Stars: basic observations

Basic properties of stars we would like to know in order to compare theory against observations:

- Stellar **mass** M
- Stellar **radius** R
- Surface temperature - **effective temperature** T_e
- Bolometric **luminosity** L

Recall definition of effective temperature:

$$L = 4\pi R^2 \times \sigma T_e^4$$

…which relates L, R and T_e - so only three independent quantities to measure - mass plus two of luminosity, radius, and effective temperature.

For the Sun, can also determine the age and many other properties.

Effective temperature

Can be determined for a single star without knowledge of the distance.

Measure spectrum of the star, then compare with theory to get the effective temperature.

e.g. for a blackbody spectrum, the peak of F_ν is at:

$$h\nu_{\mathrm{max}} = 2.82kT_e$$

…so a measure of where F_ν has a maximum determines T_e.

Real spectra are more complicated, but same independence from distance applies.

No spectrum? Can use the color of the star as a measure of the effective temperature.

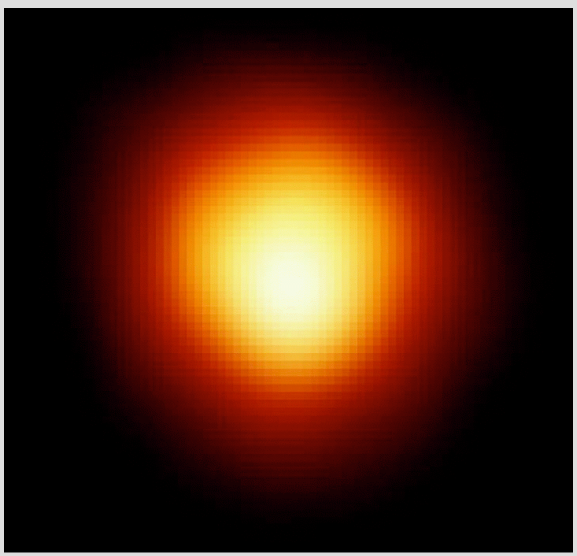
Radius

Angular diameter of the Sun at a distance of 10 pc is:

$$\theta = \frac{2R_{sun}}{10\ \text{pc}} = \frac{1.4 \times 10^{11}\ \text{cm}}{3 \times 10^{19}\ \text{cm}} = 5 \times 10^{-9}\ \text{rad} = 10^{-3}\ \text{arcsec}$$

c.f. *Hubble* resolution of about 0.1 arcsec.

→ Very difficult to measure the radii of single stars (even nearby ones) directly.



Hubble image of Betelgeuse

Some other stellar radii measured using interferometers to moderate accuracy.

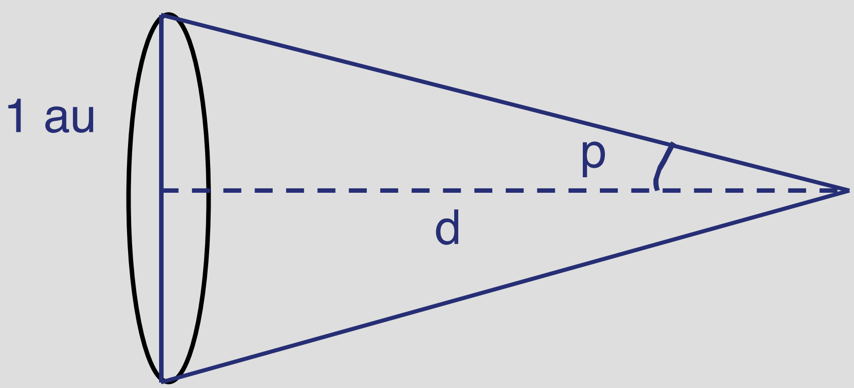
Luminosity

Measure the energy flux from the star (integrated over all wavelengths): inverse square law,

$$F = \frac{L}{4\pi d^2}$$

…gives the bolometric luminosity if the distance d is known.

Can determine the distance directly if we can measure the **parallax** - apparent stellar motion due to orbit of Earth around Sun:



For small angles:

$$p = \frac{1 \text{ au}}{\text{d}}$$

So: $$d = \frac{1}{p} \text{ pc}$$

if p is measured in arcsec.

Since nearest star is > 1 pc away, and ground-based telescopes have a resolution of ~1 arcsec, might seem impossible to measure p (and thus d) to any useful precision (e.g. for 10% error in d, need p to 0.1 arcsec for nearest star, to 0.01 arcsec for a useful sample).

Actually, possible to measure p to substantially better accuracy than the resolution of the telescope.

1838: Bessel measured p = 0.316'' for star 61 Cygni (modern value p = 0.29'')

current ground-based: best errors of ~0.001 arcsec

Hipparcos satellite: measured ~10^5 bright stars with errors also of ~0.001 arcsec

GAIA satellite: will measure positions of ~10^9 stars with an accuracy of micro-arcsecs - this is a reasonable fraction of *all* the stars in the Milky Way!

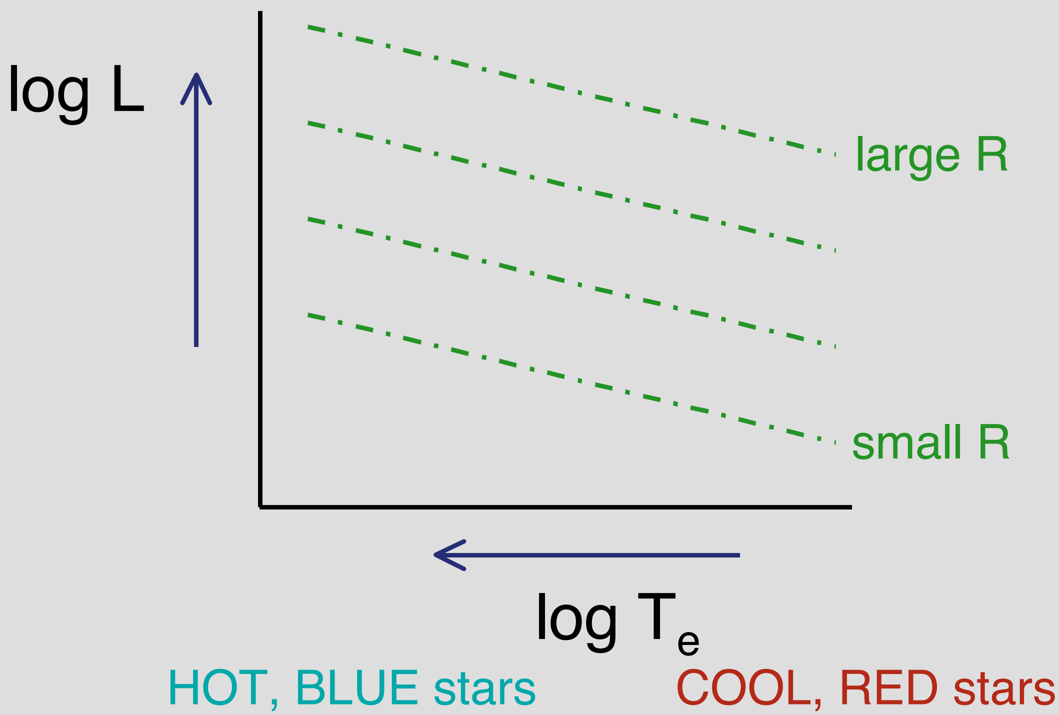
Currently: measure d accurately to ~100 pc

The Hertzsprung-Russell diagram

Measuring stellar masses is difficult. What can we learn using only observations of T_e and L?

Plot T_e against L (theorists) or color (e.g. B-V) against absolute magnitude (observers):

H-R diagram



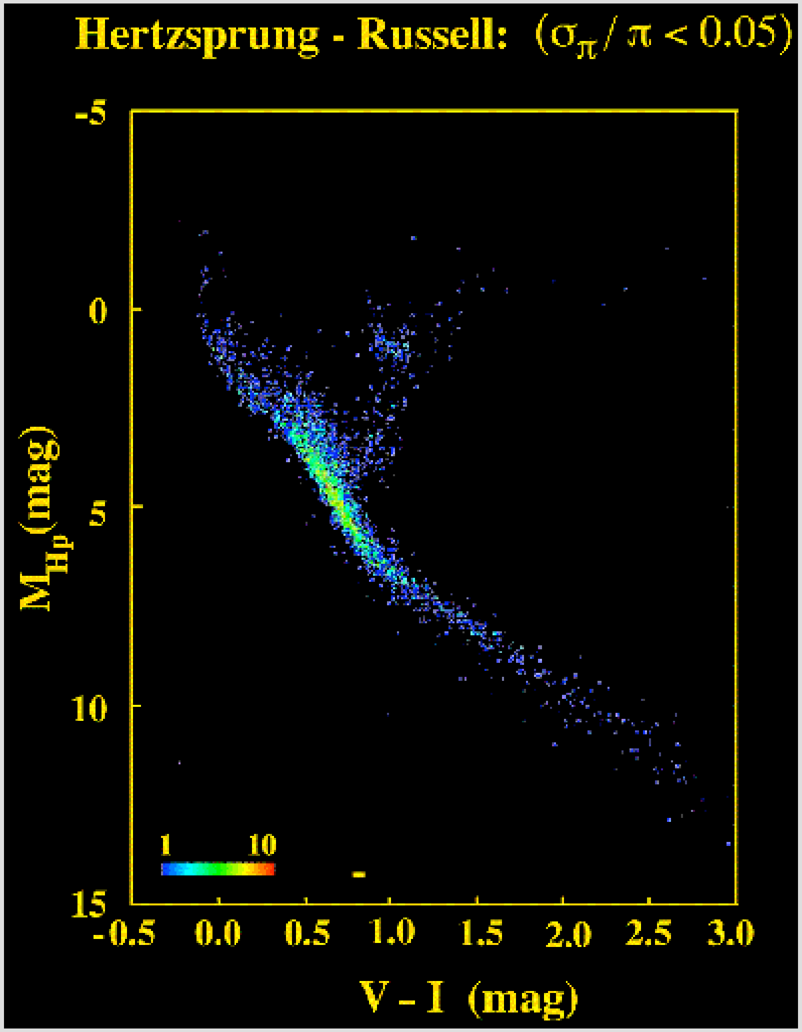
Plot lines of constant stellar radius on the H-R diagram using:

$$L = 4\pi R^2 \sigma T_e^4$$

Individual star is a single point in this plane.

H-R diagram from Hipparcos measurements

An H-R diagram for the 5000 stars with the best distance determinations from Hipparcos:

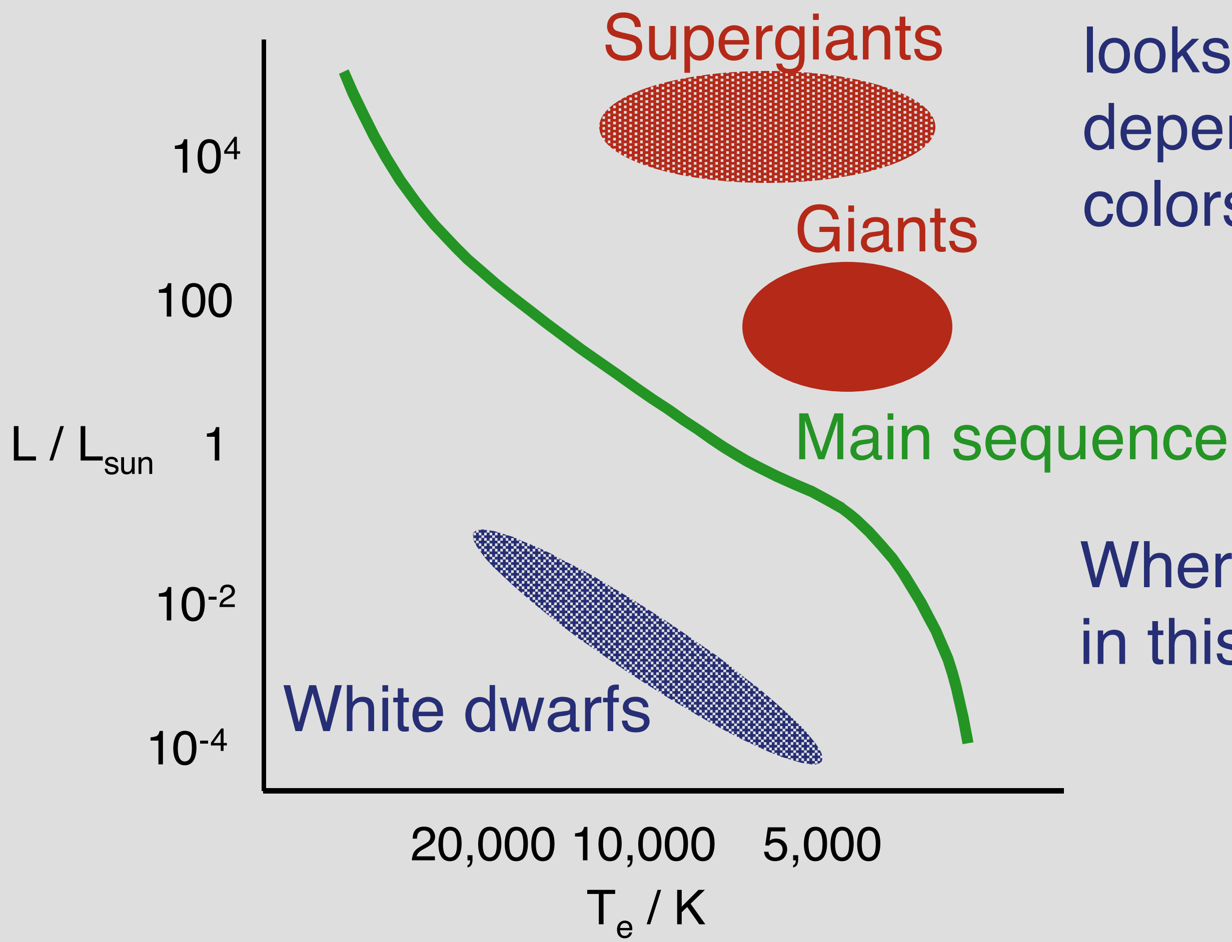


`Observational' axes: color and absolute magnitude

Colors indicate the density of stars in that part of the diagram

Most important point: most of the possible combinations of L and T_e are *not* populated by real stars - most stars occupy a thin strip in the diagram - the **main sequence.**

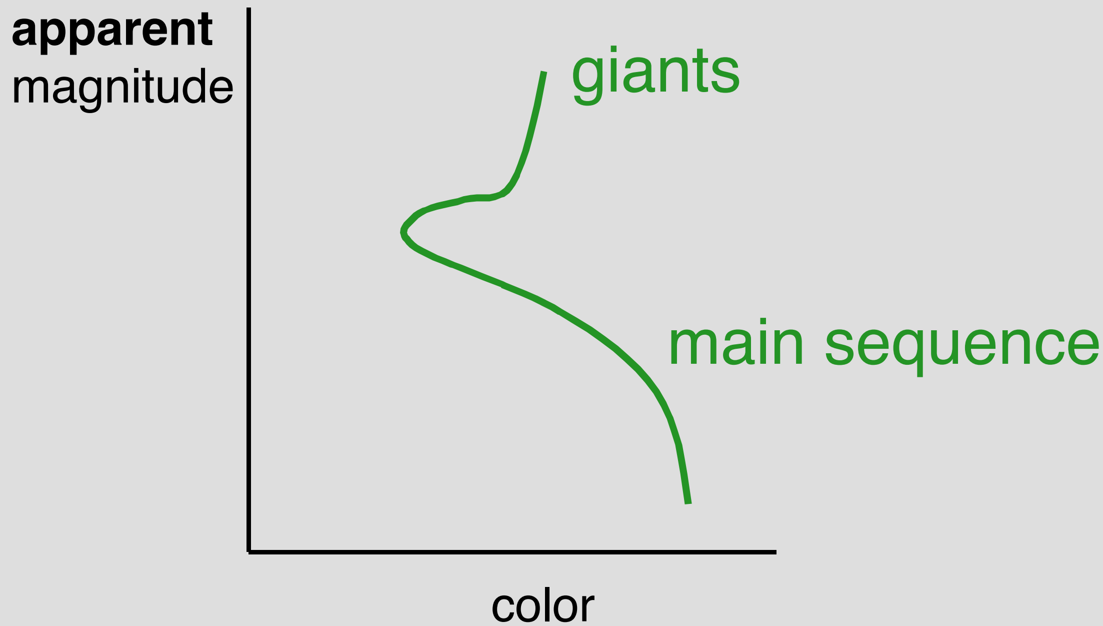
Since stars with large radius fall in the upper right corner of the H-R diagram, can determine which stars lie in different areas of the plot:



Observational diagram looks a bit different depending on what colors / bands are plotted.

Where do binaries fall in this plot?

Having determined where the main sequence is from the Hipparcos H-R diagram, can obtain more information from H-R diagrams of clusters without parallax distances:



Use Hipparcos results to determine absolute magnitude M on the main sequence for stars of given color. Compare to apparent magnitude m of stars of same color in cluster:

$$m - M = 5\log_{10}\left(\frac{d}{10\ \mathrm{pc}}\right)$$

i.e. can estimate distance