Astronomy 210

<u>This Class (Lecture 30):</u>

Stars: Physical Properties

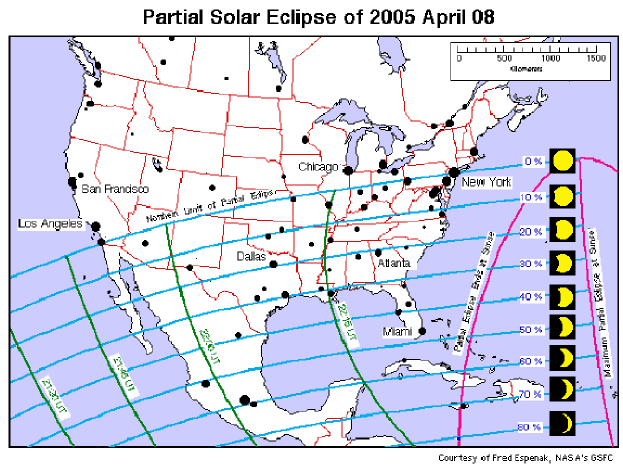
<u>Next Class:</u>

Stars: Spectra and the H-R Diagram

Solar Observing due April 15th

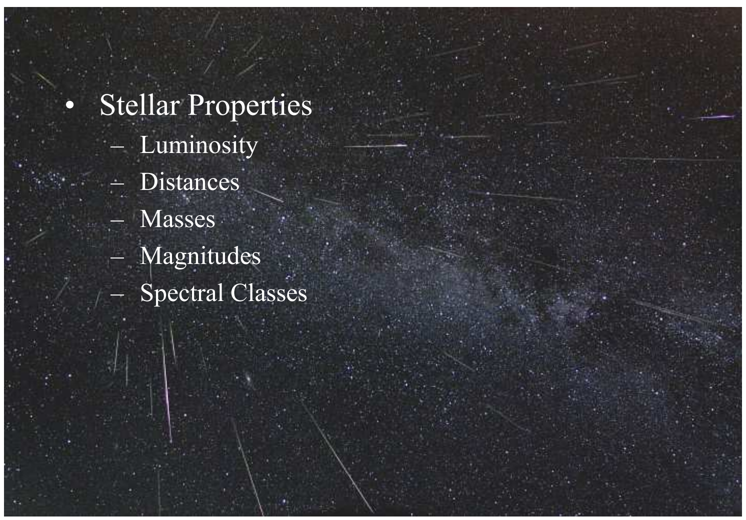
HW 9 is available– Orion 2!

Solar Eclipsing

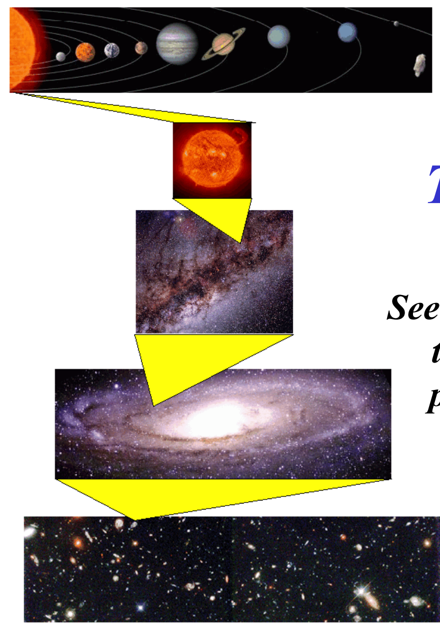


Might see a sliver around 5:15pm-ish.

Outline



- Stellar Properties
  - Luminosity
  - Distances
  - Masses
  - Magnitudes
  - Spectral Classes

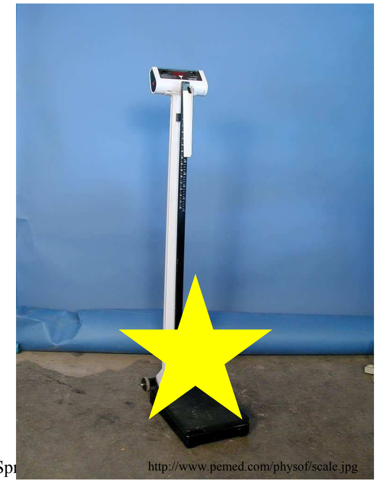


Astronomy: The Big Picture

Seeing how all these pieces fit together into a coherent picture of our Universe!

Stars Physical Properties

- Please step on scale. Turn head. Cough.
- No, really. How to measure the properties of objects that are very, very far away?
- What properties would we like to know about the stars.



Stars Physical

- Are all stars the same? Are they all just like our Sun?
- Do they have different brightnesses?
- Do they have different temperatures? Colors?
- Do they have different masses?
- Do they have different sizes?
- What happens to them? Just grow old and get retirement?

Luminosity

- **Again**, with the luminosity. What exactly is this?
- Remember, the Sun's luminosity is 3.9×10^{33} erg/s or 3.9×10^{26} Watts
- This is true no matter where I am. The Sun's luminosity is an intrinsic quantity.
- So, what do I measure on Earth?
  - The flux of the Sun in W/m^2
    - $F_{\odot}$=1370 W/m^2
    - $F_{Sirius} = 1 \times 10^{-7}$ W/m^2
  - Which star has the most luminosity?

Which is Brighter?

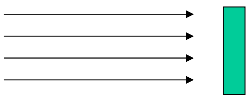
- The Moon or the streetlamp?
- Why?
- *Apparent brightness* and *luminosity* difference.

http://www.danheller.com/images/California/CalCoast/SantaCruz/Slideshow/img13.html

Flux-ing Amazing

- Define the luminosity of a source as the energy flow of the source **L = dE/dt**

- Define the flux of light:
  - Energy flow per unit area per unit time



$$dE = FAdt$$

$$F = \frac{1}{A}\frac{dE}{dt}$$

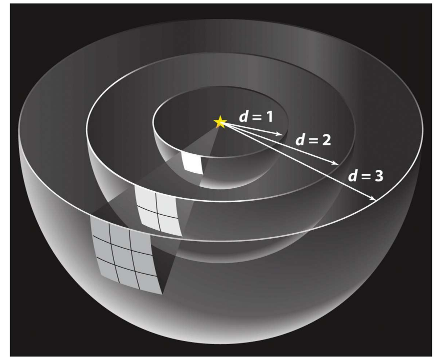
$$\text{or} \quad L = FA$$

Luminosity

- Apparent brightness ≠ luminosity!
- Apparent brightness depends on distance away.

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

- The farther, the dimmer.
- That's why it's called apparent brightness.
- SO to compare Energy rate of stars, need distances!

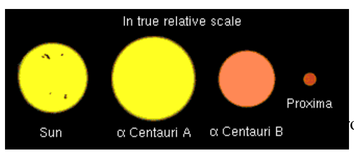


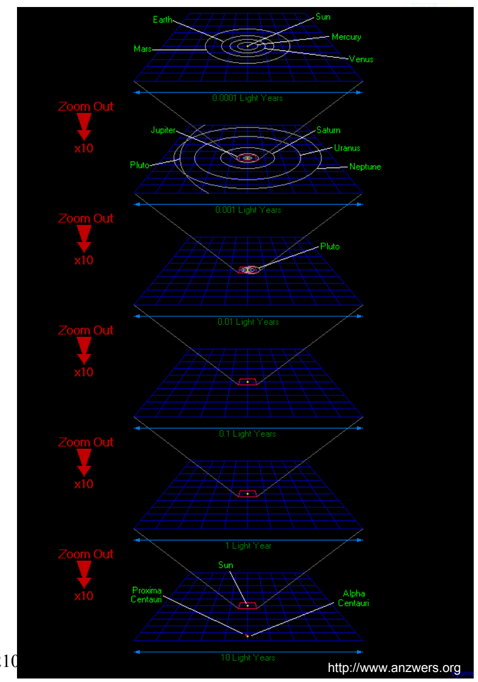
Distance

- From the geocentric vs. heliocentric arguments, we know that the stars must be far away.
- Measuring the distance is a <u>hard</u> problem.
- We've only had the technology to do it for the last 200 yrs or so.

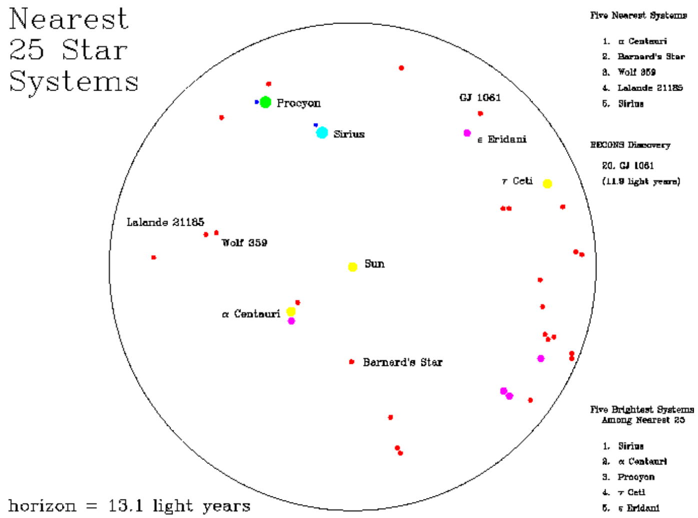
Leaving Home

- Nearest star is 4 x 10^{13} km away
  - Called Proxima Centauri
- Around 4 light years
- More than 5000 times the distance to Pluto
- Walking time: 1 billion years
- Fastest space probes (Voyagers 1 & 2, Pioneers 10 & 11) – 60,000 years at about 3.6 AU/year





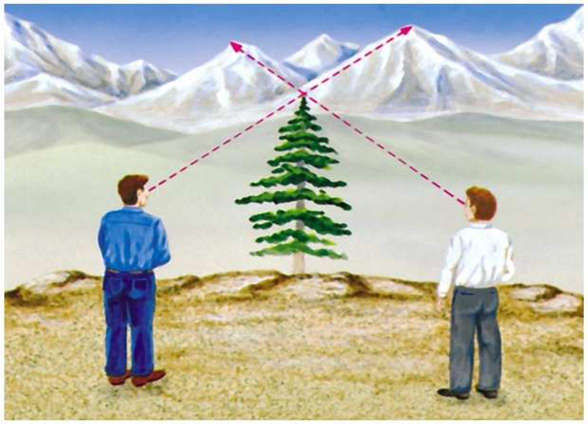
Our Nearest Neighbors



http://antwrp.gsfc.nasa.gov/apod/ap010318.html

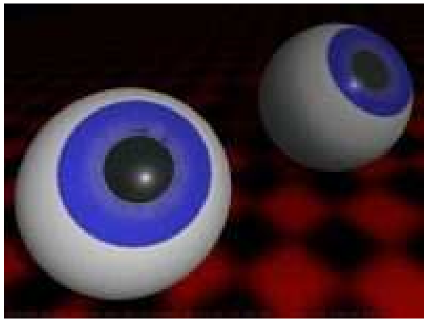
Parallax

- How do astronomers measures distances to nearby stars?



Parallax– Is Triangulation

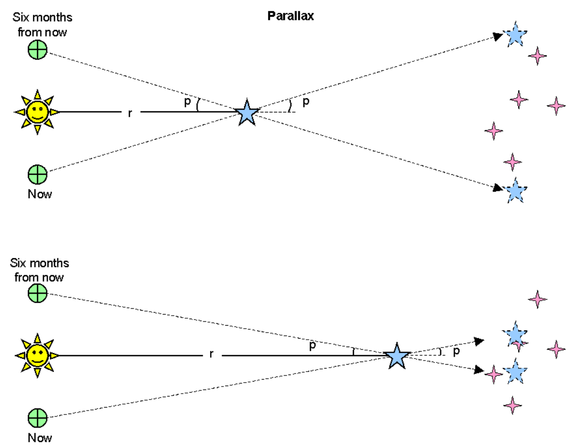
If one loses the use of an eye, then it becomes very difficult to judge distances. Usually, each of your eyes observe objects with slight shifts in position. When objects are closer, the effect is larger. Stereo-vision!



http://www.kidsdomain.com/holiday/halloween/clipart/eyes.jpg

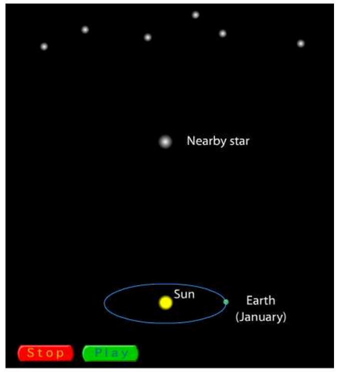
How to Measure Parallax

- Look at a star compared to background stars– and wait 6 months.
- How much, if any, have the stars moved?



Parallax and Parsecs

- **1 parsec (1 pc)** – Distance at which the <u>radius</u> of the Earth's orbit would make (subtend) an angle of 1 arcsecond
- 1 pc = 3.09×10^{13} km = 3.26 light-years



Distance to a star in parsecs = $\dfrac{1}{\text{Star's parallax in arcseconds}}$

Parallax and Parsecs

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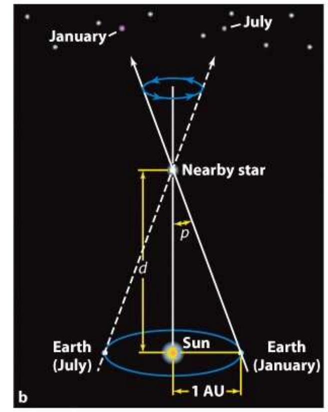


Distance to a star in parsecs = $\dfrac{1}{\text{Star's parallax in arcseconds}}$

The Distances to the Stars

Sun's disk seen from Earth

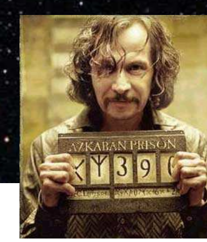
1/2 degree = 1800 arcsec

Dime at arm's length

Closest star to Earth:
Proxima Centauri
(part of α Centauri system)
Parallax: 0.77 arcseconds
Distance: 1.3 pc = 4.2 ly
like a dime 2 km away

Back to Sirius

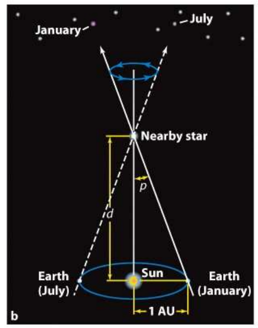
- Parallax is 0.366″
- So, d = 1/0.366 = 2.73 pc ≅ 8.4×10^{16} m
- And, $F_{Sirius} = 1 \times 10^{-7}$ W/m^2
- So what is its luminosity
- $L_{Sirius} = F \times A = F \times (4\pi d^2) = 8.9 \times 10^{27}$ W
- Remember $L_{\odot} = 3.9 \times 10^{26}$ W
- So $L_{Sirius} = 22.9 \times L_{\odot}$
- Sirius wins.



http://funtastic.fw.hu/hp/kepek/3filmbol/sirius.jpg

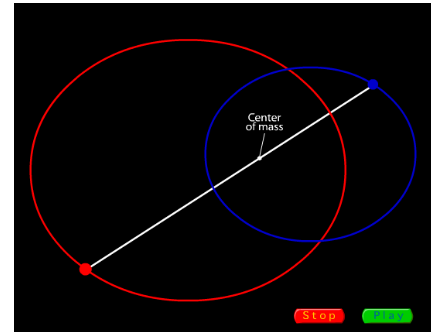
Parallax Peril

- Drawback: p measurable only for nearest stars
- Angular shift becomes tiny when star far away
- Immeasurable when star is beyond few 100's of pc
- And Galaxy is 100,000 lyr across, Universe is 10 billion lyr
- What to do? ... stay tuned...



Mass

- How can we measure that?
- How did we measure mass of Venus?



Binaries

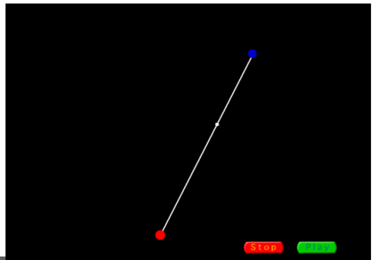
- Stars like to form in *binary* (or more) star systems
  - Stars orbit each other
  - About half of all star systems are binaries!
- Binary systems allow us to measure:
  - $m_1 + m_2$ with Newton's version of Kepler's 2^{nd}
  - and we have the center of mass relationship
- Now, the problem is how to measure the r's

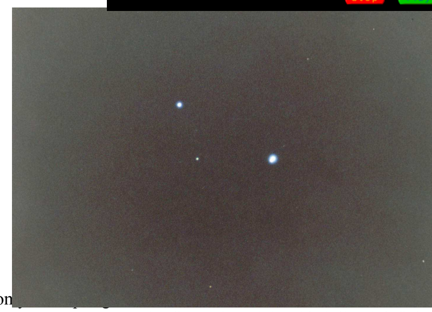
Types of Binary Stars

- **Visual binary** – can distinguish stars in the pair
- **Spectroscopic binary** – can only detect using Doppler shifts
- **Eclipsing binary** – each star passes in front of the other

Beautiful Binary: Visual

The handle of the big dipper is a visual binary Mizar/Alcor (12′). Can see both stars oribt, but we would have to wait a long time to watch them orbit.





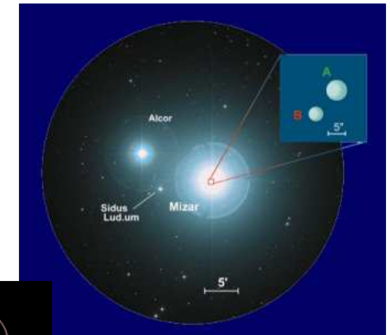
http://www.robonecela.host.sk/fotky/deepsky/velke/mizar-alcor.JPG

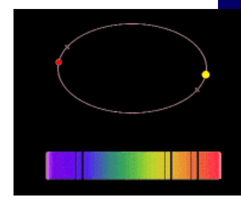
Beautiful Binary: Spectroscopic

Mizar is the first known double star (14″) and each is a double. Each of those stars is also a binary system, but very close together. Can see spectroscopic binary system from Doppler shift.

$$\frac{v_r}{c} = \frac{\Delta\lambda}{\lambda_0}$$

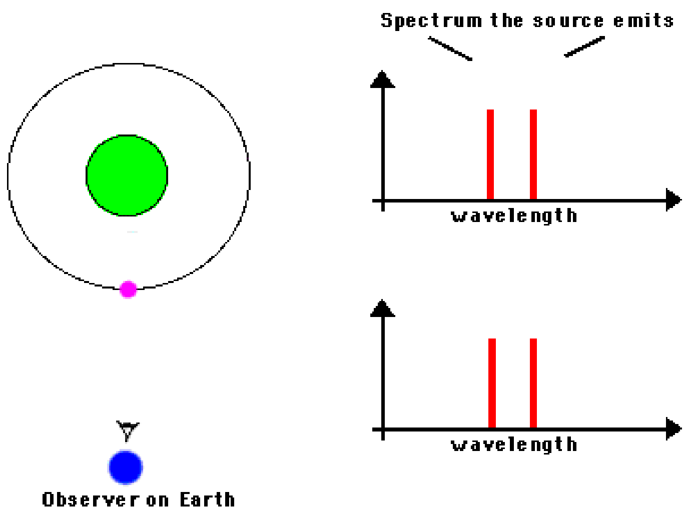
$$v_1 = r_1\omega = \frac{2\pi r_1}{P}$$





http://home-3.worldonline.nl/~ppsmeets/Sterren.html

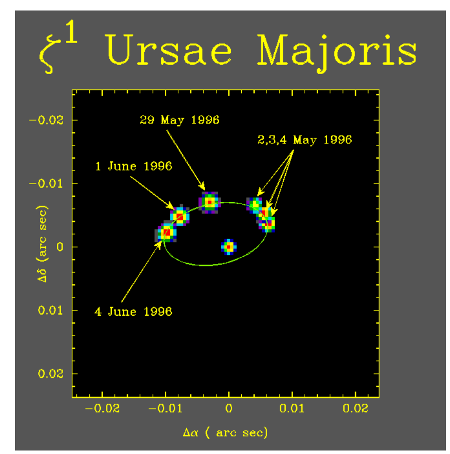
Beautiful Binary: Spectroscopic



NASA

Beautiful Binary: Spectroscopic

One of the close Mizar binaries has been observed with an optical interferometer. Separation is like a penny at 300 miles away!



http://instruct1.cit.cornell.edu/courses/astro101/java/binary/binary

http://antwrp.gsfc.nasa.gov/apod/image/9702/mizarA_npoi_big.gif

Measuring Star Brightness

- In 130 BC, a Greek astronomer, Hipparchus, classified all the stars visible to the naked eye into 6 **magnitudes**
  - 1st magnitude – the brightest stars visible
  - 21 "1st magnitude stars"
  - 6th magnitude – the dimmest stars visible
  - For magnitudes, a smaller number is brighter (sorry about that)
  - There are more dimmer stars than bright stars

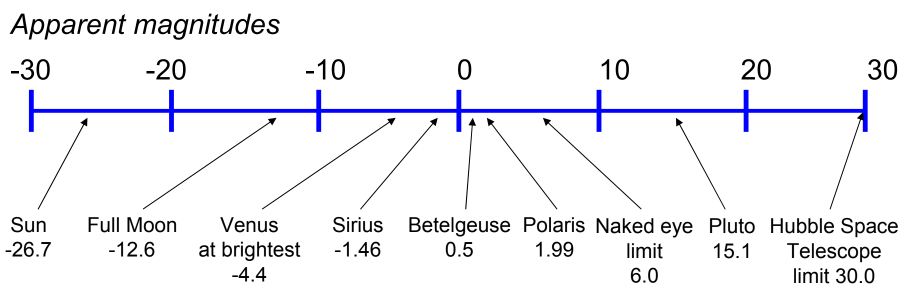
Apparent Magnitudes

- Astronomers have extended the log scale, decimalized it, and scaled it to Vega (more or less)

$$m - m_{std} = -2.5\log(F / F_{std})$$

- A star that is 5 magnitudes larger than Vega, would be 100 times less bright
- Each magnitude is 2.512 times brighter than the next magnitude down
  - 2.512 x 2.512 x 2.512 x 2.512 x 2.512 = 100

Apparent Magnitude Scale



$$m_{\odot} = -26.7 \text{ and } m_{\text{Sirius}} = -1.46$$

$$\Rightarrow \frac{F_{Sirius}}{F_{\odot}} = 10^{-(m_{Sirius} - m_{\odot})/2.5} = 7.6 \times 10^{-11}$$

Note: apparent magnitude is really flux as it is related to luminosity and distance.

Absolute Magnitudes

- To compare star brightness independently of distance, astronomers use **absolute magnitudes**
  - Equal to what the apparent magnitude would be if the star were 10 parsecs away
- This relates Luminosity!

$$M = M_{std} - 2.5\log\left(\frac{F(d_0)}{F_{std}(d_0)}\right)$$

$$= M_{std} - 2.5\log\left(\frac{L}{L_{std}}\right)$$

$$m - M = -2.5\log\left(\frac{F(d)}{F(d_0)}\right)$$

$$= -2.5\left(\frac{d_0^2}{d^2}\right)$$

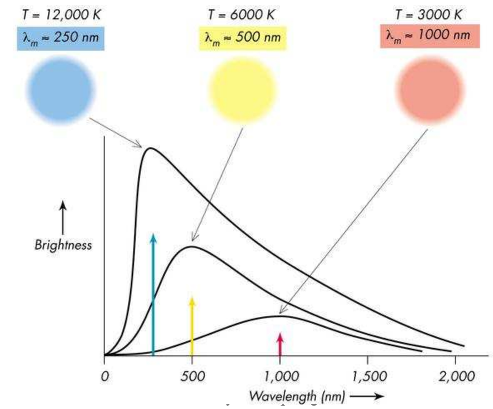
$$= 5\log(d / 10\ pc)$$

Absolute Magnitudes

- An example
  - The star Vega has an apparent magnitude of 0.03
  - It is 7.5 parsecs away
  - If it were 10 parsecs away, it would be 0.56 times as bright as it is now, or 0.62 magnitudes dimmer
  - Its absolute magnitude is therefore 0.65

Stellar Colors

- Higher temperature → brighter, bluer
- Lower temperature → dimmer, redder



Stellar Color

- In a perfect world (sometimes true)
- In real world,
  - Absorption lines can make it difficult (non-BB spectrum)
  - Full spectrum is expensive (lots of instruments)
  - We often use filters with certain observed bands.
- So, compare the flux of star at two bands (B and V)

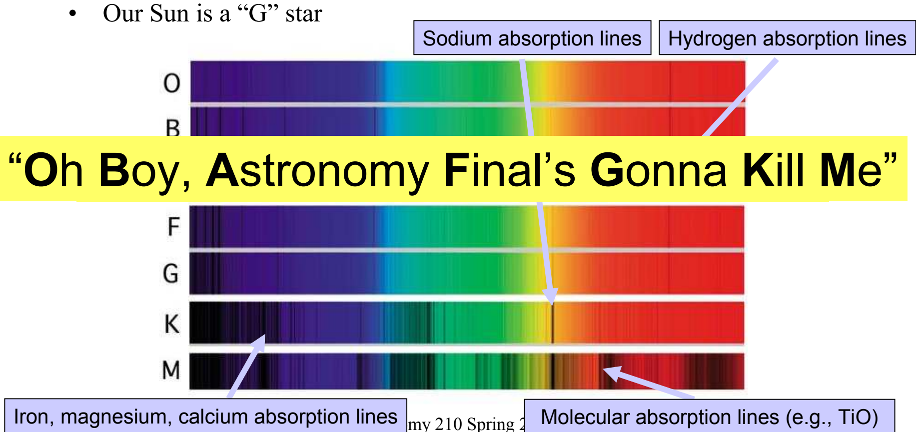
Stellar Color

- $F_B \Rightarrow m_B$ =B: Blue $\lambda \cong 440$ nm
- $F_V \Rightarrow m_V$ =V: "Visual", yellowish $\lambda \cong 550$ nm

- Define color index
  - B-V = 2.5 $\log(F_V/F_B)$ + const
  - Fix const so that B – V = 0 for a 10,000 K star
  - Then color index is a measure of temperature!
- Examples in Orion
  - Betelgeuse: B-V = 1.5 T ≅ 3,300 K
  - Rigel: B-V = -0.1 T ≅ 12,000 K

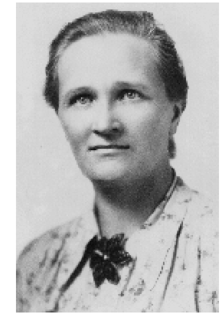
Spectral Classes

- To understand the physical nature of stars, we need to look at their spectra
- 9 classes based on spectrum lines
- Our Sun is a “G” star



What do the spectra tell us?

- The spectra tell us about both the compositions and temperatures of the stellar atmospheres
- Astronomer Cecilia Payne found that most stars’ compositions are very similar to the Sun’s
- The spectral sequence is due to *temperature*, not composition
  - M & K stars are 92% hydrogen, but their photospheres aren’t hot enough to excite it



Cecilia Payne

Properties of Spectral Classes

TABLE 10-1 The Spectral Sequence

Spectral class	Color	Temperature (K)	Spectral lines	Examples
O	Blue-violet	30,000–50,000	Ionized atoms, especially helium	Naos (ζ Puppis), Mintaka (δ Orionis)
B	Blue-white	11,000–30,000	Neutral helium, some hydrogen	Spica (α Virginis), Rigel (β Orionis)
A	White	7500–11,000	Strong hydrogen, some ionized metals	Sirius (α Canis Majoris), Vega (α Lyrae)
F	Yellow-white	5900–7500	Hydrogen and ionized metals such as calcium and iron	Canopus (α Carinae), Procyon (α Canis Minoris)
G	Yellow	5200–5900	Both neutral and ionized metals, especially ionized calcium	Sun, Capella (α Aurigae)
K	Orange	3900-5200	Neutral metals	Arcturus (α Boötis), Aldebaran (α Tauri)
M	Red-orange	2500-3900	Strong titanium oxide and some neutral calcium	Antares (α Scorpii), Betelgeuse (α Orionis)

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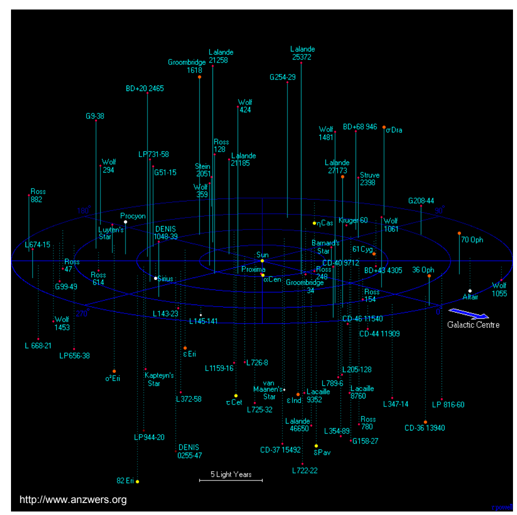
T

Hot Stars Are Rare



A Census of stars within 20 lys	
2	Type A stars
1	Type F star
6	Type G stars
16	Type K Stars
75	Type M Stars
1	Type M Brown Dwarf
1	Type L Brown Dwarf
4	Type T Brown Dwarfs
6	White Dwarfs