Study of Type Ia Supernova Explosions

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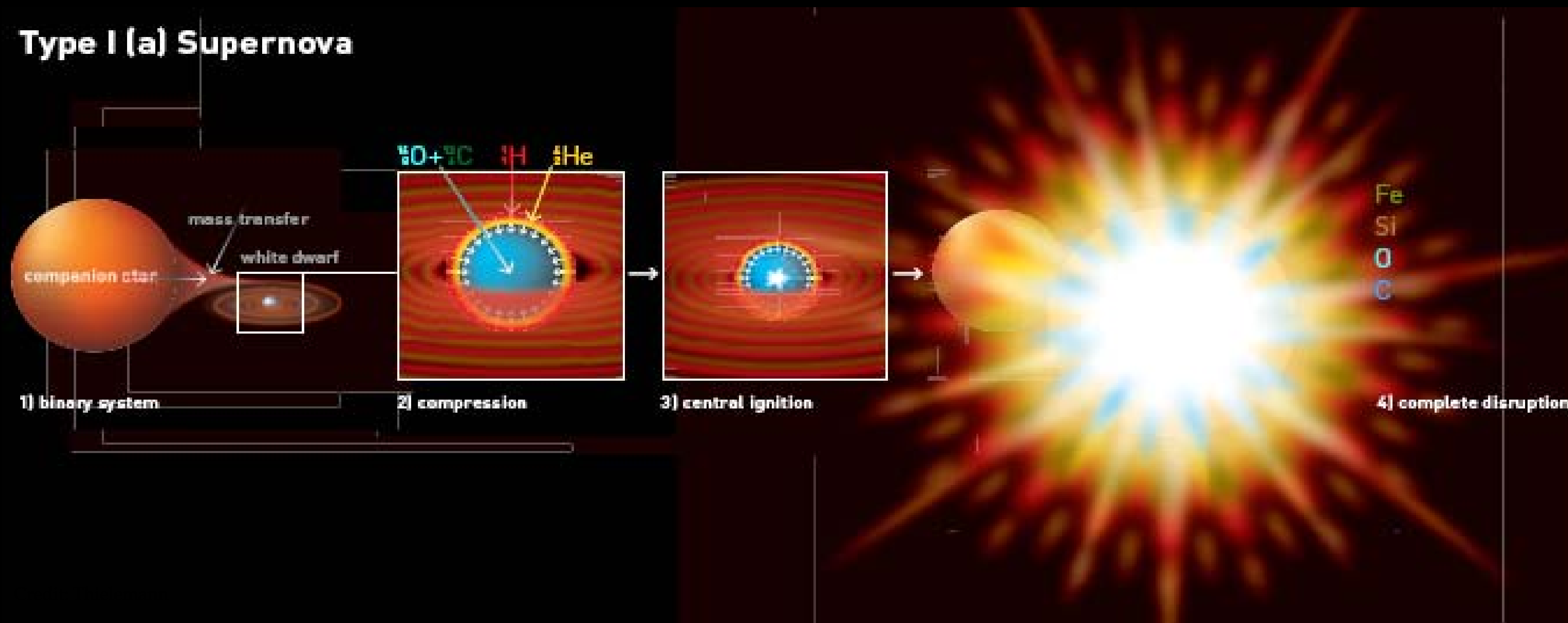
Supernova Type Ia

- Accretion from a binary companion (Whelan and Iben 1973) leads to growth of the WD composed of ^{12}C and ^{16}O.

- Thermonuclear explosions of carbon-oxygen white dwarf star (Hoyle & Fowler 1960).

- ~ 1.5×10^{51} ergs of energy released; $E_b(WD) + E_{KE}(ejecta)$

- Lightcurve powered by decay of $^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$



Two Different Regimes of Thermonuclear Burning

Thermal Process

DEFLAGRATION

- Sub-sonic
- Diffusive transfer of heat
- Three – Stage Burning:
  1. ^{12}C + ^{12}C fusion -> ^{20}Ne, ^{24}Mg, and α
  2. Conversion to Si group
  3. Conversion to Fe group

DETONATION

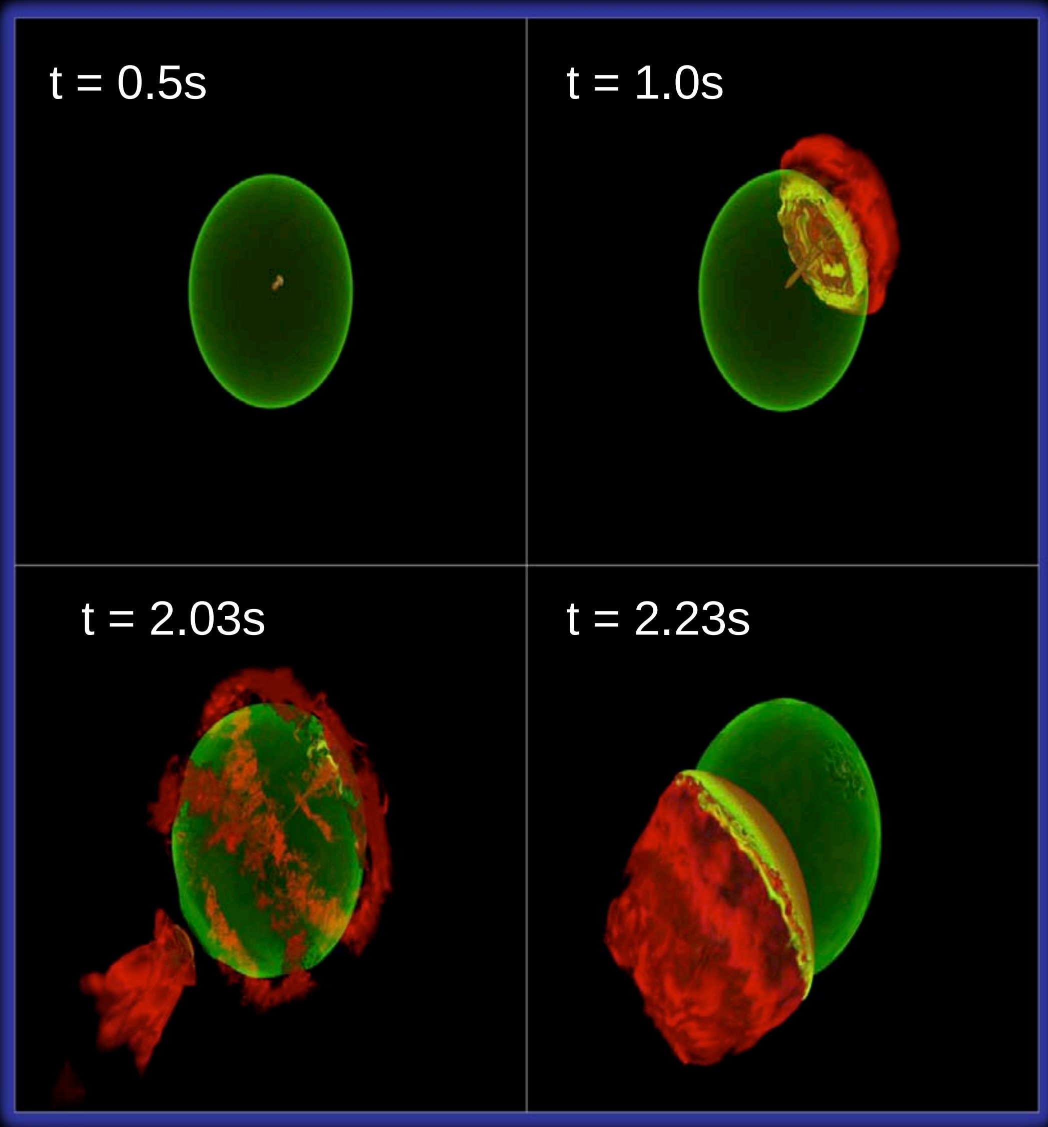
- Super-sonic
- Propagation of Supersonic pressure wave and compression of fuel to ignition point

GCD Model

Four different stages of evolution of the white dwarf star in the simulation of the gravitationally confined detonation (GCD) mechanism.

The temperature is represented in different colors; red is the coolest and orange-white is the hottest temperature.

Initially, a bubble starts to rise driven by buoyancy (top left), and breaks through the surface of the star (top right). The flow of hot ash approaches the opposition point on the surface of the star (bottom left), compresses the unburnt surface layers there, and initiates a detonation (bottom right) (Jordan et al. 2008).



Study of Deflagration/Detonation in FLASH

J I N A

FLASH?

- An Adaptive mesh Hydrodynamics Code
- Designed for compressible reactive flows
- Run on many massively-parallel systems

A coupling of a nuclear reaction network to the multidimensional hydrodynamic simulations is computationally expensive.

Two-Step Process:

1. Hydrosimulation (tracer particles added)
2. Nucleosynthesis (use the information from tracer particles as input)

Tracer Particles:

Passive Particles are added in the Eulerian grid with density-weighted distribution.

They trace and record hydrodynamic flow in the simulation along the flow.

Study of Detonation in FLASH

J I N A

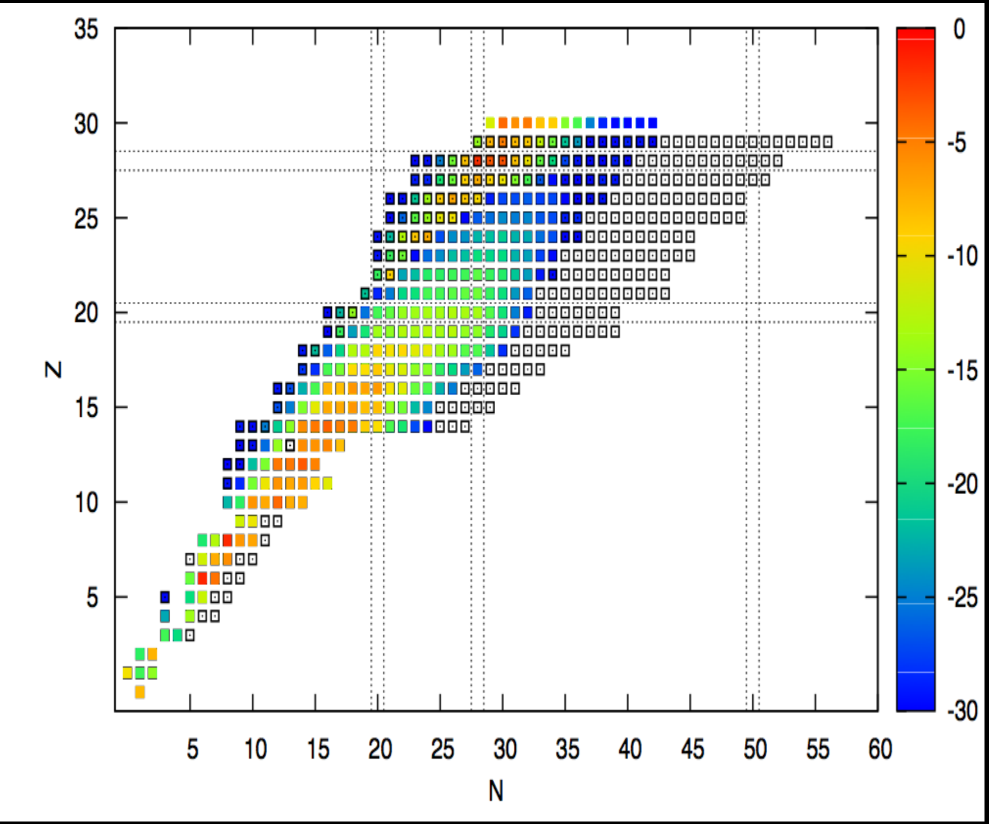
Model :

- A simple spherically symmetric one-dimensional system.
- Initial central density = 2.0e9g/cc and central Temperature = 1.e8 K
- Artificially high energy was added at the center
  point of the system to induce a detonation wave that propagates
  outward in all directions.
- 9900 tracer particles added.

Study of Detonation in FLASH

1) Nuclear Network using Tracer Particles

1. Nucleosynthesis calculation with trajectories of Temperature and Density
2. Take the yields at every 20 timestep
3. Plot all nucleosynthesis products over all times in Z-N plot
4. Overplot with nuclides included in the original network for Z $\leq$ 30.



Nucleosynthesis calculated using Libnucnet (Meyer and Adams 2007). The original total number of nuclides for Z $\leq$ 30 is 495 and it requires a run time ~ 6 minutes. The color scheme represents the abundances with red being the most abundant.
$\Rightarrow$The nuclear network has been reduced to a total of 218 species with a run time of 3 min. after discarding unused species (empty black boxes)

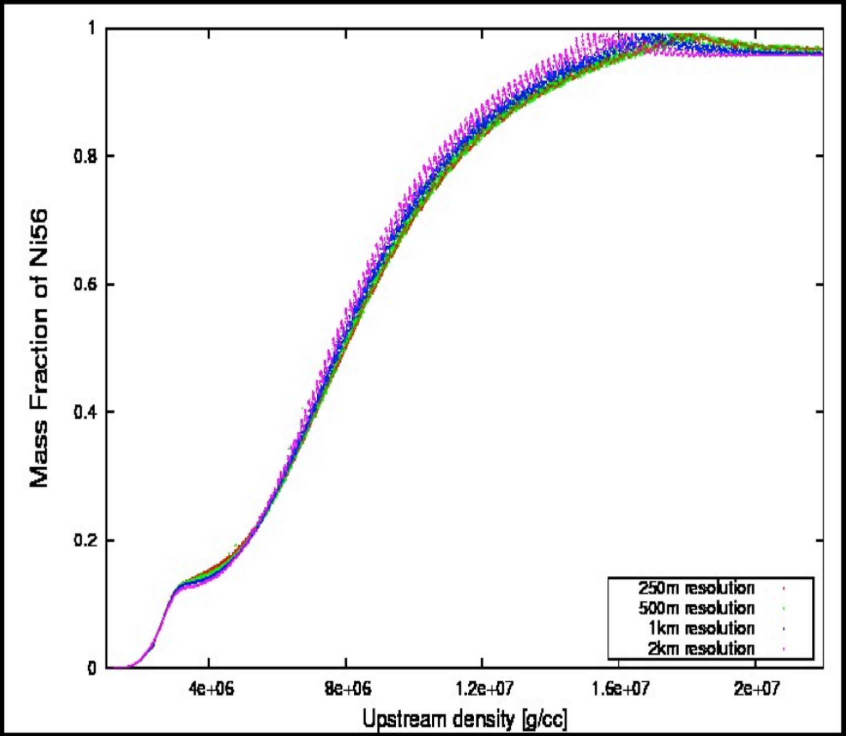
Study of Detonation in FLASH

2) RESOLUTION STUDY: 250m, 500m, 1km, and 2km

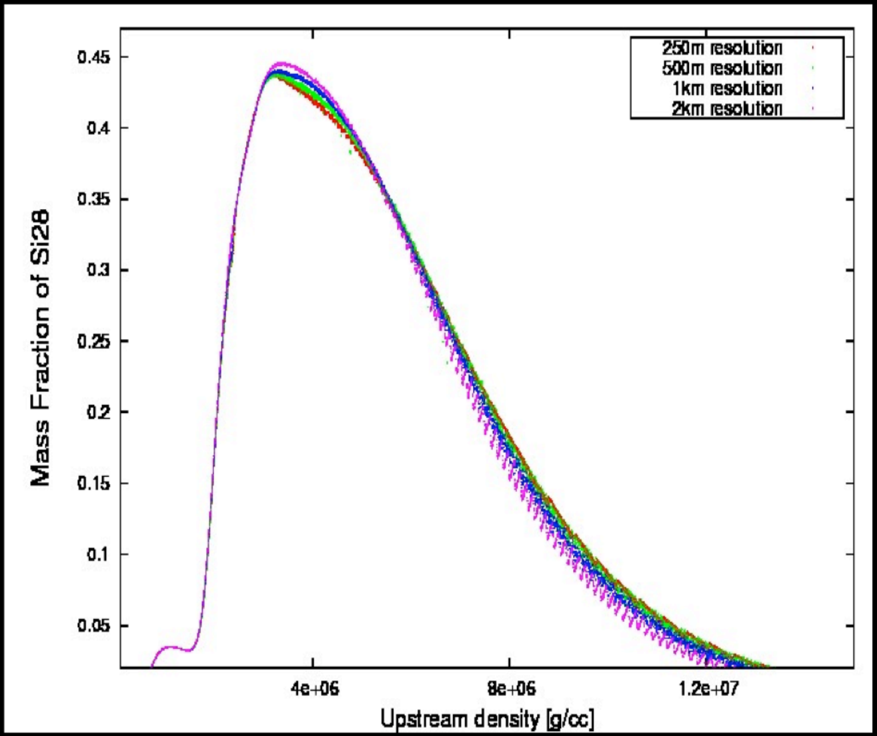
Investigate the behavior of detonation as a function of grid resolution in FLASH

CFL ~ $u\Delta t/\Delta x$; u is velocity
Δt ~ CFL * $\min\{\Delta x/u\}$

^{56}Ni



^{28}Si

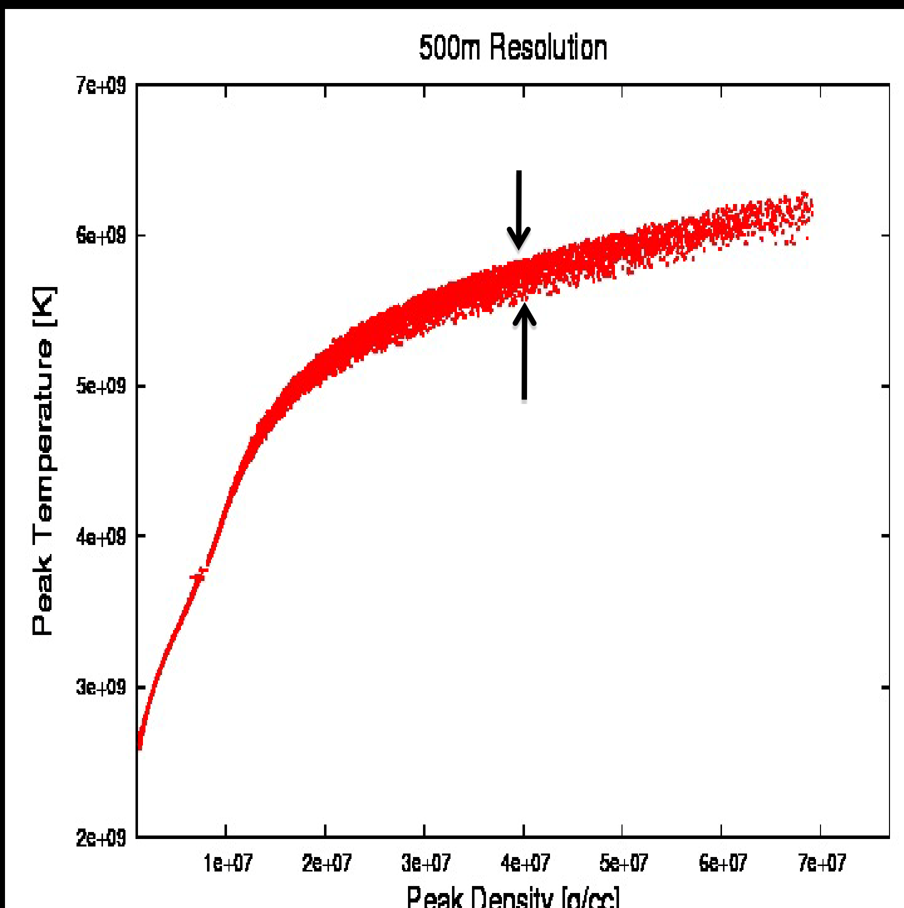


Study of Detonation in FLASH

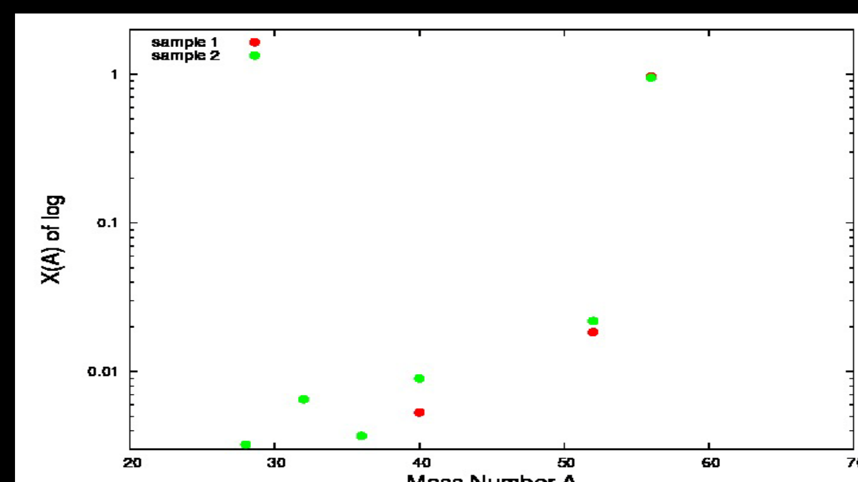
3) Temperature Sensitivity

How the shock is resolved numerically?

How the tracer particles record temperature?

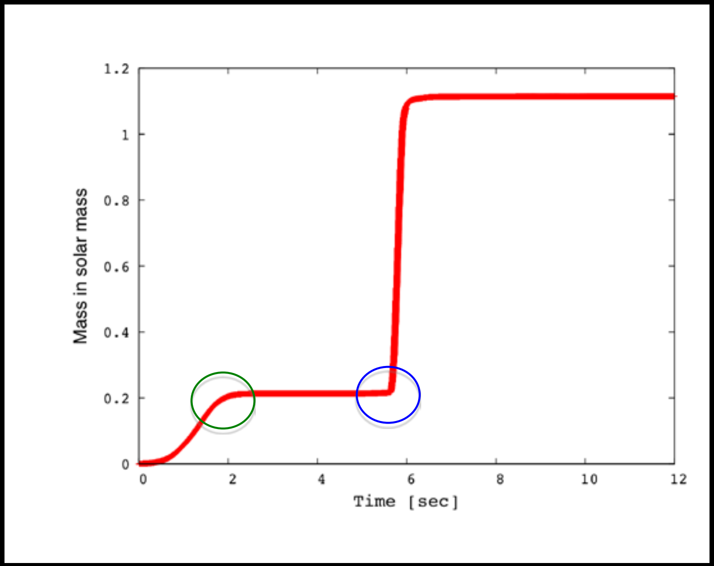


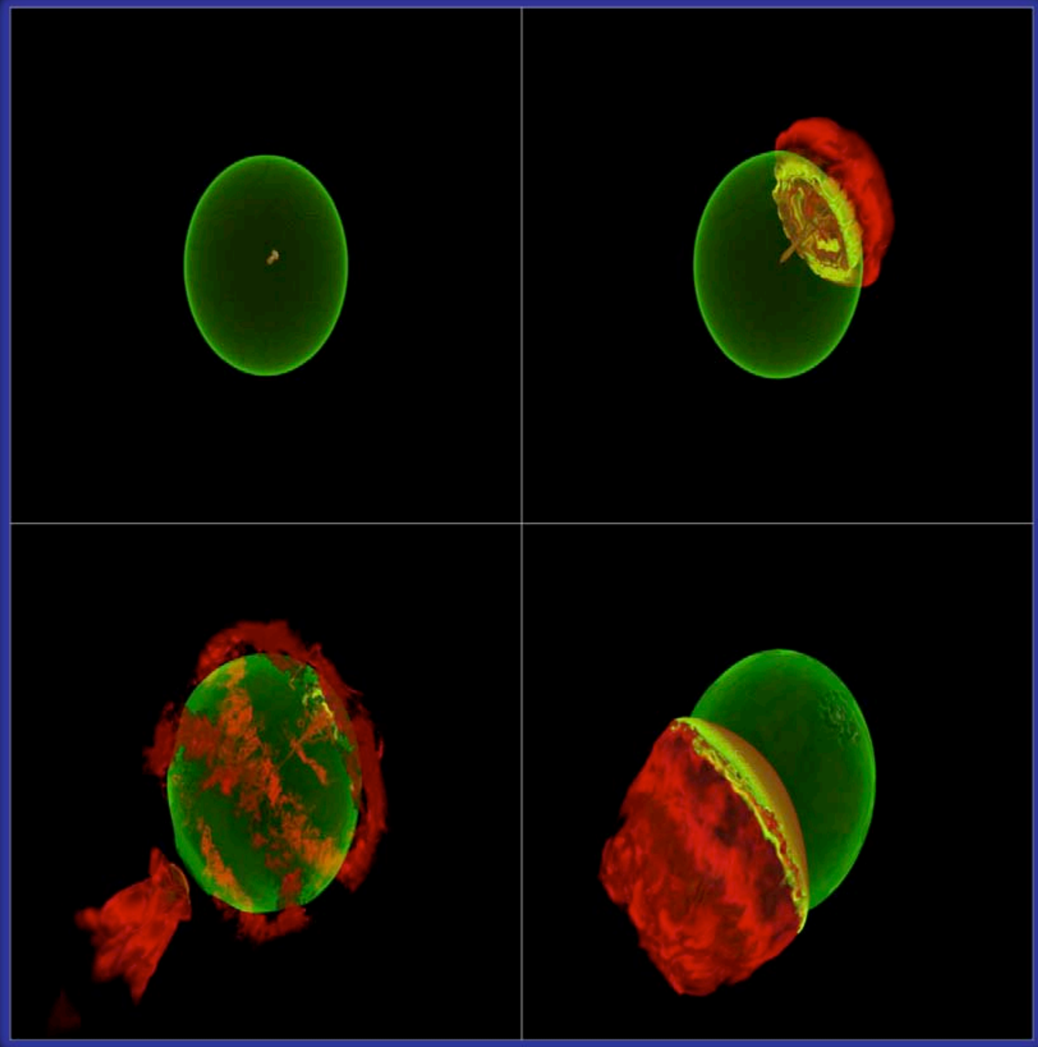
	Sample 1	Sample2
X(^{56}Ni)	0.9671	0.9522
X(^{52}Fe)	0.0184	0.0210
X(^{40}Ca)	0.0005	0.0009



Study of Deflagration in FLASH

1) GCD Model





Deflagration starts at t = 0.
Detonation initiates at t ~ 4.5 sec.
The burned mass due to deflagration goes to completion at t ~ 2 (green circle) and sharply increases due to detonation (blue circle)

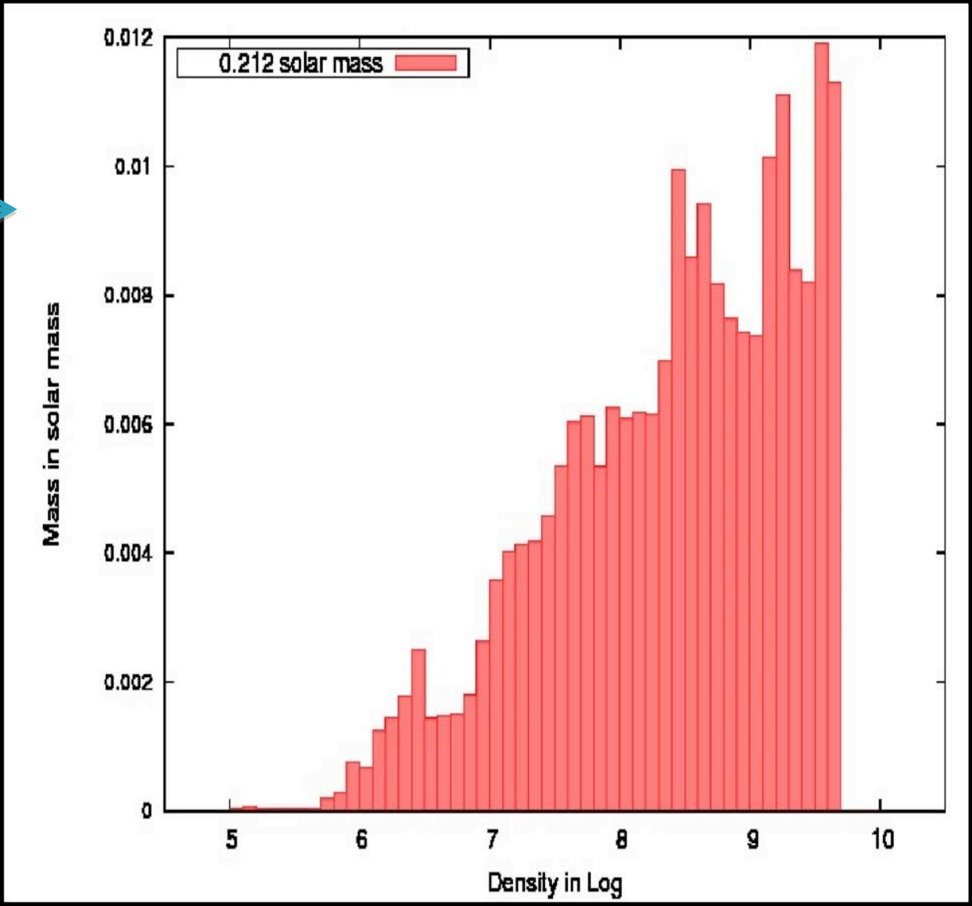
Study of Deflagration in FLASH

2) Test of behavior of Tracer Particles

Test how strong flow/particle coupling is.

The burned mass of the initial fuel in the entire star before detonation (that is, time $t \leq 5.5$) binned logarithmically with density, represented by tracer particles.
The total burned mass, $0.212 M_{\odot}$, gives a good agreement with that of the simulation with less 1% difference.
Most burning seems to happen in the high density regions.

Burned Mass from Tracer Particles during Deflagration



Future Works…

1. Further studies/tests on how well the tracer particles capture
   - detonation trajectories.
   - deflagration trajectories.

2. Further studies on detonation propagation.