Exotic Supernovae and their Back Holes

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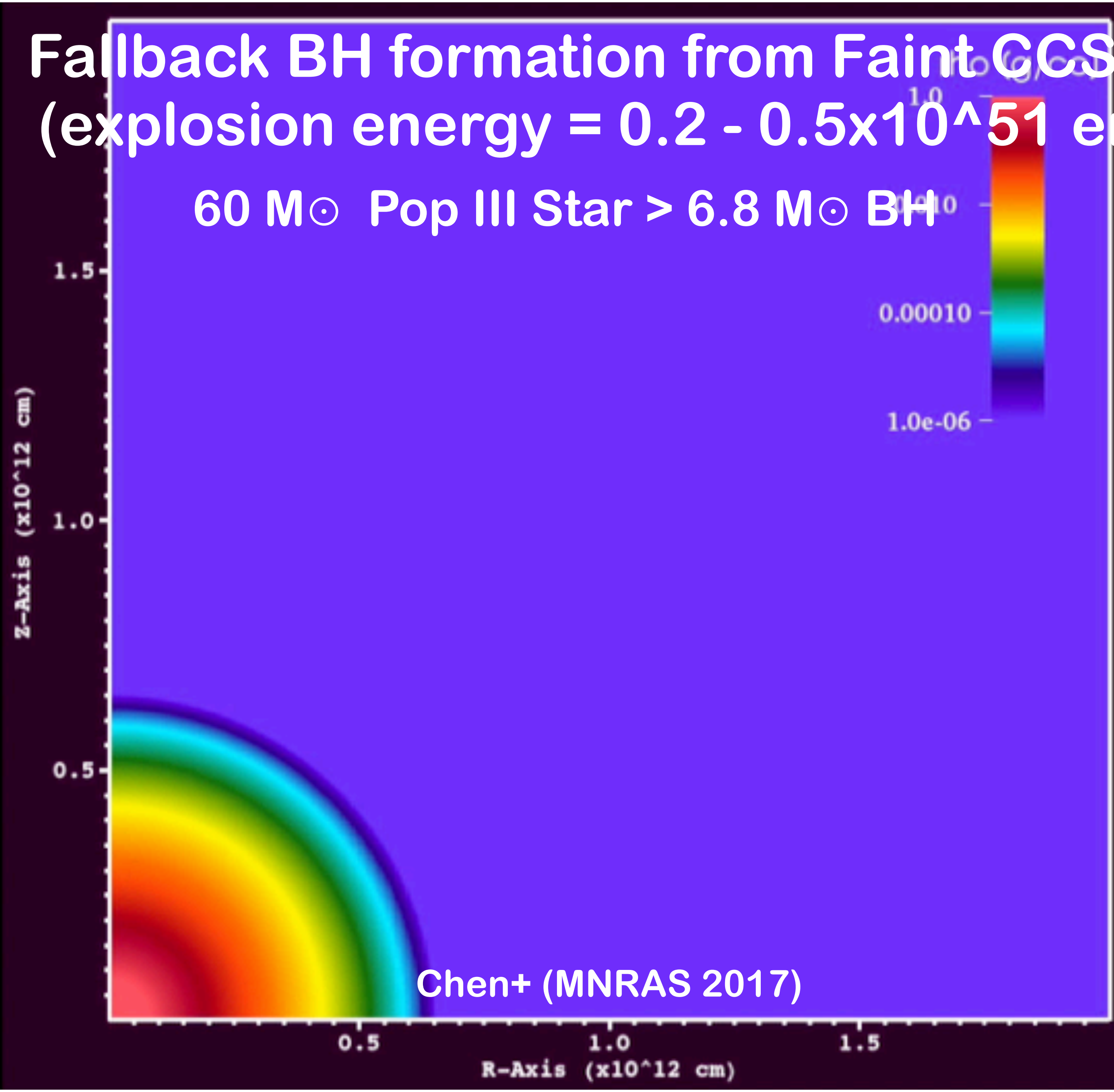
Fallback BH formation from Faint CCSNe
(explosion energy = 0.2 - 0.5x10^51 erg)

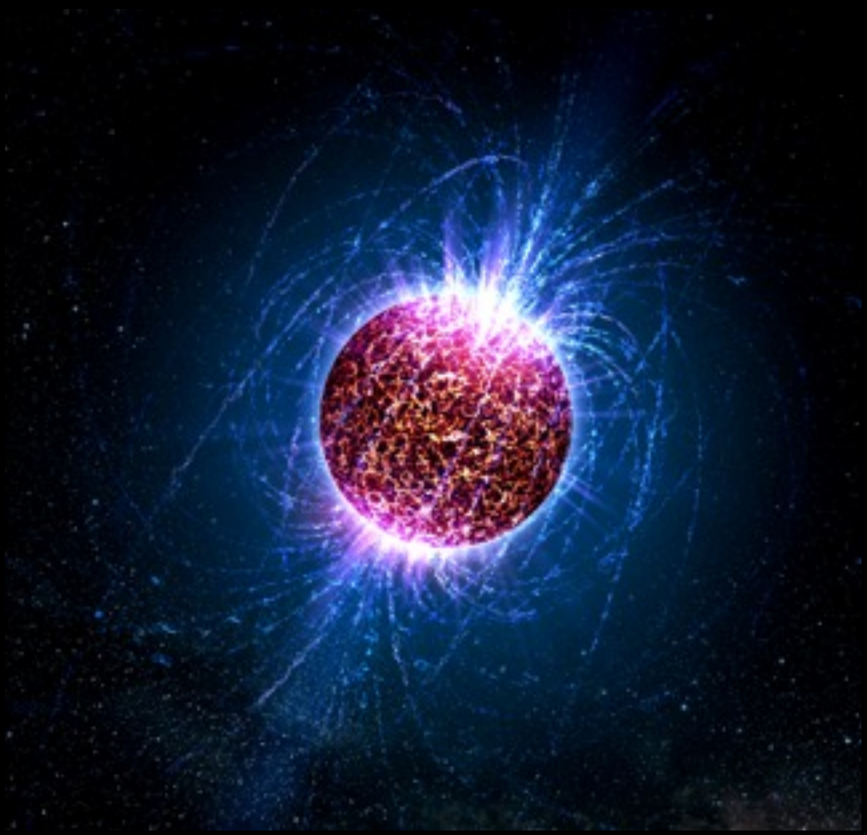
60 M☉ Pop III Star > 6.8 M☉ BH



Chen+ (MNRAS 2017)

Magnetar formation

30 M☉ > M* > 20 M☉



$$E = \frac{1}{2} I\omega^2 \approx 2 \times 10^{52} P_{ms}^{-2} \quad \text{erg.}$$

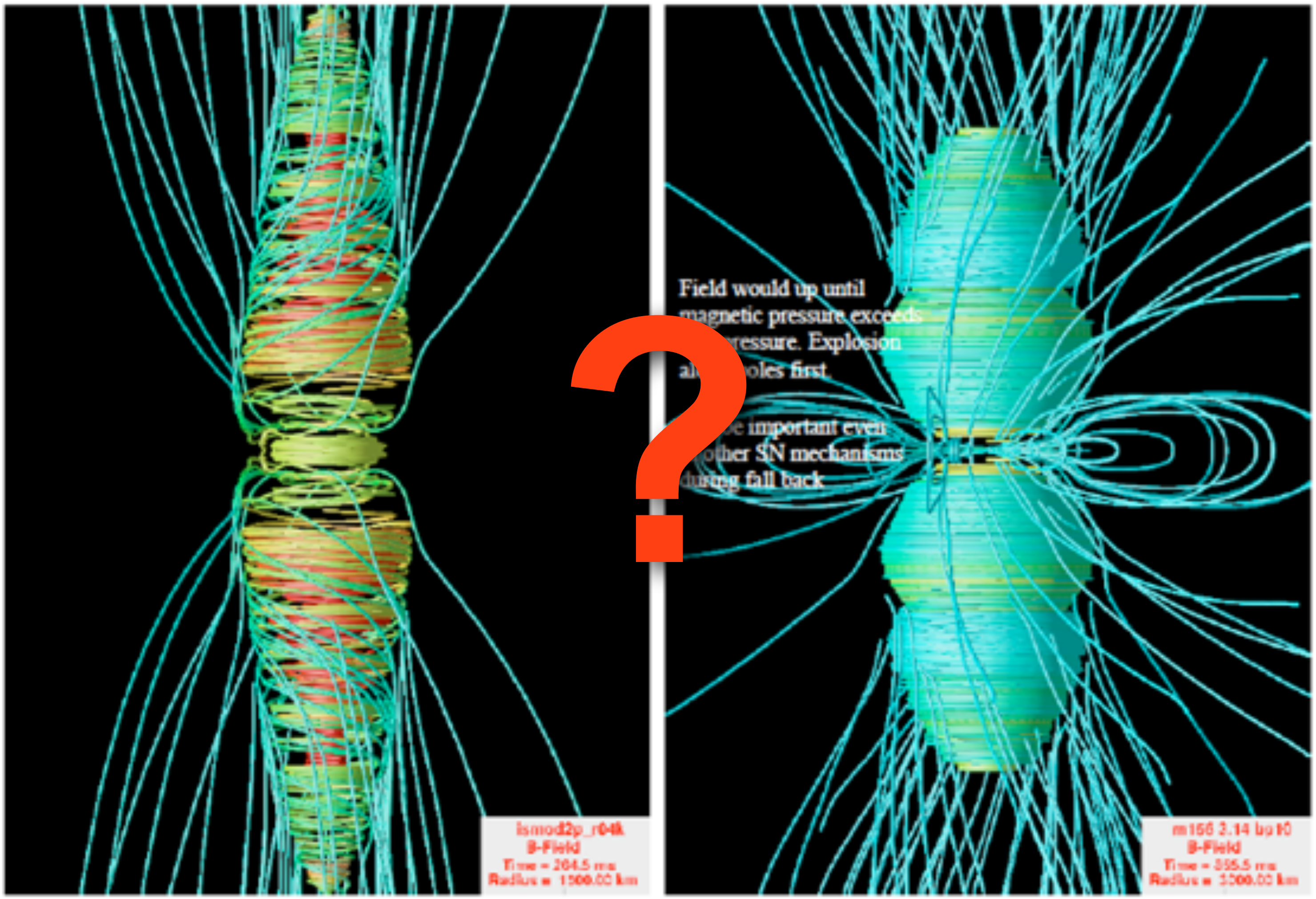
$$L_m = -\frac{32\pi^4}{3c^2}(BR_{ns}^3 \sin\alpha)^2 P^{-4}$$
$$\approx -1.0 \times 10^{49} B_{15}^2 P_{ms}^{-4} \quad \text{erg s}^{-1}$$

$$P(t) \approx (1 + t/t_m)^{1/2} P_0 \text{ ms},$$
$$L(t) \approx (1 + t/t_m)^{-2} E_0 t_m^{-1} \text{ erg s}^{-1},$$
$$E(t) \approx (1 + t/t_m)^{-1} E_0 \text{ erg},$$

where $P_0 = P_{ms}(0)$, $E_0 = E(P_0)$ and $t_m \approx 2{\times}10^3 P_{ms}^2 B_{15}^{-2}$

Jet powered Supernovae

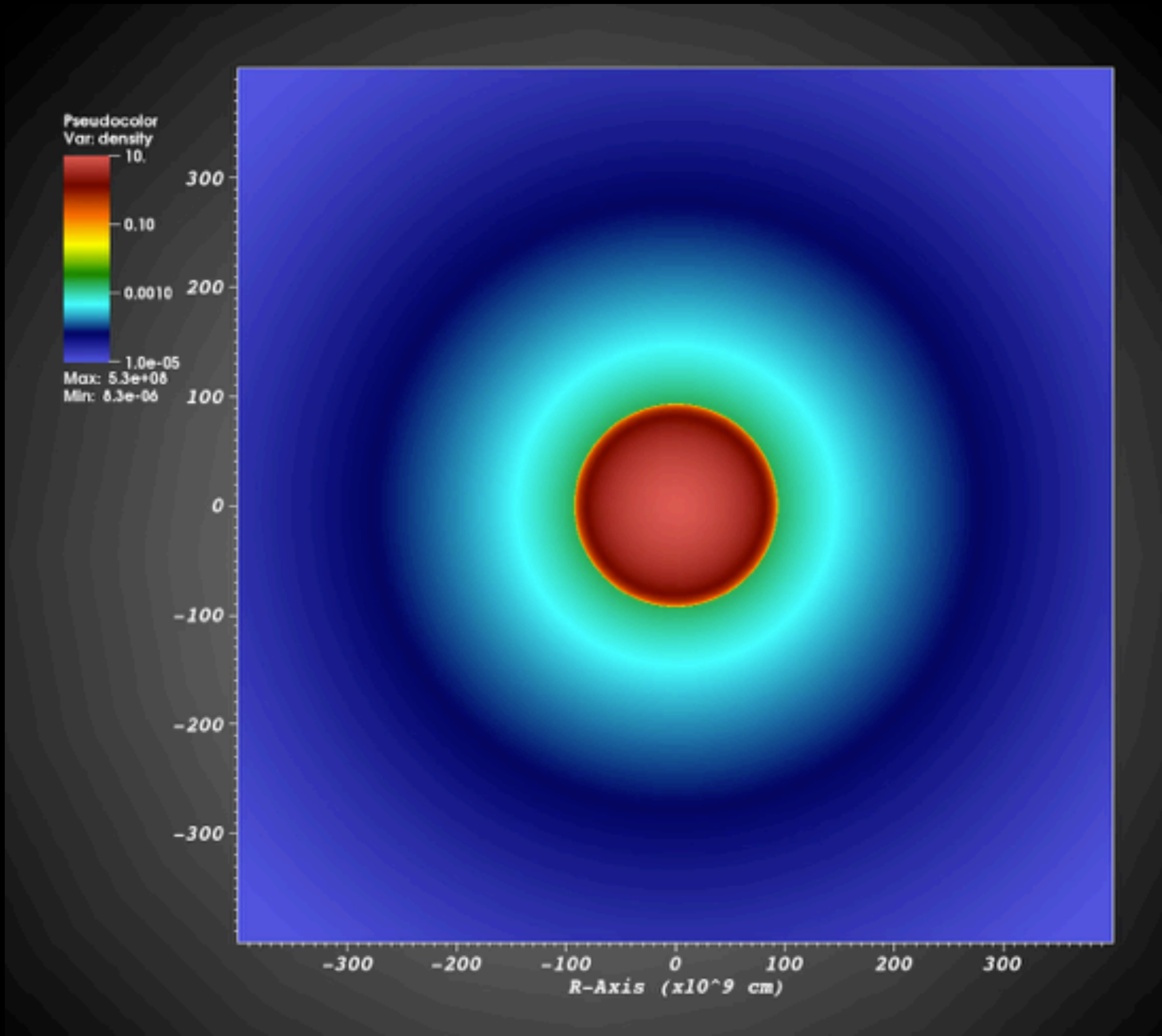
60 M⊙ > M* > 30 M⊙



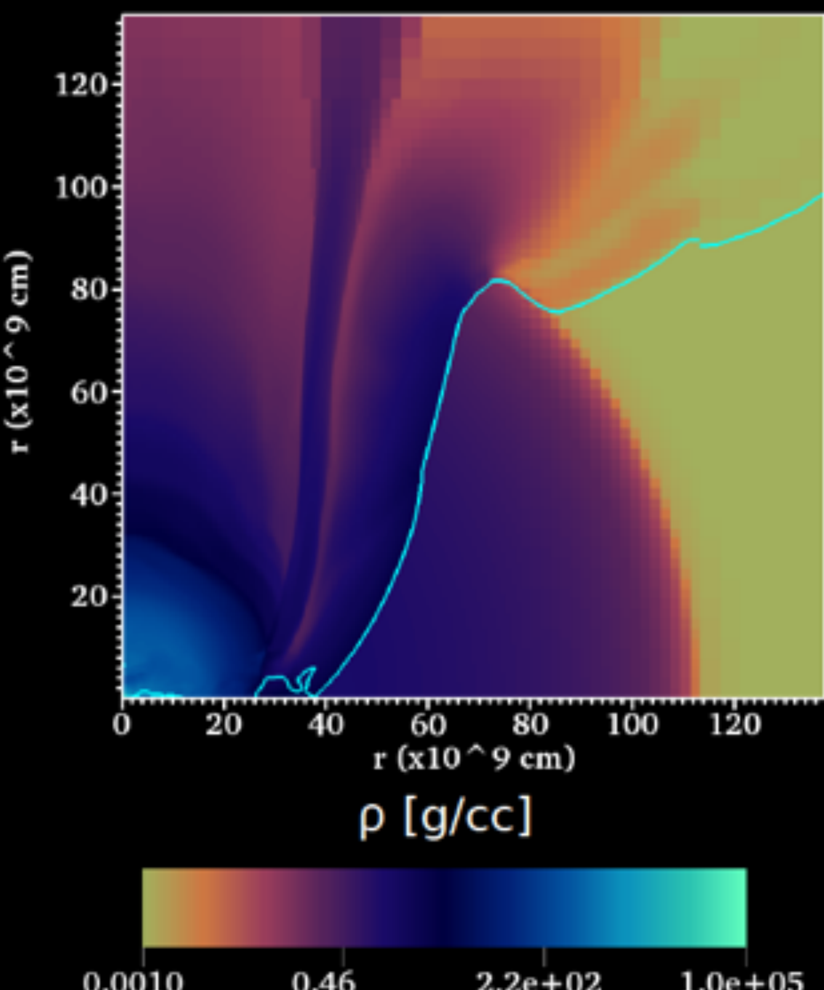
Burrows et al 2007, *ApJ*, **664**, 416

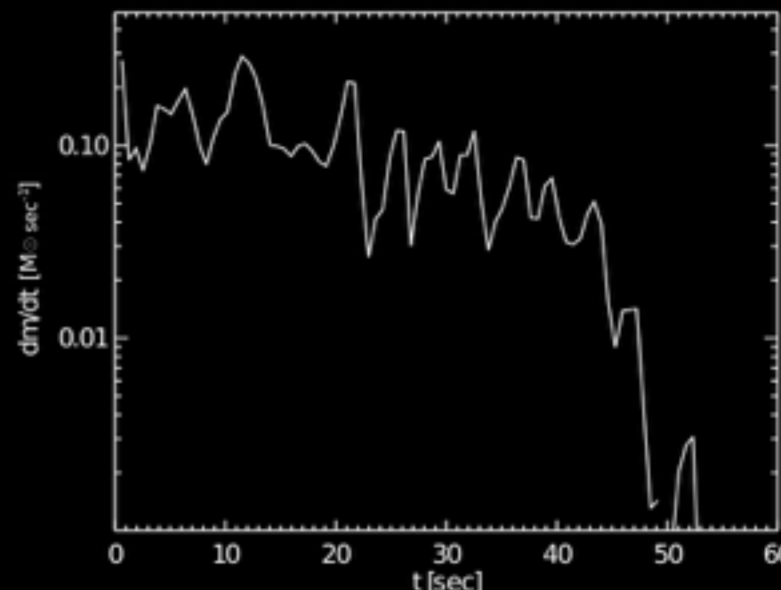
Central magnetar of B > 1e16 G, P < 1 ms

Magnetar-Powered Hypernovae and GRB



Fallback BH formation from Hypernovae



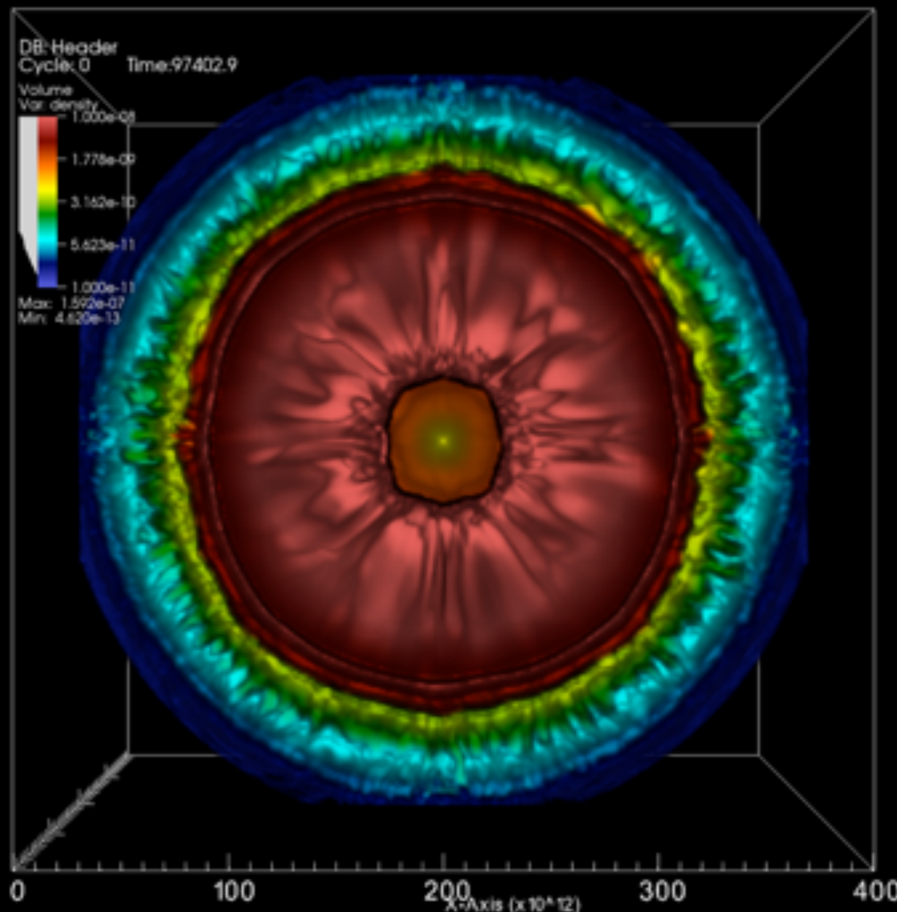


8 M⊙ CO Star > 4.54 M⊙ BH

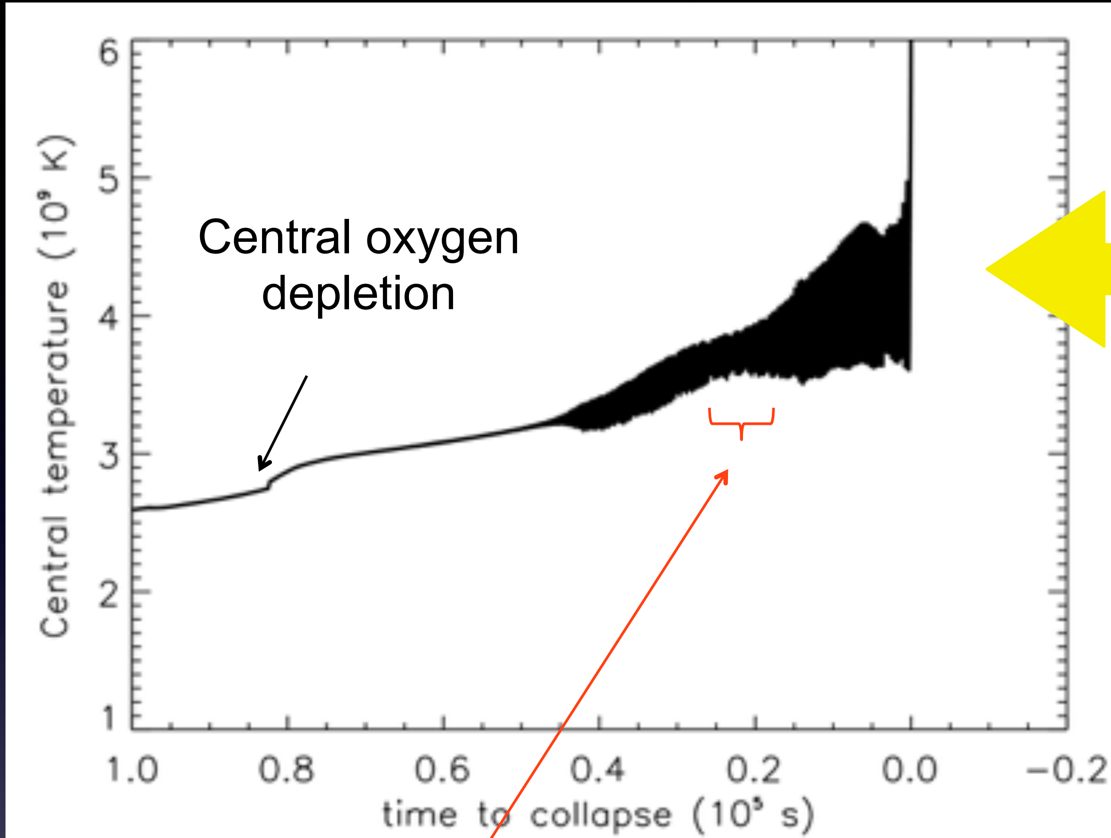
Chen+ ApJ 2017

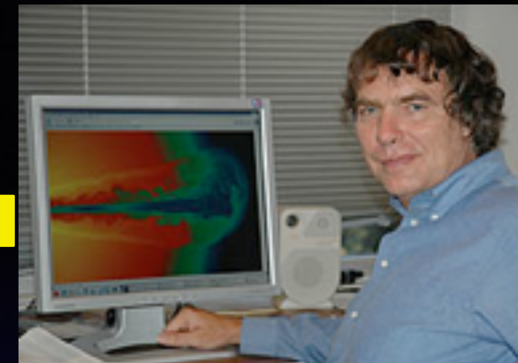
Pulsational Pair-Instability Supernovae

150 M⊙ > M* > 80 M⊙



Chen+ ApJ 792 28 (2014)





Based on Stan's Model

Woosley+ 2007, Woosley 2017

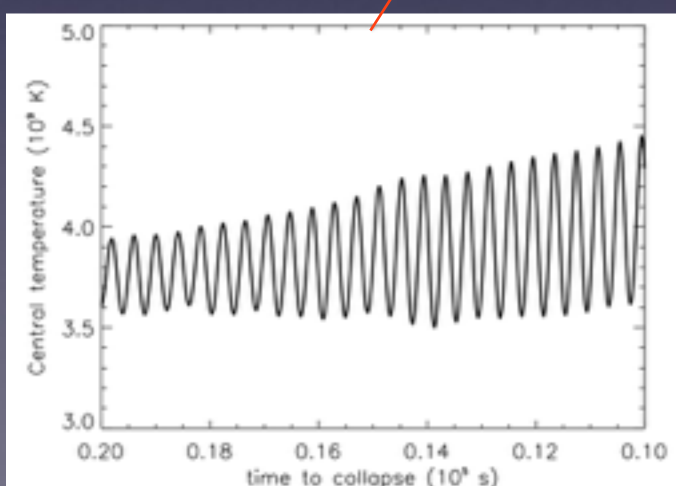
Woosley Priv. Comm.

80 M⊙ Helium core 35.7 M⊙

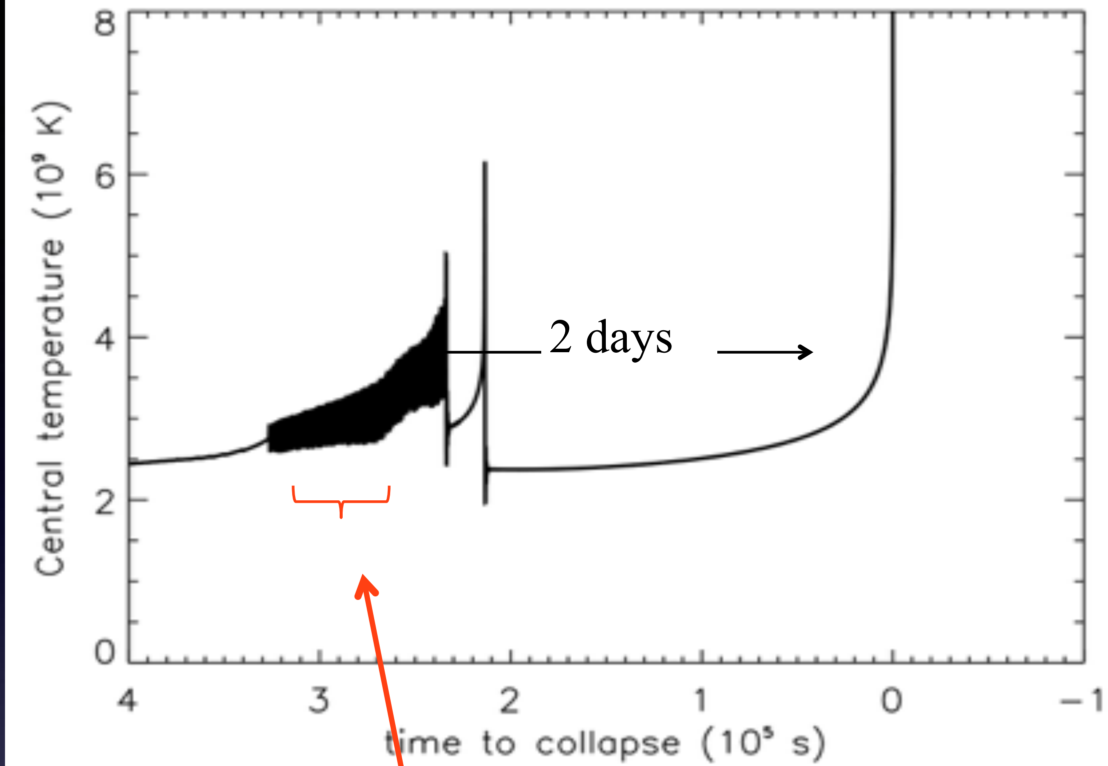
Pulsational instability begins shortly after central oxygen depletion when the star has about one day left to live (t = 0 here is iron core collapse).

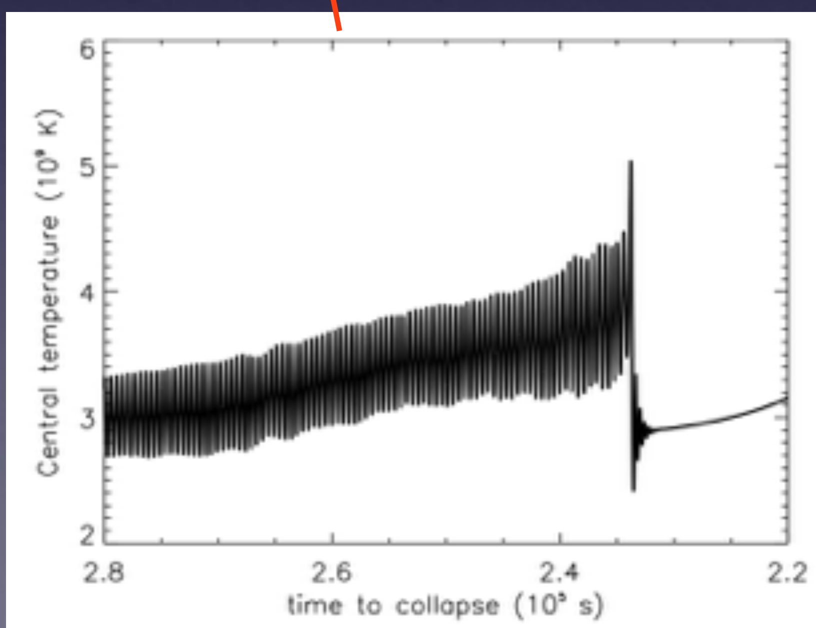
Pulses occur on a hydrodynamic time scale for the helium and heavy element core (~500 s).

For this mass, there are no especially violent single pulses before the star collapses. Nevertheless, there may be mass ejection.



80 M⊙ star > 35.7 M⊙ BH



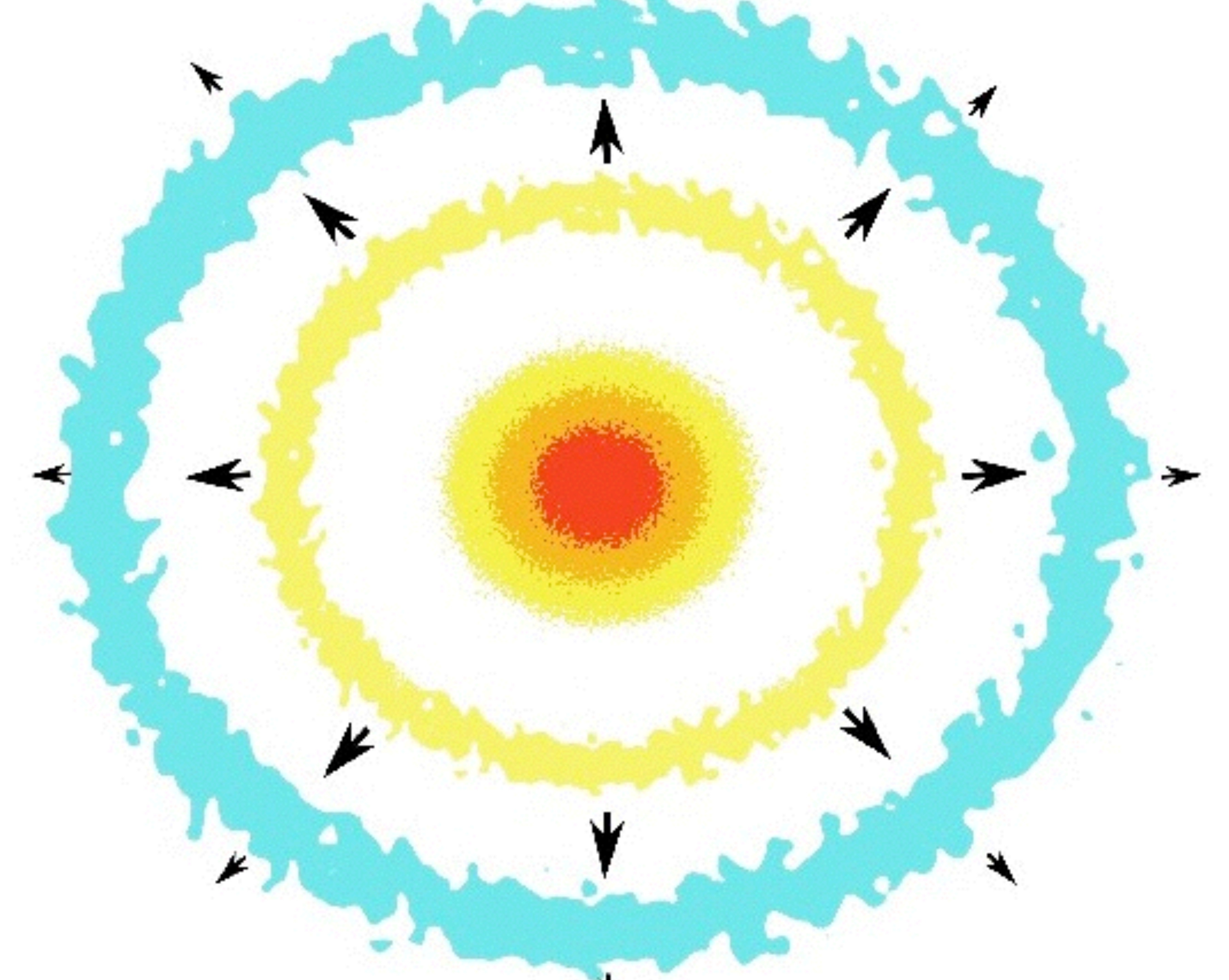


90 M⊙

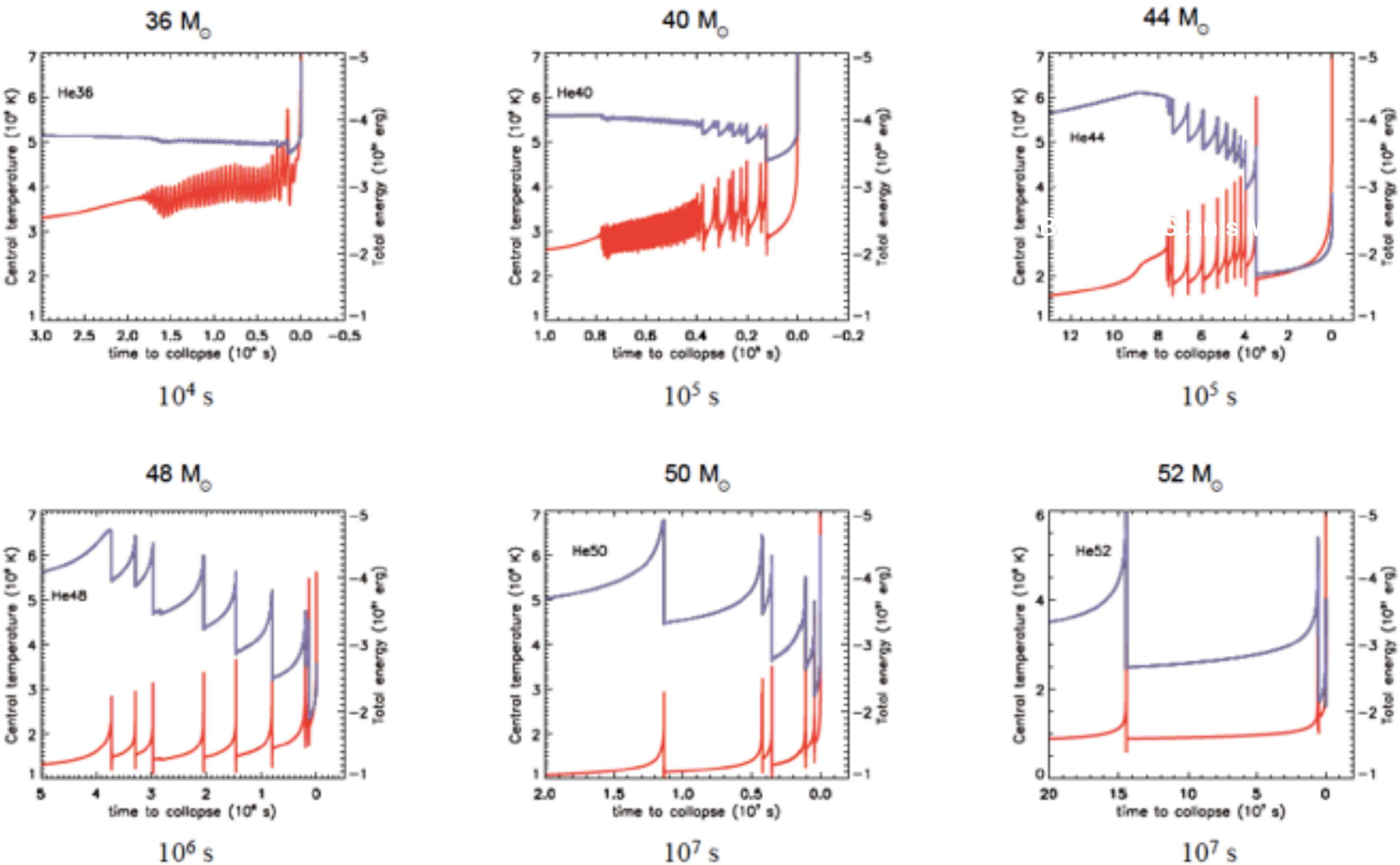
Helium core 41.3 M⊙

For still larger helium cores, the pulses become more violent and the intervals between them longer. Multiple supernovae occur but usually just one of them is very bright.

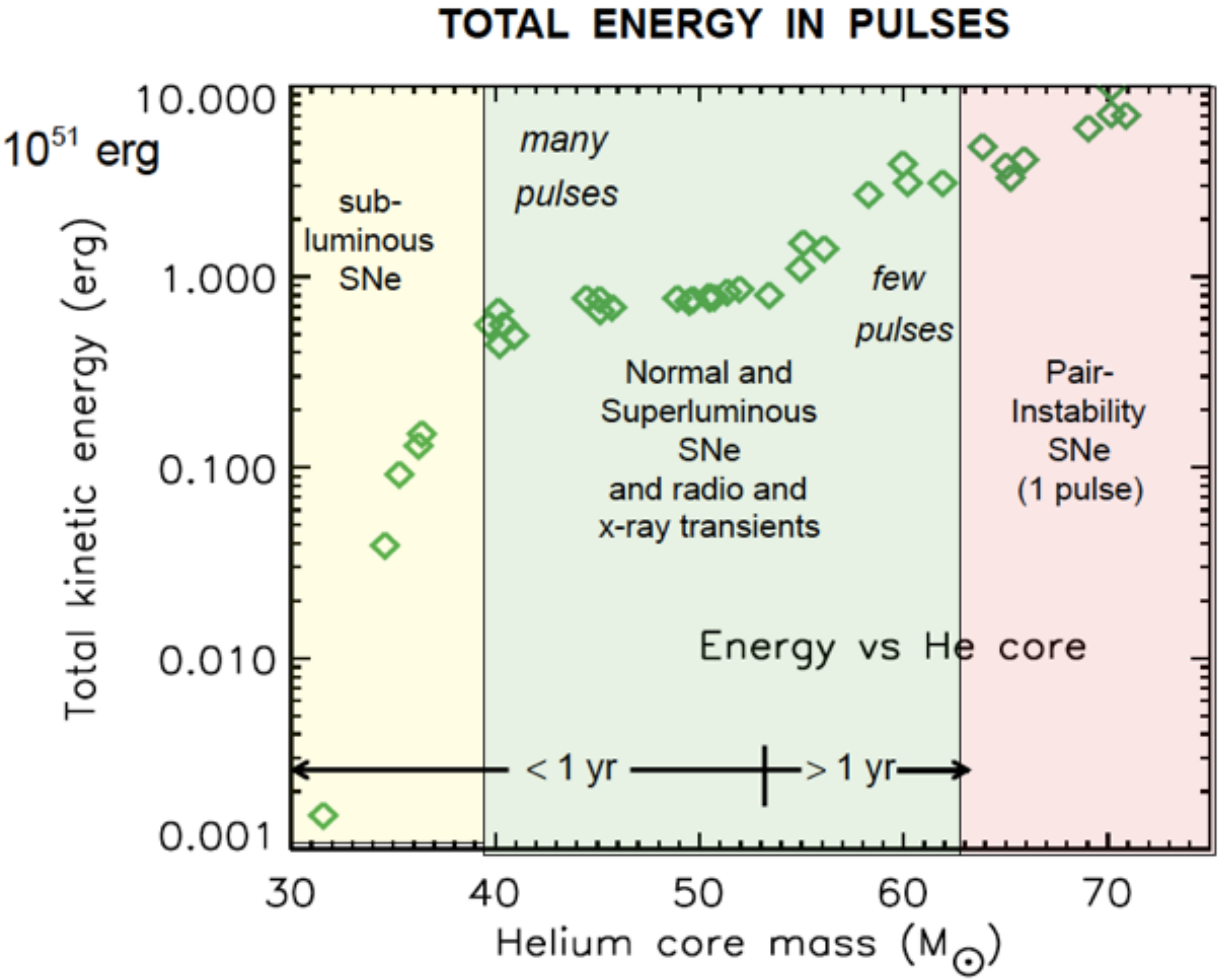
90 M⊙ star > 41.33 M⊙ BH



Stan's PPISNe Models



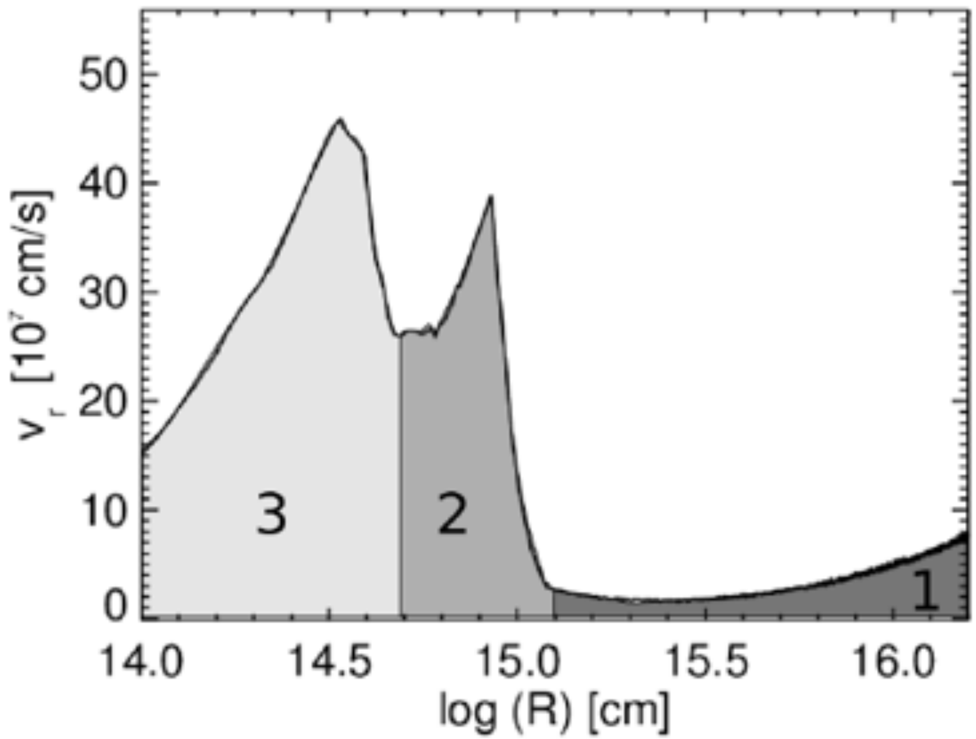
Total ejected mass from 0.1 M⊙ to 8 M⊙ depending on the helium core mass !!


TOTAL ENERGY IN PULSES
10^51 erg
Total kinetic energy (erg)
10.000
1.000
0.100
0.010
0.001
sub-
luminous
SNe
many
pulses
few
pulses
Normal and
Superluminous
SNe
and radio and
x-ray transients
Pair-
Instability
SNe
(1 pulse)
Energy vs He core
< 1 yr
> 1 yr
30
40
50
60
70
Helium core mass (M☉)

Core of 110 M⊙ star

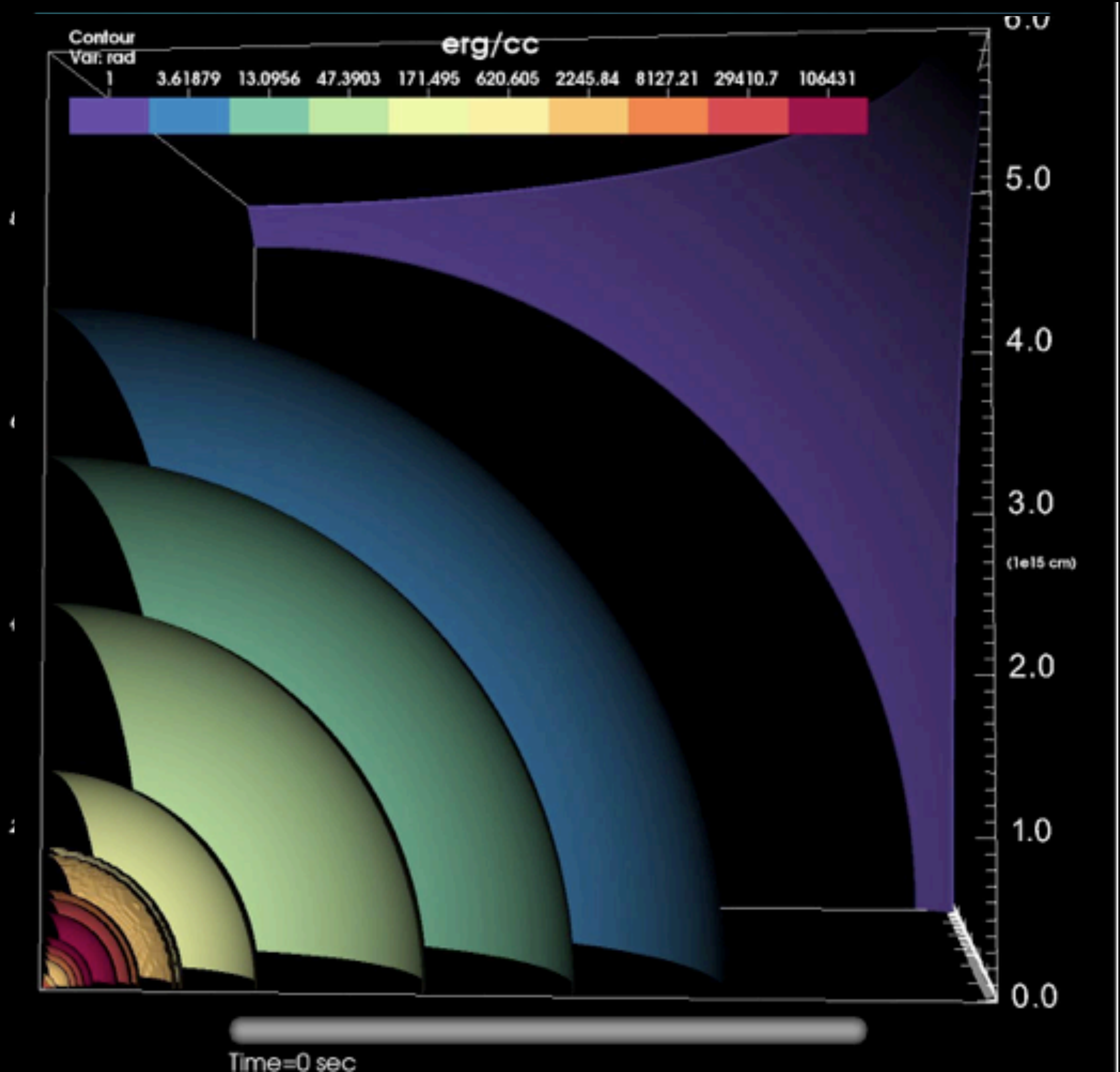
Eruption History

The star produces three violent outbursts.The first, P1, ejects most of the hydrogen envelope, making a faint Type II supernova and leaving a residual of 50.7 Msun, just a bit more than the helium core itself. After 6.8 yr, the core again contracts and encounters the pair instability, twice in rapid succession. The total mass of the second and third pulses (P2 and P3) is 5.1 Msun and their kinetic energy is 6e50 erg. P3 collides with P2 at large optical depths that are not visible to an external observer. These combined shells then overtake P1 at 1e15 cm and speeds of a few 1000 km/s.

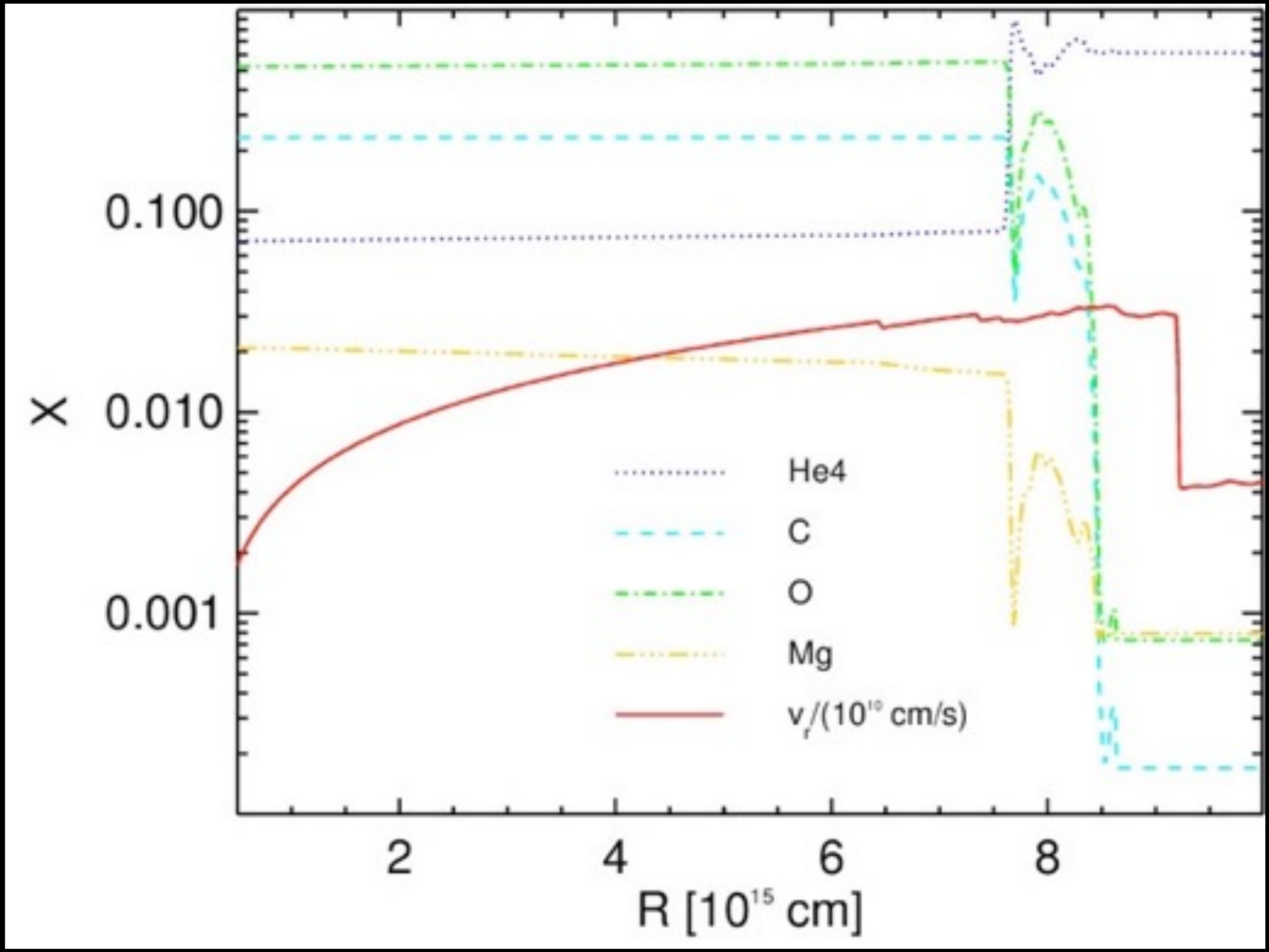


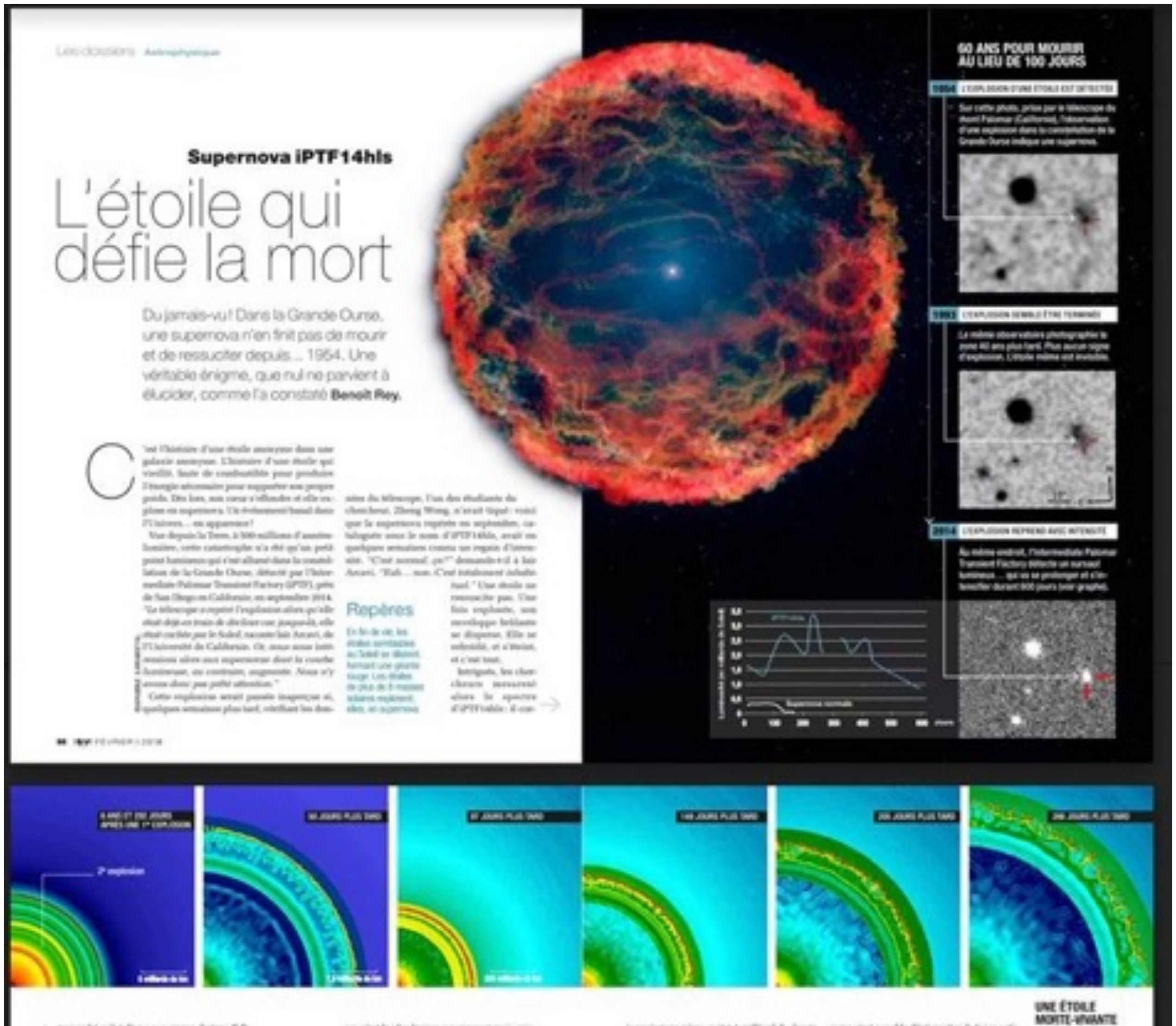
110 M⊙ star > 54.2 M⊙ BH

Physical Properties of Colliding Shells



Mixing of PPSNe





Les dossiers

Supernova iPTF14hls

L'étoile qui défie la mort

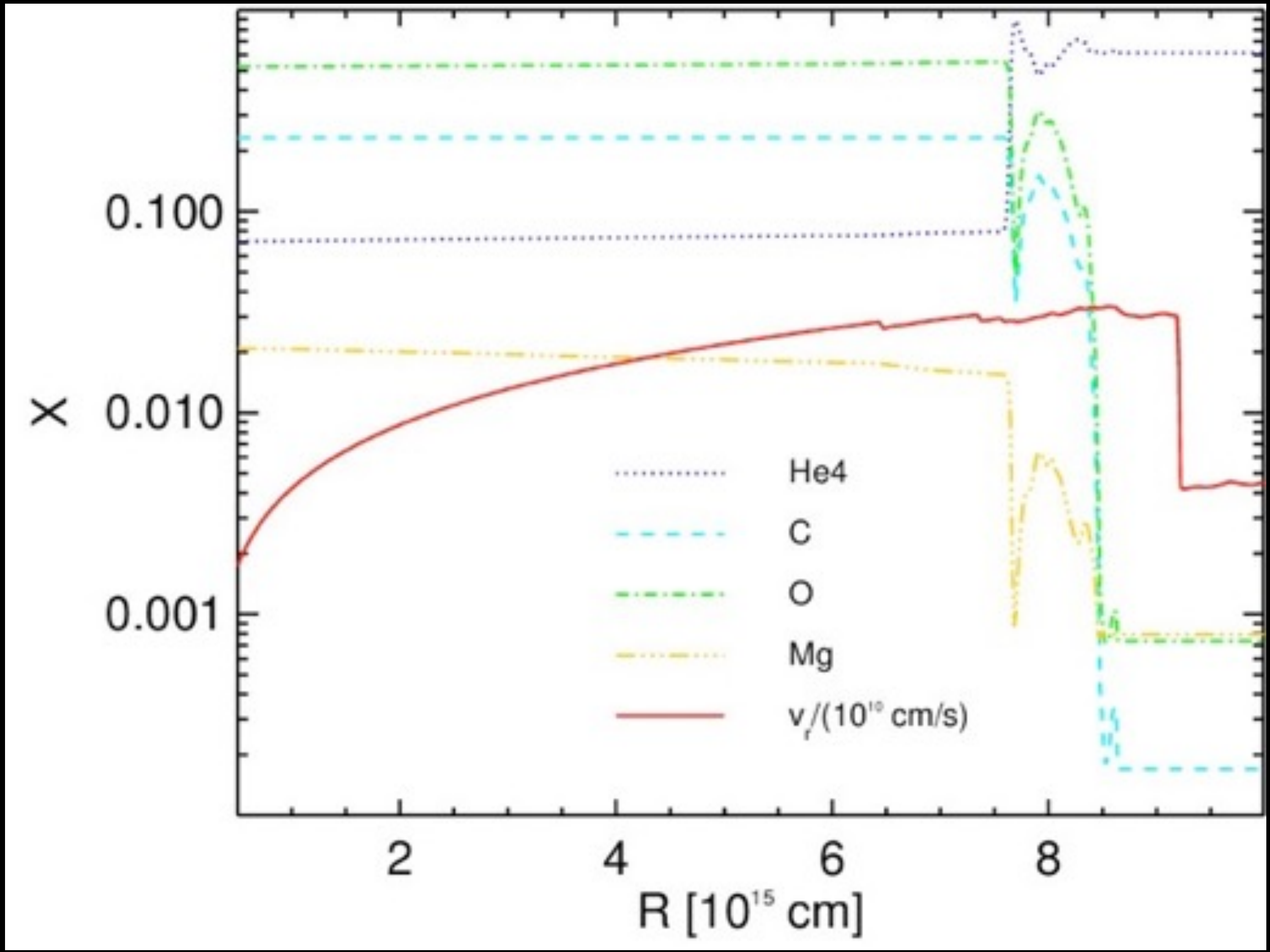
Du jamais-vu ! Dans la Grande Ourse, une supernova n'en finit pas de mourir et de ressuciter depuis… 1954. Une véritable énigme, que nul ne parvient à élucider, comme l'a constaté **Benoît Rey.**

Repères

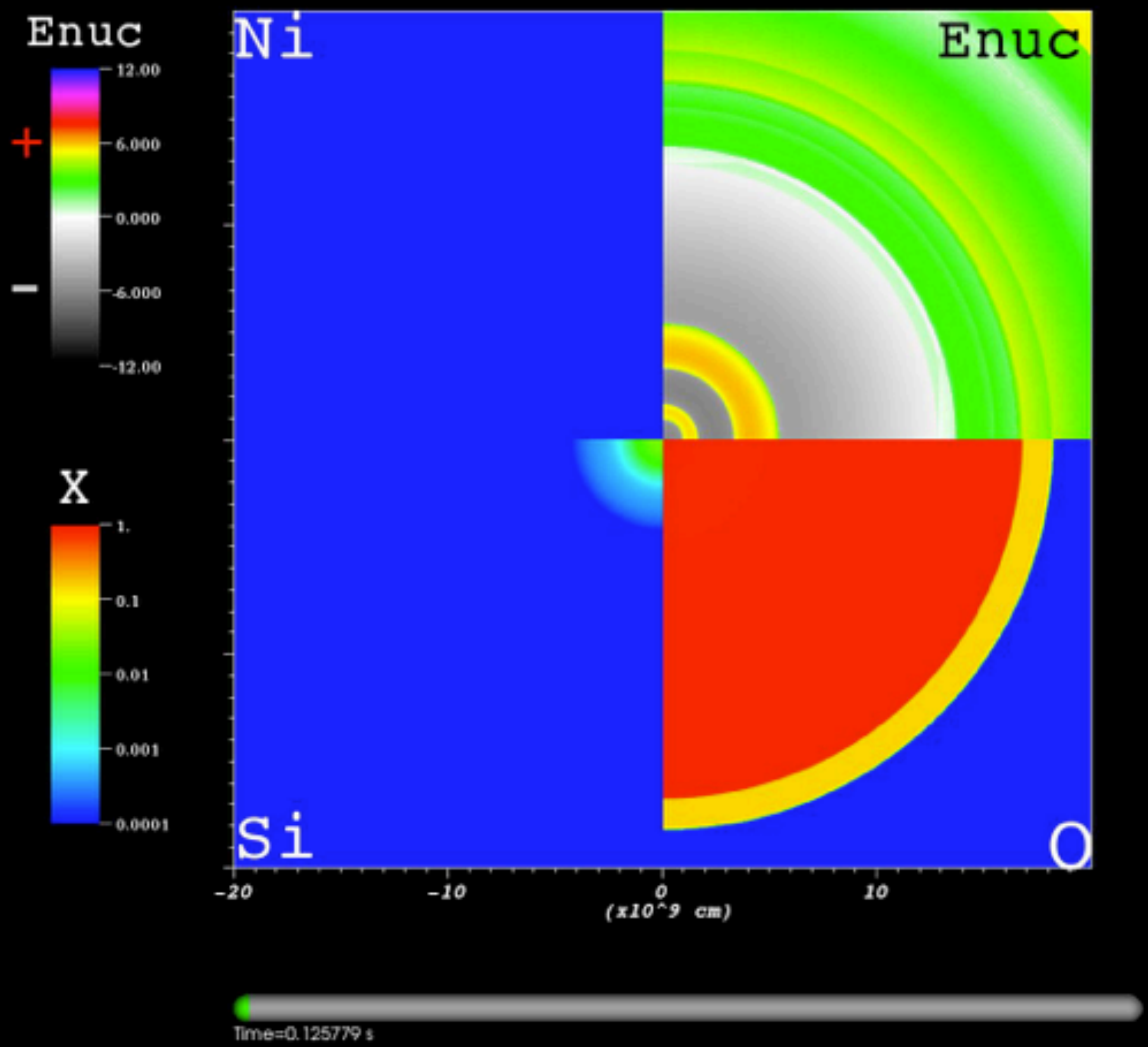
60 ANS POUR MOURIR AU LIEU DE 100 JOURS

UNE ÉTOILE MORTE-VIVANTE

Mixing of PPSNe

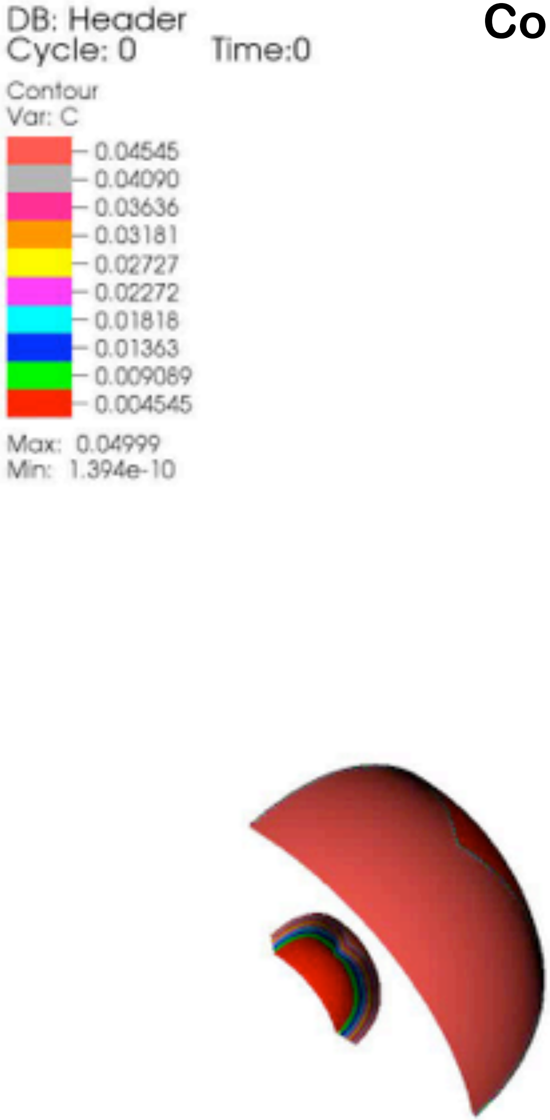


Explosive Burning of 150 M⊙ Star

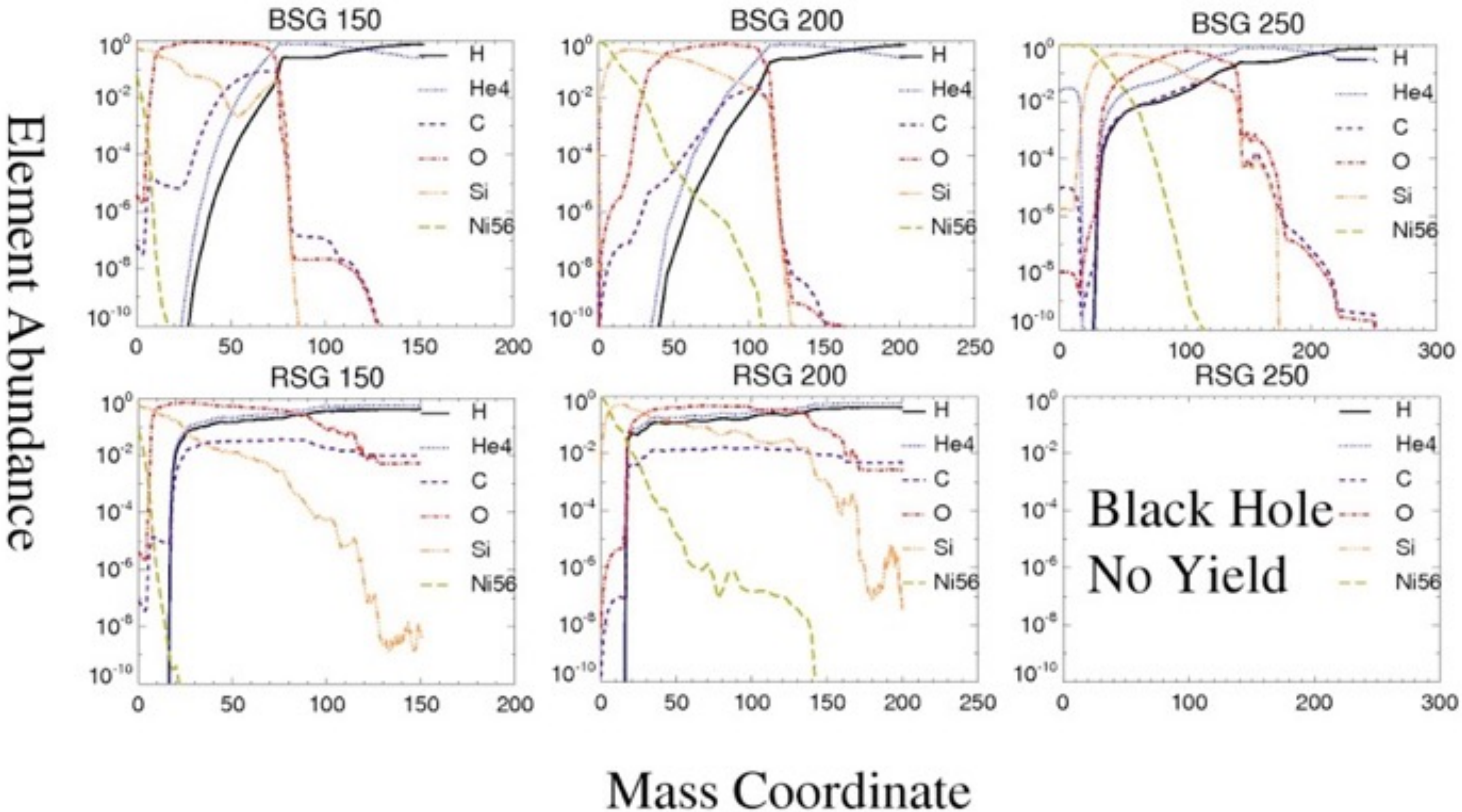


Chen+ ApJ 792 44 (2014)

Core of 150 M☉ Star



Mixing of Elements



The Death of Massive Stars and their black holes

Woosley, Heger, & Weaver (2002)

MS Mass	He Core	Supernova Mechanism
	(solar mass ⊙)	
$10 \leq M \leq 80$	$2 \leq M \leq 32$	Fe core collapse to a neutron star or black hole
$80 \leq M \leq 150$	$35 \leq M \leq 60$	Pulsational pair instability followed by core (PPSN)
$150 \leq M \leq 250$	$60 \leq M \leq 133$	Pair instability supernova (PSN)
$250 \leq M$	$133 \leq M$	All BH or any Bang??

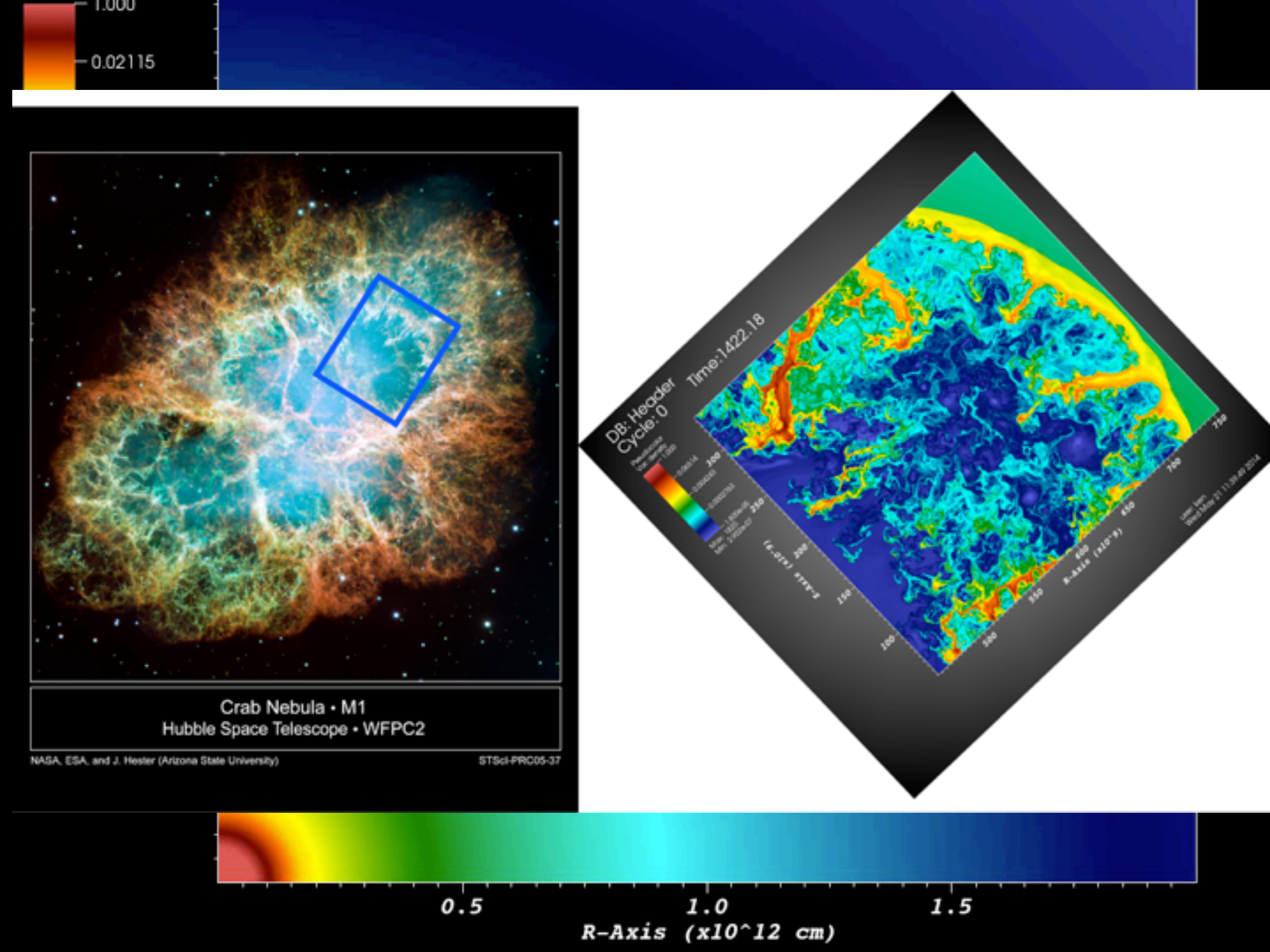
BH up to ~ 32

BH up to ~ 60, fallback can add up??

BH ~ 0 ?

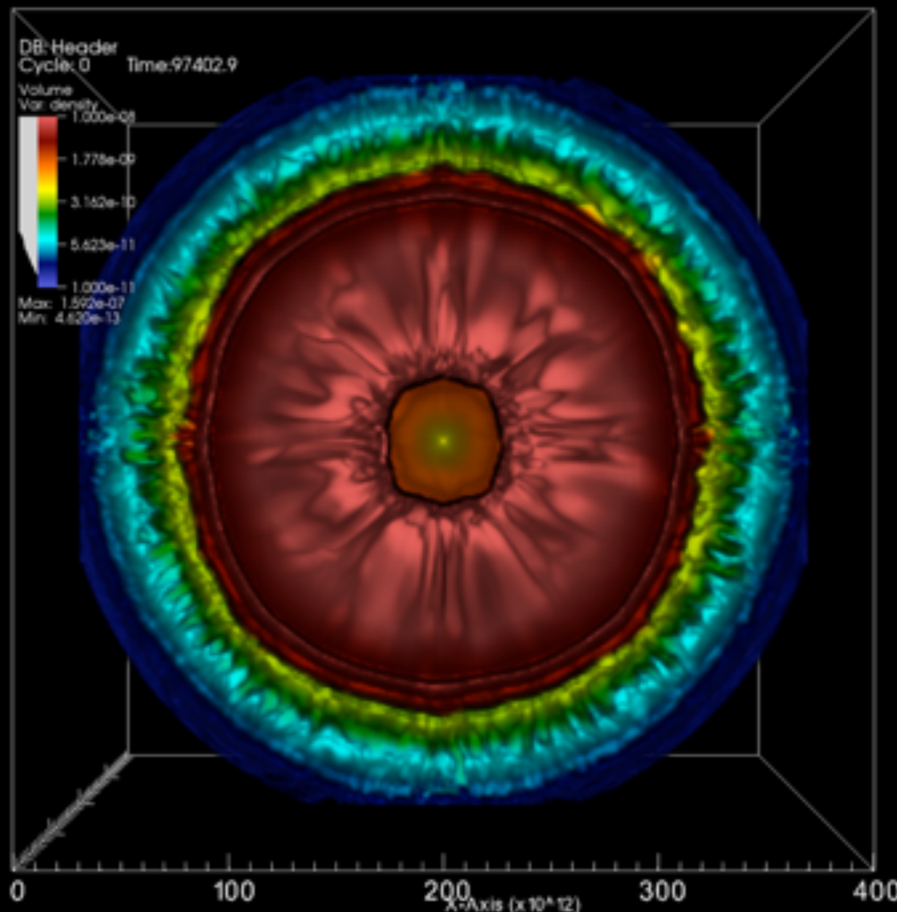
1D stellar evolution issues: mass loss, rotation, convection ?

Multi-D Explosions issues: explosion engines, fallback ?



1.000
0.02115
Crab Nebula • M1
Hubble Space Telescope • WFPC2
NASA, ESA, and J. Hester (Arizona State University)
STScI-PRC05-37
DB: Header
Cycle: 0
Time:1422.18
0.5
1.0
1.5
R-Axis (x10^12 cm)

Mulit-D Simulations of PPSNe



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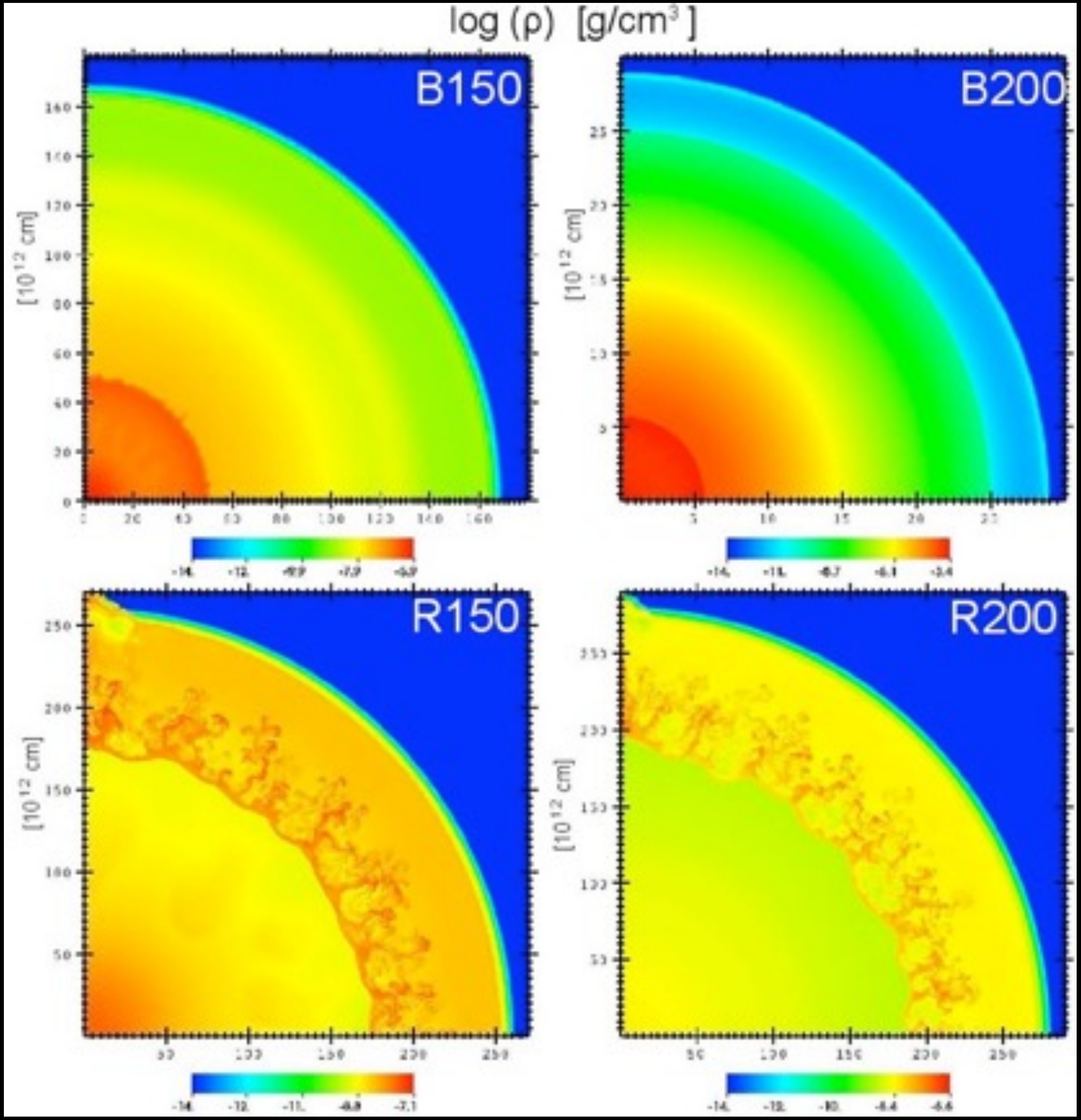
Mixing of PSNe



Results

Model	Mass [M⊙]	Core [M⊙]	E [10 ^{52} erg]	Ni [M⊙]	Instab.	Mixing
B150	150	67	1.29	0.07	Burning	weak
B200	200	95	4.14	6.57	Burning	weak
B250	250	109	7.23	28.05	Burning	weak
R150	150	59	1.19	0.1	Rev.	Strong
R200	200	86	3.43	4.66	Rev.	Strong
R250	250	156	...	...	...	...

Ni is only slightly mixed out .
The Gamma-Ray emission for PSNe is unlikely.