Turbulently-Driven Detonation Initiation in Electron-Degenerate Matter with Helium

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MS Thesis Defense

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Outline

- What is a Type Ia Supernova (SNe Ia)?
- Stellar Lifetime
- White Dwarf
- Deflagration to Detonation Transition
- Zel'dovich Gradient Mechanism
- Carbon Detonation
- Helium Detonation
- Nuclear Physics
- Method
- Results

Type Ia Supernova

- Strong silicon lines in the absence of hydrogen
- Used as standardizable candles
- Led to the discovery of the accelerated expansion of the universe
- Cosmic Rays

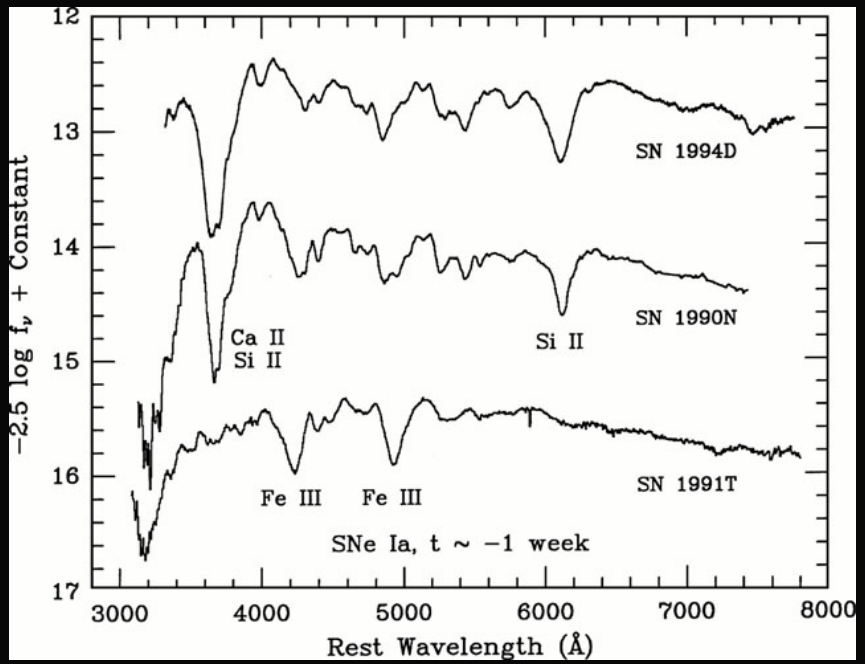


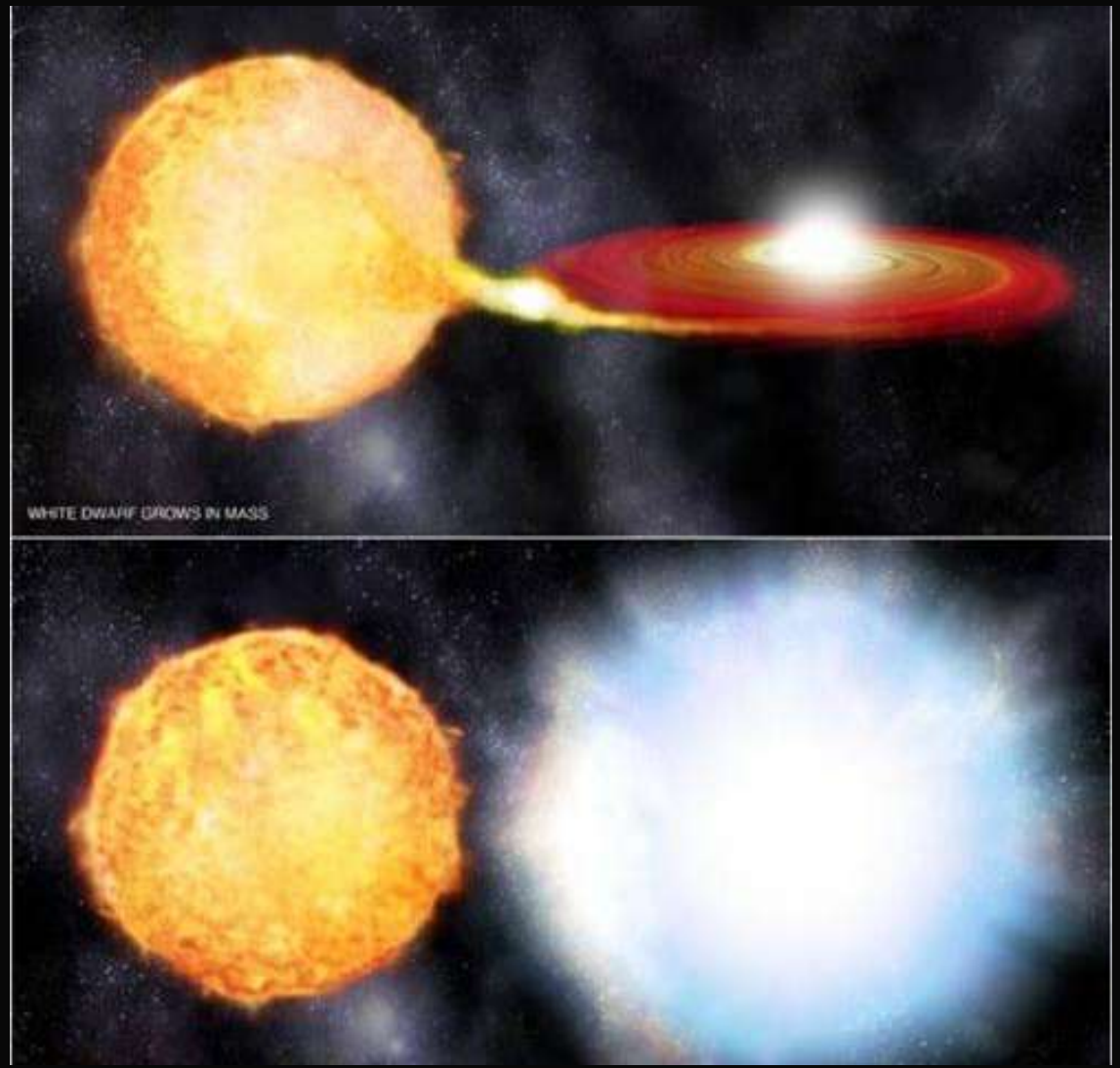
Figure: Fillipenko

Type Ia Supernova

- SN 2011fe confirmed that a compact object must be the progenitor of a SNe Ia

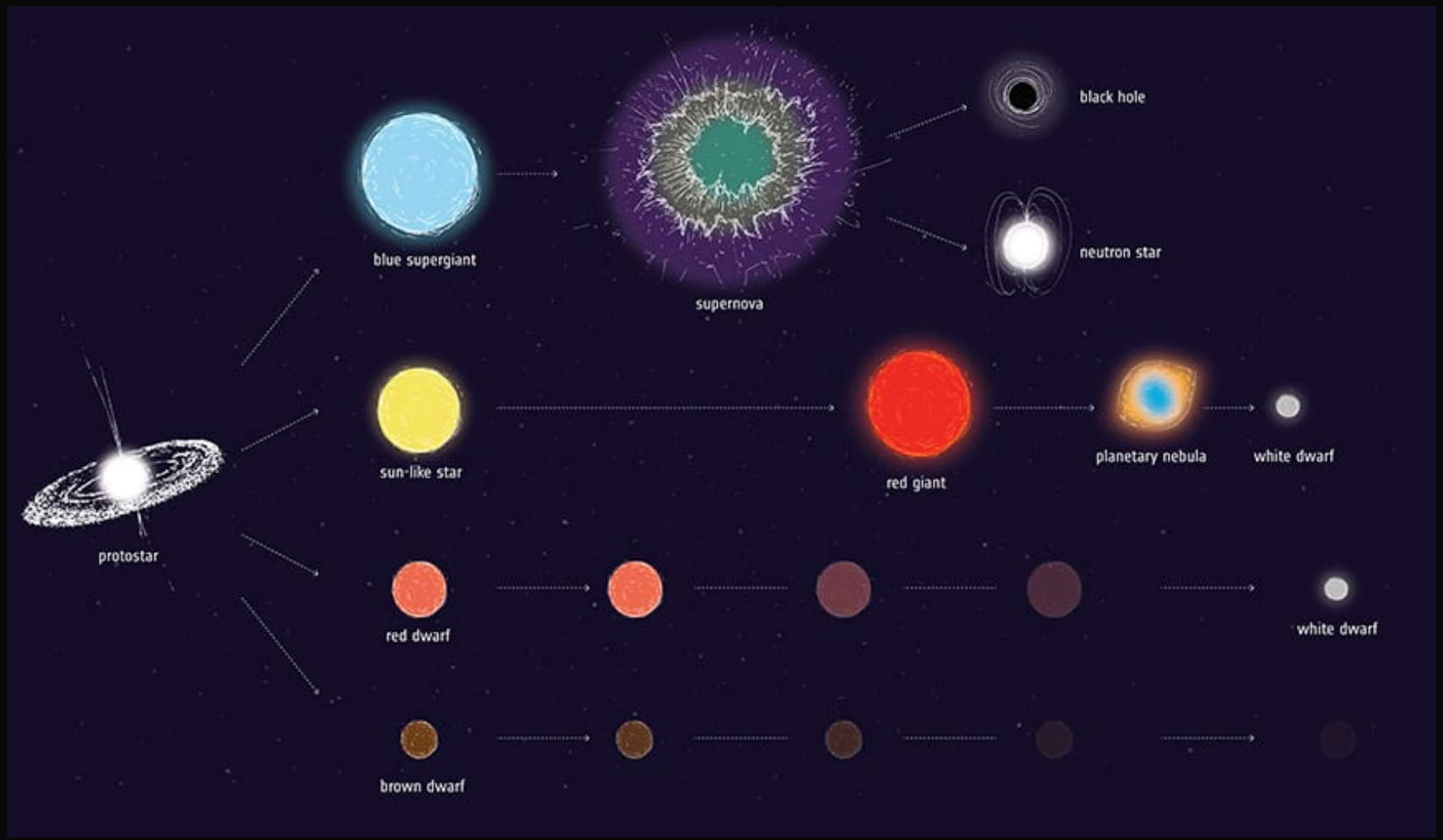
Figure: 2011fe as seen by the Palomar Transient Factory

Type Ia Supernova



NASA/CXC/M Weiss

Stellar Lifetime



White Dwarf

- Degeneracy Pressure
- Causes volume to decrease as mass increases
- Chandrasekhar Mass Limit $\simeq 1.4\ M_{solar}$

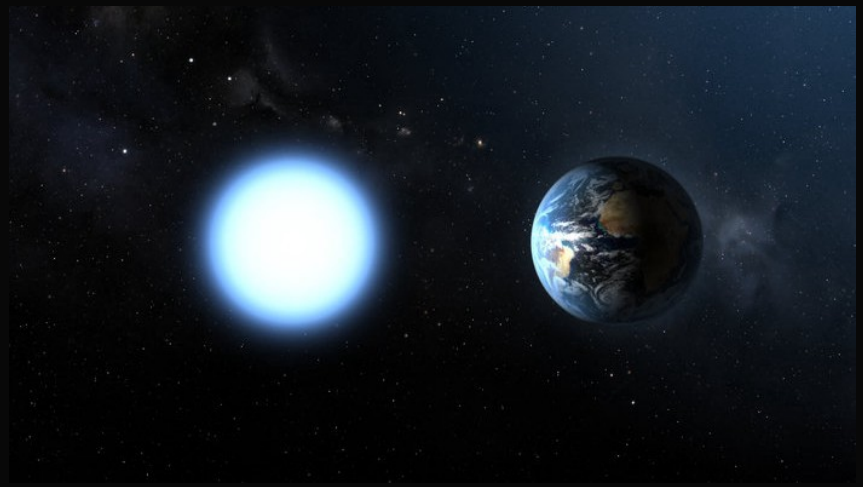
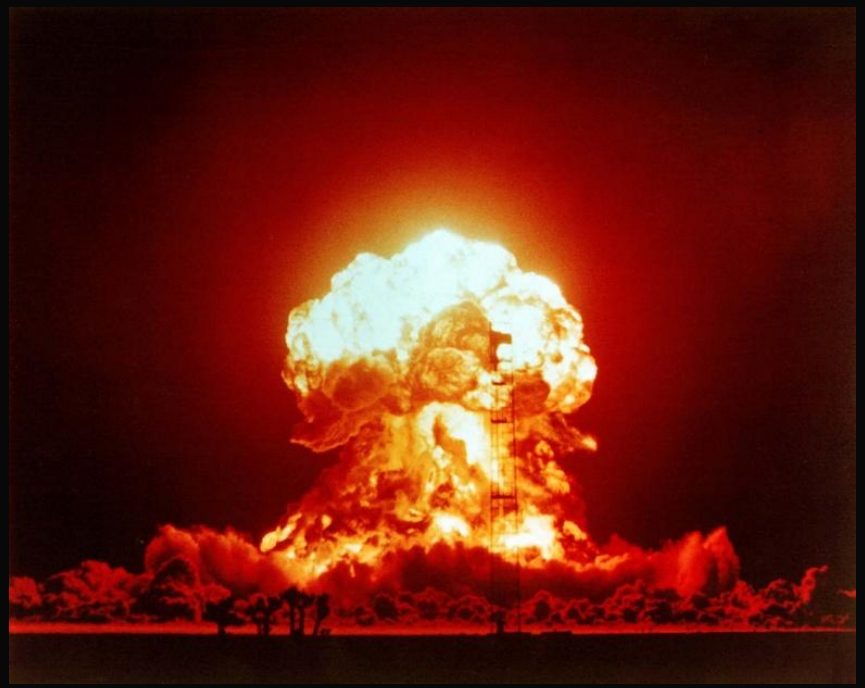
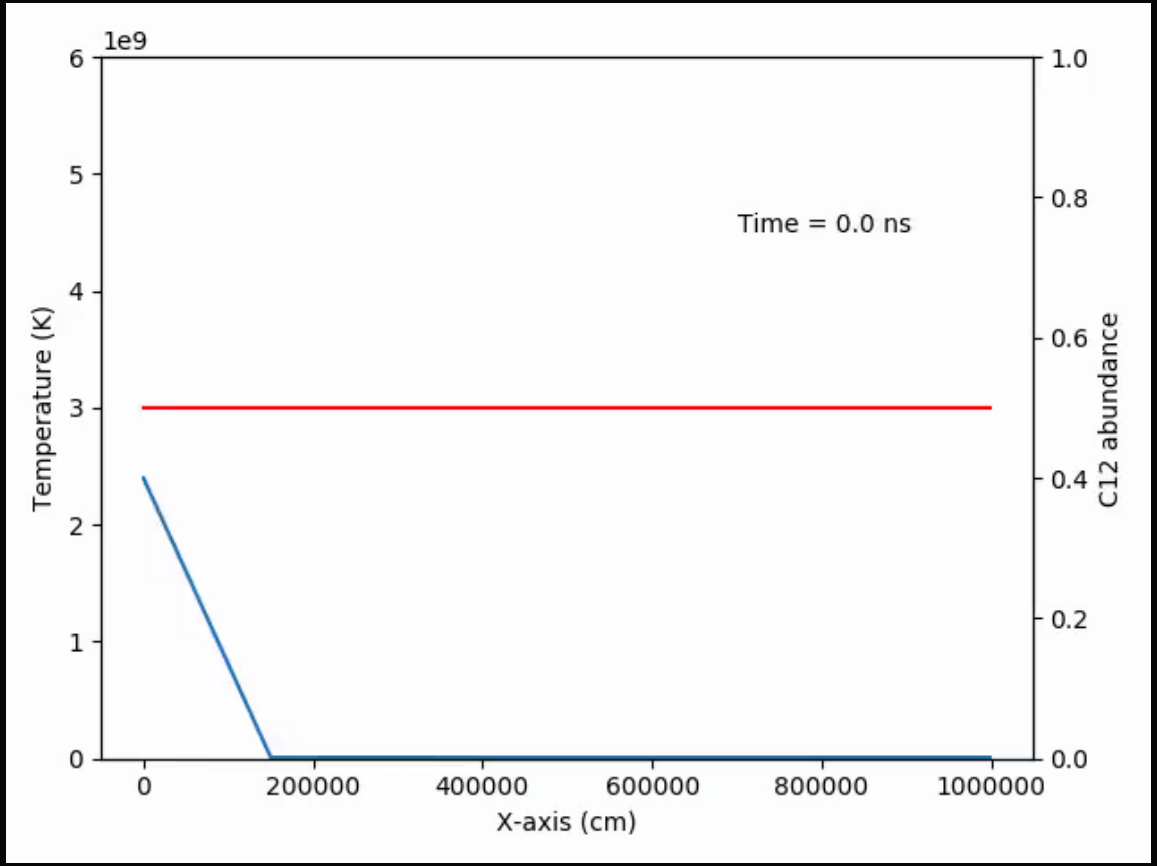


Figure: Sirius B compared to Earth (European Space Agency)

Deflagration to Detonation Transition

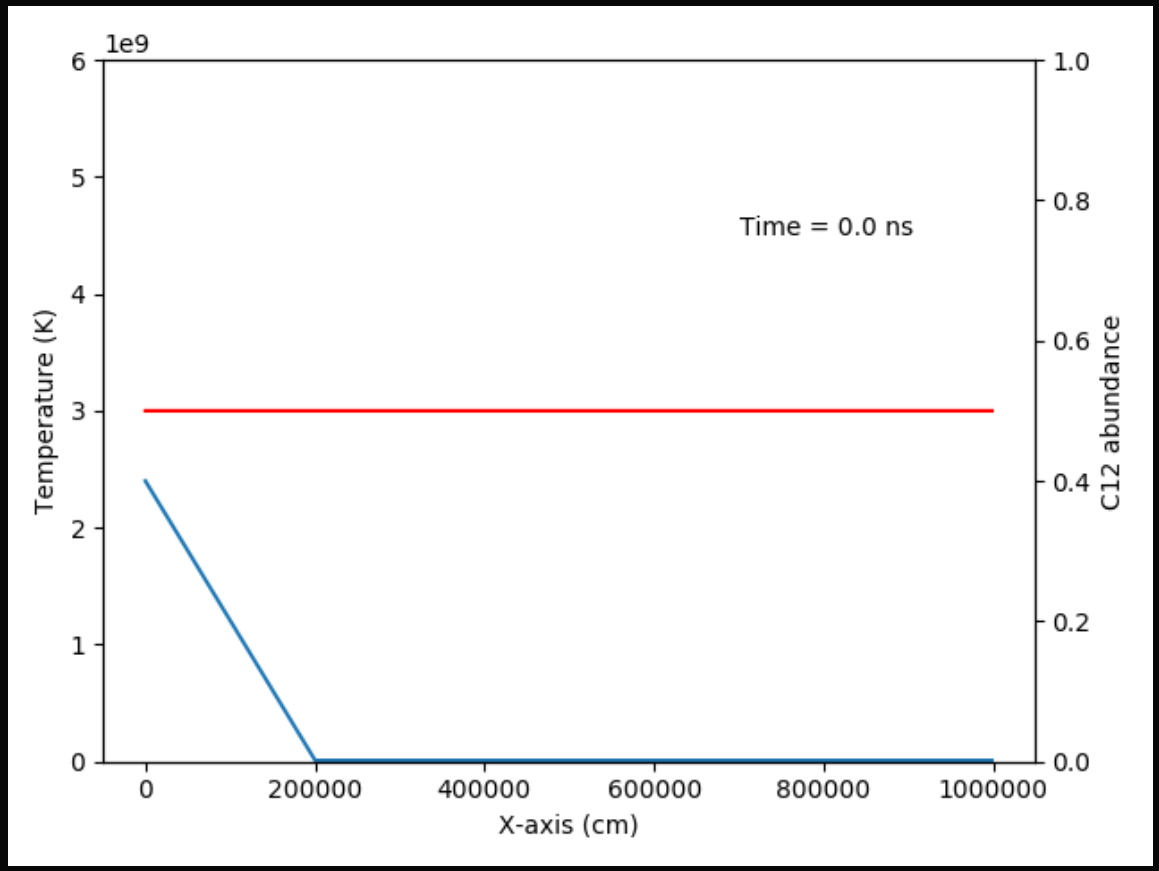


Zel'dovich Gradient Mechanism



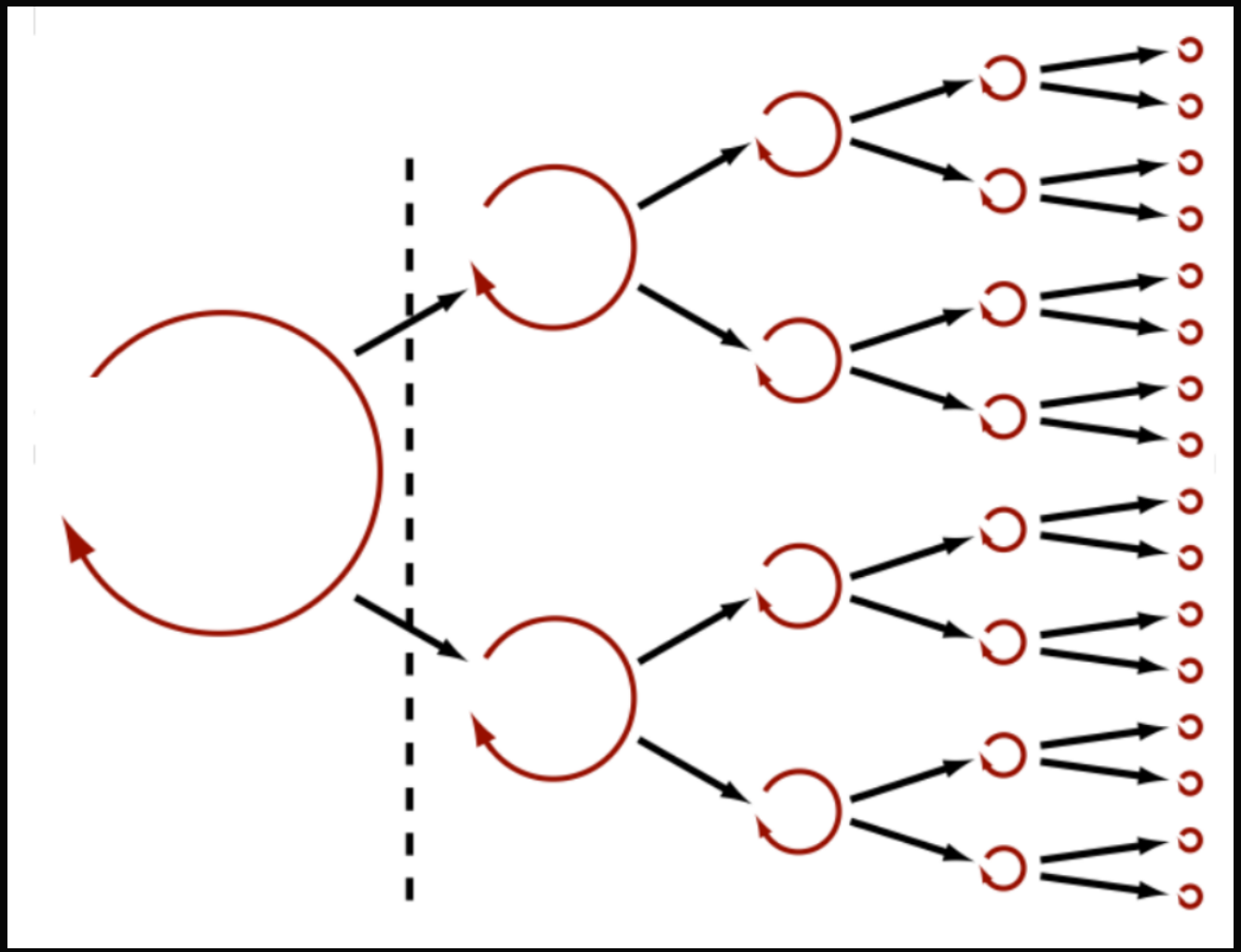
Failed detonation

Zel'dovich Gradient Mechanism



Successful Detonation

Turbulence



Kolmogorov's Theory (1941)

Carbon Detonation

- Highly Turbulent (Re $\simeq 10^{15}$)
- Karlovitz Number
  - Ka = (nuclear time scale/smallest turbulent time scale) $\simeq$ 8000
  - Distributed Burning Regime
- Turbulent dissipation of energy dominates nuclear burning prior to detonation by up to 20 orders of magnitude

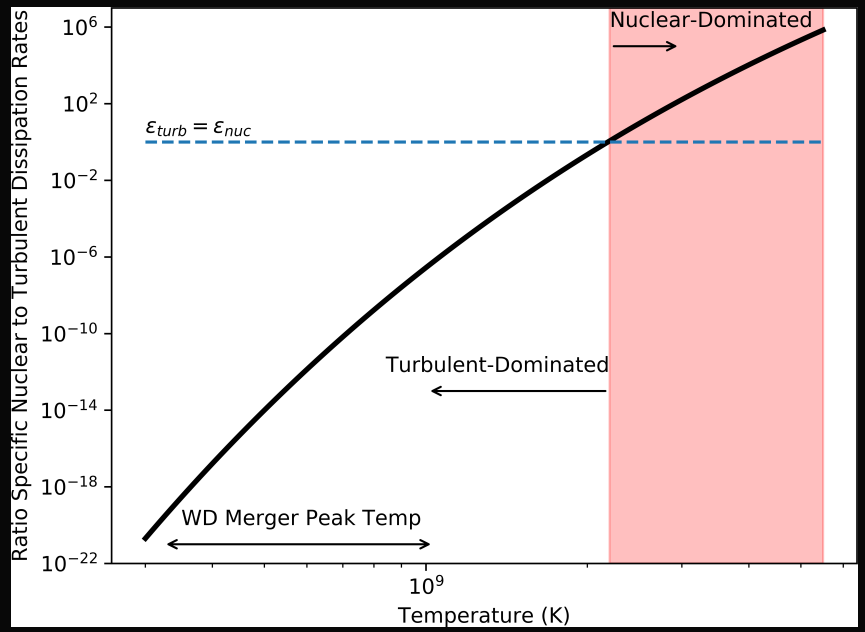
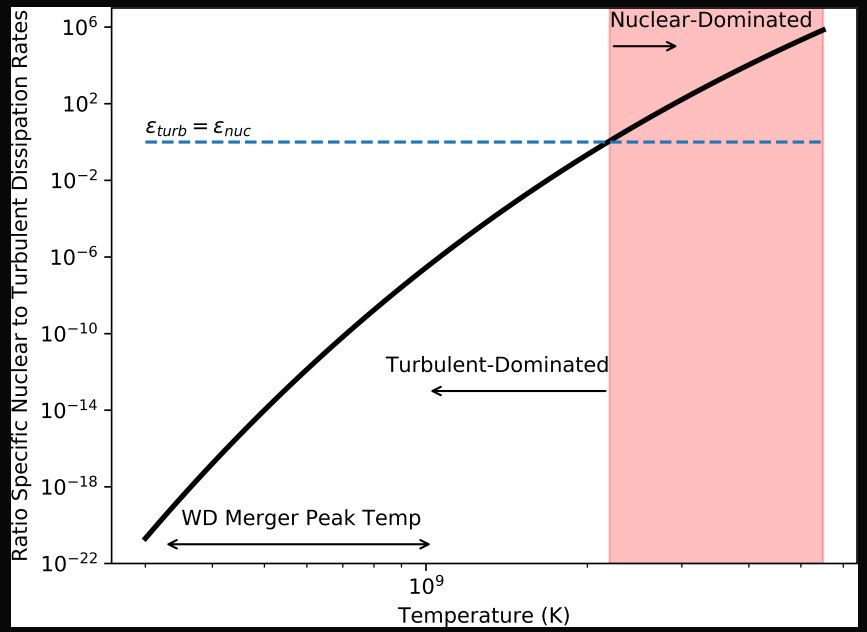


Figure: Analytic Curve for Carbon Detonation

Carbon Detonation

- Turbulently-Driven Detonation Mechanism of Carbon
- Fisher RT, Mozumdar P, Casabona G. 2019. Carbon Detonation Initiation in Turbulent Electron-Degenerate Matter. The Astrophysical Journal.



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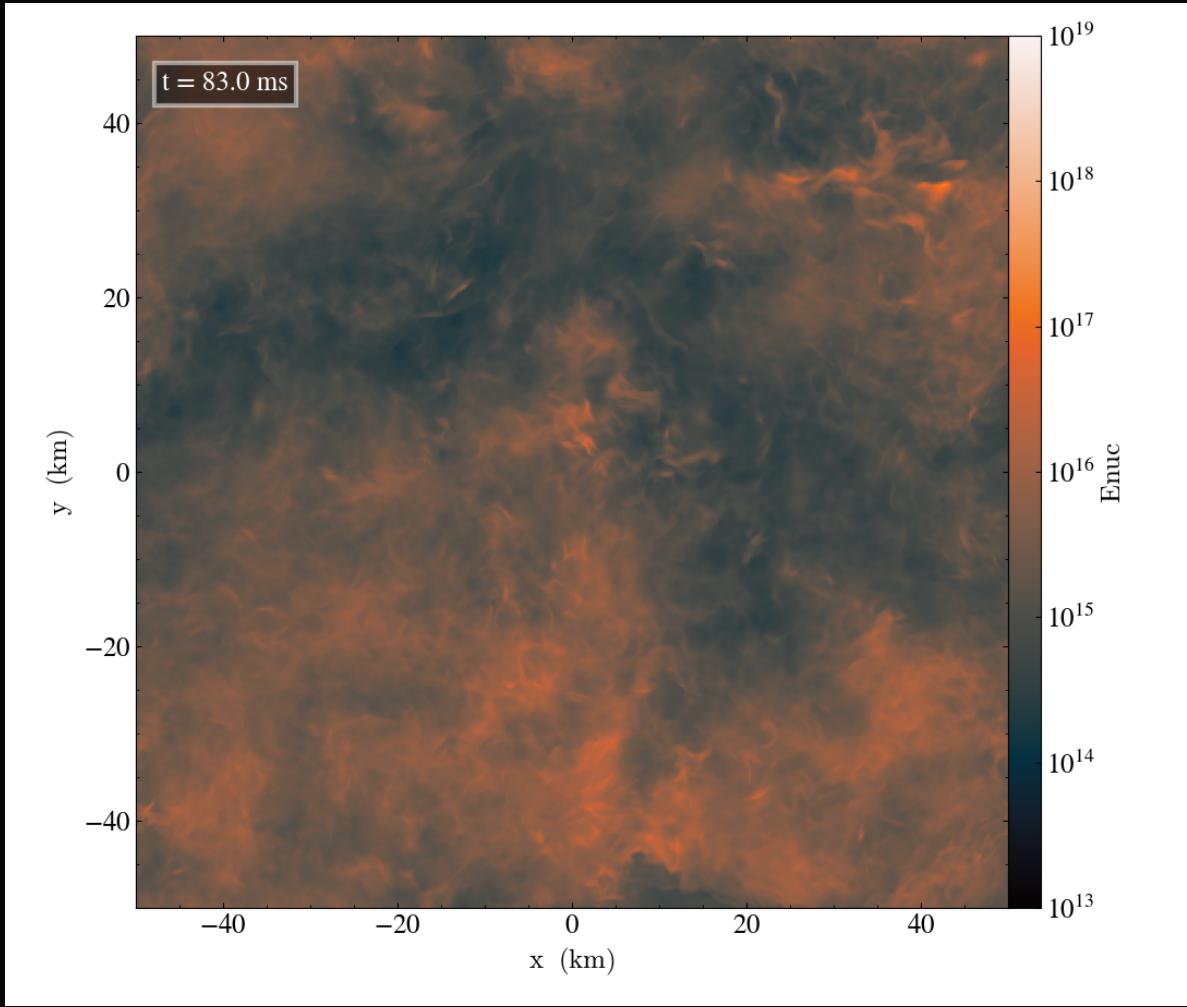
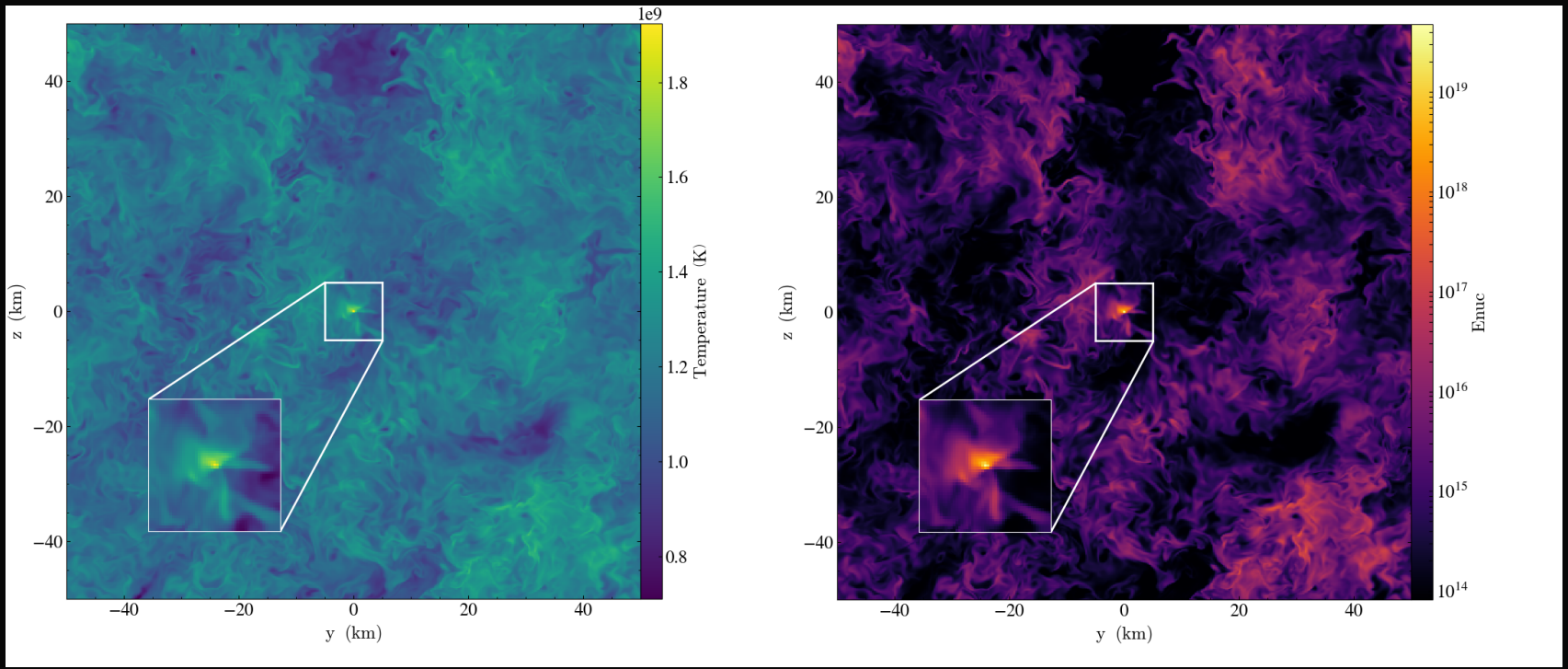
Carbon Detonation

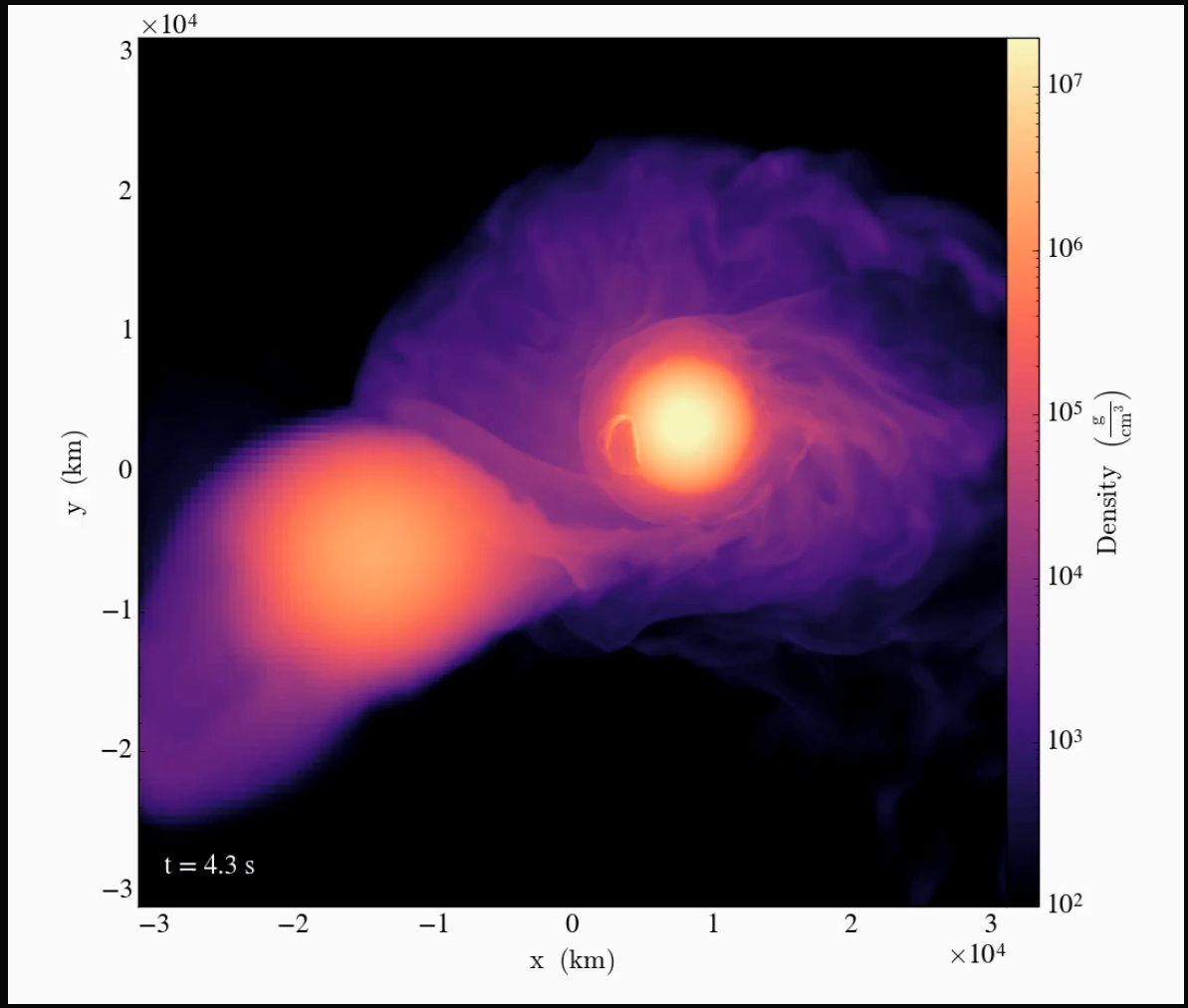


Carbon Detonation



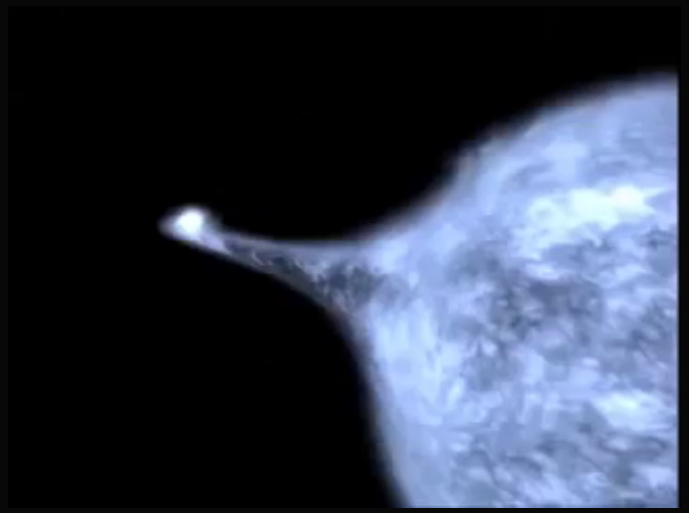
Slice plots at the moment of detonation.

Helium Detonation



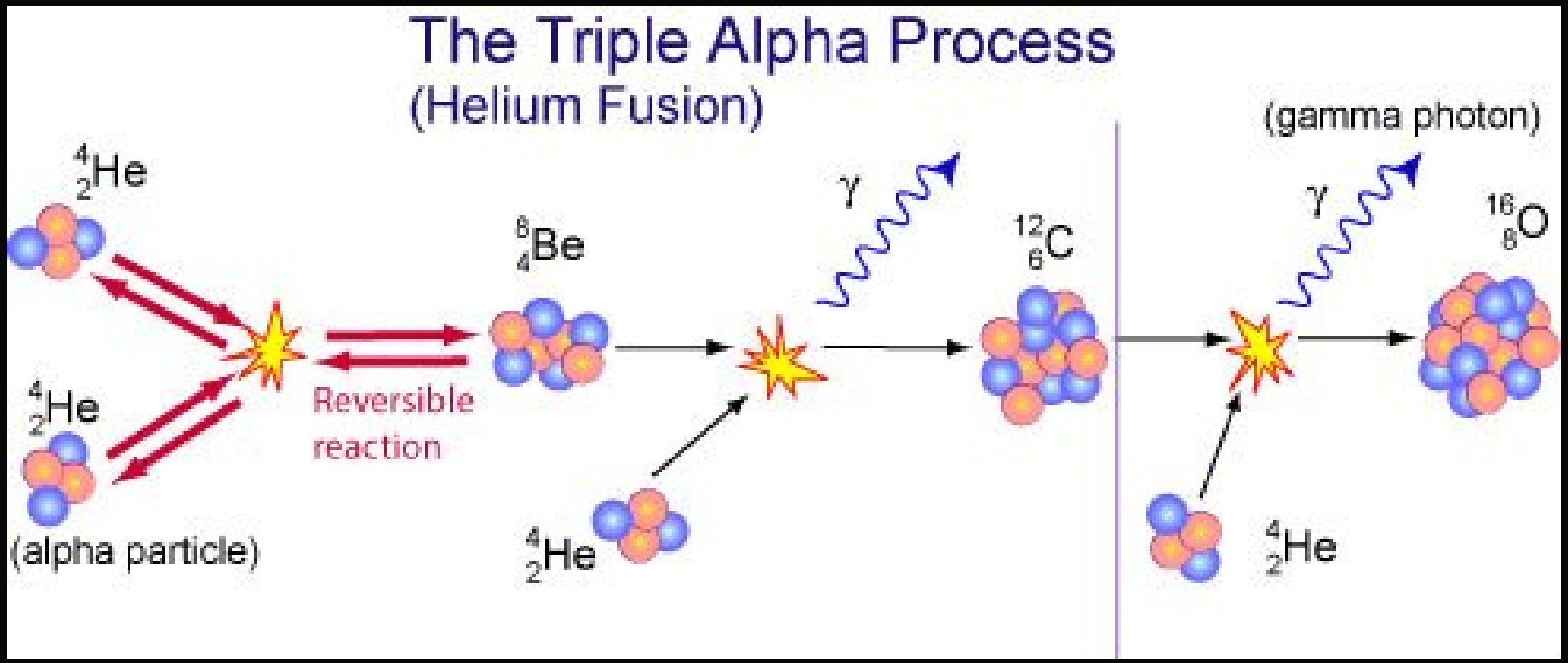
Vishal Tiwari (2019)

Helium Detonation



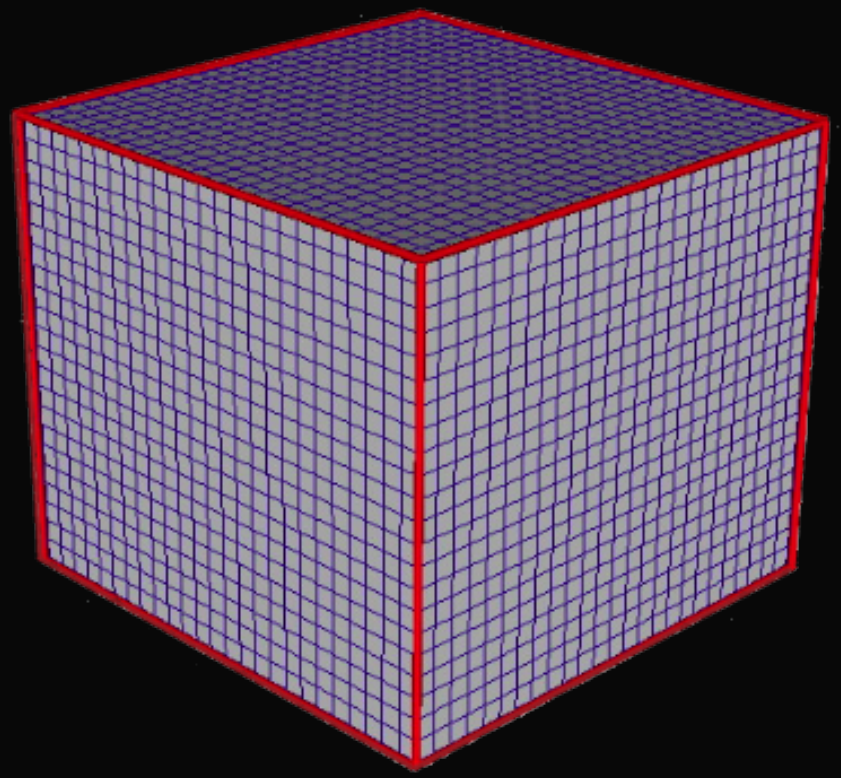
NASA, ESA and P. Ruiz-Lapuente, cut and colored by S. Geier

Nuclear Physics



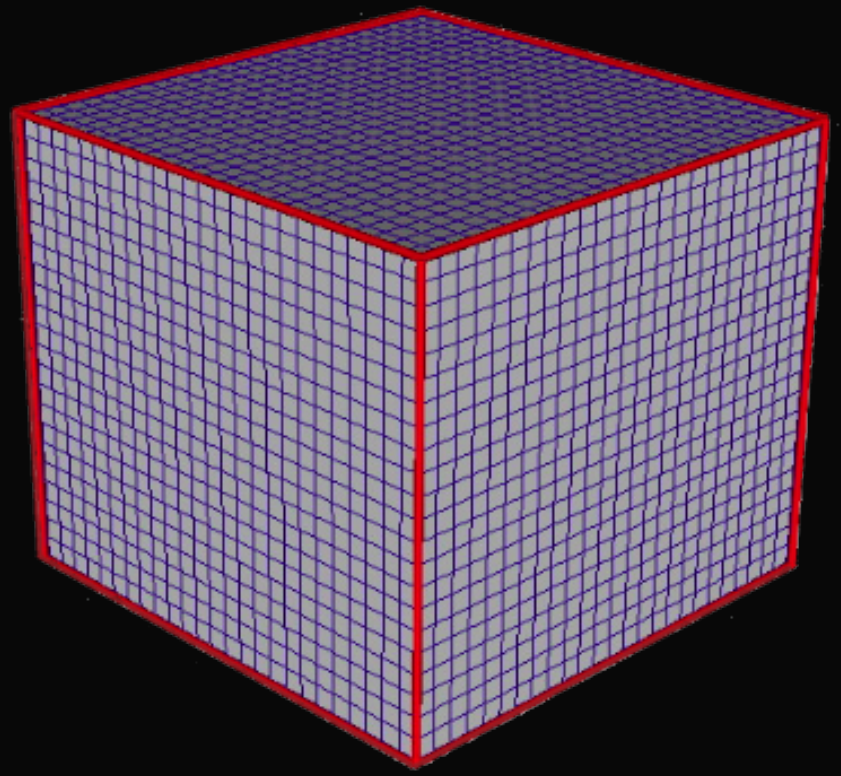
Method

- 3D Models
- 100km periodic box
- Uniform Grid
- Driving force for turbulence on a large scale
- Helmholtz Equation of State
- 19-isotope network

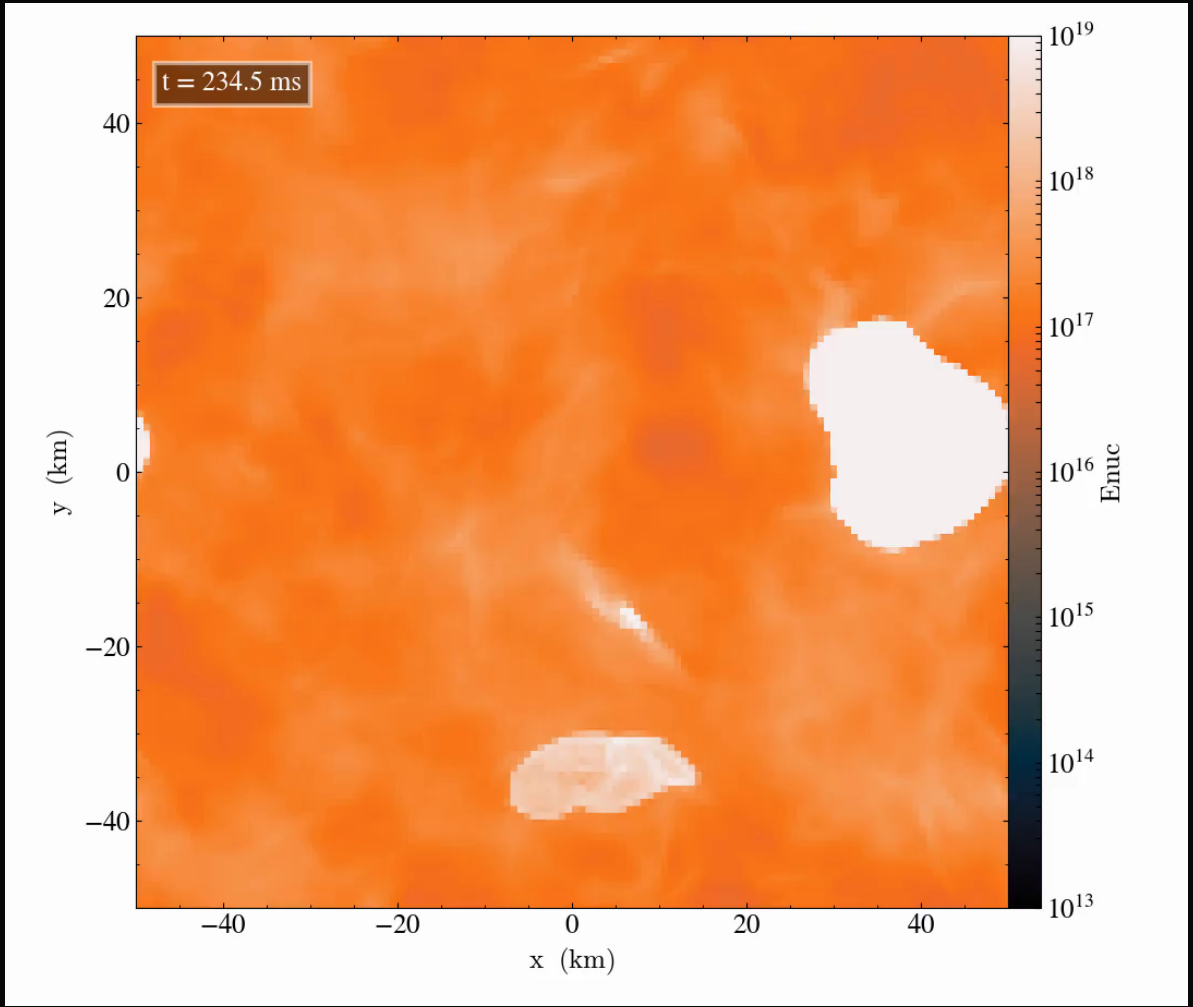


Method

- Resolution set to $128^3, 256^3, 512^3, 1024^3$
- Mass density set to $10^5, 10^6 (\frac{g}{cm^3})$
- Helium fraction set to $1.0, 0.25, 0.1$
- Used FLASH4 code on Stampede2



Results



Detonation of 128^3 run with $\rho = 10^6 \frac{g}{cm^3}$ and He fraction $= 0.25$.

Results

- Triple Alpha is more sensitive to density than carbon burning
- Helium detonation occurs sooner than carbon
- Alpha capture onto carbon and oxygen dominates at later times

Future Work

- Incorporate higher isotope network
- Keep exploring parameter space
- Nitrogen, Neon
- Expand these sub-grid models into global situations