Mass Loss and the Death of Very Massive Stars

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EACOA Fellow, NAOJ
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Mist of Mass Loss

- Rotation: Georges, Norbert, Thomas, Ilya, Pablo
- Convection: Raphael, Stan, Matteo, Eliot
- Simulation: Yan-Fei, Matteo
- SN: Thierry, Ryan, Nathan, Ken Nomoto, …

Mass Loss

Death of Fat Stars

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Mass Loss ↔ **Death of Fat Stars**

Who pays the bill for mass loss or giant eruptions?

Death of Non-rotating Massive Stars

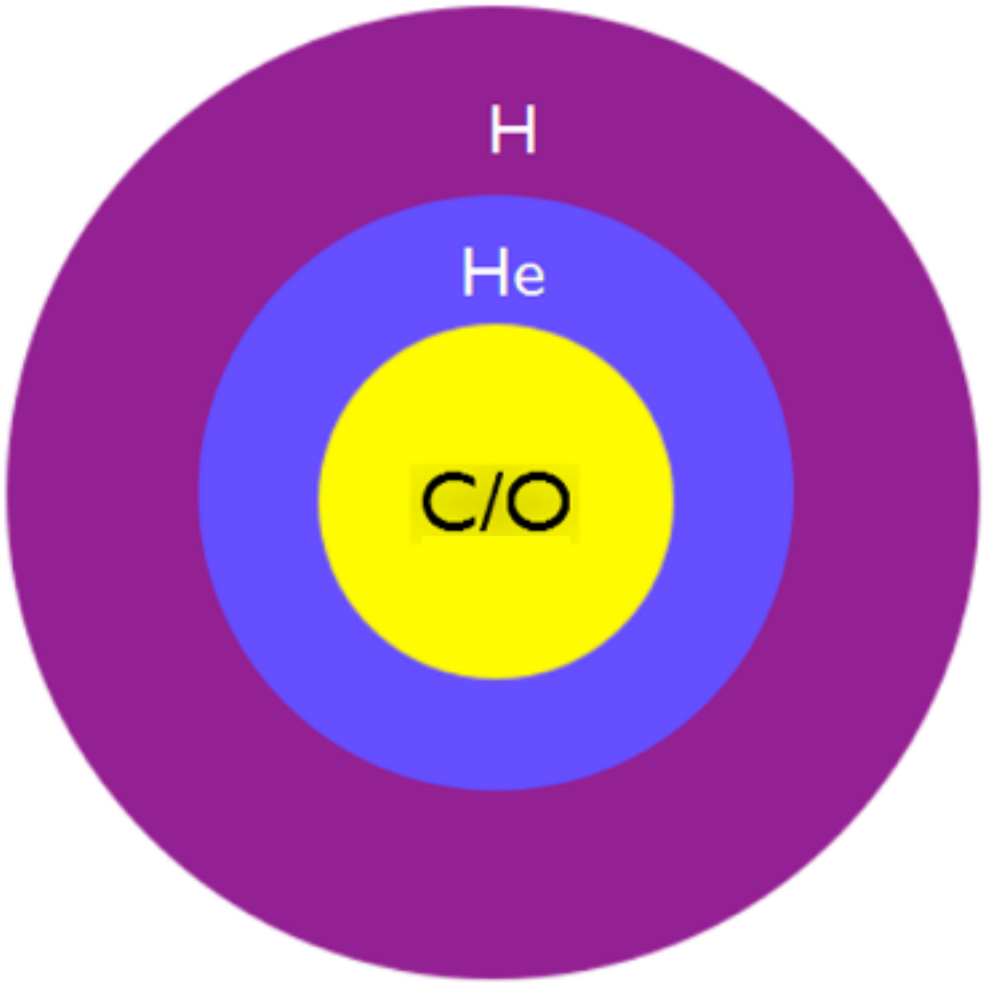
Woosley, Heger, & Weaver (2002)

MS Mass	He Core	Supernova Mechanism
Poorly known	Well known	
$10 \leq M \leq 85$	$2 \leq M \leq 32$	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??

Mass Unit: solar mass $\odot$

Fate of Very Massive Stars

Star > 80 M☉



Fate of Very Massive Stars

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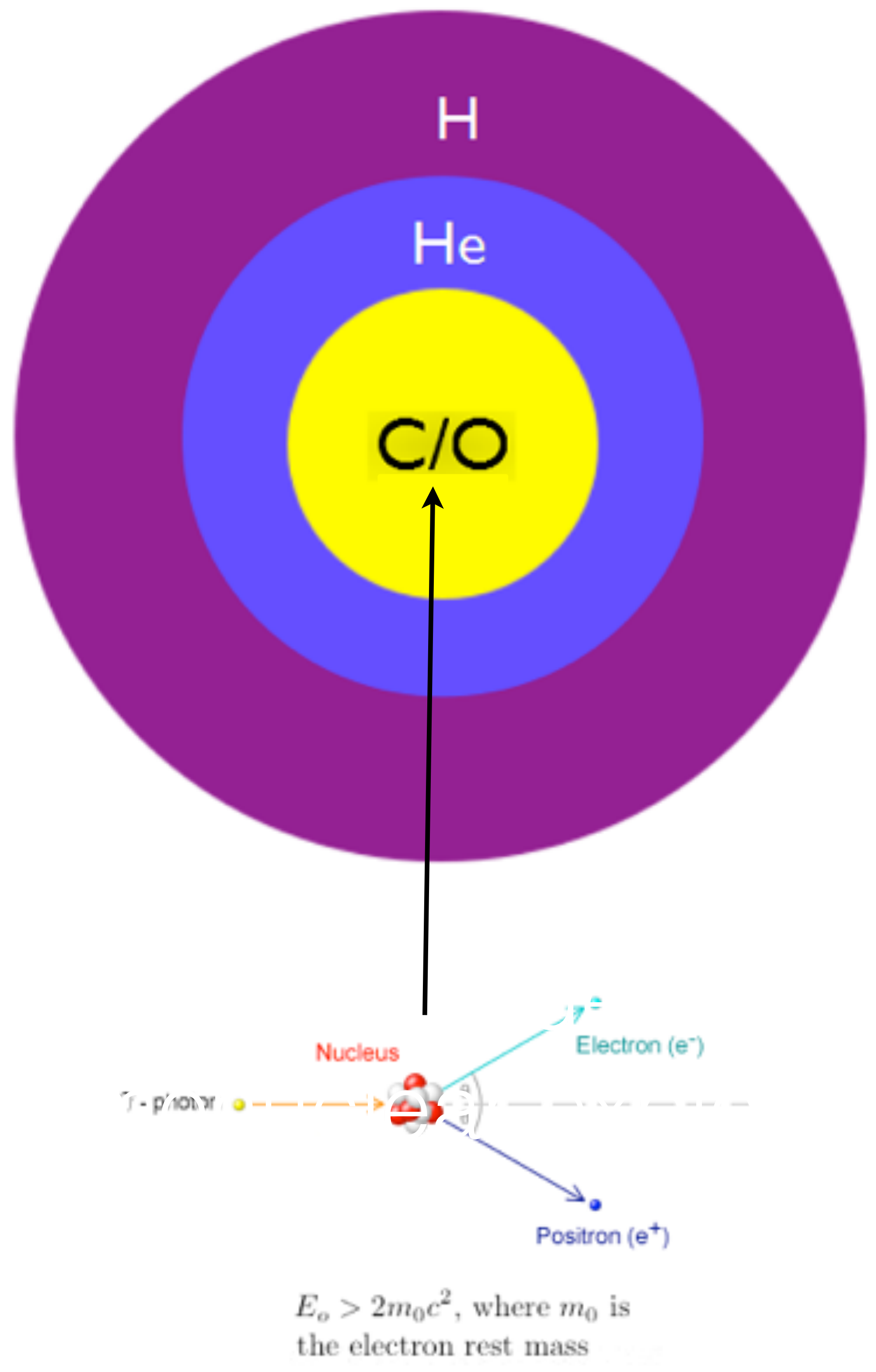

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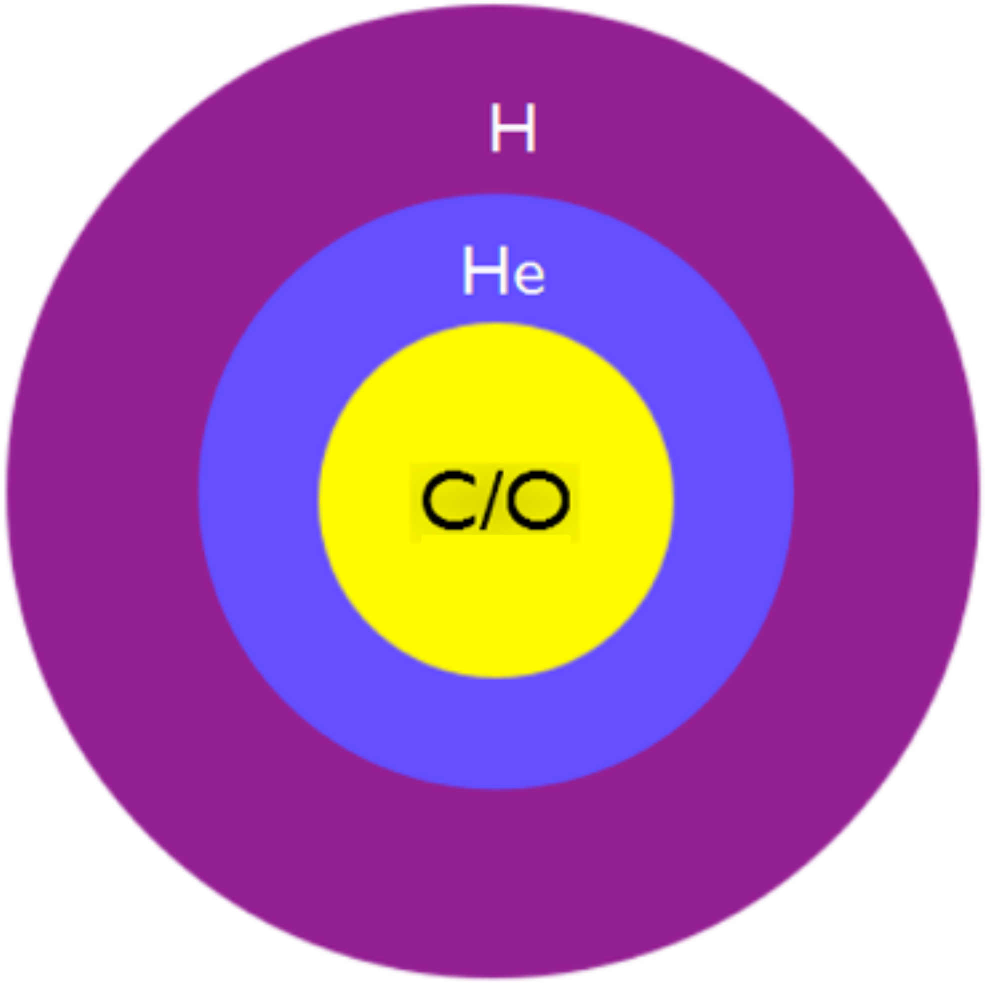

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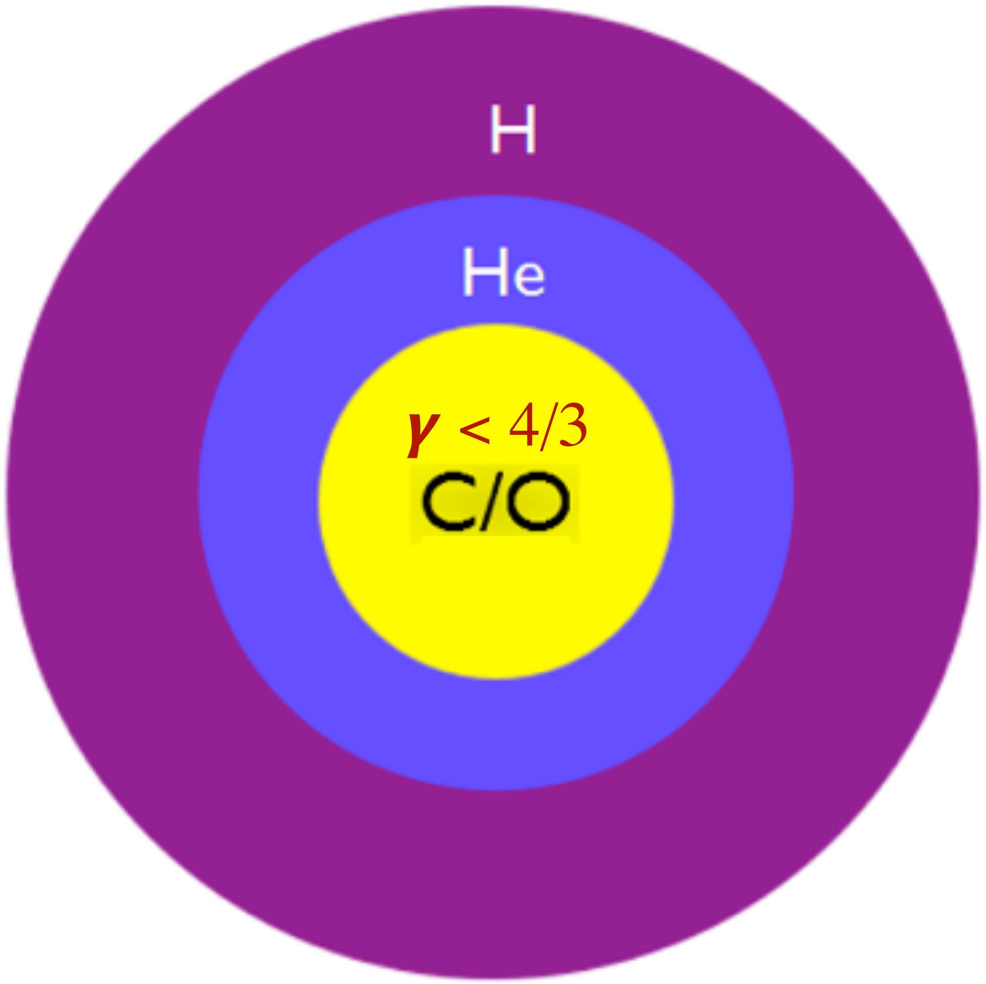

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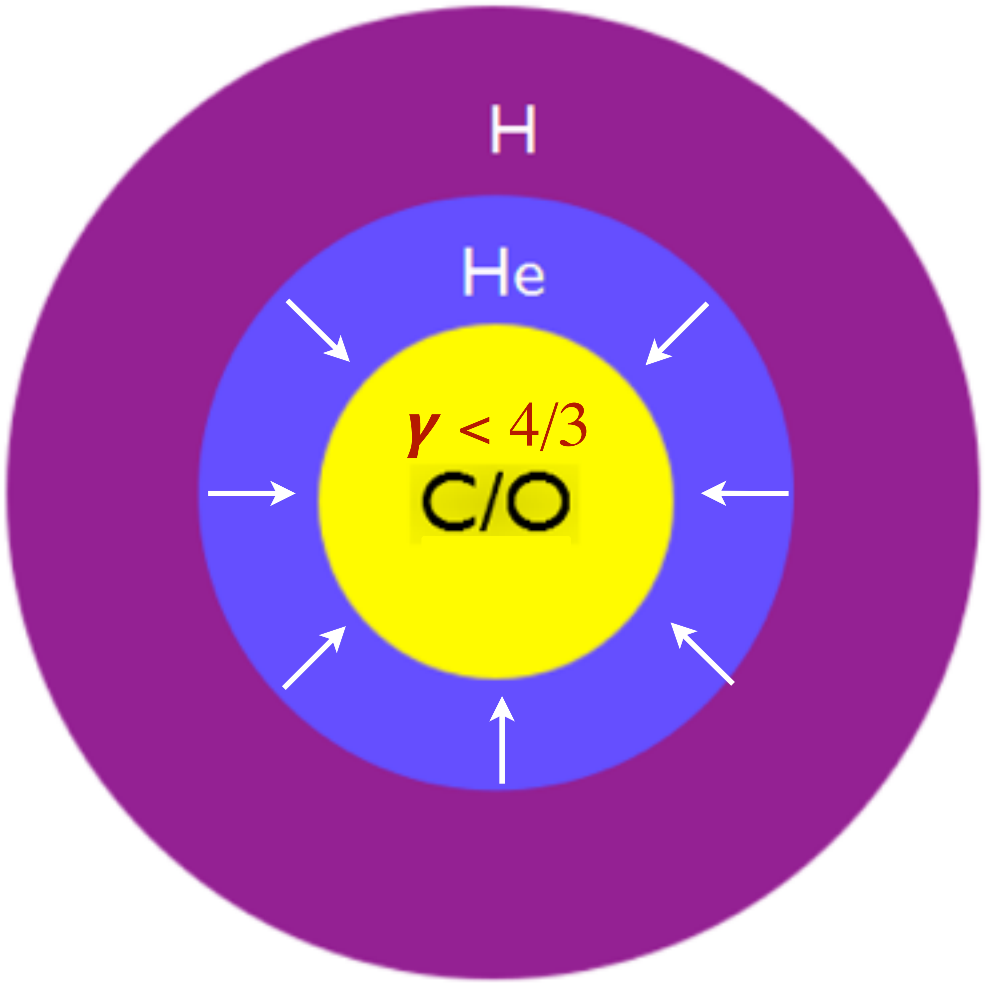

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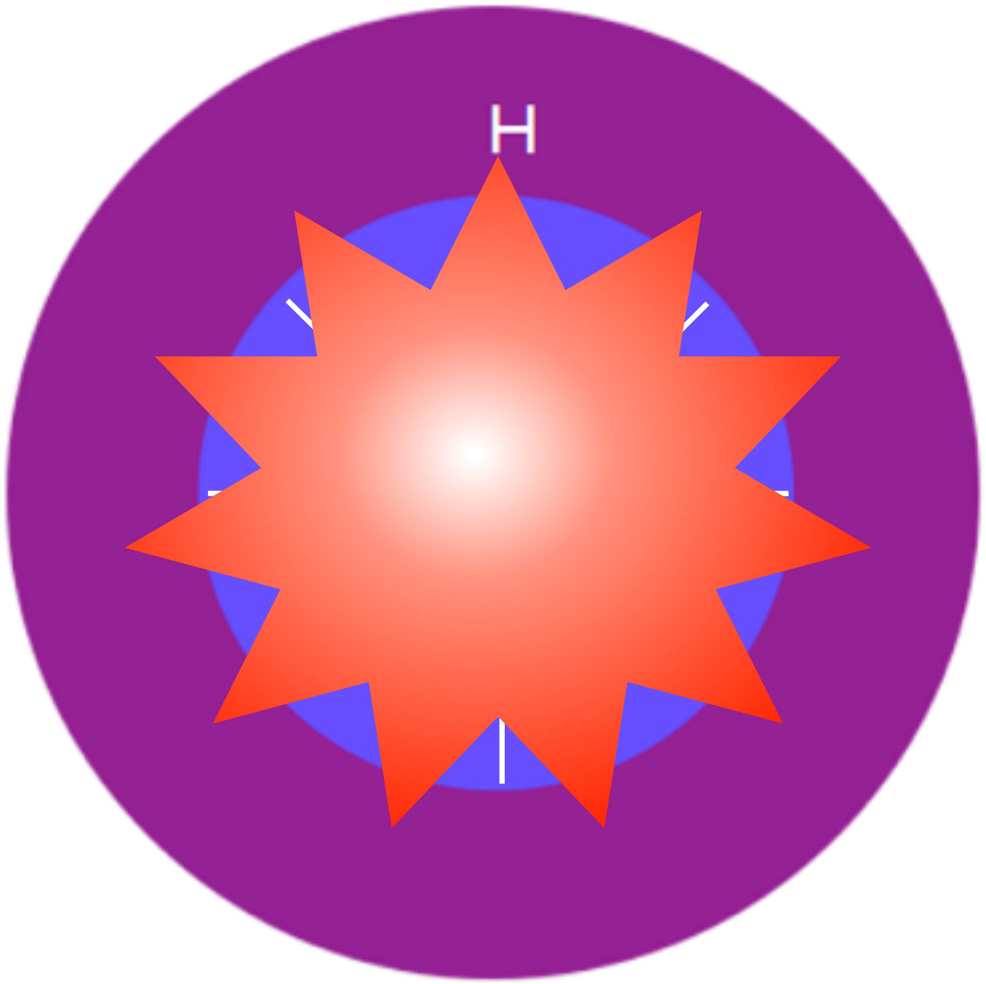
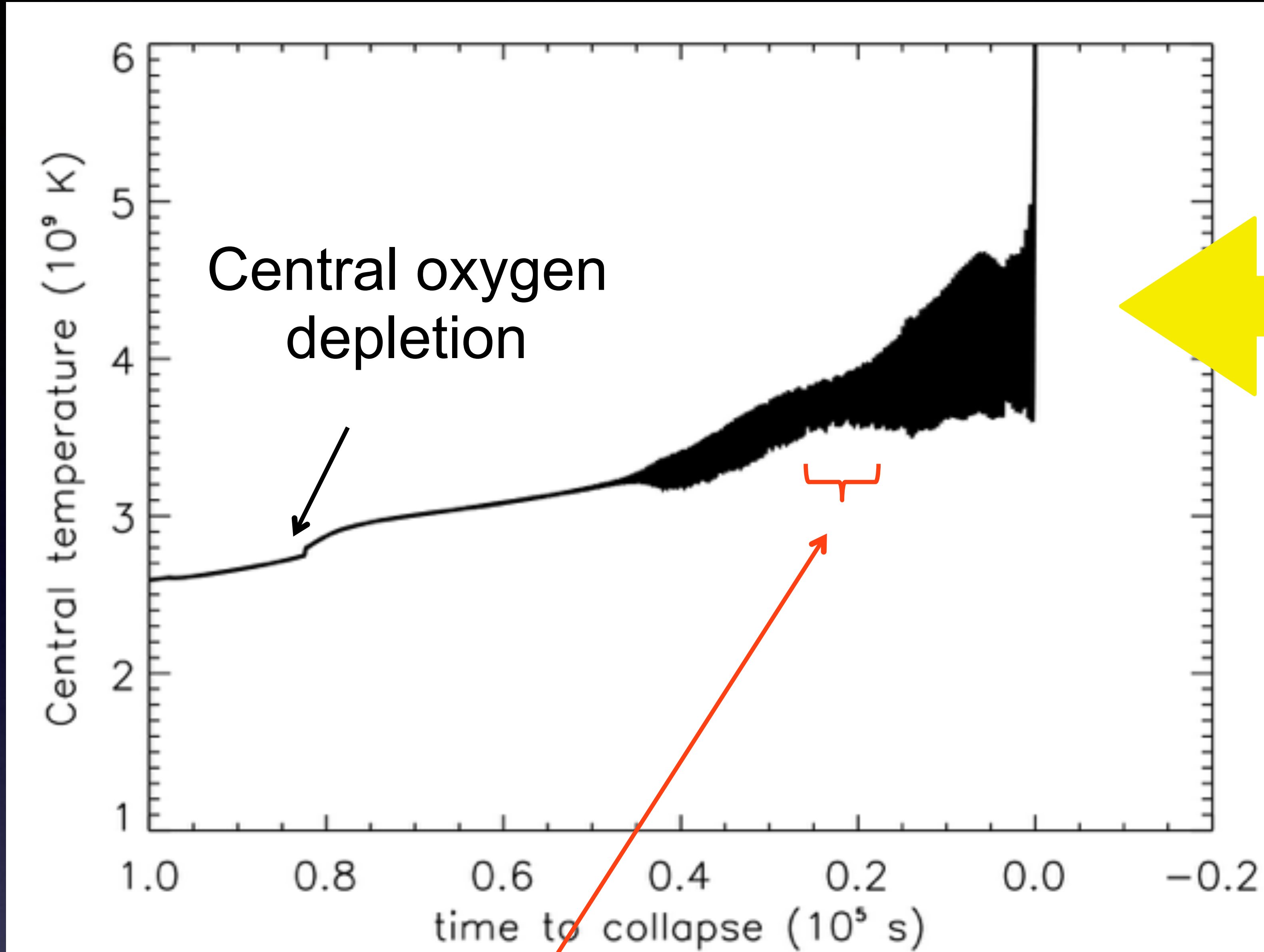
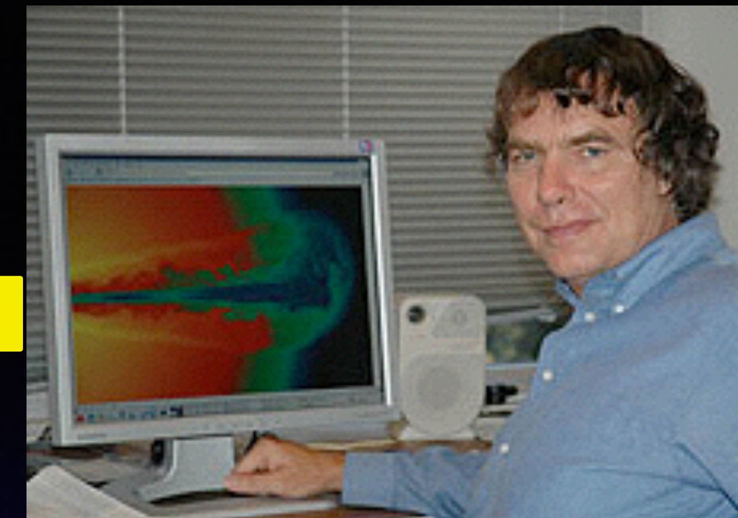



We have a better understanding of
Thermonuclear explosion





Based on Stan's Model

Woosley+ 2007, Woosley+ 2016

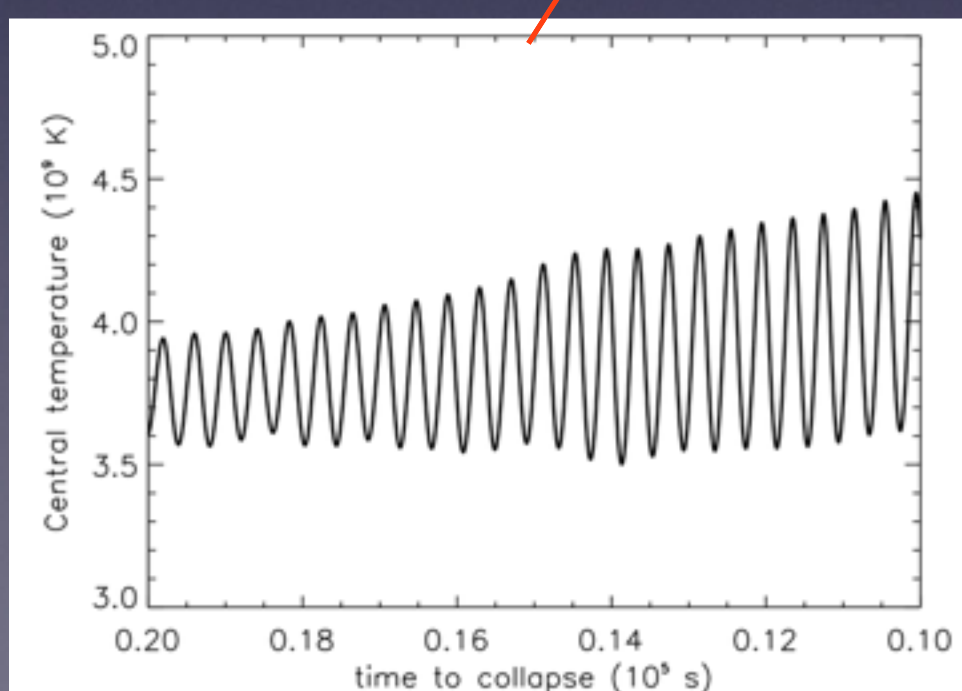
Woosley Priv. Comm.

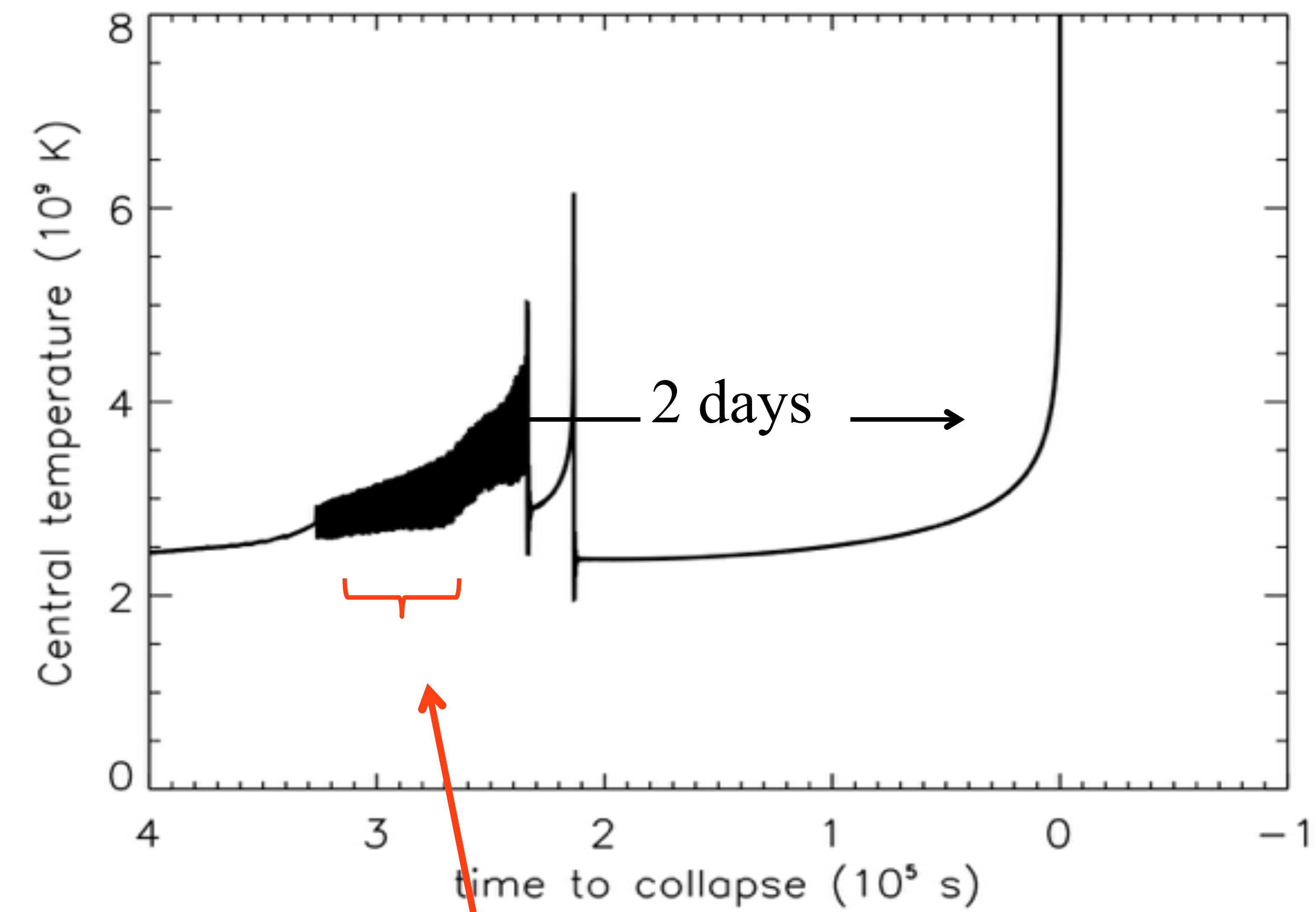
80 M⊙ Helium core 35.7 M⊙

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).

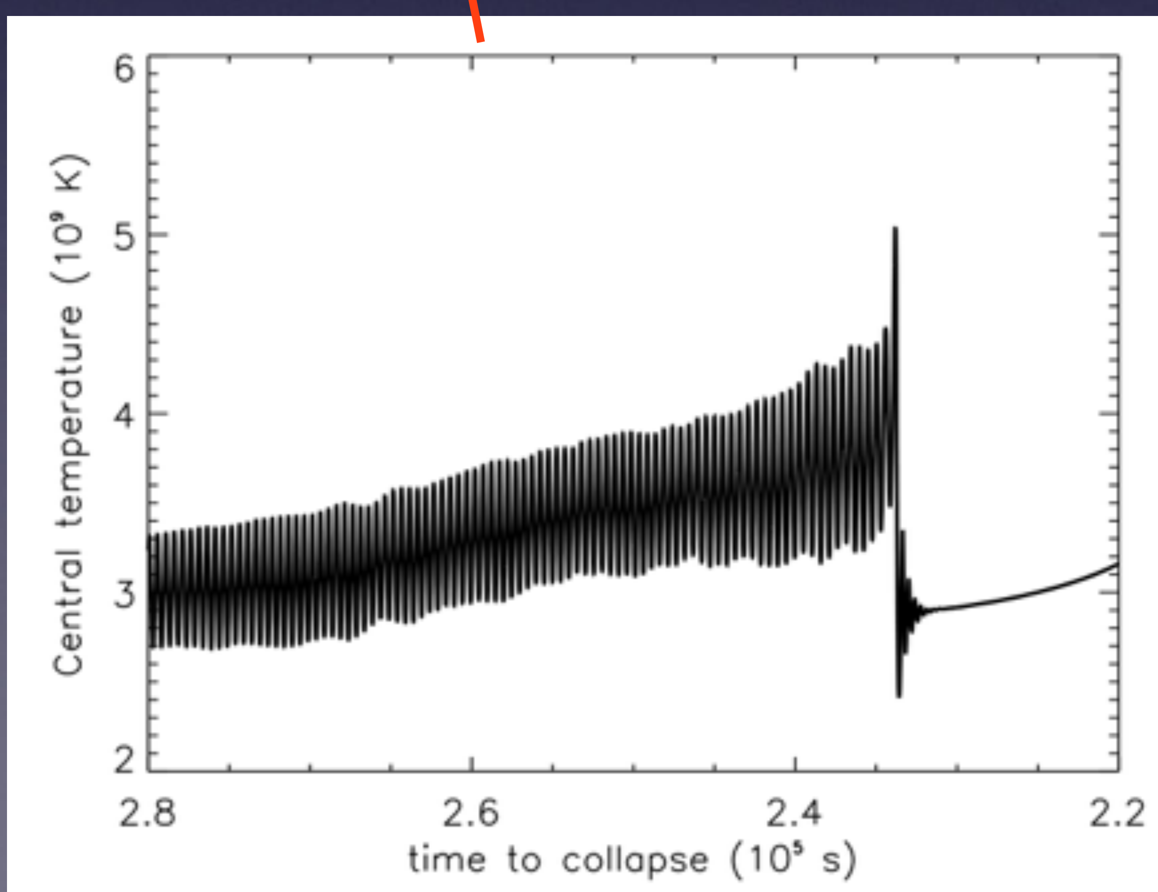
For this mass, there are no especially violent single pulses before the star collapses. Nevertheless, there may be mass ejection.



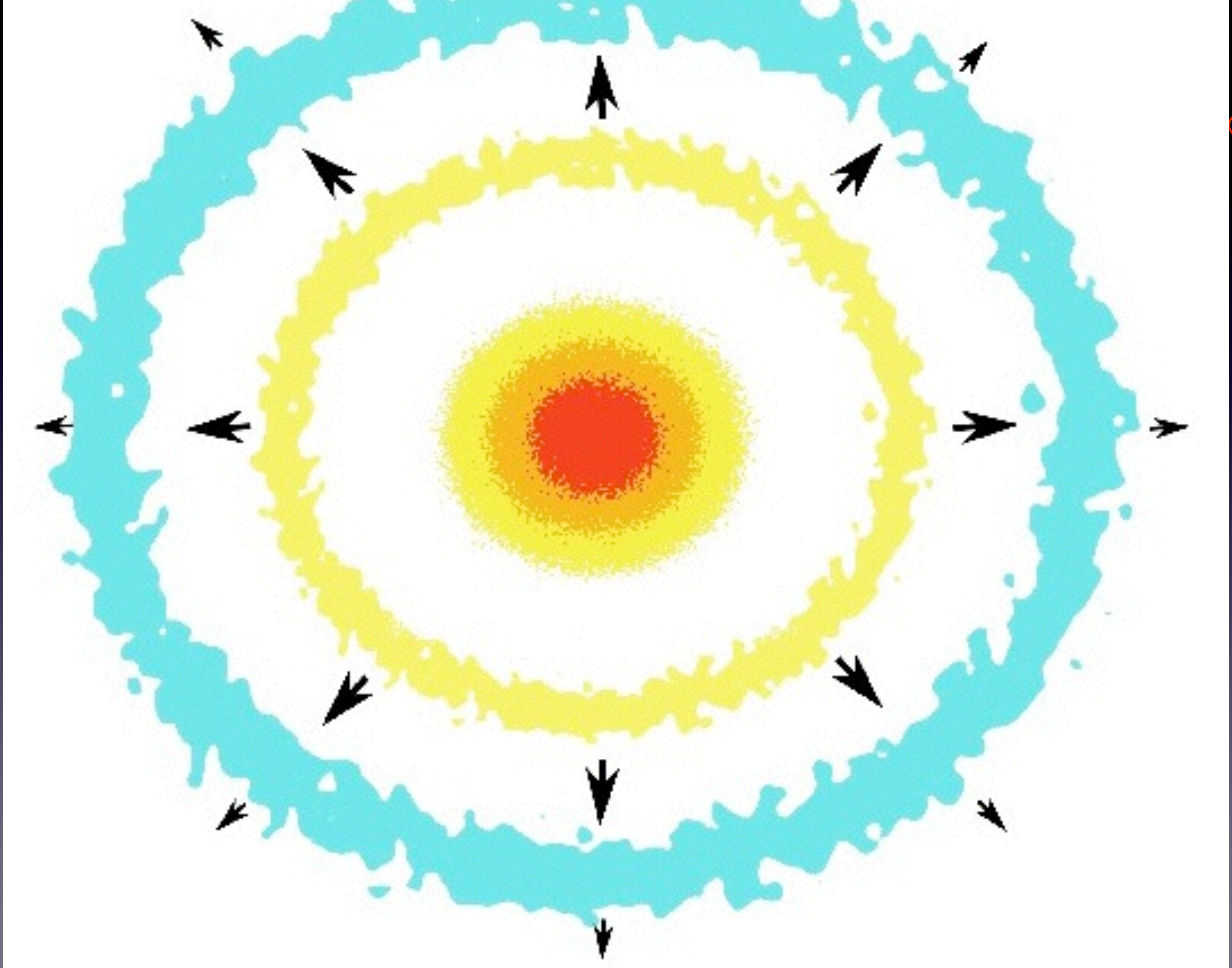


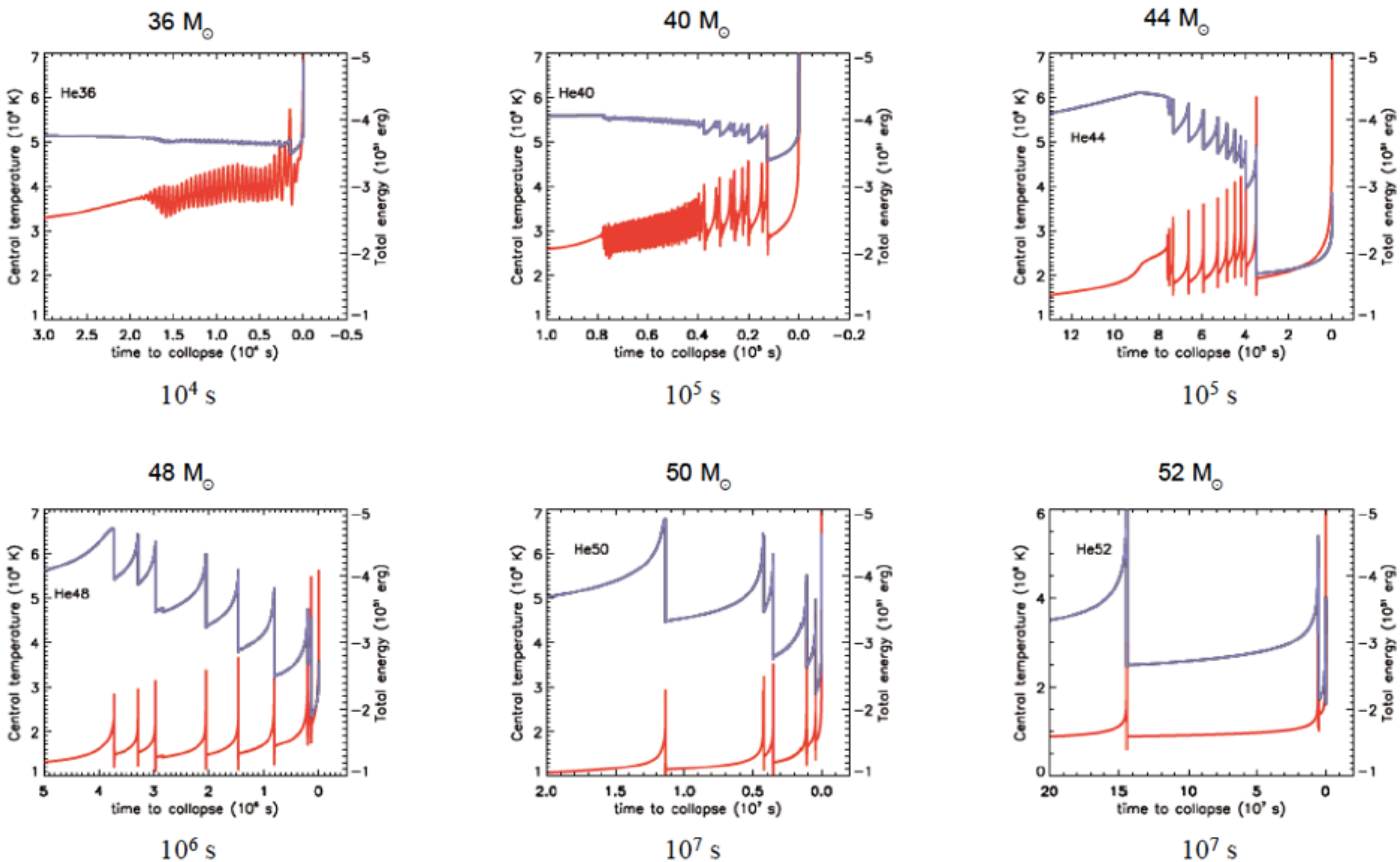
90 M⊙
Helium core 41.3 M⊙

Pulses commence again after central oxygen depletion, but become more violent. Two strong pulses send shock waves into the envelope. Two days later the iron core collapses.

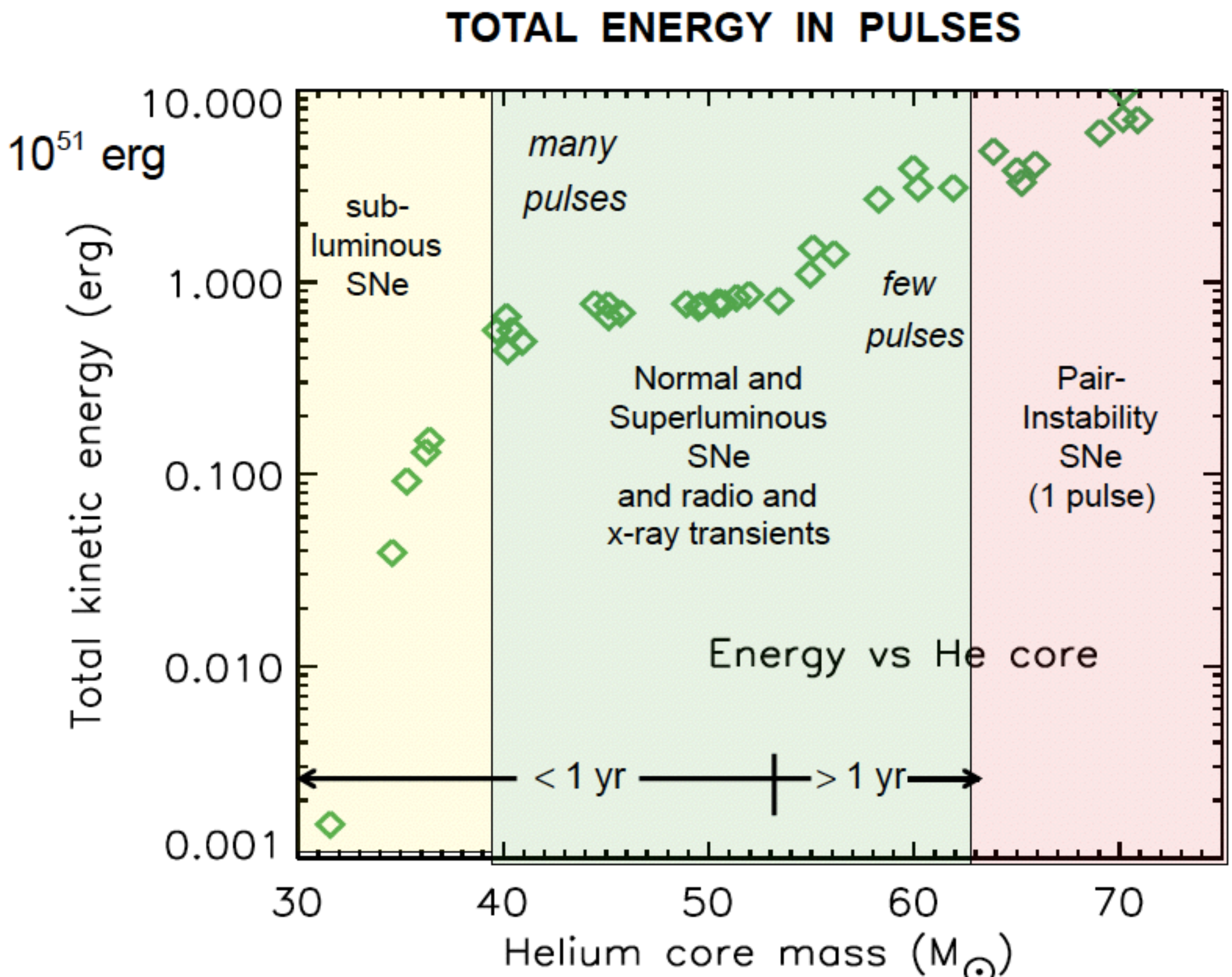


For still larger helium cores, the pulses become more violent and the intervals between them longer. Multiple supernovae occur but usually just one of them is very bright.

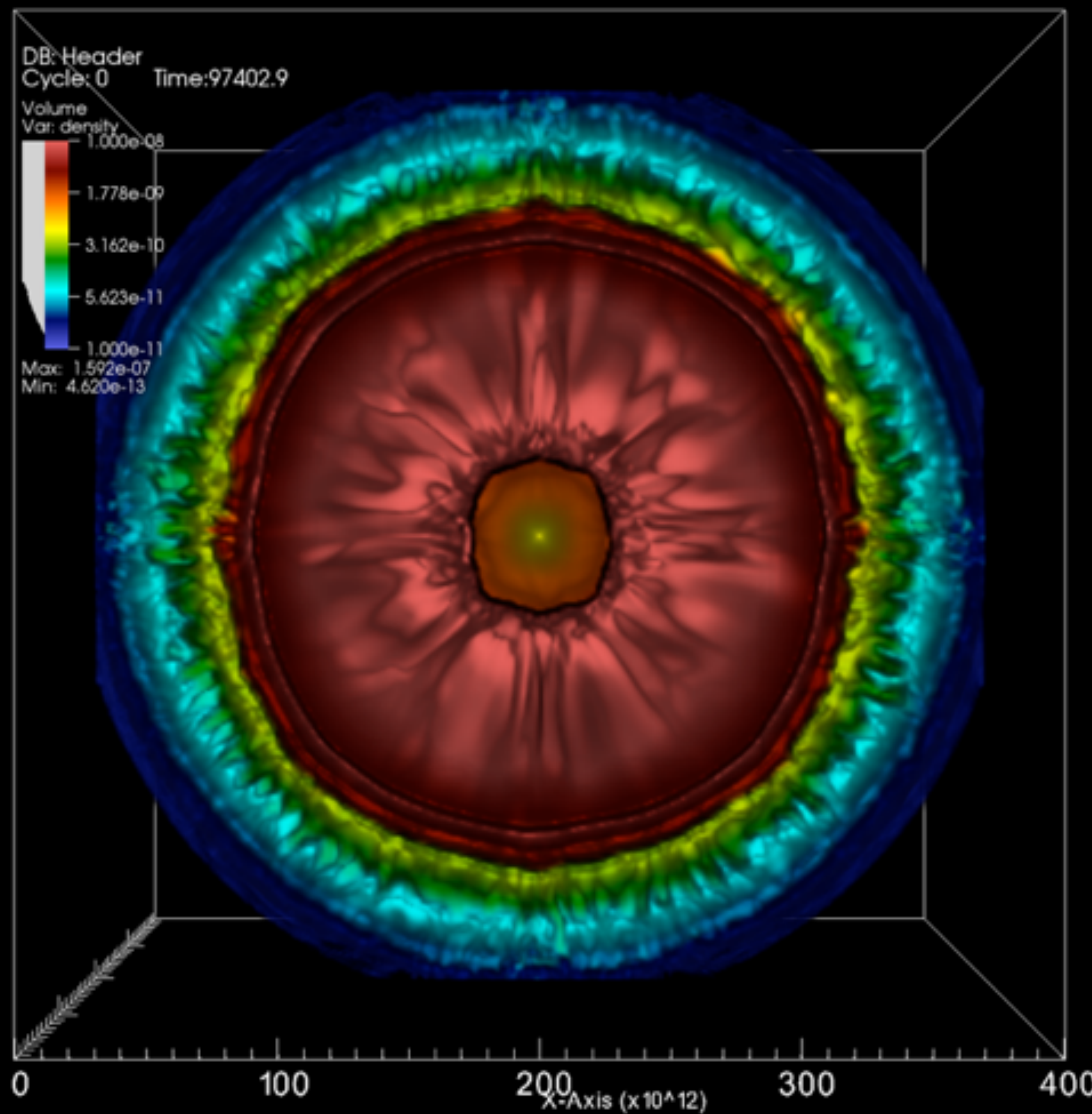




Total ejected mass from 0.1 M⊙ to 8 M⊙ depending on the helium core mass


TOTAL ENERGY IN PULSES
10.000
10^51 erg
1.000
0.100
0.010
0.001
Total kinetic energy (erg)
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☉)

Mulit-D Simulations of PPSNe



Chen+ ApJ 792 28 (2014)

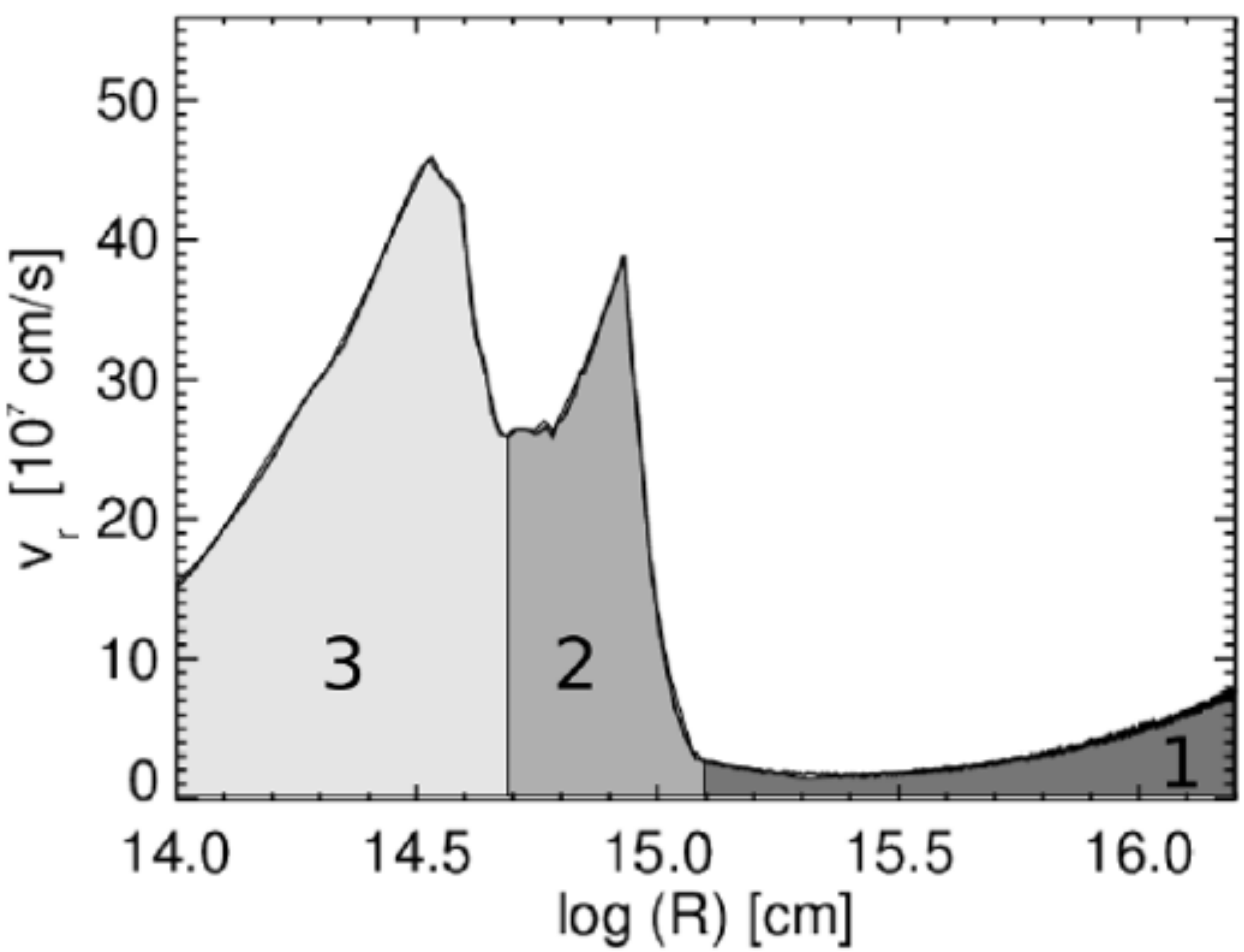
Core of 110 M⊙ star

Core of 110 M⊙ star

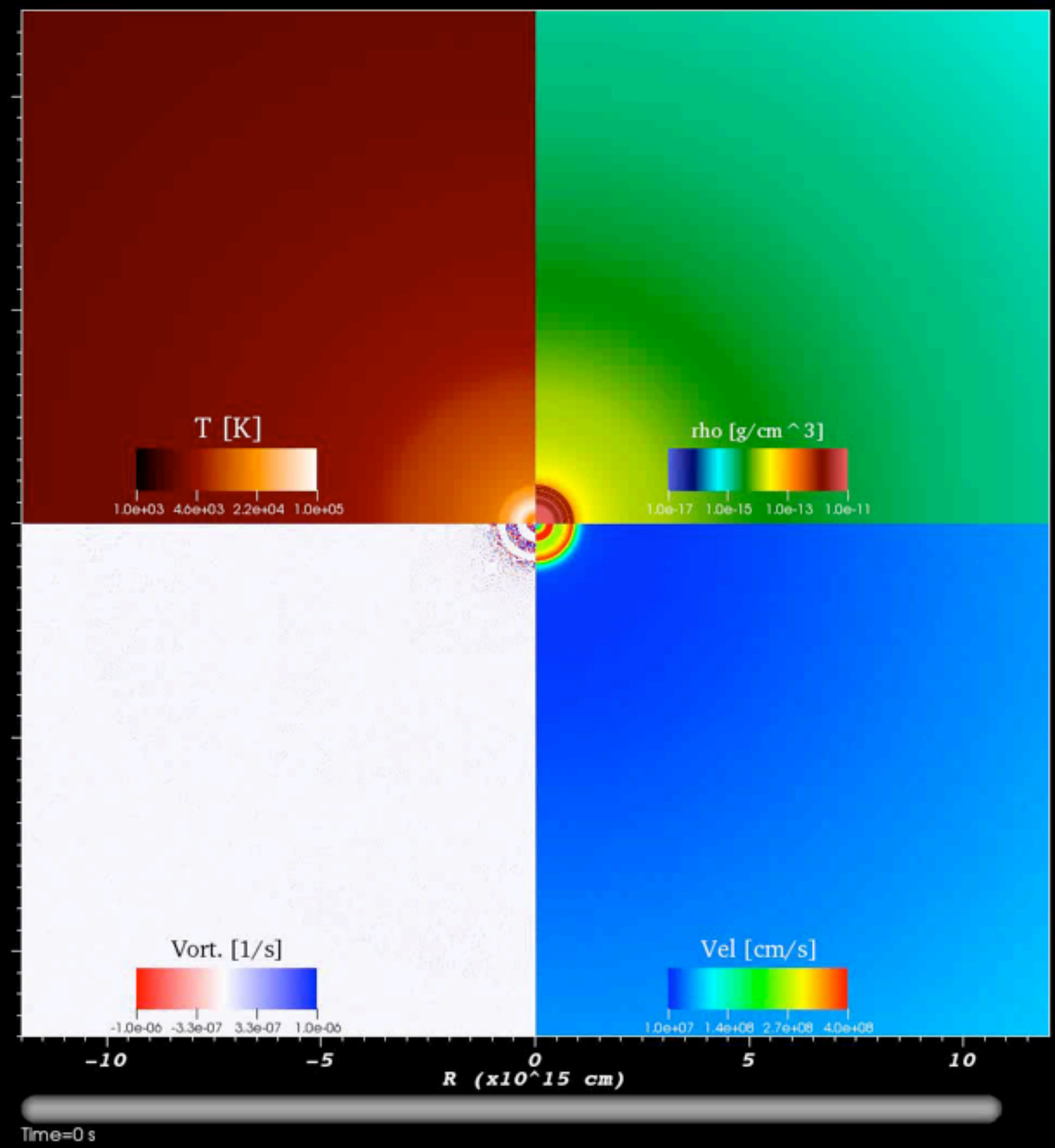
Core of 110 M⊙ star

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.



Physical Properties of Colliding Shells



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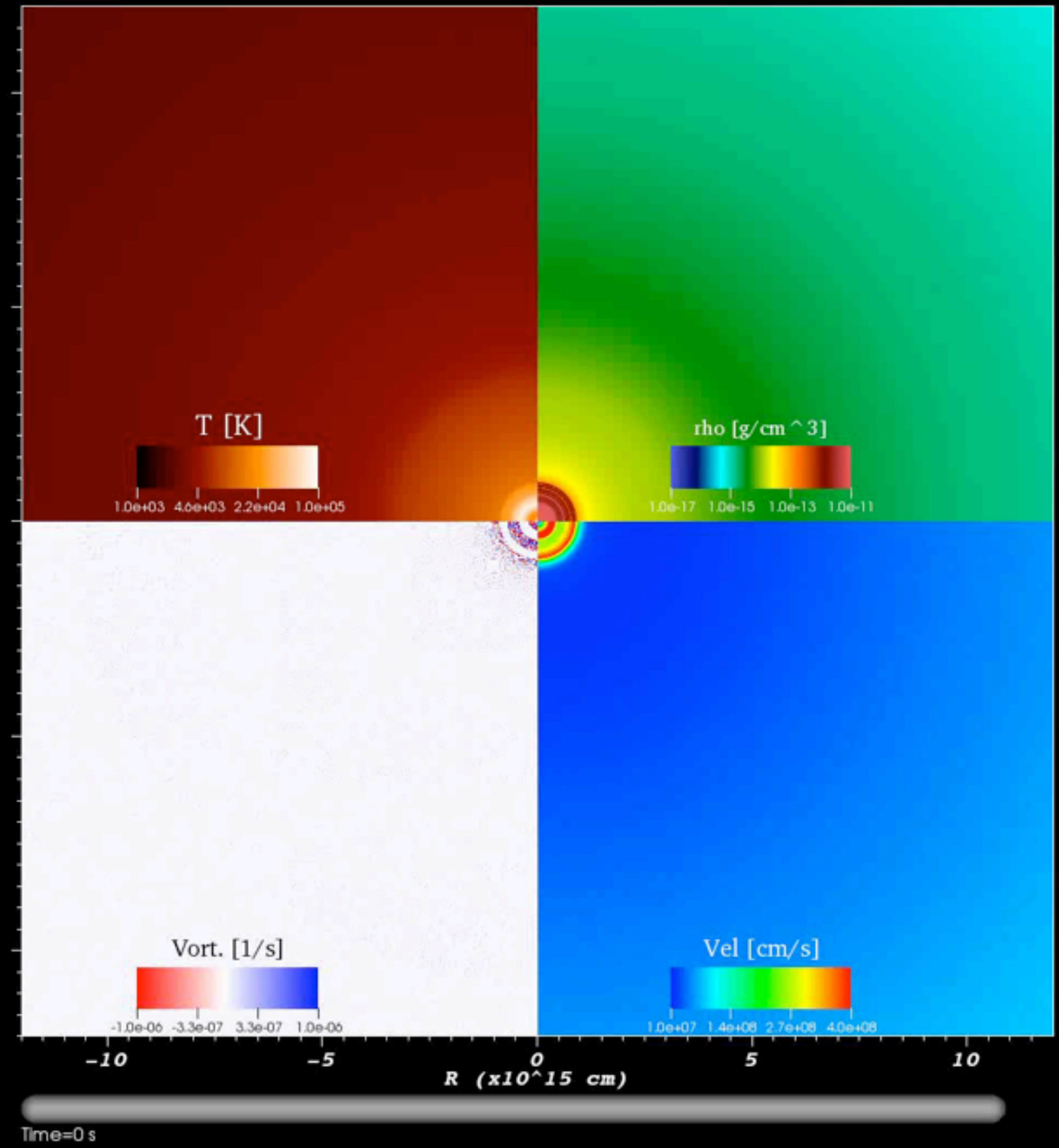

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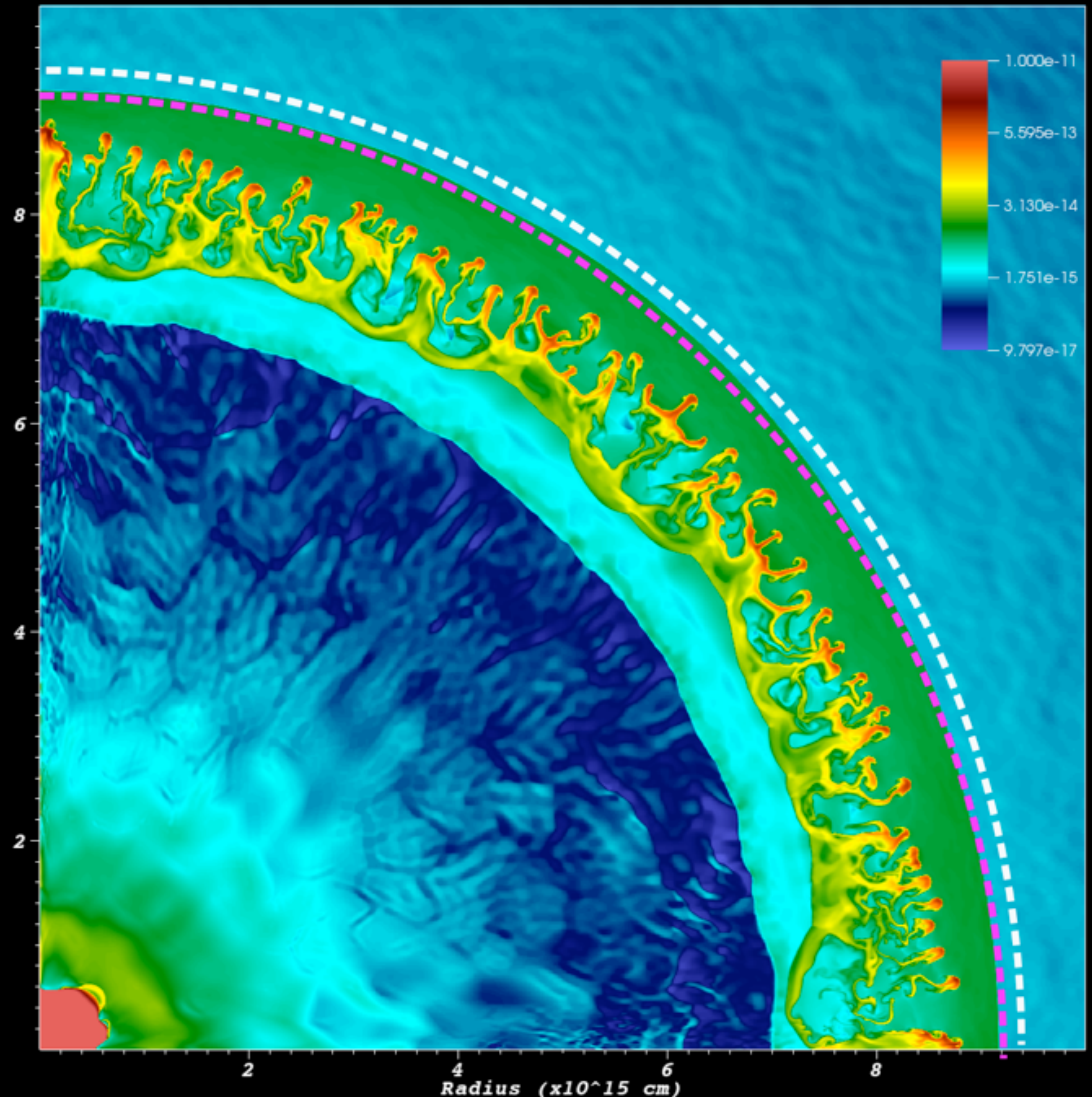
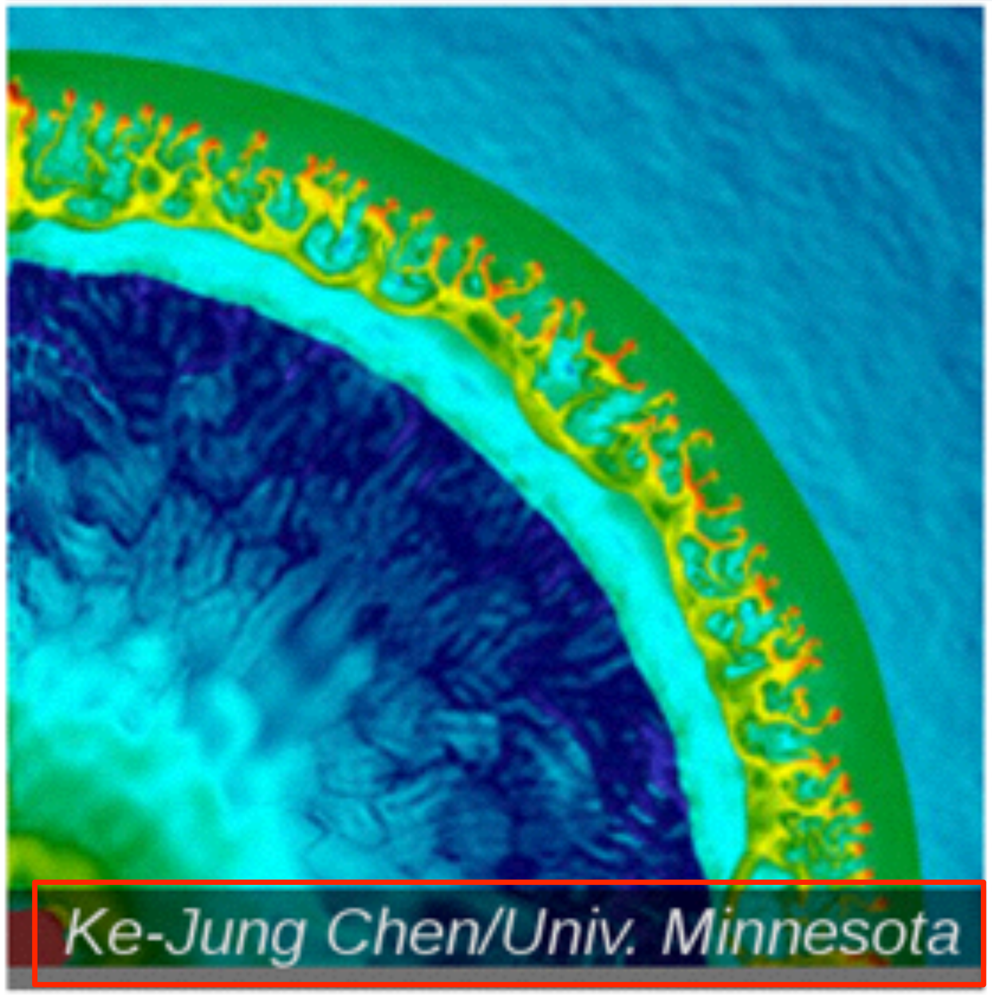


nature.com

07 February 2013



Ofek, E. O., *et al*. *Nature* (2013)
Heger *Nature* (2013)

A dying star's massive outburst

Observations of the final weeks of a massive star, just over a month before it exploded as a supernova, are reported in *Nature* this week.

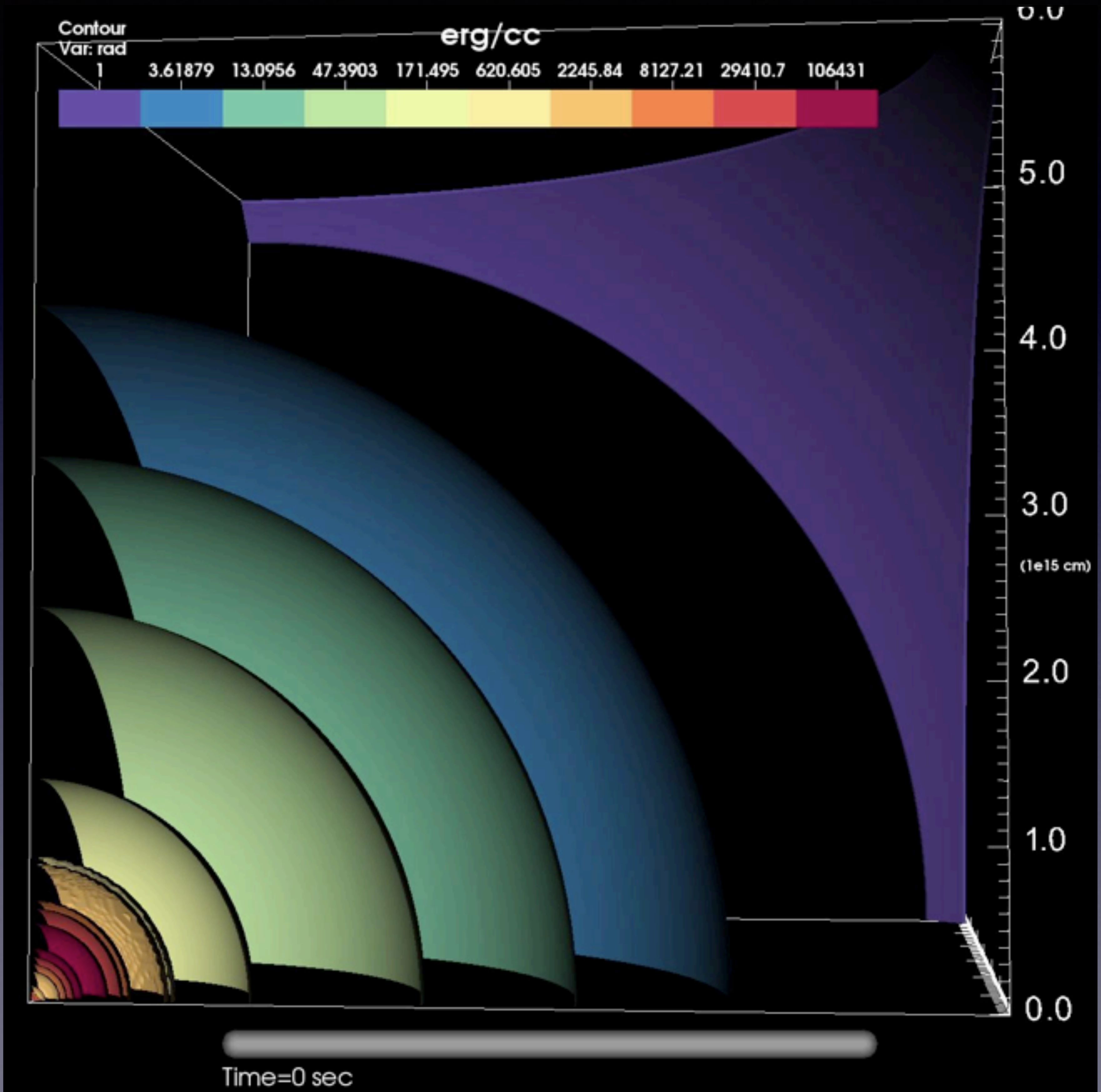
Latest news

- Europe bets on drug discovery
- Seven days: 1–7 February 2013
- Landsat 8 to the rescue

More news from nature

3D Radiation Transport Simulations of PPSNe

Chen, Woosley, & Zhang (In prep.)



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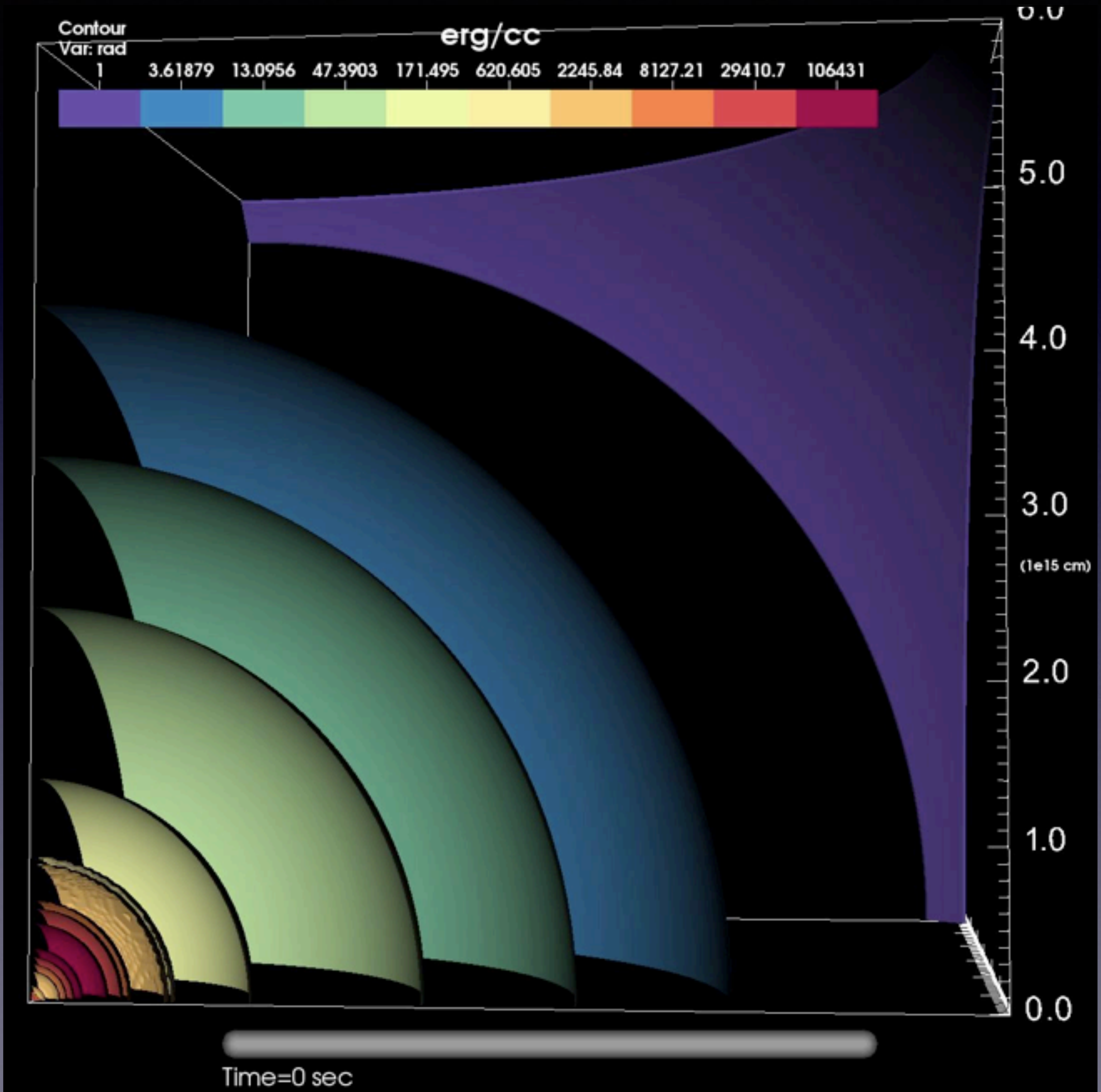

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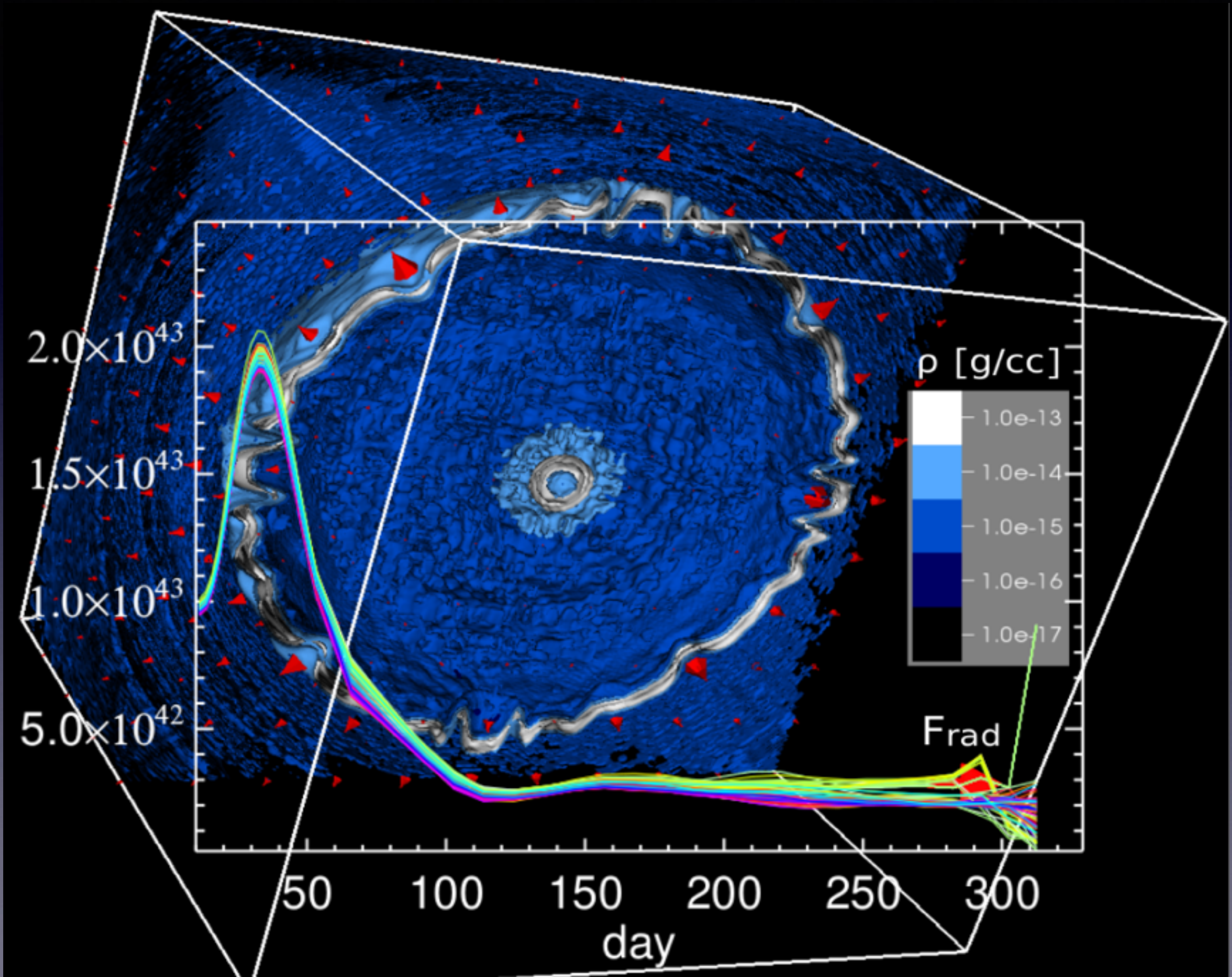
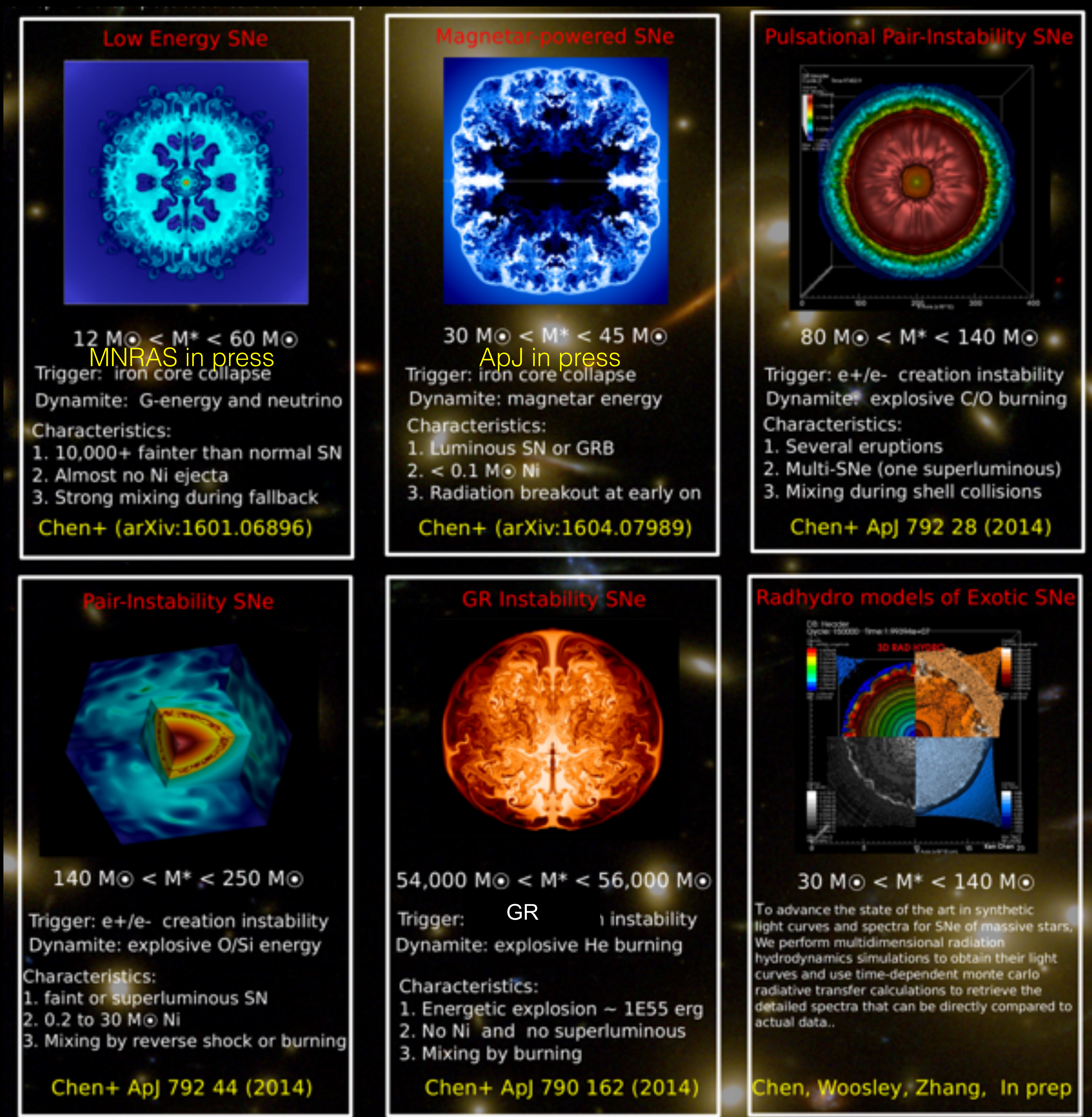


More Bangs & Advertisement



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Taiwan

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- $60,000 annual stipend (tax-free)
- $4,000 relocation
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