

Understanding How Stars Work...

- For astronomers to have confidence they understand stars, and remembering that the laws of Nature are quantitative (mathematical) laws, they need to have quantities – properties – of stars that they can put into the basic physics equations they believe may be relevant. So that's the goal of this chapter...

Chap 15: Stellar Properties: Which are important ones for Astronomers to try to measure?

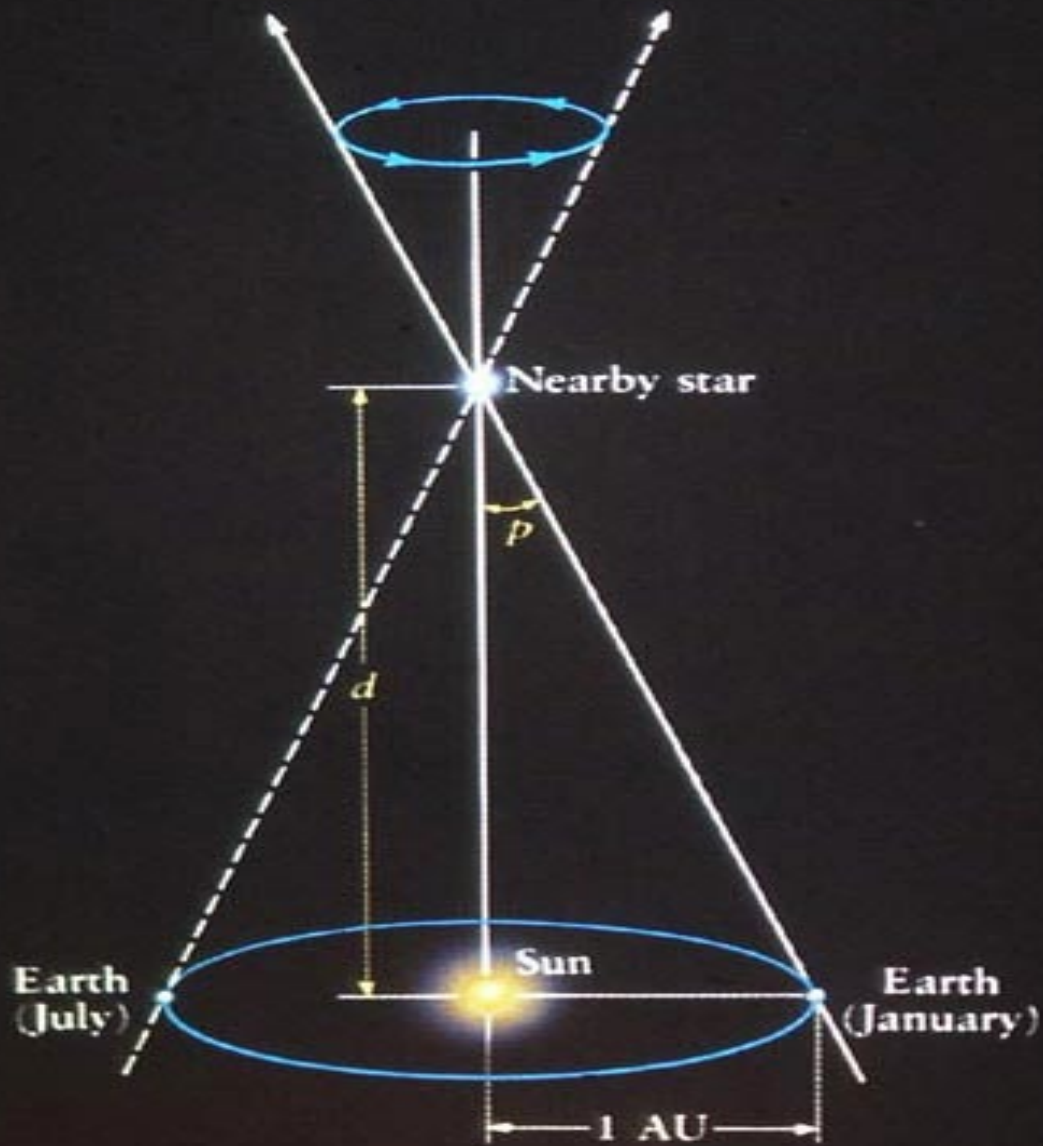
- Let's come up with a list of useful properties. Quantitatively measurable properties that we can compare with candidate theoretical predictions for helping us understanding how stars work
- Can you think of some.....?

More or less in order of importance...

- Mass
- Luminosity
- Size
- Surface temperature
- Chemical composition
- Distance, brightness

Want distance? Measure the parallax angle...

- The basic idea: Closer objects shift in direction through a bigger angle than do farther ones
- Simple geometry (see next slide) gives the formula...
- Distance (in pc) = $1/(\text{parallax angle (in arcsec)})$
- Must use the right units here: define a new distance unit, for convenience... a parsec
- 1 parsec = distance of a star with a parallax of 1 arc second
- Typical parallax shift for the nearest stars... less than one arc second! That's REALLY tiny and hard to measure
- Distances are the HARDEST thing we do in astronomy!



Knowing distance, apparent brightness can be converted to true energy output = Luminosity

- Apparent brightness of a star is quantified by a number called “magnitude”, similar to the old Greek idea: brightest stars were “First magnitude”, those a bit dimmer “second magnitude”, etc.
- 19th century astronomer N.R. Pogson proposed a formula which captures the essence of the Greek idea.
- A mag=2 star is 2.5 times brighter than a mag=3 star, and a mag 3 star is 2.5 times brighter than a mag=4 star, etc.

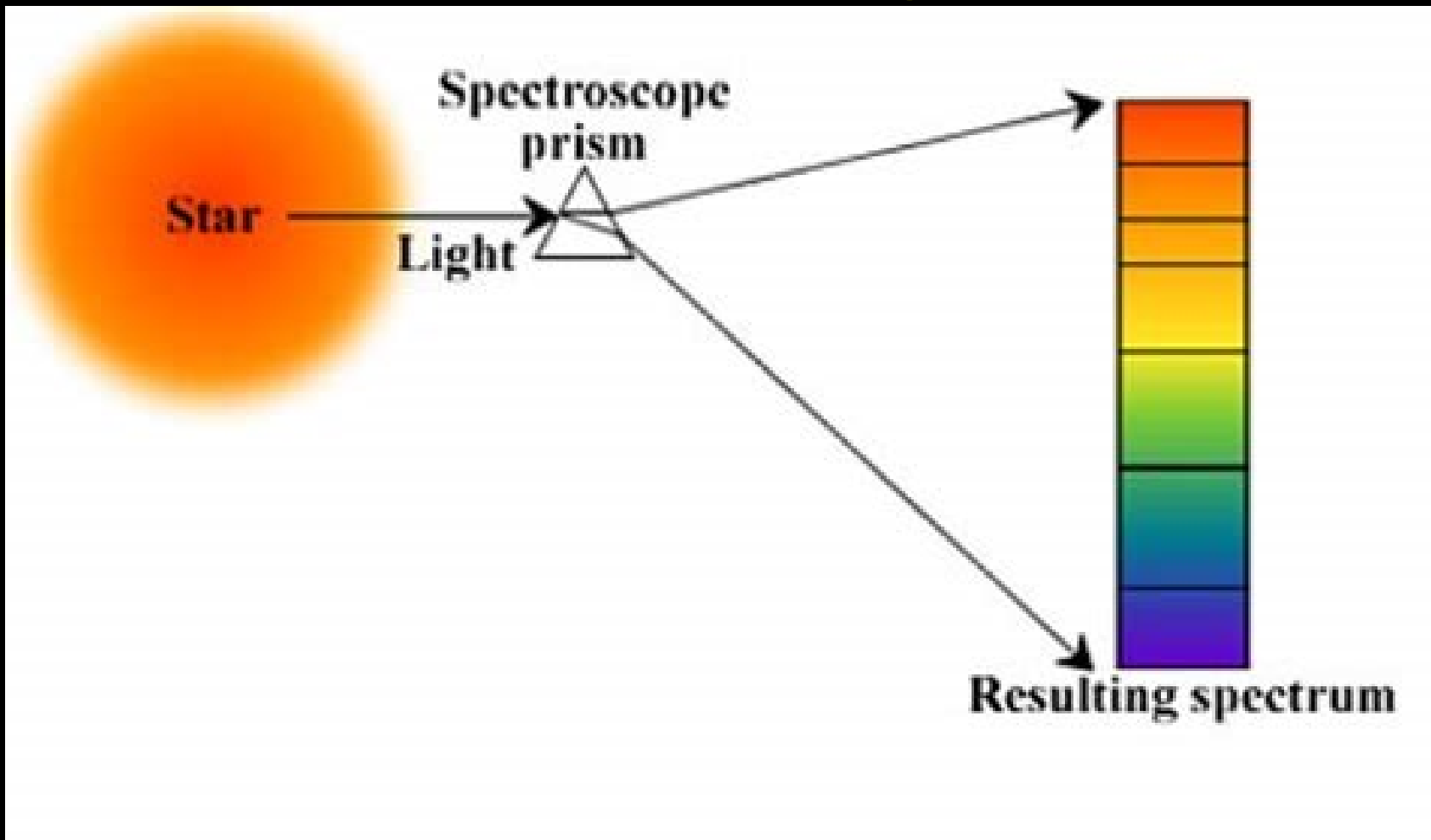
Imagine moving a star to a standard distance of 10 parsecs; its apparent magnitude is now called its absolute magnitude

- Since, in this case, the variable of distance has been removed, differences in absolute magnitude are differences in true luminosity.
- **Absolute magnitudes are a convenient, dimensionless way to quantify luminosities.**
- Read about apparent magnitudes here, and absolute magnitude here, as well as in the text. We don't have time in the course to get more mathematical than this

Spectral Types and Surface Temperature

- In the late 1800's, Annie Jump Cannon at Harvard found patterns in the growing collection of stellar spectra
- This is pre-quantum mechanics, pre-discovery of the atom, electron orbitals etc., so... we had NO idea what spectral lines meant.
- She found...

Recall – parallel light comes in from a light source, refracts differently according to its color (wavelength), and projected on to a detector. That's how we get a spectrum



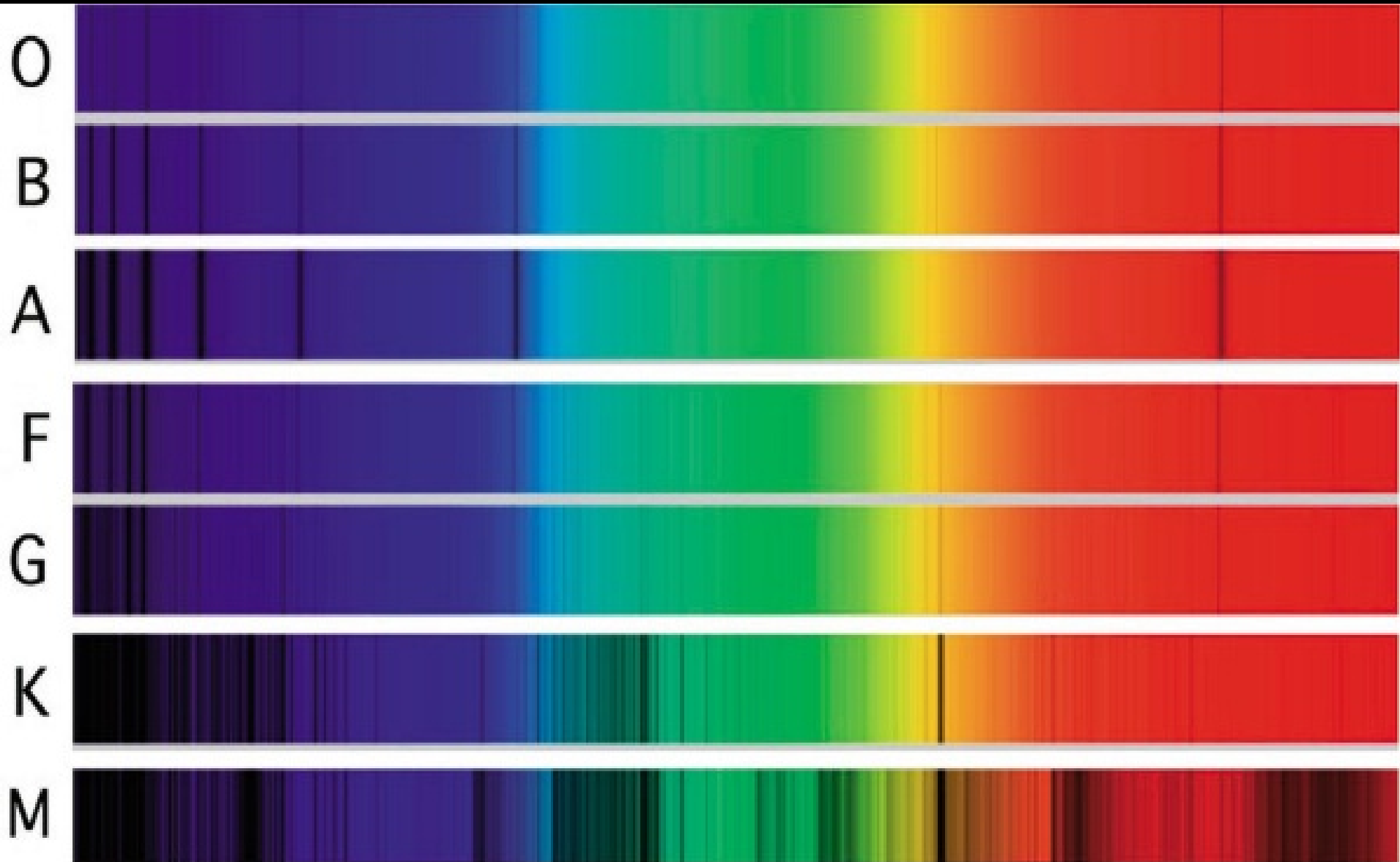
The Random Walk towards the Spectral Types...

- White Stars, with prominent hydrogen lines. Called them “A stars.”
- Blue-white stars, with less prominent H lines, and weak helium lines. Called them “B stars”
- Then, no more in this color direction, so skip some letters and... Cream colored stars, with weaker H lines and lots of very weak other lines. Called them “F stars”
- Yellow stars, with prominent double line in the yellow part of spectrum. Called them “G stars”.
- Orange stars, with very weak H lines and tons of other lines. Skip some more letters and call them “K stars”.
- Red stars, with no H lines, tons of lines, even big thick bands of light taken out by what we now know as TiO. Skip L and call them M stars
- Then, by now, found a few stars very blue and with very weak H lines and strong He lines, and nothing else. Call them O stars.

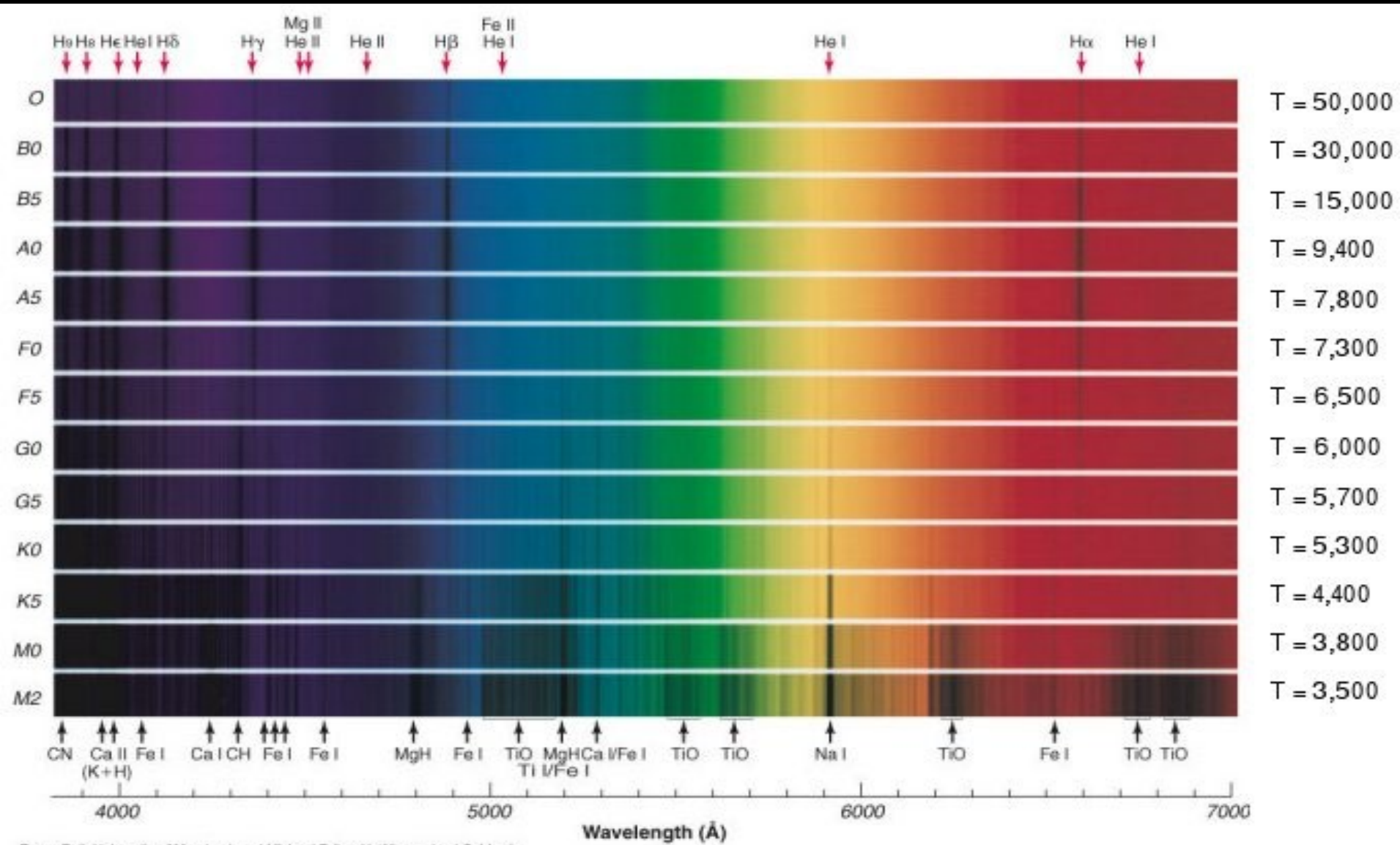
Voila'! The Spectral Sequence!

- OBAFGKM from hot to cool. Memorize it!
- Here's a mnemonic to help...
- “**O**h, **B**e **A** **F**ine **G**irl, **K**iss **M**e!”
- Don't blame me, it's been around for over a hundred years!
- You might think it has to do with chemical composition, since it's atoms which produce the lines. But we soon realized that it's a *surface temperature sequence*, and chem composition is about the same for all stars in the solar neighborhood).

On Average, cooler stars will have more absorption lines



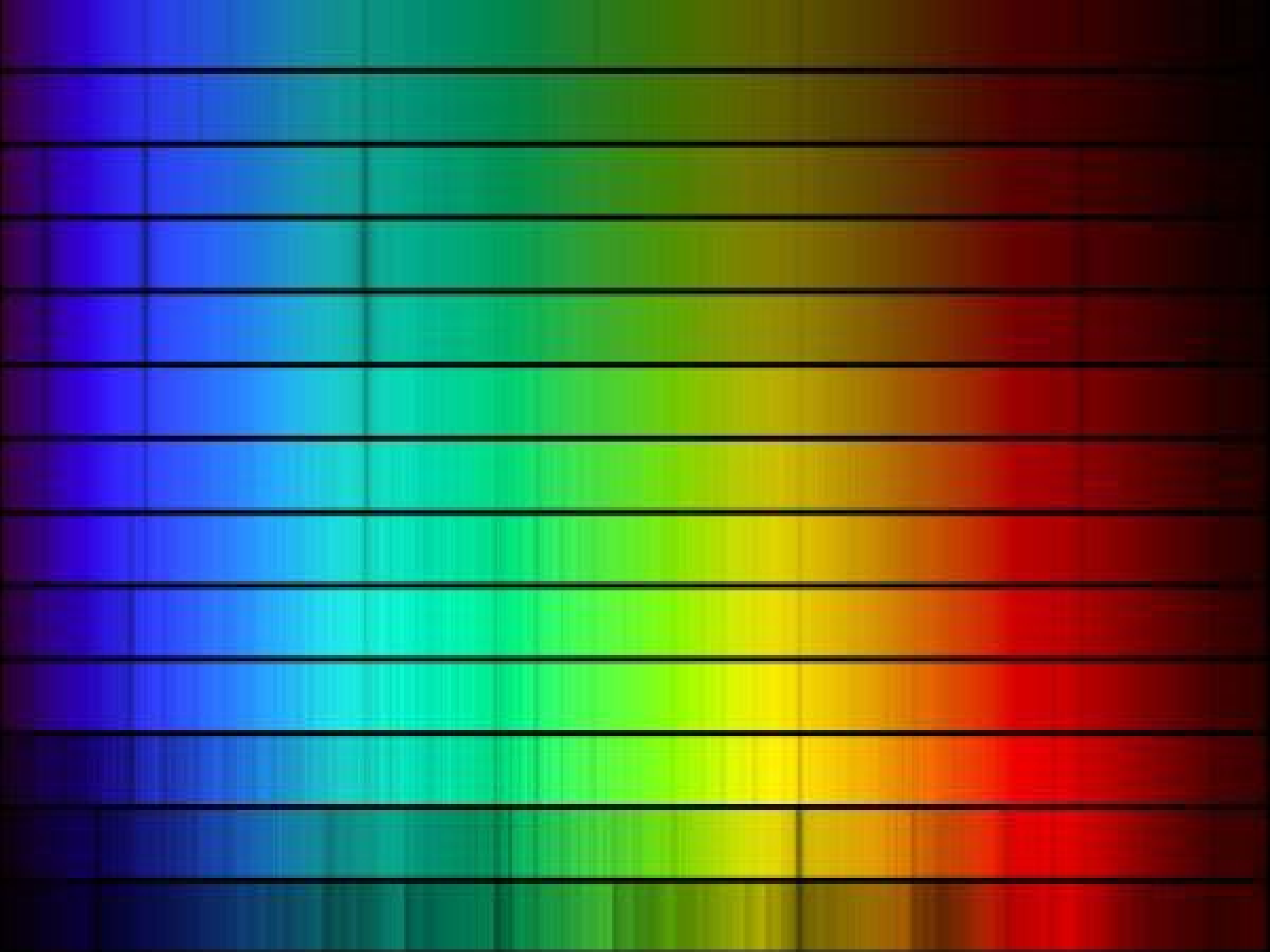
As Spectrographs got better, we subdivided these classes with a decimal number



Roger Bell, University of Maryland, and Michael Briery, U. Wisconsin at Oshkosh

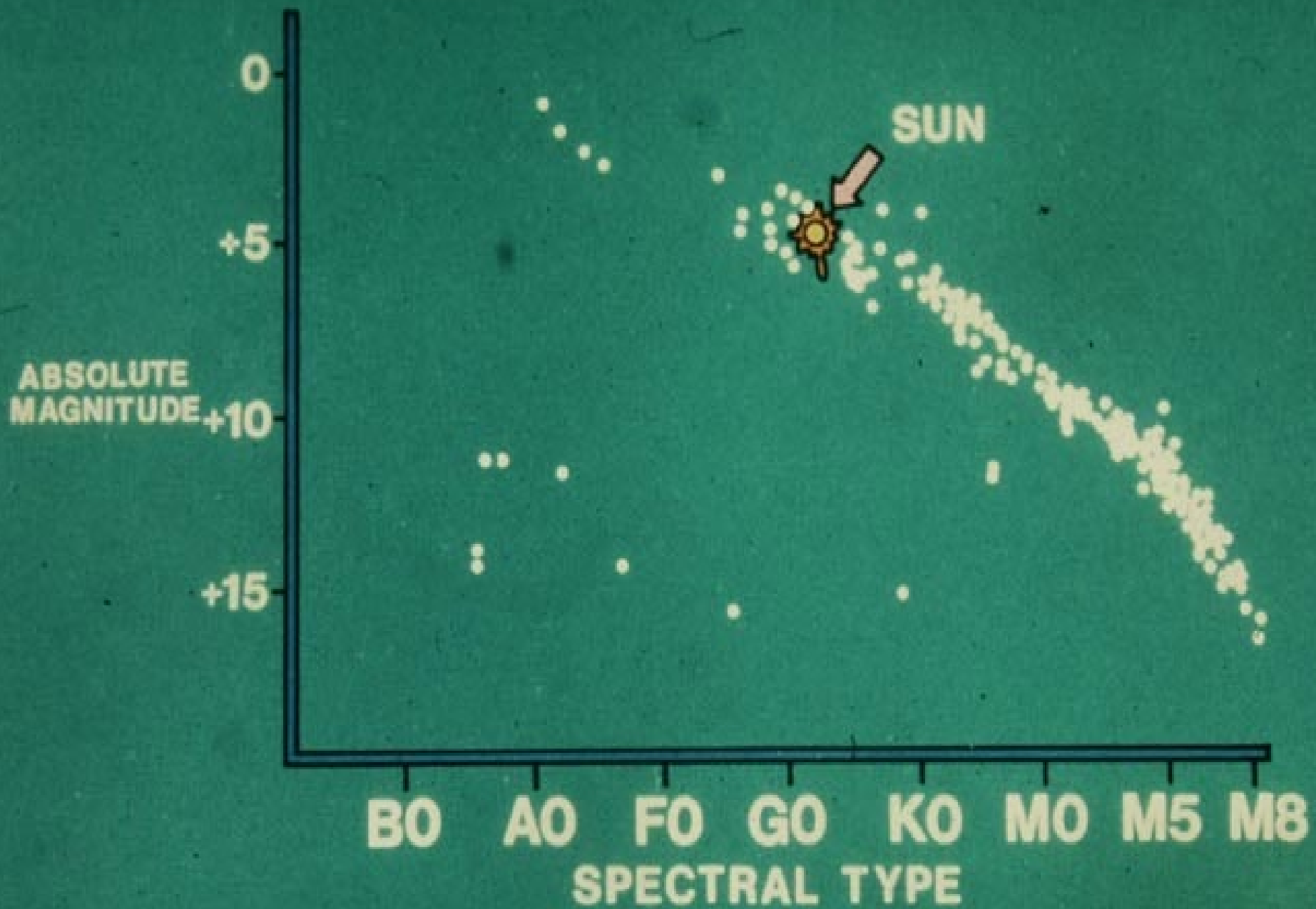
The Logic of Absorption Lines vs. Temperature

- Hot stellar atmospheres mean bluer color, and also more atoms are ionized and so show fewer lines.
- The cooler the star, the more atoms have their electrons and are available for absorption line transitions. Especially the complex atoms like iron and other metals, which have lots and lots of transitions in the visible part of the spectrum
- And recall that an electron being ionized out of the atom to some random (not quantized!) high energy, will not create an absorption LINE, its absorption loss of light will be spread out.
- **Therefore OBAFGKM hotter->cooler is also a sequence of “few lines -> many lines” in the spectrum**

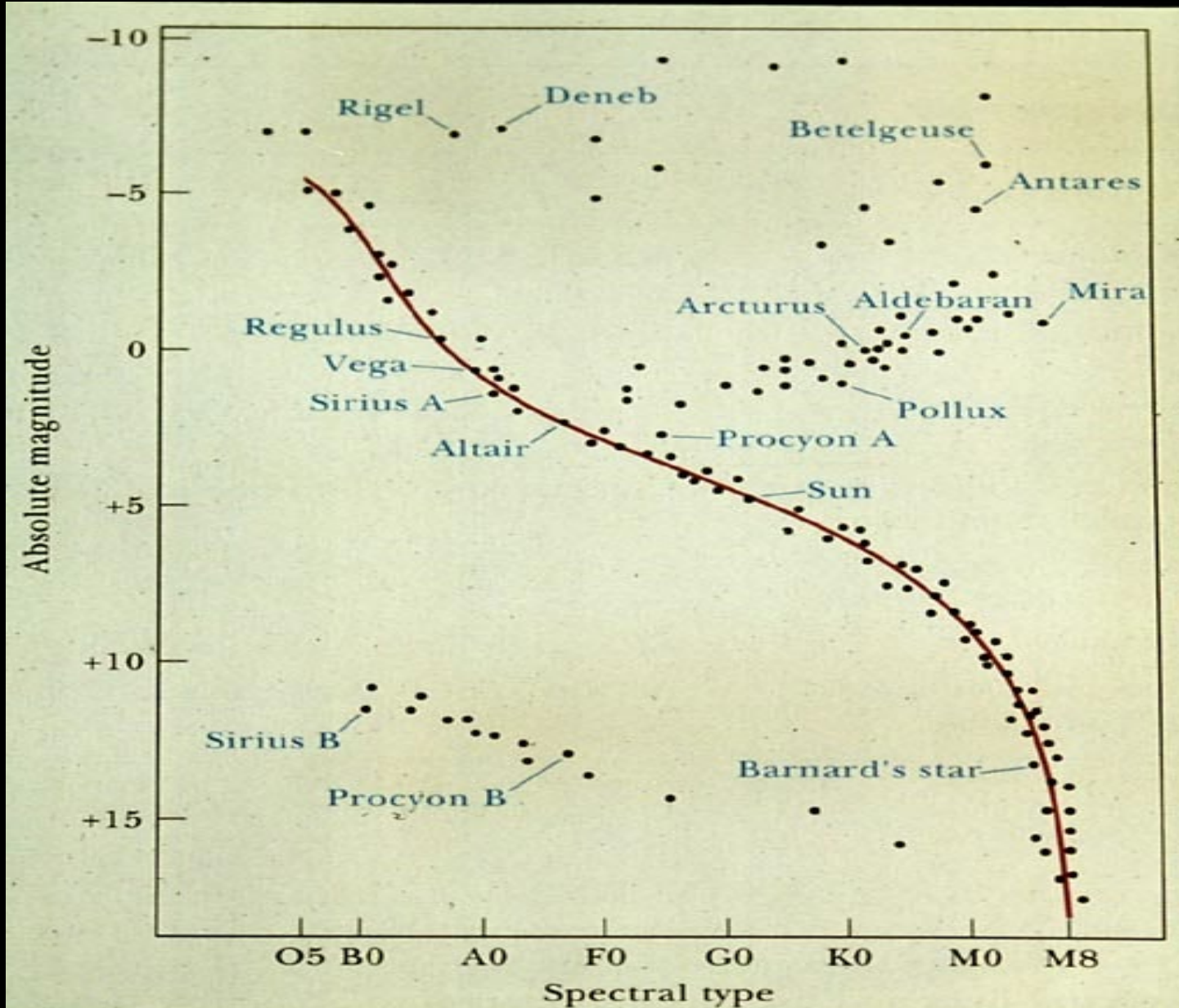


Now We've got Two Fundamental Properties of Stars...

- **2 Properties!** Scientists now get excited and the first thing they'll do is... make a Scatter Plot. Plot one against the other and see if any interesting pattern shows up
- This is the **Hertzsprung Russell Diagram** aka; the H-R Diagram - a fundamental tool of stellar astronomy
- Making the first one was HARD!
- Had to carefully measure photographs under a microscope of a bazillion stars, trying to find those tiny few which had detectable tiny parallax shifts, which gives distance, which then gives their luminosity (when combined with brightness).



Now Plot stars you can SEE above a given brightness. This brightness-limit gives very different sample. Now the rare brilliant blue and red giants appear since they can be seen from so far away, you're sampling a much bigger volume)

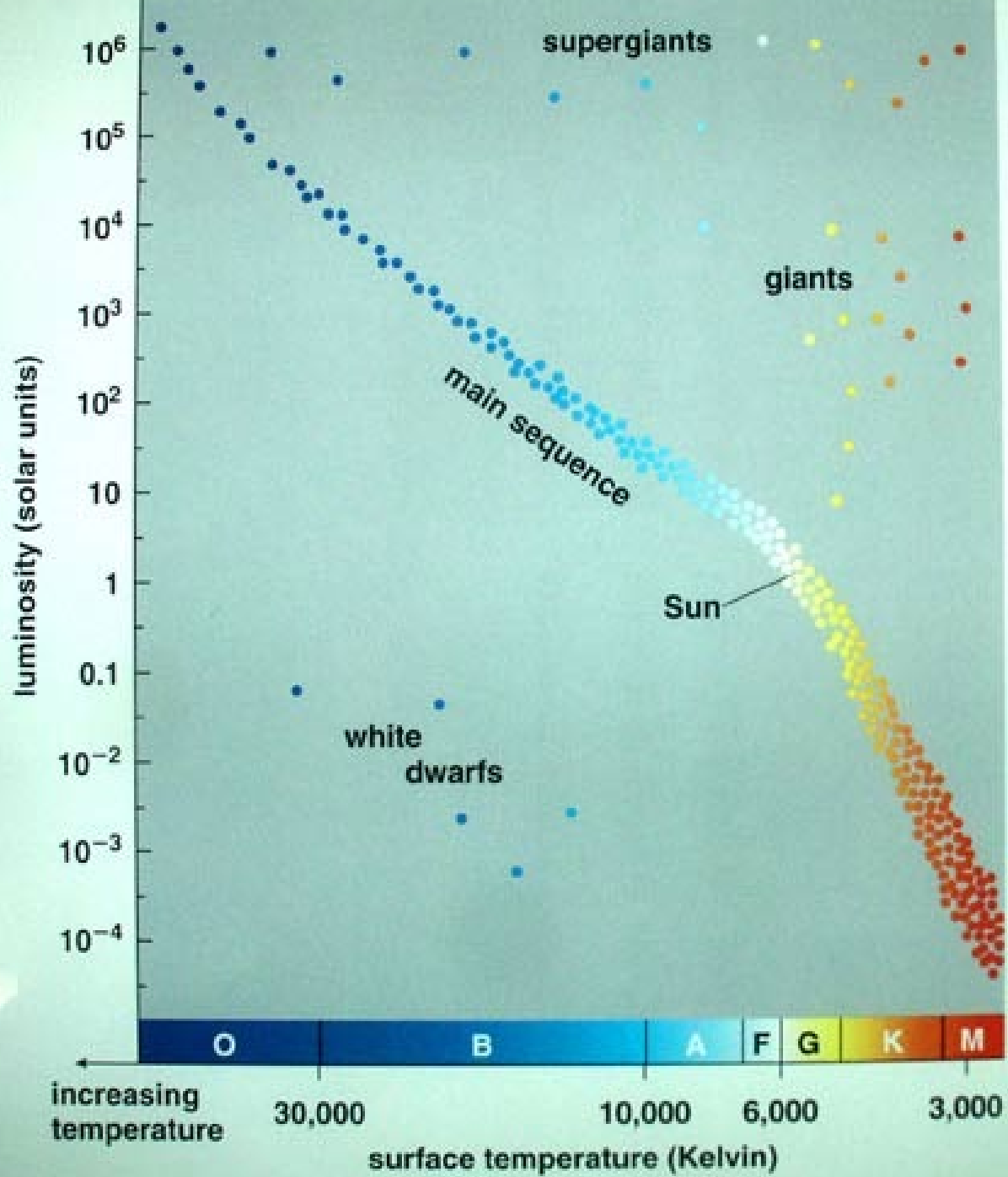


Stellar Demographics

- A given **volume** of space has a “**fair sample**” of what kind of stars are out there. These turn out to be mostly dim, reddish stars
- But look at the night sky – you see everything above some limiting brightness accessible to your eye or telescope. This is a **brightness-limited sample**, a very Unfair sample!
- It’s heavily skewed toward the most luminous stars, which you can see from much farther away and hence are sampling a much bigger volume of space

The HR diagram is Dominated by the Main Sequence

- It snakes through the diagram from upper left (hot luminous stars) to the lower right (cool low-luminosity stars).
- About 10% of the stars are not on the Main Sequence. Let's come up with some good names for them, through *Pure Reason!*
-



The H-R Diagram

90% of stars fall on the Main Sequence – why?

- Because **Main Sequence Stars = core hydrogen fusion stars**, and hydrogen is both the most high octane of nuclear fuels, and also the star starts out with the large majority of its mass as hydrogen.
- Therefore makes perfect sense that a star will spend almost all its life burning H into He, and so a random photo of the sky, with stars all of different ages, will mostly be H-burning (=Main Sequence) stars.
- **HR diagrams can be used to show stellar evolution.** We'll do this in the next chapter

How Do We Find the Masses of Stars?

- To guide our mind, we more usefully ask...
“what directly observable properties could we measure which depend sensitively and directly on mass?”
- When we have unambiguous observed masses, we can then see what our stellar computer models may need in order to reproduce stars correctly. Then we know we’ve made strides in actually understanding how stars work

Arguably The Most Useful Formulae in Astronomy...

- **Kepler's 3rd Law** and variations of it – because **mass** is so fundamental to understanding stars and galaxies and the universe, and...
- **Kepler III is how we find mass! We apply it to binary stars – a nice clean Nature's laboratory for finding stellar mass w/o complications.**
- Almost half the stars in the Galaxy are in binary systems, so there are plenty of opportunities

Kepler's 3rd Law for two stars of mass M_1 and M_2 Orbiting Each Other. So if you know the period P , and the semi-major axis a (the radius, essentially) of the orbit, you get their masses!

$$P^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

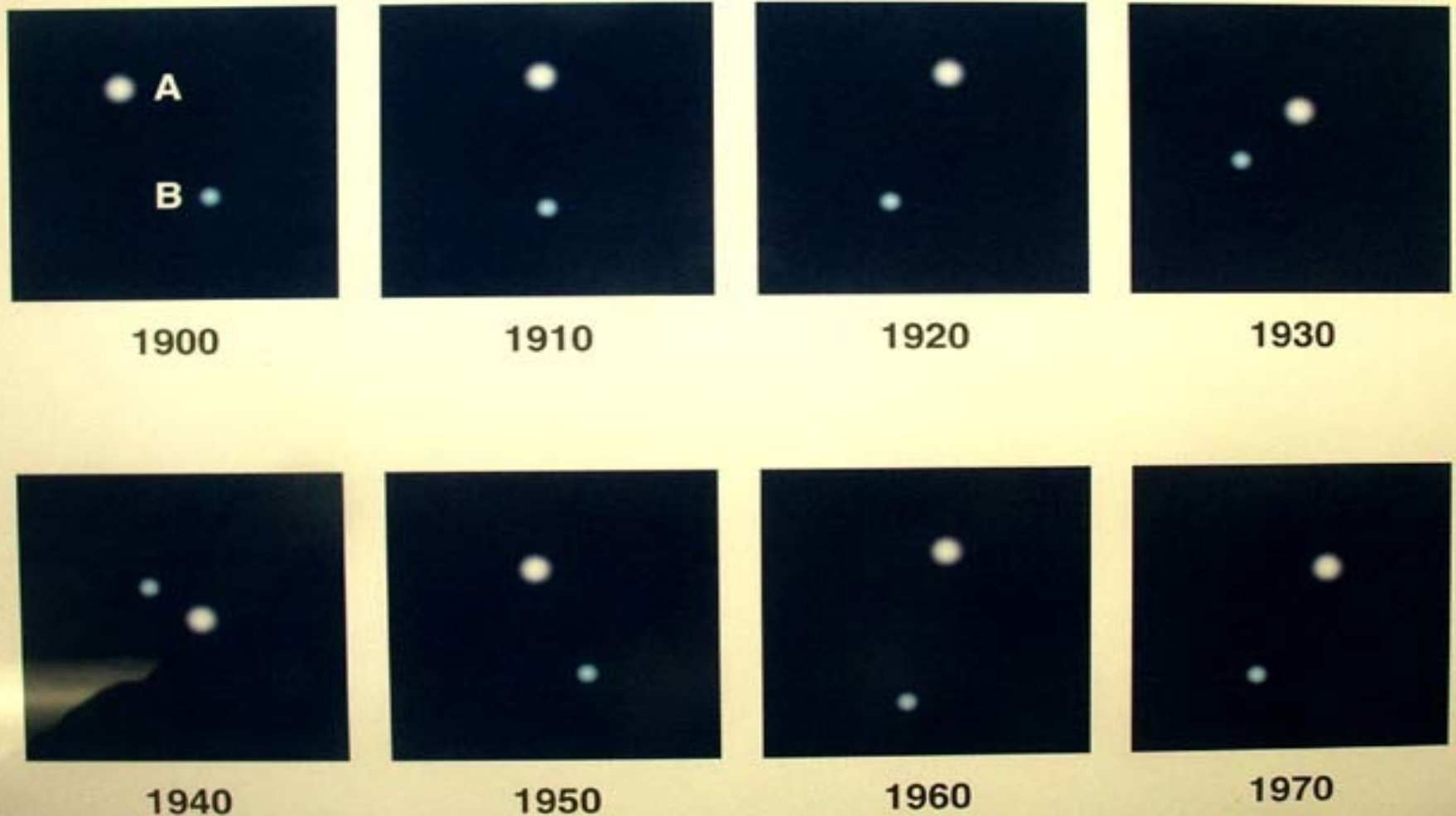
where M_1 and M_2 are the masses of the two orbiting objects in solar masses. Note that if the mass of one body, such as M_1 , is much larger than the other, then $M_1 + M_2$ is nearly equal to M_1 . In our solar system $M_1 = 1$ solar mass, and this equation becomes identical to the first.

Binary Star Types

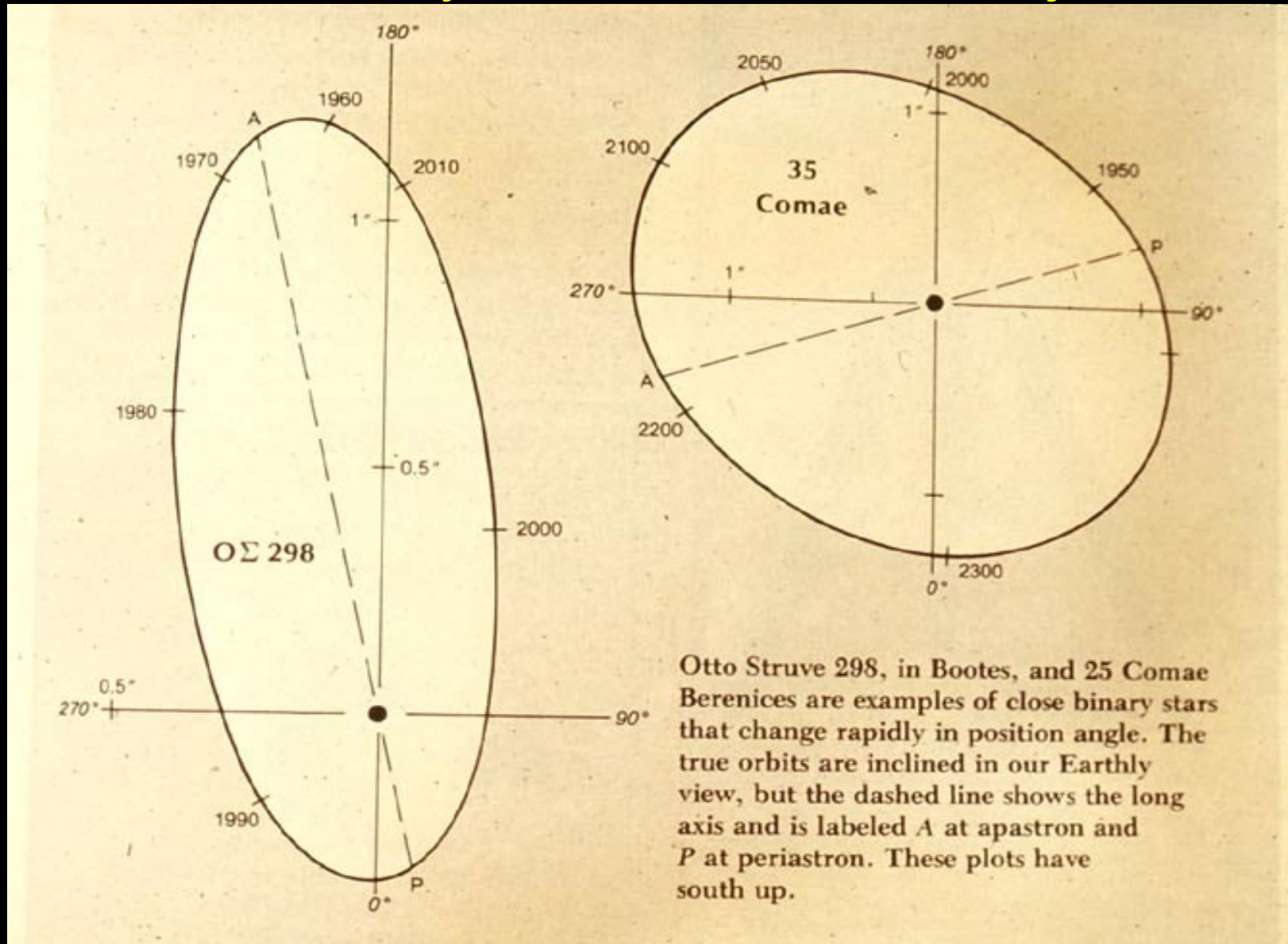
- **Visual Binaries:** You can actually see two separate stars on your images. These are relatively rare – need wide separations, like out to Pluto and beyond – to separate the stars on images
- **Spectroscopic binaries:** by far the most common, binary pairs are usually so close you can only see a blended image of both stars. It is the Doppler Shifts in the spectra of one or both stars which tell you it's actually 2, not 1 star.
- **Eclipsing Binaries:** One star passes in front of another, causing light loss in a characteristic pattern. These are the MOST USEFUL!

A famous visual binary: Sirius (The brightest star in the sky)

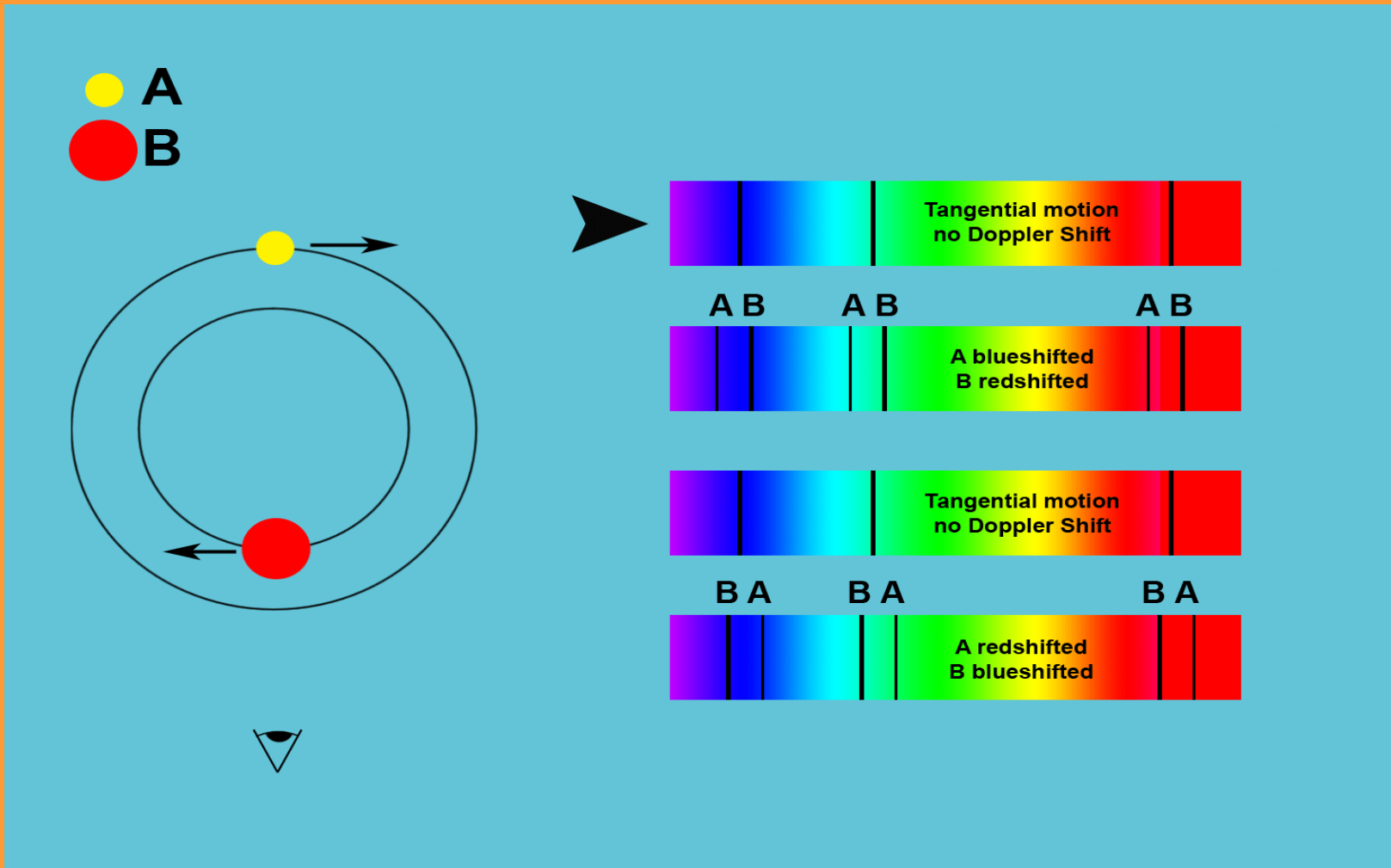
Figure 13.5 Sirius A and B orbit



Big disadvantage for Visual Binaries: If you can literally SEE two stars, they're very likely so far apart they make take a century or more to orbit even just once



Spectroscopic Binaries: The most common! But have a fatal flaw:



Measure the Doppler Shift...

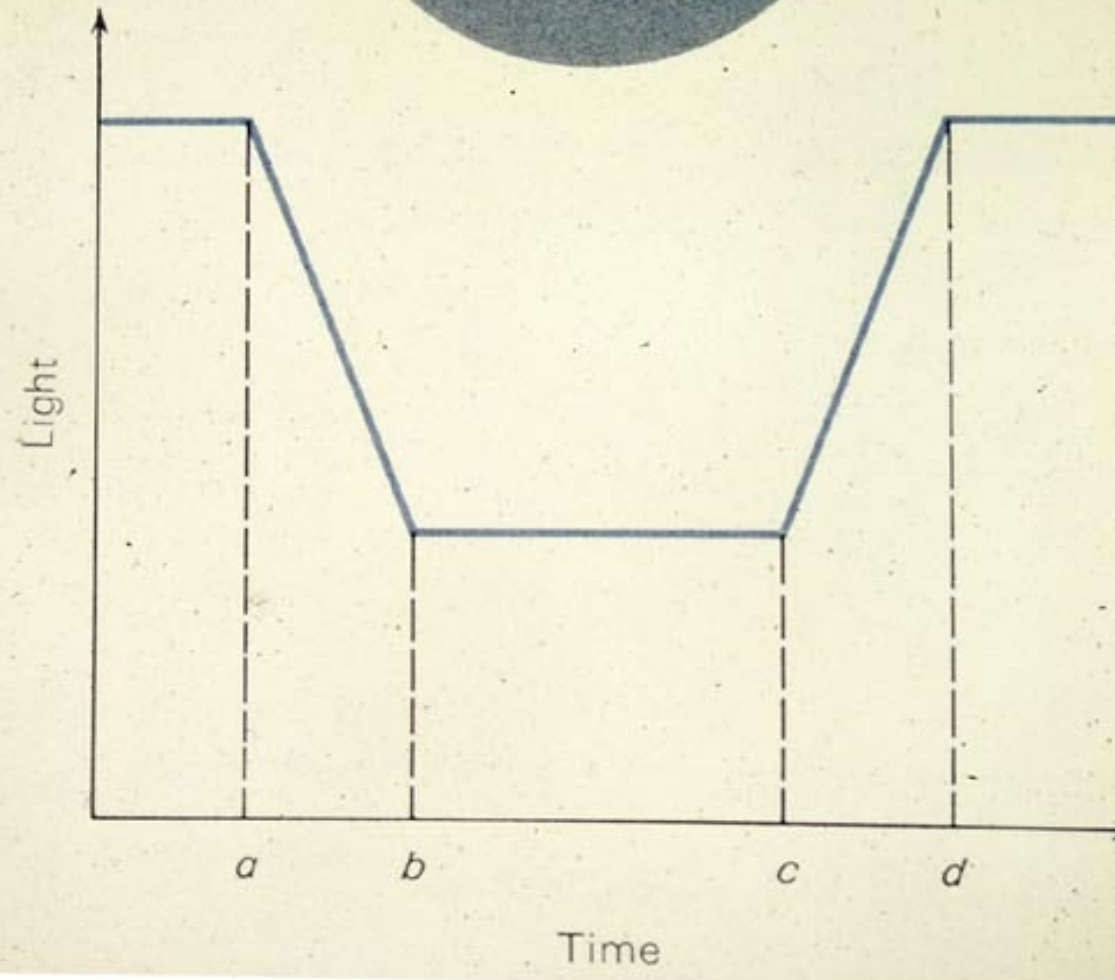
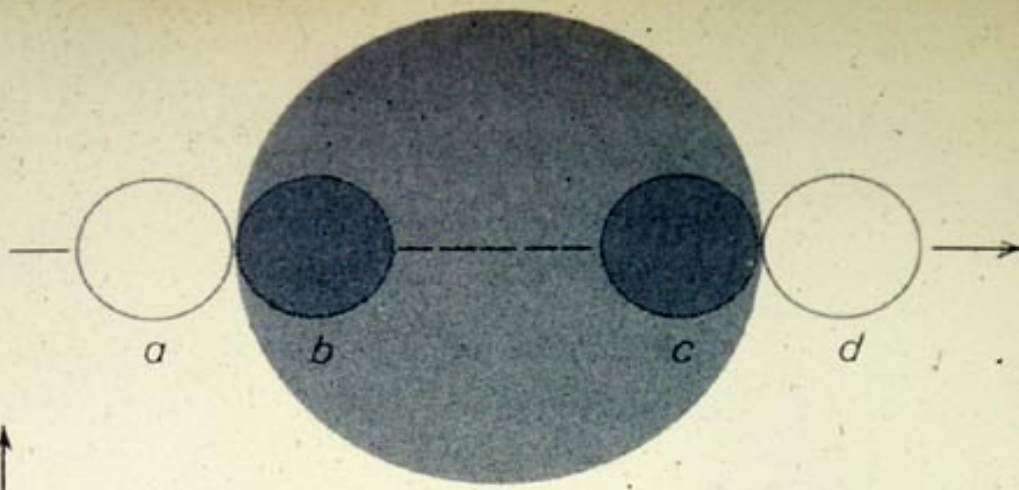
-that'll tell you the velocity of one star relative to the other.
- Multiply the velocity by the period P , that gives you the circumference of the orbit, and therefore the semi-major axis, a
- BUT, a fatal flaw in this reasoning.... Can you see what it is?

Here's the Fatal Flaw

- The Doppler Effect only tells you the velocity component along the line-of-sight, **but what you need to measure the semi-major axis is the true velocity in space; the space velocity**
- And to get the **space velocity** from the Doppler velocity, you need to know the tilt of the orbit
- Most of the time, you canNOT measure the tilt, and so all you can get is a lower limit to the masses

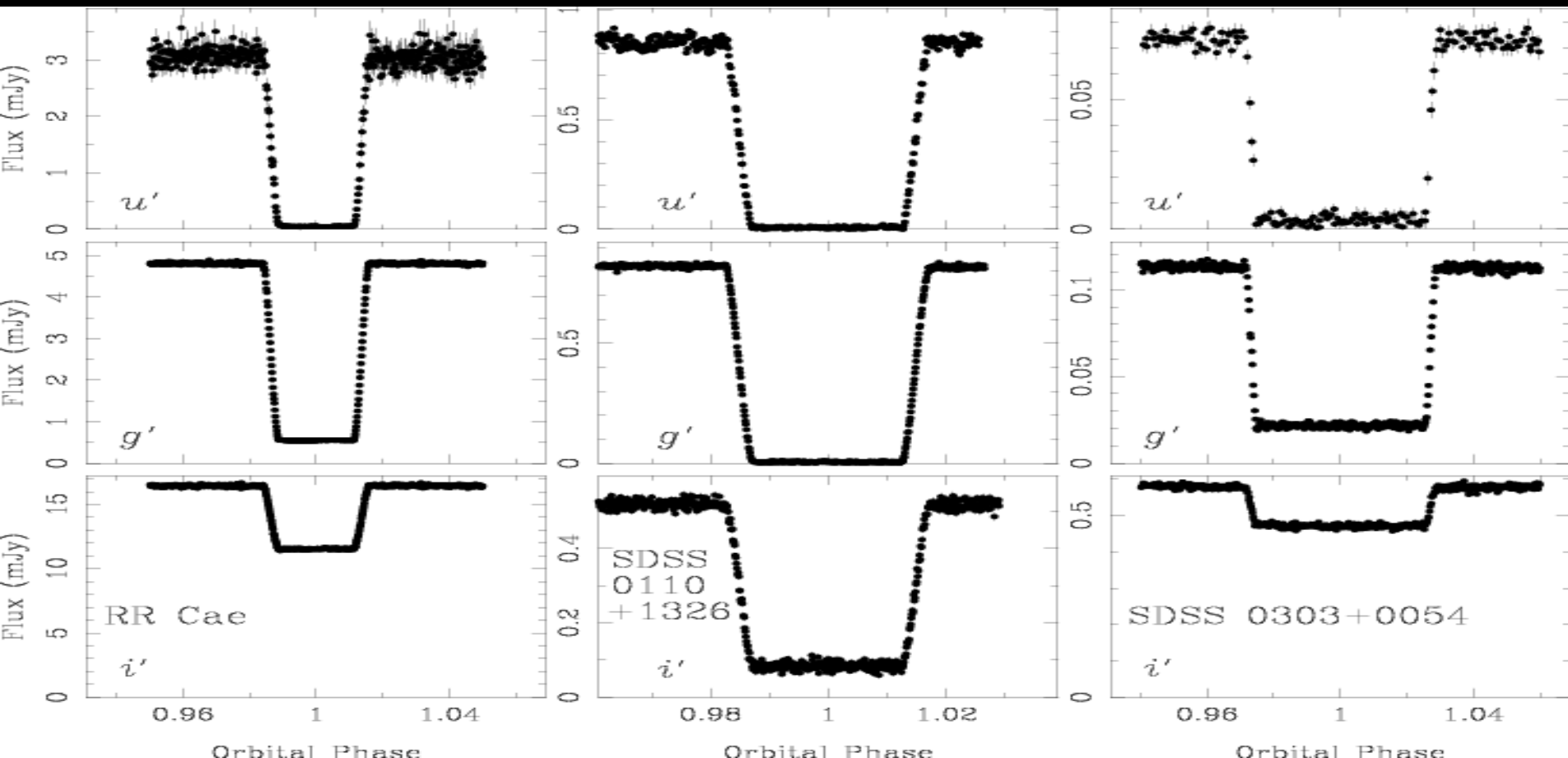
What Astronomers Love to Discover: New ECLIPSING Binary Stars

- Almost anything you could want to know about a star, if it's a member of an eclipsing binary, then with good enough measuring, you can find it.
- That includes the masses of stars

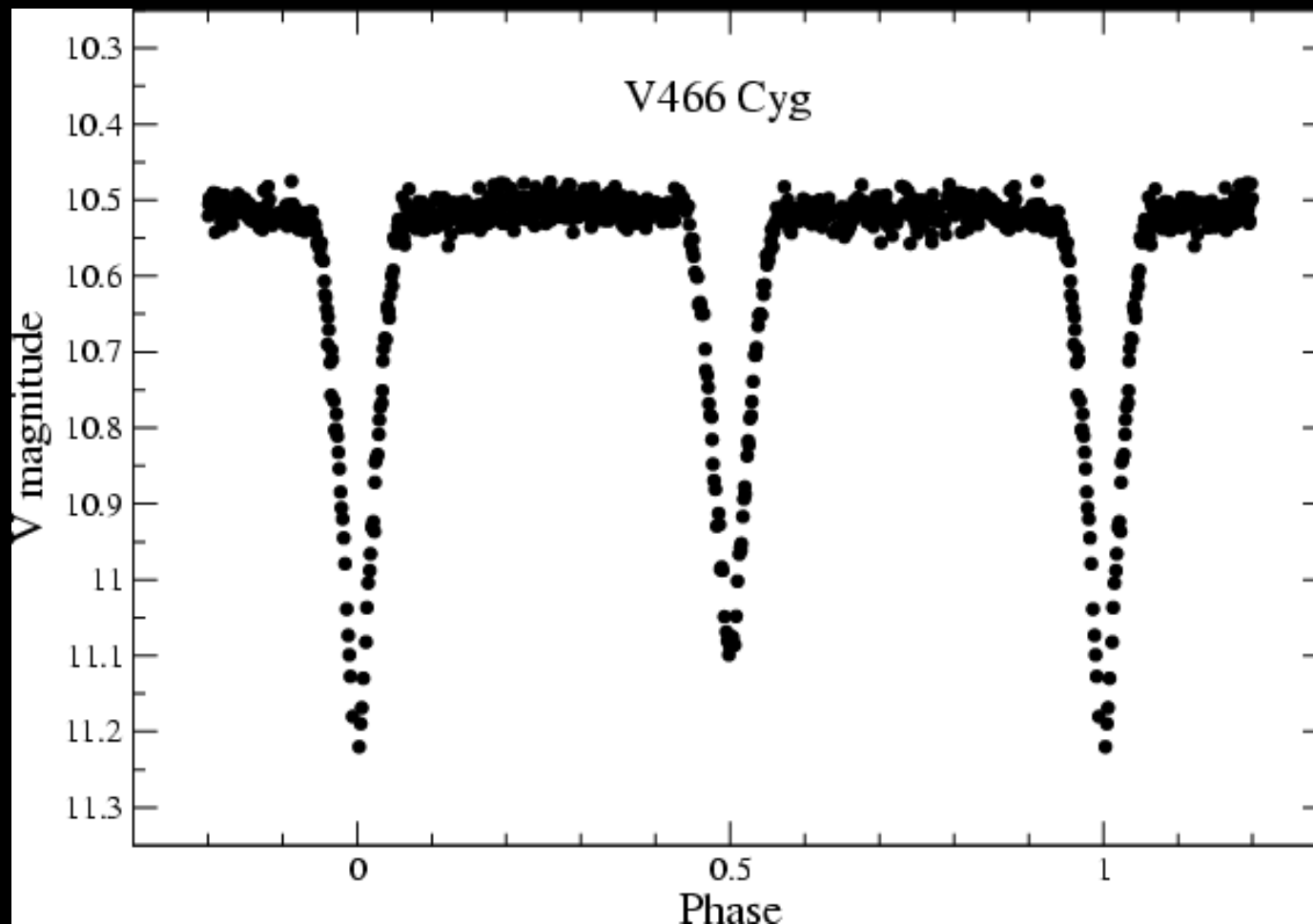


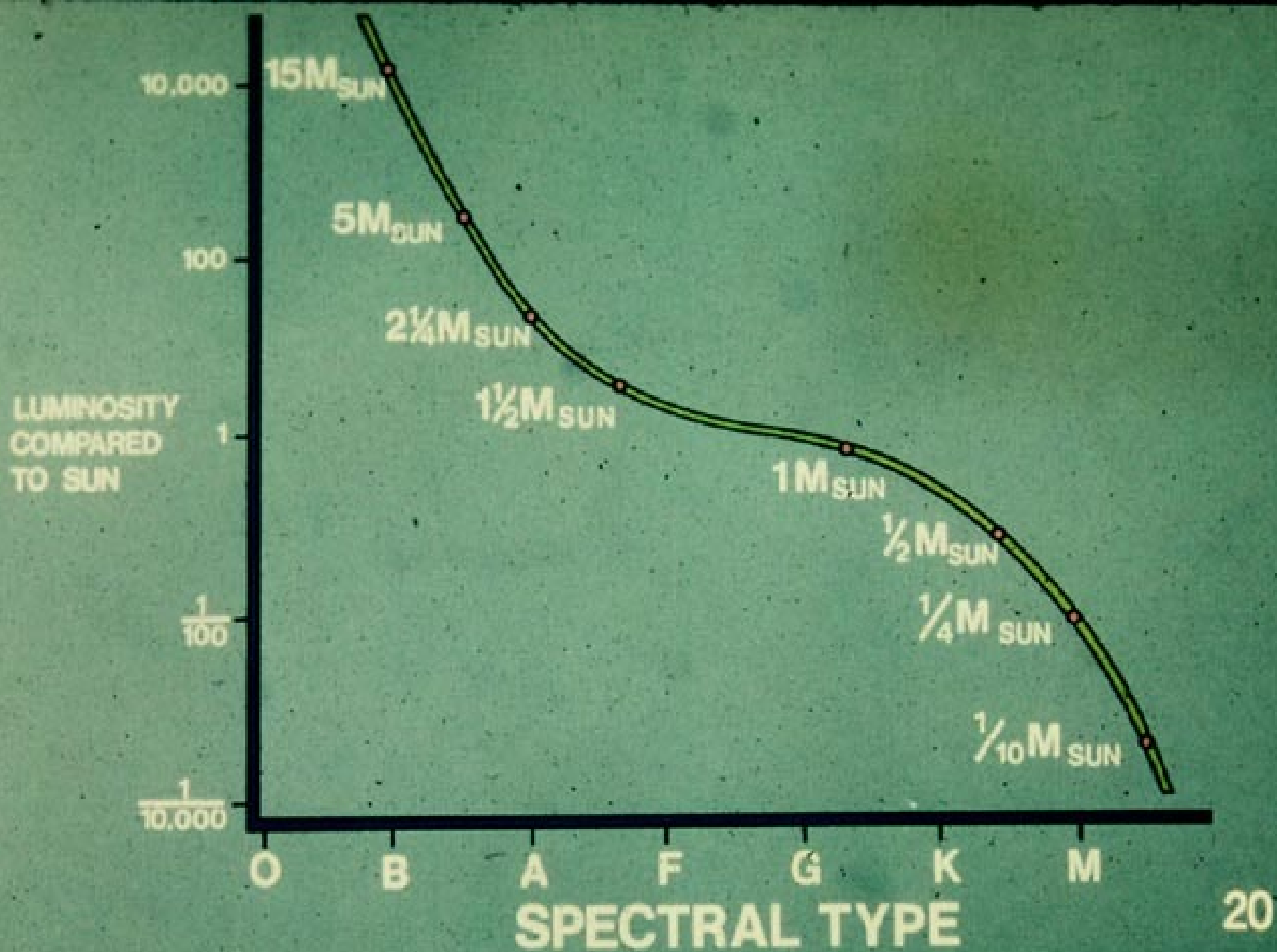
You can also get the sizes of the stars in eclipsing binaries. Can you see how?

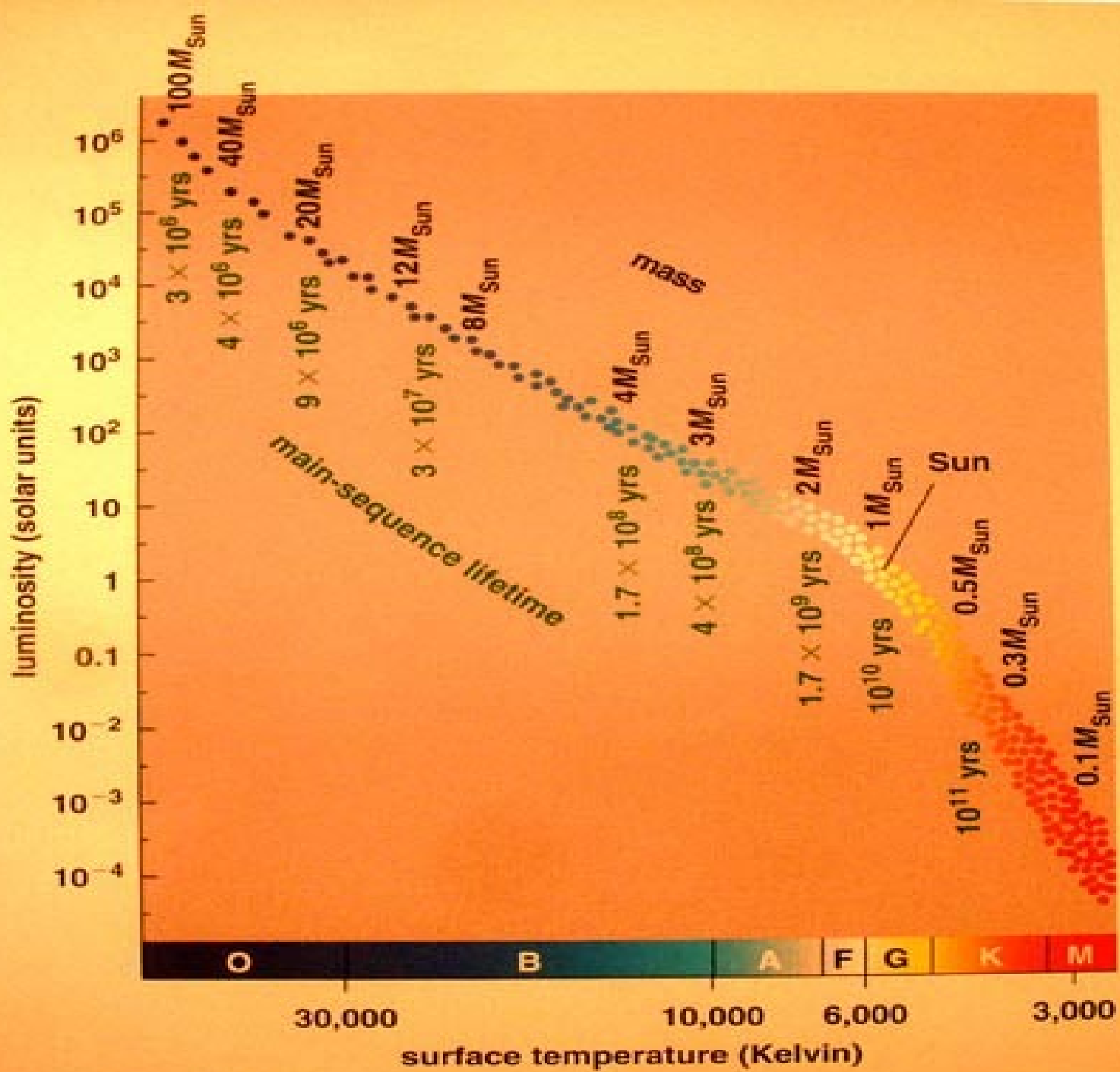
**Flat-bottom = total eclipses: one star is completely in front of the other.
These give the size of the stars much more easily**



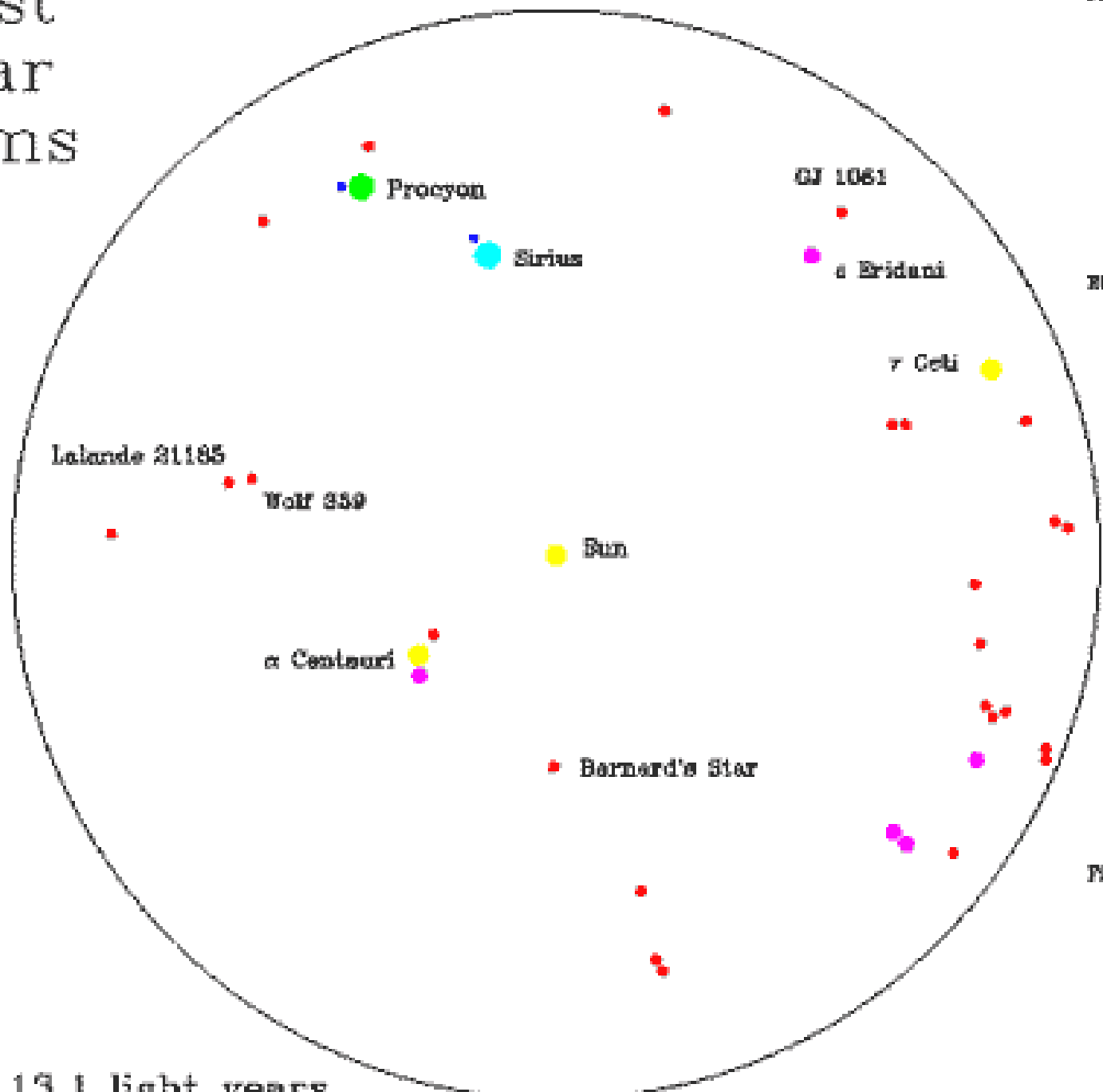
Partial Eclipses; light never levels and flattens at the bottom, but instead comes right back up







Nearest 25 Star Systems



Five Nearest Systems

1. alpha Centauri
2. Barnard's Star
3. Wolf 359
4. Lalande 21185
5. Sirius

RECONS Discovery

20. GJ 1061
(11.9 light years)

Five Brightest Systems Among Nearest 25

1. Sirius
2. alpha Centauri
3. Procyon
4. gamma Ceti
5. epsilon Eridani

horizon = 13.1 light years

Chap 15: Key Points “Stellar Properties”

- Parallax, the only direct method of finding distances to stars, except for rare eclipsing binaries
- Spectral types are a Temperature sequence: OBAFGKM hot to cool.
- 90% of all stars are on Main Sequence= hydrogen burning stars
- Main Sequence is a mass sequence, lower right to upper left is rising mass. Luminosity goes as $(\text{Mass})^{3.5}$ on the main sequence
- Lowest mass star= $0.08M_{\text{sun}}$, lower than that can't fuse hydrogen
- Highest mass stars $\sim 150M_{\text{sun}}$, higher mass would be so luminous they'd blow excess mass back out to space
- All MS stars are doing core hydrogen burning into helium. That defines the Main Sequence
- Total eclipses: flat bottomed. These are the easiest to use in getting stellar sizes
- Half of all stars are in binaries
- We find stellar masses using binary stars; measure the period and the semi-major axis and use Kepler's 3rd Law
- Stellar demographics: most stars are dim red dwarfs, but most naked eye stars you see at night are very luminous and more massive than the sun.