Understanding Stars

- What do we know?
- From observations of nearby stars:
  - luminosity/absolute magnitude
  - colour/spectral class/ surface temperature
  - chemical composition
- From observations of binary systems:
  - mass
- How do we use these to develop understanding?
  - look at relations between quantities (luminosity & temperature, mass & luminosity)
  - compare with expectations from theoretical models

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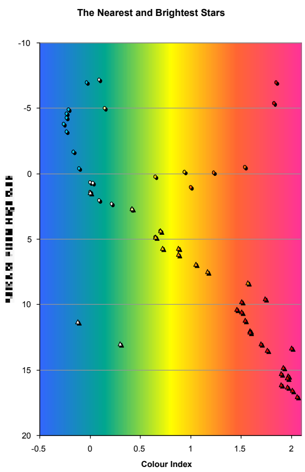
Luminosity & temperature: the Hertzsprung-Russell diagram

- Plot absolute magnitude (or log L) against spectral class (or colour, or log T)
- ➔ the ***Hertzsprung-Russell diagram***
  - for Ejnar Hertzsprung and Henry Norris Russell
- key to understanding stellar evolution



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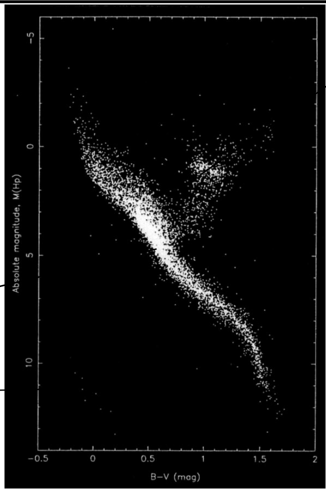
Structure of the HR Diagram

Data from the Hipparcos parallax measuring satellite



red giant branch

main sequence

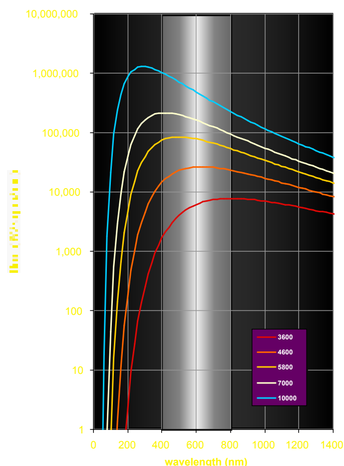
white dwarfs

Most stars lie on the main sequence

Note: faint stars are undercounted

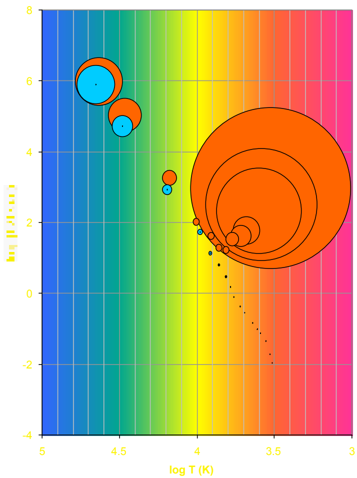
The sizes of stars

- We know cooler objects are fainter (for given size)
- But red giant branch contains cool objects which are very bright
- Therefore these stars must be much larger than the faint, cool main-sequence stars



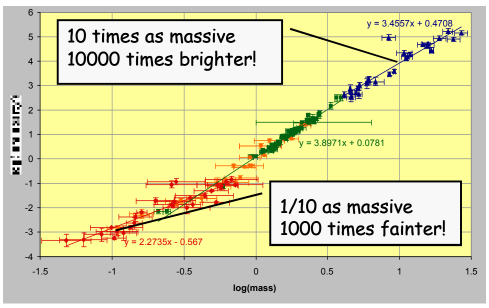
Giants and dwarfs

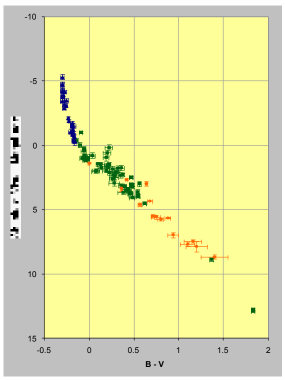
- Red giants are up to 60 times larger than the Sun (~orbit of Mercury)
- Supergiants (e.g. Betelgeuse) are larger still
- Red main-sequence stars ("red dwarfs") are only 1/3 as large as the Sun
- White dwarf stars are roughly Earth-sized



Mass and luminosity

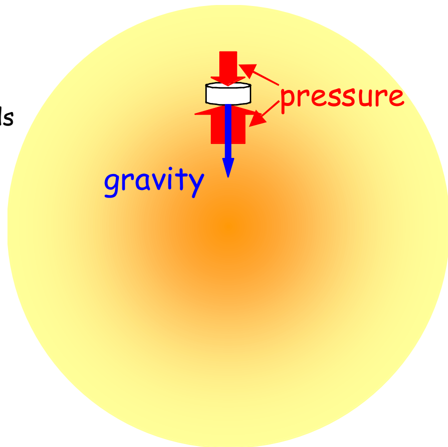
- Luminosity of main sequence stars is determined by mass
- Main sequence is a mass sequence (bright hot stars are more massive, cool faint stars are less massive)





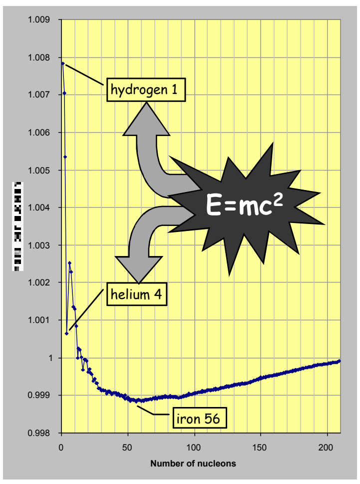
The sizes of stars

- Why are more massive stars larger and hotter?
  - force of gravity pulls stellar material downwards
  - steadily increasing pressure pushes upwards
  - larger mass needs higher pressures
  - ➔ higher temperatures (increasing downwards)
  - ➔ central energy source



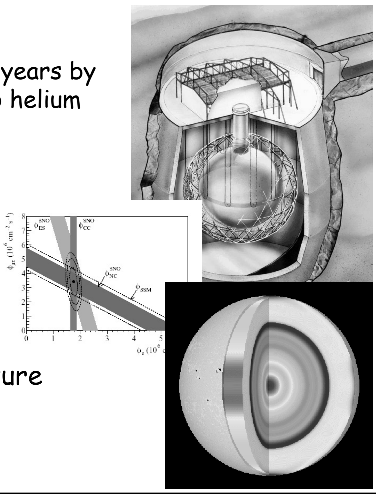
What is the energy source?

- Chemical reactions?
  - no: not powerful enough
- Gravity?
  - suppose the Sun is still contracting…
  - …would work for “only” 20 million years (remember Earth is 4.5 billion years old)
- Nuclear power?
  - YES: stars are fusion reactors



Evidence for nuclear fusion as stellar power source

- Theory: it works!
  - Sun can be powered for 5 billion years by converting 5% of its hydrogen to helium
- Theory: it produces the elements we observe
  - discussed later
- Experiment: we see solar neutrinos
  - elementary particles created as by-product of fusion
- Experiment: correct solar structure
  - as measured by helioseismology



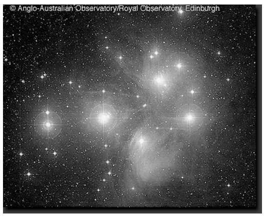
Stellar lifetimes

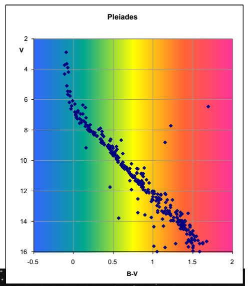
- A star 10 times as massive as the Sun has 10 times more hydrogen to power nuclear fusion
- But it is 10000 times as bright
- Therefore it should use up its fuel 1000 times more quickly

➔ ***Massive stars are very short-lived***

- Can we test this?
  - cannot watch stars age
  - need sample of stars of different masses but the same age
  - ➔ ***stellar clusters***
    - ◆ groups of stars bound together by gravity
    - ◆ formed together of the same material
    - ◆ ideal test bed for models of stellar evolution

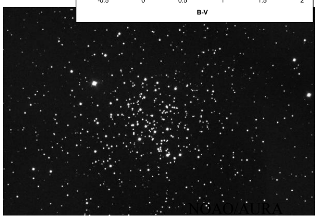
Stellar clusters

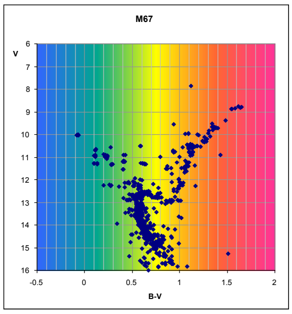




Pleiades: bright blue main sequence stars; no red giants

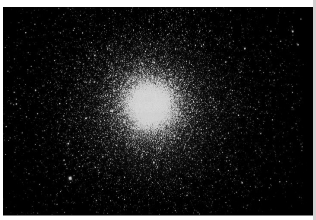
M67: many red giants; no bright blue main sequence stars

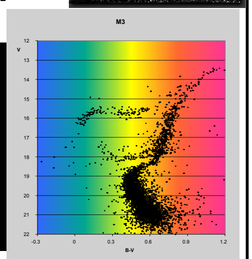




Globular clusters

- Much larger than open clusters like the Pleiades
- All have no upper main sequence stars
- All have spectra showing low or very low heavy element content
- The oldest clusters in our Galaxy (and some of the oldest objects)





What have we learned?

- If we plot luminosity against temperature
  - stars fall into well defined bands
  - most stars are on the main sequence
- If we plot luminosity against mass
  - main sequence stars fall on one line
  - more massive stars are brighter, bluer and have shorter lives
- If we look at the Sun
  - stars must be powered by nuclear fusion
    - provides enough power
    - produces neutrinos
- If we look at stellar clusters
  - clusters with short-lived bright blue stars have few red giants
  - clusters with many red giants have no short-lived blue main sequence stars
  - ➔ ***clues to stellar evolution…next lecture***