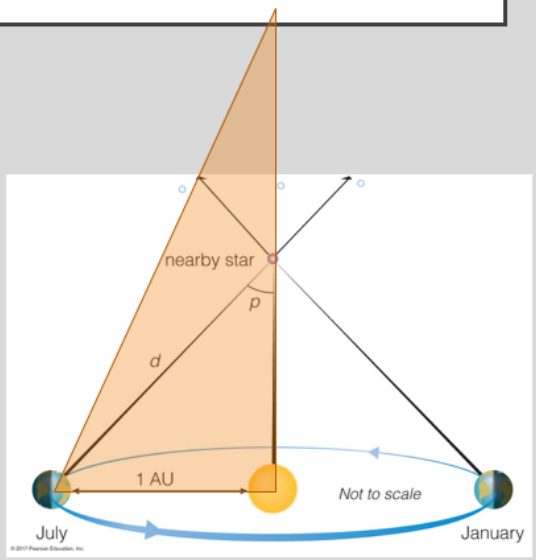
Melotte 15

Recap from last time: parallax

- d (in pc) = 1 / p (in arcsec)
- Example: a star with a parallax angle of 0.5 arcsec
  - d = 1 / (0.5") = 2pc
- Example: a star with a parallax angle of 0.1"
  - d = 1 / (0.1") = 10pc
- Parsecs take prefixes like other SI units:
  - 1000pc = 1kpc
  - 1,000,000pc = 1Mpc
- 1pc = 3.26ly



Notice as the parallax angle gets smaller, the distance gets bigger… does this make sense?

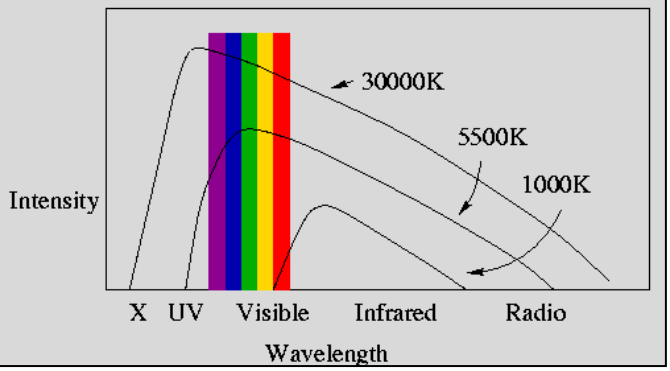
Patterns in stars

- What do you notice about this picture?
  - Stars are in a cluster: assume they're all at about the same distance
  - Biggest, brightest ones are red or blue-white
  - Rest are different sizes, some blue, most yellow-white-ish, some small red dots
  - There's some kind of relationship between stars' color and luminosity

More about this.. Next time.

Stellar temperature

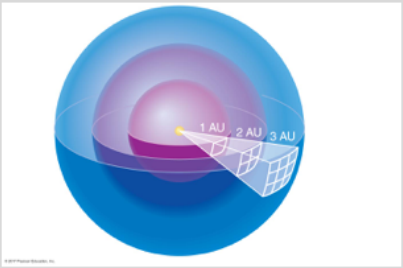
- We see the stellar surface, and can only directly measure its temperature
  - Recall from thermal radiation: peak wavelength depends on the temperature of the object
  - Wavelength vs color



(this is where we stopped)

Apparent magnitude, absolute magnitude, luminosity

- Apparent magnitude is how it appears to us on the sky
  - Light decreases with distance as $1/r^2$
  - Decreases due to dust/gas in line of sight scattering, absorbing
- Absolute magnitude: what is magnitude if you take apparent magnitude and assume star is at 10pc
  - This is actually quite close-- Proxima Centauri is 1.3 pc, or 4.2 ly away
- Luminosity is how bright the star is right next to it: how much power is it emitting over its surface
  - Luminosity depends on both the power emitted and the surface area of the star
  - $L = 4\pi r^2 \sigma T^4$ → recall Stefan-Boltzmann law for power emitted by thermal radiation



Spectral types

- Can roughly tell a star's temperature based on two different colors of light. Can more precisely tell from its spectrum!
- Before we knew about quantum mechanics, we measured and classified stellar spectra
- And by "we," I mean…

https://www.space.com/34707-annie-jump-cannon-biography.html

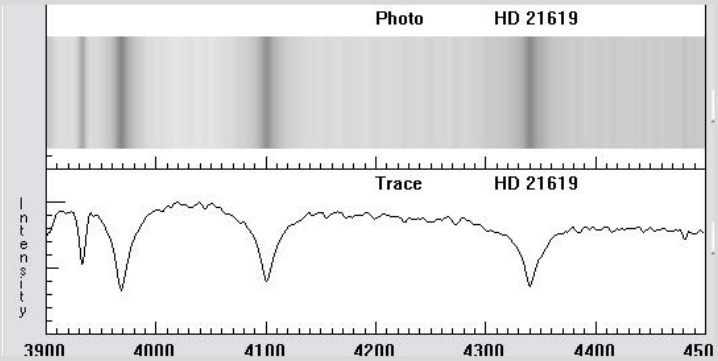
The "computers"

Often women's college graduates who were not allowed to obtain degrees or jobs in science fields.. Hired because they could be paid less. Hiring women at all in the first place was a cynical precedent set by an exasperated man in power

https://www.sciencenews.org/article/astronomys-unsung-heroines-celebrated-glass-universe

Spectral types

- How would you go about sorting something when you don't know what it is?
  - Size
  - Shape
  - Color
  - …
- The "computers" sorted on all these things. Were lines present? Yes, no. Are they weak, or strong?



Spectral types

- "Pickering had turned to women out of exasperation with a male assistant. Declaring that even his maid could do a better job, he hired Williammina P. Fleming, a twenty-four year old Scottish immigrant, to assist him." –The Perfect Machine: Building the Palomar Telescope, Ronald Florence (p. 13-14)
- Paid half the rate a man would earn, Williammina/Wilhelmina Fleming was a BOSS. She discovered and catalogued over 10,000 stars, nebulae, and the existence of white dwarf stars.
- worked to define a spectral order
  - Gave spectra letters based on strength of Hydrogen lines
- She also oversaw the work of Annie Jump Cannon and Henrietta Swan Leavitt

https://www.atlasobscura.com/articles/how-female-computers-mapped-the-universe-and-brought-america-to-the-moon

Spectral types

- Annie Jump Cannon
  - Defined spectral sequence as we know it today
  - Sorted sequence in order of descending stellar surface temperature
  - Divided into sub-classes: A0, A1, A2, etc: higher number → lower surface temperature
  - Classified over 400,000 spectra over her career
  - Why don't we know her name? (Spoiler: who paid for the catalog? Henry Draper/his estate)
  - The sequence was visually clear, but it wasn't known **why** stars were in this order until Cecilia Payne-Gaposchkin realized stellar composition was mostly H, He, and surface temperature determined properties of stellar spectra
- Henrietta Swan Leavitt discovered Cepheid variables: regularly pulsating stars, periods related to luminosity

https://www.atlasobscura.com/articles/how-female-computers-mapped-the-universe-and-brought-america-to-the-moon

Stellar masses

- How might we measure stellar masses?

Can't put a star on a scale… what do we know about right now that could allow us to measure a star's mass?

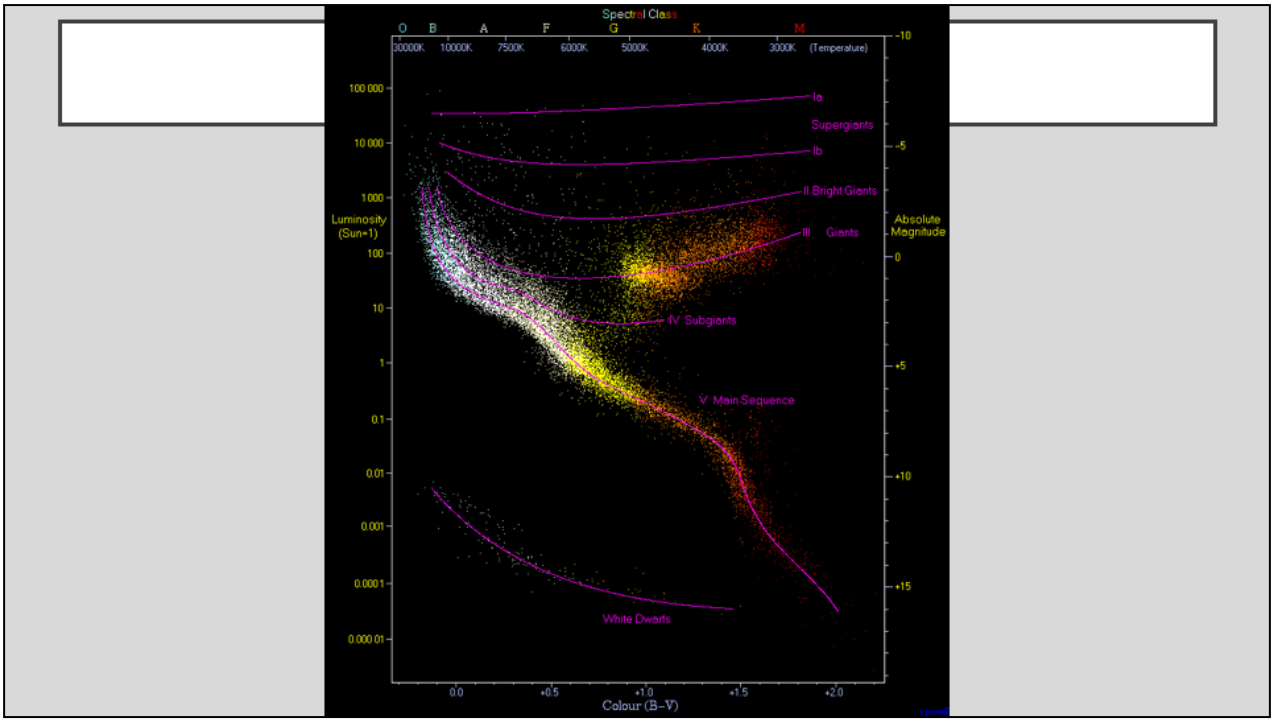
Stellar masses

- How might we measure stellar masses?
  - F_g! Gravitational interactions!
    - With what?
    - Binary stars! Almost half of all stars are in binaries.
      - Visual
      - Spectroscopic
      - Eclipsing

Can't put a star on a scale…

The H-R diagram

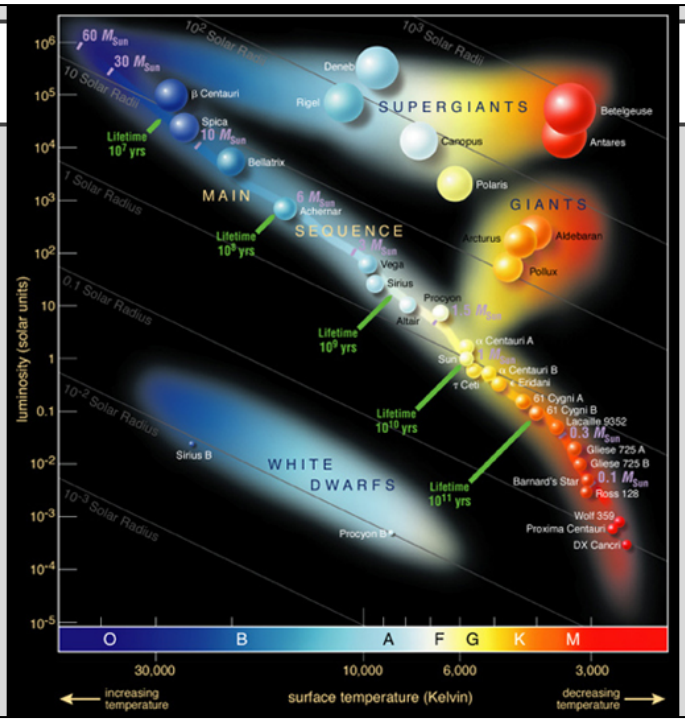
- How would you organize stars?
  - Colors
  - Spectra
  - Brightness
  - What if these things were related to each other somehow?

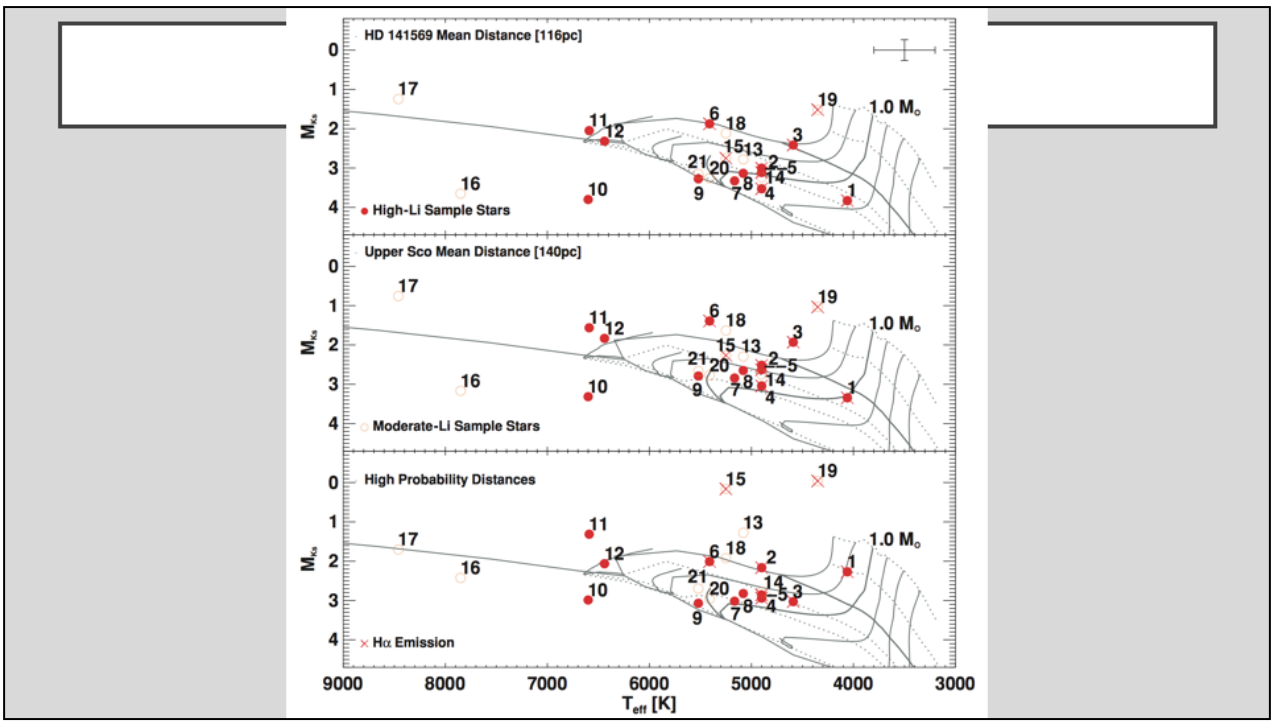


https://en.wikipedia.org/wiki/Hertzsprung–Russell_diagram#/media/File:HRDiagram.png

The H-R diagram

- Rosenberg, Hertzsprung and Russell were working on this around the same time.. 1910, 1911, 1913
  - Plotting spectral lines indicative of temperature against stars' apparent magnitudes, absolute magnitudes, and eventually, luminosities
  - Shows a relationship between fundamental stellar properties: temperature and brightness


luminosity (solar units)
surface temperature (Kelvin)
increasing temperature
decreasing temperature
30,000
10,000
6,000
3,000
O
B
A
F
G
K
M
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
Arcturus
Aldebaran
Pollux
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Altair
Procyon
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
60 M Sun
30 M Sun
10 M Sun
6 M Sun
3 M Sun
1.5 M Sun
1 M Sun
0.3 M Sun
0.1 M Sun
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^10 yrs
Lifetime 10^11 yrs
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius



This is a figure from my first paper where I made a H-R diagram for a group of stars I didn't know the distance to.

What is the H-R diagram really telling us?

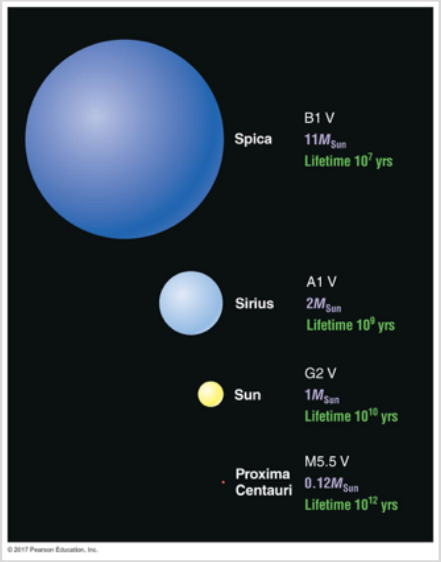
- Almost everything, tbh.
- Once brightness is corrected for distance, intermediary effects, H-R diagram can tell us
  - Stellar temperature
  - Stellar radius
  - Stellar mass
  - Stellar age
- Is this easy to measure/model? No! But ideally, yes- you can get all of this information out of the H-R diagram

What is the most fundamental stellar property?

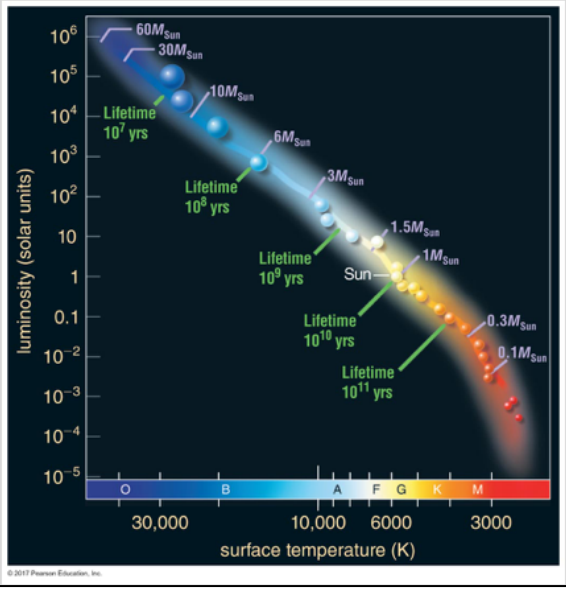
- What determines everything about a star?
  - How long it lives (fuses at its core)?
  - How hot its surface gets?
  - It's radius and brightness?

What is the most fundamental stellar property?

- What determines everything about a star?
  - How long it lives (fuses at its core)?
  - How hot its surface gets?
  - It's radius and brightness?
- Its mass!



The main sequence



- Stars on the main sequence are burning H in their cores
- Stars of different masses have both varying amounts of H to burn, and different rates of burning

After the main sequence...

- What happens when stars run out of H?
  - Recall: fusion reactions decrease the numbers of light elements in the core of a star
  - Proton-proton chain no longer functions
  - Heavier elements start to fuse
  - Reactions begin in outer layers of star: instabilities develop

Star clusters

- Remember how sun-like stars born from cloud of gas and dust?
- More than one star can be born in one of these clouds, depending on its size and mass distribution!
- Entire star-forming regions are observed
  - Associations and moving groups
  - Open clusters
  - Globular clusters

Star clusters

- How do we know how old a cluster of stars is?
  - For young clusters, elements in the stars themselves (Lithium)
  - Where they are on the H-R diagram