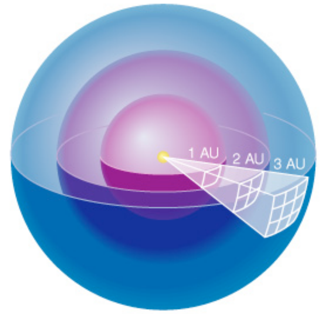
Agenda for Ast 309N, Sep. 25

- Feedback on Quiz 2 and 9/20 card activity
- The Hertzsprung-Russell (HR) Diagram
- Binary stars: stellar masses
- Card on binary stars – *homework, due 9/27*
- Coming up: low-mass stars, brown dwarfs
  - Read Wheeler, pages 10 - 16
  - Quiz 3, Thurs. Sep. 27 – spectra; stellar properties
  - Exam 1, Thurs. Oct. 4 – Study guide by 9/28

The Inverse-Square Law of Light



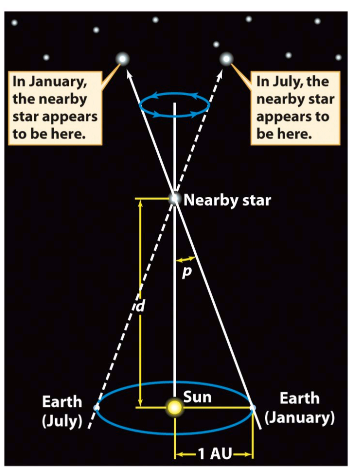
The apparent brightness of a star depends on its luminosity & distance:

$$b = \text{flux} = \frac{\text{Luminosity}}{4\pi\,(\text{distance})^2}$$

Why? Because light spreads out in all directions - in a spherical way - and the surface area of a sphere is $4\pi d^2$.

(Divide a fixed luminosity evenly over a larger surface area, and there will be less energy per unit surface area.)

Measuring Stellar Distances



Parallax of a nearby star

Figure 17-2a
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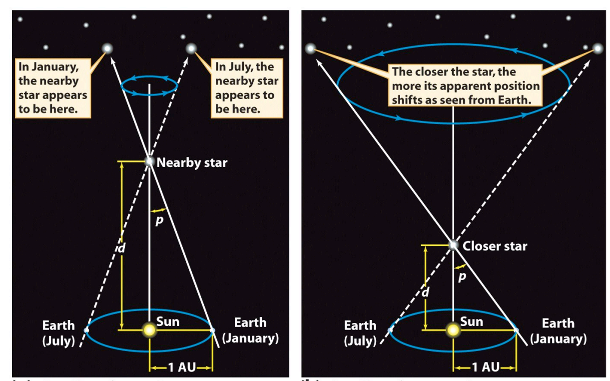
A star's parallax is measured by comparing images taken at different times, and measuring the shift of the nearby star relative to more distant stars.

- The nearest stars have tiny parallax shifts, smaller than one arcsecond.
- More distant stars have even smaller parallaxes.
- The angular shift is inversely proportional to the distance.

Measuring Stellar Distances



(a) Parallax of a nearby star (b) Parallax of an even closer star

Figure 17-2
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Astronomers use a unit called the parsec, which is the distance at which a star has a parallax of 1 arc second.

Stellar Luminosities

By measuring distances and apparent brightnesses, we have found that the most luminous stars are about

$10^6 \times L_\odot$ (solar L)

and the least luminous about

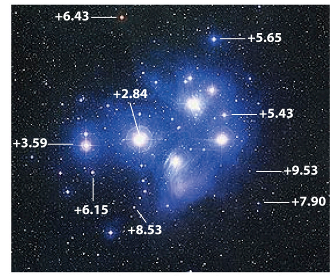
$10^{-4} \times L_\odot$

This is a factor of 10^{10}!

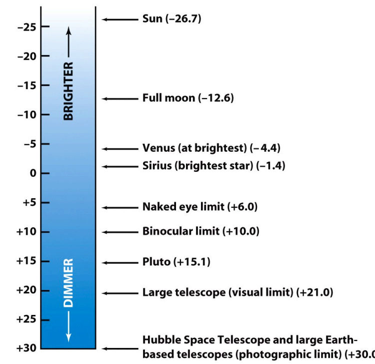
Stellar Apparent Brightness

We often use a special scale based on *ratios*, similar to using decibels for sound or the Richter scale for earthquakes.

For historical reasons, the scale runs backwards: the bigger the number, the ***fainter*** the star.!



Apparent magnitudes of stars in the Pleiades



Some apparent magnitudes

Apparent and Absolute Magnitudes

apparent magnitude

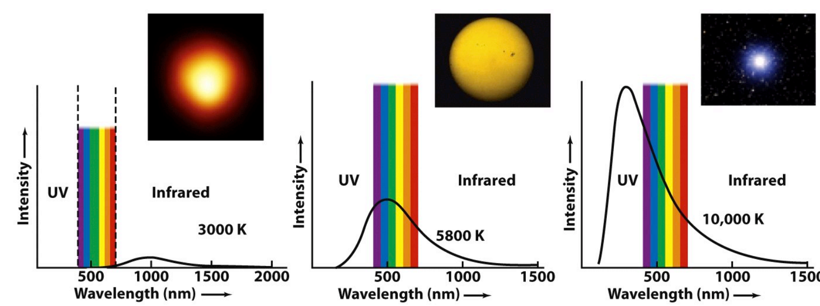
- brightness of a star as it *appears* from Earth
- one magnitude fainter = factor of 2.5 dimmer
- five magnitudes fainter = factor of 100

absolute magnitude

- an alternate scale for luminosity
- the apparent magnitude a star would have if it were 10 pc away (removes distance dependence)

Temperatures from Spectral Shape or Color

Stars of different temperatures have different relative amounts of light at different colors: more blue than red, or vice versa.



(a) A cool star with surface temperature 3000 K emits much more red light than blue light, and so appears red.

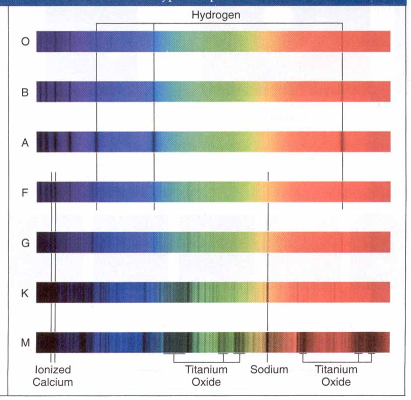
(b) A warmer star with surface temperature 5800 K (like the Sun) emits roughly equal amounts of all visible wavelengths, and so appears yellow-white.

(c) A hot star with surface temperature 10,000 K emits much more blue light than red light, and so appears blue.

Temperatures from Spectral Types

Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features	Brightest Wavelength (color)
O	Stars of Orion's Belt	>30,000 K	Lines of ionized helium, weak hydrogen lines	<97 nm (ultraviolet)*
B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	97–290 nm (ultraviolet)*
A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines	290–390 nm (violet)*
F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*
G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480–580 nm (yellow)
K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules	580–830 nm (red)
M	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong	>830 nm (infrared)

Typical Spectrum



How Spectral Types Work

- Spectral types are ***defined*** by which absorption lines of various elements, ions, and molecules, are seen in a star's spectrum and the relative strengths of these lines.
- Spectral type *is not* (usually) determined by composition.
- Instead, the vast majority of stars have ***the same*** surface composition: roughly ¾ H, ¼ He, 2% other elements.
- Molecules can survive only at low temperatures; as T rises, they break up into separate atoms. As T rises further, the atoms start to become ionized.
- Temperature determines *which ions* or molecules of each element are abundant, and *which energy levels* contain most of the electrons, which in turn determines the number and relative strengths of the absorption lines you see.

Spectral Types are a Temperature Sequence

Table 17-2 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 dwarfs Gliese 229B, HD 3651B

Table 17-2
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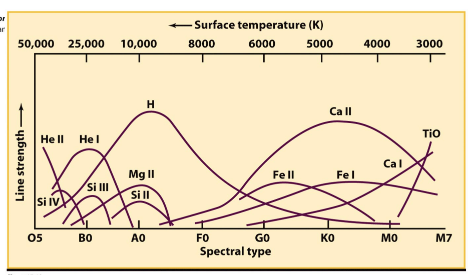

Figure 17-12
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The Sequence of Spectral Types

Three new spectral types!

Oh Be A Fine Girl/Guy, Kiss Me!

50,000 K ← 3,000 K

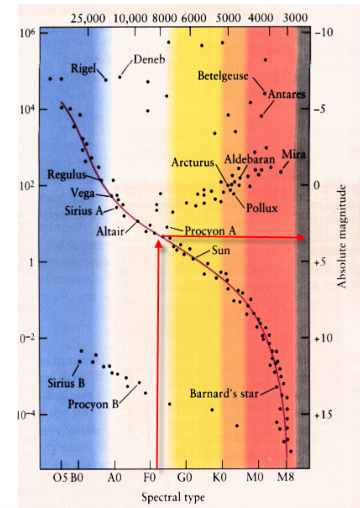
Temperature

The Hertzsprung-Russell Diagram

If you plot stars according to their temperature (on the x-axis) and luminosity (y-axis), patterns emerge.

Most stars (roughly 90%) fall along a diagonal line called the Main Sequence.

Note: By convention, temperature *increases from right to left.*



The Hertzsprung-Russell Diagram

A curious fact: Mira and Barnard's Star have the same spectral type, hence the same temperature, but they have wildly different luminosities.

How is this possible?

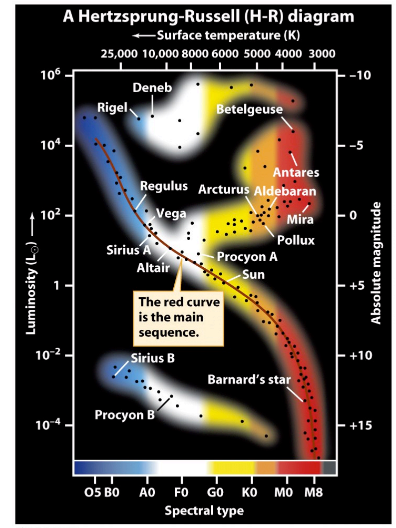


Figure 17-15a
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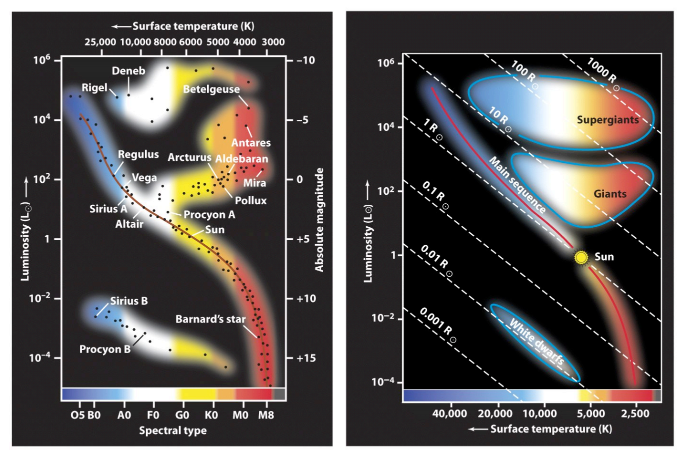
Radius from Luminosity & Temperature

- The luminosity of a star is:

  Surface Area × Energy emitted per unit S.A. =

  $(4\pi R^2) \times (\sigma T^4)$ = Luminosity
- If you know L and T, you can directly calculate R.
- This is, *in practice*, the way most stellar radii are estimated (indirectly, from L and T).
- A luminous star of low T must be *large;* a high-T star can only have a low luminosity if it is *very small.*
- We infer that Mira is a "red giant." Its enormous surface area makes up for its low temperature.

Radius in the Hertzsprung-Russell Diagram



(a) A Hertzsprung-Russell (H-R) diagram **(b)** The sizes of stars on an H-R diagram

Figure 17-15
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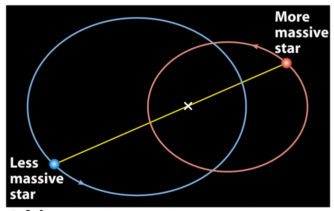
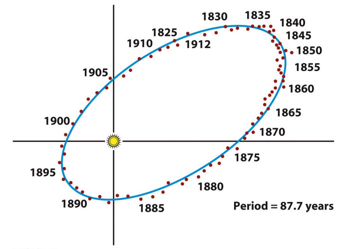
Masses of Stars

- We will find that the initial mass of a star is its most important property, determining how long it will liv, and by what method it will die.
- The mass of a star can be measured directly ***only*** by observing its gravitational effect on another object
- This is done by observing stars that orbit each other and thus belong to ***a binary star system.***

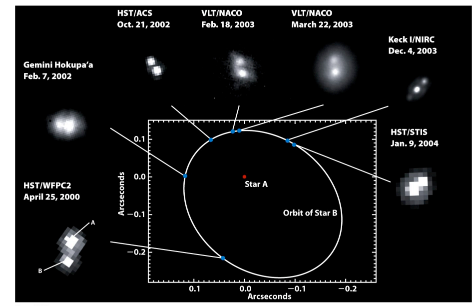


A binary star system

Visual or Astrometric Binaries

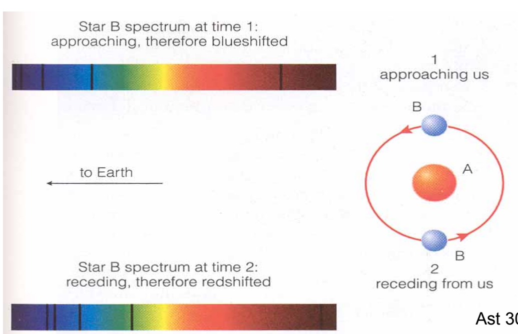


For a visual binary, you follow the positional changes of one or both stars over the orbit. Note: This can take a long time!

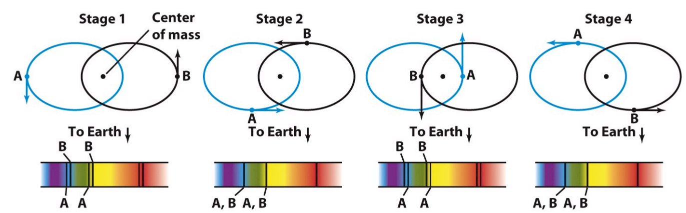


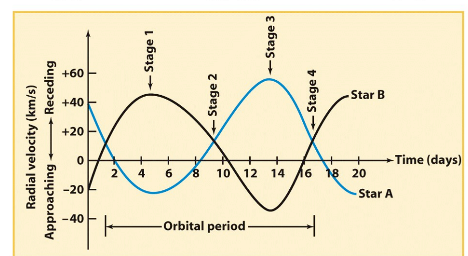
Spectroscopic Binaries

- Some binaries are not resolved as two images on the sky, but you see evidence of the orbit in their spectra
- "double-lined binary" - see two sets of spectral lines
- "single-lined binary" – see only one star's lines, infer the presence of the other star from the periodic Doppler shift



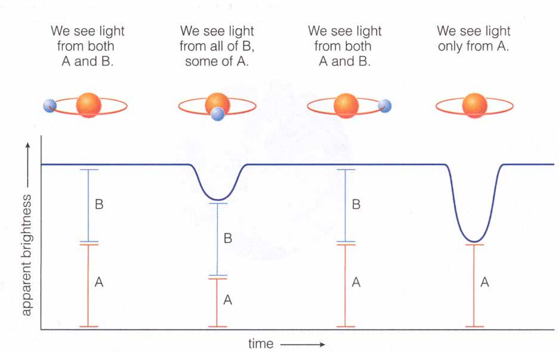
By taking a series of spectra, you can trace out a "radial velocity curve." A similar method is used to find exoplanets.





Eclipsing Binaries

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



Card Activity: Homework, due Sep. 27

Today we talked about three types of binary stars:
1. visual – where you see the stars move back and forth
2. eclipsing – where the combined brightness shows "dips" when one star moves in front of the other, and
3. spectroscopic binaries – where the spectral lines shift back and forth in wavelength due to the Doppler effect

(a) What causes a particular binary star system to fall into one of these categories?
(b) Can a given binary star belong to more than one of these categories? Explain.

(**Hint**: Recall the activity of last Thursday, Sep. 20.)