What we know so far about stars:

- Distances
- True 3-D motion
- Luminosity/Absolute magnitude
- Temperature/Spectral type/Color
- Mass (for some)
- Radii

=> synthesize this information (except motions) into the Hertzsprung-Russell (H-R) diagram.

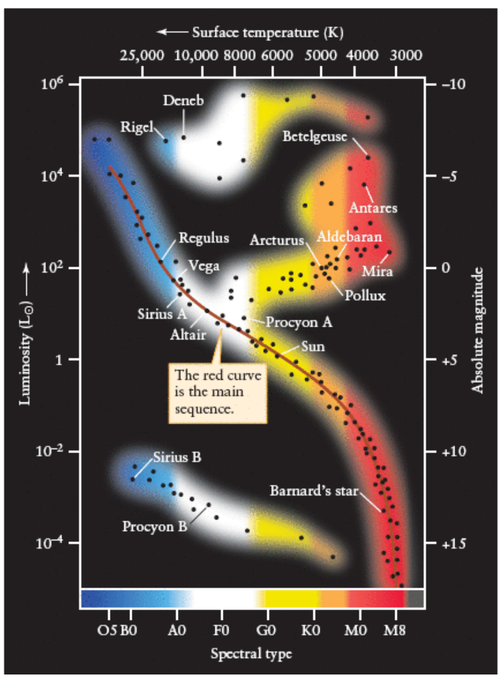
The Hertzsprung-Russell (H-R) Diagram (1911)

- Simple in concept, but a VERY powerful tool to examine stellar structure and evolution
- Hertzsprung and Russell independently asked themselves: "What are the two basic things about stars we can measure"?

1. Luminosity (when distance known)
2. Temperature (or color or spectral type)

H-R diagram is a plot of L (or Abs. Mag.) vs. T (or color, spectral type) for stars.

H-R diagram of some nearby and bright stars



(y-axis may also be absolute magnitude in some filter, e.g. V. x-axis may be b_b/b_v color. "Color magnitude diagram")

Since we know

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

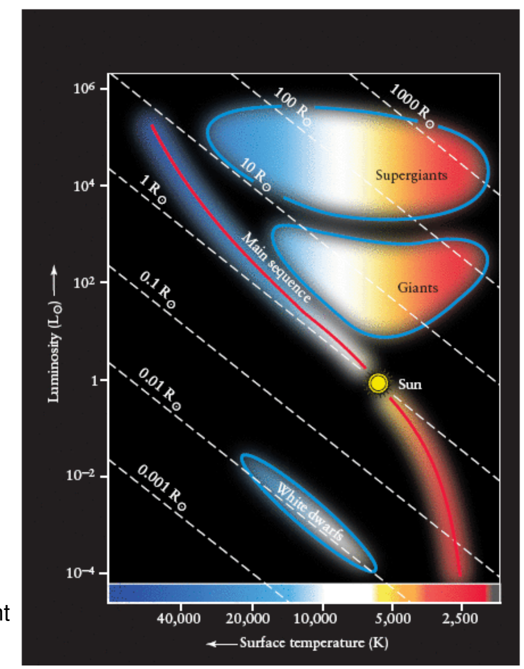
we can plot lines of constant R if both axes are log.

A star's position in H-R diagram depends primarily on mass and evolutionary state.

Main Sequence stars are in the longest phase of their lifetime where they fuse H into He. They move little in this diagram.

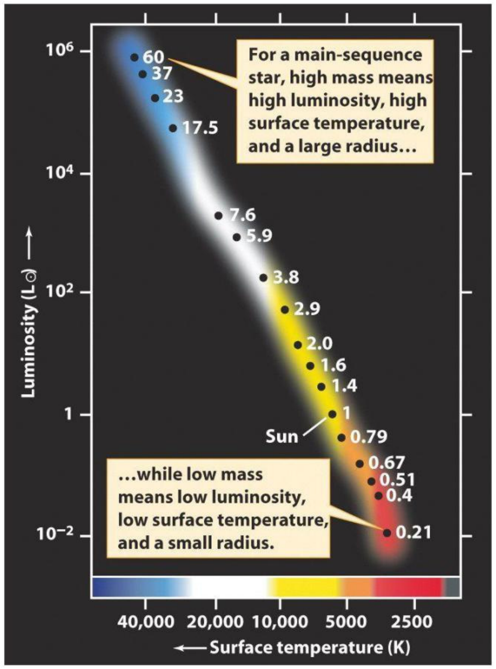
Other stars are at late evolution stages.

How do we know? Our stellar models predict L and T for different masses and stages of evolution.

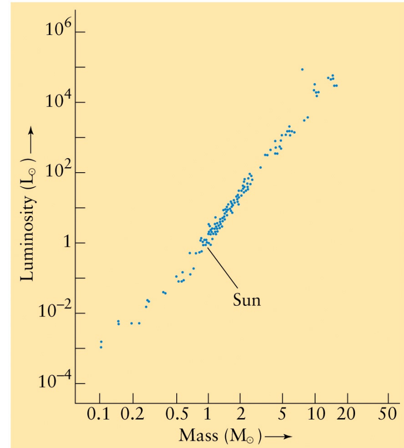


Main Sequence is a sequence of mass.

So M, L, T, R all related for Main Sequence stars.

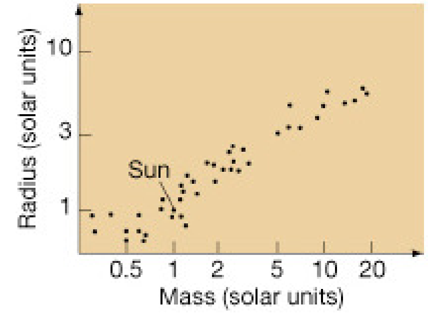


With various quantities determined, can start relating to each other. For Main Sequence stars only:



$L \propto M^{3.5}$

or $L/L_\odot = (M/M_\odot)^{3.5}$



$R \propto M^{0.8}$

or $R/R_\odot = (M/M_\odot)^{0.8}$

How Long do Stars Live (as Main Sequence Stars)? See Box 19.2

Main Sequence stars fuse H to He in core. Lifetime depends on mass of H available and rate of fusion. Mass of H in core depends on mass of star, roughly linearly. Fusion rate is proportional to luminosity (fusion reactions make the radiation energy).

$$\text{lifetime} \propto \frac{\text{mass of H in core}}{\text{fusion rate}} \propto \frac{\text{mass of star}}{\text{luminosity}}$$

So,

since luminosity $\propto$ (mass)$^{3.5}$,

$$\text{lifetime} \propto \frac{\text{mass}}{(\text{mass})^{3.5}} \quad \text{or} \quad \frac{1}{(\text{mass})^{2.5}}$$

Or can write:

$$\tau/\tau_\odot = (M_\odot/M)^{2.5}$$

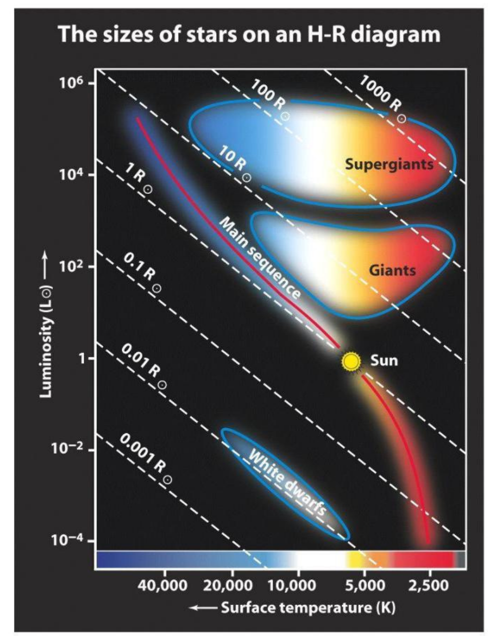
So if the Sun's lifetime is 10 billion years, a 10 $M_\odot$ star's lifetime is only:

$$1.0\times10^{10} \text{ yrs} \times \frac{1^{2.5}}{10^{2.5}} = 3 \times 10^7 \text{ years.}$$ Such massive stars live only "briefly".

What if we find a star with T=5000 K and measured incident flux, but don't know its distance?

Can we place it in the H-R diagram and find its luminosity, and thus distance?

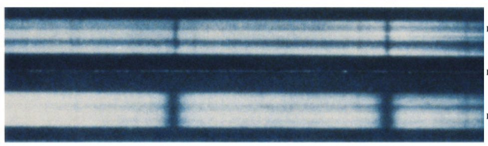
How do we know where to place it on the *L* axis?



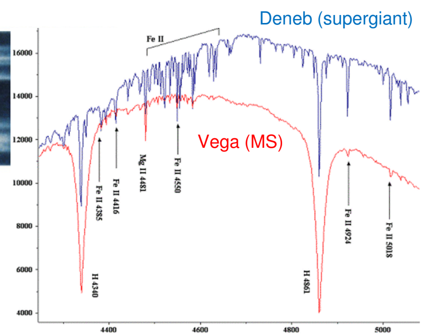
Line width and stellar size

- Atmospheric pressure affects width of absorption lines:
  - Lower pressure => decreased line width
  - Higher pressure => increased line width
- The atmospheric pressure is lower in the photosphere of an extremely large red giant than in a main sequence star of similar temperature
  => giant's spectral lines are *narrower*

H_γ H_δ

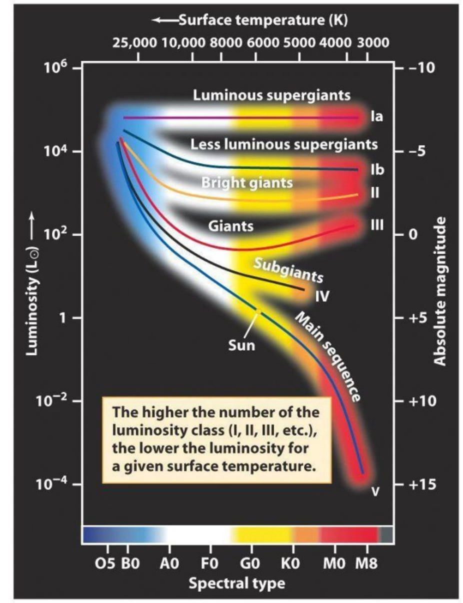


B8 supergiant (top), main sequence (bottom).



Luminosity classes

- We classify stars in luminosity classes; I - V (from narrow lines to wide lines, which also is from very luminous to less luminous)
- Thus a star is classified by its spectral type and its luminosity class.
- Full description of the Sun is G2 V.



Spectroscopic parallax

- Without knowing a star's distance, we can place it on the H-R diagram (spectral type and width of lines).
- This yields a luminosity, to be compared to the star's apparent brightness.
- => distance can be estimated (to about ±10%).

This is how we infer distances to most isolated stars! (We'll return to clusters)