Announcements

- Quiz#3 today at the end of 60min lecture.
- Homework#3 will be handed out on Thursday.
  – Due October 14 (next Thursday)
- Review of Mid-term exam will be handed out next Tuesday.
  – Mid-term exam will be variants (if not identical) of some of the problems in the review.
  – Study it to prepare well for mid-term!

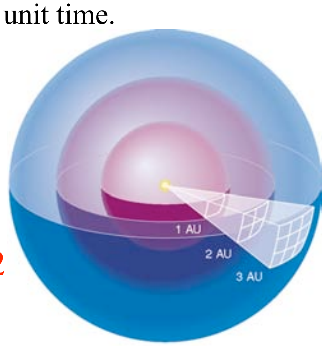
Lecture 11
Properties of Stars

Reading: 16

Luminosity of Stars: How bright they actually are!

Luminosity – the total amount of power radiated by a star into space. Or, the total amount of energy radiated per unit time.

- **But, we observe something APPARENT to us.**
- **Apparent brightness** refers to the amount of a star's light which reaches us *per unit area*.
  - the farther away a star is, the fainter it appears to us
  - how much fainter it gets obeys an *inverse square law*
  - its apparent brightness decreases as the $(\text{distance})^2$



$$\text{App Bright} = L / 4\pi d^2$$

- The apparent brightness of a star depends on two things:
  - How much light is it emitting: luminosity (L) [watts]
  - How far away is it: distance (d) [meters]

The "Brightness" of Stars: How they look

Astronomers still use an ancient method for measuring stellar brightness which was proposed by the Greek astronomer Hipparchus (c. 190 – 120 B.C.)

Magnitude Scale

- The scale determined by naked eye observations.
- This scale runs backwards.
  - The bigger the number, the fainter the star
  - Brightest stars are #1, next brightest are #2, etc.
- Physicists absolutely hate this scale.

The Modern Magnitude System

•Don't rely on eyes, but use precise, mathematical definition:

apparent magnitude = -2.5 log (app bright)

• brightness of a star as it *appears* from Earth

• each step in magnitude is roughly 2.5 times in brightness

  •100 times brighter --> 5 magnitudes brighter

absolute magnitude

• the apparent magnitude a star *would* have *if* it were 10 pc away

Colors of Stars: Not only beautiful, but also very important!

Stars come in many different colors.

The color tells us the star's ***temperature*** according to Wien's Law.

Bluer means hotter!

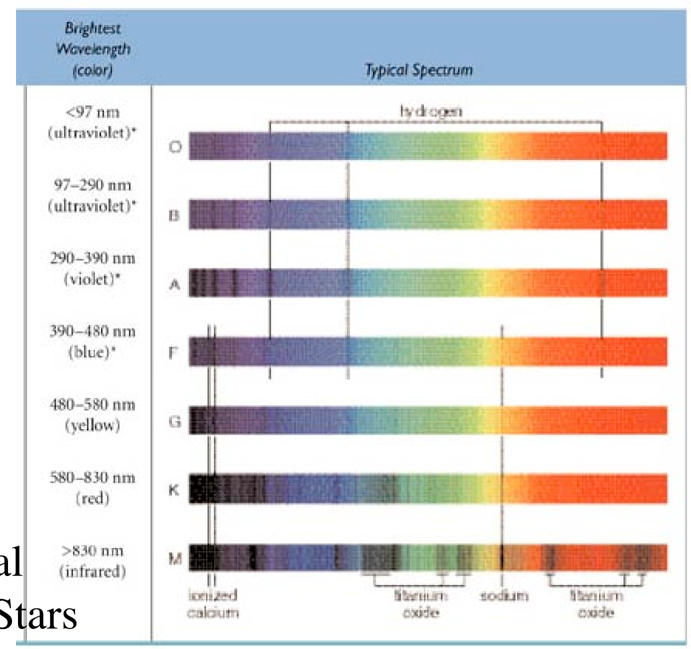
Spectral Type Classification System

O B A F G K M (L)

Oh Be A Fine Girl/Guy, Kiss Me!

50,000 K ← 3,000 K

Temperature



Spectral Types of Stars

Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features
O	Stars of Orion's Belt	>30,000 K	Lines of ionized helium, weak hydrogen lines
B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines
A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines
F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium
G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium
K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules
M	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong

Spectral Types of Stars

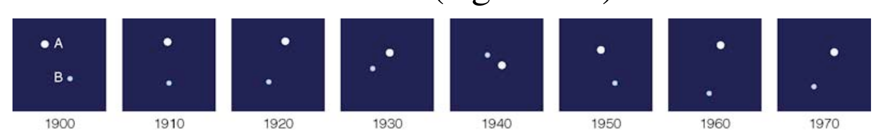
- Spectral types are defined by the:
  - existence of absorption lines belonging to various elements, ions, & molecules in a star's spectrum
  - the relative strengths of these line
- However, spectral type is ***not*** determined by a star's composition.
  - **all stars are made primarily of Hydrogen & Helium**
- Spectral type is determined by a star's surface temperature.
  - temperature dictates the energy states of electrons in atoms
  - temperature dictates the types of ions or molecules which exist
  - this, in turn, determines the number and relative strengths of absorption lines in the star's spectrum
  - this fact was discovered by Cecilia Payne-Gaposchkin in 1925

Masses of Stars

- **Mass** is the single most important property of any star.
  - at each stage of a star's life, mass determines…
    - what its luminosity will be
    - what its spectral type will be
- The mass of a star can only be measured directly by …
  - observing the effect which gravity from another object has on the star
- This is most easily done for two stars which orbit one another…a binary star!

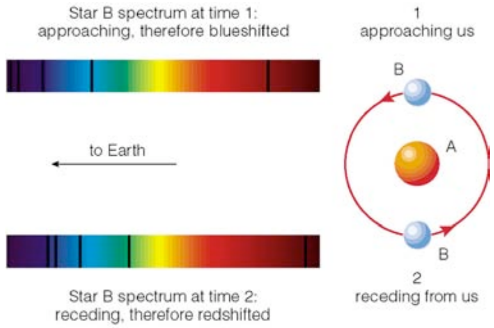
Binary Stars
(two stars which orbit one another)

- Optical doubles
  - two unrelated stars which are in the same area of the sky
- Visual binaries
  - a binary which is spatially resolved, i.e. two stars are seen (e.g. *Sirius*)



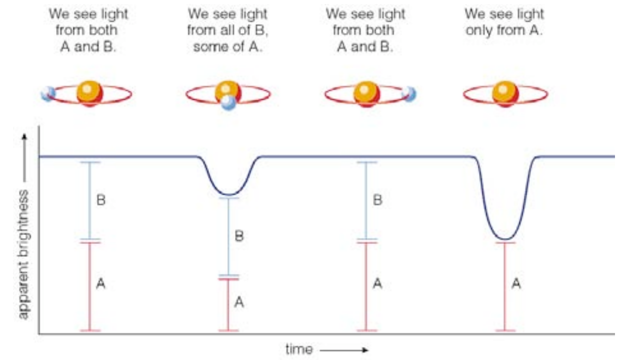
Binary Stars

- Spectroscopic binaries
  - a binary which is spatially unresolved, i.e only one star is seen; the existence of the second star is inferred from the Doppler shift of lines.



Binary Stars

- Eclipsing binaries
  - a binary whose orbital plane lies along our line of sight, thus causing "dips" in the light curve.



Binary Stars

- The stars orbit each other via gravity.
  - So the laws of Kepler & Newton apply!
- Newton's version of Kepler's Third Law:

$$P^2 = 4\pi^2 a^3 / G(m_1 + m_2)$$

- If you can measure the orbital period of the binary (P) and the distance between the stars (a), then you can calculate the sum of the masses of both stars ($m_1 + m_2$).

The Hertzsprung-Russell Diagram

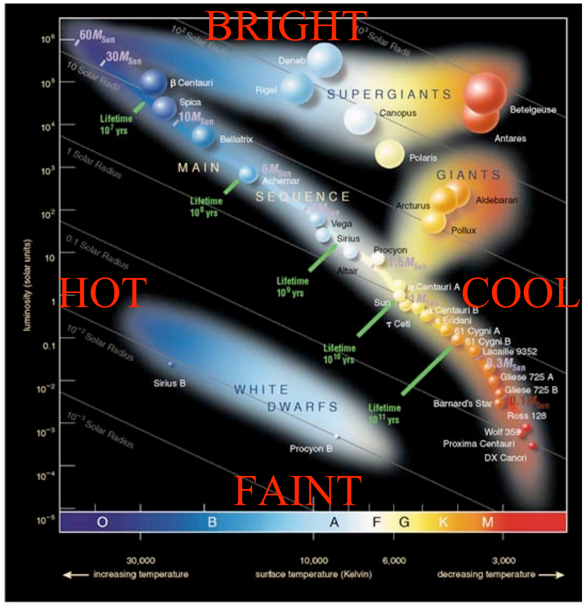
- A very useful diagram for understanding stars
- We plot two major properties of stars:
  - Temperature (x) vs. Luminosity (y)
  - Spectral Type (x) vs. Absolute Magnitude (y)
- Stars tend to group into certain areas

bright

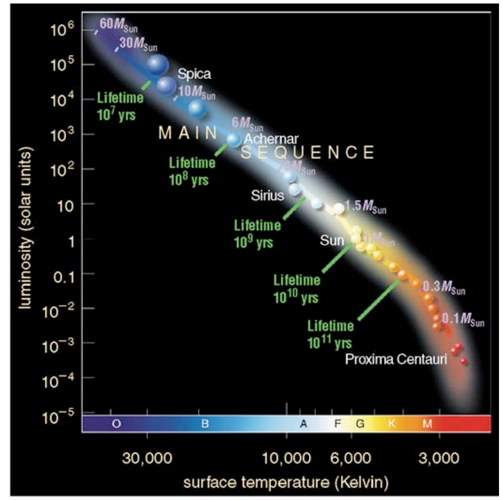
M_V

faint

hot Spectral type cool



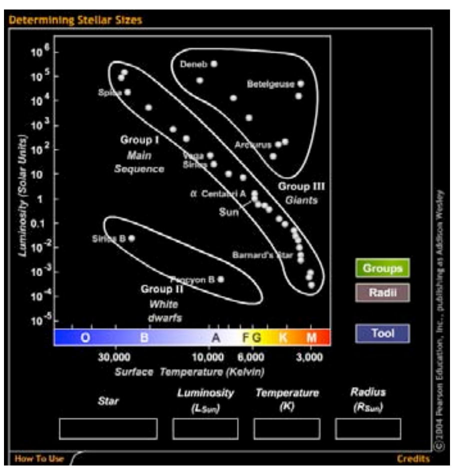
The Main Sequence (MS)



90% of all stars lie on the main sequence!

Stellar Luminosity

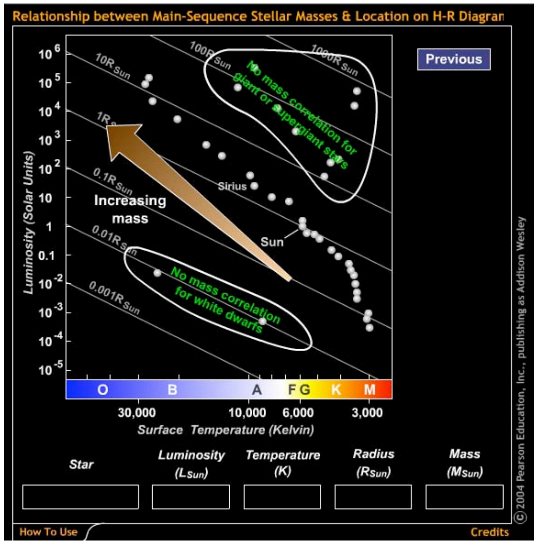
- How can two stars have the same temperature, but vastly different luminosities?
- The luminosity of a star depends on 2 things:
  - surface temperature
  - surface area (radius)
  - $L = \sigma T^4 4 \pi R^2$
- The stars have different sizes!!
- The largest stars are in the upper right corner of the H-R Diagram.



Stellar Luminosity Classes

Class	Description
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main sequence

Stellar Masses on the H-R Diagram



We use binary stars to measure directly the masses of stars of every type. This leads to the:

Mass-Luminosity Relation

$$L \propto m^{3.5}$$

for main sequence stars only

- As one moves to the upper-left of the main sequence:
  - stars become more massive
  - stars become even much more luminous
  - stars become fewer in number

Mass–Luminosity Relation: Why?

- All main sequence stars fuse H into He in their cores.
- Luminosity depends directly on mass because:
  - more mass means more weight from the star's outer layers
  - more gravitational force --> contraction!
  - nuclear fusion rates must be higher in order to maintain gravitational equilibrium

Lifetime on the Main Sequence

How long will it be before MS stars run out of fuel? *i.e. Hydrogen?*

How much fuel is there? M

How fast is it consumed? $L \propto M^{3.5}$

How long before it is used up?

$$M/L = M/M^{3.5} = M^{-2.5}$$

Lifetime on the Main Sequence

- O & B Dwarfs burn fuel like a bus!
- M Dwarfs burn fuel like a compact car!

- Our Sun will last 10 billion years on the Main Sequence
  - MS Lifetime τ = 10 billion yrs / $M^{2.5}$

Lifetime on the Main Sequence

So for example:

B2 dwarf (10 $M_\odot$) lasts 32 million yr

F0 dwarf (2 $M_\odot$) lasts 1.8 billion yr

M0 dwarf (.5 $M_\odot$) lasts 56 billion yr

But the Universe is 13.7 billion yr old!

Every M dwarf that was ever created is *still* on the main sequence!!

Star Clusters I: Open Clusters

- 100’s of stars
- million to billion years old
- irregular shapes
- gas or nebulosity is sometimes seen

Pleaides (80 million yrs)

Star Clusters II: Globular Clusters

- 100,000 stars
- 8 to 15 billion years old
- spherical shape
- NO gas or nebulosity

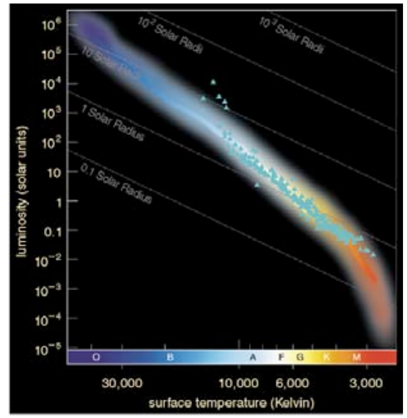
M 80 (12 billion yrs)

Clusters are useful for studying stellar evolution!

- all stars are the same distance
  - use apparent magnitudes
- all stars formed at about the same time
  - they are the same age

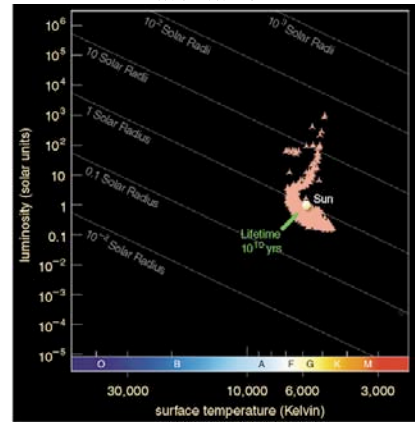
Plot an H-R Diagram!

Pleiades H-R Diagram

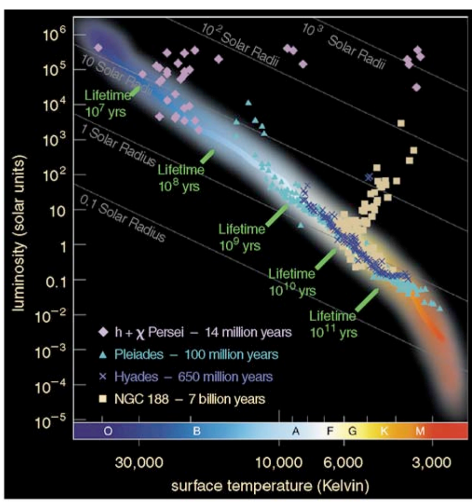


Globular Cluster H-R Diagram

Palomar 3



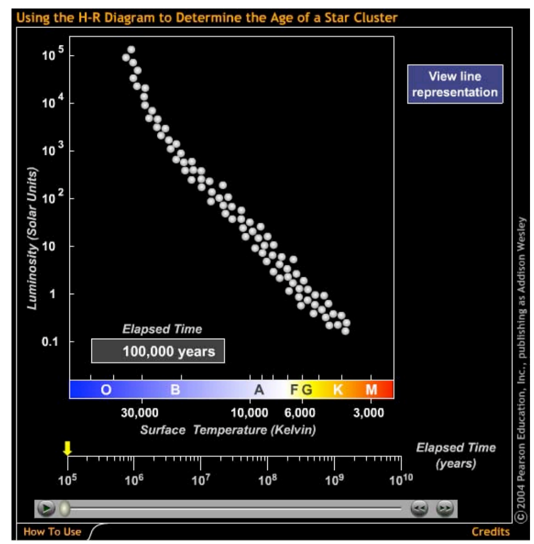
Cluster H-R Diagrams Indicate Age



- All stars arrived on the MS at about the same time.
- The cluster is as old as the most luminous (massive) star left on the MS.
- All MS stars to the left have already used up their H fuel and are gone.
- The position of the hottest, brightest star on a cluster's main sequence is called the

  main sequence turnoff point.

Older Clusters have Shorter Main Sequences



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