Multidimensional Simulations of Pair Instability Supernovae Explosions

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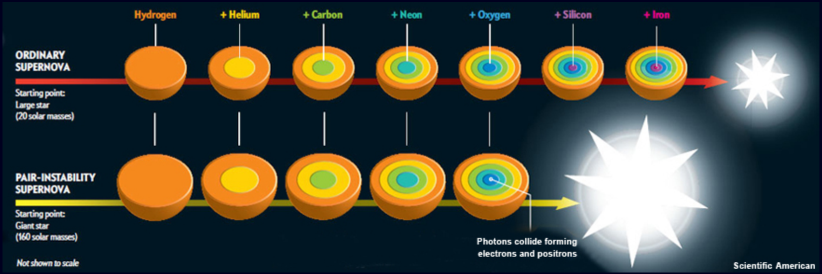
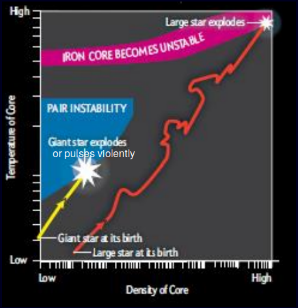
Massive stars



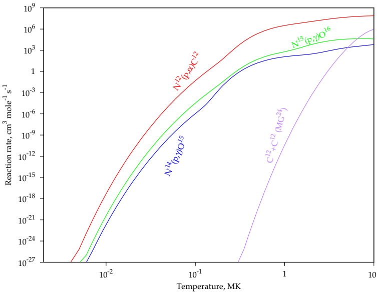


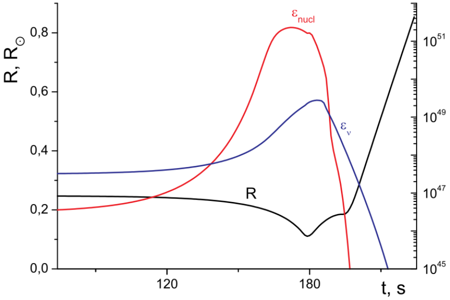
$\gamma + \gamma = e^{+} + e^{-}$ - Pair Instability

* Outcome most sensitive to helium core mass
  Pair-instability may be infrequent in solar metallicity stars
* Happens at high entropy (low density at a given T) and thus in the most massive stars.

The Key point: the thermal instability

The rate of reactions are very sensitive with T:
the rates increase rapidly with T

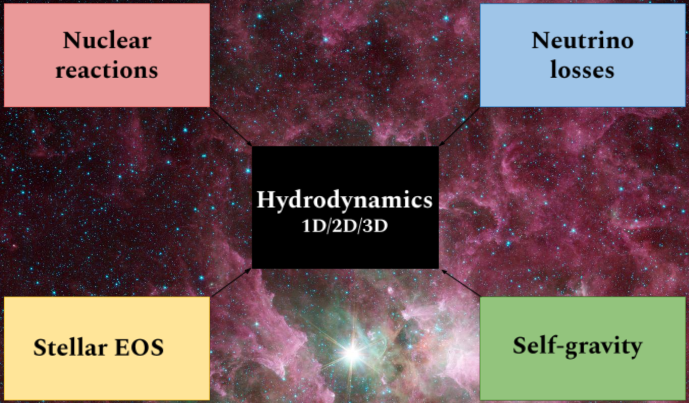




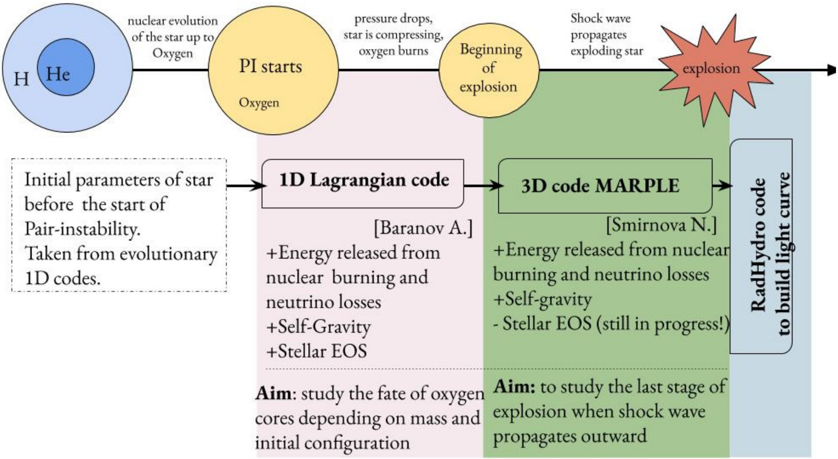
Above some critical temperature where the nuclear energy released overcomes the energy losses, self acceleration of nuclear reaction is possible

$$\dot{E}_{nuc}(\rho, T) \neq \dot{E}_\nu(\rho, T) + div(\kappa \vec{\nabla} T)$$

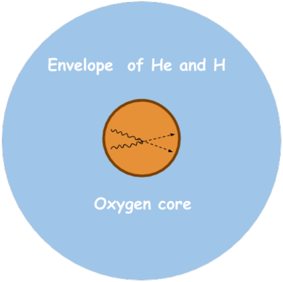
Physical models in simulation



Our codes for PISN Simulations



Initial configuration



Presupernova configuration from 1D code

Baranov et al.(2013)

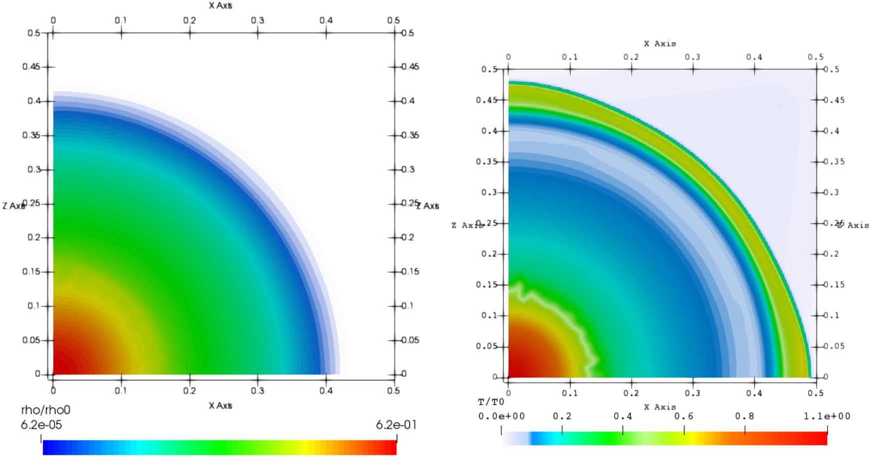
Polytropic model with $\gamma = 4/3$

100% Oxygen core. No envelope!

TABLE 4.1: Pre-supernova models and parameters of explosion.

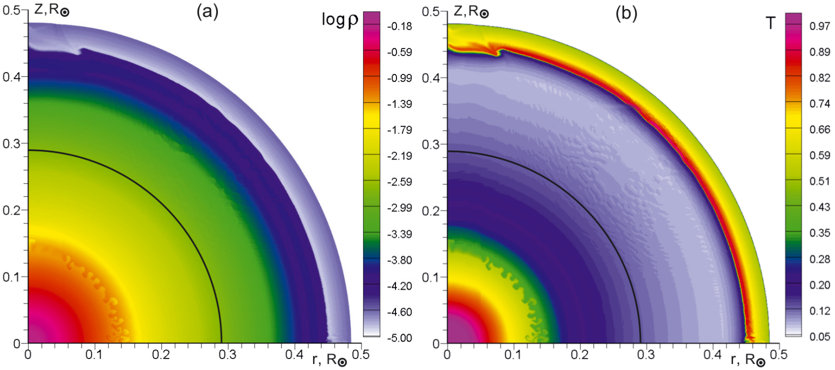
Model	$M_{\rm tot}$ $[M_\odot]$	$E_{\rm bind}$ $[10^{51}$ erg$]$	ρ_c $[10^5$ g/cc$]$	$T_{\rm max}$ $[10^9$ K$]$	$E_{\rm nuc}$ $[10^{51}$ erg$]$	Fate
95(1)	95	-4.93	1.50	—	—	CC
95(2)	95	-2.41	2.40	—	—	CC
95(3)	95	-1.61	2.60	4.39	39.9	PISN
95(4)	95	-1.11	2.80	4.31	37.1	PISN
95(5)	95	-0.63	3.00	4.20	35.0	PISN
100(1)	100	-2.43	2.00	—	—	CC
100(2)	100	-1.12	2.50	4.56	44.7	PISN
100(3)	100	-0.69	2.65	4.32	41.5	PISN

PISN explosion simulation (central ignition)



PISN model with central ignition for $t = 28s$. Logarithm of density (on the left plot) is shown in units of $\rho_c = 2.65 \times 10^5 g/cm^3$. Temperature (on the right plot) is shown in units of $T_c = 2.36 \times 10^9 K$. Grid $148 \times 148 \times 148$

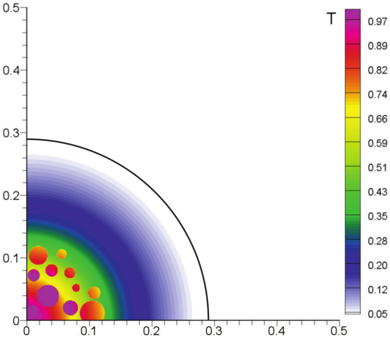
2D Simulation with PPML code



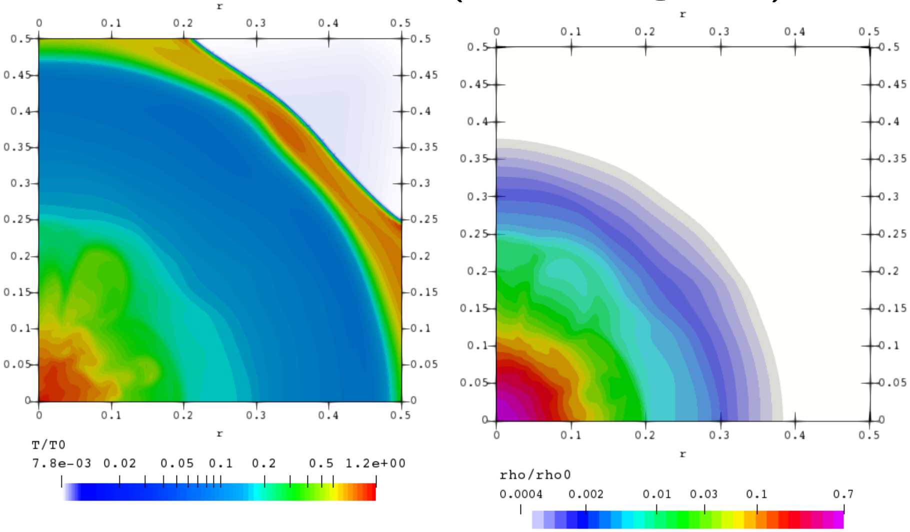
PISN model with central ignition(a) for $t = 28s$. Logarithm of density (a) is shown in units of $\rho_c = 2.65 \times 10^5 g/cm^3$. Temperature (b) is shown in units of $T_c = 2.36 \times 10^9 K$. Grid 1024 × 1024 × 1024

NEW PARADIGM: MULTICORE EXPLOSION

- Nuclear burning could cause the development of large-scale convection (Arnett 2011)
  if convection occurs prior the moment of pair instability the contraction and explosion could be non symmetrical.
- Inhomogeneities in T and ρ could cause ignition of spots to occur in the core.
- Explosion in the simulation was set by 21 ignition points, which were distributed randomly. Total energy inserted is $5 \times 10^{52} erg$

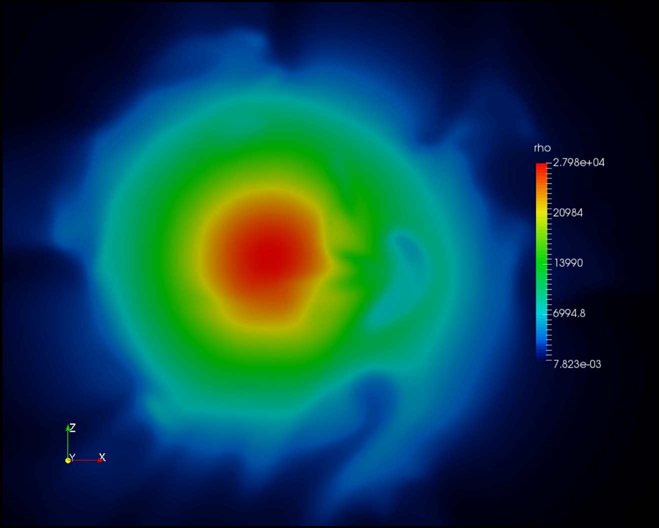


PISN explosion simulation (multicore ignition)



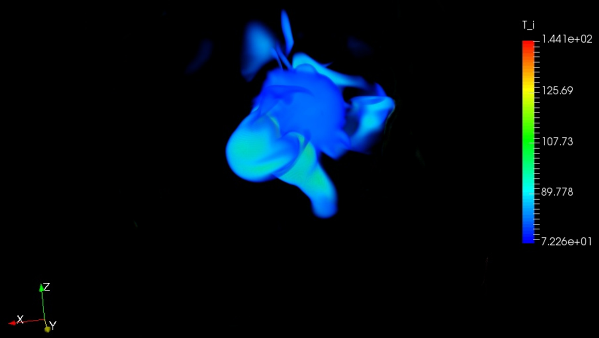
PISN model with multicore ignition for $t = 28s$. Logarithm of density (right plot) is shown in units of $\rho_c = 2.65 \times 10^5 g/cm^3$. Temperature (left plot) is shown in units of $T_c = 2.36 \times 10^9 K$.

3D Simulation of PISN



PISN with $100 M_{\odot}$ with multicore ignition for $t = 28s$ after beginning of explosion. Density is shown in g/cm^3.

3D Simulation of PISN



PISN with $100 M_{\odot}$ with multicore ignition for $t = 28s$ after beginning of explosion. Temperature is shown in units of keV $(1keV = 1.16 \times 10^{7} K)$.

IN VERY CLOSE FUTURE...

- Add into 3D code MARPLE Stellar EOS (in a progress).

- Simulate symmetrical and asymmetrical explosions in 3D with all physics included for different initial configurations of star (mass, rotation, central temperature and density).

- Compare a prediction of the elements abundance produced during core explosion.

- Build a light curves for PISN.

Thank you

for your attention!

2D Simulation of PISN with $100M_{\odot}$ with multicore ignition .