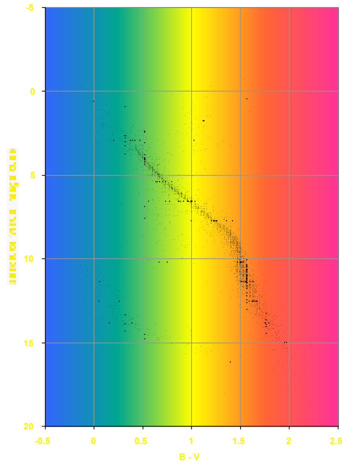
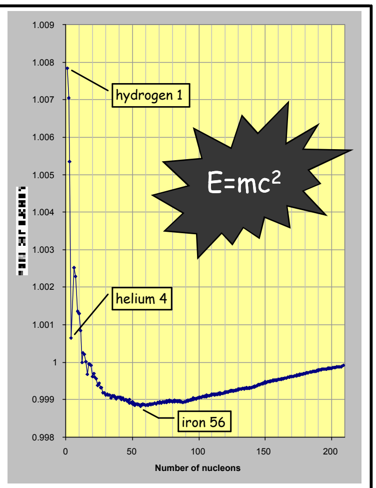
The Lives of Stars

- From studying nearby stars and stellar clusters
  - most stars are on the main sequence
  - stars become red giants after leaving the main sequence
- How does this relate to the internal structure of the stars and their nuclear fusion reactions?



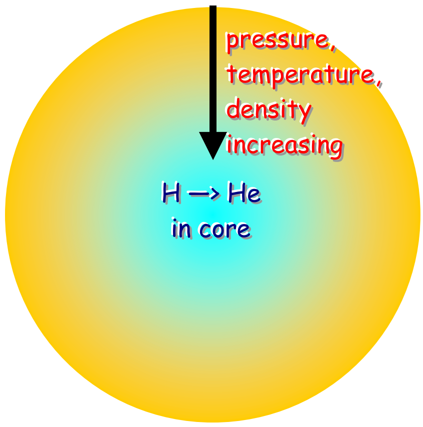
Fusion reactions

- Generate energy up to iron
- But, need to get two positively charged nuclei close enough to fuse together
  - need fast movement
  - high temperature (and high density)
- Converting hydrogen-1 to helium-4 is the easiest and most efficient fusion reaction
  - 0.7% of initial mass converted to energy



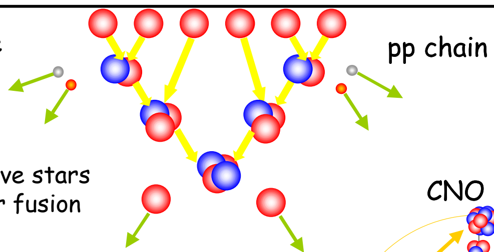
Stellar structure and fusion

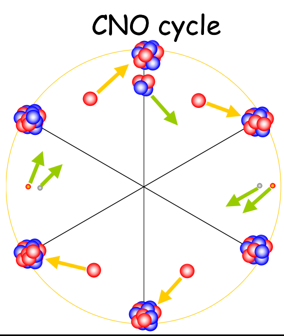
- To keep star stable need pressure to increase downwards
  - temperature increases
  - density increases
  - fusion most likely in central core of star
- Stars are mainly hydrogen
  - expect main sequence stars to fuse hydrogen to helium in core



Hydrogen fusion reactions

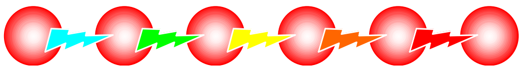
- Reaction rate increases as temperature increases
  - more massive stars have higher fusion rates
- Reaction can be direct or use carbon-12 as catalyst
  - this tends to increase abundance of nitrogen and oxygen





Getting the heat out

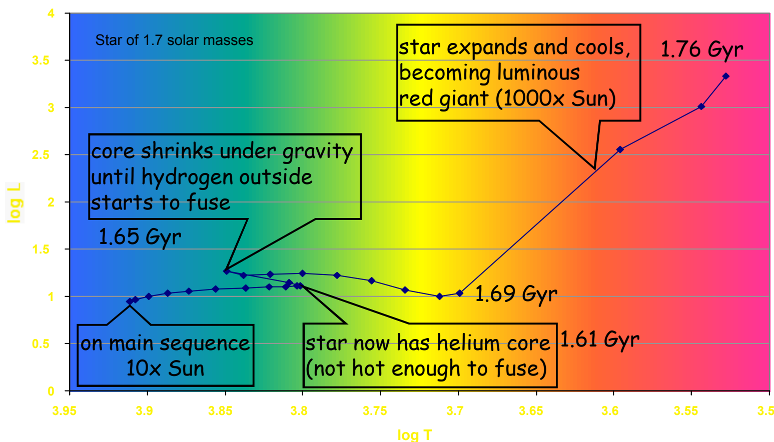
- Energy generated in stellar core has to be transported to surface
- Two options:
  - radiation
    - absorption and re-emission of photons



  - convection
    - hot gas rising towards surface, cool gas falling

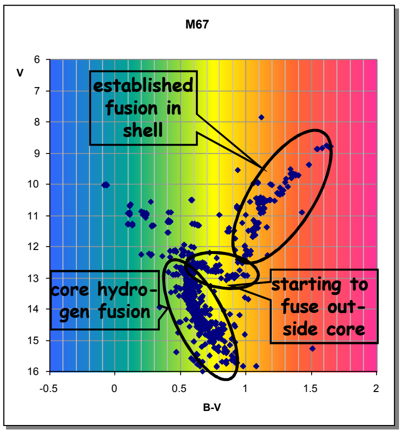
- Giant stars have convective outer layers
  - transports out the heavy elements produced by fusion

What happens when the core hydrogen runs out?



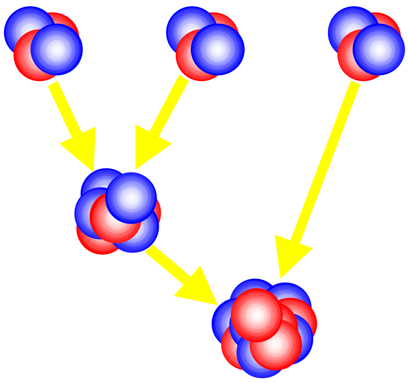
Stages of hydrogen fusion

- Main sequence stars fuse hydrogen to helium in core
- Red giants (and subgiants) fuse hydrogen to helium in shell outside helium core
- Stars have nearly constant luminosity on main sequence, but red giants get brighter as they age
- Red giant stage lasts only 10% as long as main sequence

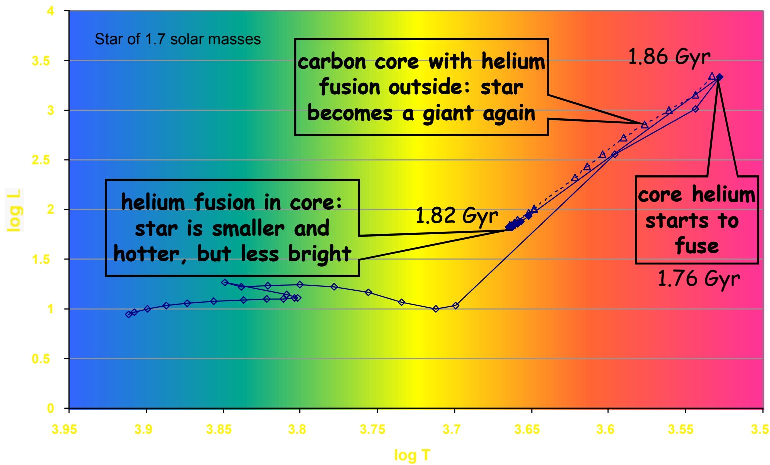


Helium fusion

- Neither beryllium-8 nor boron-8 is stable
  - need to combine three helium nuclei to get stable carbon-12
  - beryllium-8 serves as intermediate stage
  - need high temperature and density (else ^{8}Be decays before it gets converted to ^{12}C)



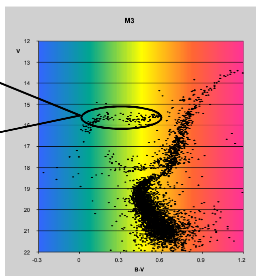
Stages of helium fusion

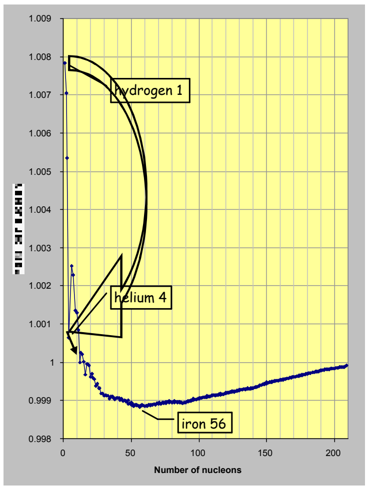


Helium fusion on the HR diagram

- Helium fusion is much less efficient than hydrogen fusion (0.07% instead of 0.7%)
  - helium fusion stage lasts for a much shorter time

helium core fusing stars: the hori-zontal branch of a globular cluster





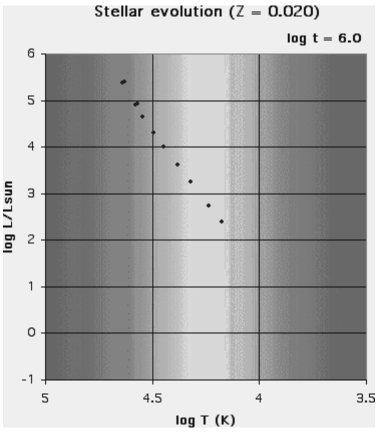
Side effects of helium fusion

- Adding more helium nuclei to carbon can produce the alpha-process elements
  - oxygen-16, neon-20, etc.
- Adding helium to carbon-13 or neon-22 produces free neutrons
  - which can easily combine with nuclei (no charge) to produce different elements
- Why does helium fusion make mostly carbon?
  - because carbon nuclei have an energy level at exactly the right place
  - otherwise carbon would be a rare element
  - and we would not exist!

Fred Hoyle, 1953

Stellar evolution

- Note step is in log (age): each frame is 60% older than the one before
  - massive stars evolve very quickly
  - post-main-sequence life of star is always comparatively short
  - massive stars change colour a great deal, but don't change brightness much
  - less massive stars become much brighter as red giants



After helium fusion

- Fusion of heavier elements gets more difficult
  - higher mass means lower speed at given temperature
  - higher charge means more electrostatic repulsion
- Stars like the Sun never get beyond helium fusion
- More massive stars (>8 M_S) can fuse elements up to iron
- What happens to Sun-like stars when the helium is used up?
- What happens to massive stars when they reach iron?
  - fusion beyond iron requires energy
- How are the heavy elements formed in stellar cores dispersed into space?

…next lecture!