Killer Skies

- Homework 6 due Monday
- Night Observing continuing
- Last time: Nature of Stars
- Today: Nature of Stars 2

Music: *We are all connected* – Symphony of Science

Night Observing

Night Observing probably last week

- if you do it, need to go one night
- allow about 1 hour

When: W, Th: 7-9pm (to see Venus south of Marrow Plots)

3 observing stations:

- Large telescope in observatory dome
- 2 outdoor telescopes
- Night sky constellation tour

Subscribe to Night Observing Status Blog
http://illinois.edu/blog/view/413
Get weather cancellation updates

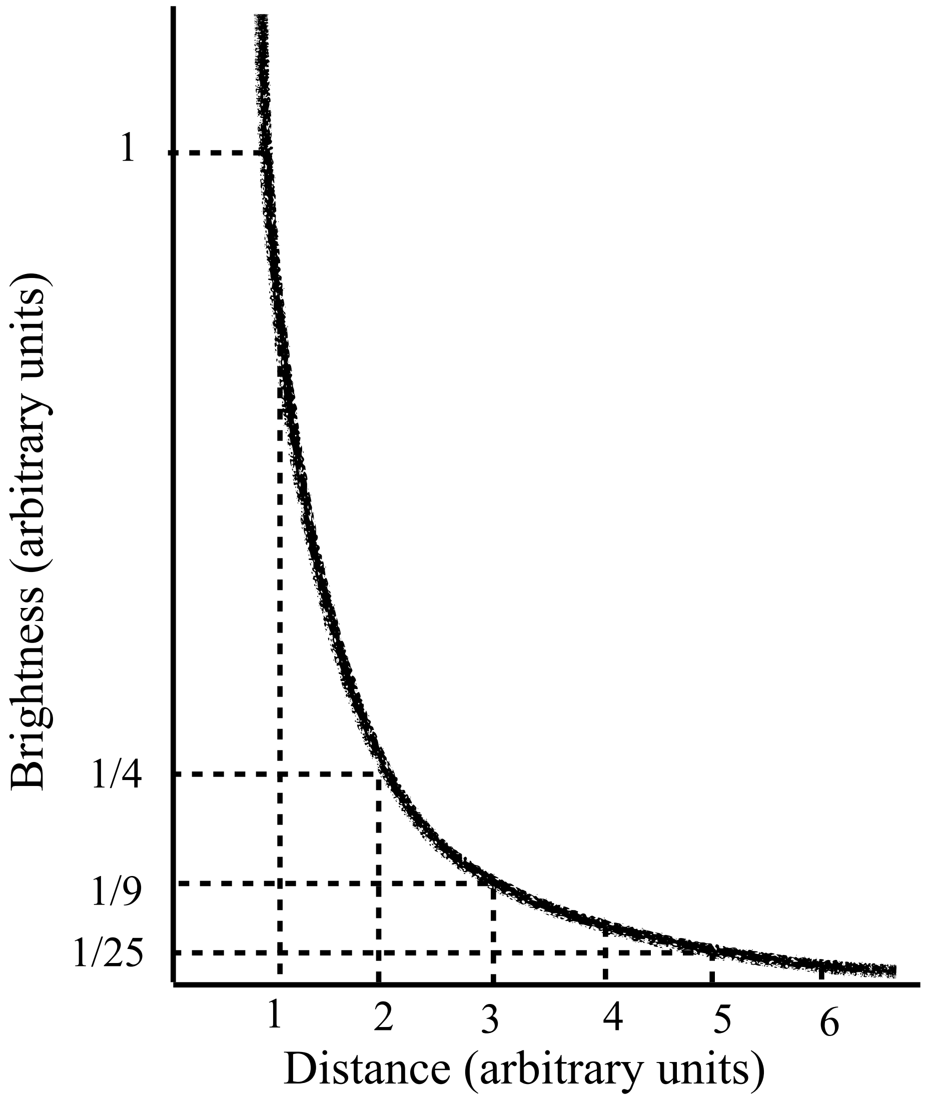
Assignment details on class website

Read rubric before you go!

- Complete report due on or before Nov. 11th

Brightness vs. distance follows the inverse-square law

If the distance between two objects doubles, the apparent brightness drops by a factor of 4!



Graph shows how the brightness drops with distance.

Thought Question

How would the apparent brightness of Alpha Centauri change if it were three times farther away?

A. It would be only 1/3 as bright
B. It would be only 1/6 as bright
C. It would be only 1/9 as bright
D. It would be three times brighter

Answer: C. 3 squared is 9. And it gets dimmer.

So Now We Need the Distance

- **We know that the stars must be very far away.**
  - **They don't move much as we orbit the Sun.**
- **But measuring the distance is a hard problem.**
- **We've only had the technology to do it for the last 200 yrs.**

Parallax

How do astronomers measures distances to nearby stars?

How to Measure Parallax

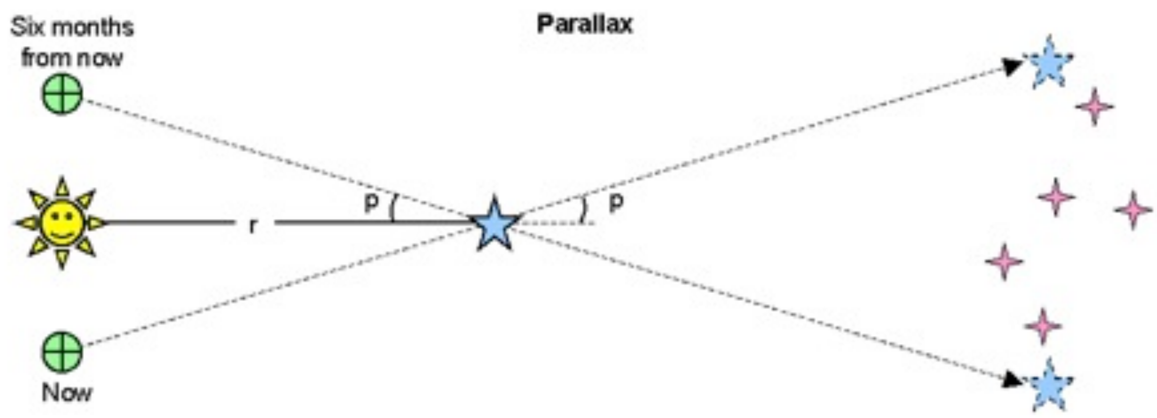
Look at a star compared to background stars.

Wait 6 months and look again.

How much, if any, has the star moved?

The amount moved is called parallax.

Experiment: thumbs-up

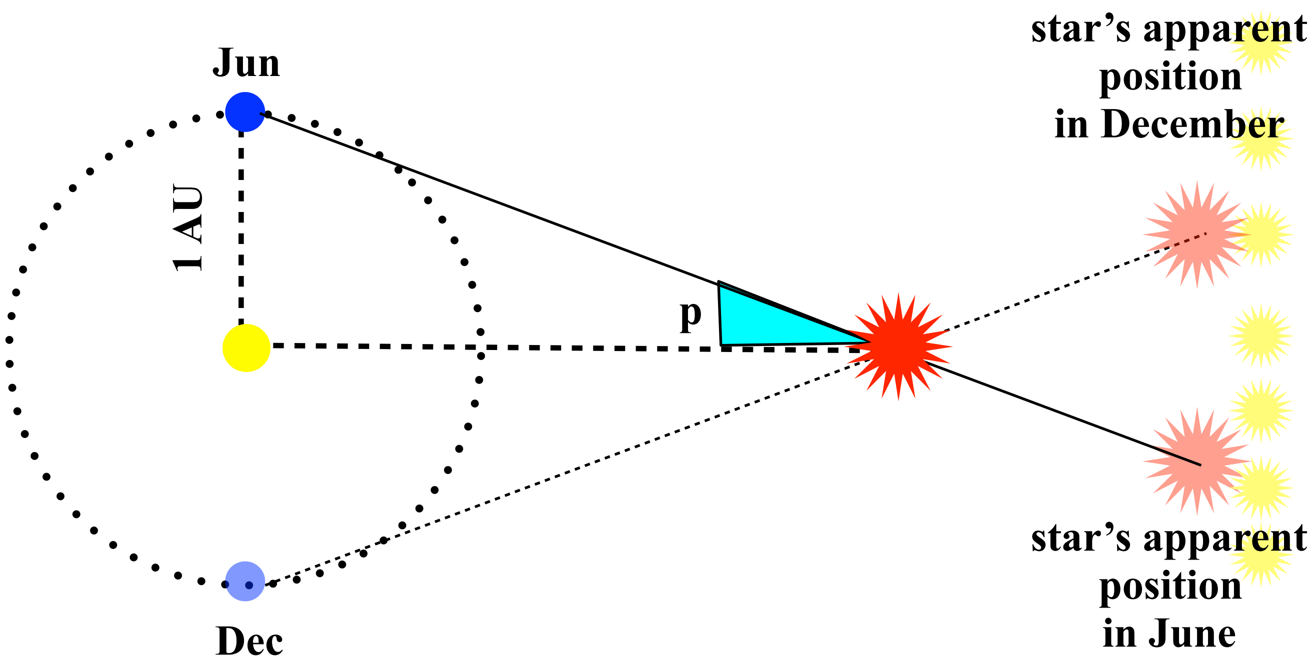


Thumb Experiment

1 2 3 4 5 6 7 8 9

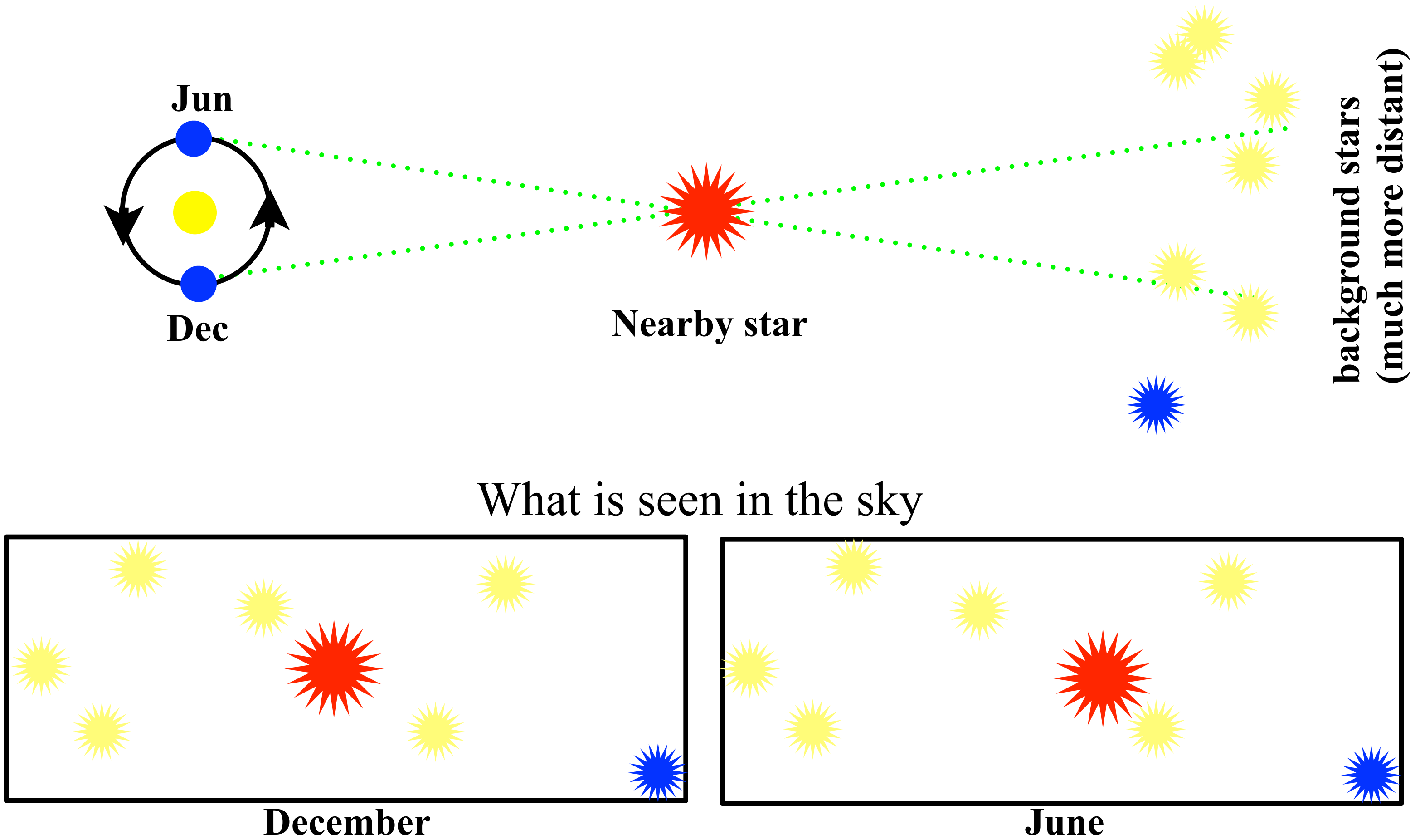
Measuring stellar distances with parallax

- As seen from the Earth, the nearby star appears to sweep through the angle shown.
- Half of this angle, is the parallax, **p**.



In the picture above, the line of sight to the star in December is different than that in June, when the Earth is on the other side of its orbit. As seen from the Earth, the nearby star appears to sweep through the angle shown. Half of this angle, is the parallax, p.

Stellar Parallax



Parallax is used to measure the distance to stars that are relatively nearby

Astronomers use this same principle to measure the distance to stars. However, instead of switching back and forth between eyes, they use the biggest possible difference in observing position without leaving Earth – our planet's orbit around the Sun. To do that, they observe a star, and they note where the star appears to be relative to more distant stars. Then, they wait 6 months; during this time, Earth moves from one side of its orbit around the Sun to the other side. When they observe the star again, parallax will cause the star to appear in a different position relative to more distant stars. From the size of this shift, they can calculate the distance to the star.

iClicker Poll: Parallax

Star A is closer than star B

The parallax p_B of the more distant star B will be

A. larger than p_A = bigger shift on sky for B

B. smaller than p_A = smaller shift on sky for B

C. the same as p_A: same Earth orbit = same shift

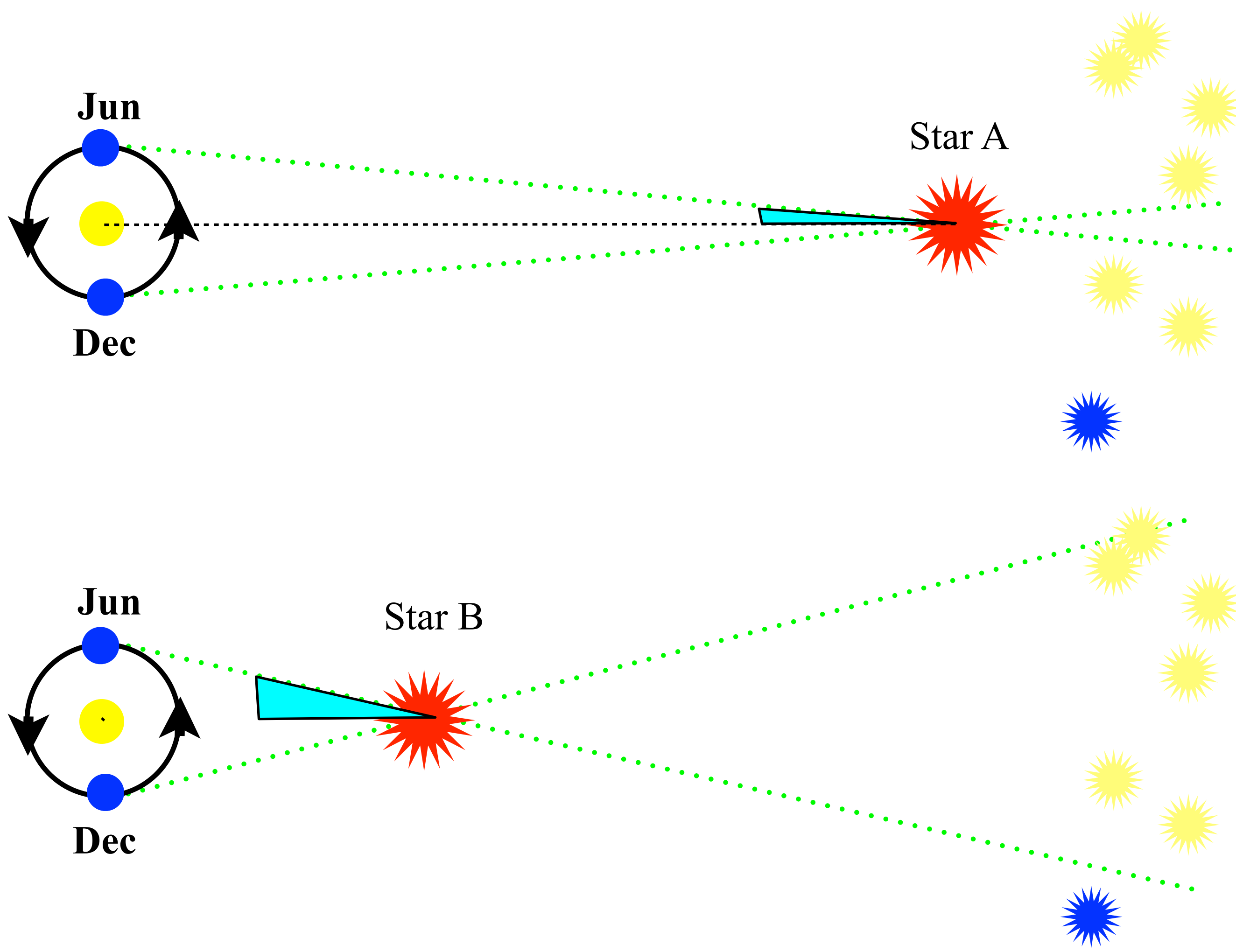
Hint: in thumb's up experiment, can adjust thumb distance!

Answer B

Thumb Experiment

1 2 3 4 5 6 7 8 9

The larger the parallax angle, the CLOSER the star

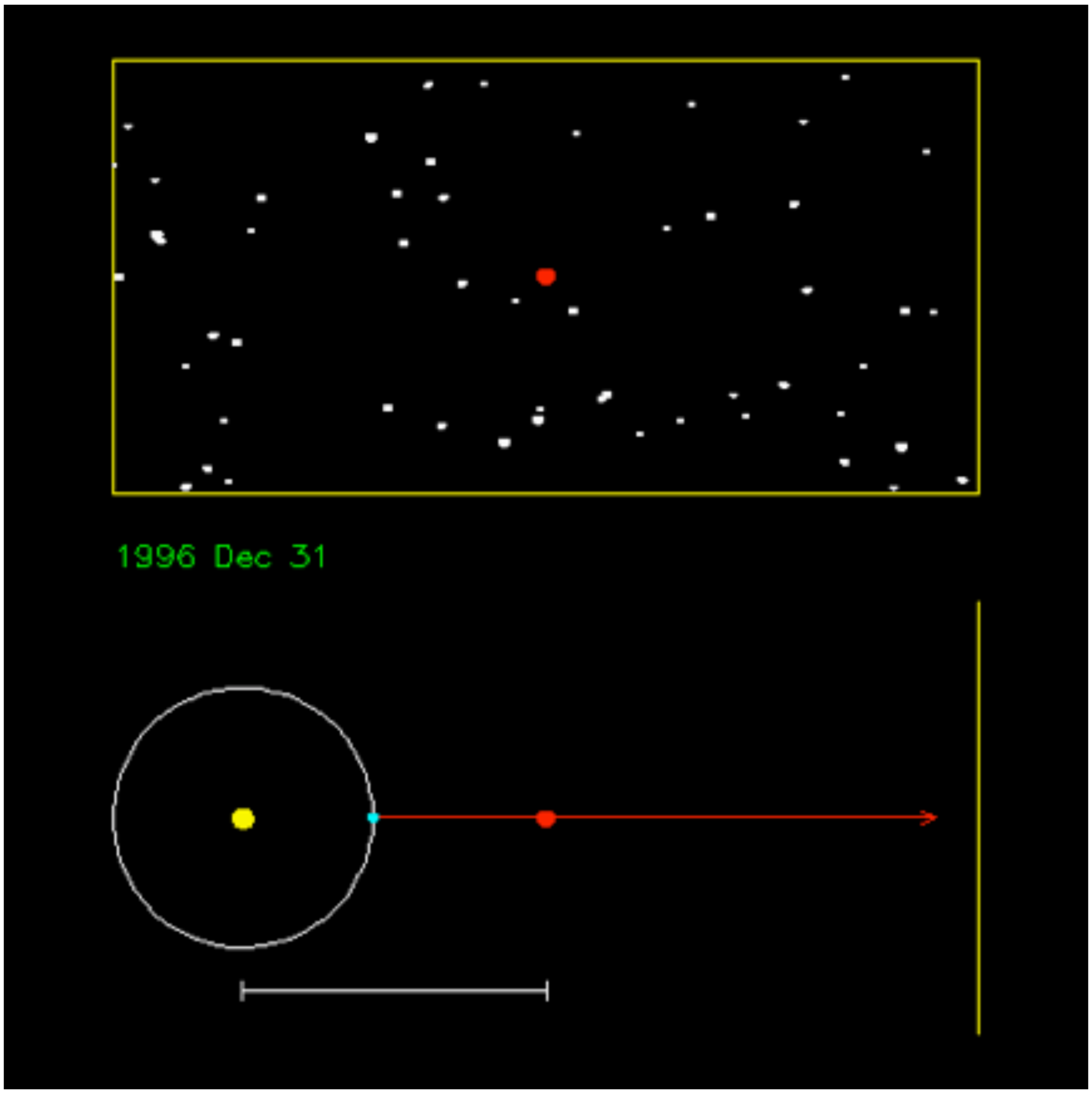


The parallax of Star B is much bigger than the parallax of Star A

As the distance to a star increases, the its parallax decreases. This is easy to see in the above figures.

In the upper figure, the star is about 2.5 times farther than the star in the lower figure, and has a parallax angle which is 2.5 times smaller.

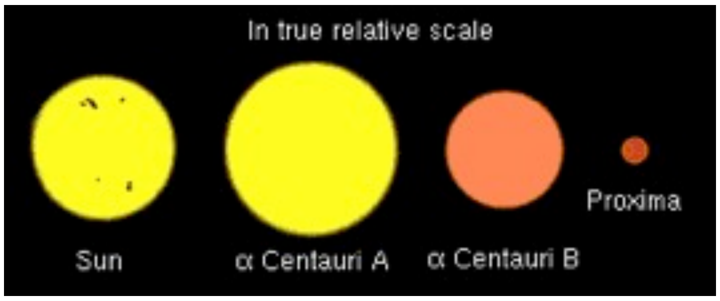
The larger the parallax angle, the CLOSER the star

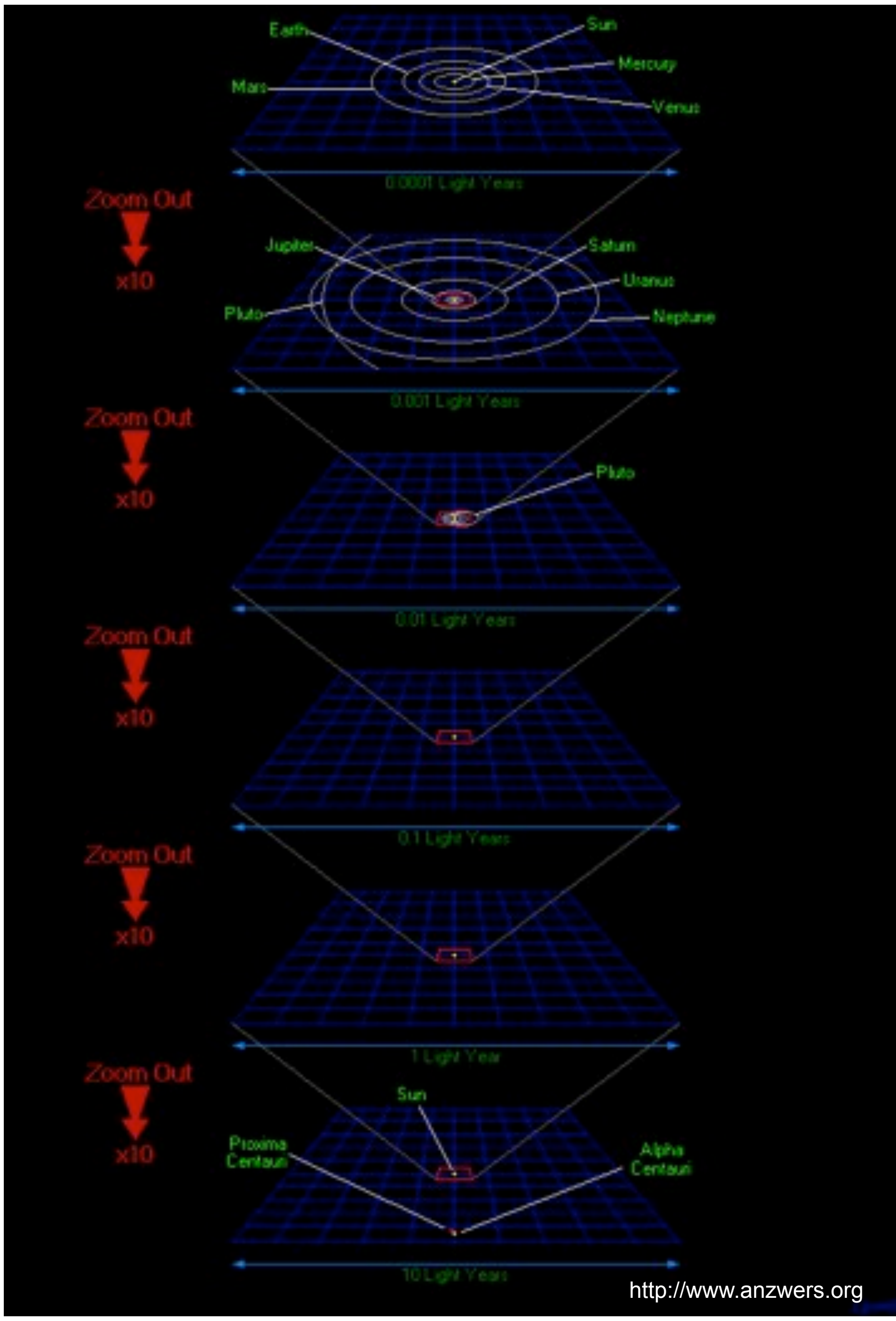


As the distance to a star increases, the its parallax decreases.

Leaving Home

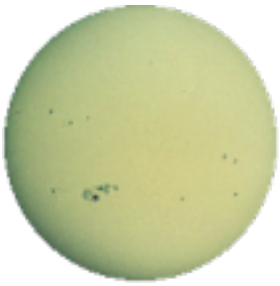
- Nearest star is 4 x 10^{13} km away
  - Called Proxima Centauri
- Around 4.2 light years
- More than 5000 times the distance to Pluto
- Walking time: 1 billion years
- Fastest space probes: Voyagers 1 & 2, Pioneers 10 & 11) – 60,000 years at about 3.6 AU/year (38000 mi/hr)





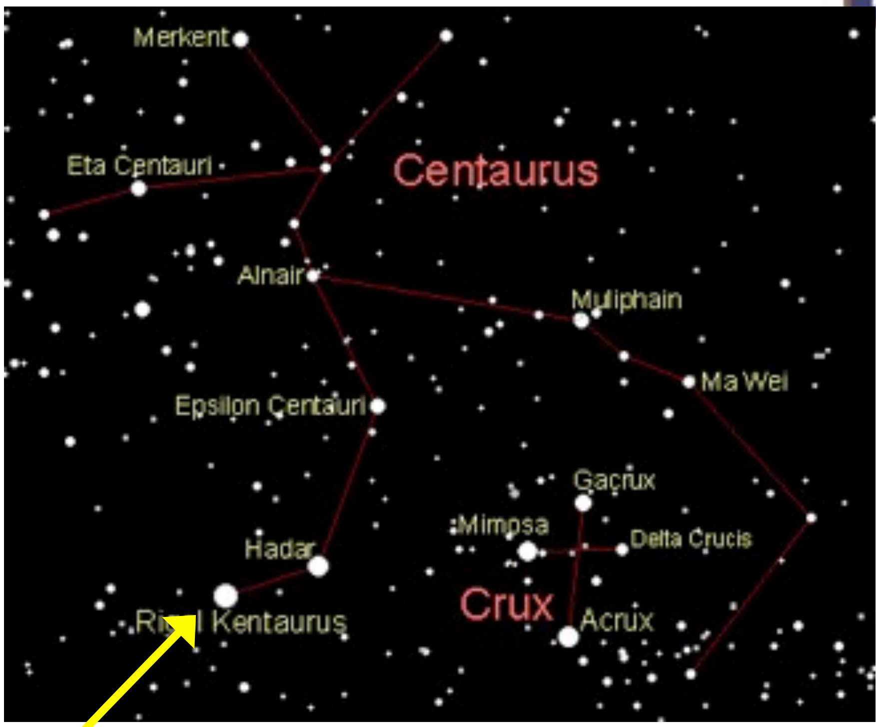
Distances to the Stars

Sun's disk seen from Earth



1/2 degree = 1800 arcsec

Dime at arm's length



Closest star to Earth:
Proxima Centauri
(part of α Centauri system)
Parallax: 0.77 arcseconds
Distance: 1.3 pc = 4.2 ly
like a dime 2 km away

Thought Question

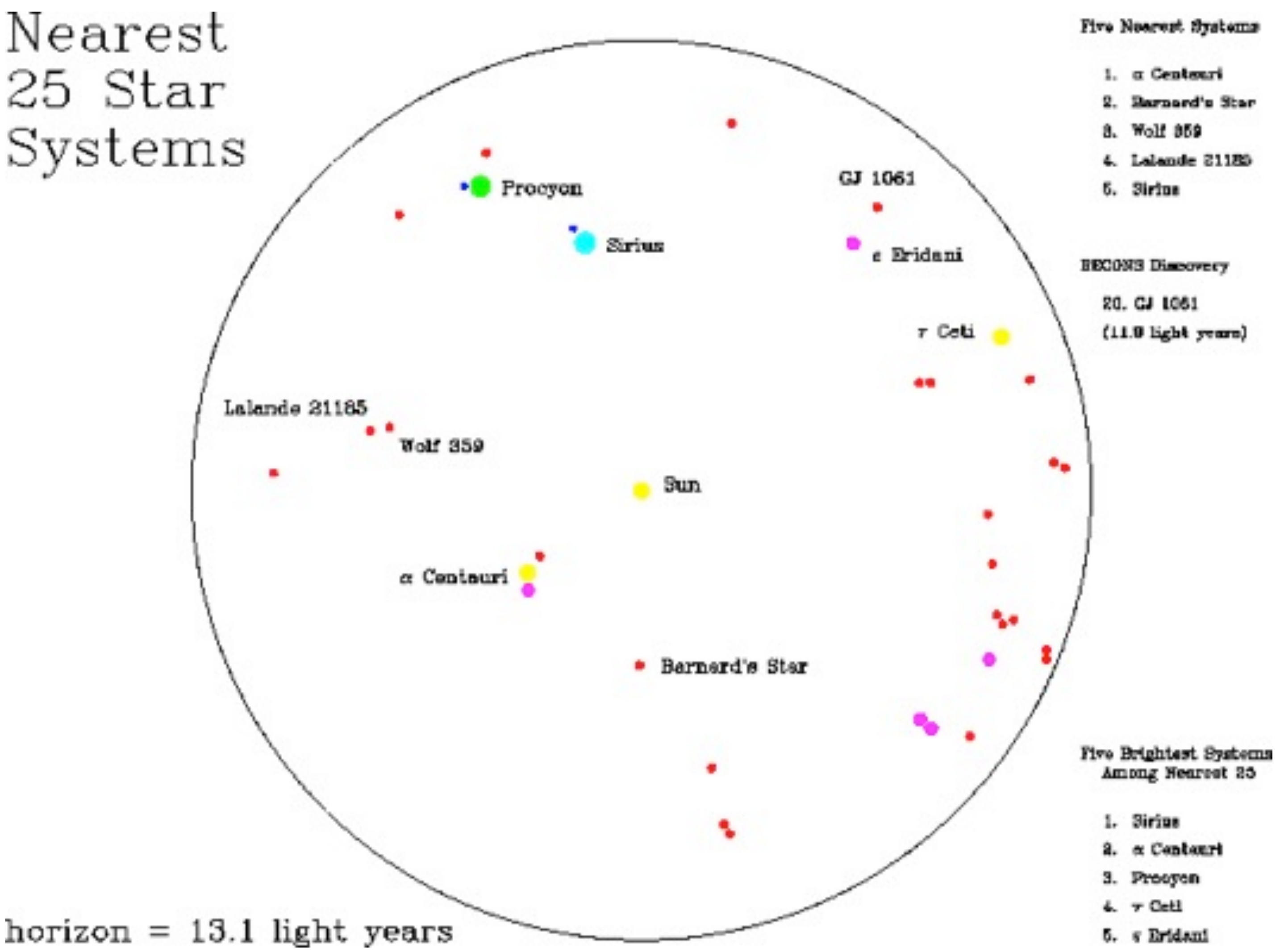
The parallaxes (in arc seconds) for four stars are given below. Which of the following stars is **closest**?

A. Capella
B. Polaris
C. Rigel
D. Sirius

Capella	0.0794
Polaris	0.00757
Rigel	0.00422
Sirius	0.38

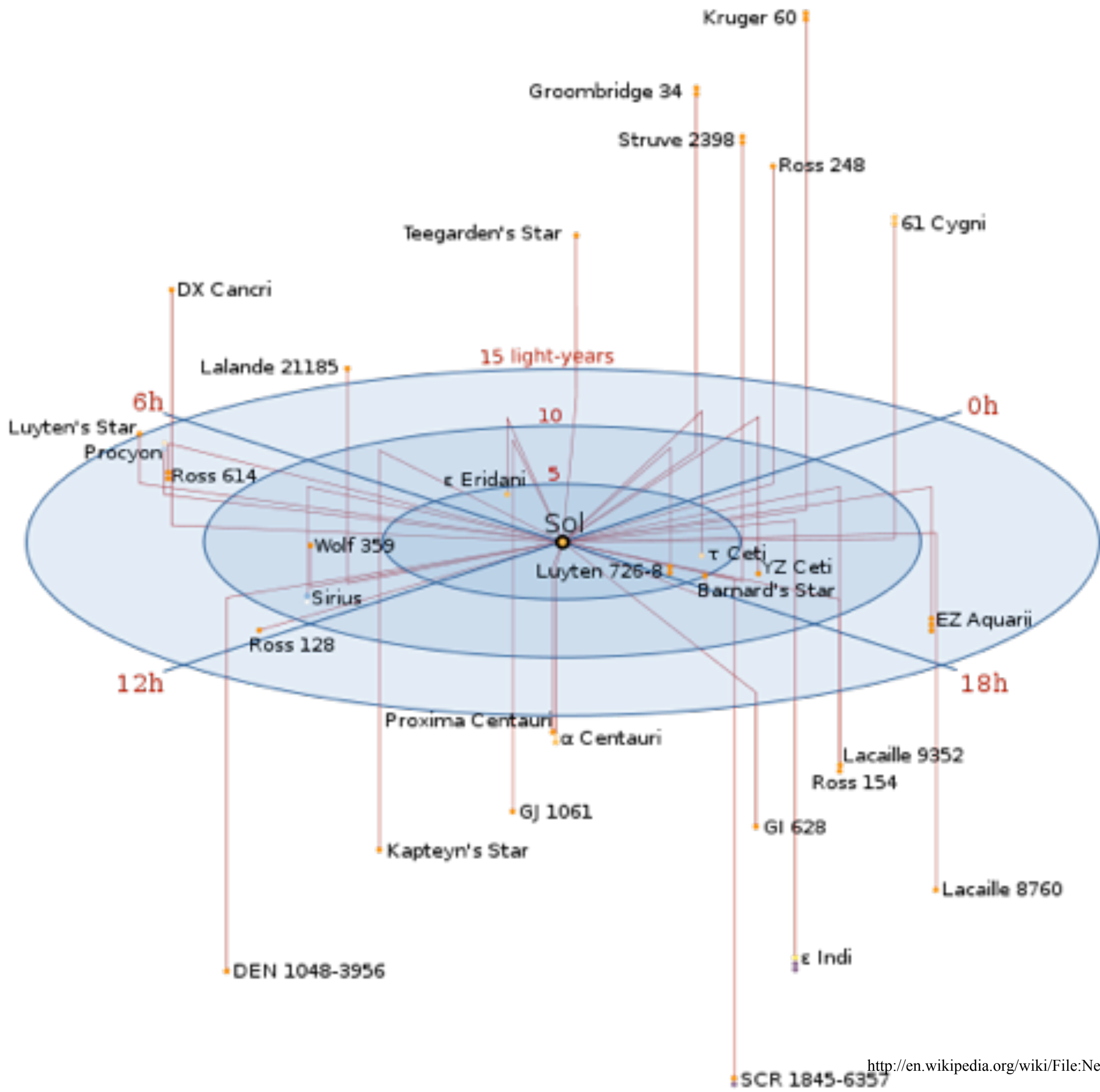
Answer: D. The closest star will have the largest parallax. The largest parallax is 0.38 arc seconds.

Our Nearest Neighbors



http://antwrp.gsfc.nasa.gov/apod/ap010318.html

Our Nearest Neighbors: 15



http://en.wikipedia.org/wiki/File:Nearby_Stars_(14ly_Radius).svg

Parallax Peril

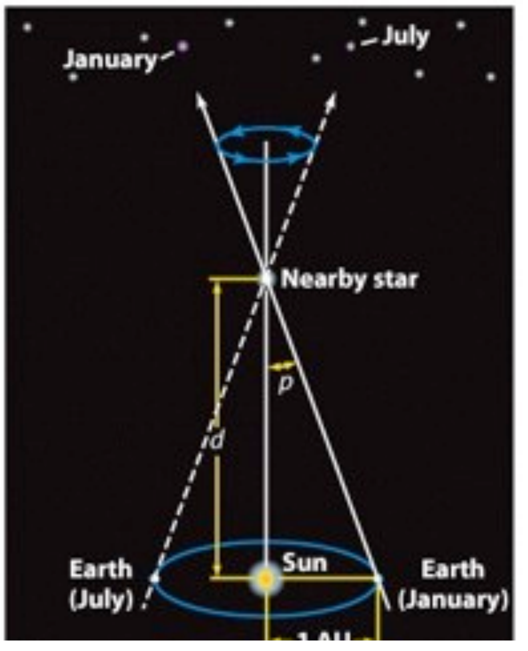
Drawback:

- parallax measurable only for nearest stars
- Angular shift becomes tiny when star very far away

Parallax immeasurable when star is beyond few 100's of lyrs

And Galaxy is 100,000 lyr across, Universe is 14 billion lyr

What to do? ... stay tuned...



How luminous are stars?

- To determine luminosities of stars:
  - Observe apparent brightnesses
  - Measure distances using parallax
- Most luminous stars
  - $\sim 10^6\ L_{Sun} = \sim 1{,}000{,}000\ L_{Sun}$
- Least luminous stars
  - $\sim 10^{-4}\ L_{Sun} = \sim 0.0001\ L_{Sun}$
- How do their masses compare?

Stars have a very wide range of luminosities

The most luminous stars are 10 billion times more luminous than the least luminous stars!

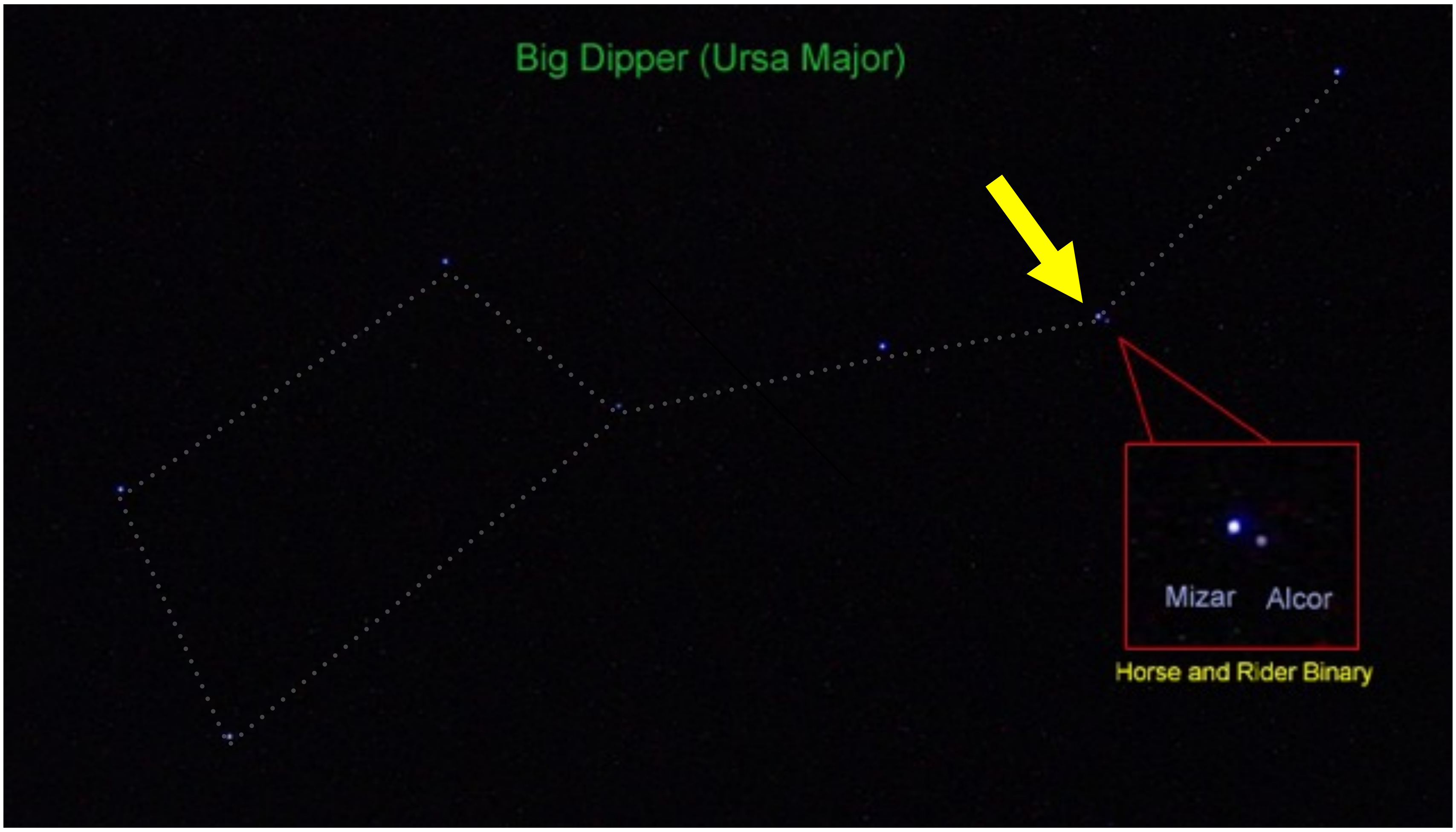
How do we measure stellar masses?

We can't simply put a star on a scale!

Astronomers measure the masses of stars by observing stars orbiting each other.

More than half of all stars are members of binary star systems, where the stars orbit each other, bound together by gravity.

Alcor & Mizar, an example multiple star system

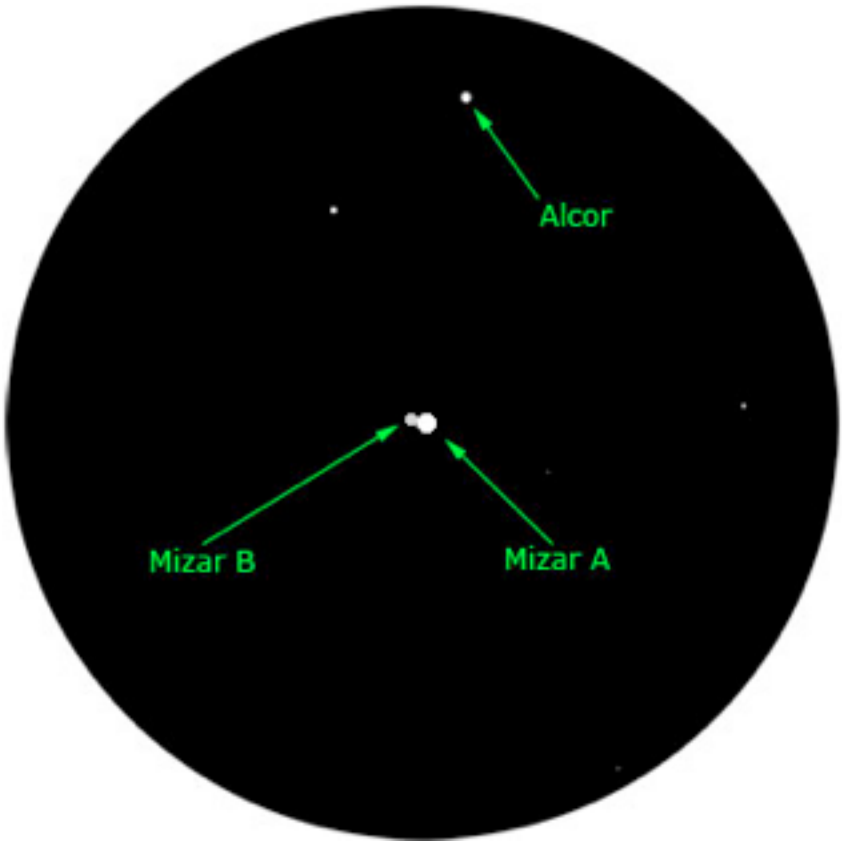


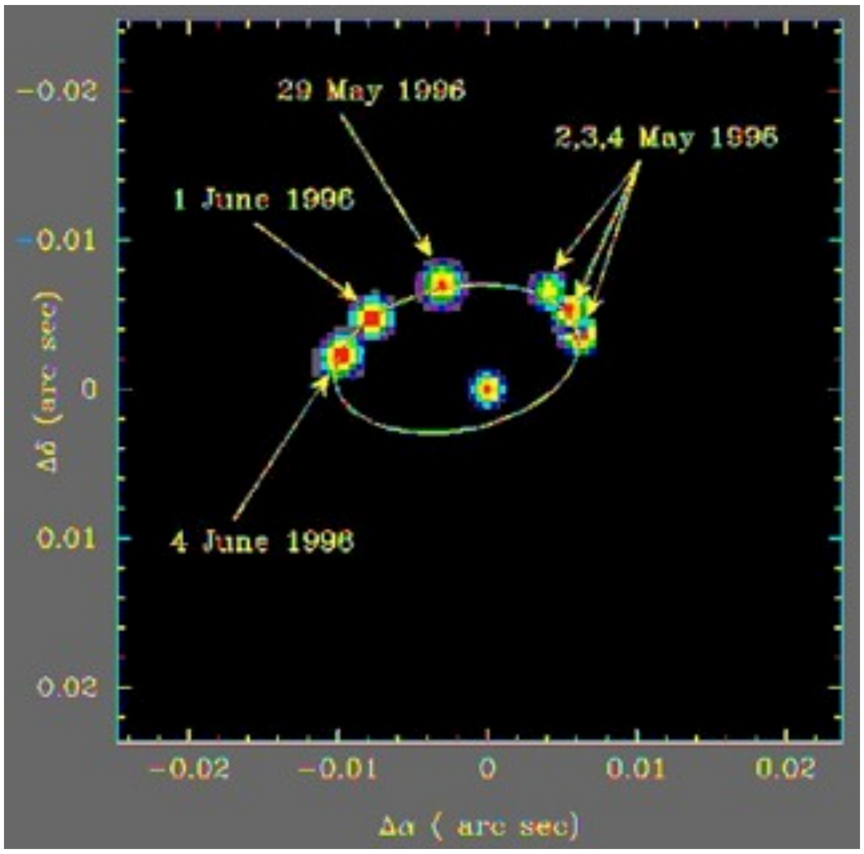
Alcor and Mizar in the Big Dipper are a multiple star system! You can just barely see it with your naked eye.

Mizar and Alcor together are sometimes called the "Horse and Rider," and the ability to resolve the two stars with the naked eye is often quoted as a test of eyesight, although even people with quite poor eyesight can see the two stars.

Mizar is itself a binary star system! But not one you can see with your naked eye.

Stars in a binary system orbit around each other





Mizar A & B orbit around their center of mass

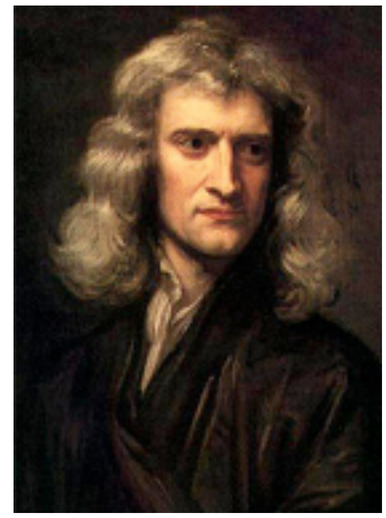
In a binary star system, each star of the pair follows an elliptical orbital path. Mutual gravity causes the stellar companions to glide around their orbits as if tied to the ends of an elastic string passing through a balance point between them.

How can this tell us the masses of the stars?

We can use Kepler's 3rd Law* to determine the masses of the stars

***Fortified with vitamin Newton!**

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



P in years; a in AUs

M_1, M_2 in **solar masses** (M_{Sun})

Note: For planets orbiting the Sun, $M_1 + M_2 \approx 1\ M_{Sun}$

Kepler 3rd Law gives us a relationship between the average distance of a planet from the Sun and the amount of time it takes a planet to orbit the Sun once. For objects orbiting the Sun, $P^2 = a^3$ (P in years, a in AUs).

Kepler's relation does not work for objects that are not orbiting the Sun, for example, the Moon orbiting the Earth. Newton solved this problem with his law of universal gravitation, and discovered that the masses of the orbiting bodies also play a part. Newton developed a more general form of what was called Kepler's Third Law that could apply to any two objects orbiting a common center of mass. This is called Newton's Version of Kepler's Third Law.

M_1 and M_2 are the masses of the objects; the masses must be measured in solar masses, where one solar mass is 2×10^{30} kg.

This relation has many uses: determining the mass of a planet by looking at its moon(s), studying binary star systems, even determining the mass of the Galaxy!

For a planet orbiting the Sun, $M_1 >> M_2$, so The mass of the planet is inconsequential, and we can assume that $M_1+M_2=M_1$. The error caused by assuming the planet mass to be zero for Earth = 0.00015%, for a Jupiter-sized planet at Earth's orbit = 0.048%. So, it is a great assumption.

How massive are stars?

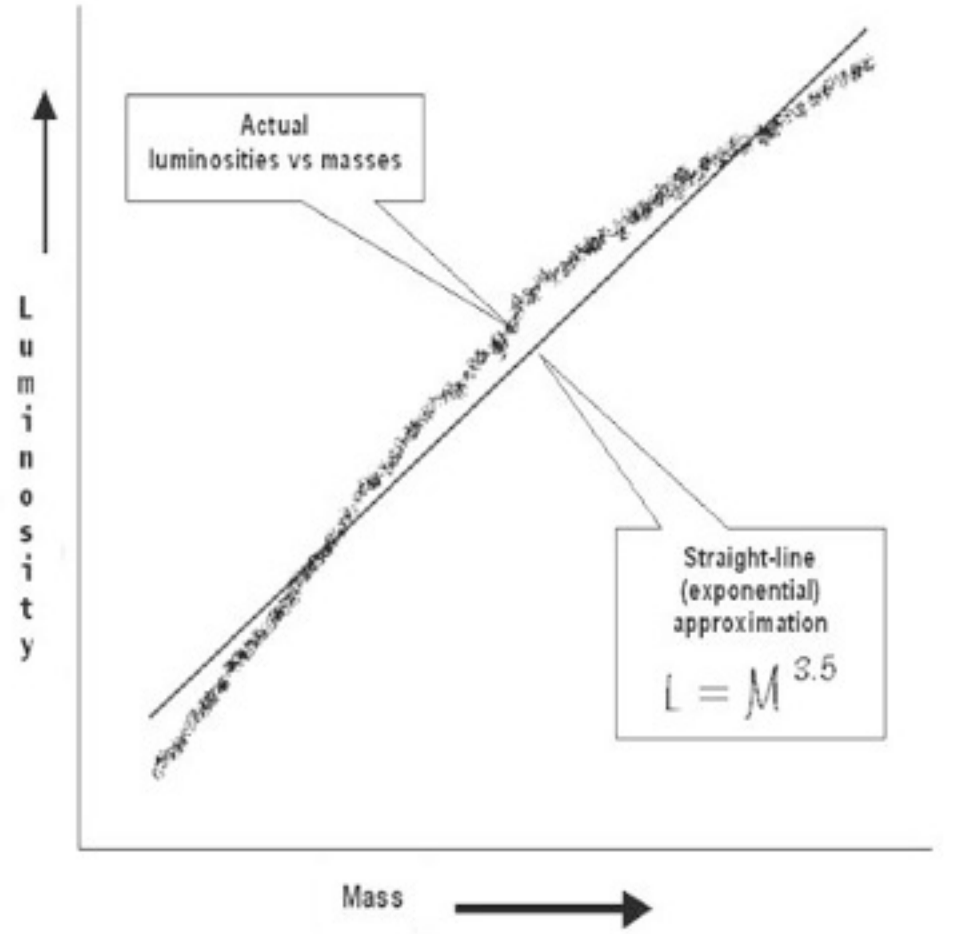
- Most massive stars: 150 M_{Sun}
- Least massive stars: 0.08 M_{Sun}
- Most massive stars are over 1,500 times greater in mass than the least massive stars!

Stars come in a variety of masses

But remember that the luminosity range is 10 billion!!!

Mass-Luminosity Relationship

- For all main sequence stars:
  - More massive stars are more luminous
  - Luminosity ~ $Mass^{3.5}$
- Example:
  - Mass ≈ 10 M_{Sun}
  - Lum. ≈ 3000 L_{Sun}
- This rule applies to about 90% of stars
- Only main sequence



Star masses vs. luminosities

Thought Question

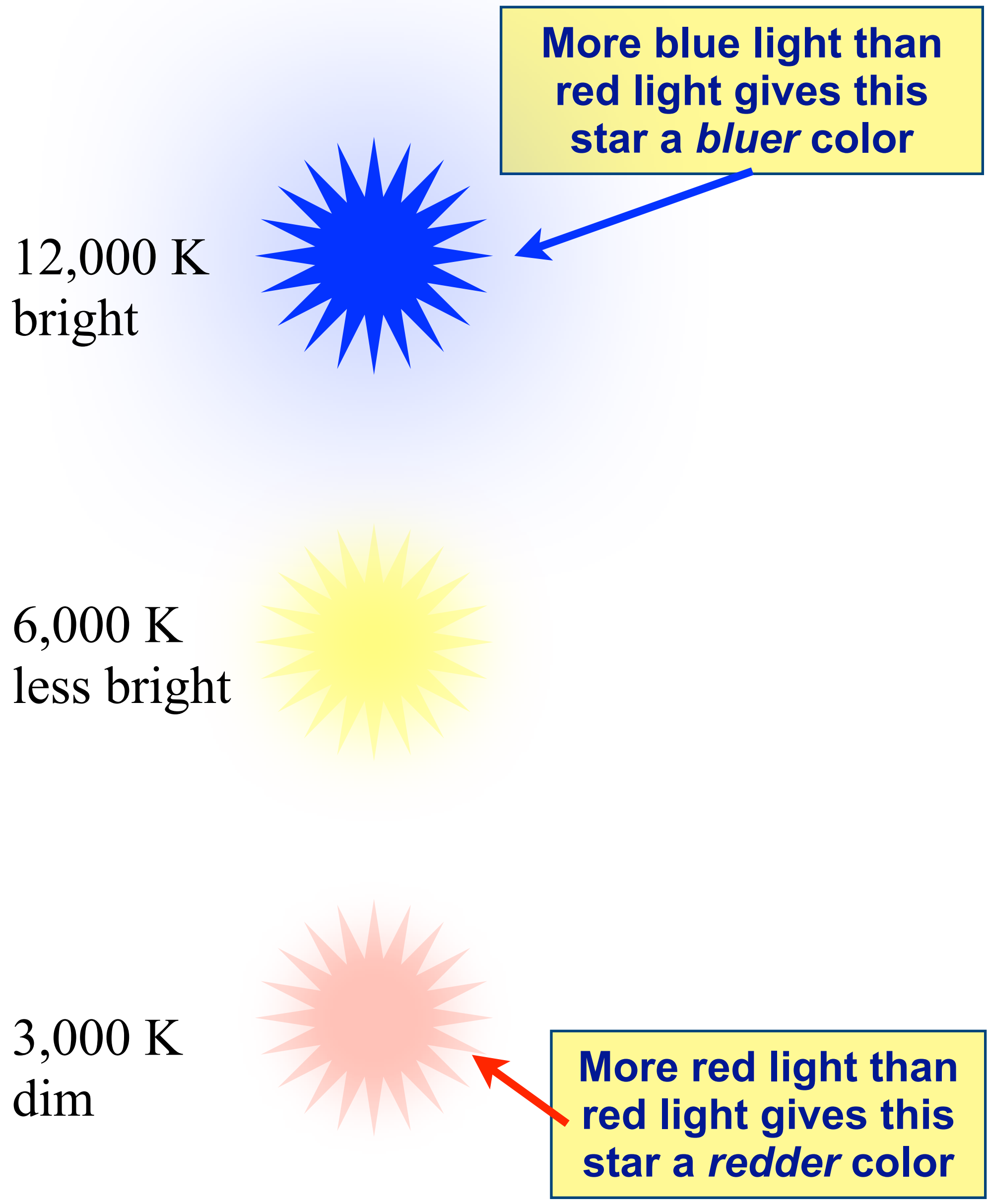
What is the luminosity of a star with twice the mass of our Sun?

A. 0.5 L_{Sun}
B. 1 L_{Sun}
C. 2 L_{Sun}
D. 10 L_{Sun}
E. 100 L_{Sun}

Answer: D. Doubling the mass of the star increases the luminosity by a factor of 10, i.e. $2^{3.5} = 11.3$

Review: Thermal Radiation

- A hot object radiates at all wavelengths
- The hotter an object is, the shorter is the wavelength of its maximum output
  - Hot stars look “bluer” than cool stars
- Hotter objects emit more energy than cooler objects of the same size



Hot opaque objects emit thermal radiation – and the object’s spectrum depends on its temperature. Hotter objects emit more energy than cooler objects of the same size at all wavelengths. The hotter an object is, the shorter is the wavelength of its maximum output. Hot stars look “bluer” and brighter than cooler stars.

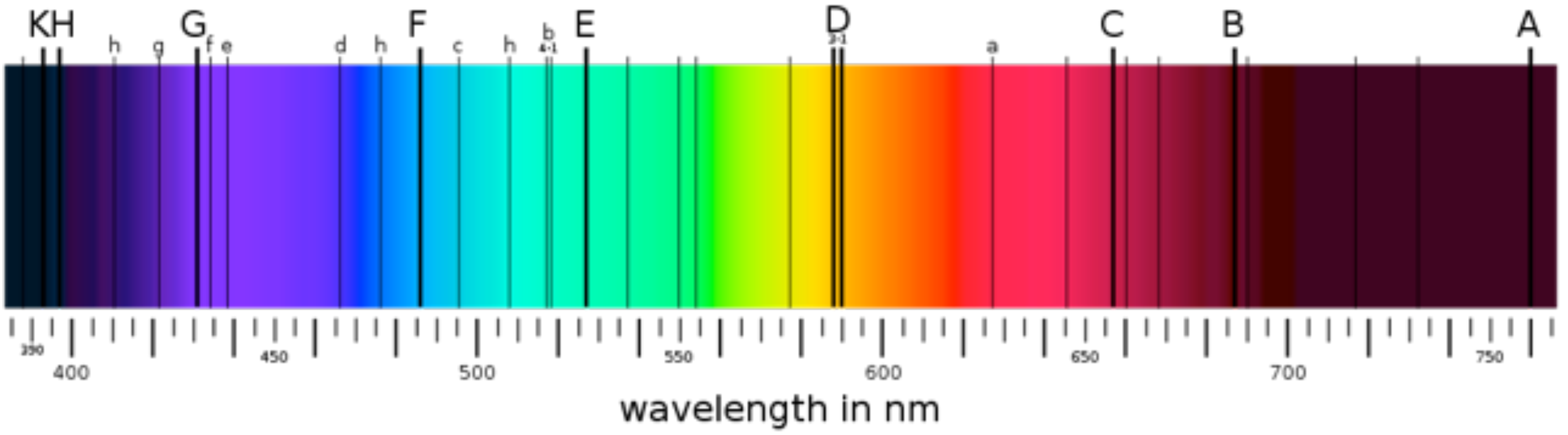
Warm-Up Question

What might an astronomer say about the way color is used to denote temperature on the controls in the picture below?

For Astronomers Blue is hotter than Red!

Although everyone thinks that blue is for cold and red is for hot, astronomers would prefer the colors were switched to match thermal radiation.

Lines in the Sun's Spectrum

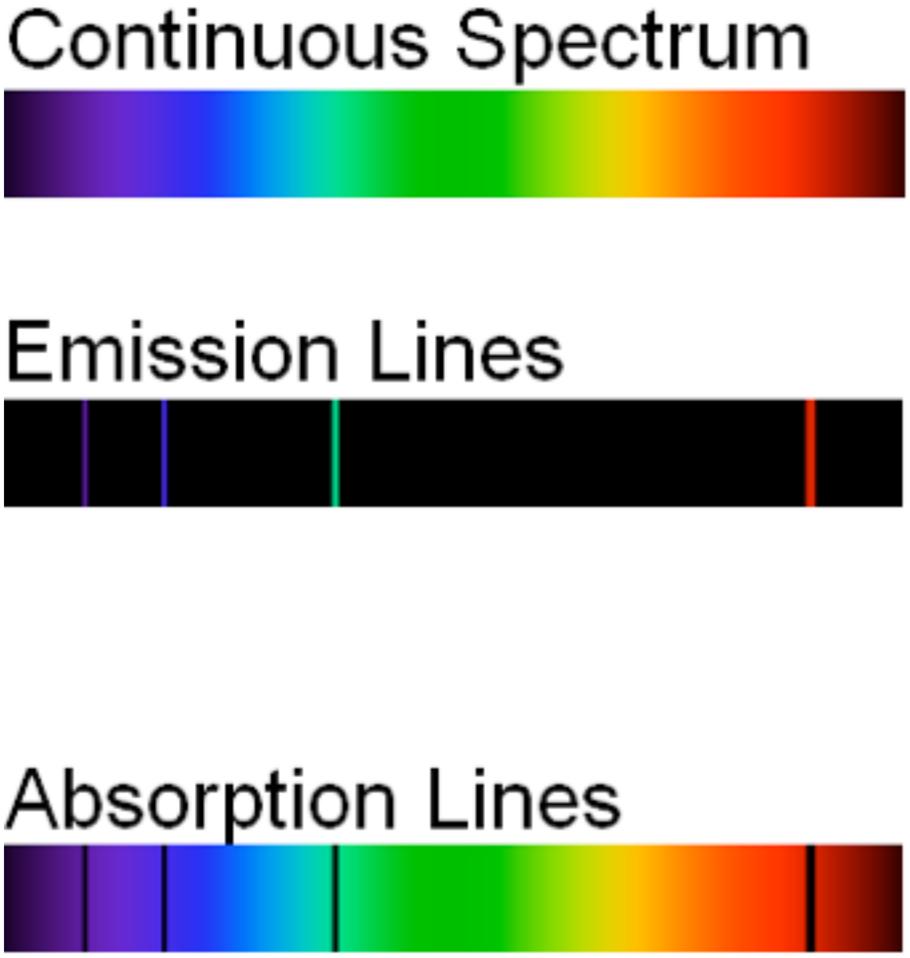


In the early 19th century, Joseph von Fraunhofer studied the solar spectrum and found it interrupted by dark lines

Earthbound humans knew almost nothing about the sun until the early 19th century. Then, the German optician Joseph von Fraunhofer studied the solar spectrum and found it interrupted by some 600 dark lines. These represented colors that are missing from the sunlight Earth receives.

How are these lines created? What do they tell us about the Sun?

The three basic types of spectra



A complete rainbow of colors

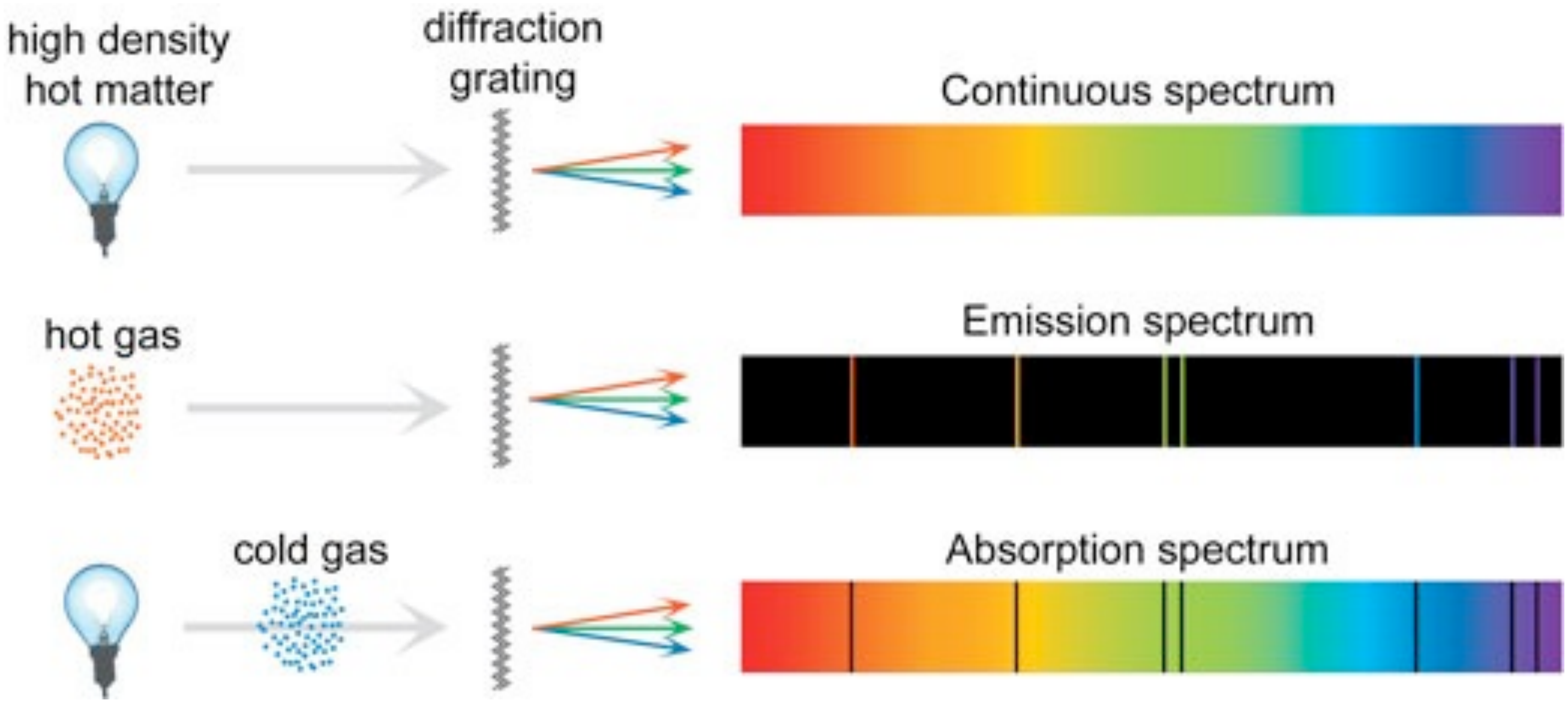
Bright lines against a dark background

Dark lines among the colors of the continuous spectrum

There are several kinds of spectra, such as: continuous; emission line; and absorption line.

- A continuous spectrum is, as the name implies, a parade of all the colors from the deepest red to the ultraviolet – of which the rainbow in the sky is a good example.
- An emission (or bright) line spectrum consists of a few isolated bright lines of color.
- An absorption (or dark) line spectrum appear as individual dark lines superimposed on a continuous spectrum.

Spectrum Depends on Source



Different sources create different spectra.

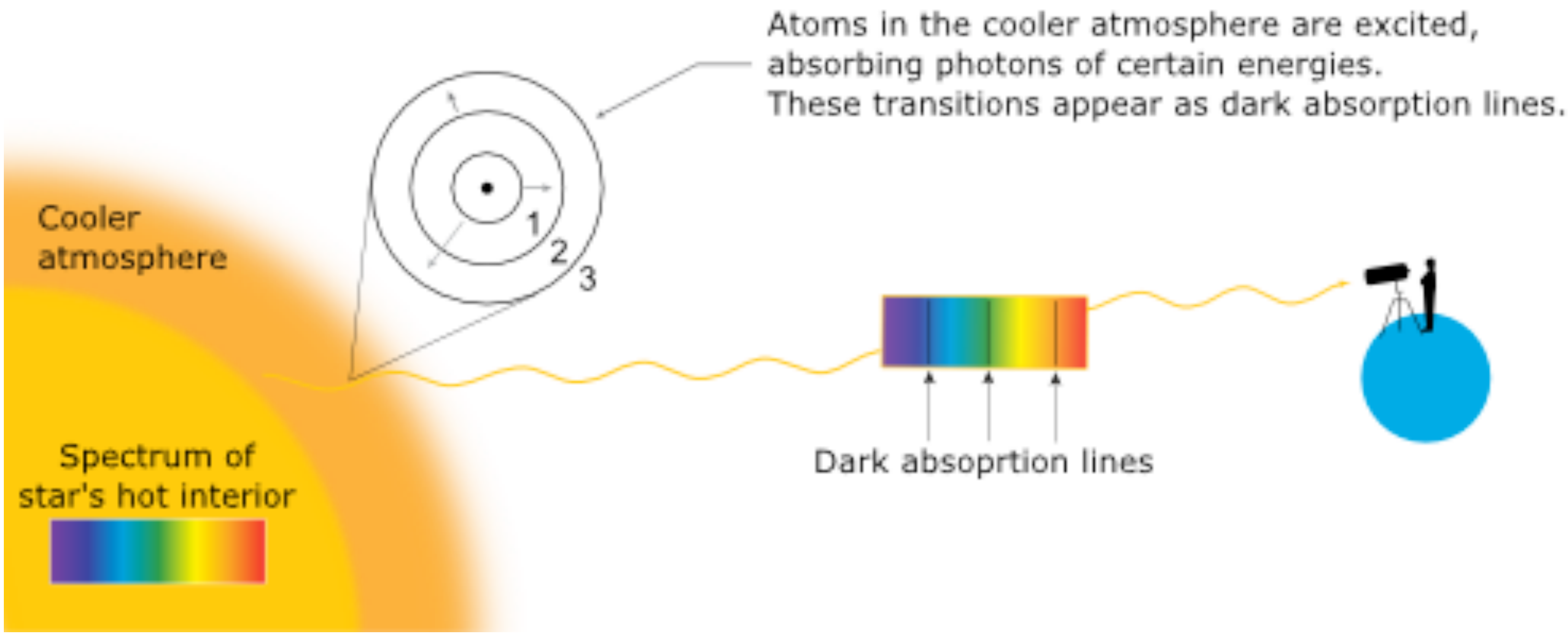
A hot, high density source, like a glowing pizza oven or lava, would produce a continuous spectrum you expect to see for a blackbody.

A hot, low density source, like a neon sign, produces certain emission lines without the continuous spectrum.

A hot, high density source produces a continuous spectrum, but if it is behind a cooler low density gas (which absorbs certain colors), then you see an absorption spectrum, just like the Sun.

The Sun's Absorption Line Spectrum

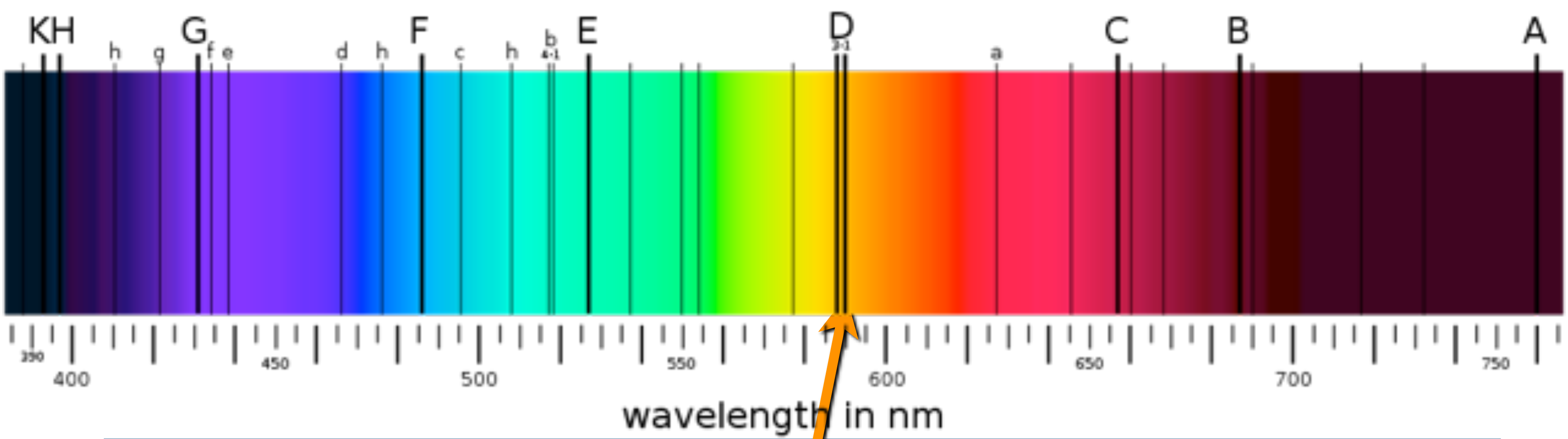
- The Sun's photosphere produces a thermal radiation (continuous) spectrum
- Absorption lines are caused by atoms in the Sun's (or Earth's) atmosphere



The light that moves outward through the sun is a continuous spectrum since the interior regions of the sun have high density. However, when the light reaches the low density region of the solar atmosphere called the chromosphere, some colors of light are absorbed. Thus, when astronomers take spectra of the sun and other stars they see an absorption spectrum due to the absorption of the chromosphere.

How does the Sun's spectrum tell us about its composition?

- Each type of atom absorbs (and emits) a unique set of spectrum lines
- For example, only sodium can produce the pair of lines indicated below
- So, the Sun must contain sodium

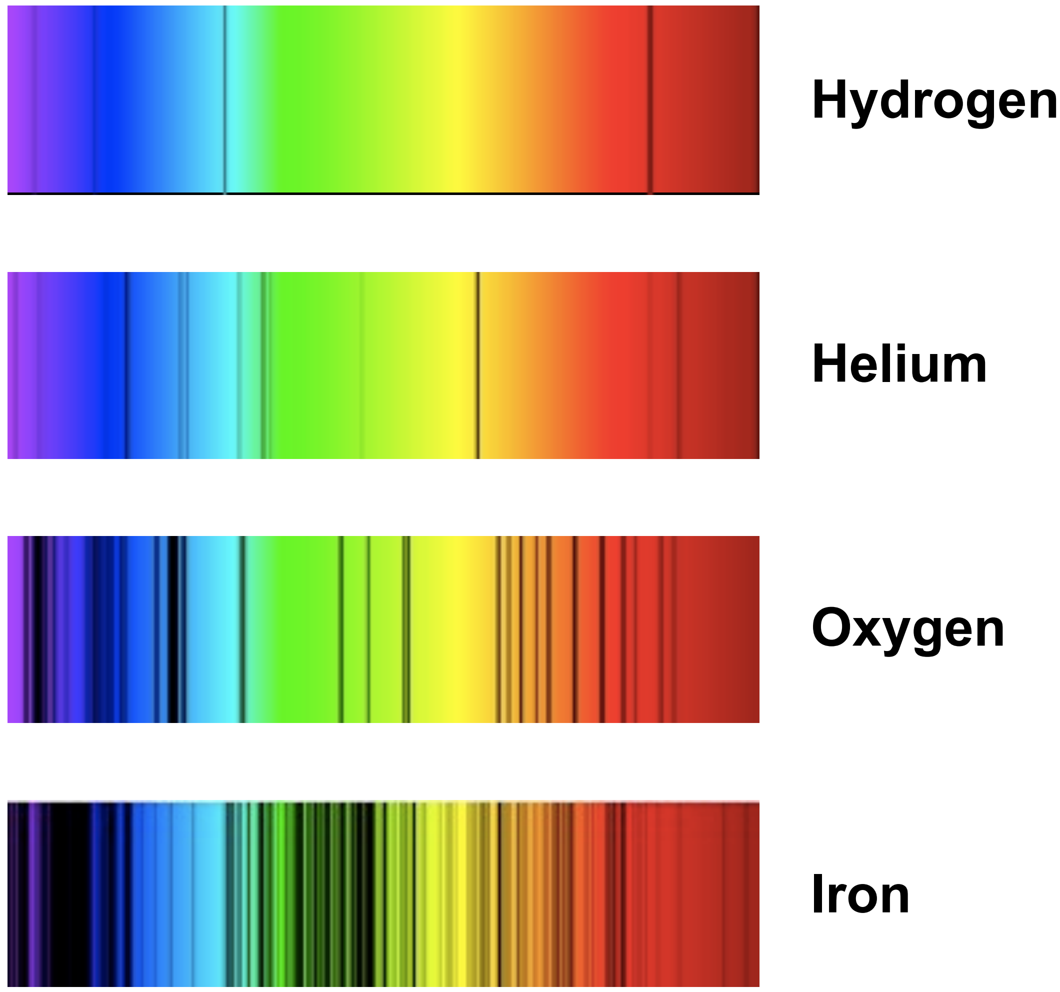


Sodium lines in the Sun's spectrum

Spectrum Lines = Atomic Fingerprints

An atom's spectrum is like a fingerprint...

...or a unique barcode



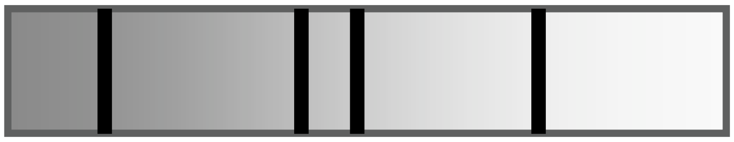
Note that the lines are the same in absorption or emission.

Identifying the elements in the Sun's atmosphere by identifying the lines in its spectrum is a relatively straightforward procedure. Over 90 elements in the Sun have been identified this way.

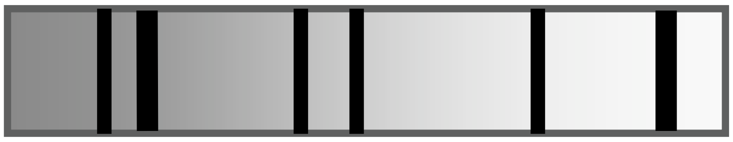
The element helium was discovered in the Sun's spectrum first — before helium (from the Greek word helios, meaning 'Sun') was found on Earth.

Thought Question

Below are two spectra of the Sun. One of the spectra was obtained from a telescope on Earth's surface. The other was obtained from a telescope in space. Which one was observed from Earth's surface?



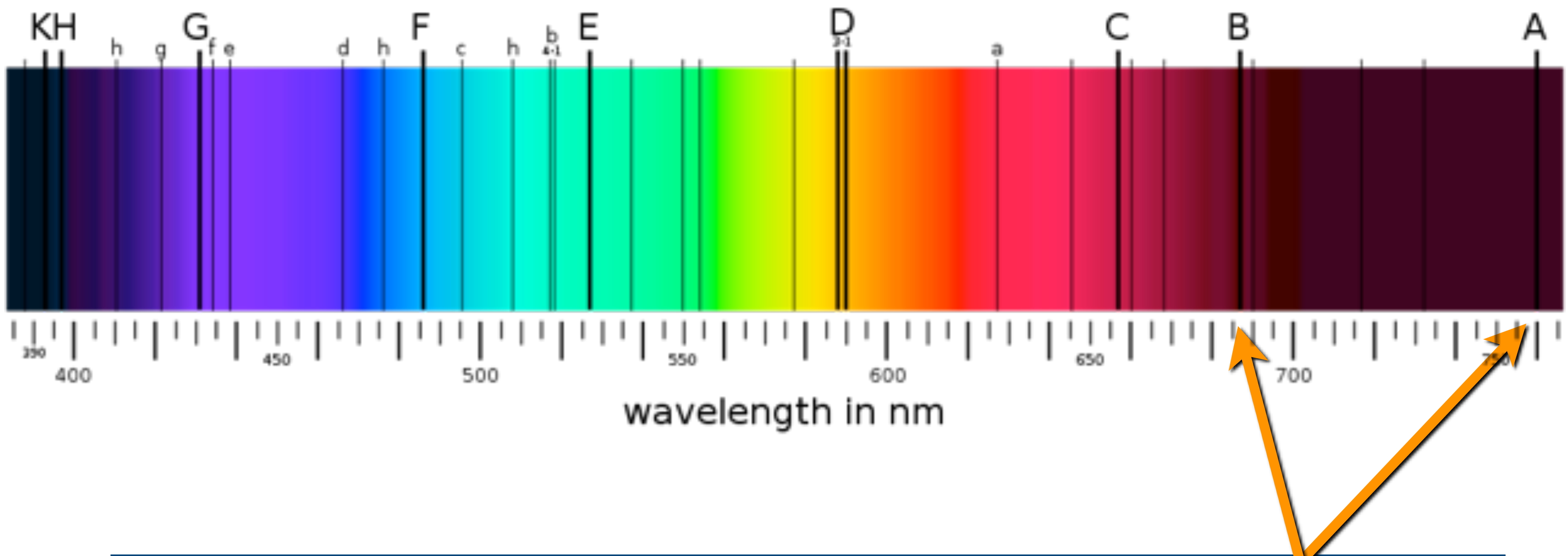
Spectrum A



Spectrum B

Answer: Spectrum B

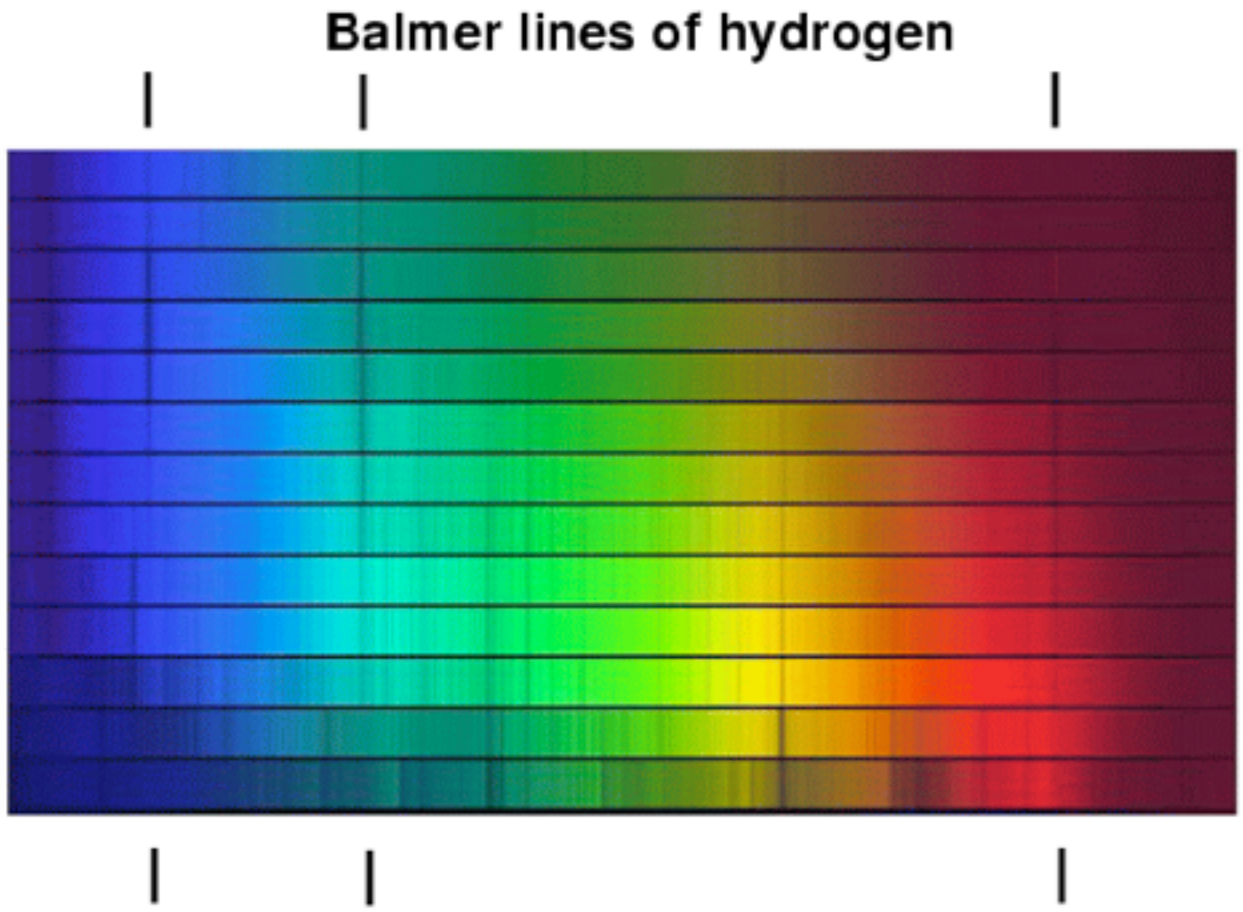
The Earth's atmosphere is cooler than the Sun's surface so elements in the Earth's atmosphere will create extra absorption lines.



Lines A & B are absorption lines from O_2 in the *Earth's atmosphere*!

How does a star's spectrum tell us it's temperature?

Different stars have different spectra



Notice that we see different patterns of spectrum lines for different stars

An early classification scheme divided stars into classes A–Q based on the the strength of hydrogen absorption lines.

The varying strength of spectrum lines was initially interpreted as stars of different compositions, i.e. a star with weak hydrogen lines would have little hydrogen. It was assumed that stars had an overall composition similar to the Earth.

Annie Jump Cannon revises spectral classification

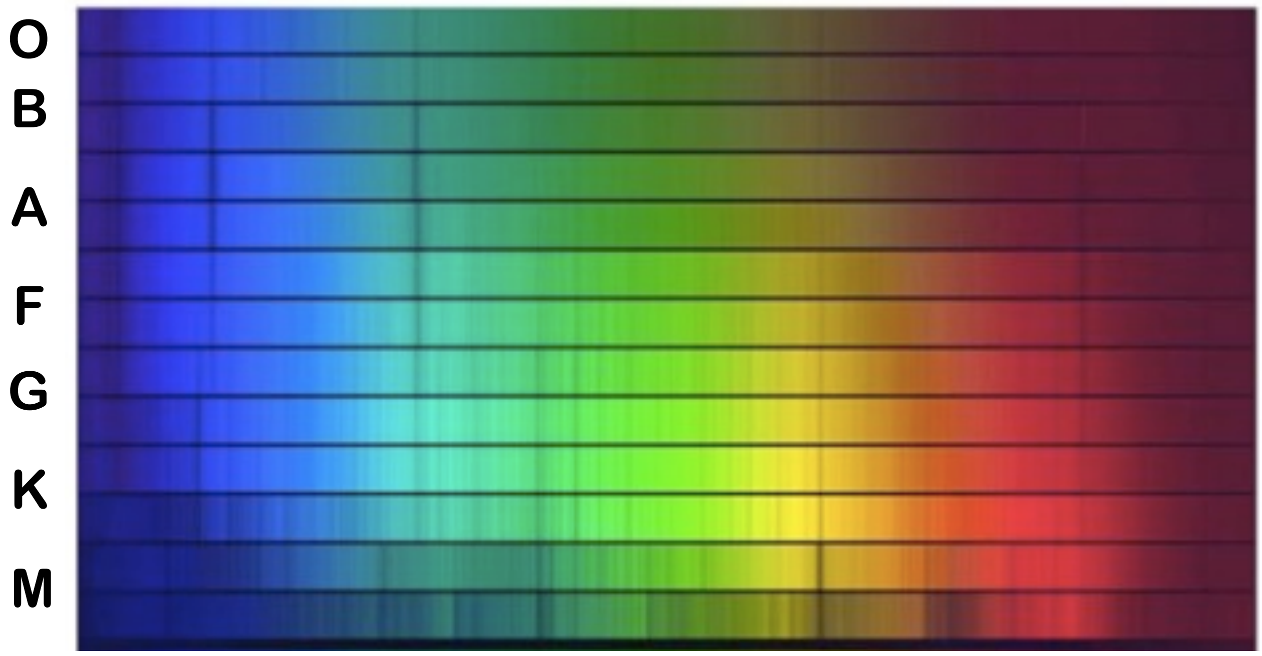
- Worked at the Harvard Observatory starting in 1896
- Classified stellar spectra for star catalog
- Reduced the spectral classes from 17 (A-Q) to 7 (A B F G K M O)

Classified the spectra of over 230,000 stars!

Much of the basic work of classification was done by Annie Jump Cannon. She worked at Harvard Observatory on the Draper Catalog, mapping and defining all the stars in the sky to photographic magnitude of about 9. Her Henry Draper Catalogue listed nearly 230,000 stars was valued as the work of a single observer.

At this time the women astronomers doing this groundbreaking work at Harvard Observatory were paid 25 cents a day. The secretaries at Harvard were paid more.

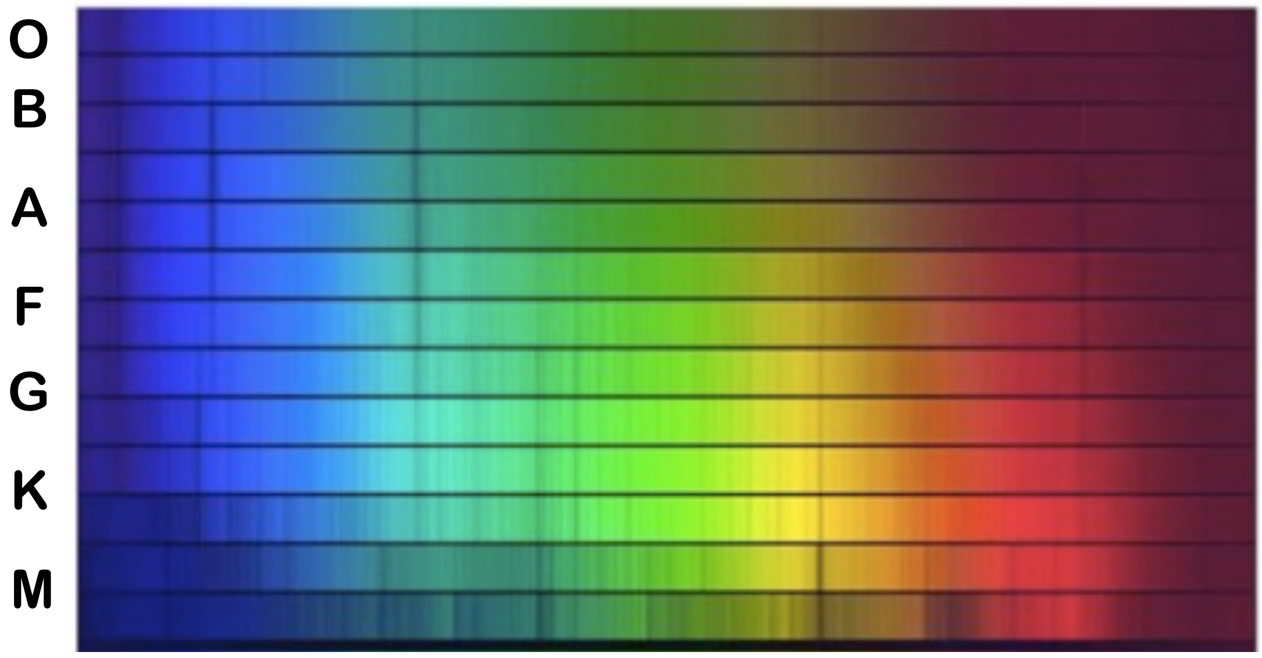
A Pattern



- Annie Cannon ordered the classes by common spectrum lines
- **O B A F G K M**
- Called the *spectral sequence*

But what do the classes mean?

Oh Be A Fine Girl, Kiss Me!

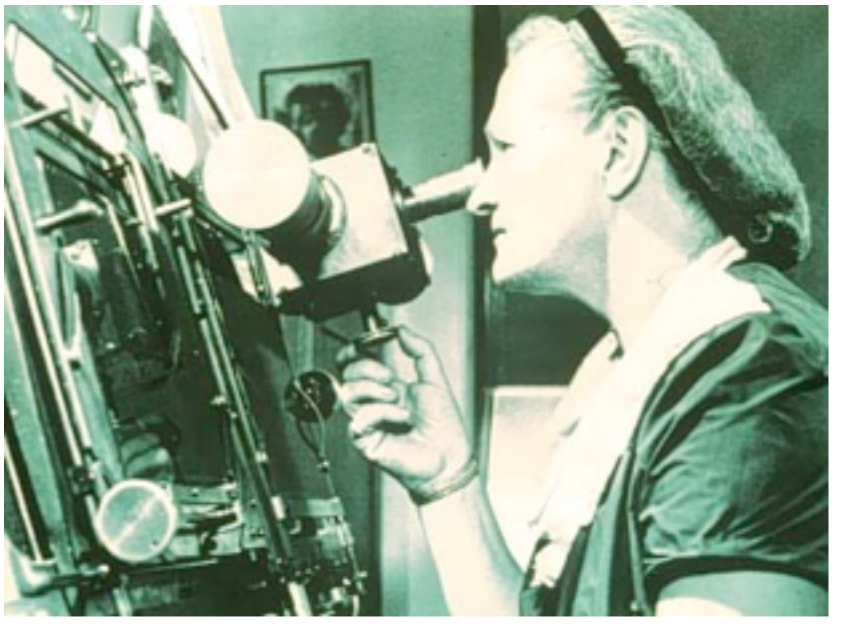


- **O B A F G K M**
- One mnenomic is: **O**h, **B**e **A** **F**ine **G**uy/**G**irl **K**iss **M**e

But what do the classes mean?

Cecilia Payne discovered what stars are made of

- Wrote her Ph.D. thesis on how **temperature** affects the strength of spectrum lines
- Suggested stars actually all have similar make-ups
  - 98% H and He
  - Small amounts of heavier elements



Cecilia Payne figured out the true chemical composition of the universe!

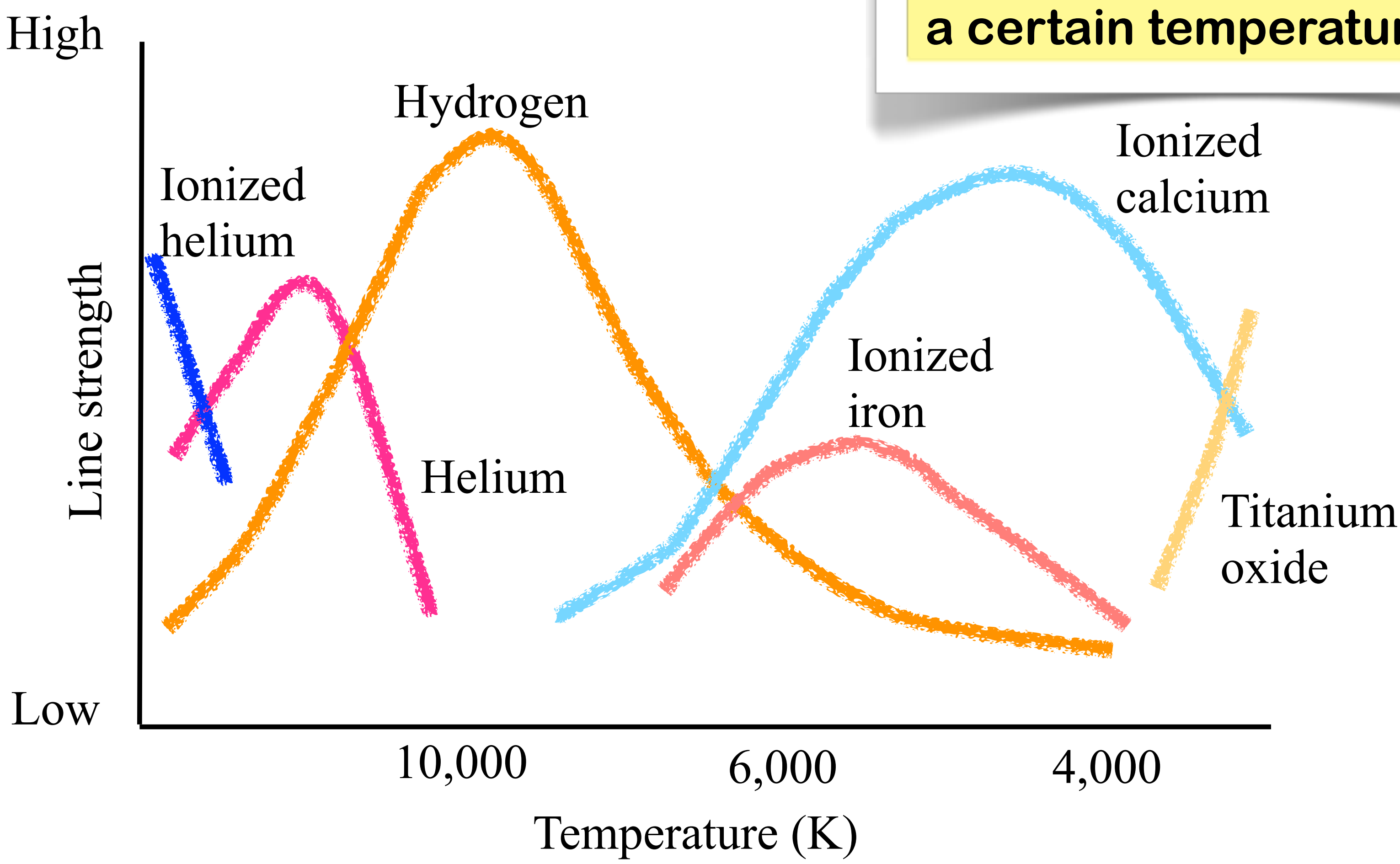
At that time, scientist thought the Sun had the same make-up as the Earth.

The first Ph.D. in astronomy from Harvard University (male or female). It is fair to say that Cecilia Payne—whose thesis has been called the most important doctoral work in the history of astronomy—figured out the true chemical composition of the universe.

Also, first woman to be promoted to full-professor from within the faculty at Harvard's Faculty of Arts and Sciences. Later, with her appointment to the Chair of the Department of Astronomy, she also became the first woman to head a department at Harvard.

Strength of spectrum lines varies with temperature

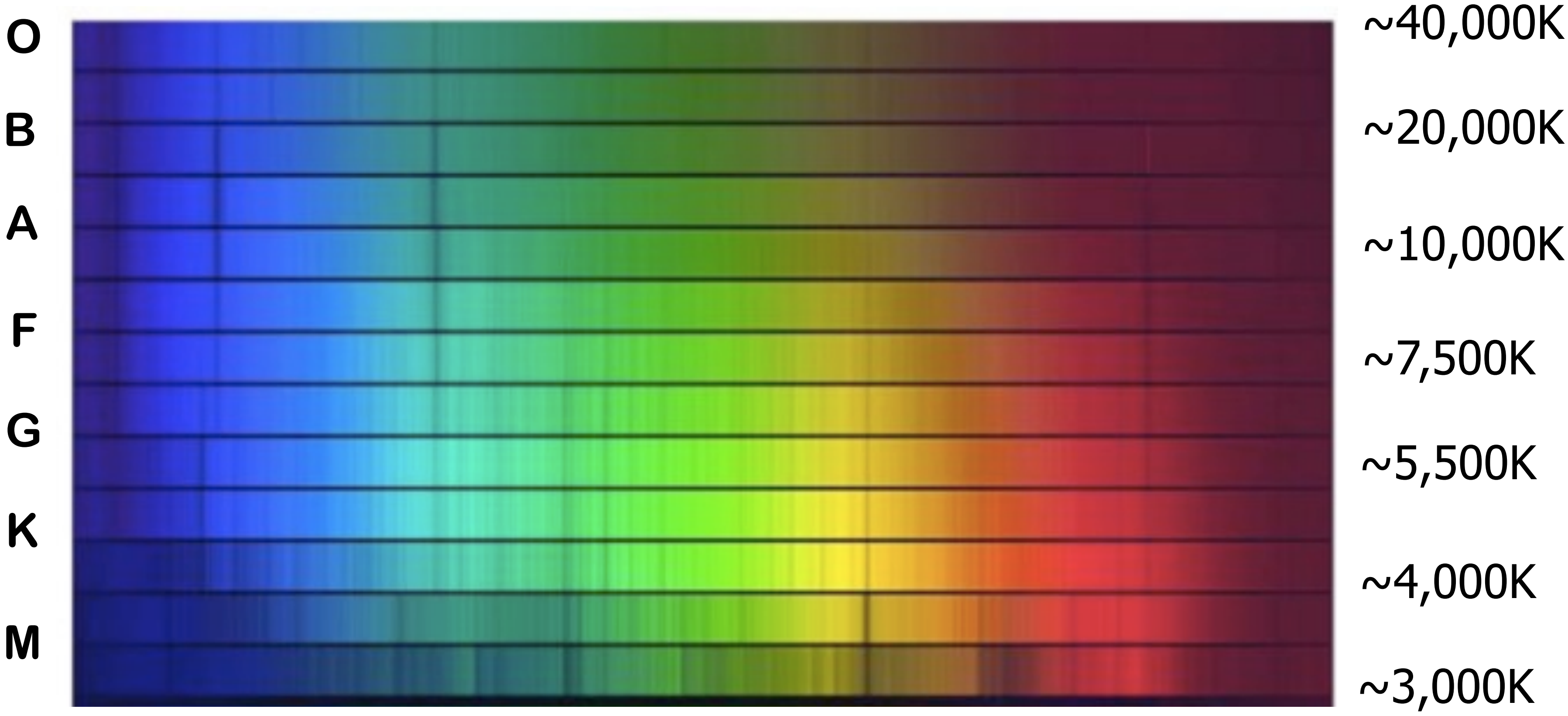
The lines of each atom or molecule are strongest at a certain temperature



The wavelength of spectrum lines does not change with temperature. Each type of atom, ion, or molecule produces spectral lines that are weak at high and low temperatures and strong at some intermediate temperature.

Note – Hydrogen lines are strongest at 10,000K. So ‘A’ stars, those with the strongest hydrogen lines, have temperatures of about 10,000 K.

Spectral class reveals a star's temperature…



Stellar spectral classes, arranged from hottest (O) to coolest (M)

Surface Temperatures of Stars

- Hottest stars
  - ~50,000 K
  - Blue in color
- Coolest stars
  - ~3,000 K
  - Red in color
- Sun's surface temperature is ~5,800 K

Stars come in a wide range of surface temperatures!

Properties of Stars

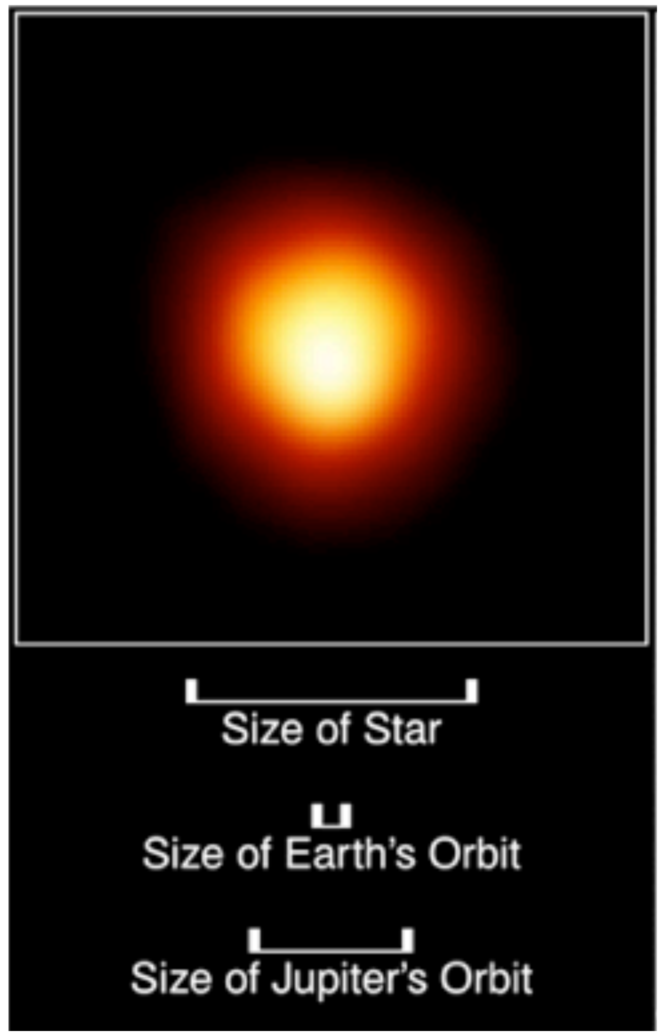
- Luminosity
  - From 0.0001 L_{Sun} to 1,000,000 L_{Sun}
- Mass
  - From 0.08 M_{Sun} to 150 M_{Sun}
- Temperature
  - From 3,000 K to 50,000 K
  - T_{Sun} ~ 5,800 K

Stars come in a wide variety!

A review of the properties of stars we have studied so far.

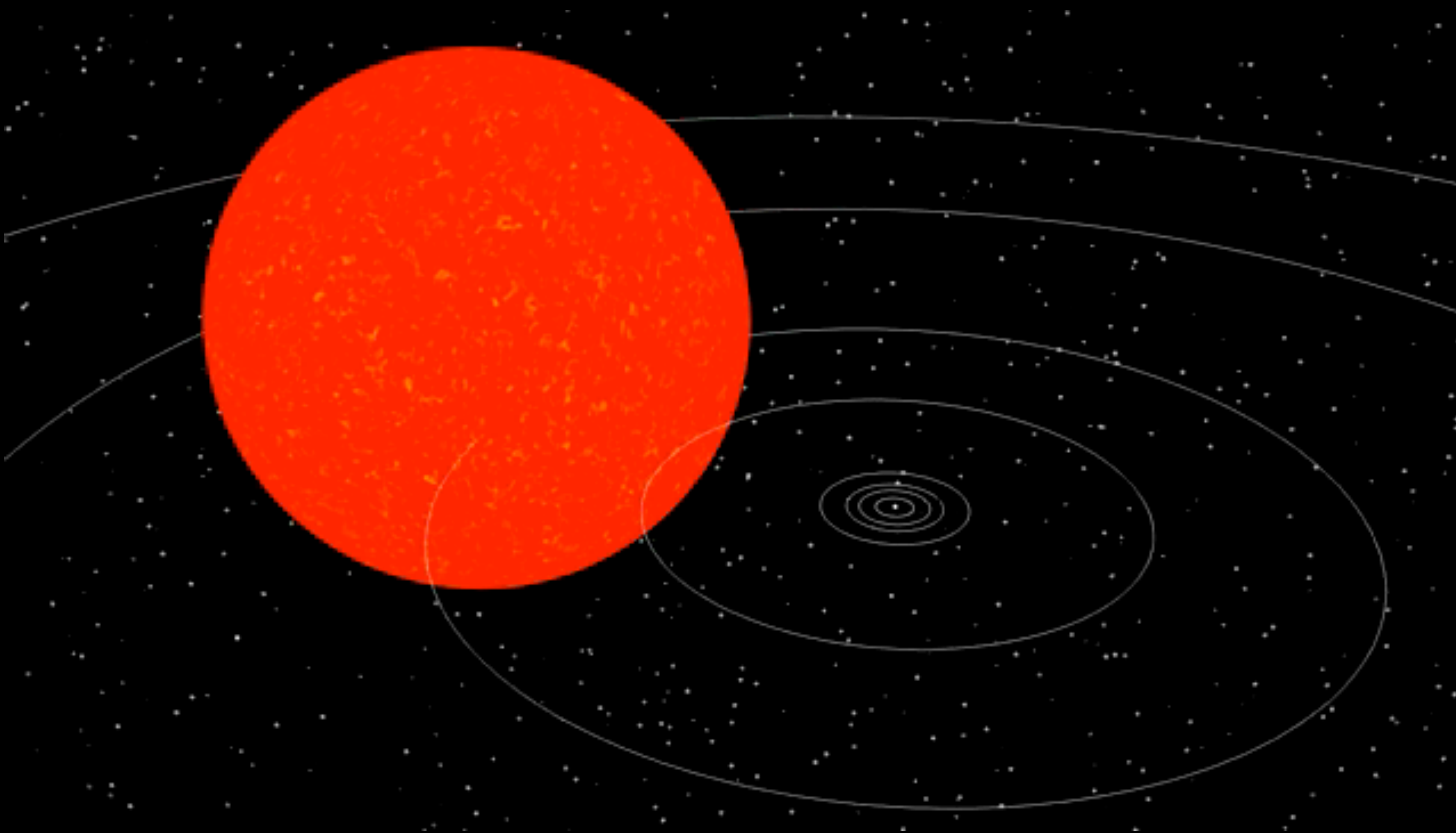
Measuring Star Diameters

- The vast majority of stars are too far away to measure their sizes
  - Only ~12 can be imaged as disks
  - The rest are seen as points of light
- So, astronomers determine their sizes from **luminosity** and **temperature**



Betelgeuse imaged by the Hubble Space Telescope

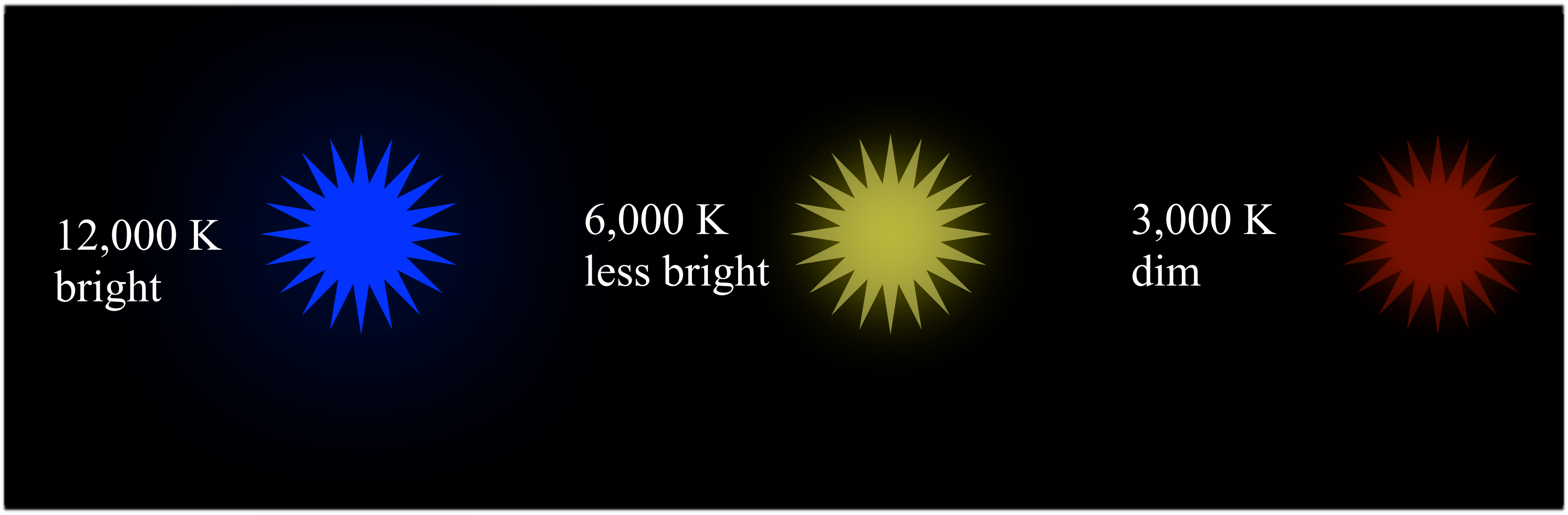
Betelgeuse Compared to our System



http://www.youtube.com/watch?v=zppa-Zkp74E

What is the relationship between luminosity, temperature, and size?

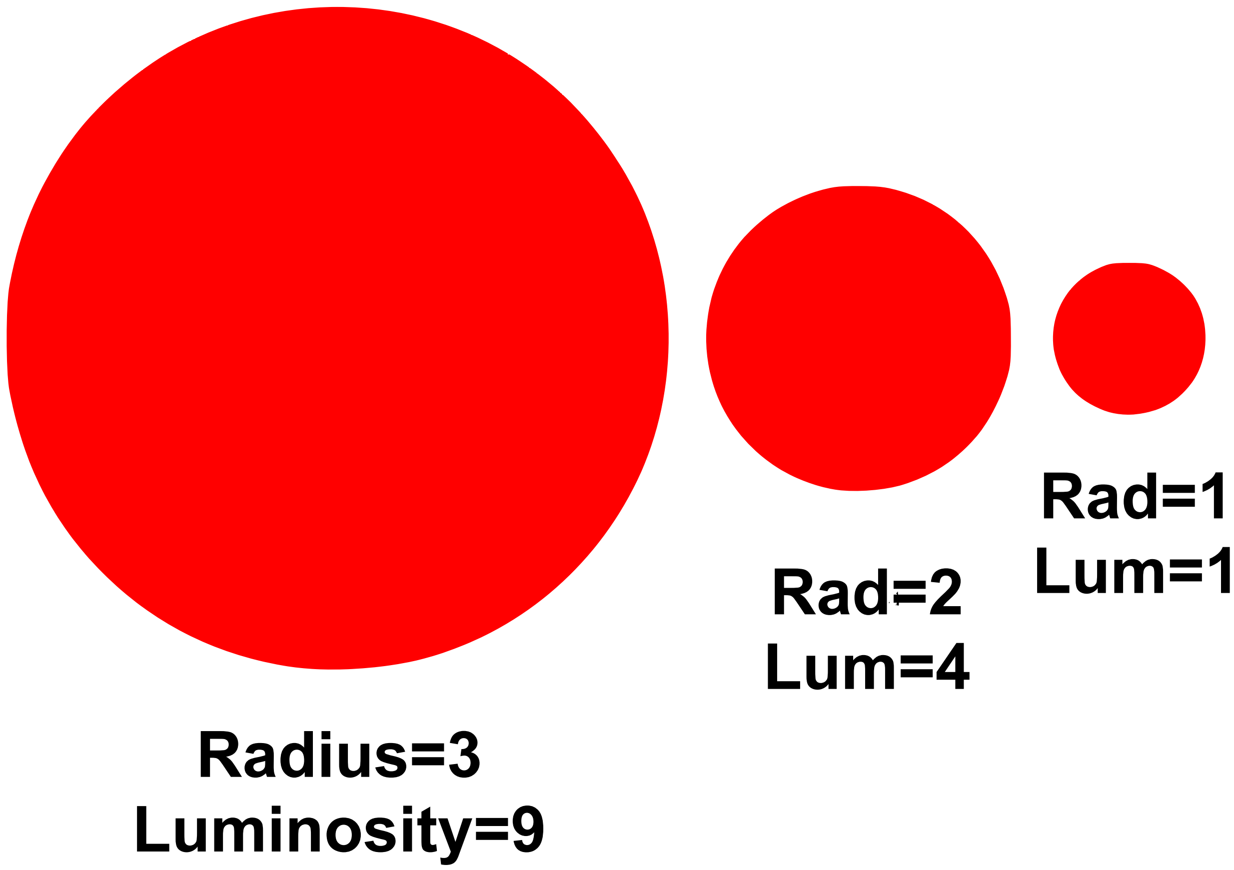
Hotter objects are brighter



For stars of the same size, the hotter one emits the most (and the bluest) light

Remember thermal radiation: (1) Hotter objects emit more light per unit area, and (2) Hotter objects emit light with a shorter (bluer) peak wavelength.

But Bigger objects are also brighter



For stars of the same temperature, the larger the star, the greater the luminosity

Luminosity also depends on the surface area of the star. Bigger surface area means more energy radiated.