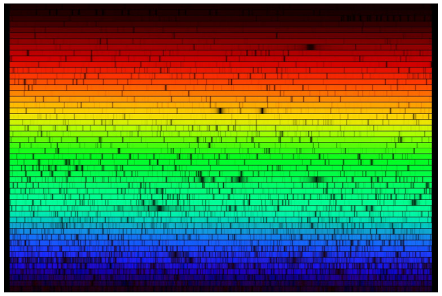
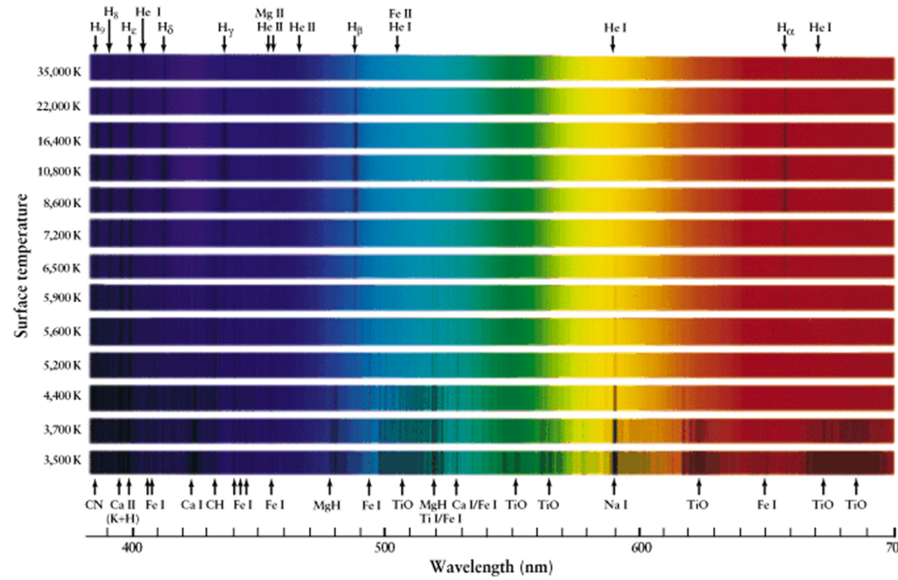
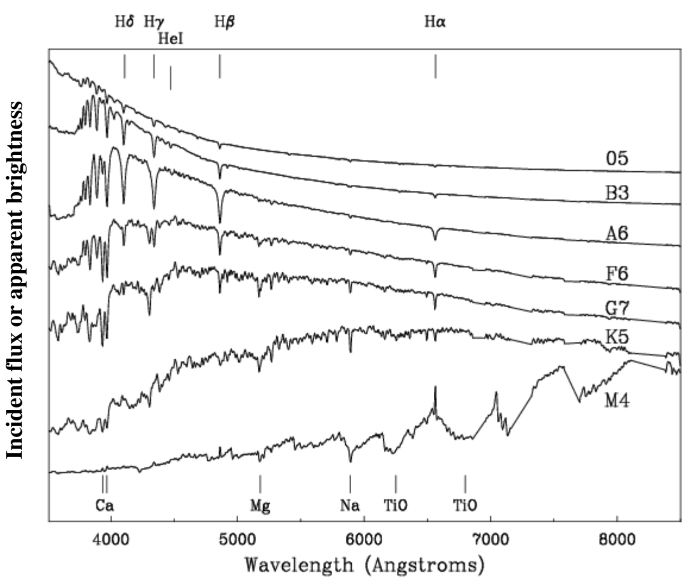
Stars - spectral types

- 1901: Led by Annie Jump Cannon, Harvard astronomers looked at the spectra of >200,000 stars. Classified them as A, B, C etc. Cannon rearranged them into OBAFGKM based on how lines of H, He, "metals" (Ca, Mg, etc), and complex bands would come and go. Knew colors changed too.

- In 1910's it became clear that spectral lines related to photosphere temperature because of known connection with colors (blackbody radiation was understood), and some lab spectroscopy. In 1920's, using quantum mechanics, Cecilia Payne explained how temperature governed spectral lines, and this explained OBAFGKM. Subdivisions: 0 (hotter) - 9 (cooler). Sun is G2.







Just to prove that the hot stars really do show lines of Helium:

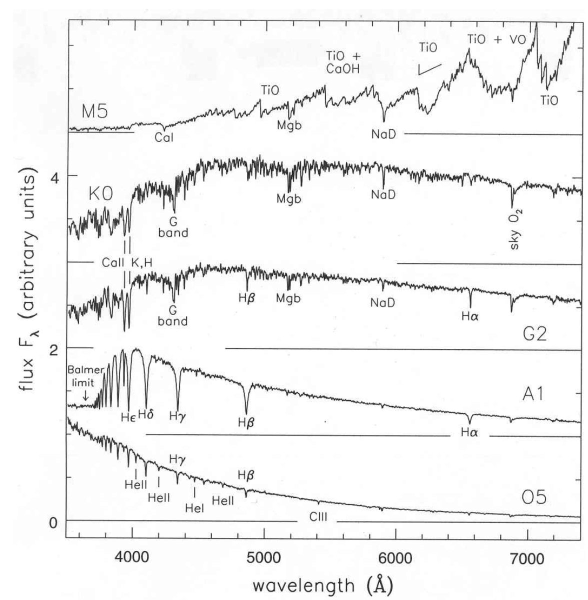


Figure 1.1 Optical spectra of main-sequence stars with roughly the solar chemical composition. From the top in order of increasing surface temperature, the stars have spectral classes M5, K0, G2, A1, and O5 – G. Jacoby *et al.*, spectral library.

Mnemonics

Oh Be A Fine Girl/Guy Kiss Me

Oh Bother, Another F's Gonna Kill Me

Oh Bother, Astronomers Frequently Give Killer Midterms

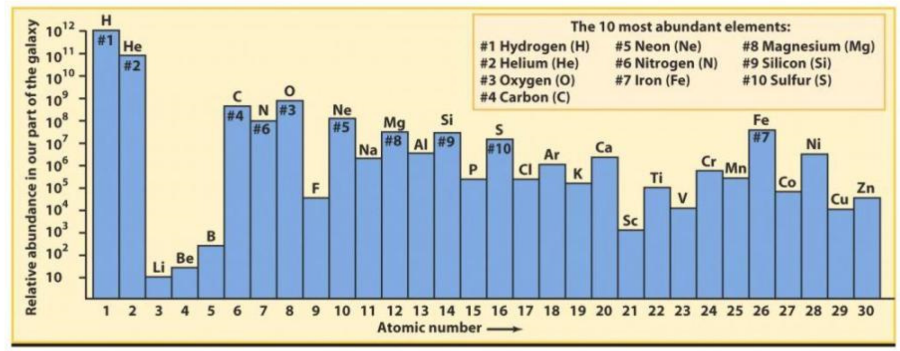
One Bug Ate Five Green Killer Moths

Oven-Baked Ants, Fry Gently, Keep Moist

Only Boring Astronomers Find Gratification Knowing Mnemonics

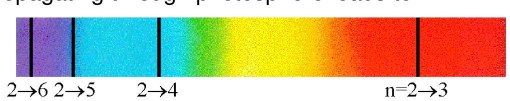
- Differences in strengths of the lines are NOT primarily due to a difference in abundance of elements.
- Almost all stars' atmospheres are about 74% H, 25% He and <1% heavier elements by mass. Small variations exist – these give clue to time of stellar birth.

Abundances (in "local" interstellar gas, but star atmospheres about same)

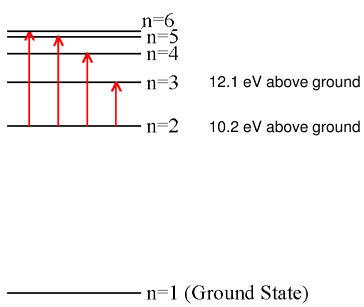


Why do spectra change with temperature?

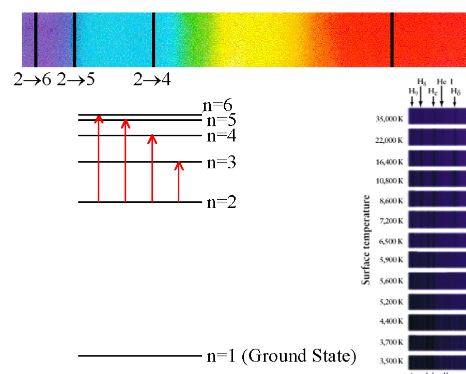
- Higher T => more energetic collisions and photons, excitation of higher levels (collisions actually more important in populating the various levels, even though radiation from deeper down propagating through photosphere leads to absorption lines).

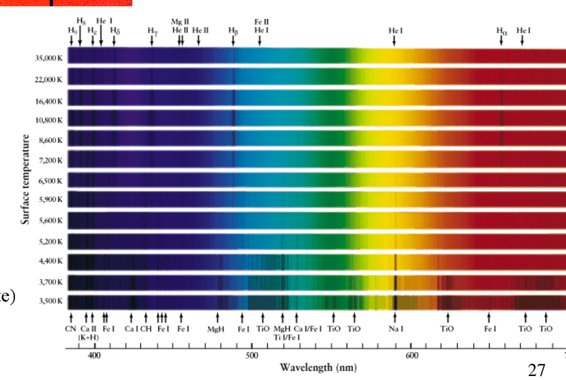


- Example hydrogen: if T= 5000 K, most electrons are in the n=1 orbital state => cannot absorb visible light (Balmer photons).
- Typical atom kinetic energy is ~3/2 kT ~ 0.6 eV. Excitations to n=2 require 10.2 eV and are rare.

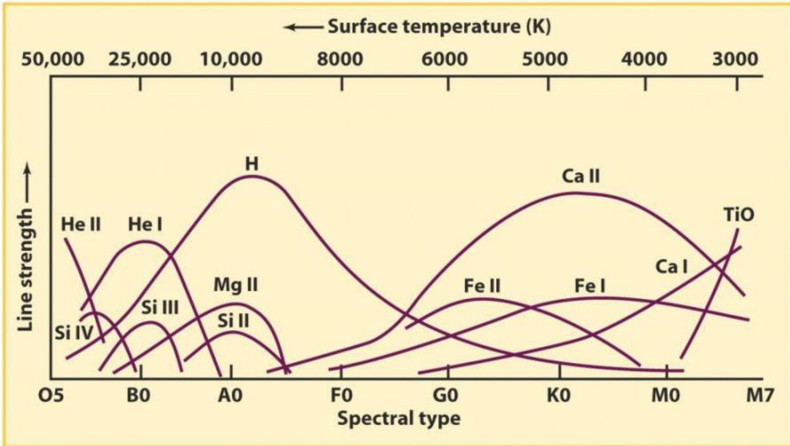


- If T~10^4 K, 3/2 kT ~ 1.3 eV. Still low, with almost all H in ground state, but enough collisions have energy to excite to n=2 state and give noticeable Balmer absorption lines.
- If T>>10^4 K, dramatic rise in UV photons that can ionize H due to Wien and Stefan-Boltzmann Laws. H starts to become significantly ionized by UV photons. Balmer lines weaken again.





- Balmer lines of H are most prominent at about 10,000 K, peaking around A0.
- He requires even higher energies to excite or ionize – only seen in hottest stars.
- Why are other elements' lines comparably strong, despite lower abundances? They have lower lying energy levels (1 – few eV) so easy to excite at lower temperatures. Also typically less energy to ionize than H.

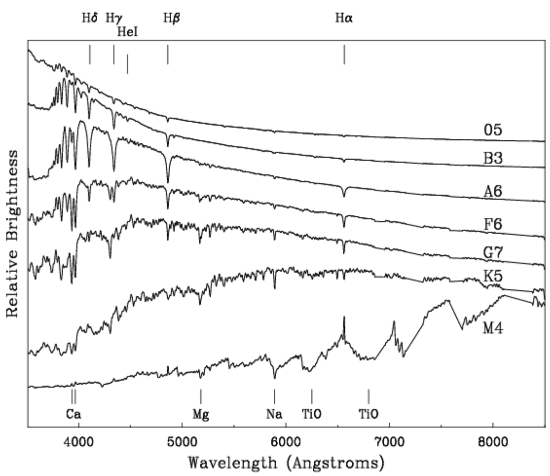


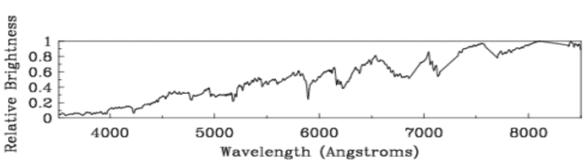
Spectral class	Color	Temperature (K)	Spectral lines	Examples
O	Blue-violet	30,000–50,000	Ionized atoms, especially helium	Naos (ζ Puppis), Mintaka (δ Orionis)
B	Blue-white	11,000–30,000	Neutral helium, some hydrogen	Spica (α Virginis), Rigel (β Orionis)
A	White	7500–11,000	Strong hydrogen, some ionized 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

table 19-2 The Spectral Sequence

There is much more detailed information about a star's temperature (and other properties) from its spectrum than from its color!

(So why measure colors with filters?)





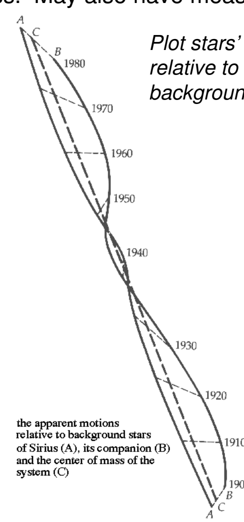
Binary stars and masses

1. Visual binaries - can see both stars. Binaries (any type) always orbit around the mutual center of mass. May also have measurable proper motion.

Plot stars' positions relative to background stars

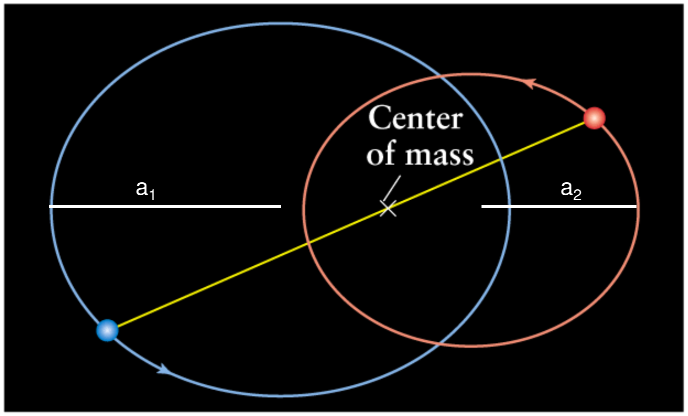
Assume orbit in plane of sky.
Only one straight line can be drawn (C) that divides a line connecting the stars into the same ratio at all times. This marks the unaccelerated center of mass at common focus of orbits.

More complicated if orbit not in plane of sky but center of mass can still be found.



the apparent motions relative to background stars of Sirius (A), its companion (B) and the center of mass of the system (C)

Assume distance known. In frame of center of mass:



b

$$a_1M_1=a_2M_2$$

where a = semimajor axis, M = mass

Recall semimajor axis = half of the long axis of ellipse

Visual binaries allow direct calculation of stellar masses. Use Newton's generalization of Kepler's third law:

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

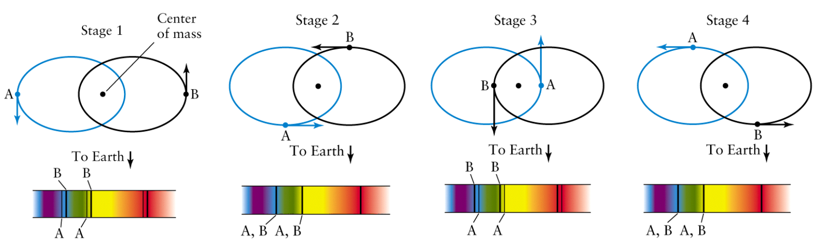
M_1, M_2 are masses of the two stars (in $M_\odot$).

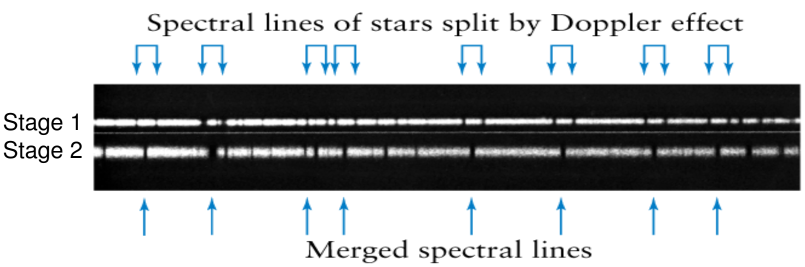
$a = a_1 + a_2$, which is also the mean separation over the orbit, in AU (note text says a is semimajor axis of one star's orbit around the other – not true). Can also do this if orbit not in plane of sky.

P = orbital period (in years)

So we have two equations in two unknowns => can solve for individual masses, as long as distance, inclination and tilt axis are known.

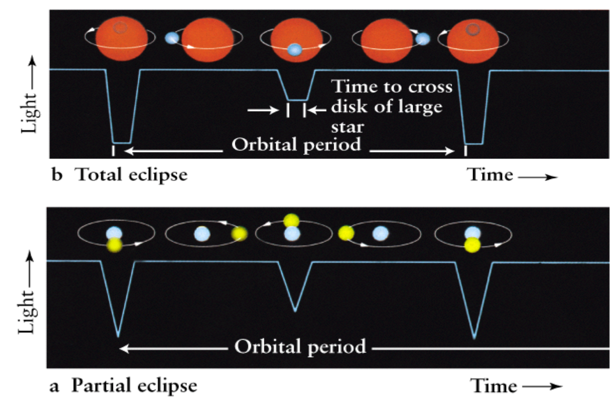
2. Spectroscopic binaries - even if you can't see both stars, might infer binary from spectrum. Below is a “double-lined” spectroscopic binary.





Spectroscopic binary applet (http://www.phys.unm.edu/~rjr/spectroscopicBinaries_scaleable.html)

3. Eclipsing binaries - stars periodically eclipse each other. If not resolved into 2 stars, can tell it's binary from "light curve" - plot of brightness vs. time.



4. Astrometric binaries - one star can be seen, the other can't. The unseen companion makes the visible star "wobble" on the sky.

Results for stellar masses

- Masses known for about ~200 stars in binaries, within a range of 0.08 - 60 $M_\odot$. Most massive star known may be up to 200 $M_\odot$?

Stellar radii

- Direct radius measurements hard because of large distances (the Sun at 1 pc distance would have an angular diameter of 9.3 milliarcseconds).

  So how do you do it?

- Recall for a blackbody:

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

  If L, T known, find R.