An introduction to

Stellar Nuclear Power

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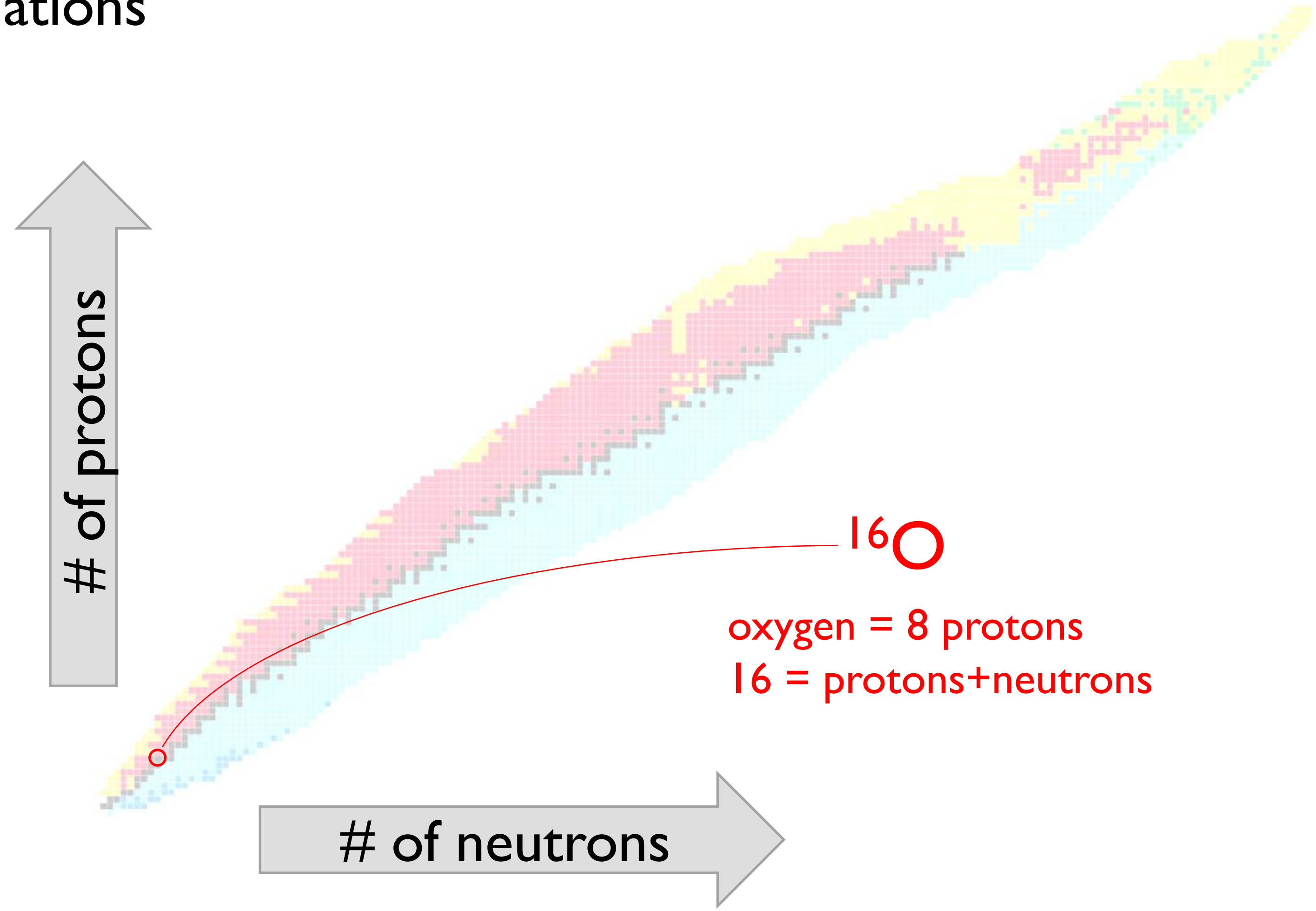
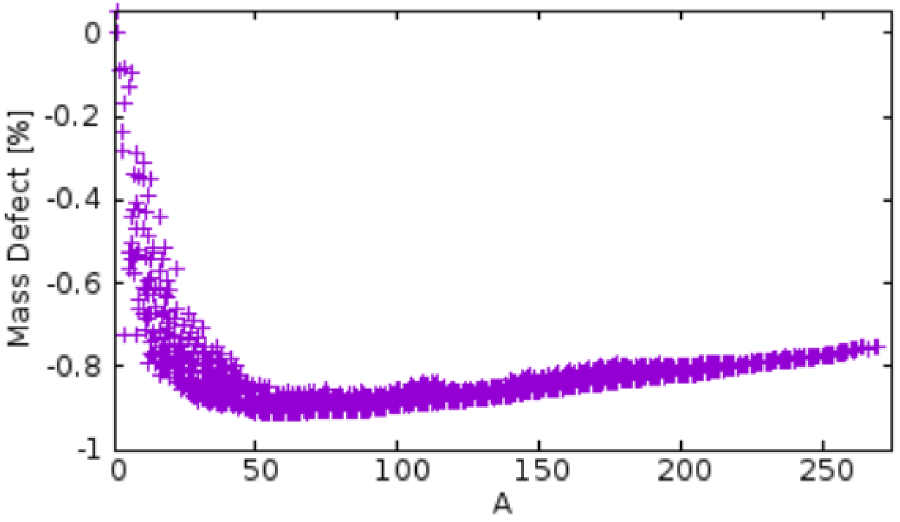
The atomic nucleus

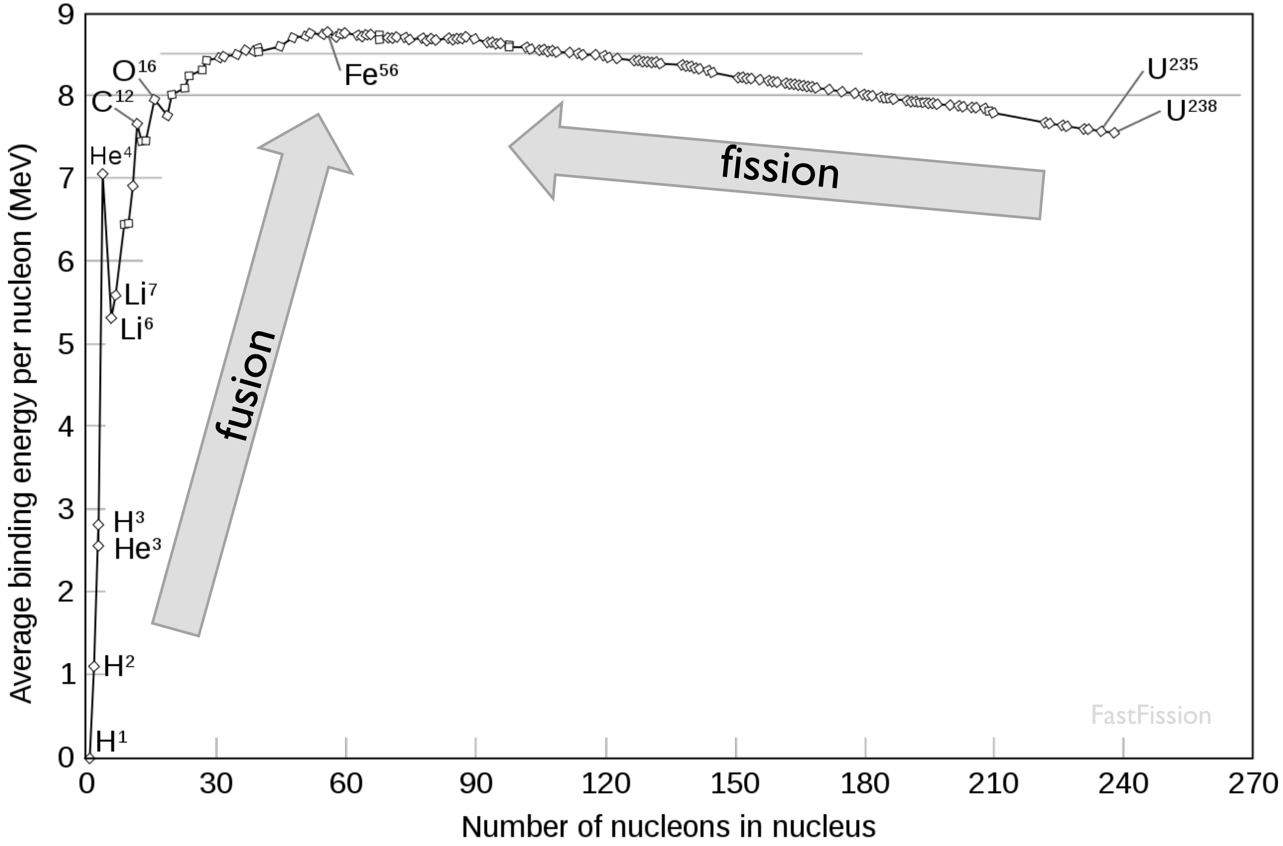
- A collection of protons and neutrons, weighing ~10^{-27} kg and roughly 10^{-15} m in size
- Nuclei come in lots of different combinations of protons and neutrons, where each combination is called an "isotope"
- Each isotope can have several different configurations, known as states, each one corresponding to a certain amount of binding energy
    - the "ground state"
    - and "excited states"



Nuclear binding energy

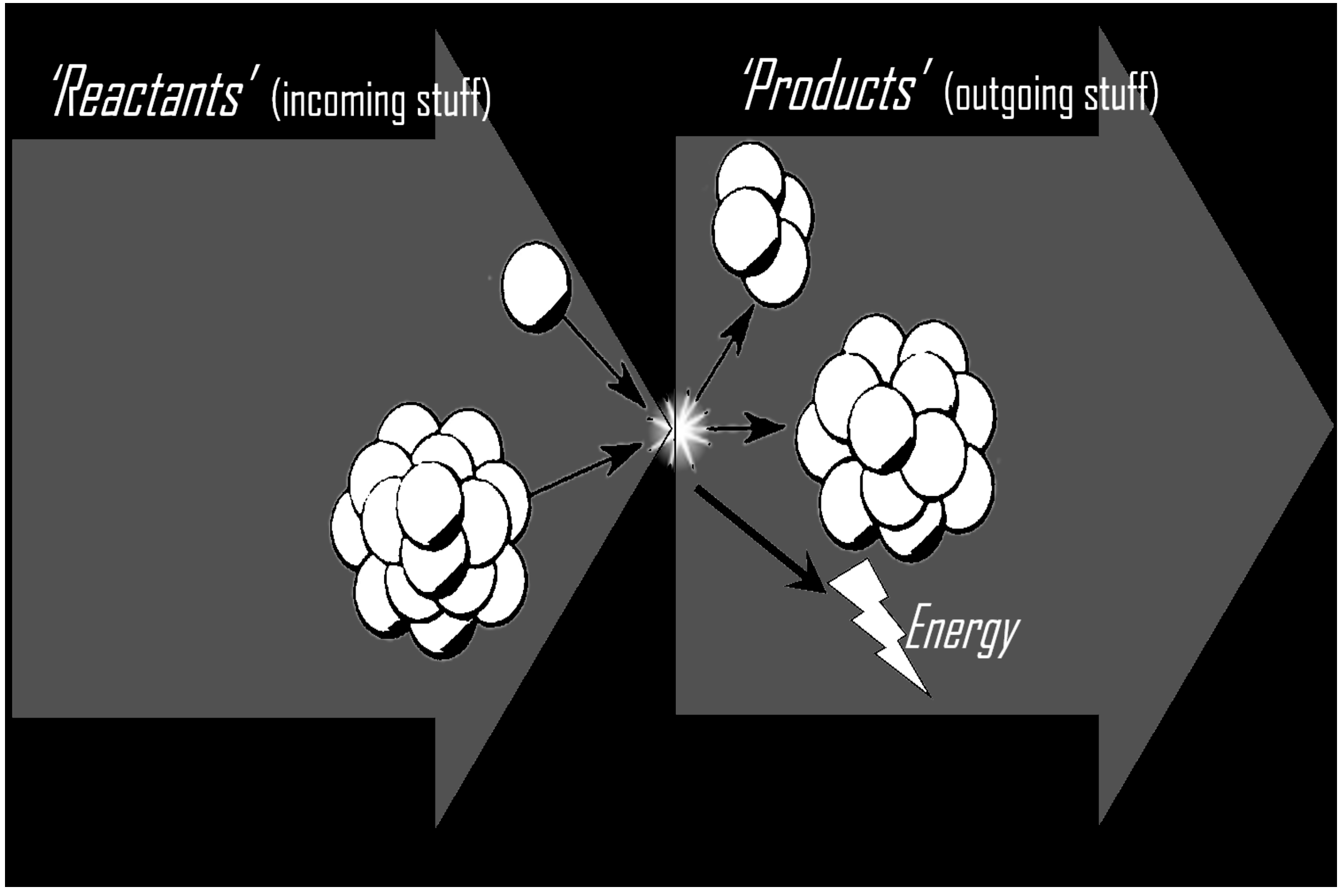
- Nuclei exist because of binding energy:
  the mass of the nucleus is less than the sum of the mass of the nucleons in the nucleus (the "mass defect")
- This is mass-energy equivalence in action: $E = mc^2$
- Looking at the ground state energies, there are trends in nuclear binding across the nuclear landscape
- Converting from one or more isotopes to another one or more isotopes can release the excess binding energy
  - Fusion = light-to-heavy nuclei
  - Fission = heavy-to-light



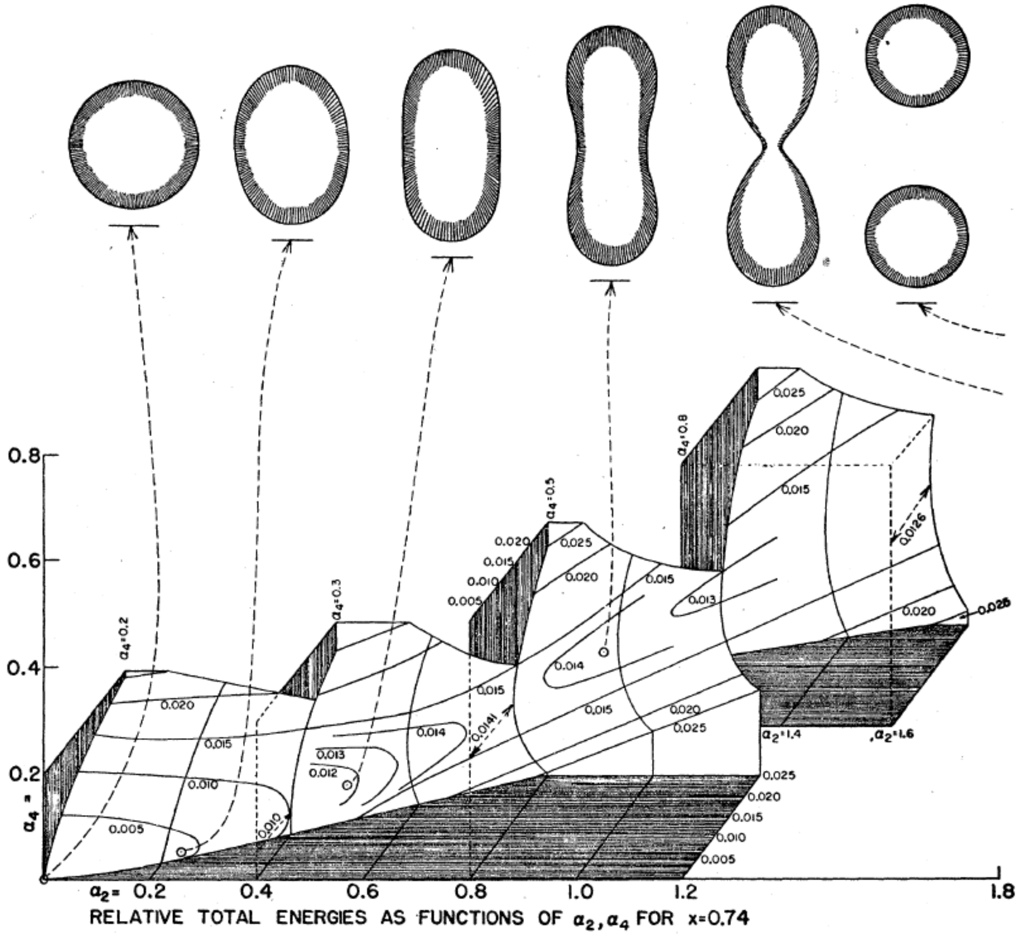


Fusion vs Fission

Fusion



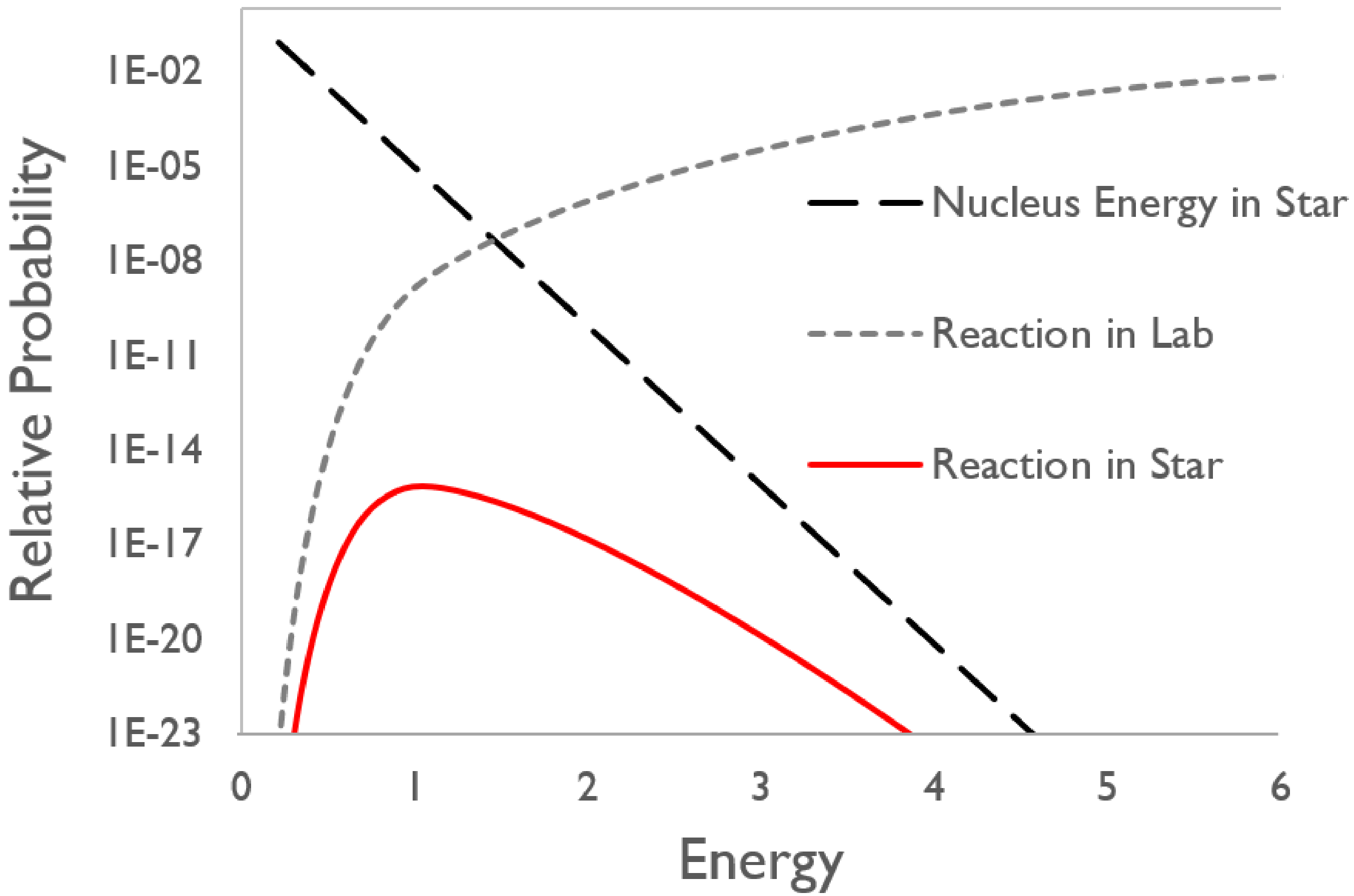
Fission



Hill & Wheeler, Phys. Rev. 1953

Fusion in stars

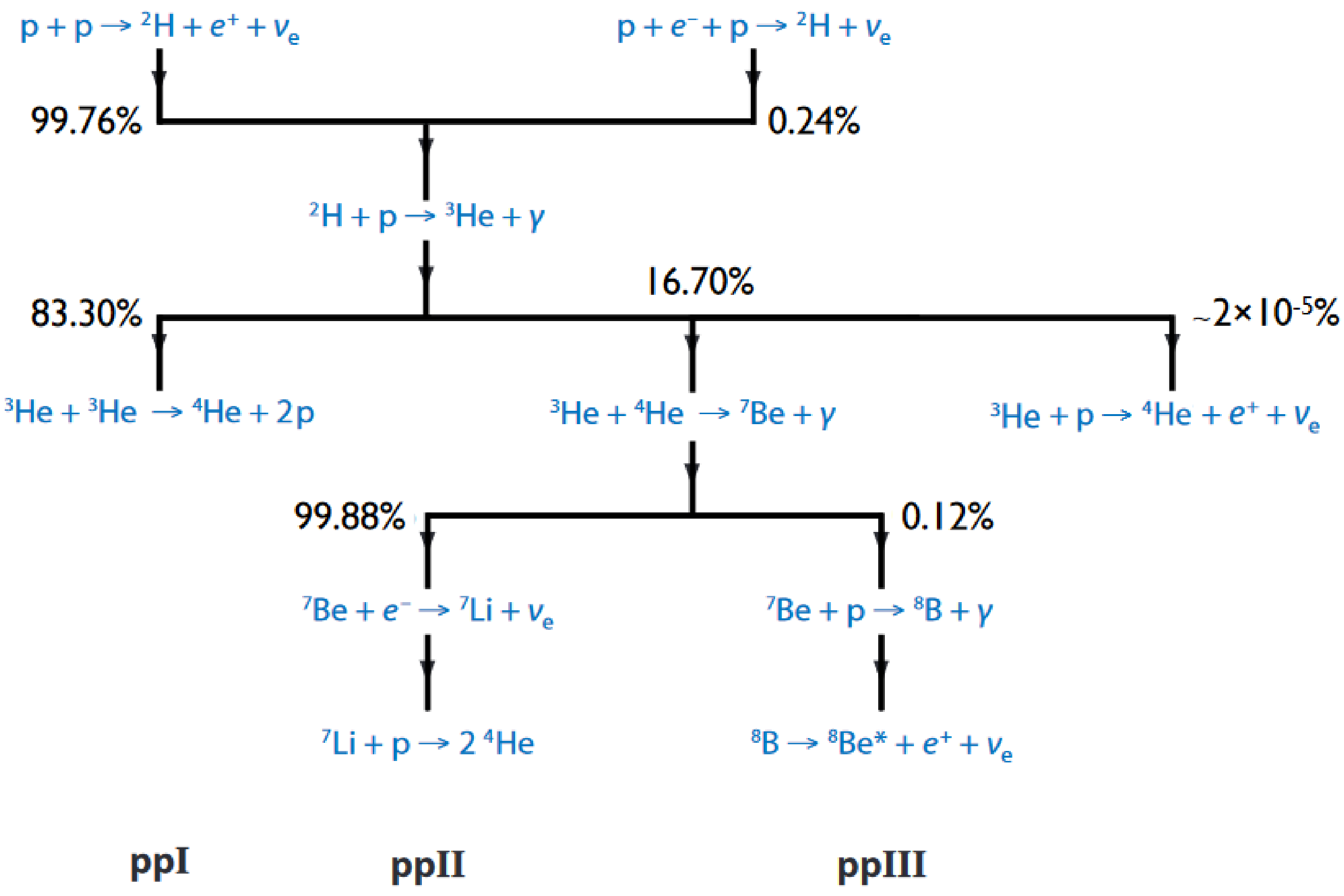
- The high temperatures in stars gives nuclei the kinetic energy needed to overcome the Coulomb repulsion between charged particles
- The reaction rate at the energies of interest are rather small
  - Good! *Stars live a long time*
  - Bad! *Hard to measure*



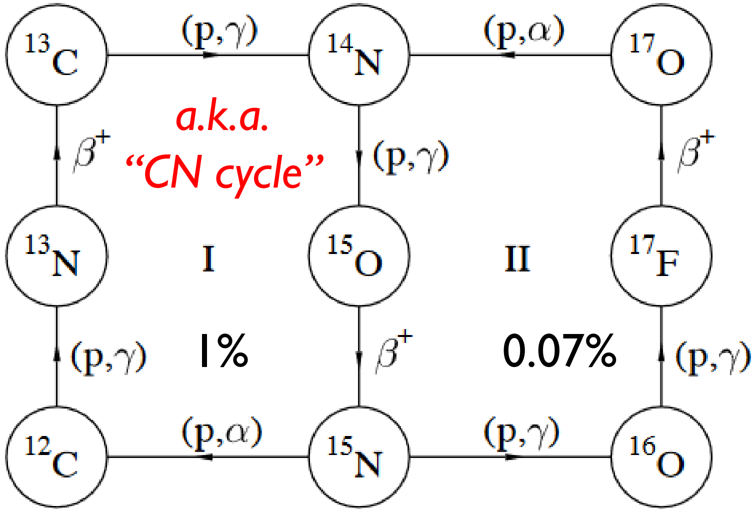
Fusion in the sun

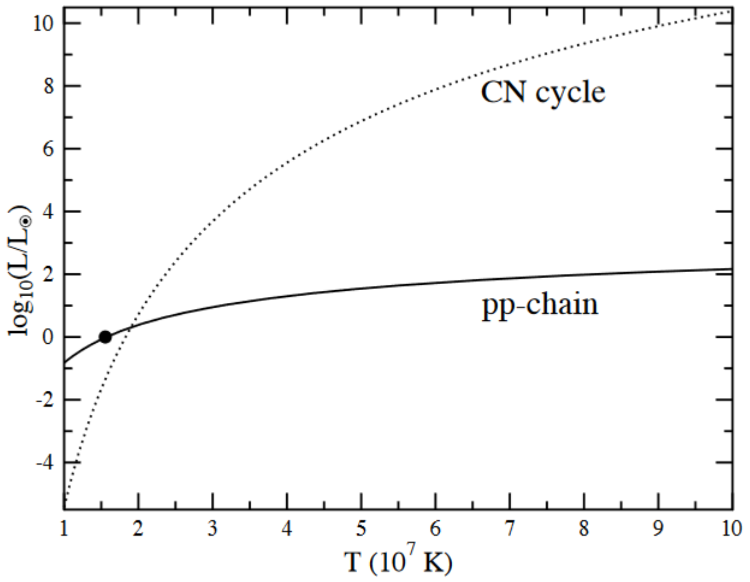
PP chains

percentages are for solar temperature



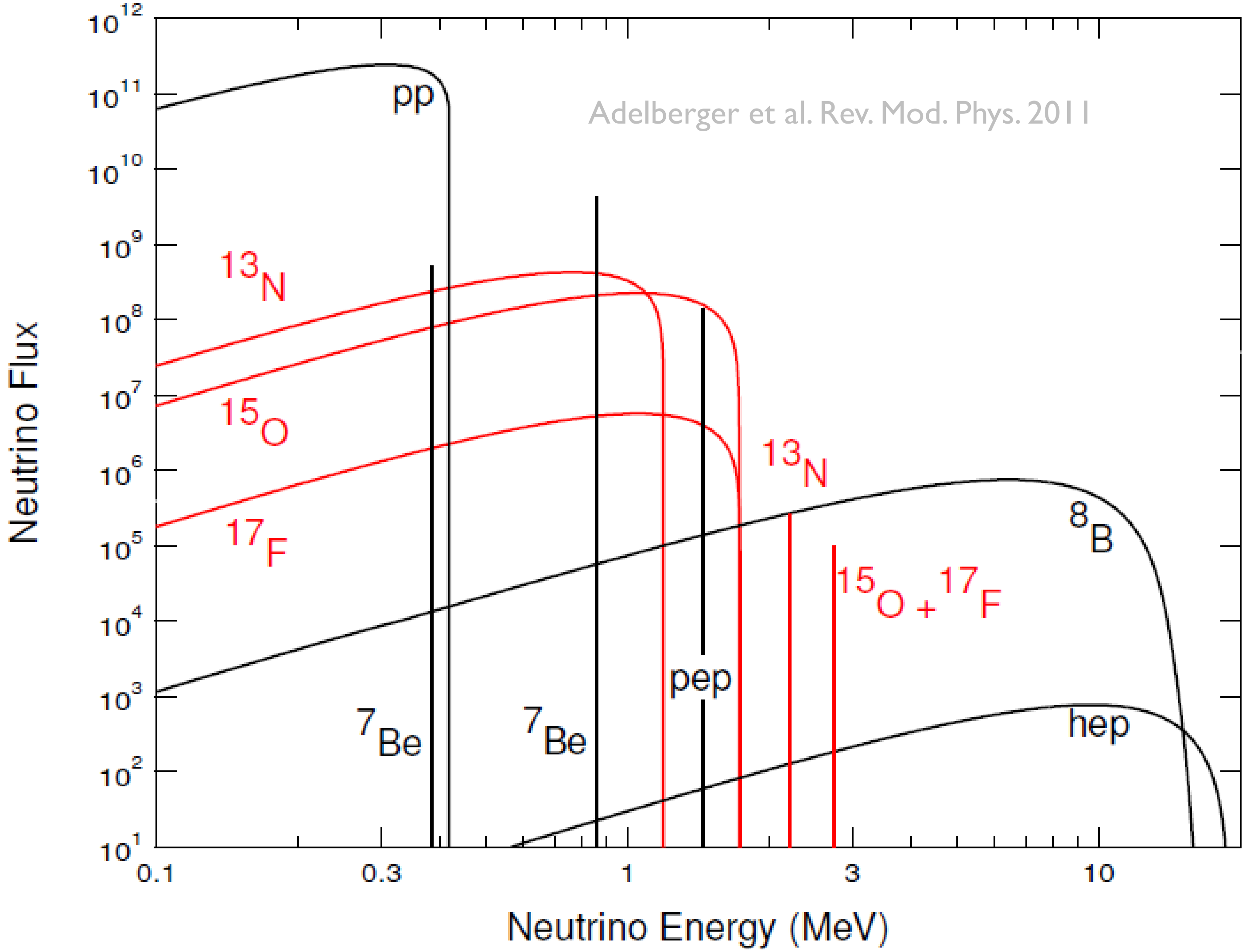
(cold) CNO cycles

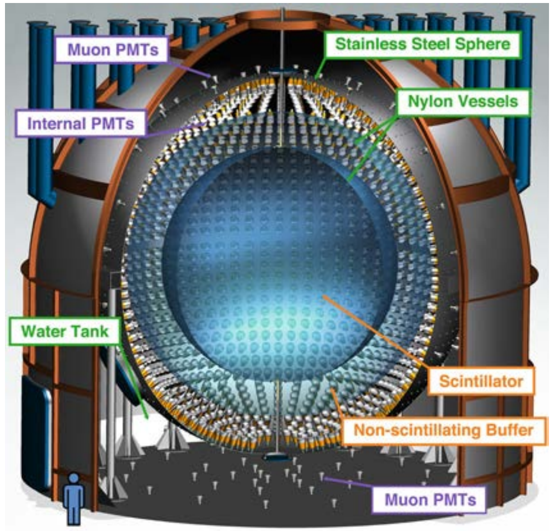




Adelberger+ Rev. Mod. Phys. 2011

Fusion in the sun: *direct evidence from neutrinos*





~280,000 kg of liquid scintillator surrounded by ~2200 PMTs detect ν via scattering with e-

BOREXINO collaboration, arXiv:2006.15115 (2020)