

# Implementing a 19 Isotope Reaction Network in Cosmos++

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Mentors: Rob Hoffman, Peter Anninos

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- ▶ Used to simulate a wide variety of problems in astrophysics
  - ▶ Supernovae
  - ▶ Accretion of matter by black holes
  - ▶ Big bang simulations
- ▶ Many physics packages
  - ▶ Fluid dynamics
  - ▶ Radiation transport
  - ▶ Radiation pressure
  - ▶ Magnetic fields
  - ▶ Gravity
  - ▶ Nuclear energy generation

## Goal of Project

Compute nuclear energy generation more accurately

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$$\epsilon_{\text{nuc}} = N_A \sum_i B_i \Delta Y_i$$

- ▶  $B_i$ 
  - ▶ Binding energy for nuclide  $i$
- ▶  $Y_i$ 
  - ▶ Dimensionless abundance for nuclide  $i$

Need  $\Delta \vec{Y}$  to compute energy generation

- ▶ A reaction network is the set of isotopes chosen to model a reactor
- ▶ Each isotope has its own *Conservation Equation* that describes the evolution of its abundance

## Conservation of Nuclide $i$

$$\underbrace{\frac{dY_i}{dt}}_{\text{Change Rate}} = \underbrace{\sum_{j,k} Y_j Y_k \lambda_{k,j}(\ell)}_{\text{Gain Rate}} - \underbrace{\sum_{j,k} Y_i Y_j \lambda_{j,k}(i)}_{\text{Loss Rate}}$$

- ▶ Number of nucleons is conserved
- ▶ The set of conservation equations in a reaction network forms a system of coupled Ordinary Differential Equations

- ▶ The system of conservation equations is of the form

$$\mathbf{J} \vec{Y} = \frac{d\vec{Y}}{dt}$$

- ▶ Tracking more isotopes makes the Jacobian larger and more expensive to solve
  - ▶ The network solve is just one of many physics packages to be run for each cell and time step

Need to reduce the number of isotopes tracked while maintaining accuracy

# Network Approximations

- ▶ Track as few isotopes as required
- ▶ Balance functionality, accuracy and computational expense
- ▶ 7 isotope network
  - ▶ Current network in Cosmos
  - ▶ Simplified alpha network
  - ▶ 17 reactions
  - ▶ No hydrogen burning
  - ▶ Inaccurate  $^{28}\text{Si}$  to  $^{56}\text{Ni}$  equilibrium link

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## Alpha Network





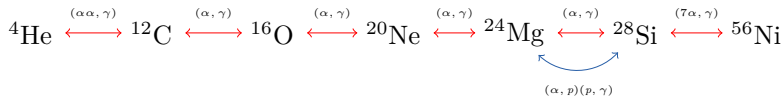
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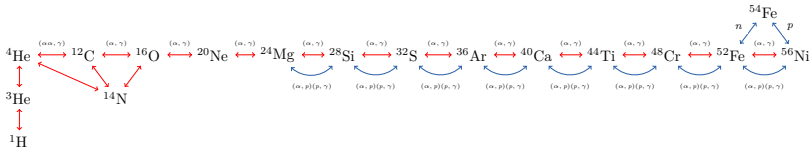
## 7 Isotope Network



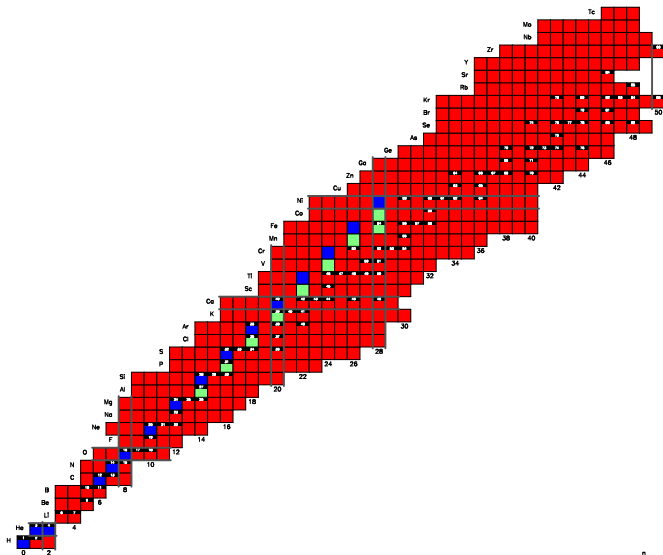
# 19 Isotope Network

- ▶ New network added to Cosmos
- ▶ 101 reactions
- ▶ Complete alpha network
- ▶ Has hydrogen burning capability
- ▶ Photodisintegration

19 Isotope Network



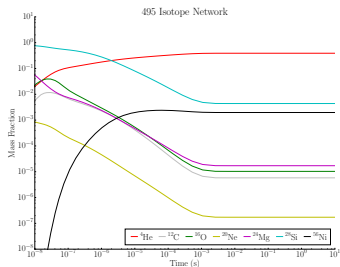
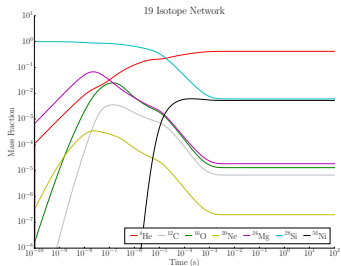
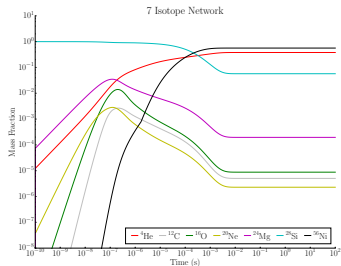
# 495 Isotope Network



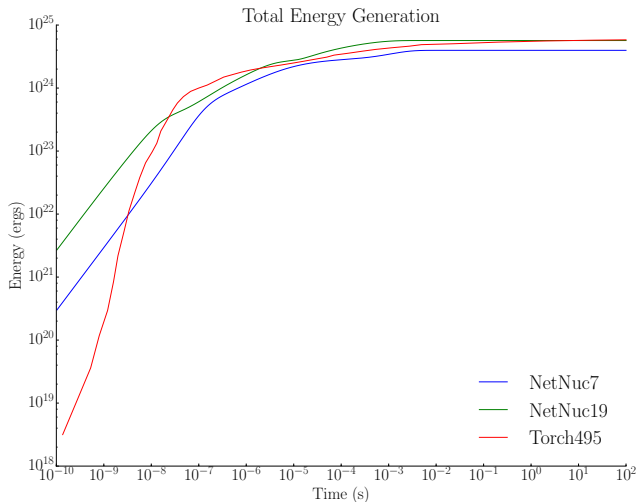
- ▶ Compare timing and accuracy of 19 and 7 isotope networks for known test problems
- ▶ Isolate the nuclear energy generation package
- ▶ Non dimensional point star
- ▶ Evolve the isotopes under a constant temperature and pressure

# Hydrostatic Isotope Evolution

Si burn:  $T = 6 \times 10^9$  K,  $\rho = 1 \times 10^7$  g/cm<sup>3</sup>



# Hydrostatic Energy Generation



# Hydrostatic Verification Results

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**19 isotope network is only 3% slower!**

- ▶ The 19 isotope network provides an increase in accuracy for almost no additional computational cost
- ▶ 19 is more accurate than 7 for heavy nuclide burns
- ▶ Cosmos now has hydrogen burning and full photodisintegration support
- ▶ Future Work
  - ▶ Verify 19 isotope network under hydrodynamic conditions

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