Numerical Simulations of Type Ia Supernova Explosion

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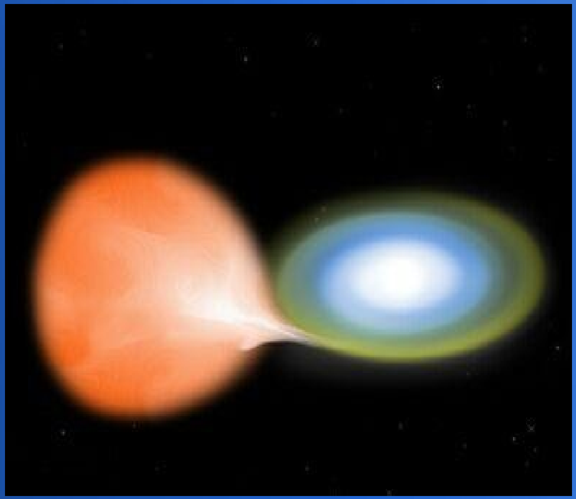


SciDAC CAC Meeting May 19th,2001

CASTRO

- Compressible hydrodynamics code
- Eulerian grids with AMR
- Unsplit Godunov Scheme
- Subcycling in time advance
- Parellel code with good scaling up to more than 10,000 processors
- Solve radiation transfer

Explosion Mechanism and Numerical Setup

Explosion Models:

Shock-driven Detonation

Subsonic Deflagration

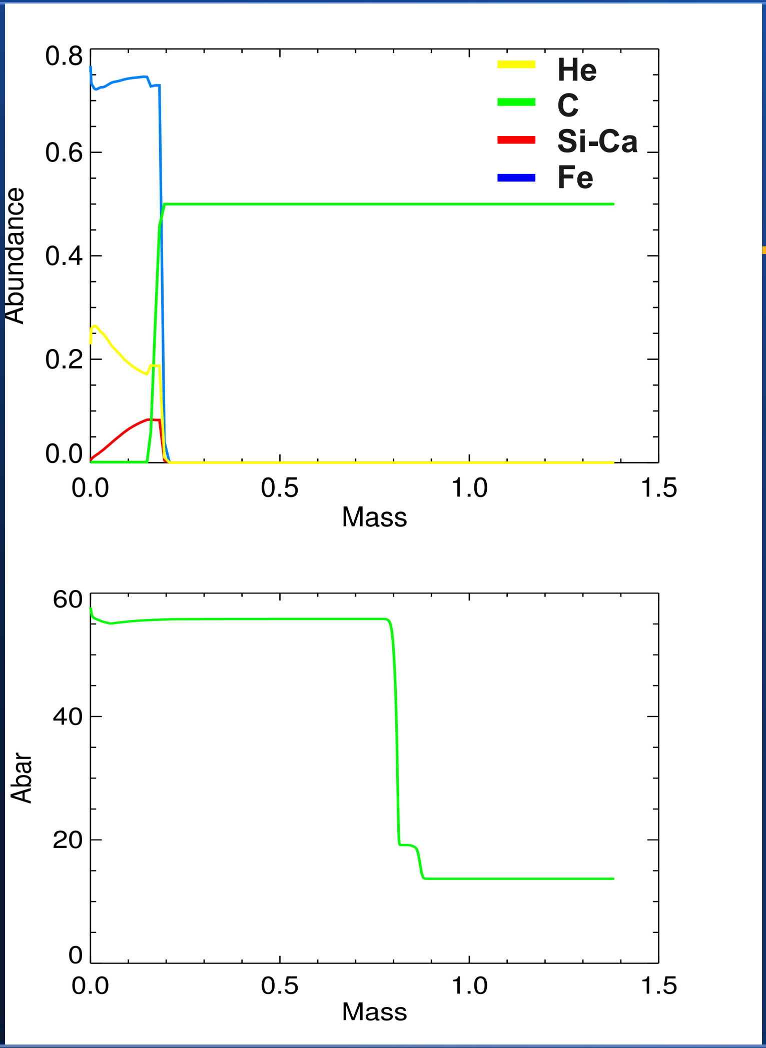
Deflagration-Detonation Transition (DDT)

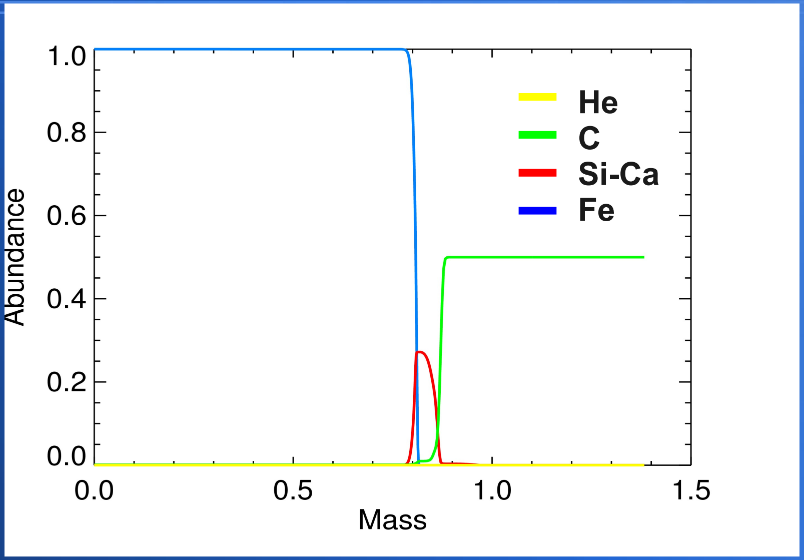
Numerical Setup:

- Initial composition 50% C 50% O
- Products depend on fuel density, and NSE is considered
- 10 species carried in the calculation
- Nuclear burning times scale = Thermal diffusion time scale
- Compute gravity as one-dimentional integral
- Make ignition pattern assumptions

1D Sharp-Wheeler Model

V = 0.1 g A t





Total Burned Mass : 0.86 solar mass

Produced Iron : 0.81 solar mass

Intemediate elements : 0.03 solar mass

Final kinetic energy : $8.9 * 10^{50}$ ergs

3D Models

- Different Ignition Pattern

  Central ignited

  Off-Center ignited

- Different pre-defined laminar flame speed

  v = 50 km/s, 100 km/s, 200 km/s

3D Flame Propagation

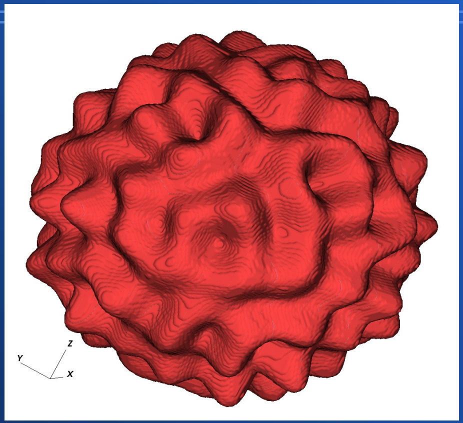
Central ignited

Flame Speed = 100 km/s.

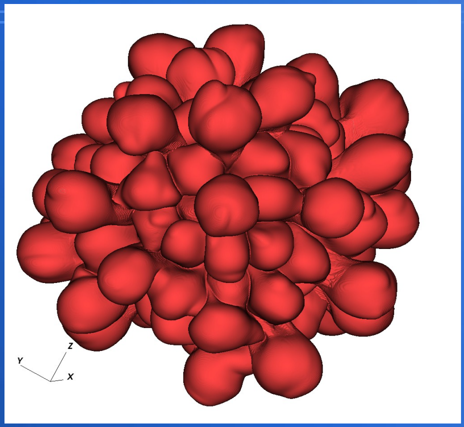
Initialize inner 100 km as hot ashes with perturbed surface.

4 levels of refinement, and finest cell size is 1 km.

~ 1 Million CPU hours so far, mostly run on 8192 processors.



0 s



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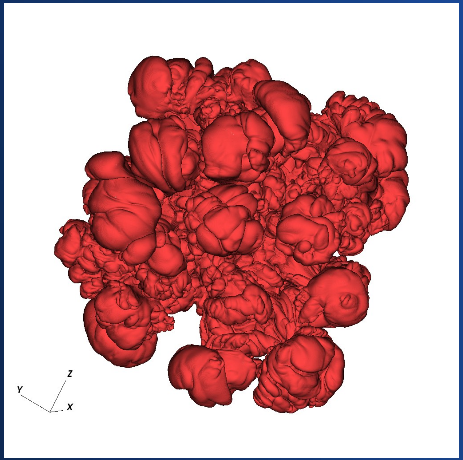
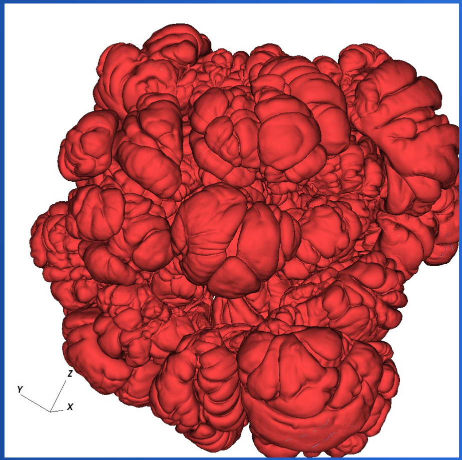
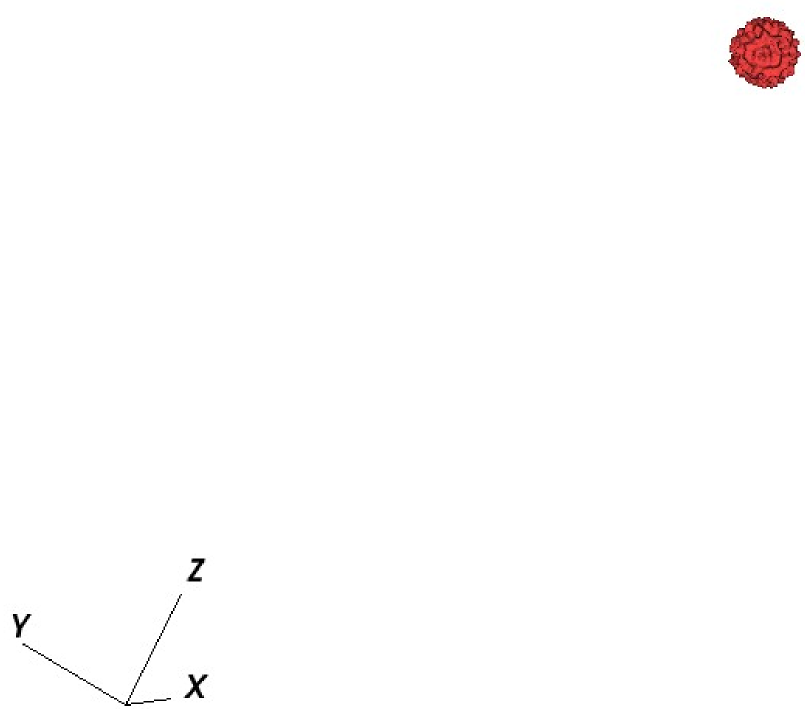
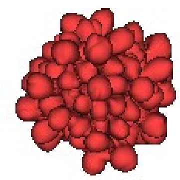


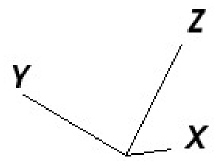
0.63 s



0.93 s


Z
Y
X

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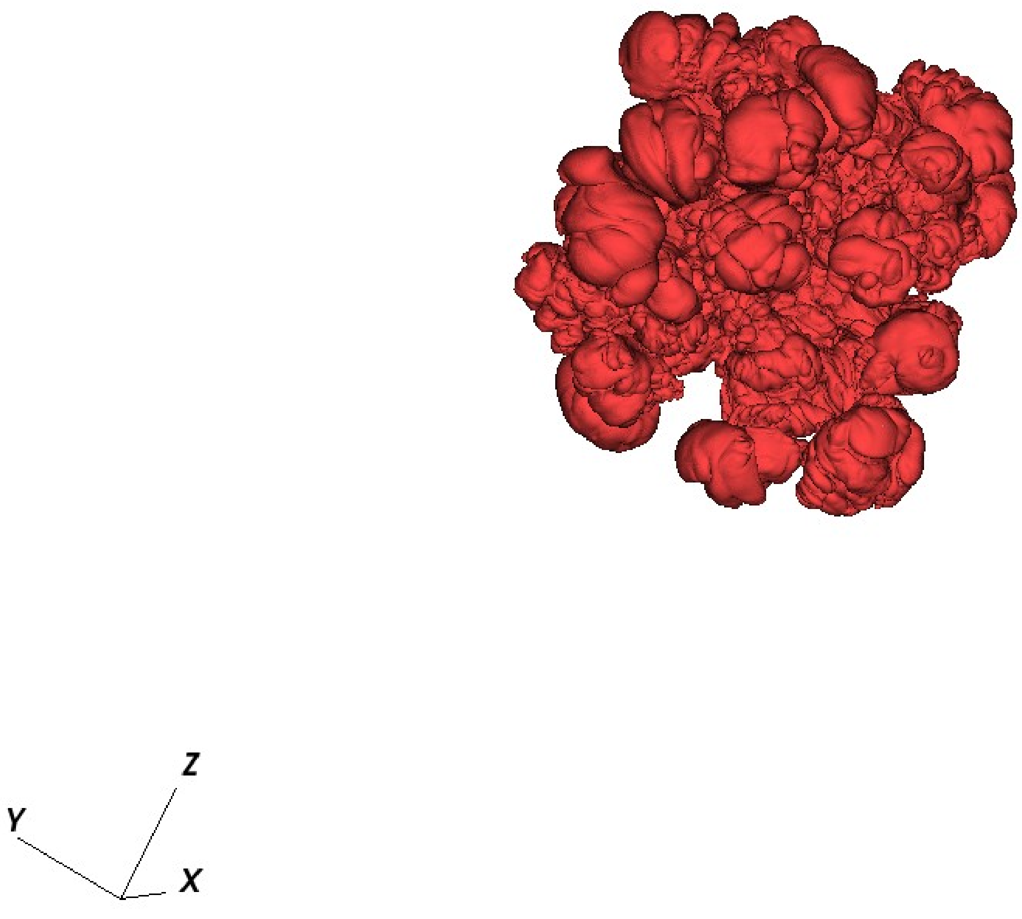
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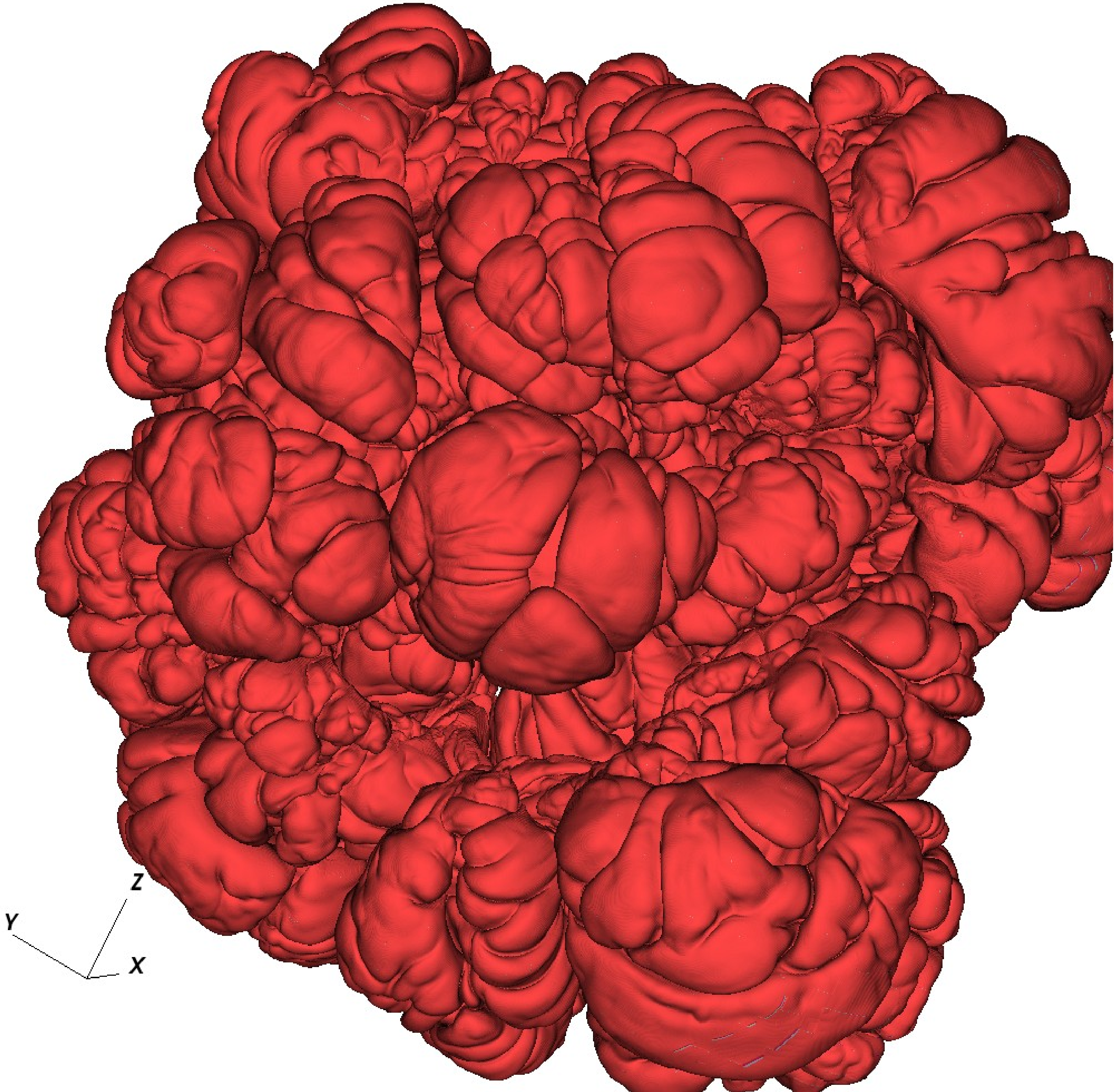


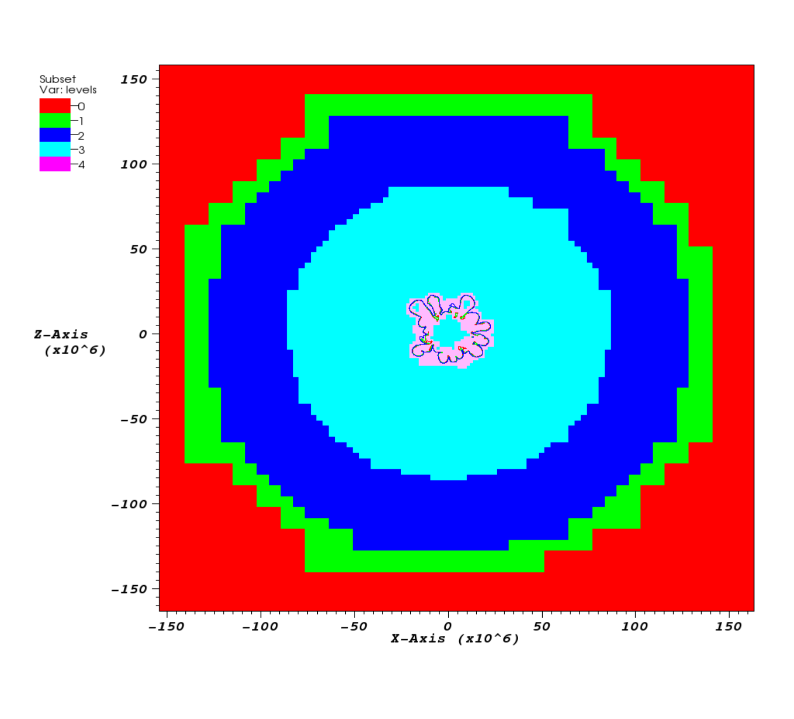
Z
Y
X

AMR Criterions :

Flame always has the finest cells

Density is the other criterion

Drop resolution as star expands.



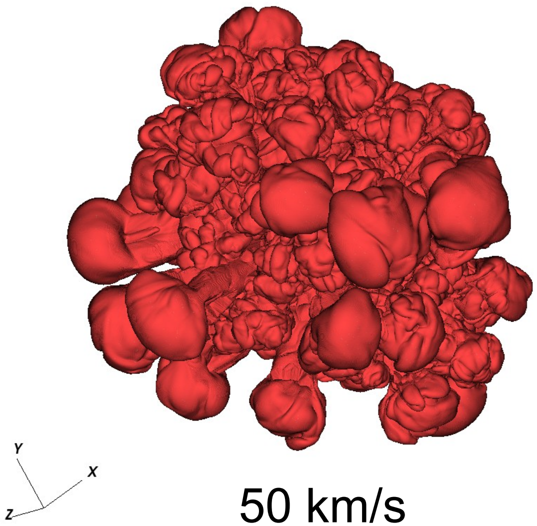
So far (at star time ~ 1 s),

0.53 solar mass iron group elements are produced .

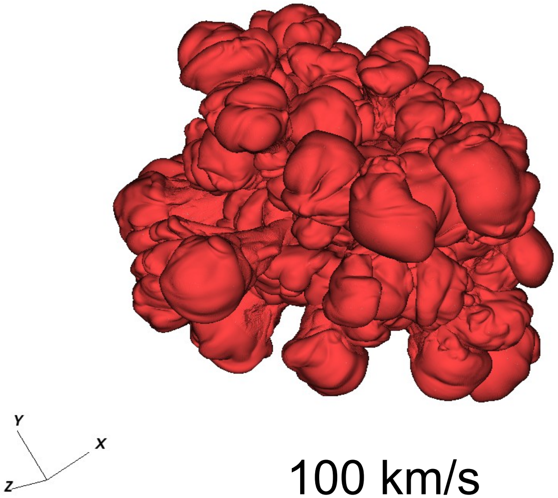
0.03 solar mass intemediate elements are produced.

At different flame speeds

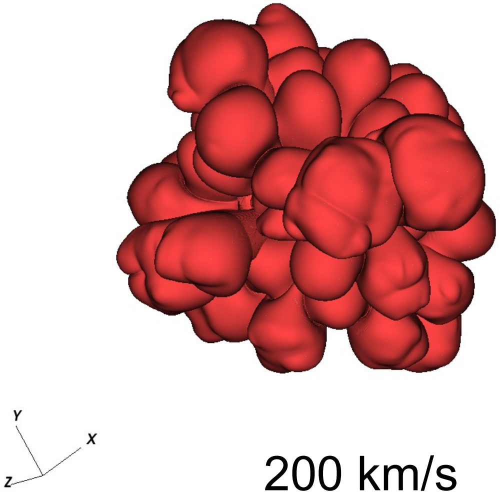
t ~ 0.5 s,



50 km/s



100 km/s

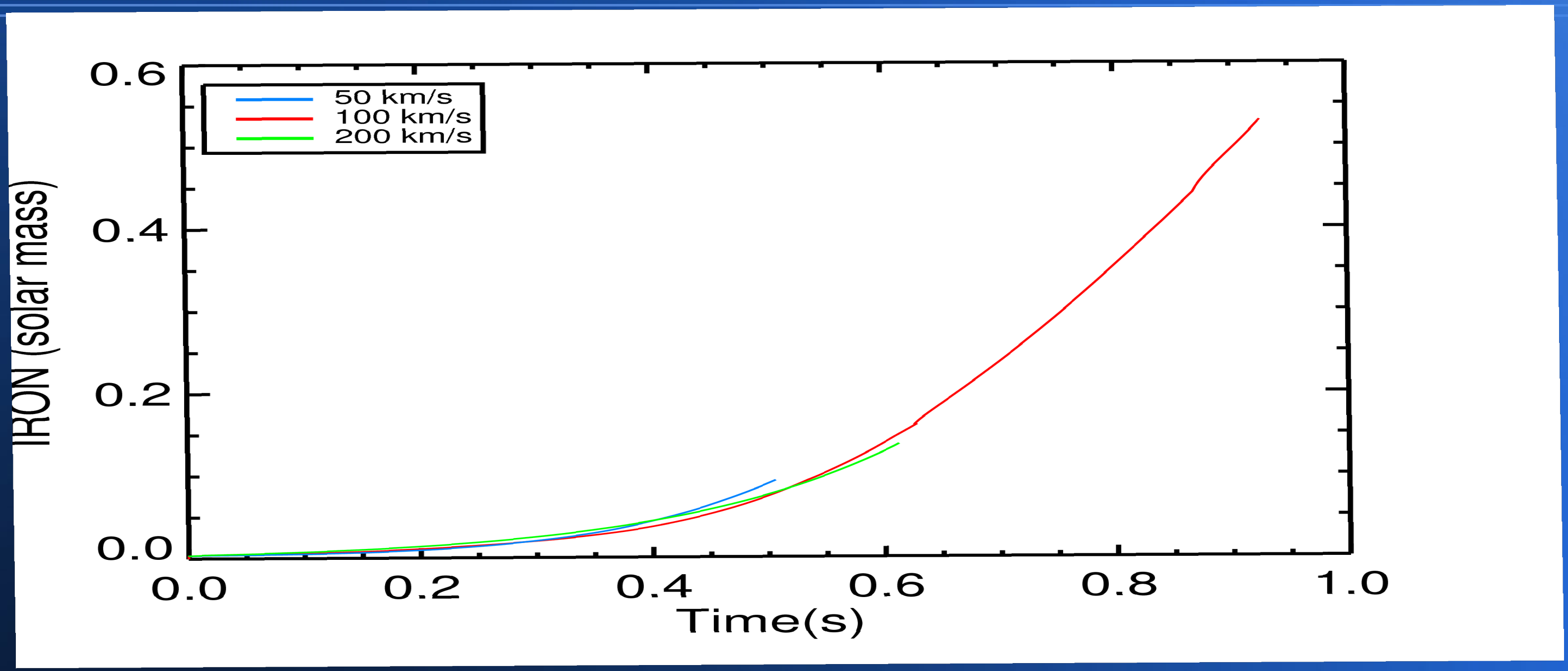


200 km/s

higher flame speed --> larger fire polishing length → less structure

Any perturbation in the flame surface below fire polishing length will be polished out by burning.

Iron Production



- Probably this run can only give a faint type Ia.
- A converged answer at different flame speeds?

2D & 3D Flame Propagation

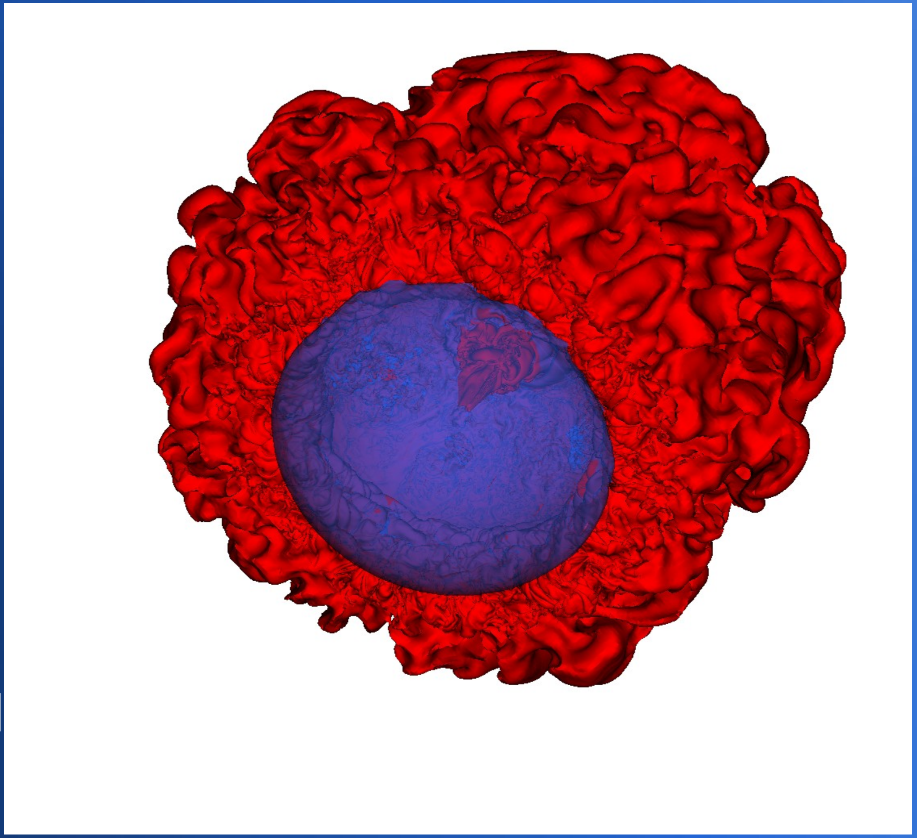
Off-center ignited

GCD (Gravitational Confined Detonation) model

- Pre-SN convection could be dipole flow and the WD Ignited on one side of the star

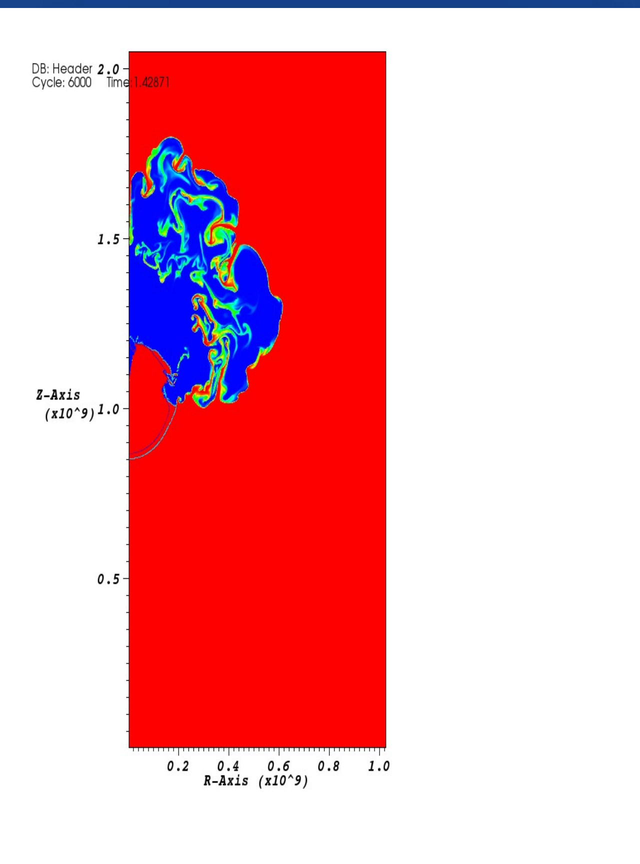
- A small part of star on one side is burned, unable to unbind the star.

- Hot ash sweeps around the star along with fresh fuels, collides on the opposite side, and trigger a detonation.

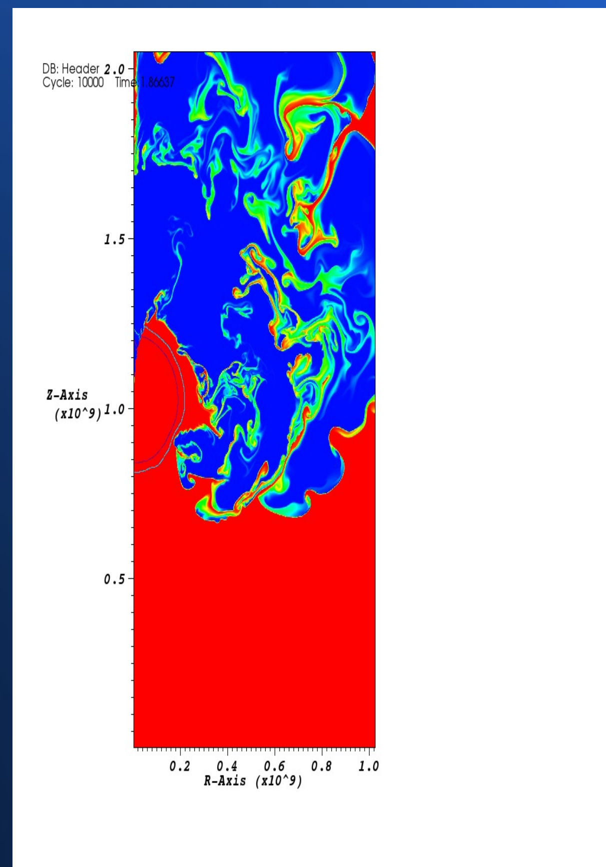


2D off-center Calculation

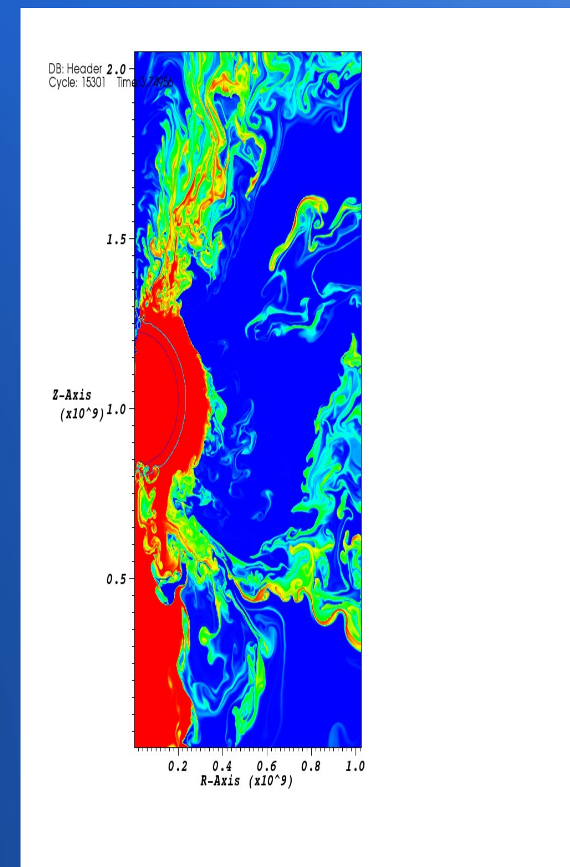
Initial spherical bubble has a radius of 20 km, 30 km away from the center



1.43 s



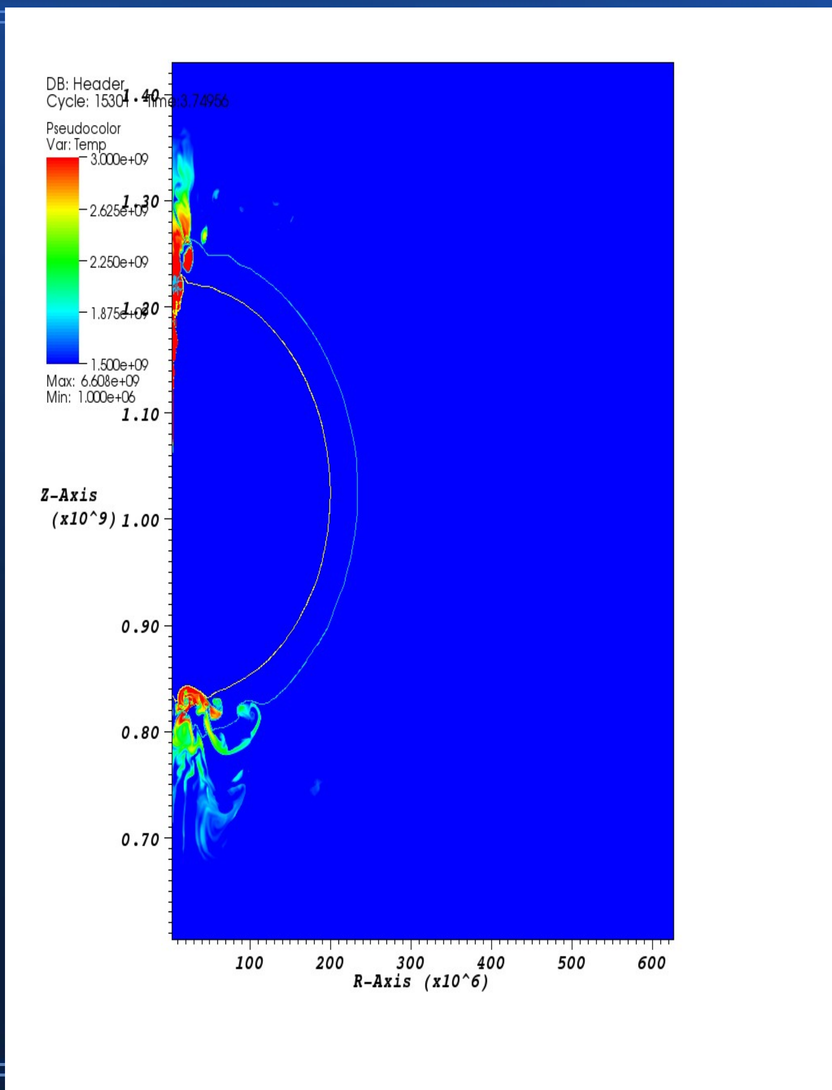
1.87 s



3.75 s

Totally about 0.8 solar mass burned. Finest cell size 1.25 km.

Trigger a later detonation?



At the density of 2*10**7 g/cc, the temperature is higher than 3*10**9 K!

Groups at Chicago and MPA agree on 2D results, but disagree on 3D off-center study!

Our 3D calculation will have enough resolution to see if there is an inward jet

3D Off-center Calculation