Astronomy 122

<u>This Class (Lecture 12):</u>

Stars

Homework #5 is posted.

Nightlabs have started!

<u>Next Class:</u>

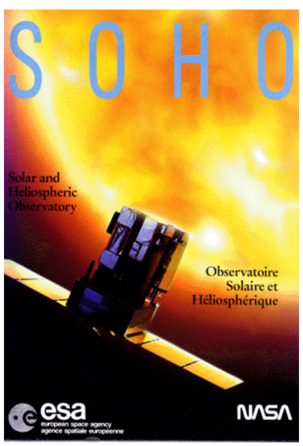
The Nature of Stars

Music: *We Only Come Out at Night* – Smashing Pumpkins

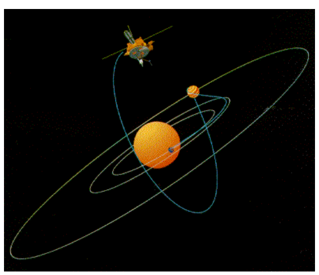
Outline

- Stellar properties
  - Parallax (distance)
  - Colors
  - Spectral Classes

Spacecraft Observing the Sun



SOHO



Ulysses

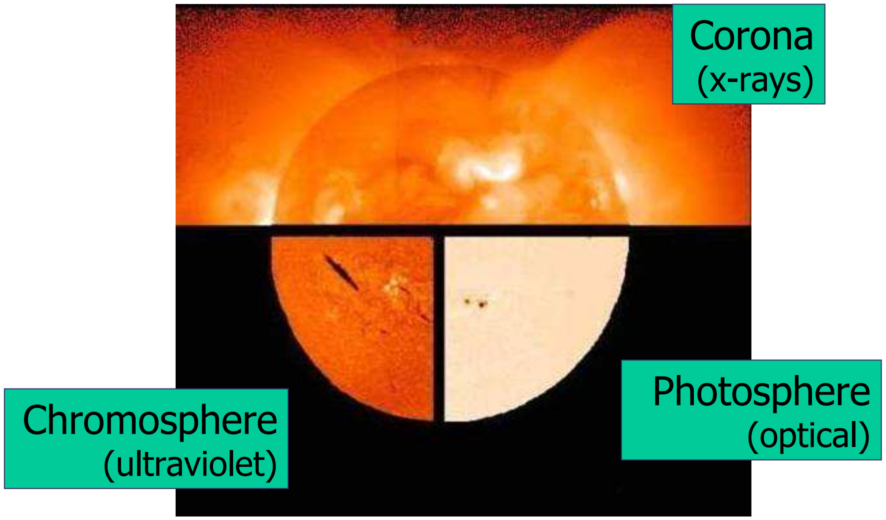
TRACE

RHESSI

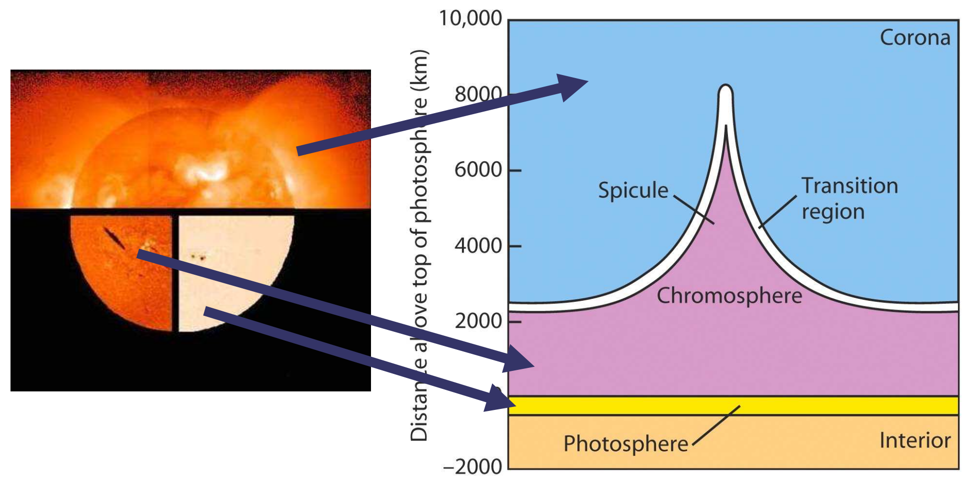
Think-Pair-Share

If we could sustain fusion in the lab we could meet humankind's energy needs forever! Why is it so difficult to achieve this, when stars do it every day?

The Outer Layers of the Sun

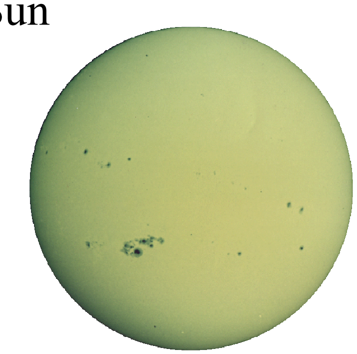


Structure of the Outer Layers



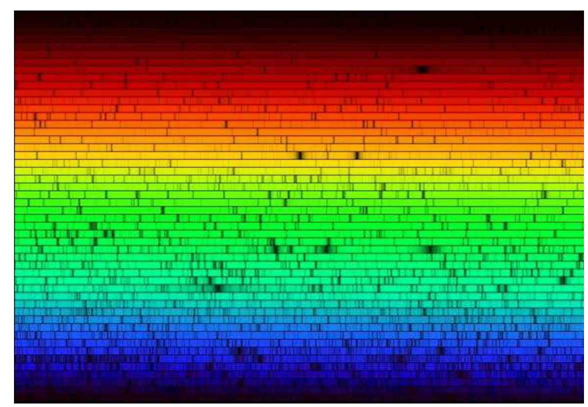
The Photosphere

- Apparent "surface" of the Sun
  - Ionized atoms make the gas highly opaque
- Most of the Sun's light we see comes from the photosphere
- Temperature, about 5800 K
  - Hotter as you go deeper into the Sun



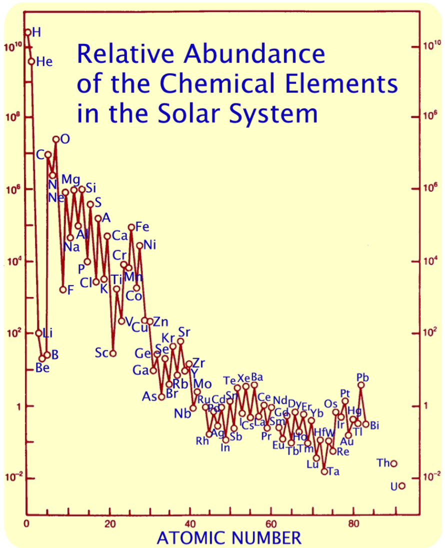
Solar Spectrum Lines

- The Sun shows dark spectrum lines
- Upper part of the photosphere is cooler than the lower part
- Cooler gas around a continuous spectrum source
- Therefore, we get an absorption spectrum!



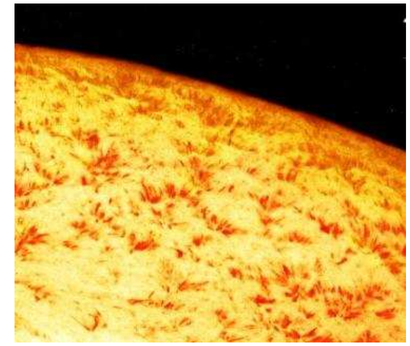
Solar Composition

- From the spectrum lines, we can determine the Sun's composition
  - 92% Hydrogen
  - 8% Helium
  - Less than 0.1% other stuff



The Chromosphere

- Very sparse layer of gas above the photosphere
- Hot – Over 10,000 K
- Produces very little radiation – too sparse
- Only seen during eclipse or with special instruments
- Helium was first discovered in the chromosphere



The Corona

- Sun's outer atmosphere
- Visible only by blocking light from photosphere
- Heated by magnetic activity
- Temperatures about 2 million K
- Hot enough to produce X-rays!

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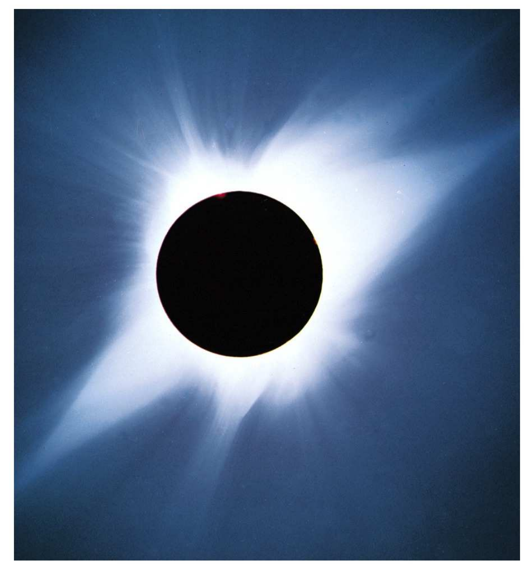
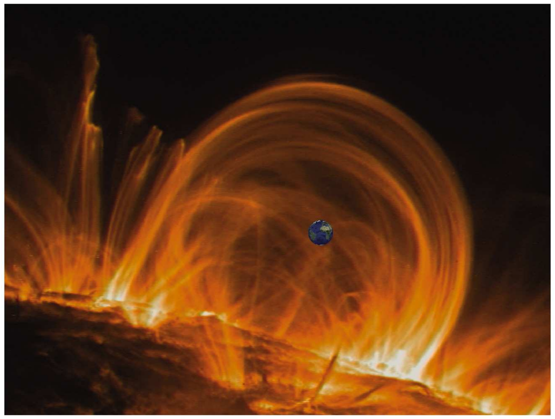
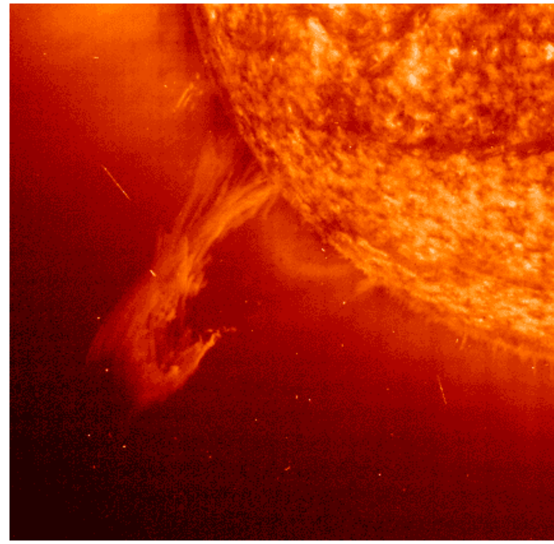


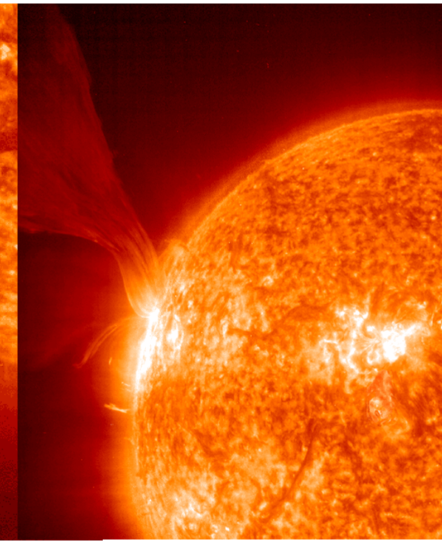
Prominences

- Ropes of gas trapped in magnetic loops
- Almost always associated with sunspots
- Gas can reach temperatures of 50,000 K!

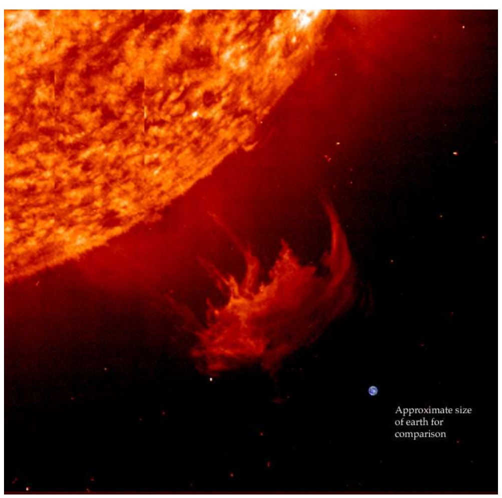


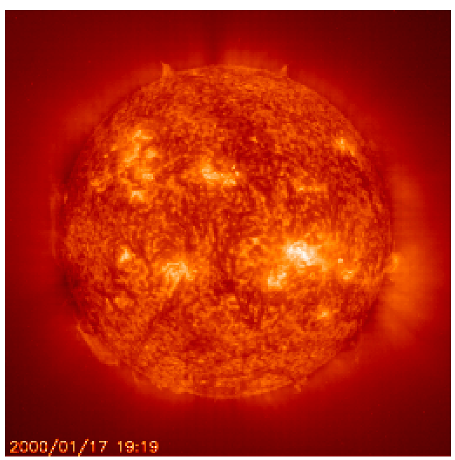
And more…



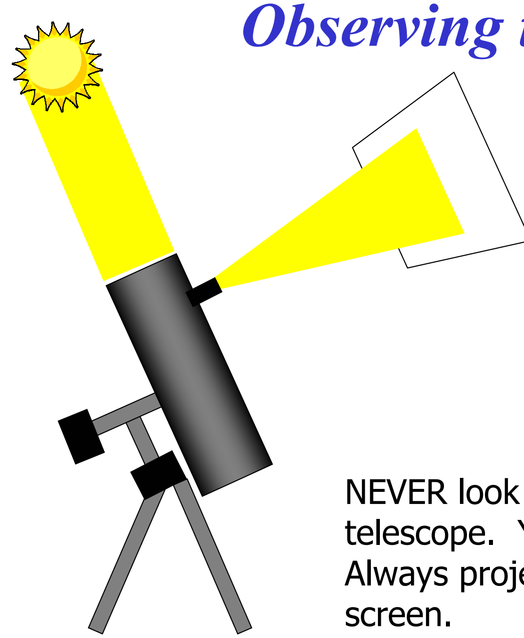


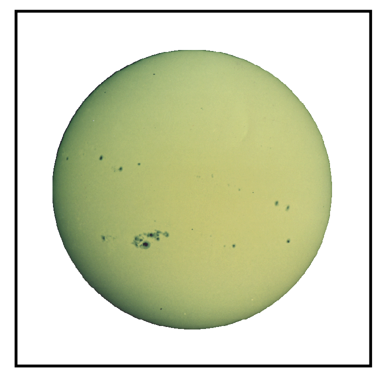
And more!





Observing the Sun

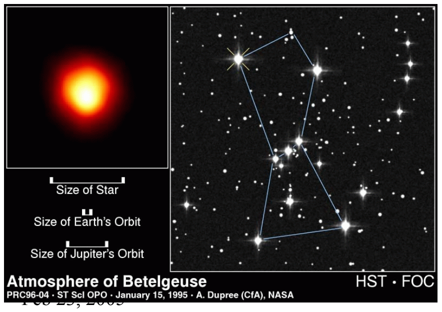


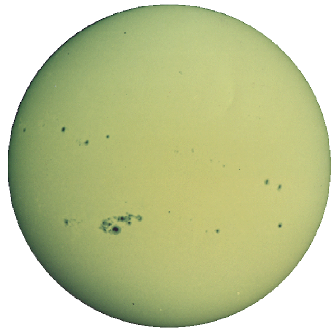


NEVER look at the Sun through a telescope. You will damage your eyes! Always project the Sun's image onto a screen.

Stars as Suns

- The Sun is a nuclear reactor, but I'm saying much more than that: Sun is a typical star
- So all stars are run by thermonuclear fusion
- Night sky, Universe lit up ultimately by dense nuclear furnaces scattered everywhere
- How do we know Sun is typical?





Star's Physical

- 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.

Star's Physical

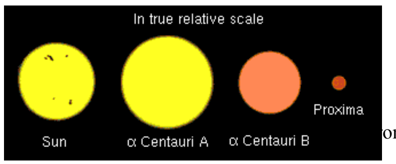
- Are all stars the same? Are they all just like our Sun?
- Do they have different brightnesses?
- Do they have different temperatures? Colors?
- Do they have different masses?
- Do they have different sizes?
- What happens to them? Just grow old and get retirement?

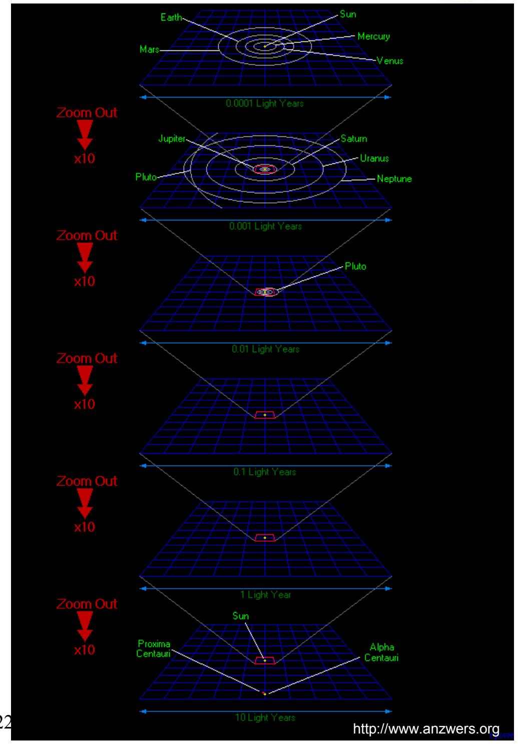
Distance

- 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.

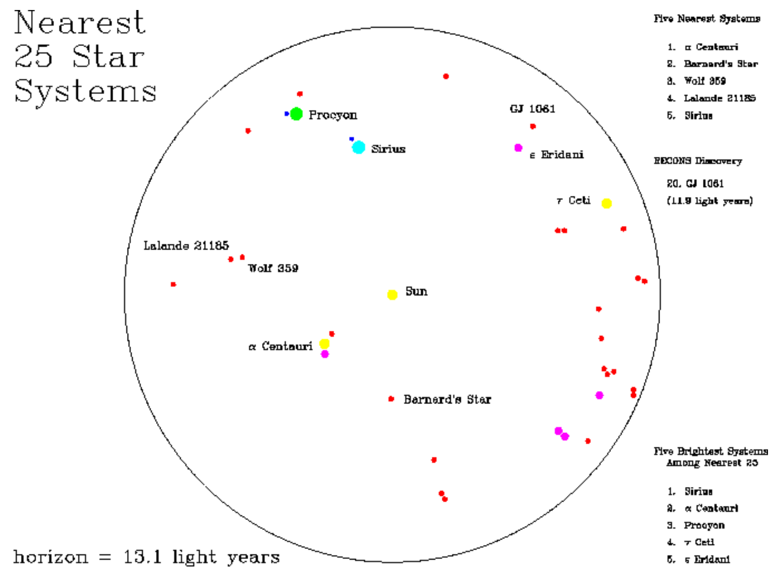
Leaving Home

- 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 (38000 mi/hr)





Our Nearest Neighbors



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

Parallax

- How do astronomers measures distances to nearby stars?

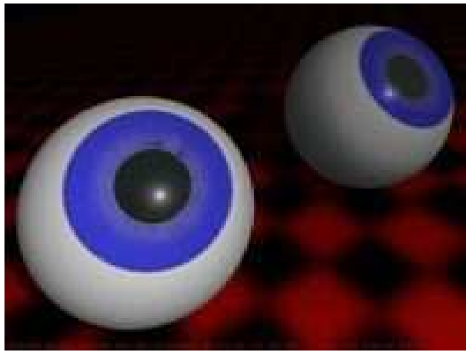
Stupid Demo #6

1. Close one eye
2. Hold out arm at full length
3. Place my face under your thumb
4. Now, switch eyes. Blink back and forth a few times.
5. Hold out arm at half-length
6. Repeat

http://www.ibiblio.org/john/photos/thumb.jpg

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!



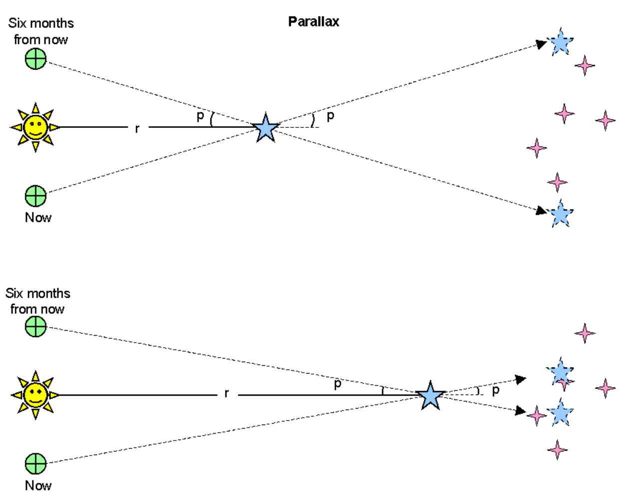
http://www.kidsdomain.com/holiday/halloween/clipart/eyes.jpg

Angular Sizes

How far away am I– with parallax?

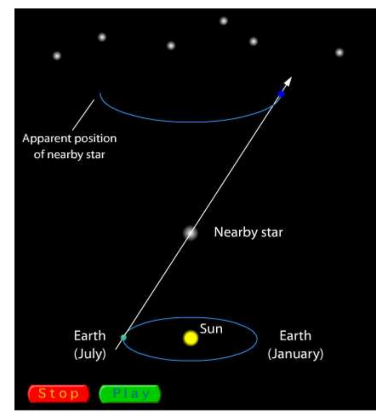
How to Measure Parallax

- 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



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

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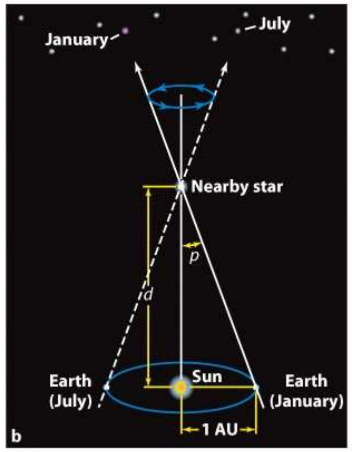
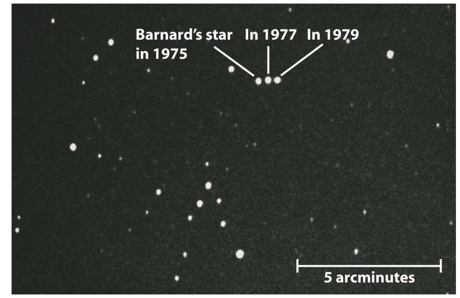


$$\text{Distance to a star in parsecs} = \frac{1}{\text{Star's parallax in arcseconds}}$$

Barnard's Star

Has a measured parallax of 0.547 arcseconds.



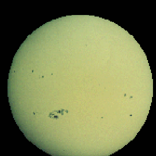
$$d = \frac{1}{p} = \frac{1}{0.547} = 1.83 \text{ pc}$$

Because 1 parsec is 3.26 light-years, this can also be expressed as

$$d = 1.83 \text{ pc} \times \frac{3.26 \text{ ly}}{1 \text{ pc}} = 5.96 \text{ ly}$$

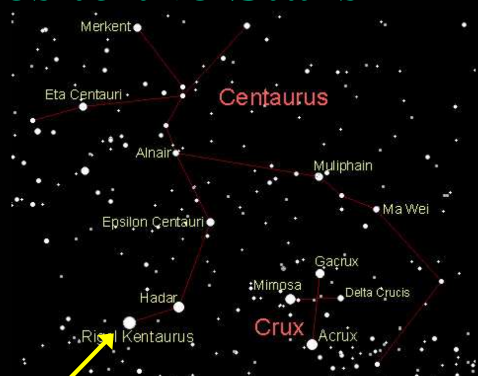
The Distances to the Stars

Sun's disk seen from Earth



1/2 degree = 1800 arcsec

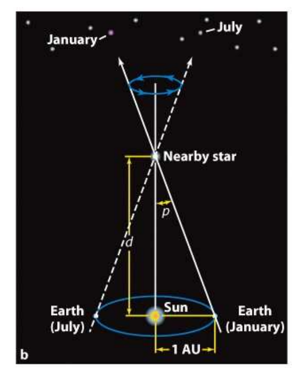
Dime at arm's length



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

Parallax Peril

- Drawback: p measurable only for nearest stars
- Angular shift becomes tiny when star very 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...



Which is Brighter?

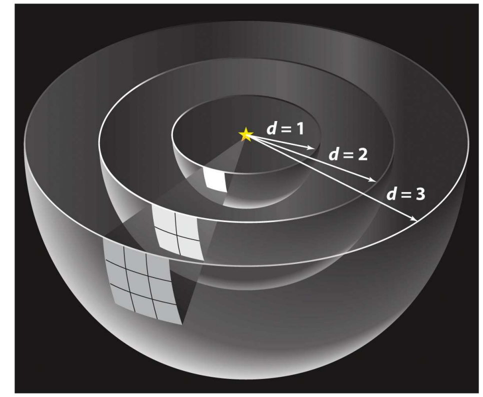
- The Moon or the streetlamp?
- Why?
- *Apparent brightness* and *luminosity* difference.
- Luminosity measures how much energy object emits per second.

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

Luminosity

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

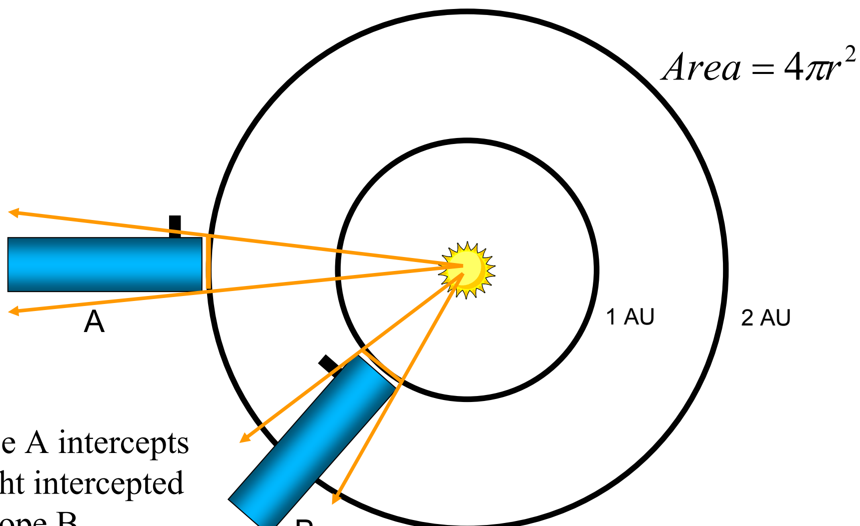
$$b = \frac{L}{4\pi d^2}$$



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

Why do more distant objects look so much fainter?

- More distant stars of a given luminosity appear dimmer
- Apparent brightness drops as square of distance



Telescope A intercepts ¼ the light intercepted by telescope B

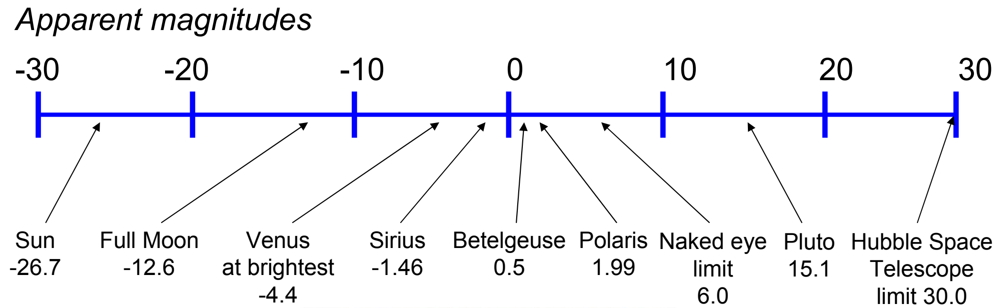
Measuring Star Brightness

- 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
    - They are 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

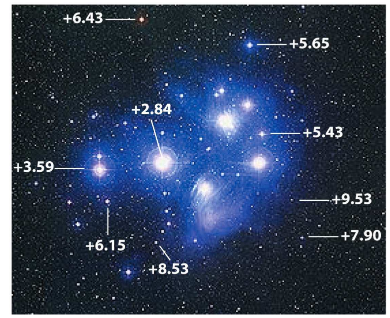
Apparent Magnitudes

- Astronomers have extended the log scale, decimalized it, and scaled it to Vega (more or less)
- A star that is 5 magnitudes larger than Vega, would be 100 times less bright
- So, 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
  - logarithmic scale - human senses are approximately logarithmic.

Apparent Magnitude Scale



Apparent magnitudes in Pleiades



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!

$$m - M = 5\log(d/10\ pc)$$

- m is the apparent magnitude
- M is the absolute magnitude (apparent mag at 10pc)
- d is the distance to the star in pc

Absolute Magnitudes

- An example
  - The star Vega has an apparent magnitude of 0.03
  - It is 7.5 parsecs away .

$$\begin{aligned} M &= m - 5\log(d/10\ pc) \\ &= 0.03 - 5\log(7.5/10) \\ &= 0.03 - (-0.62) \\ &= 0.65 \end{aligned}$$

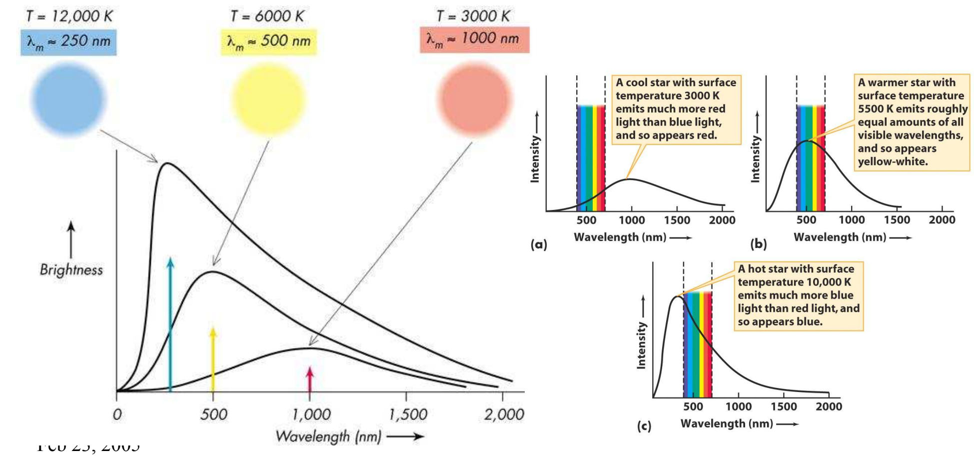
Absolute Magnitudes

- An example
  - The Sun has an apparent magnitude of -26.7
  - It is $4.8\text{x}10^{-6}$ parsecs away .

$$M = m - 5\log(d/10\ pc)$$
$$= -26.7 - 5\log(4.8\times10^{-6}/10)$$
$$= -26.7 - (-31.57)$$
$$= +4.8$$

Stellar Colors

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

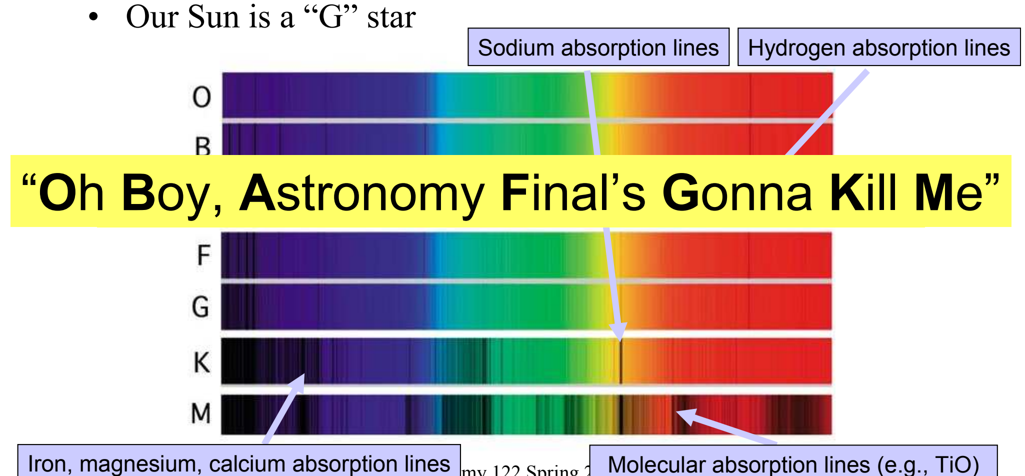


Color me..

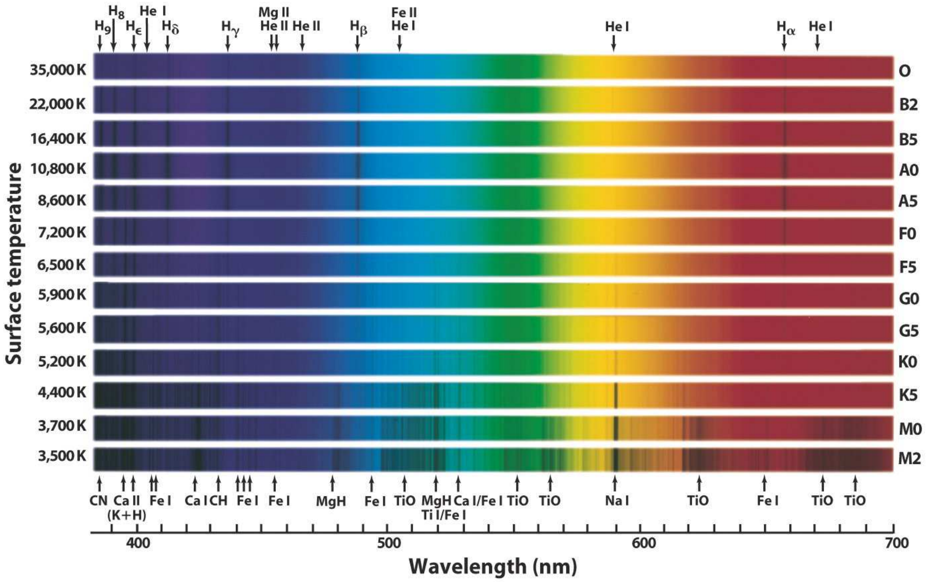
White hot Sirius to a red supergiant Betelgeuse

Spectral Classes

- To understand the physical nature of stars, we need to look at their spectra (tells us composition too)
- 9 classes based on spectrum lines
- Our Sun is a "G" star

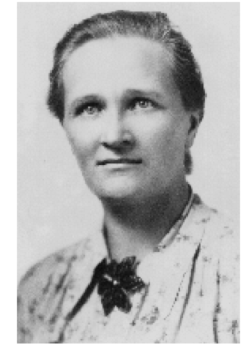


Spring Spectra



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 19-2 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)
L	Red	1300–2500	Neutral potassium, rubidium, and cesium, and metal hydrides	Brown dwarf Teide 1
T	Red	below 1300	Strong neutral potassium and some water (H_2O)	Brown dwarf Gliese 229B

Brown dwarfs were added later. Very cool and very red – named L and T spectral classes. Brown dwarfs are too small to sustain fusion.