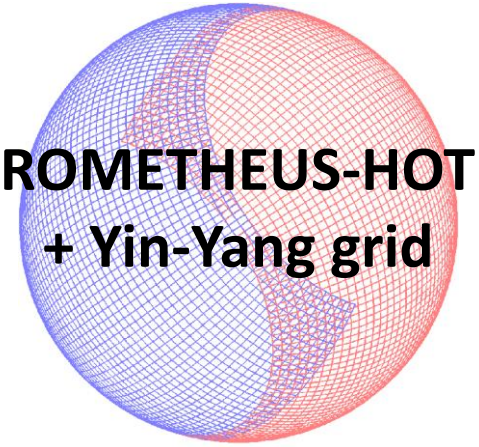
State-of-the-art long-time simulations

Stellar evolution model

PROMETHEUS-HOTB

1D

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 Tuesday

1D

CRAB Lagrangian radiation hydrodynamics

Light curves calculations

Numerics

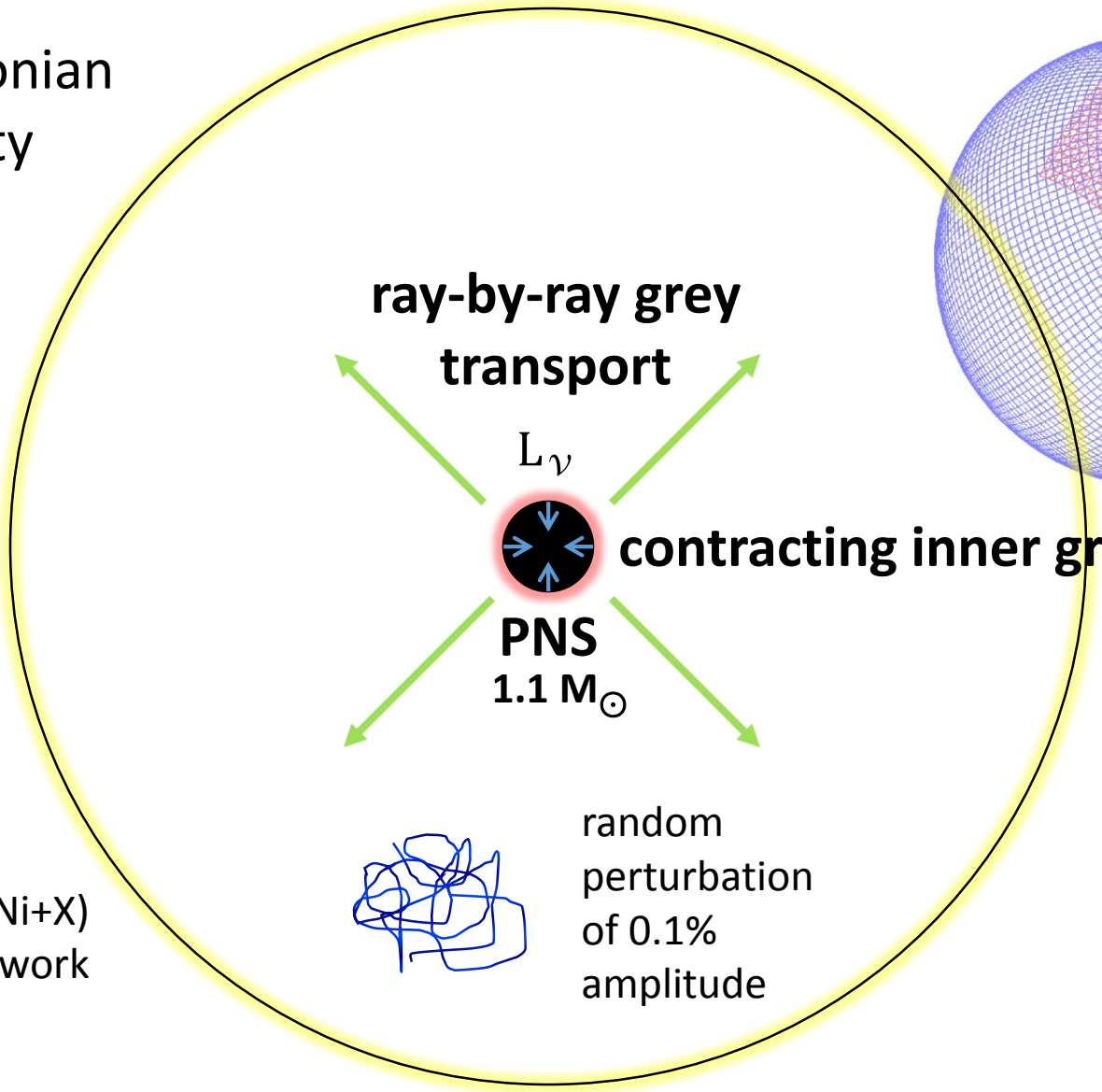
3D Newtonian self-gravity

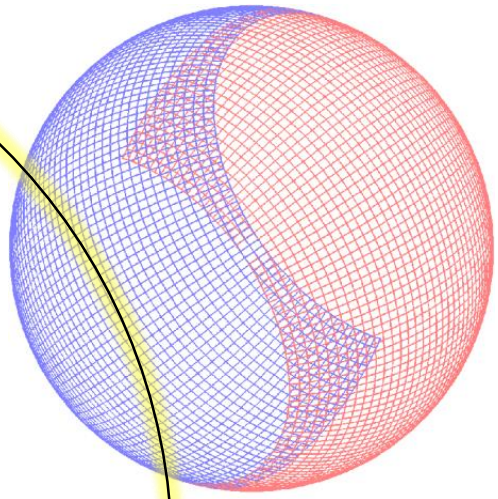
monopole GR correction

tabulated EOS by Janka & Müller (1996)

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

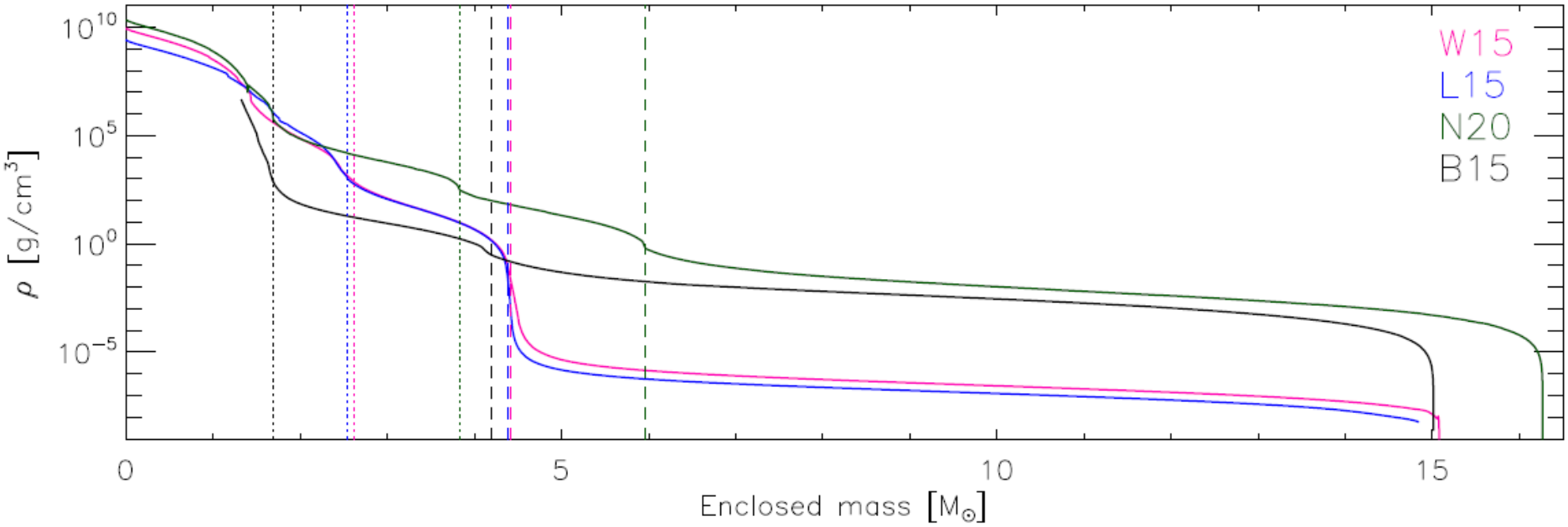
14 species (^{4}He- ^{56}Ni+X) alpha-reactions network



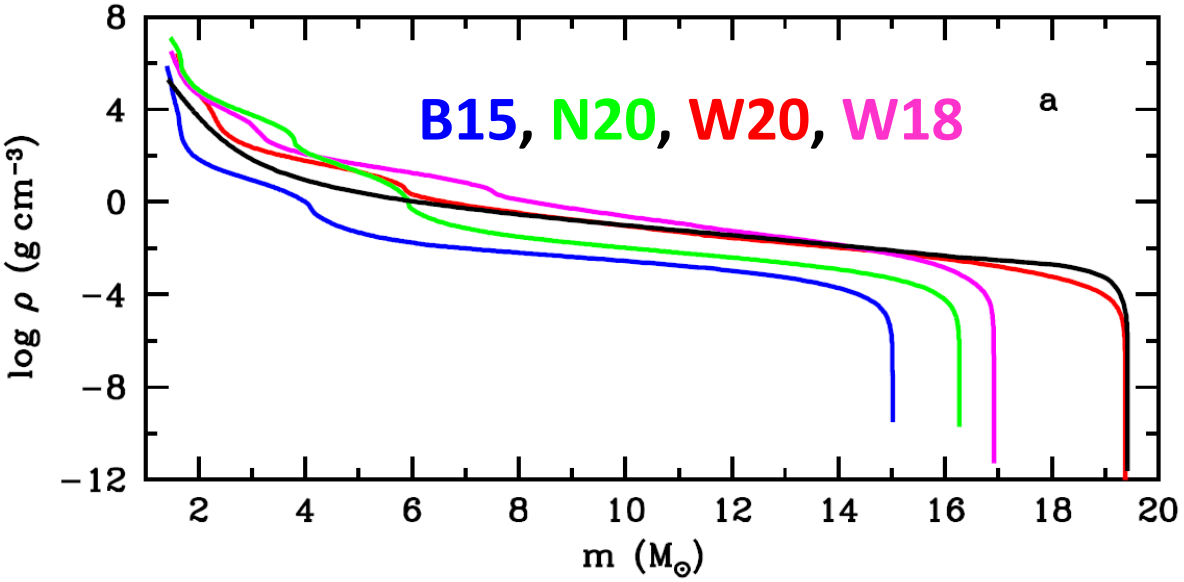


Explore several progenitors, varying expl. energies

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

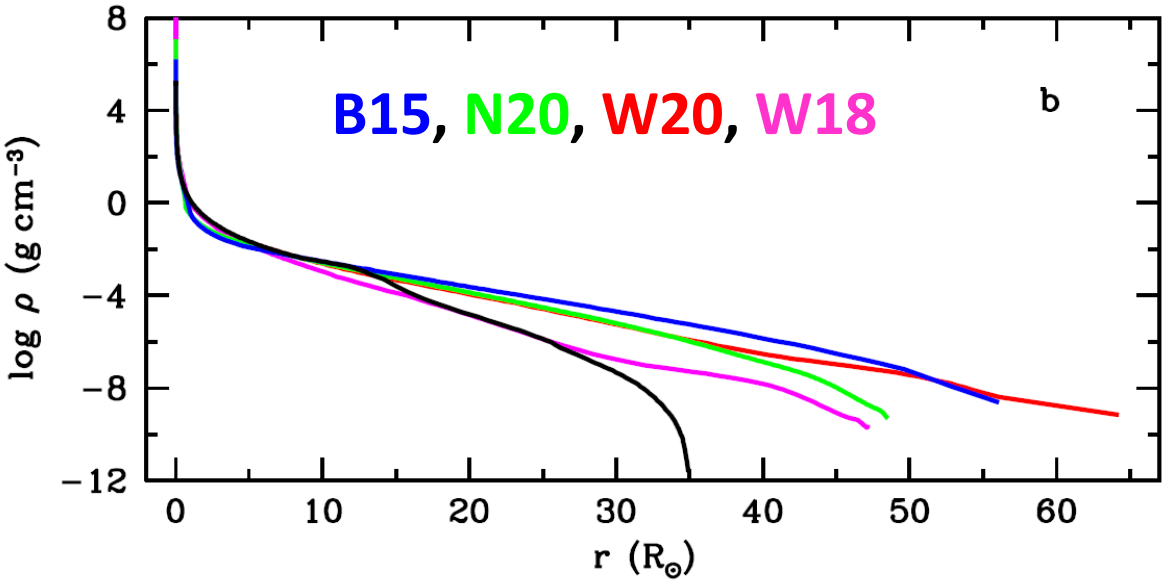


Progenitors for SN1987A



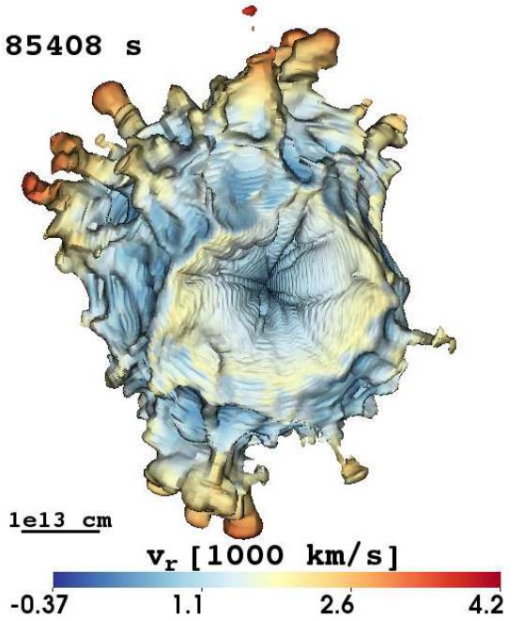
Black line: optimal non-evolutionary model for SN1987A by Utrobin (2005)

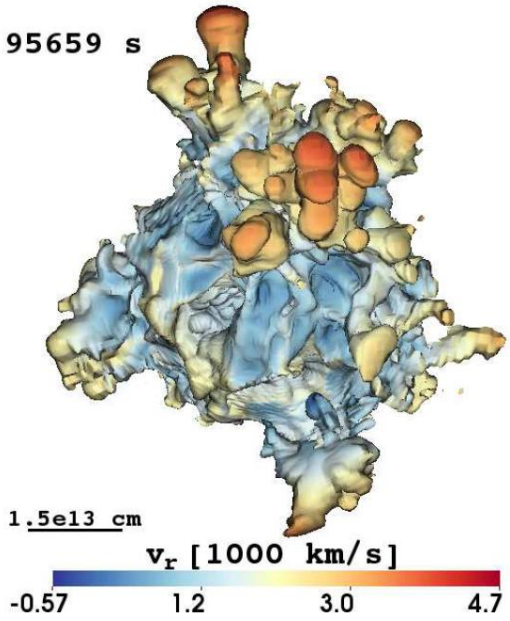
Model	R_{pSN} ($R_\odot$)	M_{He}^{core} ($M_\odot$)	M_{pSN} ($M_\odot$)	M_{ZAMS} ($M_\odot$)	X_{surf}	Y_{surf}	Z_{surf} (10^{-2})	$\xi_{1.5}$
B15	56.1	4.08	15.02	15.02	0.767	0.230	0.34	0.24
N20	47.9	5.96	16.27	~20.0	0.560	0.435	0.50	0.83
W18	46.8	7.50	16.92	18.0	0.480	0.515	0.50	0.68
W20	64.2	5.83	19.38	20.10	0.738	0.256	0.56	0.78

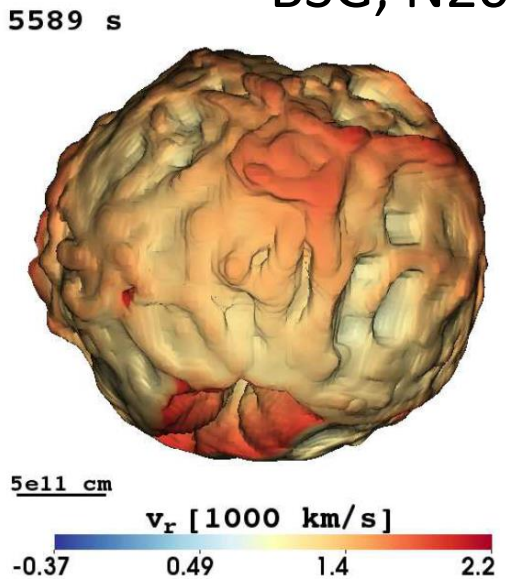


Ejecta at shock breakout

Shigeyama&Nomoto (1990)
BSG, N20



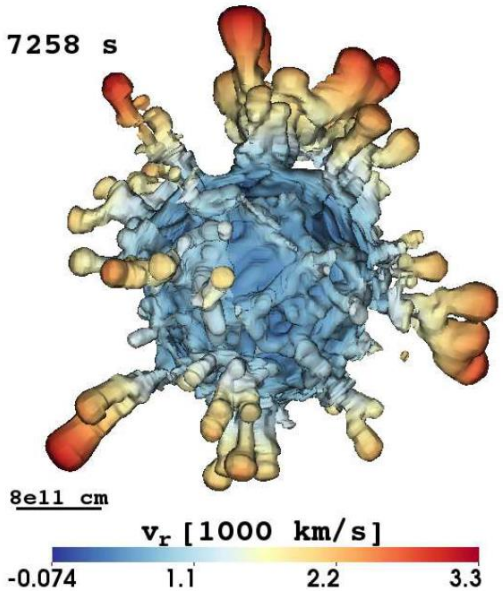




Woosley&Weaver (1995)
RSG, W15

Limongi+ (2000)
RSG, L15

Nickel-rich ejecta at shock breakout



Woosley+ (1988) BSG, B15

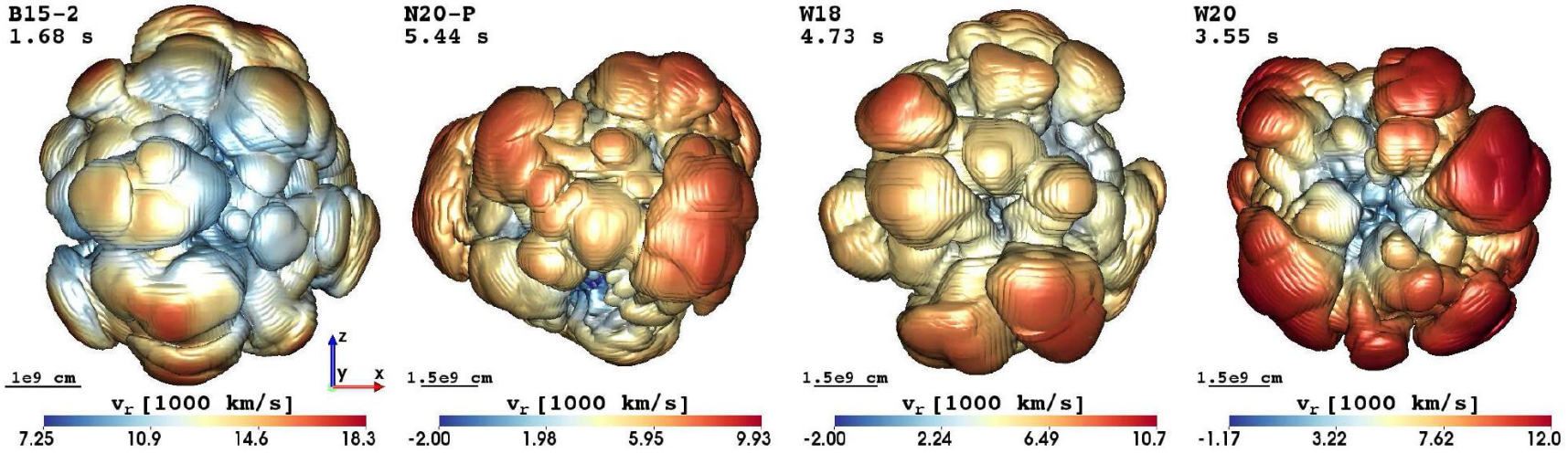
SN1987A models

Woosley et al. (1988)

Shigeyama & Nomoto (1990)

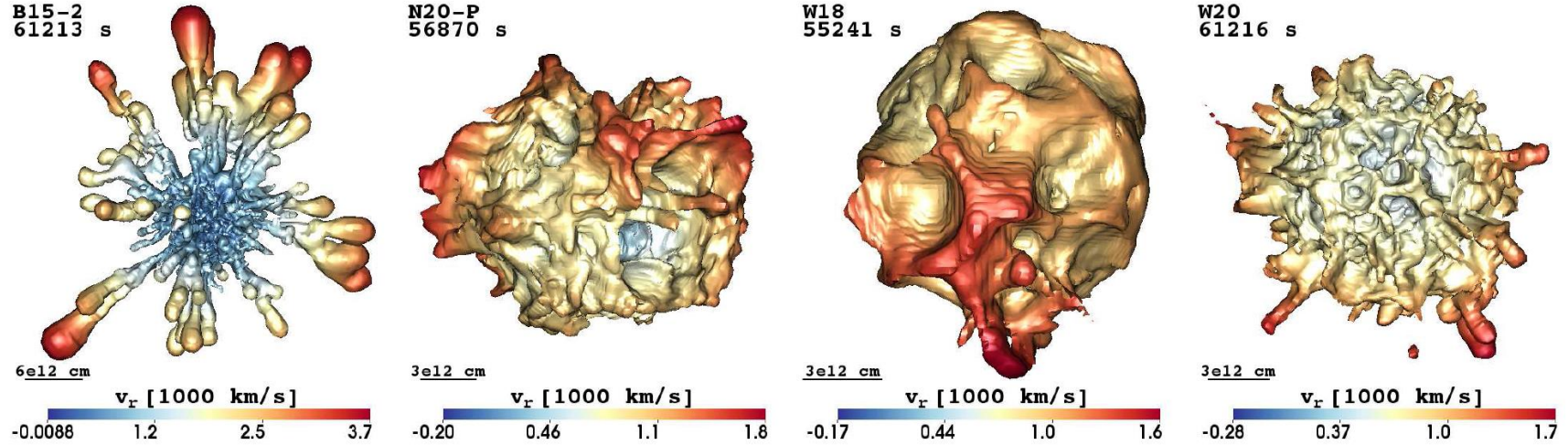
Woosley (2007)

Woosley et al. (1997)



~ 3700 km/s

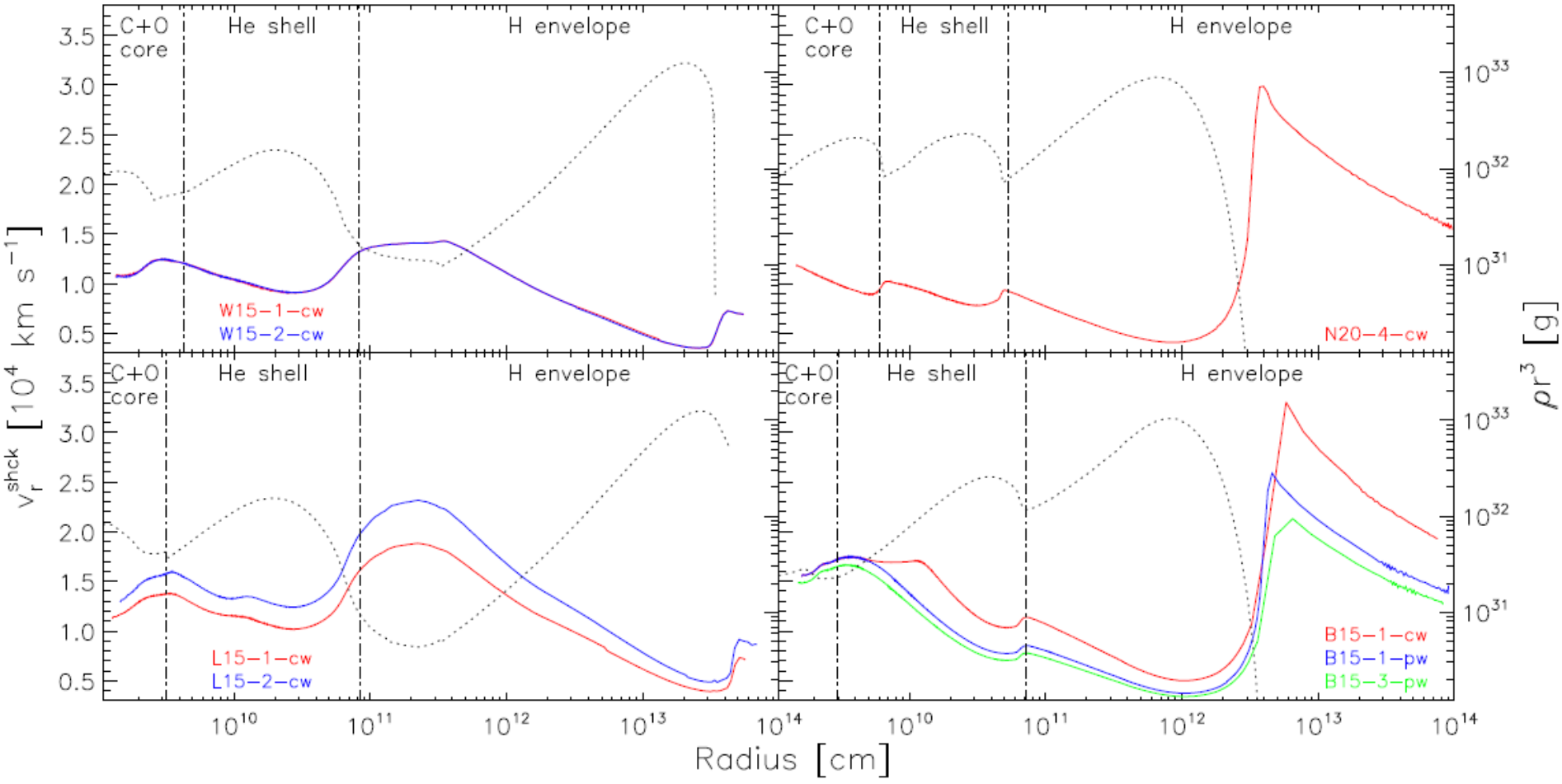
< 2000 km/s



Shock dynamics

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

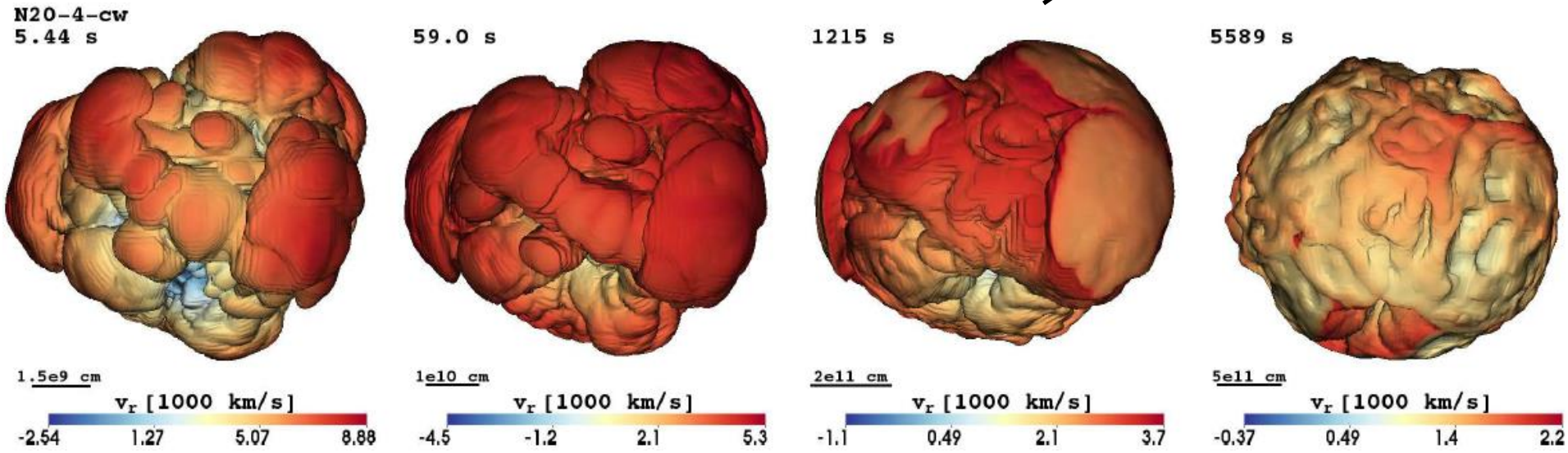
accelerates when ρr^3 decreases, and vice versa



N20 vs B15

roundish structure

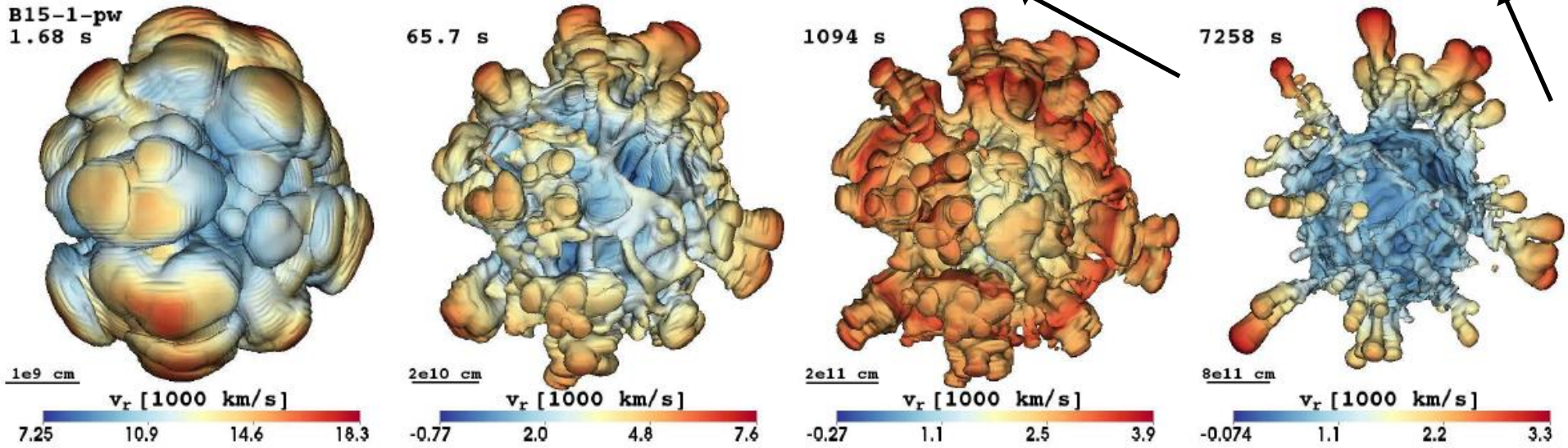
BSG



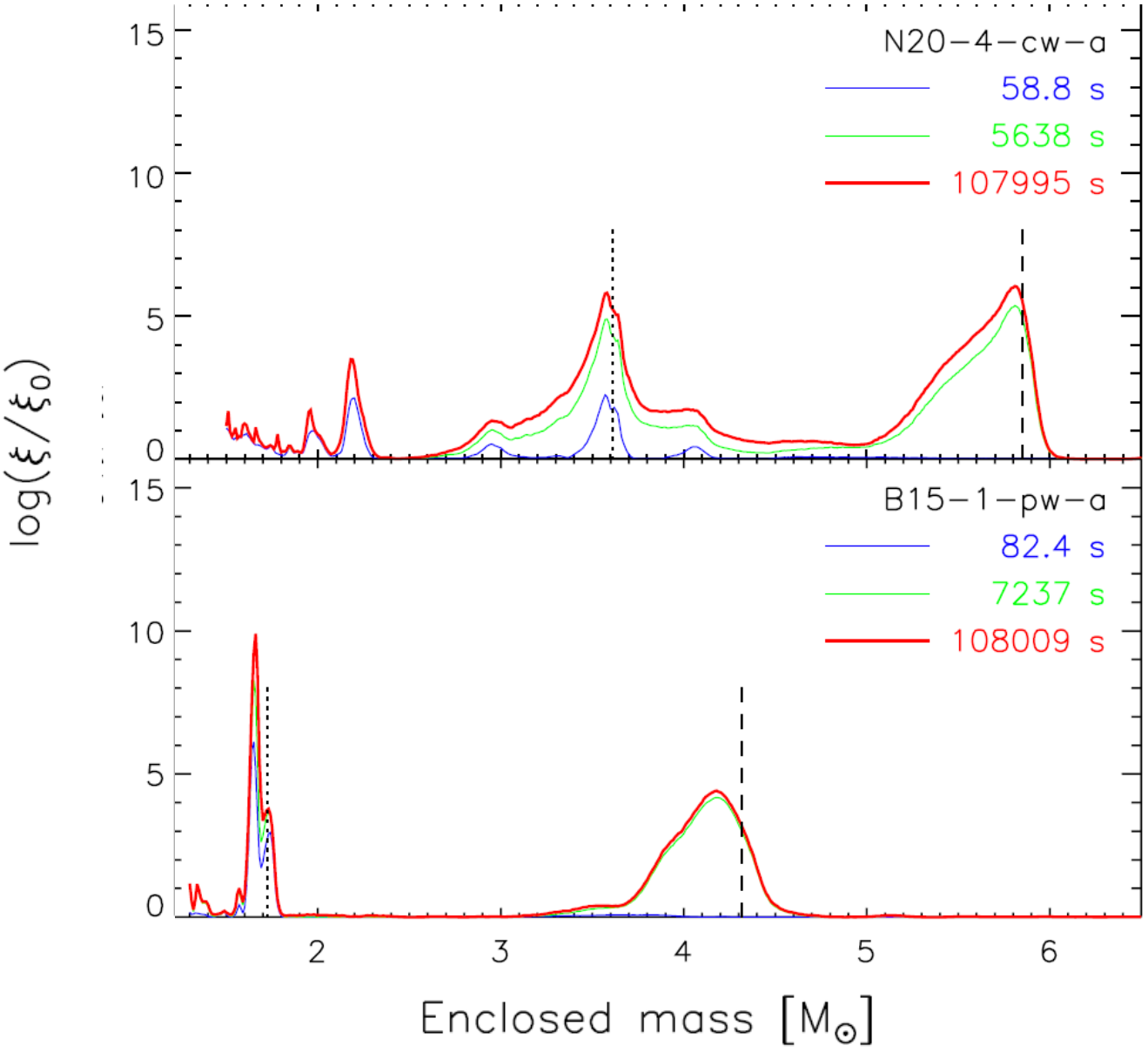
very different morphology
also different from RSG models

many RT fingers
into H-envelope

same progenitor as
Hammer+ (2010)

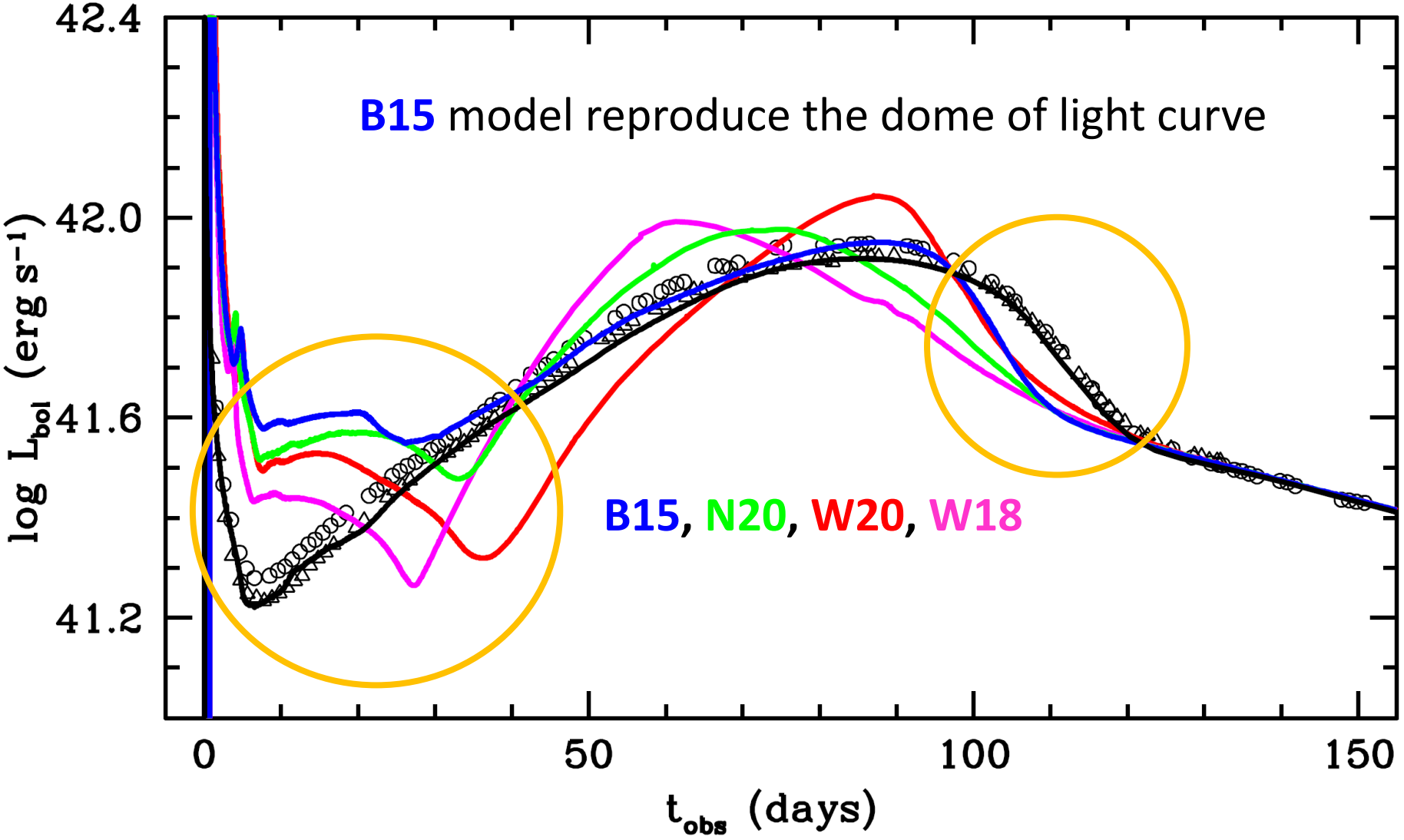


RT growth rate

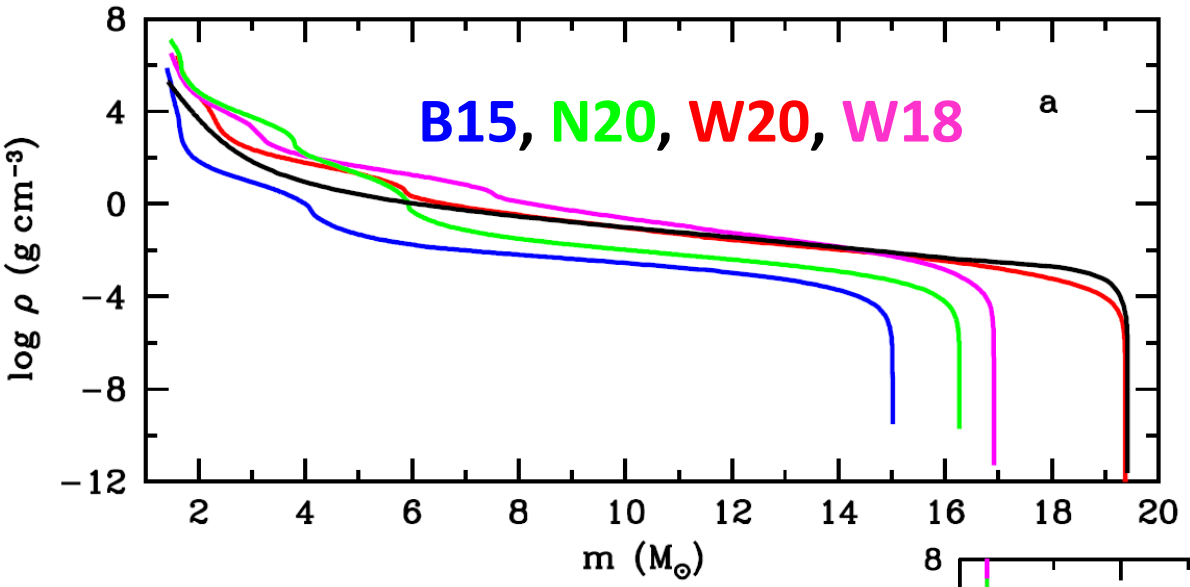


Light Curves of SN1987A

Utrobin et al. (2015)

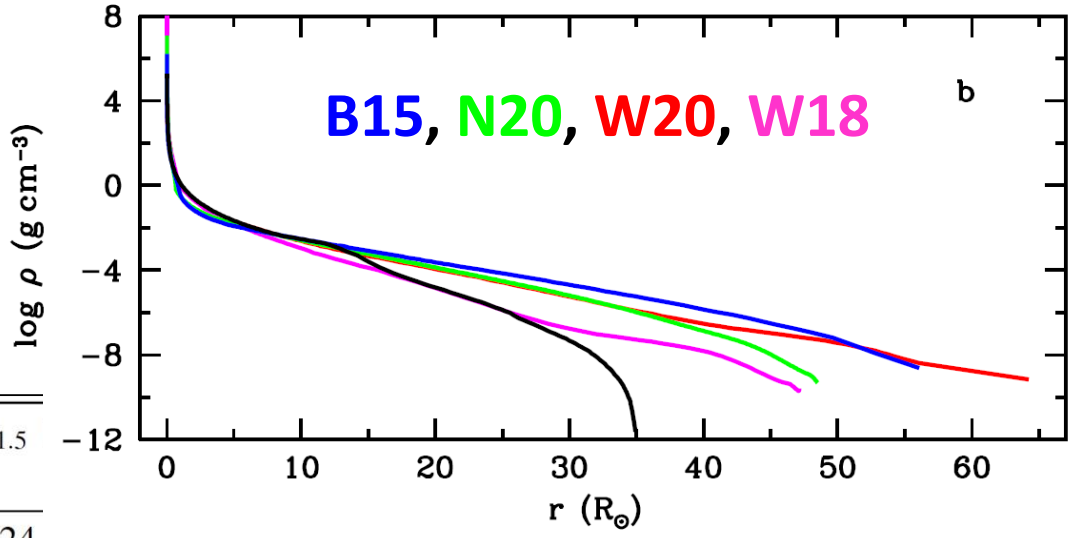


Progenitor structure



Black line: optimal non-evolutionary model for SN1987A by Utrobin (2005)

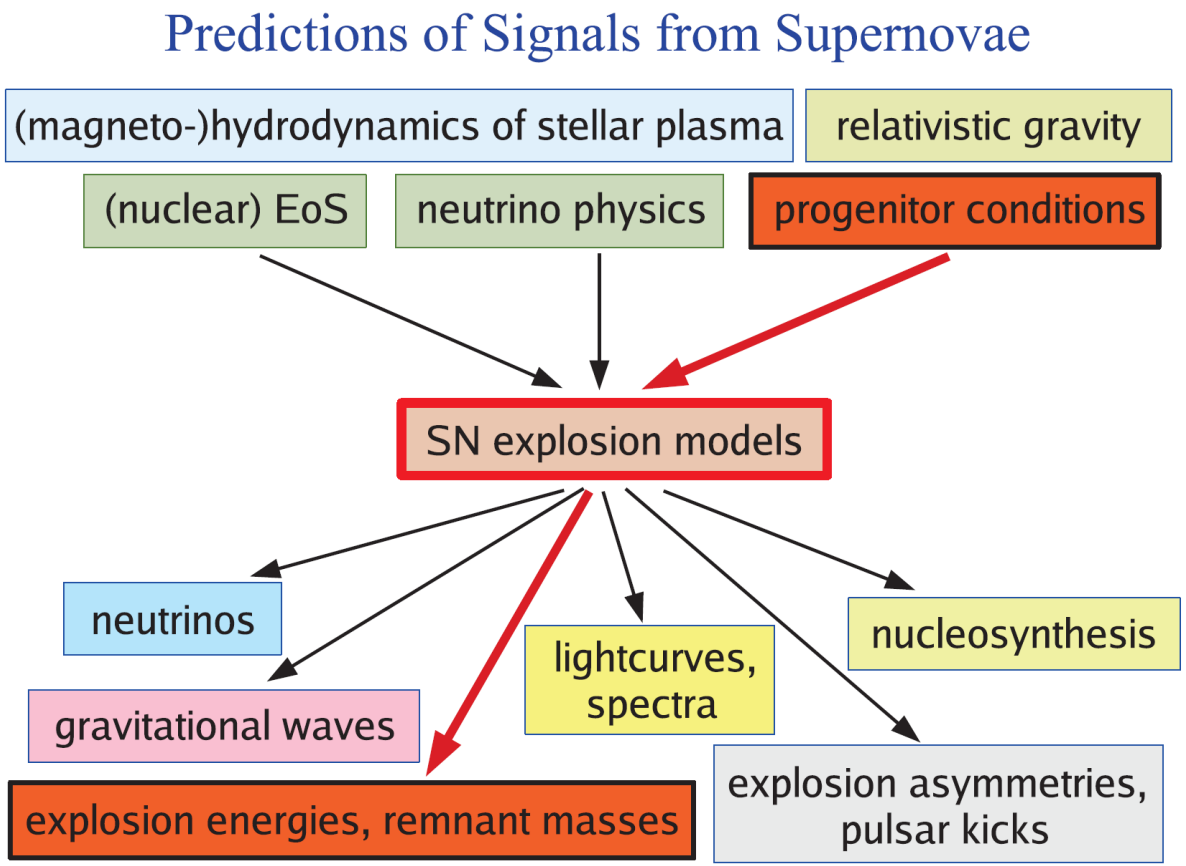
Lightcurve --> mixing --> progenitor structure --> stellar evolution



Model	$R_{\rm pSN}$ ($R_\odot$)	$M_{\rm He}^{\rm core}$ ($M_\odot$)	$M_{\rm pSN}$ ($M_\odot$)	$M_{\rm ZAMS}$ ($M_\odot$)	$X_{\rm surf}$	$Y_{\rm surf}$	$Z_{\rm surf}$ (10^{-2})	$\xi_{1.5}$
B15	56.1	4.08	15.02	15.02	0.767	0.230	0.34	0.24
N20	47.9	5.96	16.27	~20.0	0.560	0.435	0.50	0.83
W18	46.8	7.50	16.92	18.0	0.480	0.515	0.50	0.68
W20	64.2	5.83	19.38	20.10	0.738	0.256	0.56	0.78

Conclusions

Figure from Janka et al. (2012)



- perform 3D simulations of CCSN from shortly after core bounce until shock breakout
- We are making progresses towards direct comparison with SN/SNR observations !!!

Outlook

- more progenitors, e.g. across progenitor mass range, rotation
- for type IIb (Cas A) model, see Thomas Janka's talk on Wednesday
- longer time evolution, see Michael Gabler's talk on Tuesday
- connect with SN/SNR observers, e.g. lightcurves, spectra, polarization