Astronomy 122

This Class (Lecture 13):

The Nature of stars

Homework #6 is posted.

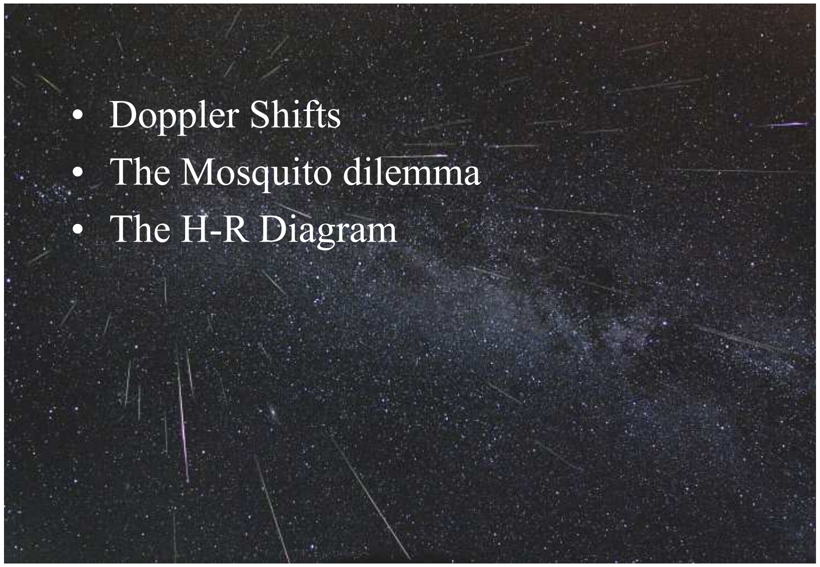
Nightlabs in 2nd week!

Next Class:

Star Formation

Music: *Blister in the Sun* – Violent Femmes

Outline



- Doppler Shifts
- The Mosquito dilemma
- The H-R Diagram

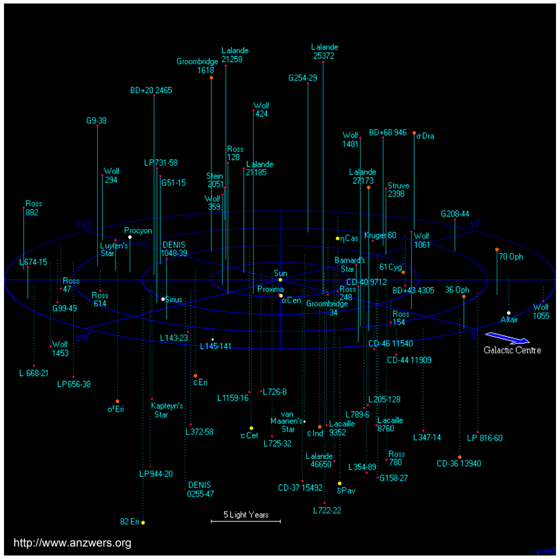
Properties of Spectral Classes

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.

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

Mass

- How can we measure the mass of stars?
- We use Kepler's 2nd Laws (modified by Newton).

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:
  - with Newton's version of Kepler's 2nd

$$M_1 + M_2 = \frac{a^3}{P^2}$$

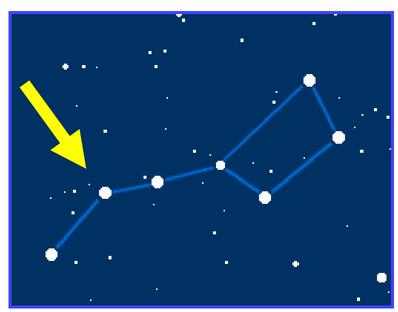
- Now, the problem is how to measure the a's and P's

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 orbit, but we would have to wait a long time to watch them orbit.



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

Doppler Effect

Those of you familiar with racing events like the Indy 500 or the sound of a police siren, are use to the Doppler effect.

Doppler Shift

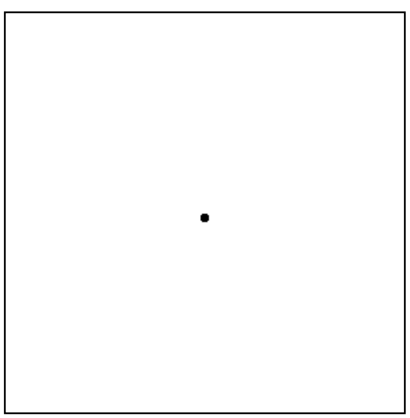
- The amount of shift in wavelength depends on the *relative* velocity of the source and the observer

$$\lambda_{obs} - \lambda_{source} = \lambda_{source} \times \left(\frac{v_{source}}{c} \right)$$

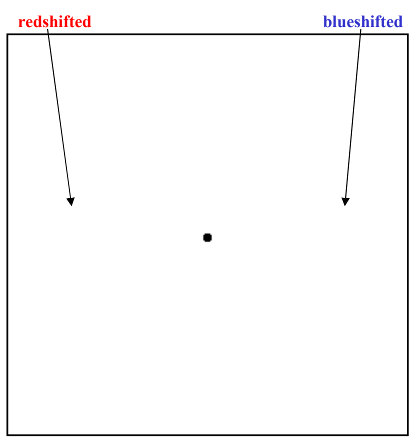
- By measuring the Doppler shift of the light we observe, we can study the motions of the planets and stars
- The Doppler effect is also used by modern storm-tracking radar

The Doppler Effect

The effect arises from the relative motion of the observer and the source of light, sound, etc. The waves get squashed in the direction of motion and stretched in the opposite direction.



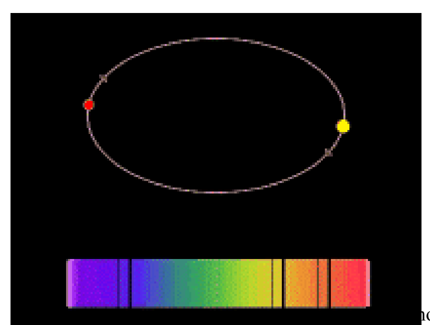
Source standing still

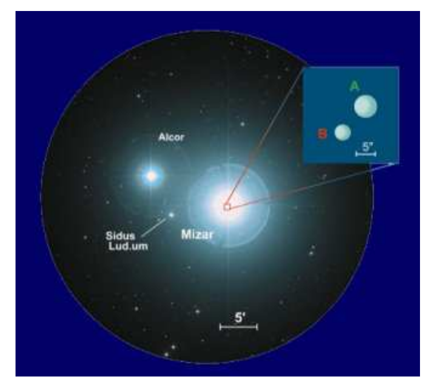


Source moving to right

Beautiful Binary: Spectroscopic

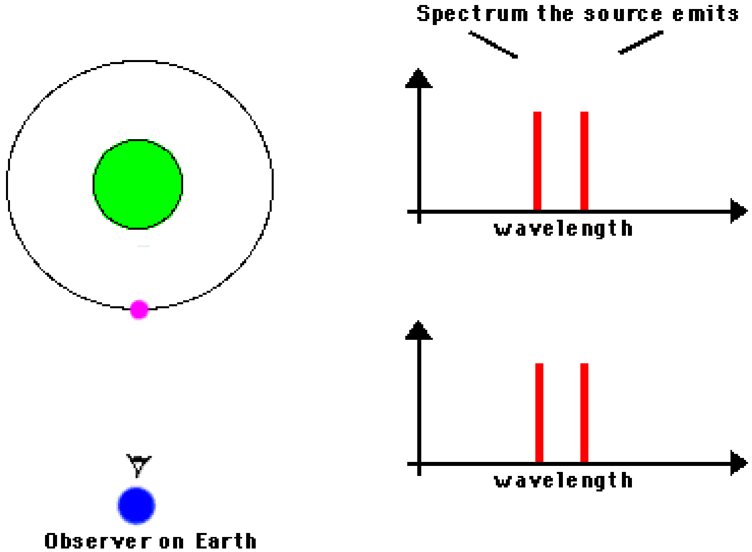
Mizar is the first known double star (14″). Each of those stars is also a binary system, but very close together. Can see spectroscopic binary system from Doppler shift.





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

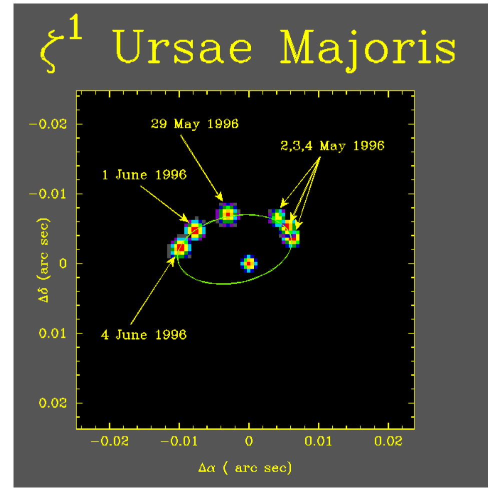
Beautiful Binary: Spectroscopic



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

Stellar Properties

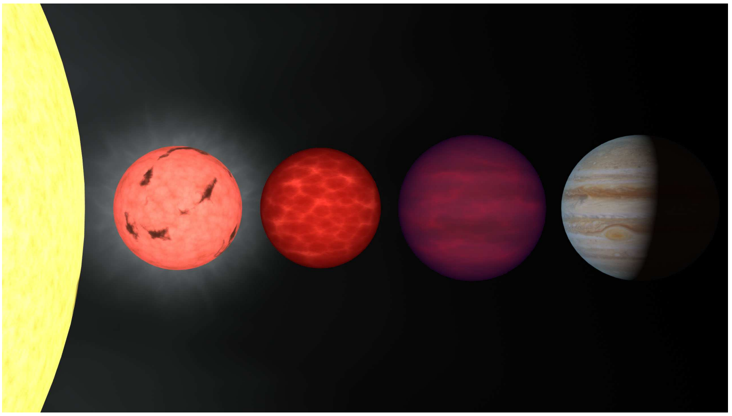
- Apparent brightness
- Luminosity
- Distance
- Masses of binary systems
- Color
- Stellar spectra

The Mosquito Dilemma

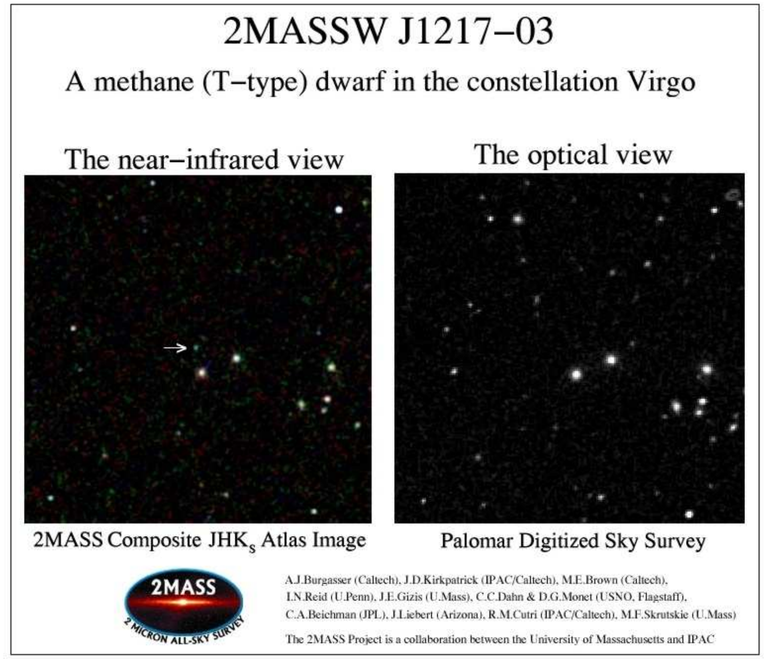
- It's like a mosquito trying to understand humans.
- They don't live long enough to watch humans be born and die, so they have to extrapolate.
- How do we understand stars that live for 10 billion+ years?

http://news.uns.purdue.edu/html3month/2004/040823.Williams.fallwnv.html

Dwarfs



T Dwarves



L and T

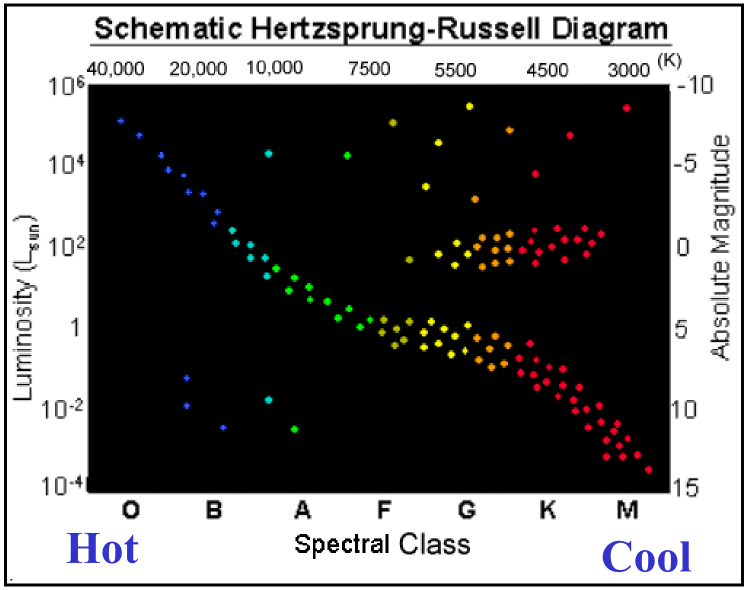
- We have the luminosity and temperature of stars.
- How do they correlate?
- Think about it.
- If we can have any L for any T, what do we expect?
- If only one L for one T, then what?

The H-R Diagram

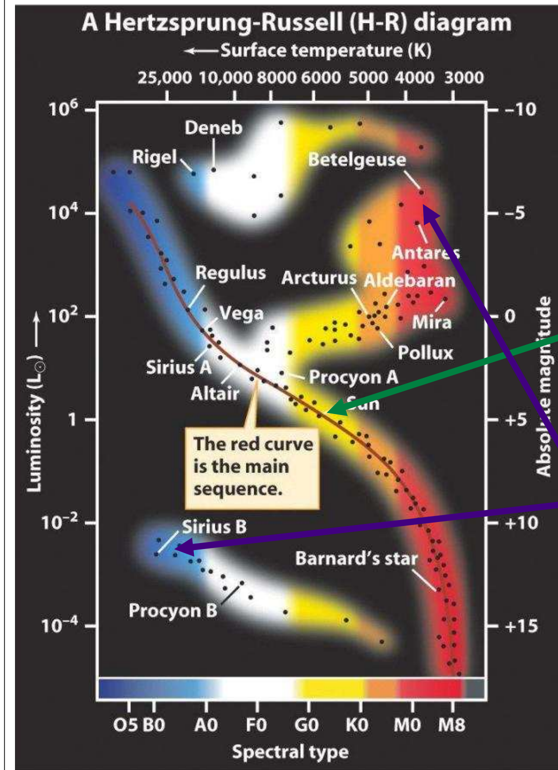
- In the early 20th century, two astronomers plotted luminosity vs. temperature and found an interesting correlation in different regimes.
- It is not a random plot of points!
- The resulting plot is now named for them
- The **Hertzsprung-Russell Diagram**

Hertzsprung-Russell Diagram

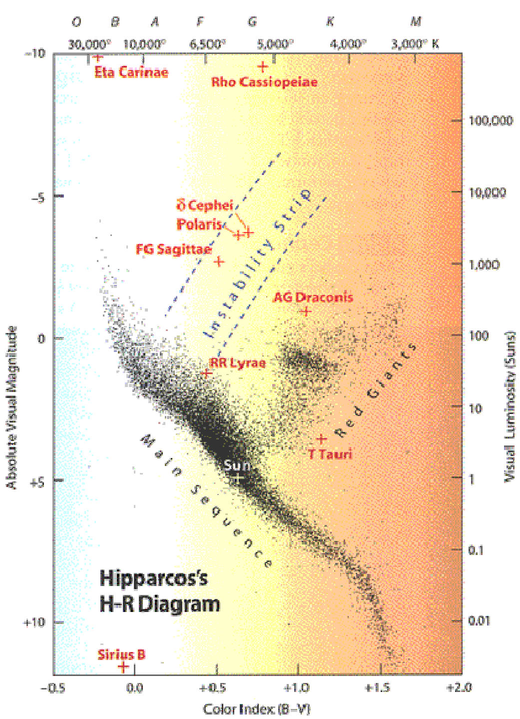
Bright



Dim



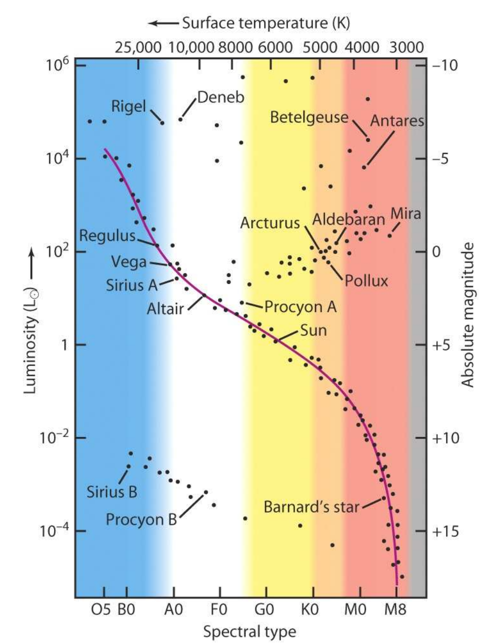
- Stars do not have random temperatures and brightness
- 91% of all stars are on the Main Sequence.
  - Why?
- But, there are also very bright cool stars and very dim hot stars



A Real Example

- Notice the large number of stars on the main sequence.
- The Sun is very average.

The H-R Diagram



How does the size of a star near the top left of the H-R diagram compare with a star of the same brightness near the top right of the H-R diagram?

– They are the same size

– The star near the top left is larger

– The star near the top right is larger

Luminosity and Size

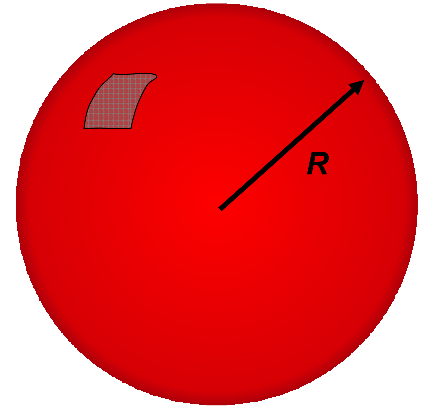
$$L = 4\pi R^2 \sigma T^4$$

A star's brightness depends on its temperature and its size.

A small hot star can be less bright than a huge cool star.

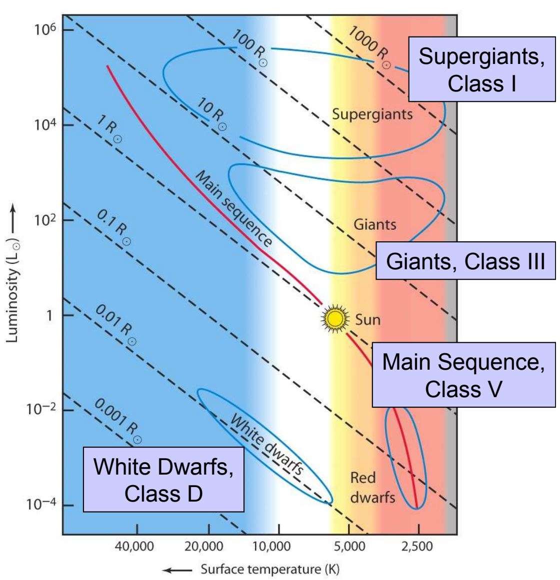
Luminosity

- Bright cool stars must be large
  - **Giants & Supergiants**
- Dim hot stars must be small
  - **White dwarfs**



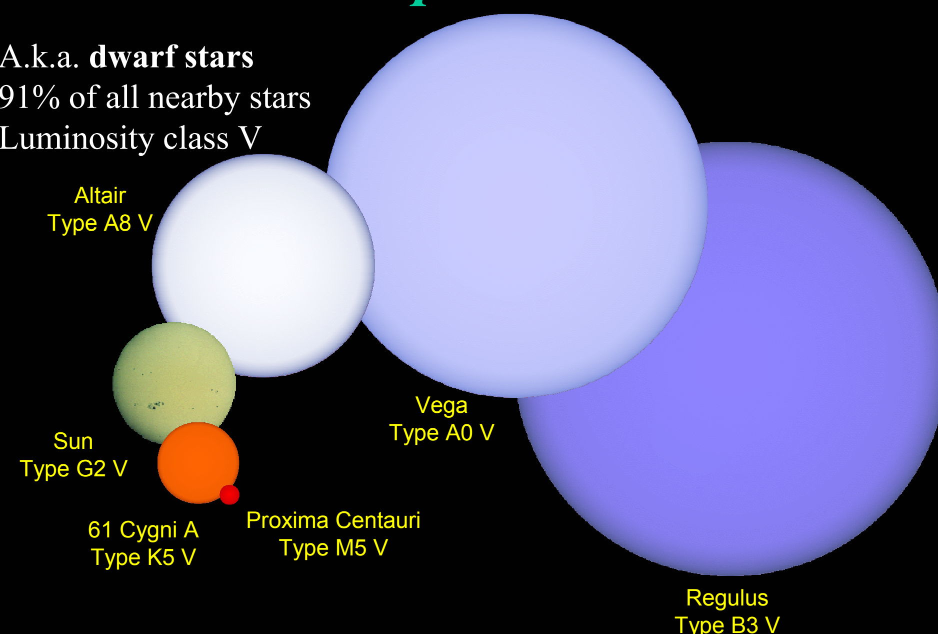
Luminosity Classes

- Stars on the H-R diagram are also divided into **luminosity classes**
- Appended to a star's spectral class
- The Sun is a class "G V" star



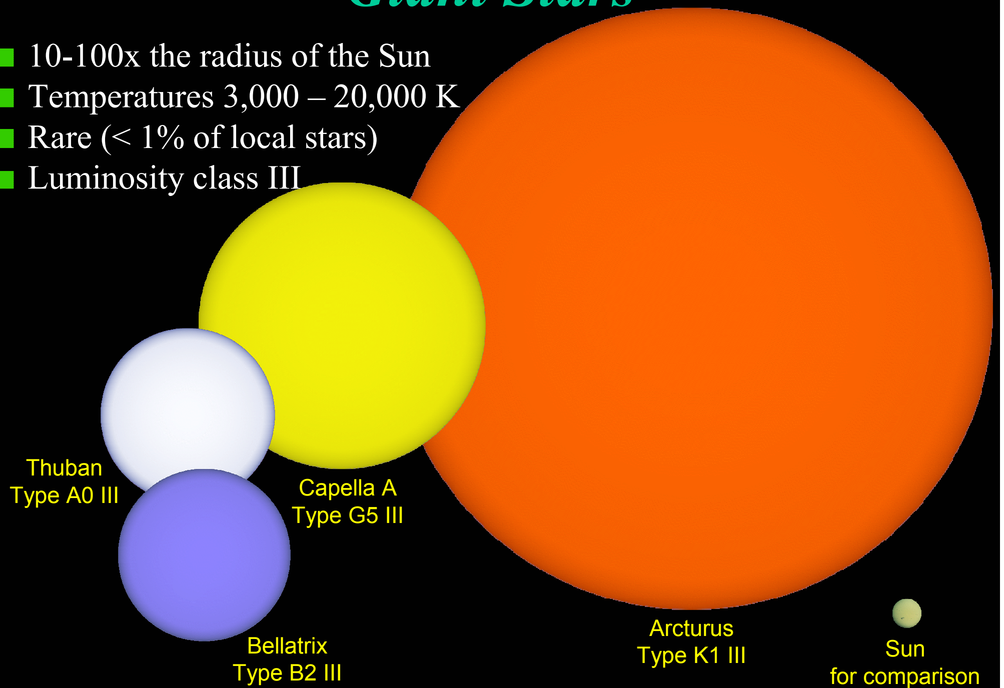
Main Sequence Stars

- A.k.a. **dwarf stars**
- 91% of all nearby stars
- Luminosity class V



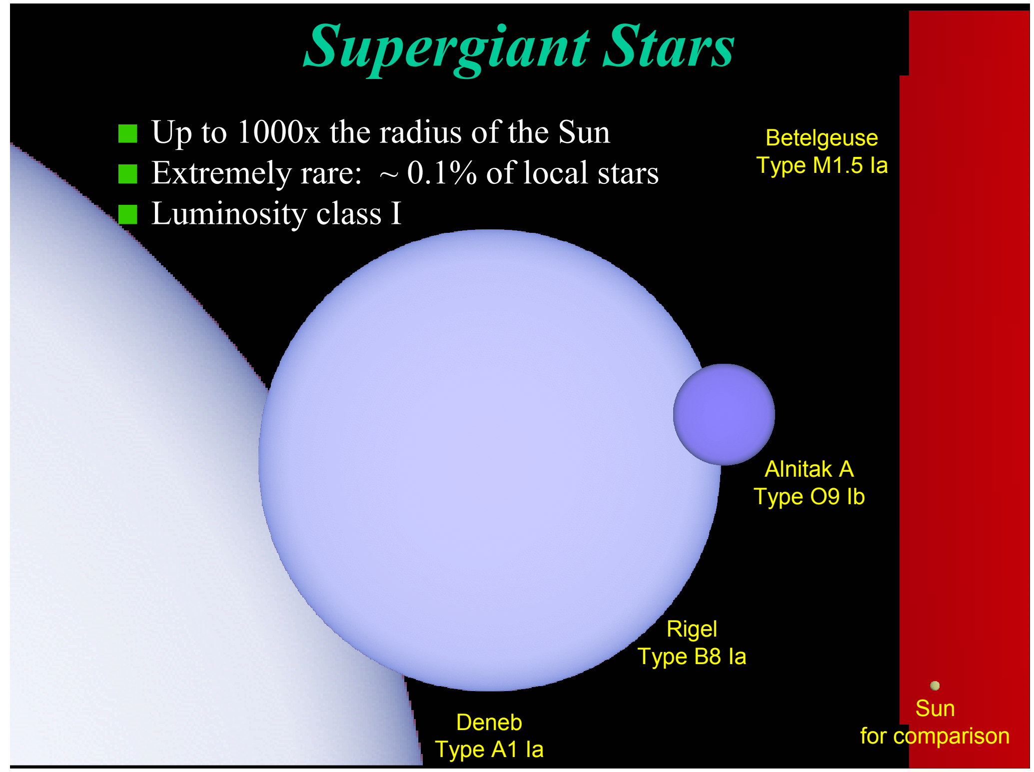
Giant Stars

- 10-100x the radius of the Sun
- Temperatures 3,000 – 20,000 K
- Rare (< 1% of local stars)
- Luminosity class III



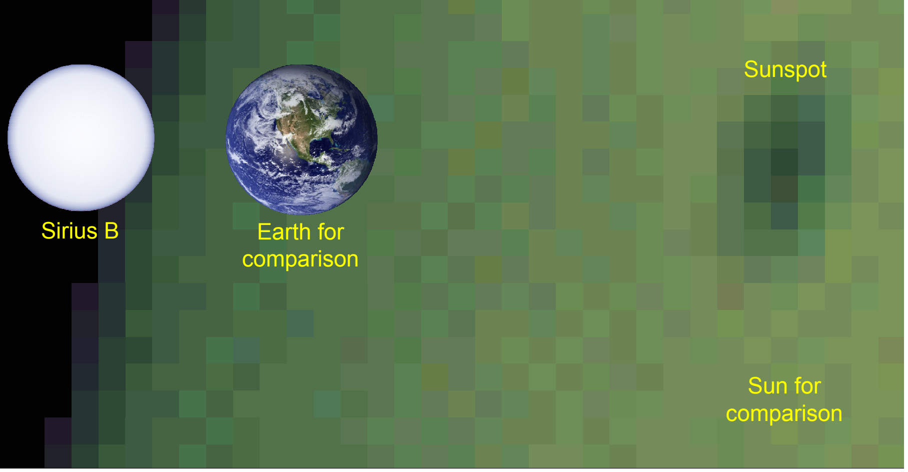
Supergiant Stars

- Up to 1000x the radius of the Sun
- Extremely rare: ~ 0.1% of local stars
- Luminosity class I



White Dwarf Stars

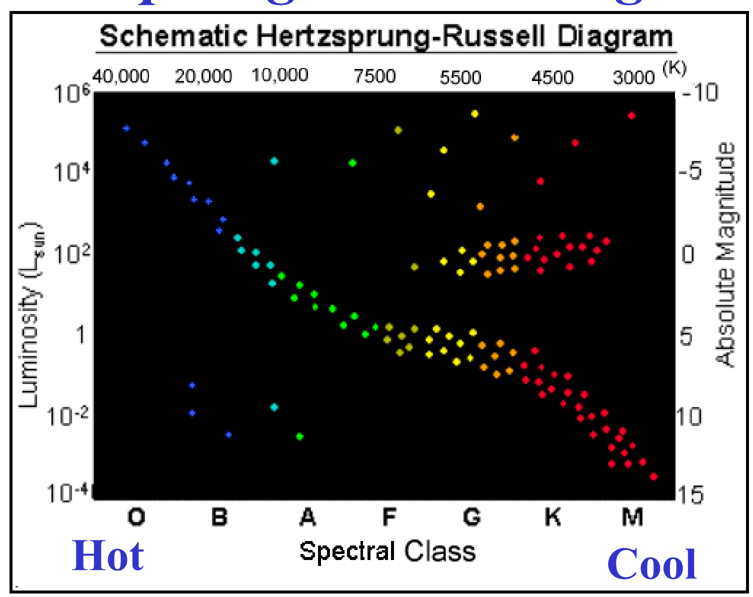
- About the size of the Earth
- Very hot: 5,000 – 20,000 K
- About 8% of local stars
- Luminosity class D



Hertzsprung-Russell Diagram

Bright

Dim

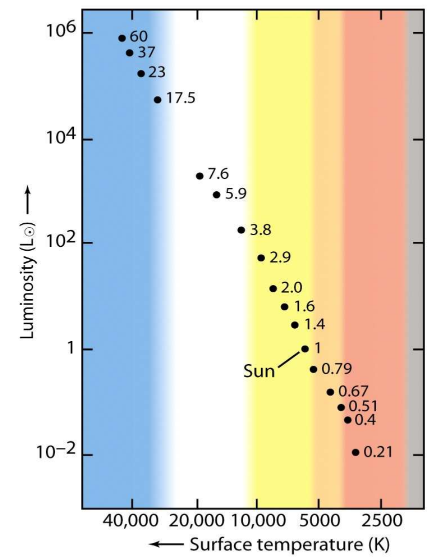


What do the regions of the H-R Diagram mean?

- One big question - What are the differences between stars in the regions of the H-R diagram?
- The regions of the H-R diagram reflect different states of stellar evolution (aging)
  - Main sequence stars are “adult stars”
  - Giants and supergiants are “aged stars” (nearing the end of their lives)
  - White dwarfs are “dead stars”

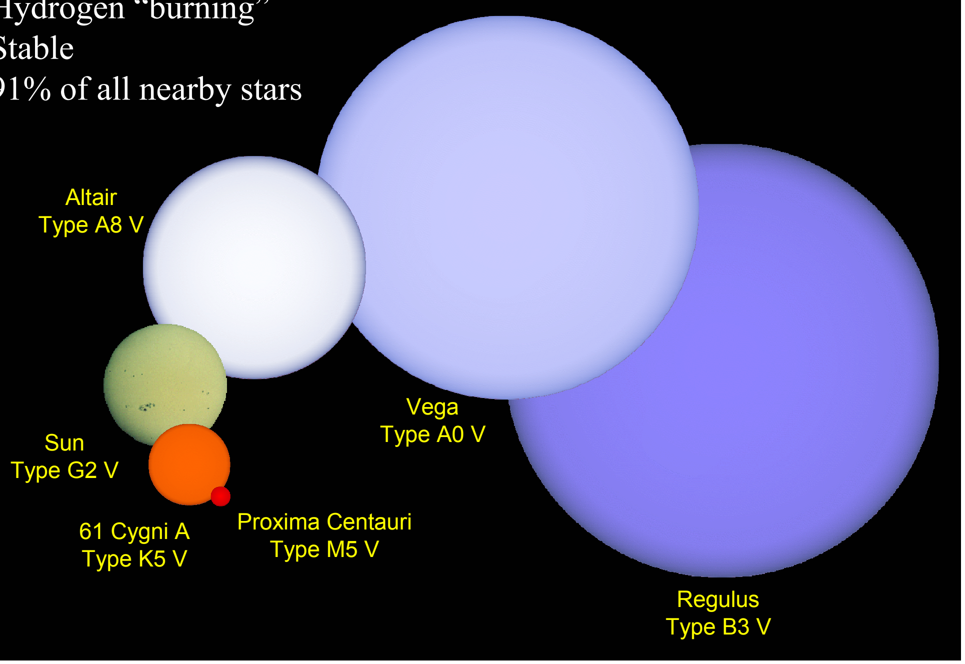
The Mass-Luminosity Relationship

- Luminosity is proportional to Mass
- Much larger range in luminosity than in mass
- Higher mass = higher luminosity, higher temp, and large radius
- Lower mass = lower luminosity, lower temp, and smaller radius
- Non-main sequence stars



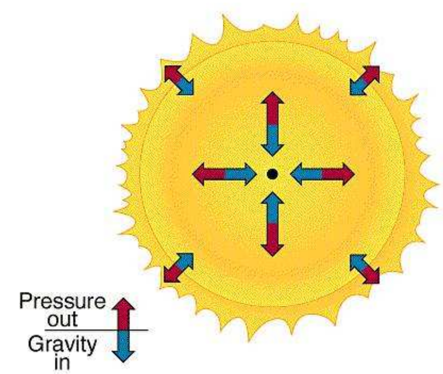
Main-Sequence Stars

- Hydrogen “burning”
- Stable
- 91% of all nearby stars



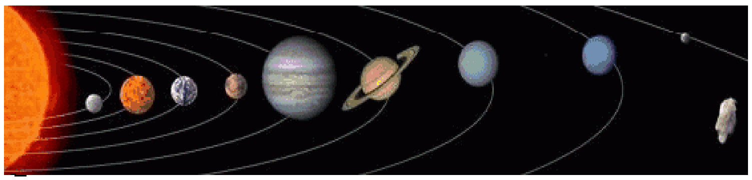
Hydrostatic Equilibrium

- The battle between Gravity and Pressure is a draw for these stars.
- Pressure pushes out and gravity pulls in – an equilibrium
- This is why a main sequence star isn’t shrinking even though it’s a big ball of gas
- A star’s life is all about this battle!



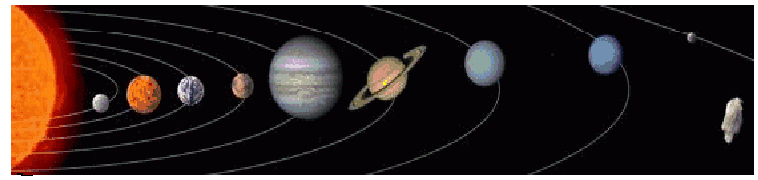
Explain Star Formation!

- We have our solar system.
- We understand some aspects of it, such as
  - Different planets properties
  - Orbital patterns (Kepler's Laws)
- What are the aspects (globally) that we have to explain?



Explain It!

- Could take a whole class, but the main aspects are:
  - Orbits, spins
  - Terrestrial/Jovian differences:
    - Composition
    - Location
    - Size
    - Spacing
  - Debris: comets, asteriods



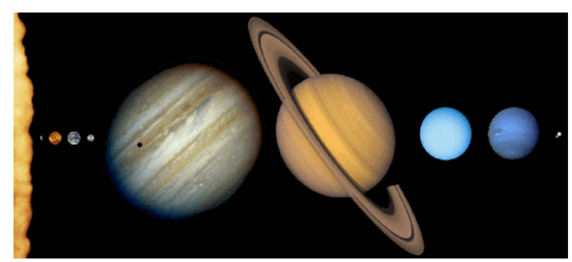
What is the origin of the Solar System?

- Explain present-day Solar System data.
- Predict results of new Solar System data.
- Should explain and predict data from other stars!

What are clues to solar system origins?

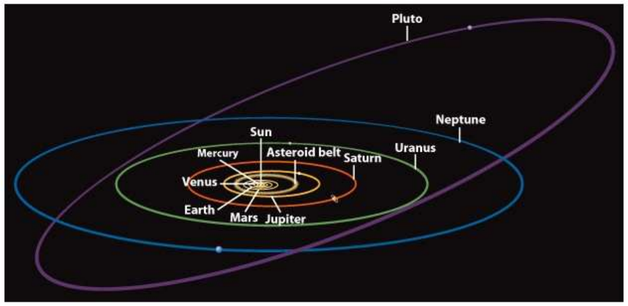
Some Facts of the Solar System

- Mass of solar system
  - 99.85% in the Sun (planets have 98% of ang. mom.)
  - Outer planets more massive than the inner ones
  - Jupiter is more than twice as massive as the rest of the planetary system combined!
- The inner planets are rocky and the outer planets are gaseous



Planetary Orbits

- Most of the motions in the Solar System are counter clockwise in a flat system (pancake-like)



  - There are some exceptions
  - Venus, Uranus, and Pluto rotate clockwise
  - Some moons orbit backwards

http://janus.astro.umd.edu/javadir/orbits/ssv.html

What is the Age of the Solar System?

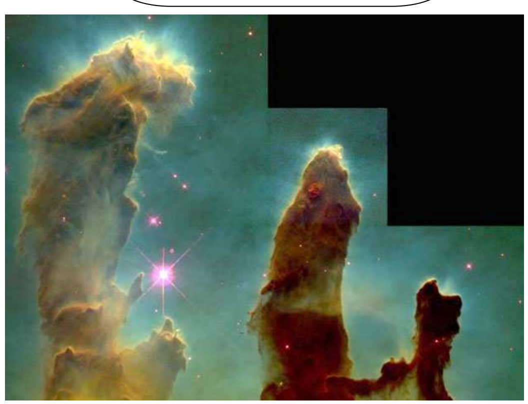
- Earth: oldest rocks are 4.4 billion yrs
- Moon: oldest rocks are 4.5 billion yrs
- Mars: oldest rocks are 4.5 billion yrs
- Meteorites: oldest are 4.6 billion yrs
- Sun: models estimate an age of 4.5 billion yrs

- **Age of Solar System is probably around 4.6 billion years old**

Solar Nebula Theory

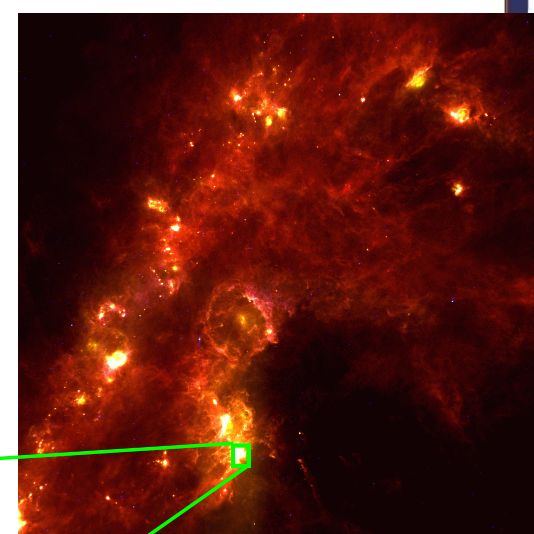
"*nebula*" = space cloud

- Proposed by Immanuel Kant (the philosopher)
- The solar system formed from a spinning cloud of gas, dust, and ice
  - Mostly hydrogen and helium
  - 4.6 billion years ago



Giant Molecular Clouds

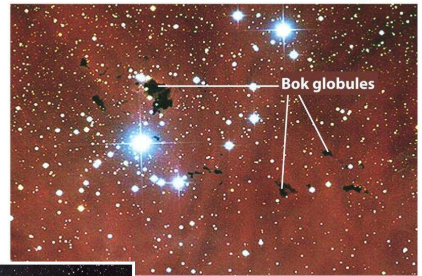
- Cool: < 100 K
- Dense: $10^2 – 10^5$ H_2 molecules/cm^3 (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 – 10^6$ solar masses
- CO molecular & dust emission structure

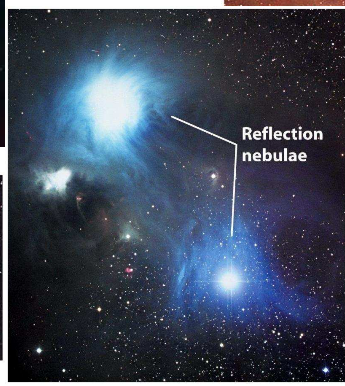


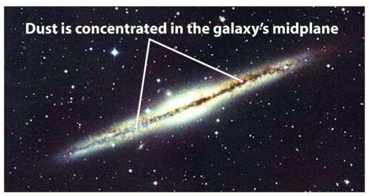
100 degrees

Infrared image from *IRAS*

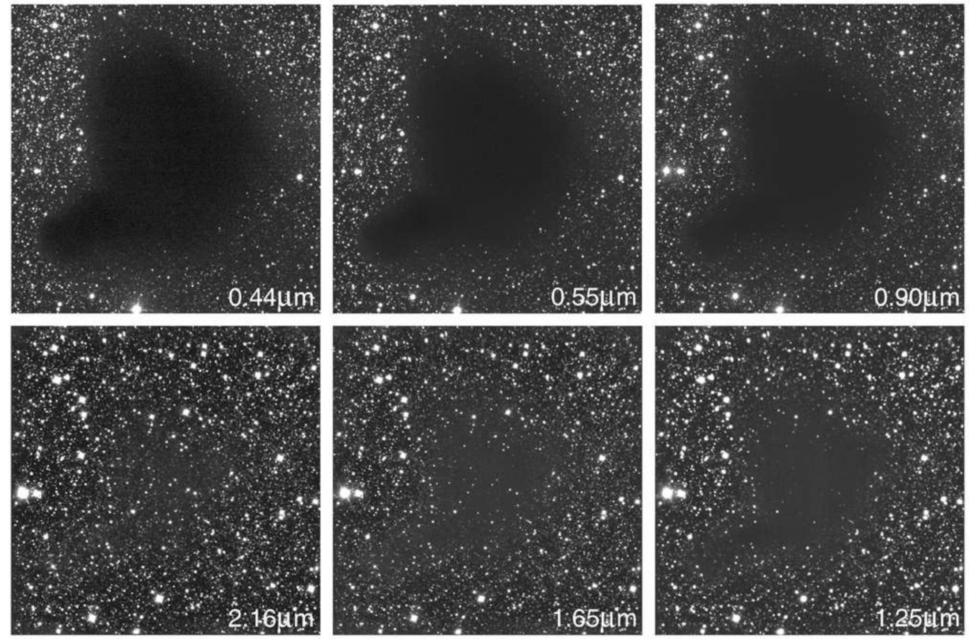
Interstellar Clouds







We see spiral galaxy NGC 891 nearly edge-on

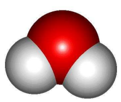


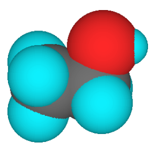
The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

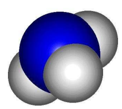
ESO PR Photo 29b/99 (2 July 1999)

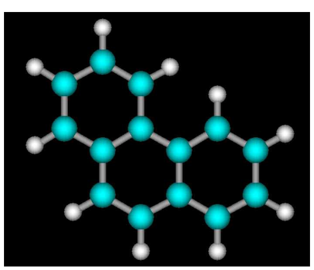
Other Things Besides Hydrogen in Molecular Clouds

- Molecules (e.g.)
  - Carbon monoxide (CO)
  - Water (H_2O)
  - Ammonia (NH_3)
  - Formaldehyde (H_2CO)
  - Glycine (NH_2CH_2COOH)?
  - Ethyl alcohol (CH_3CH_2OH)
  - Acetic Acid (CH_3COOH)
  - Urea [$(NH_2)_2CO$]
- Dust particles
  - Silicates, sometimes ice-coated
  - Soot molecules

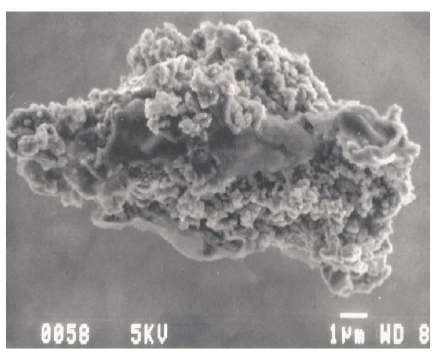








Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)

Solar Nebula Theory

- In these clouds are small clumps that become gravitationally unstable
- The gas and dust has mass (thus gravity)
- Gravity pulls it toward the center – contracts!
- **Question:** What do you think happens?

Gravity follows the inverse square law, so closer = stronger. Once it falls in a little, it gets pulled in more.

RUNAWAY GRAVITY!