Announcements

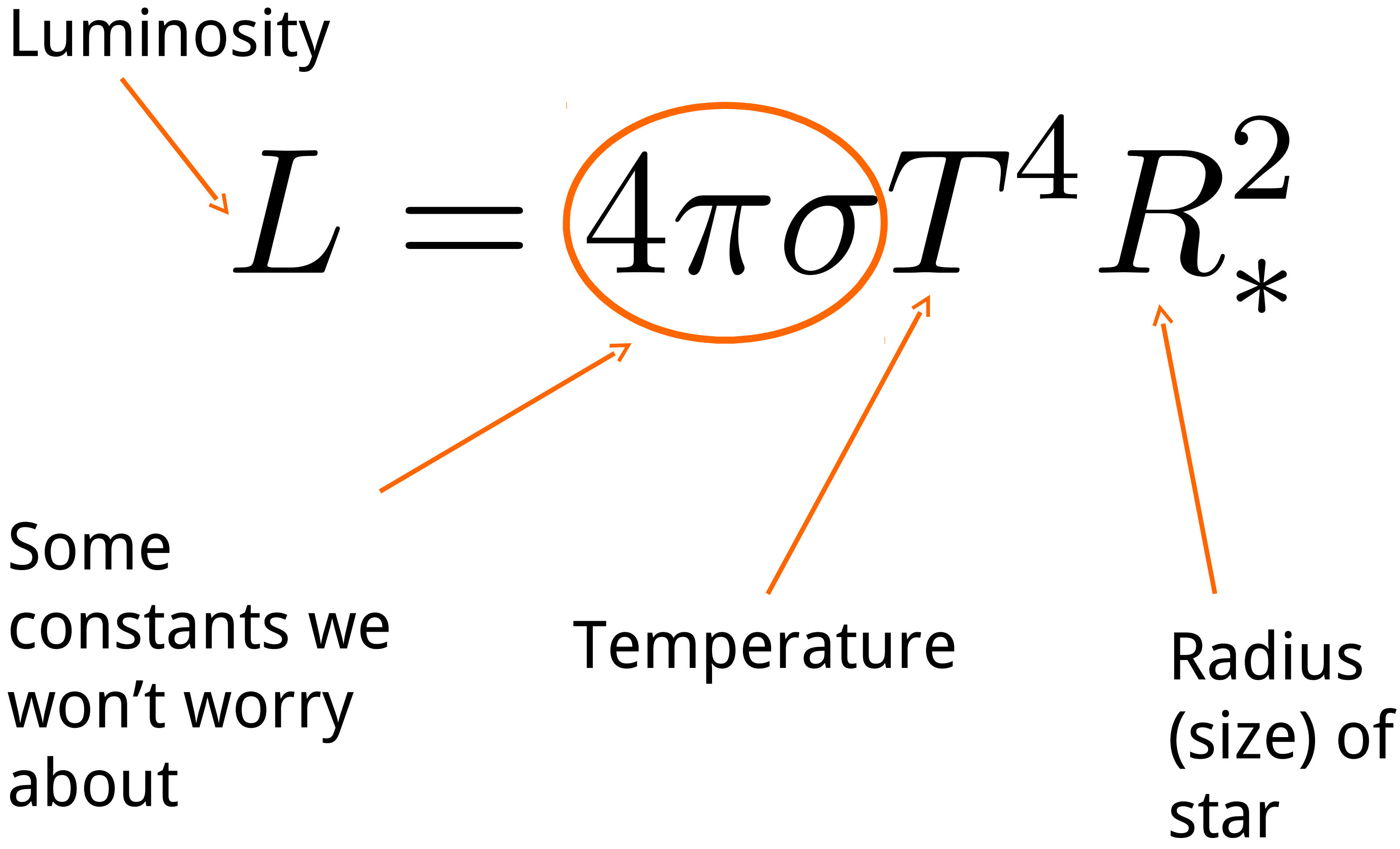
- Quiz 6 due Monday – this covers stars, Chapter 10
- Practice problems: Problem sets 6A and 6B
- Upcoming schedule: we'll start Chapter 11 on Monday

Astronomy 103

The Stars

Please read chapter 10

The brightness of a star depends on its **temperature** and its **size**. Hot stars are (much!) brighter, and larger stars are also brighter.



Luminosity

$$L = \boxed{4\pi\sigma} T^4 R_*^2$$

Some constants we won't worry about

Temperature

Radius (size) of star

Let’s get some practice using this formula:

The sun shines with 1 solar luminosity.
The sun is 1 solar radius.
And the temperature is 6000 K.

1. How much brighter is a star that is 4 times larger, but the same temperature?

$$L = 4\pi\sigma T^4 R_*^2$$

A the same

B 2 times brighter

C 4 times brighter

D 16 times brighter

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And the temperature is 6000 K.

2. How much brighter is a star that is the same size, but 2 times hotter?

$$L = 4\pi\sigma T^4 R_*^2$$

A the same

B 2 times brighter

C 4 times brighter

D 16 times brighter

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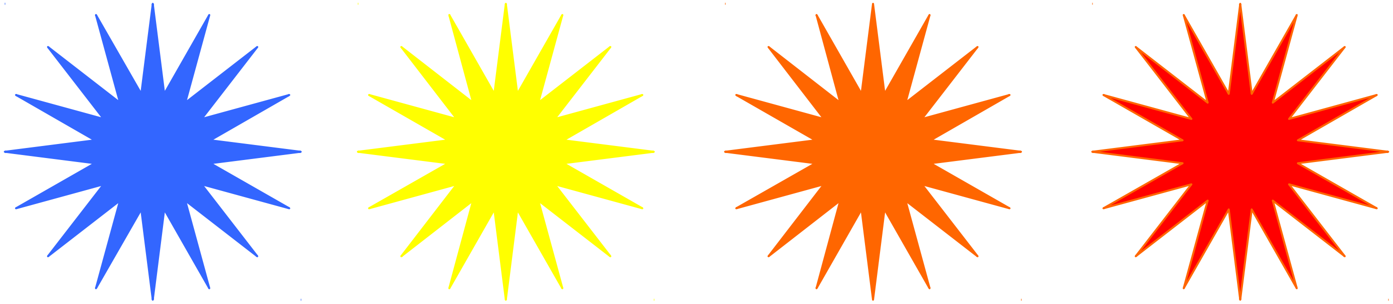


The temperature of the four stars is indicated by their color: the blue star is the hottest, followed by the yellow and orange stars, and the red star is the coldest.

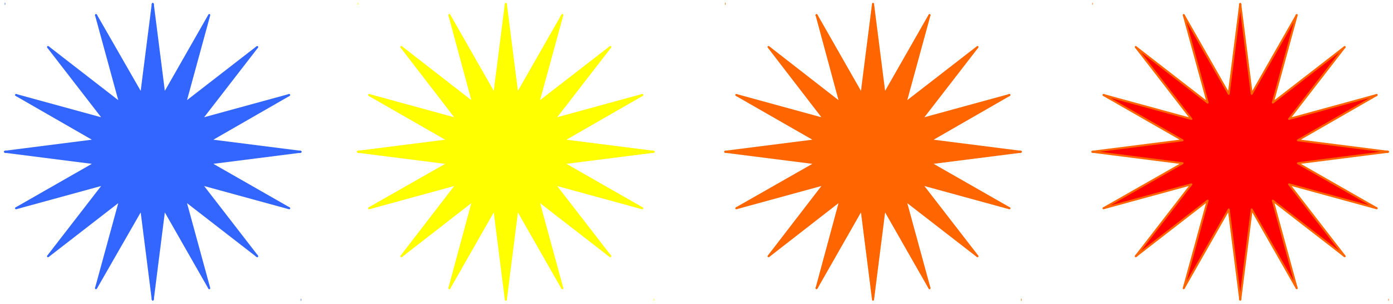
You are studying the red star at right. How many of the four stars shown above could have the same luminosity as the red star?

A 1

B 2

C 3

D 4



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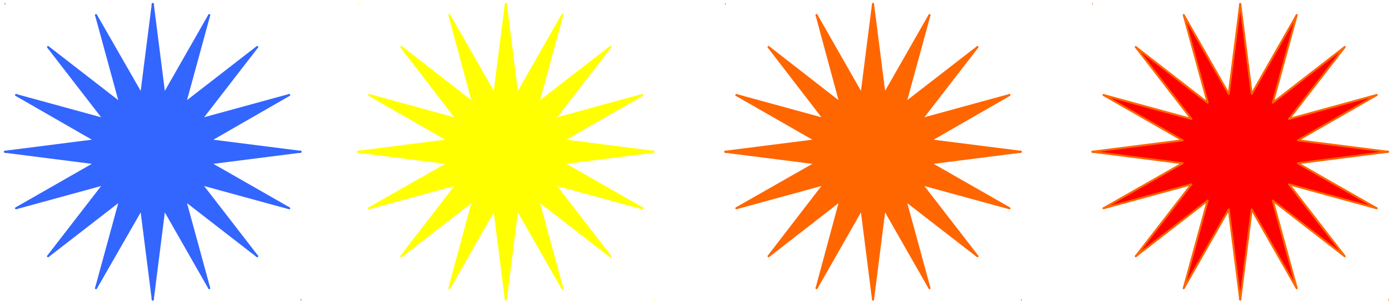
A 1

B 2

C 3

D [✓ 4]



The temperature of the four stars is indicated by their color: the blue star is the hottest, followed by the yellow and orange stars, and the red star is the coldest.

You are studying the red star at right. How many of the four stars shown above could have the same luminosity as the red star?

Luminosity depends on both temperature and radius, so the two red stars will have the same luminosity if they are the same size. Any of the hotter stars could also have the same luminosity if they are smaller.

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The H-R Diagram:

The Most Fundamental Plot in Astronomy

By 1910 astronomers knew the surface temperature of stars and began to ask whether surface temperature was related to brightness.

Ejnar
Hertzsprung

Henry Norris
Russell

The H-R Diagram

In 1911, Hertzsprung looked at the spectra and the brightness of stars in a single cluster of a stars. He plotted each star on a graph whose axes measured brightness and temperature (spectral class) and found a remarkable pattern.

Because all stars in a cluster are at about the same distance, the differences in apparent brightness came from differences in **real** brightness or luminosity (energy emitted per second).

By 1913, Russell had made a similar graph for nearby stars whose distances were known by stellar parallax and so whose luminosities were known.

The H-R Diagram

A plot of temperature vs luminosity for a collection of stars is called the Hertzsprung-Russell diagram or H-R diagram, and it’s the most important tool for classifying and understanding stars.

Luminosity

proportional to

If the stars are all at the same distance:

$$L \propto B$$

Apparent brightness

This is what Hertzsprung did

Or if we know the distances to the stars

$$L = B \times 4\pi d^2$$

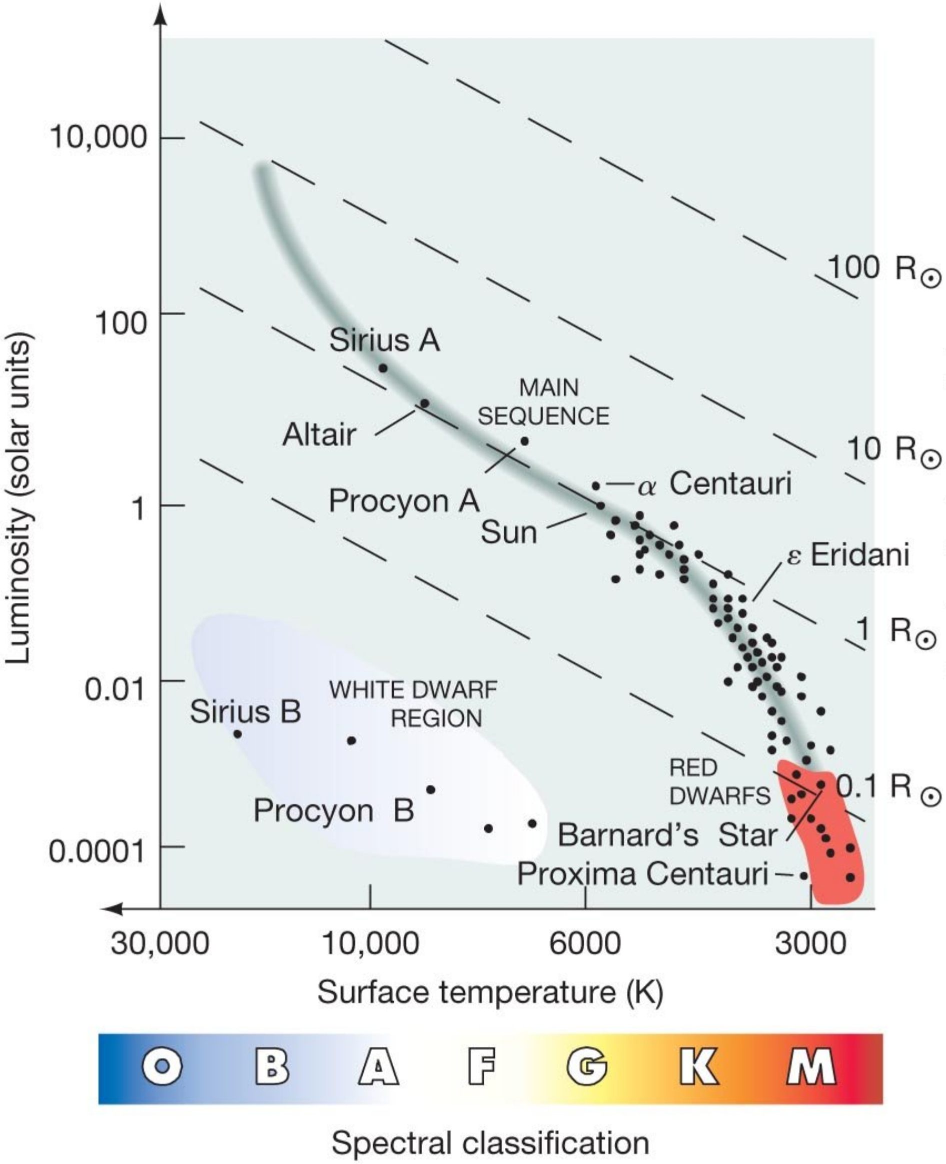
This is what Russell did

distance

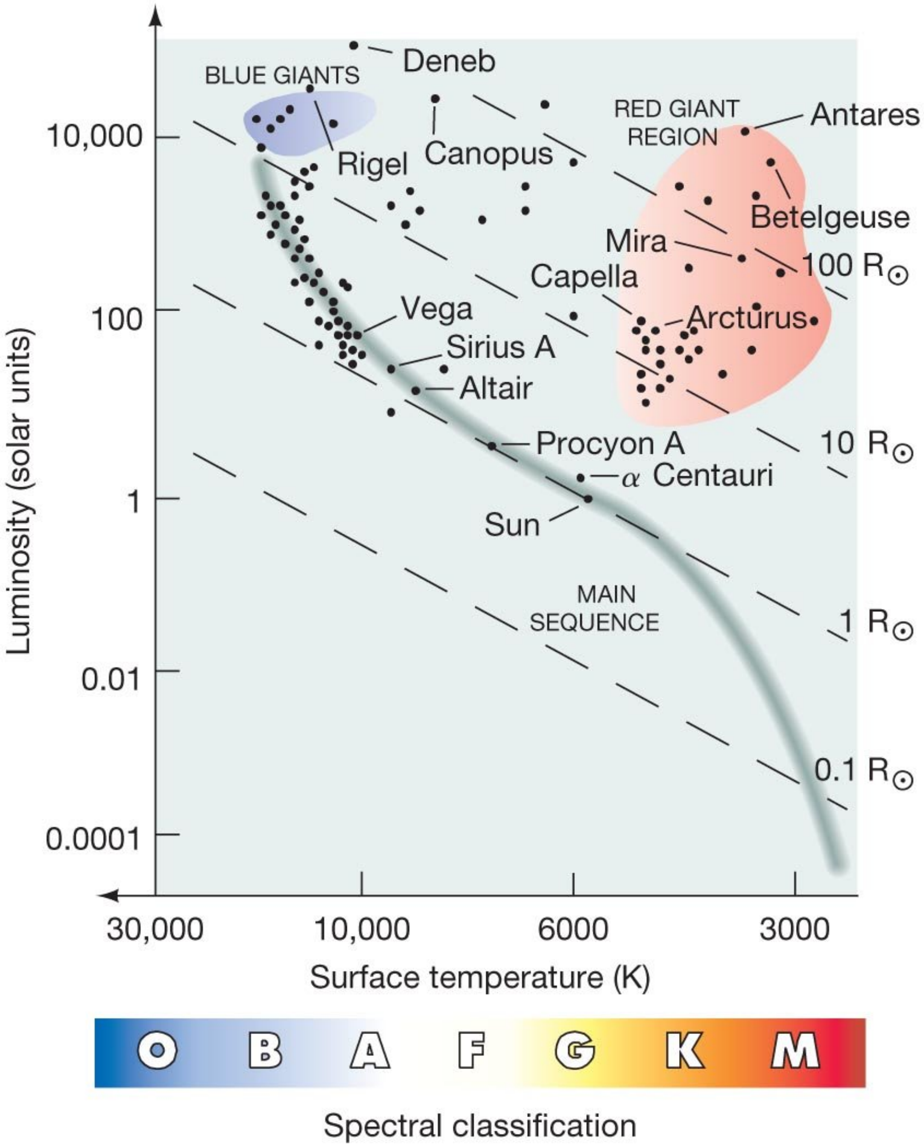
Hertzsprung-Russell Diagram

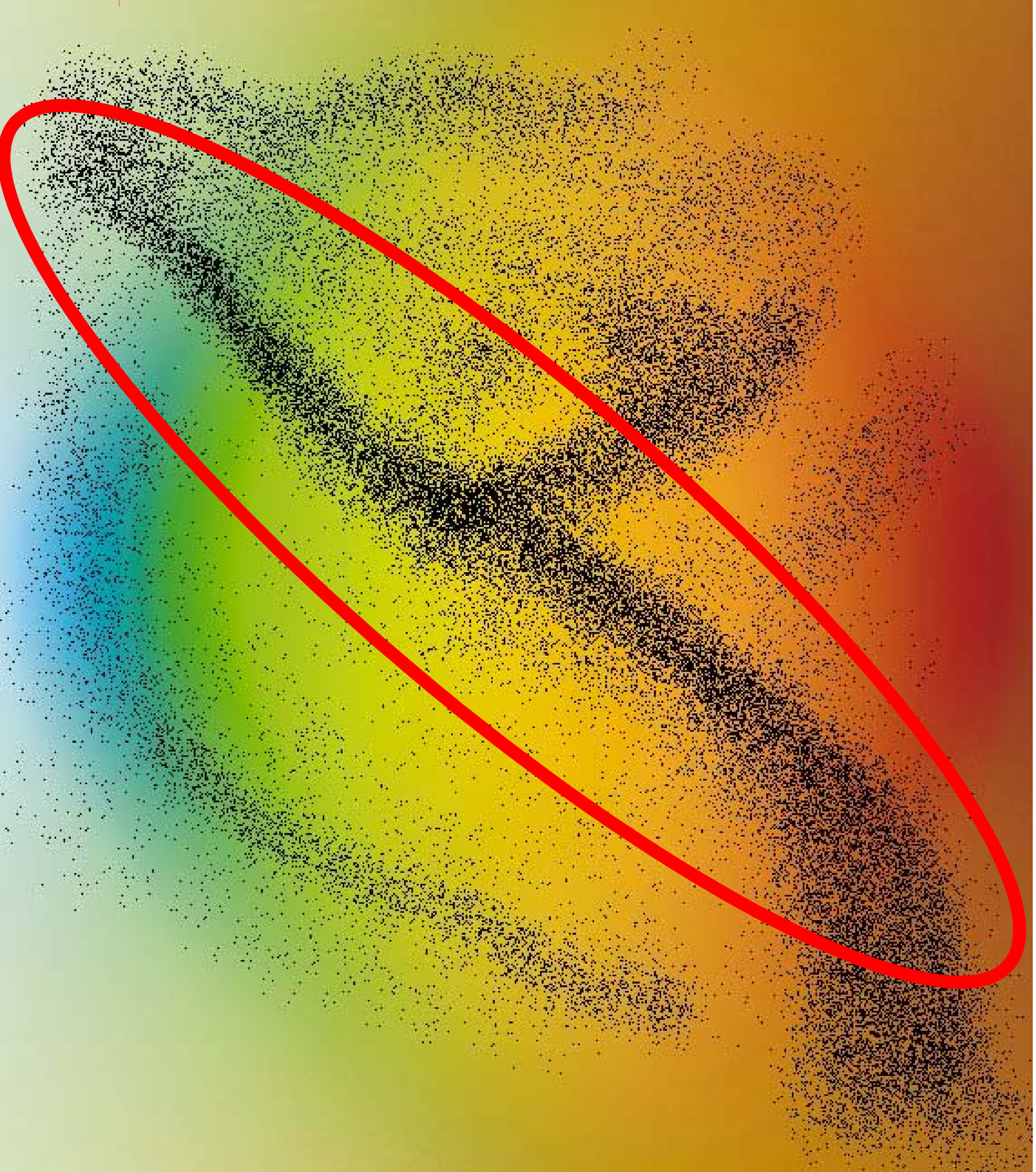
Source: https://www.youtube.com/watch?v=jiSN95WX1NA

H-R diagram for nearby stars



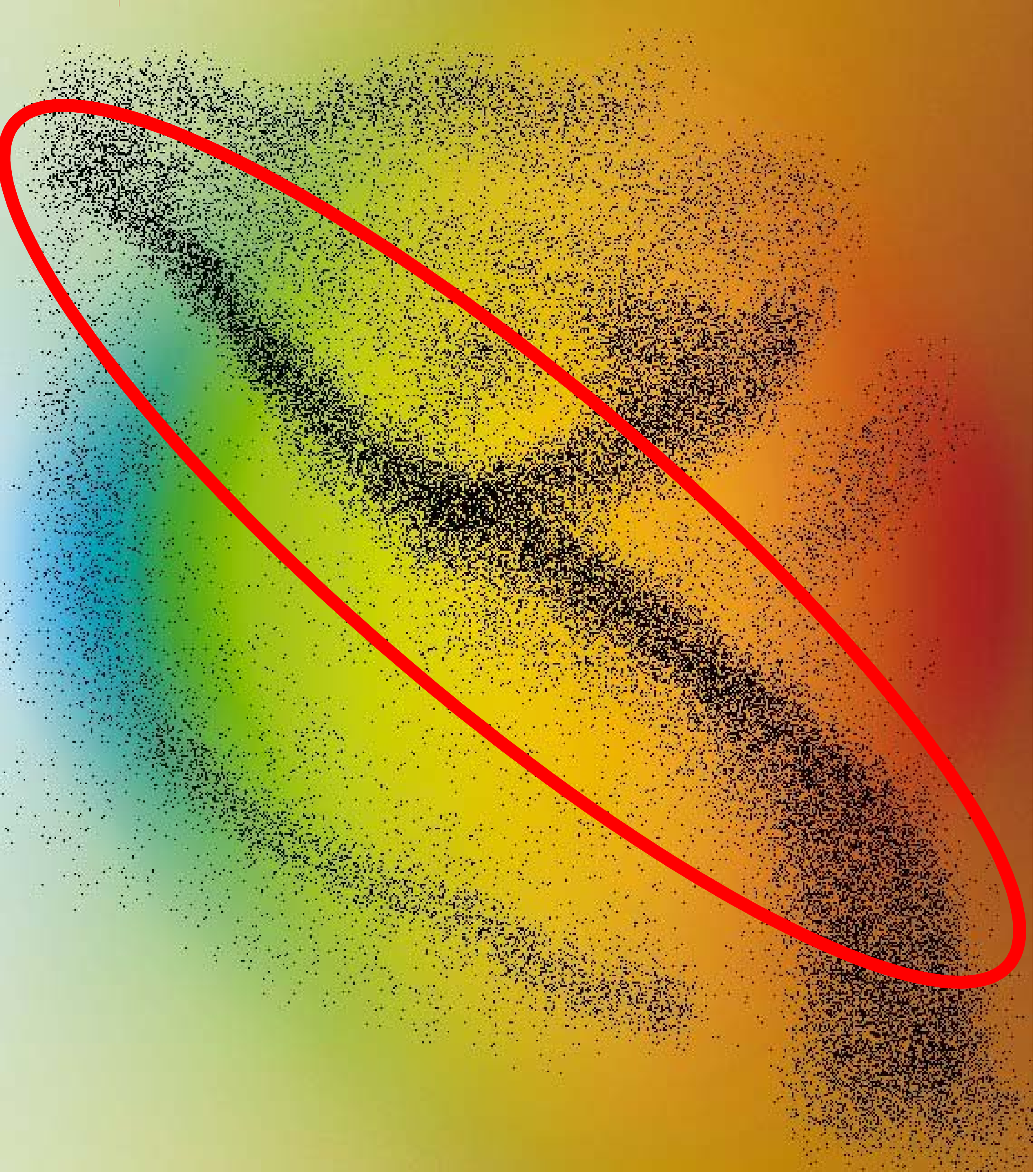
H-R diagram for bright stars





On the H-R diagram, almost all stars lie along a curve called the **main sequence**.

The hottest stars on the sequence are also the most luminous stars, and the coolest stars are the dimmest (least luminous).



About 90% of all stars lie on the main sequence, almost all of them below the Sun (cooler and less luminous than the Sun).

But there were two major surprises that came from finding the temperature and luminosities of stars.

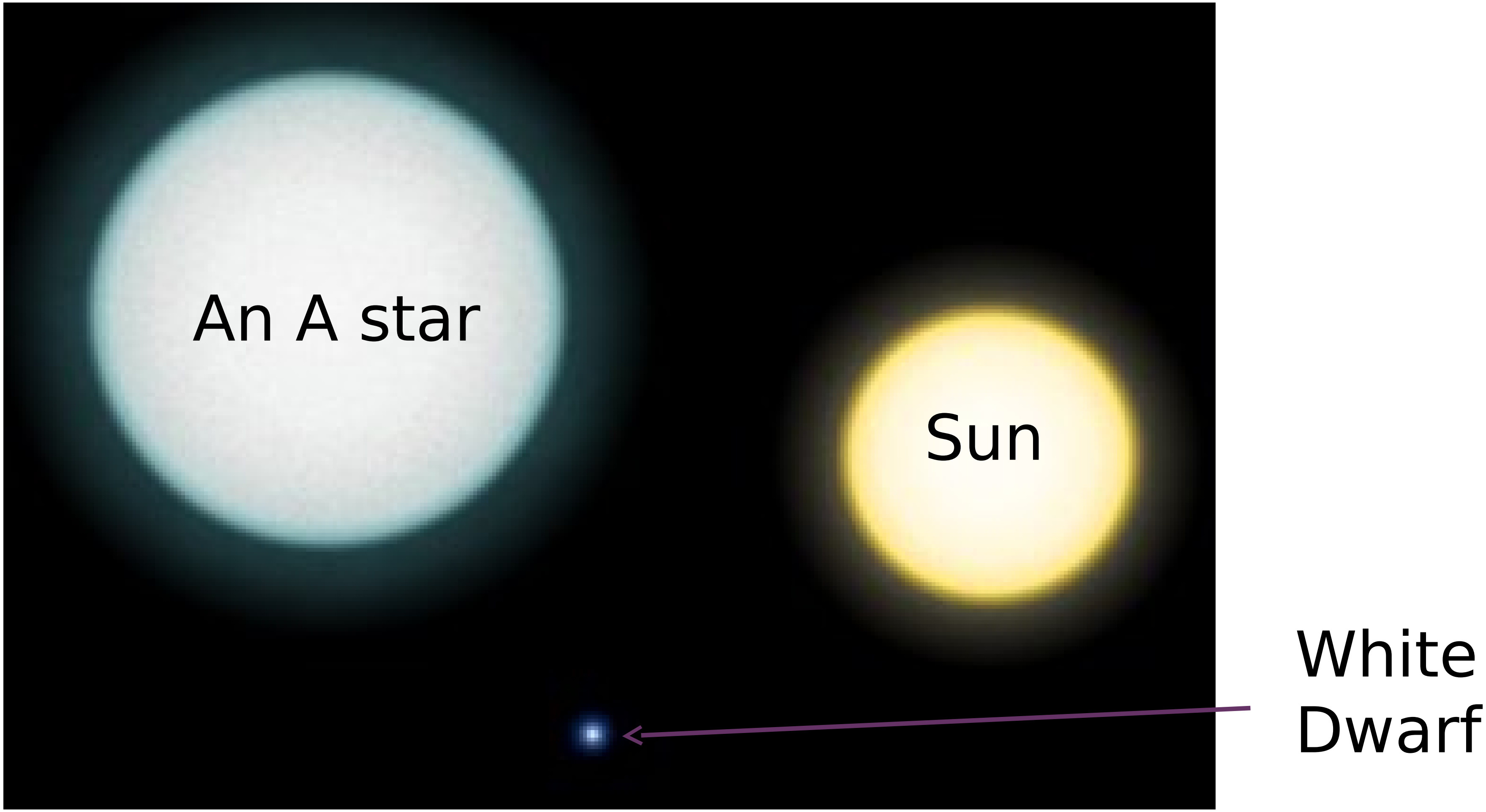
First surprise: There were hot stars that were very dim – their luminosities were very small. What does that mean?

Because it is hotter, each square meter of its surface is bright, emitting more energy than a square meter of the Sun’s surface. Because the total energy emitted by the star is small, the star is much smaller than the Sun.

About 9% of all stars are hot (surface temperatures about 10,000K), but very dim (low luminosity), and are called **white dwarfs** – white = hot, dwarf = small

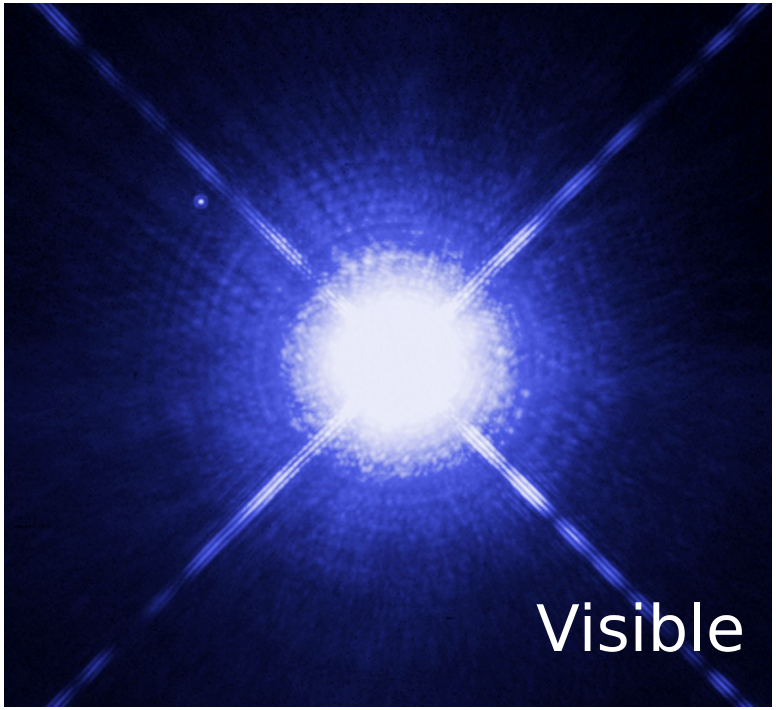
These stars are tiny! About the size of the earth!

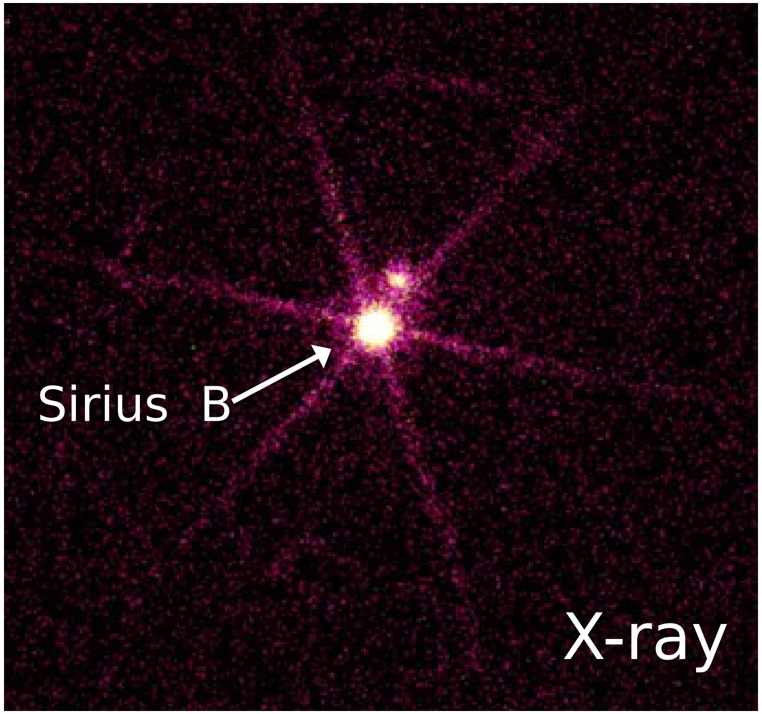
They are tiny – about the size of Earth, 100 times smaller than the sun.



They are hot but not bright because they are so small!

Sirius B: A white dwarf





- Binary companion to Sirius, brightest star in the sky
- Hypothesized in 1844 from observing motion of Sirius, first observed in 1862
- Mass of Sun, smaller than Earth, 25,000 K surface!

Second surprise: A small fraction of stars have cool surfaces but are very luminous.

About 1 % of stars are very luminous, but with cool surfaces, and are called **red giants** – red = cool, giant = large.

These are rare. There are none among the 50 closest stars, but a number of red giants are visible in the night sky because they are so bright.

They are huge, about 100 times larger than the sun in size.

White dwarfs and red giants both represent late stages in the evolution of stars, as we'll learn later.

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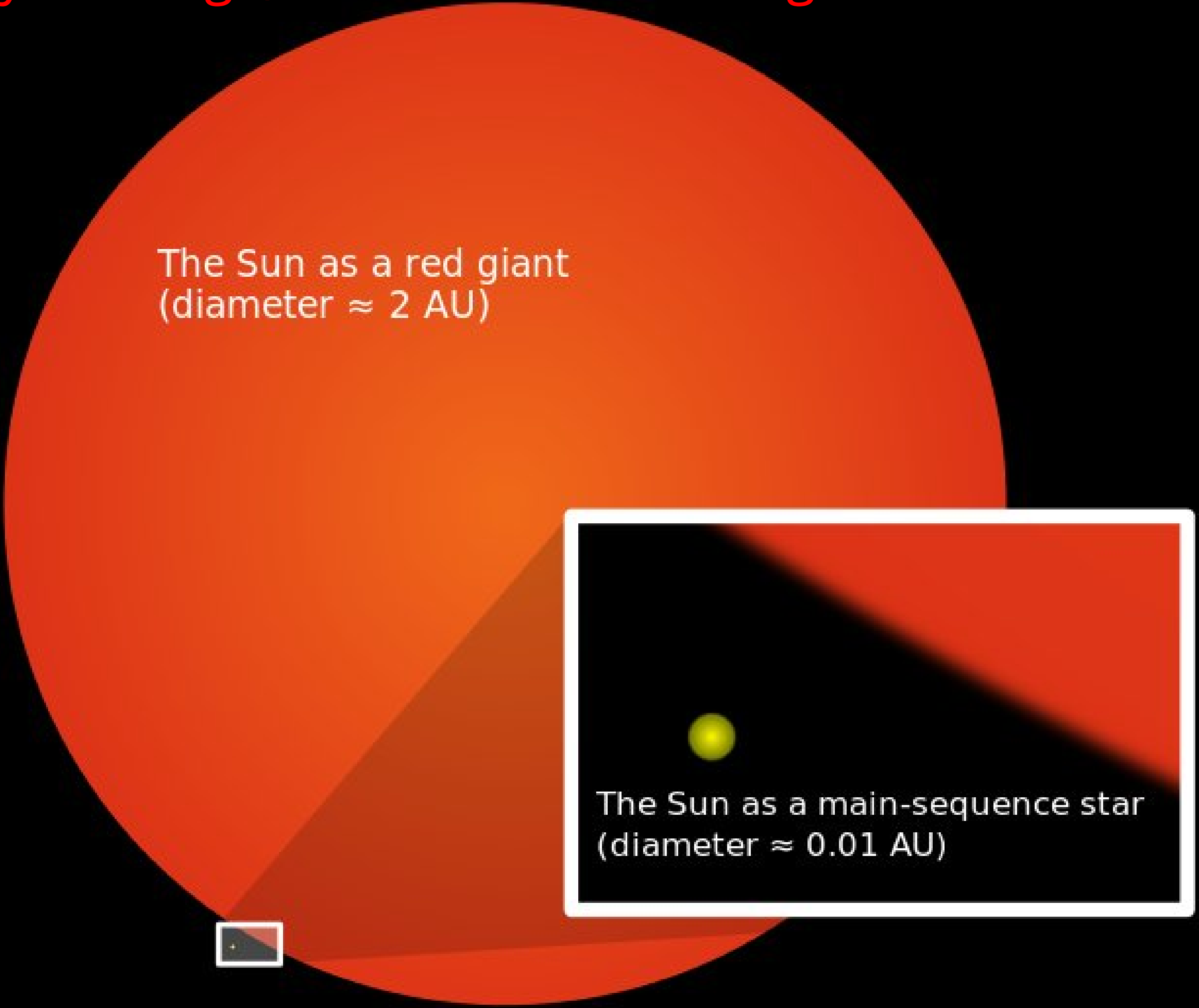
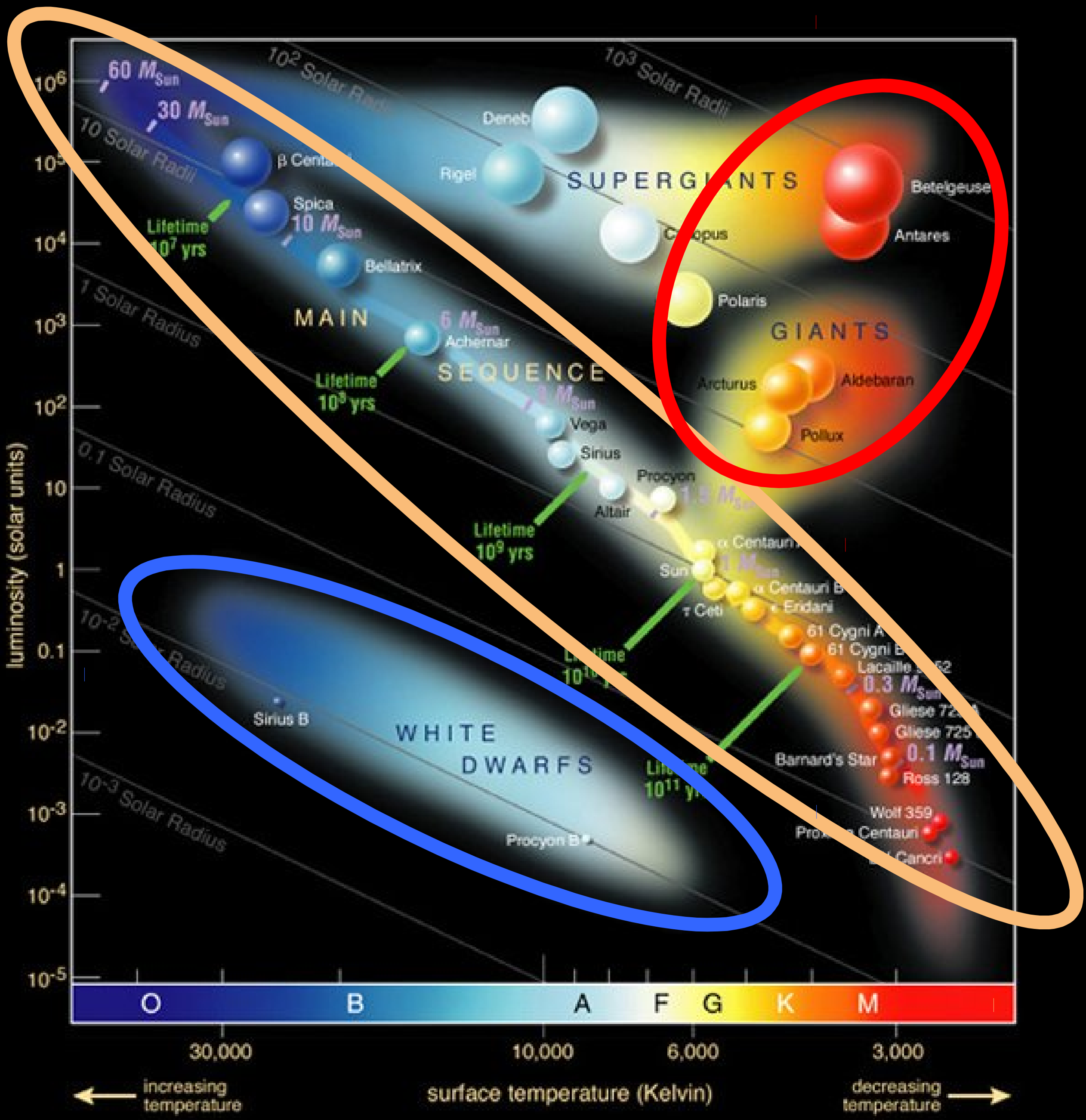
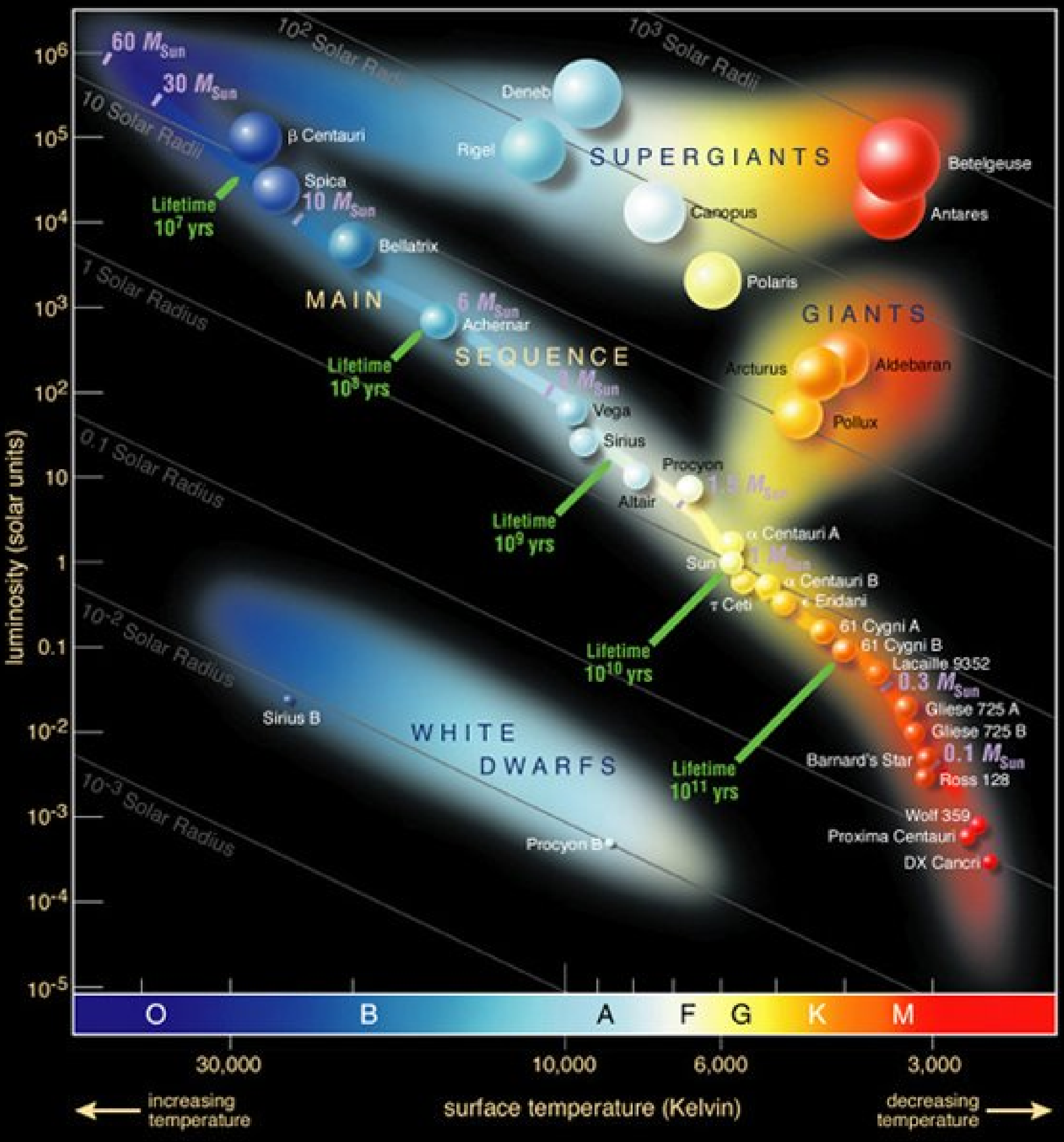


They are bright because they are so BIG!


60 M_{Sun}
30 M_{Sun}
10 M_{Sun}
6 M_{Sun}
3 M_{Sun}
1.5 M_{Sun}
1 M_{Sun}
0.3 M_{Sun}
0.1 M_{Sun}
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Procyon
Altair
α Centauri
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille
Gliese 725
Gliese 725
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
Cancri
Deneb
Rigel
Canopus
Polaris
Betelgeuse
Antares
Arcturus
Aldebaran
Pollux
Sirius B
Procyon B
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

Every star lives on the HR diagram, since all stars all have a temperature and a luminosity.

Understanding how they live and evolve on the HR diagram is an important subject we will study later.

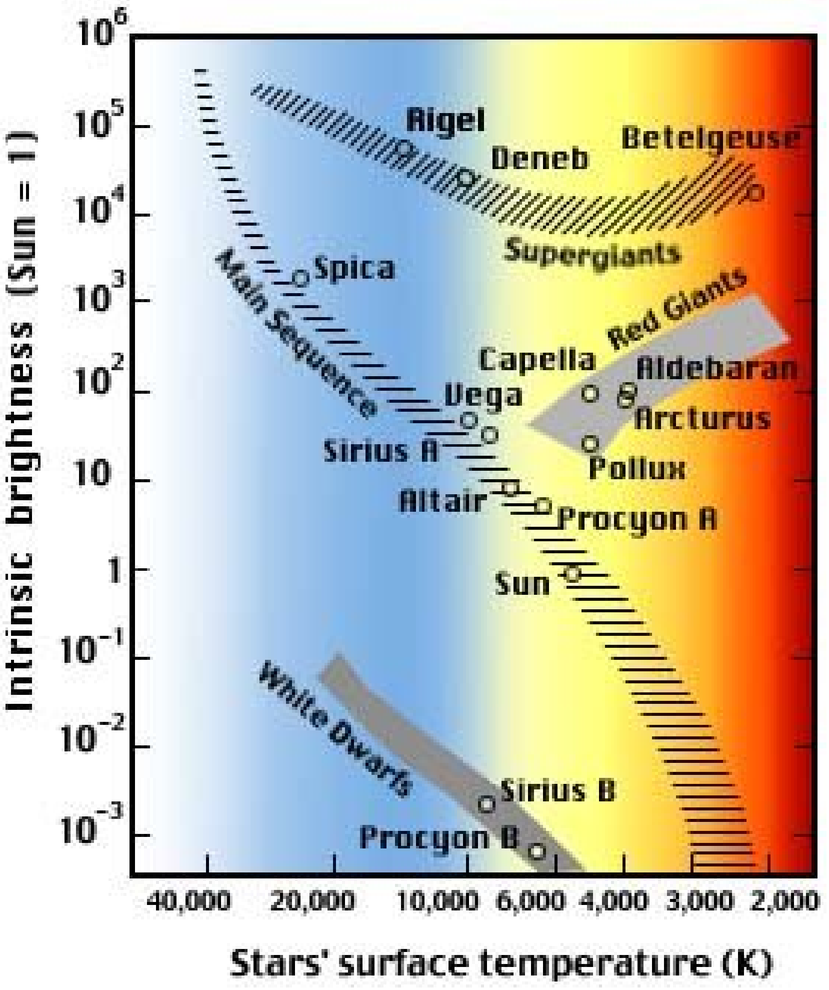


H-R Diagram: Summary

The H-R diagram plots **luminosity** versus surface **temperature**

More than 90% of all stars lie on the **main sequence**.

The hottest stars on the **main sequence** are also the brightest stars, and the dimmest are also the coolest.



Now that we know how to classify stars…. back to their distances

- We start with the distance to close things, and then build on that for farther things
- The first thing was the size of the earth
- From the size of the earth we can deduce the size of earth’s orbit
- From the size of earth’s orbit (1 A.U.), we can get the distance to the nearest stars – stellar parallax
- Now knowing the stellar parallax we can get the luminosity of the nearest stars

Standard Candles

From the distances to the closer stars, we know the luminosity of each type of main sequence star.

Main sequence stars in this way become **standard candles** – something of a known luminosity.

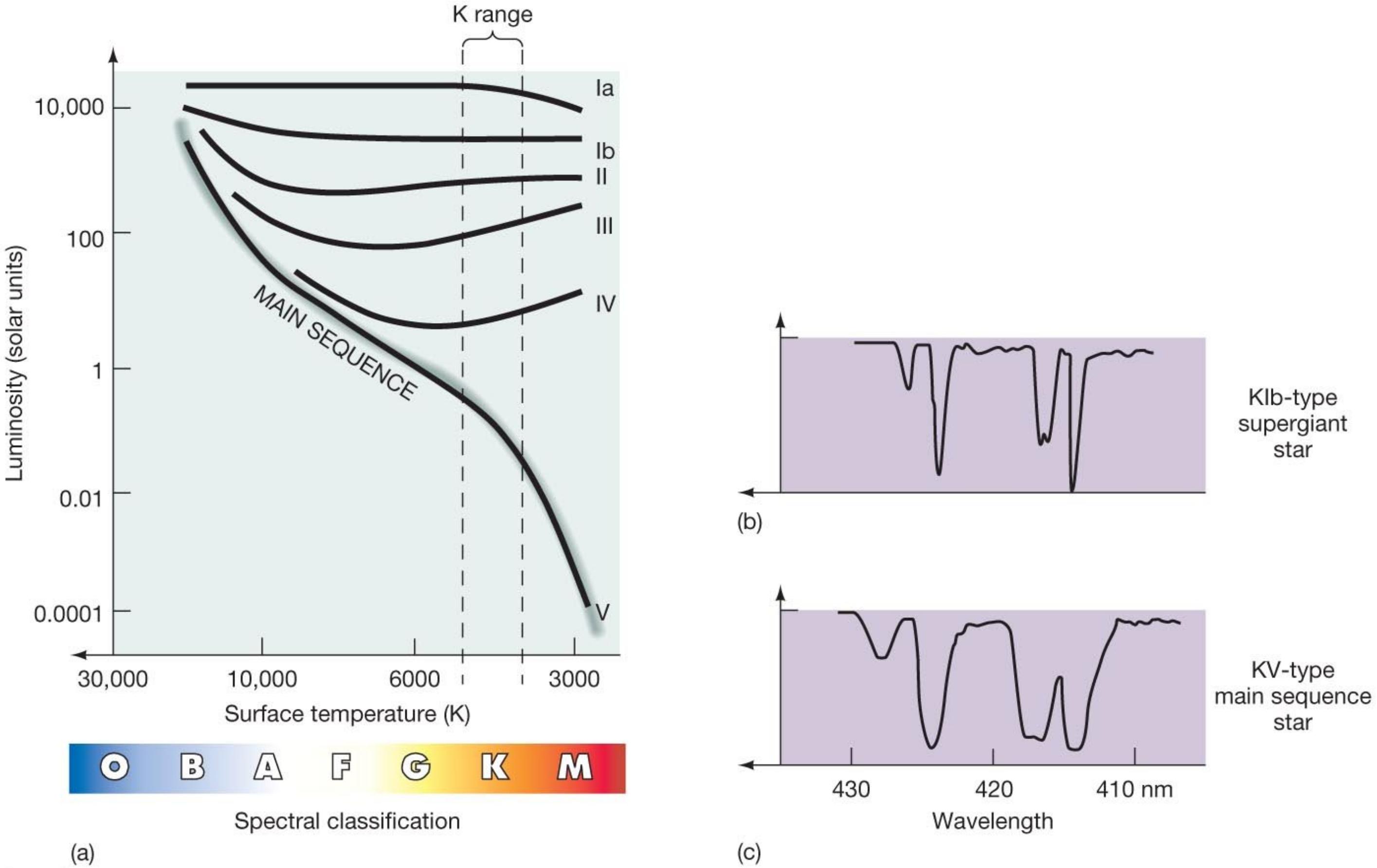
When we have identified a star as a particular kind of main-sequence star, type B for example, we know its luminosity. By measuring its apparent brightness we can find its distance (using the luminosity-distance relation again). This allows one to find distances to stars throughout the galaxy.

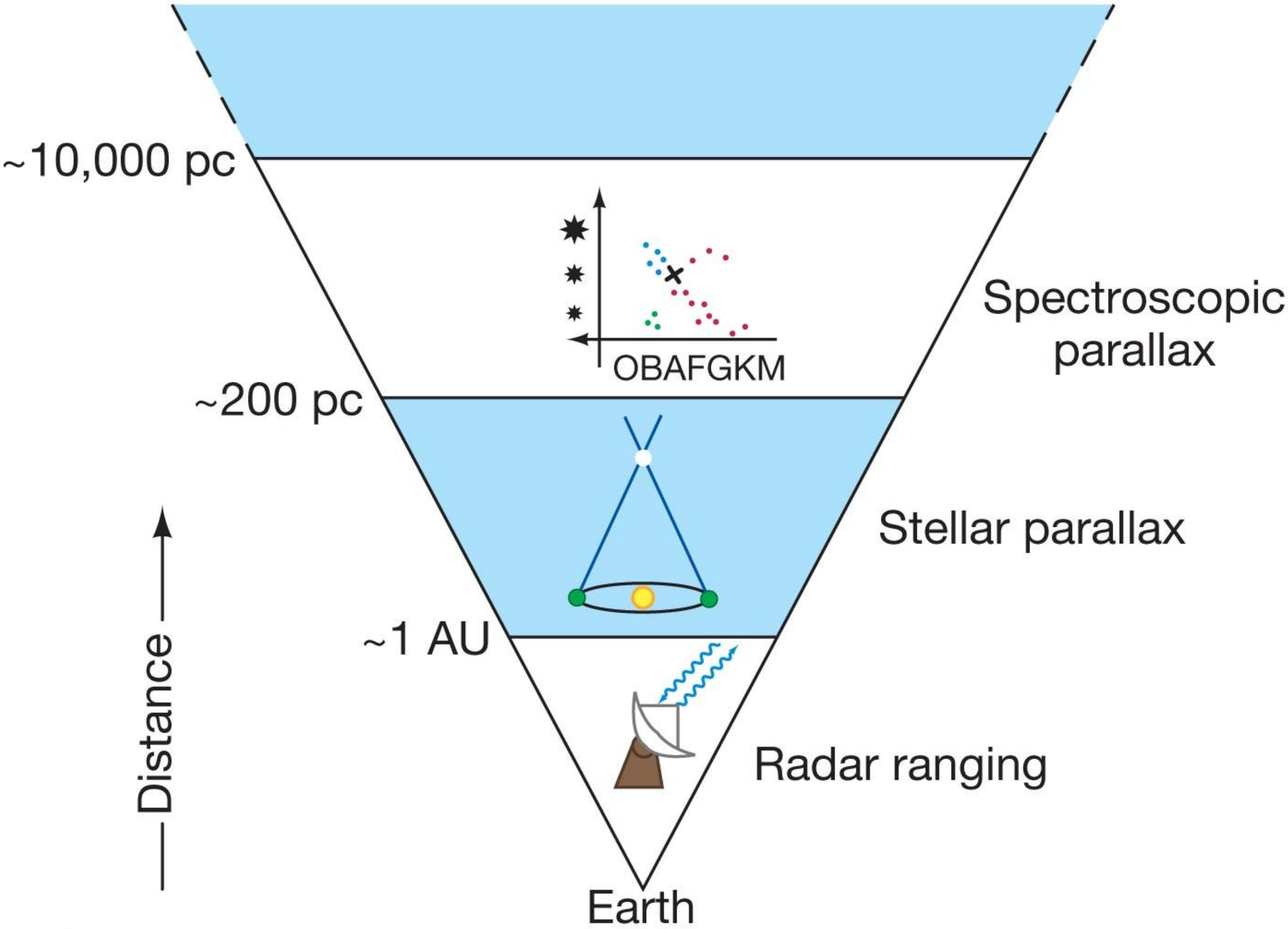
Standard Candles: How it works

1) You measure the brightness and spectral type of a star
2) you use the spectral type to estimate the luminosity (assuming it lies on the main sequence)
3) you use the inverse square law to determine the distance to the star

$$\underset{\text{from spectral type}}{L} = \underset{\text{measure this}}{B} \times 4\pi \underset{\text{find this!}}{\boxed{d}}^2$$

You study and classify the spectra of nearby stars (whose distance you can measure by parallax method), then you see where the star falls on the H-R diagram




~10,000 pc
OBAFGKM
Spectroscopic parallax
~200 pc
Stellar parallax
~1 AU
Radar ranging
Distance
Earth

Measuring Stellar Masses: Binary Stars

Herschel, starting in 1782, looked for parallax by observing pairs of stars that looked close to one another. He expected that the stars would not really be close to one another, but were simply in the same direction, with one star farther away than the other, and hoped that he could see the apparent motion of the nearer star due to the Earth's motion about the Sun.

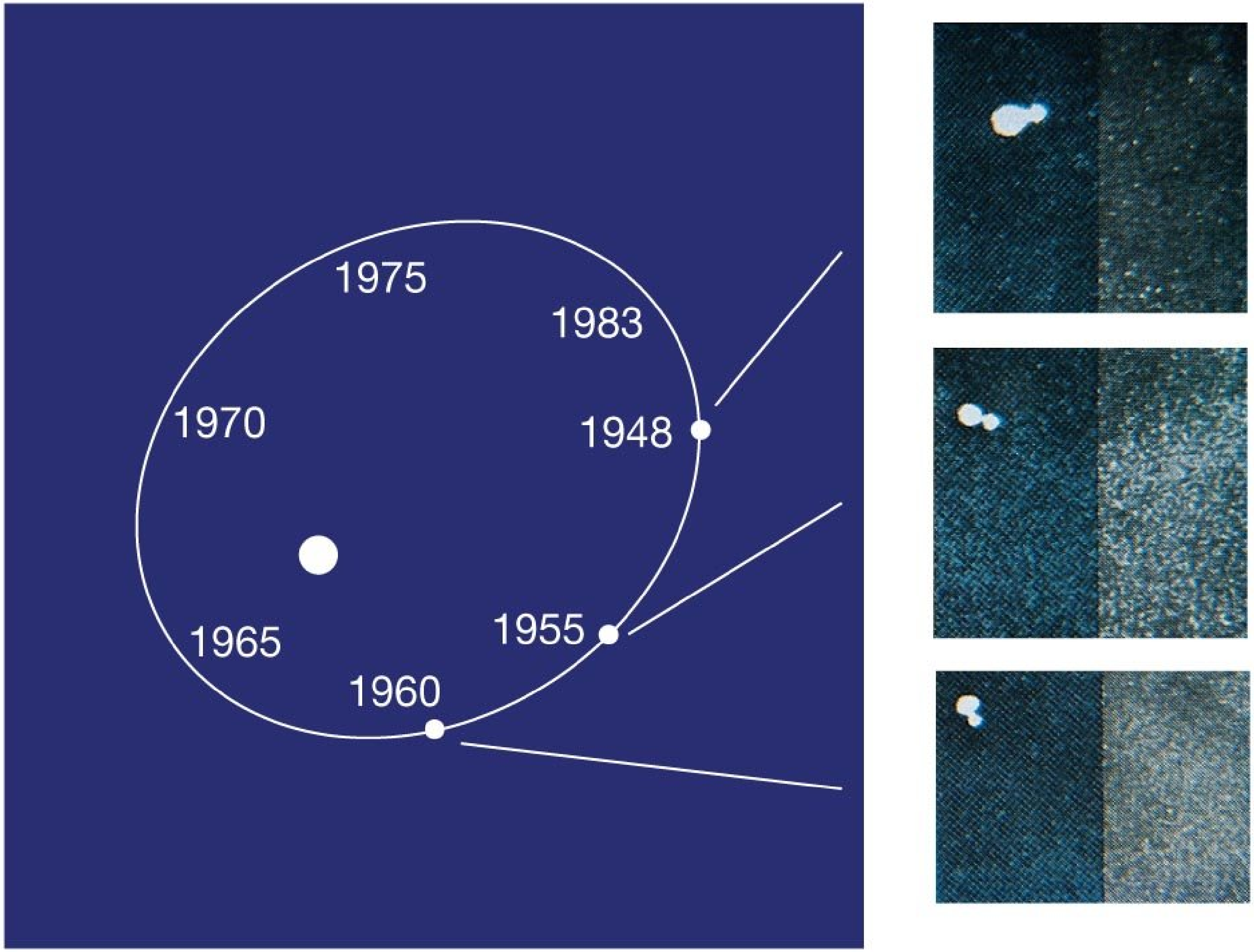
Instead, Herschel found that the pairs of stars were genuinely close together and that they orbited their common center of mass, with periods of several years. Some 64,000 visual binaries have been catalogued (800 by Herschel), but most of these have long periods (>1000 yrs). For the visual binaries that are closer to each other, one can plot the elliptical orbits and see that the stars obey Newton's laws.

Binary Stars

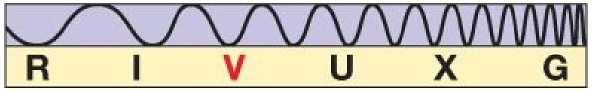
About half of all stars are in binary systems – so the Sun is unusual in that it does not have a companion.

- A **visual binary** is a binary system whose stars can be distinguished with a telescope.
  In most binary systems, stars are too close to be able to tell them apart with a telescope --- even through a telescope, they look like a single star. Close stars, however, move more quickly, and the spectral lines of each star are first blue-shifted and then red-shifted.
- **Spectroscopic binaries** are observed by a periodic Doppler shift in the spectral lines of each star.
- **Eclipsing binarie**s are observed by periodic changes in the “light curve”

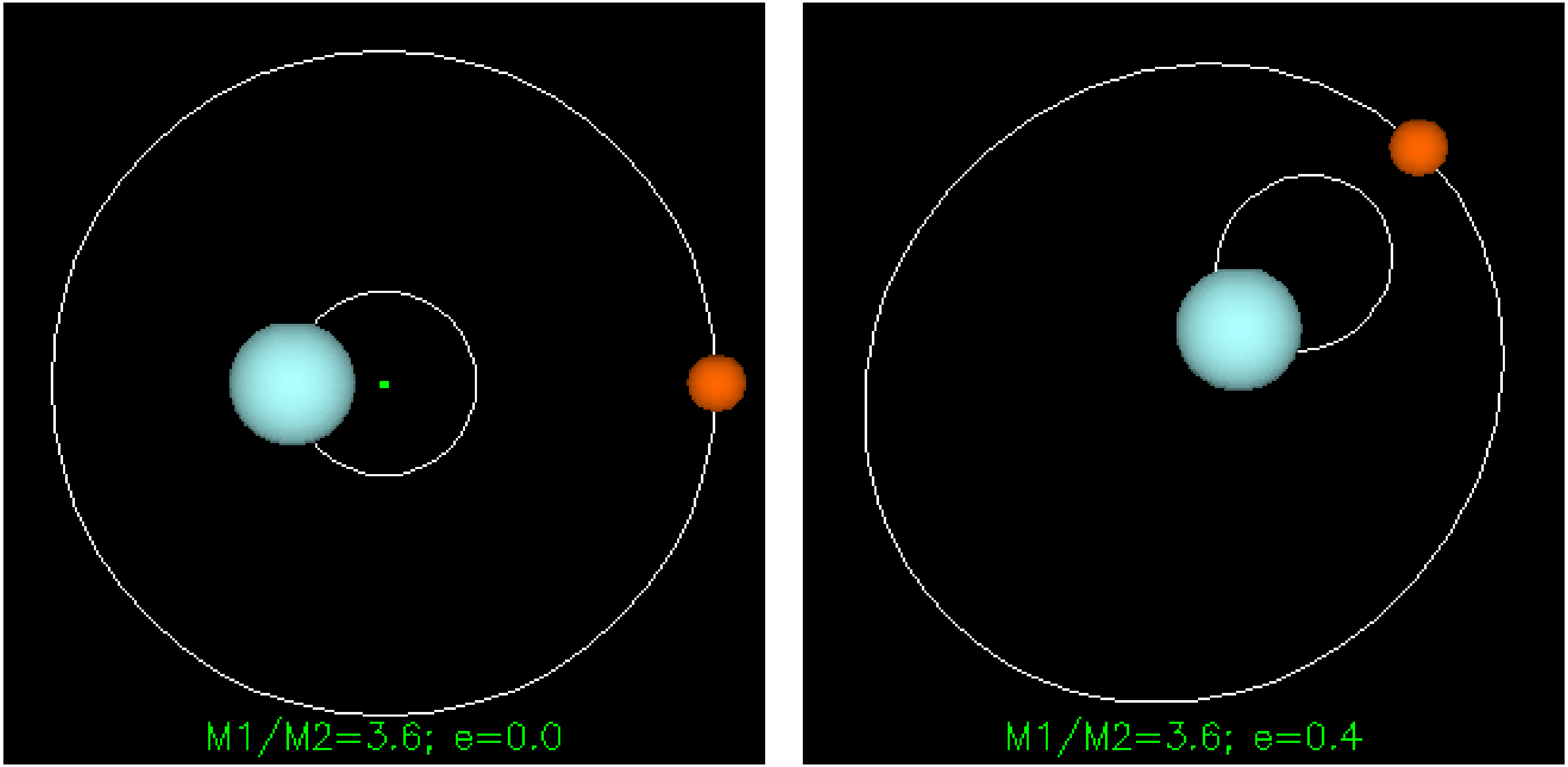
Visual binaries



(a) Visual



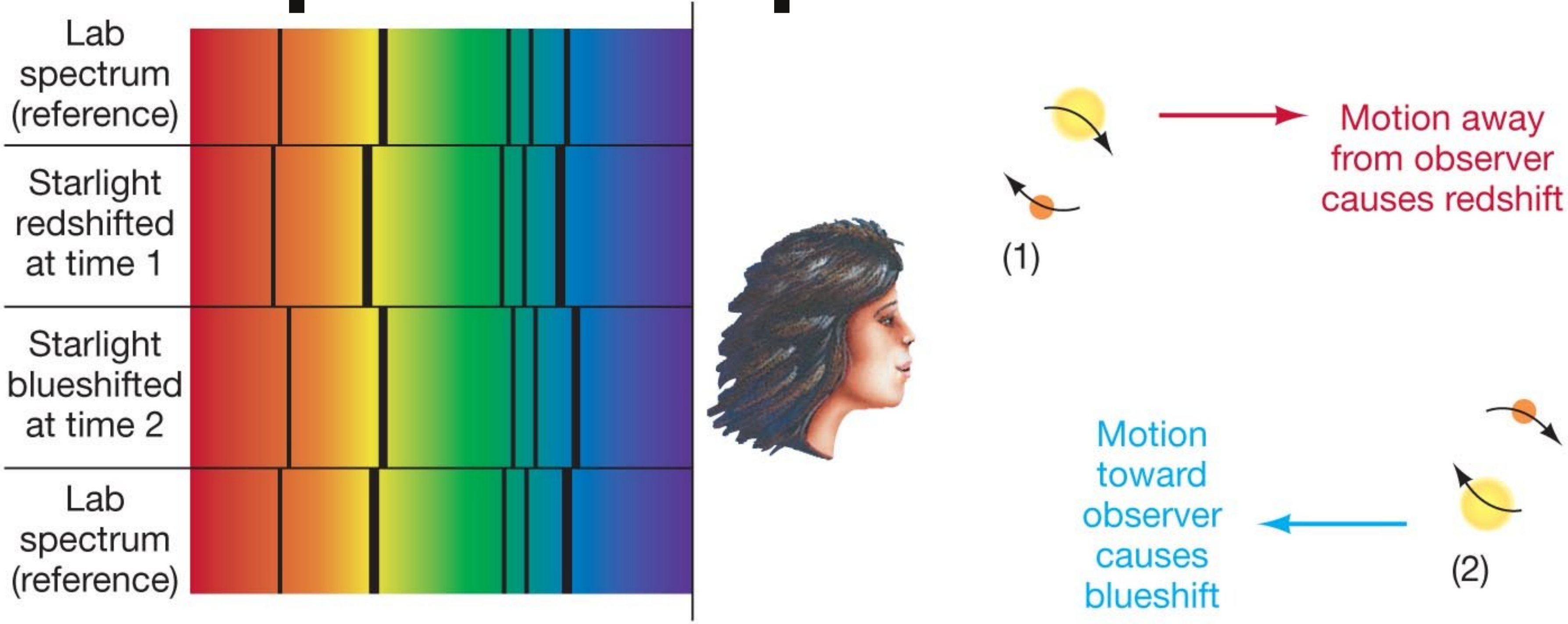
Binary Stars



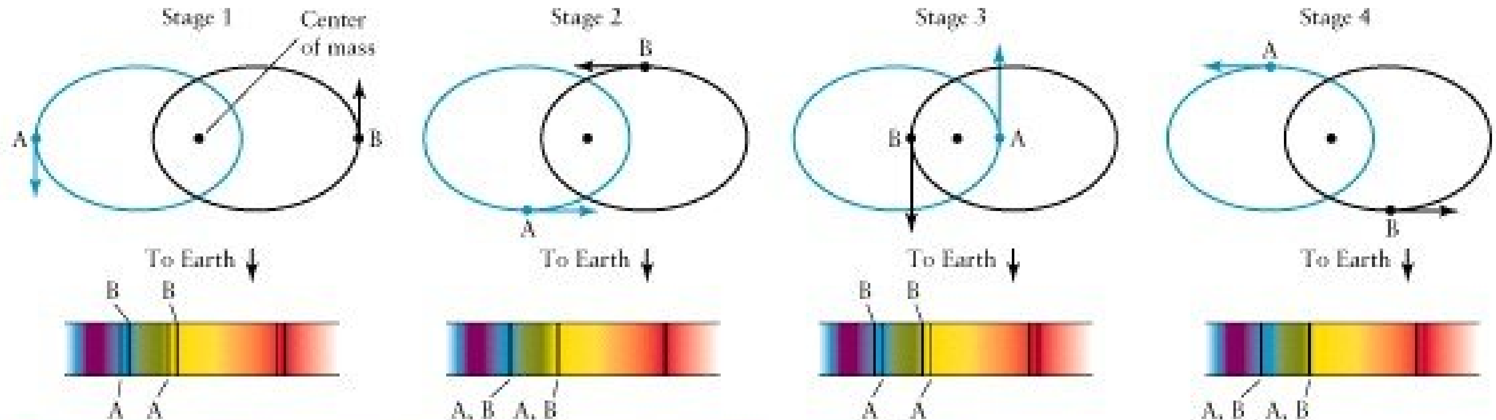
Binary stars orbit their common center of mass

Source:
Pogge, Ohio State

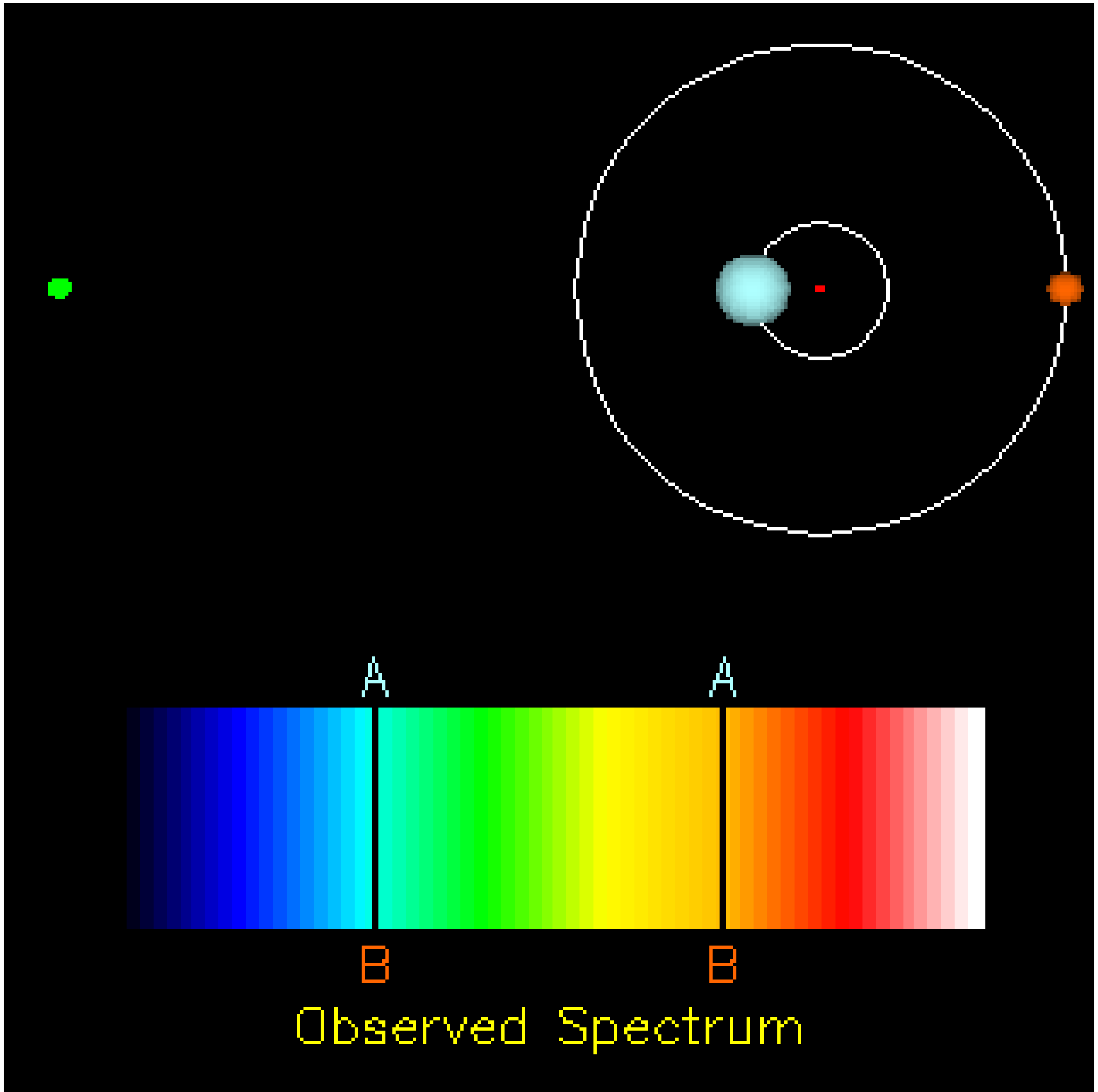
Spectroscopic binaries



(b) Spectroscopic

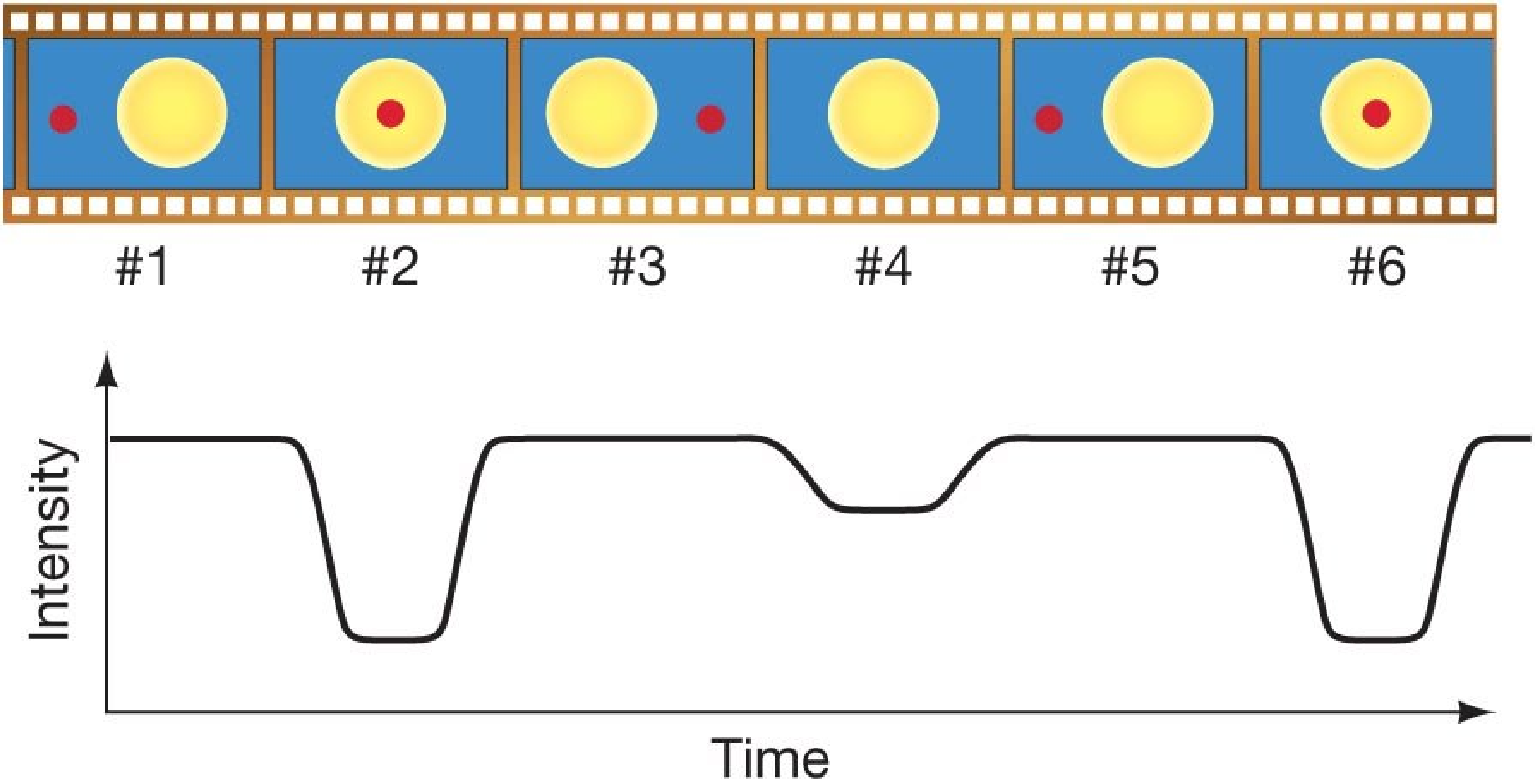


Spectroscopic Binary



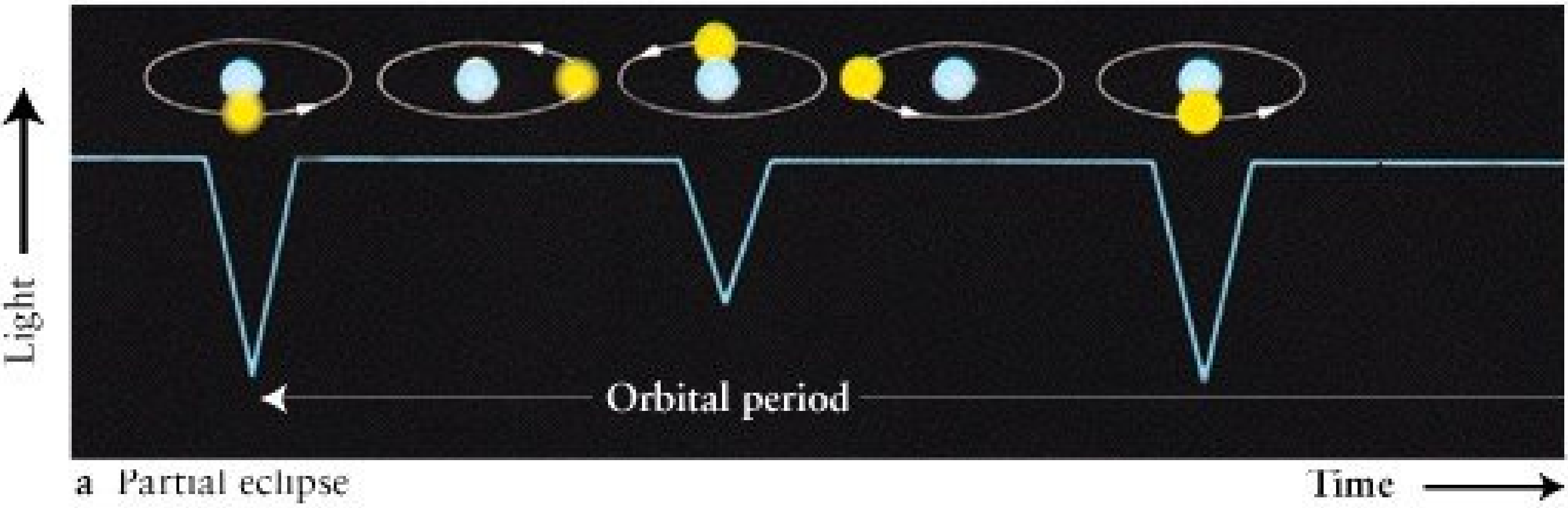
Source:
Pogge, Ohio State

Eclipsing binaries

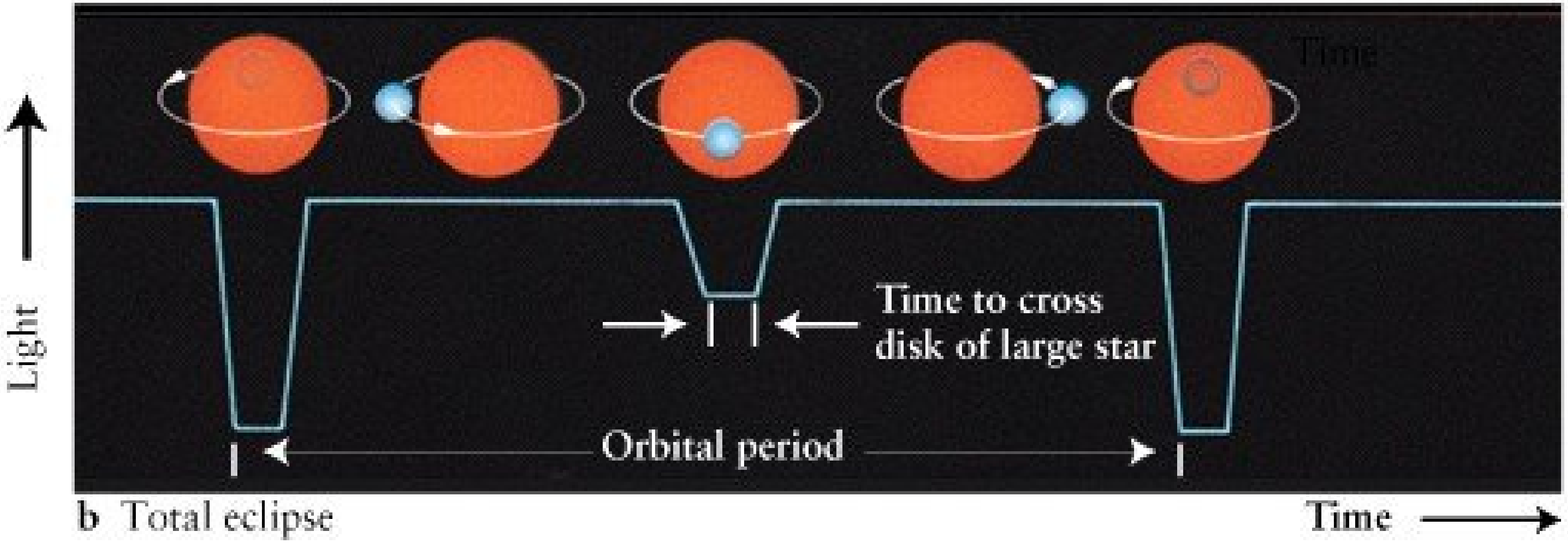


(c) Eclipsing

Eclipsing binaries

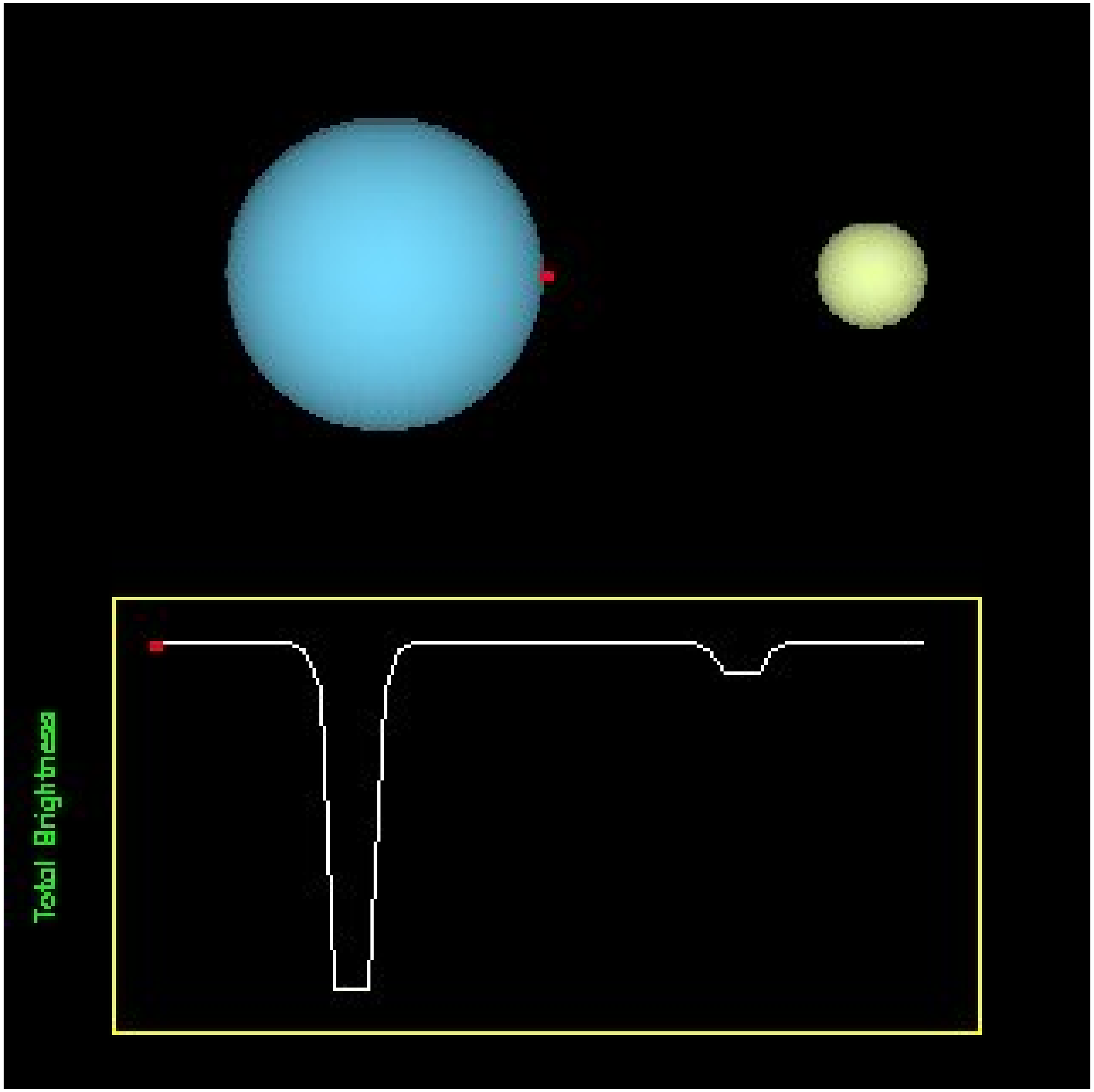


a Partial eclipse



b Total eclipse

Eclipsing Binary



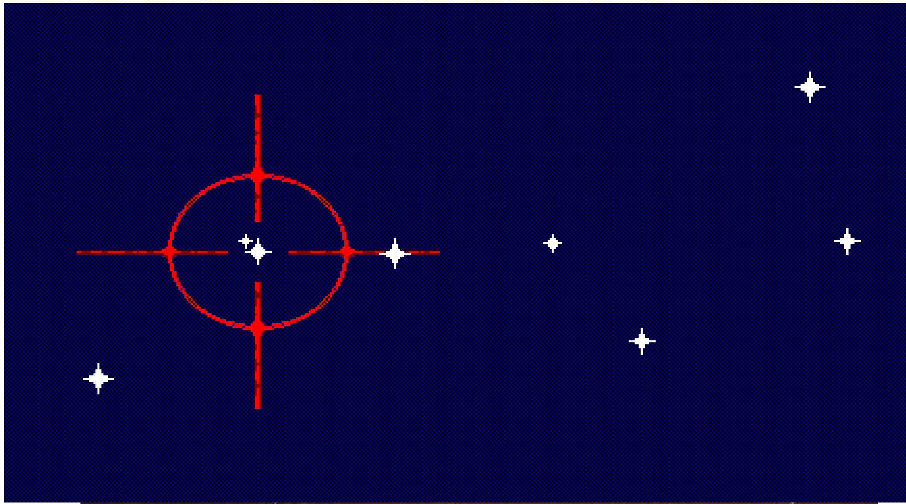
Source:
Pogge, Ohio State

Example: Mizar in the Big Dipper

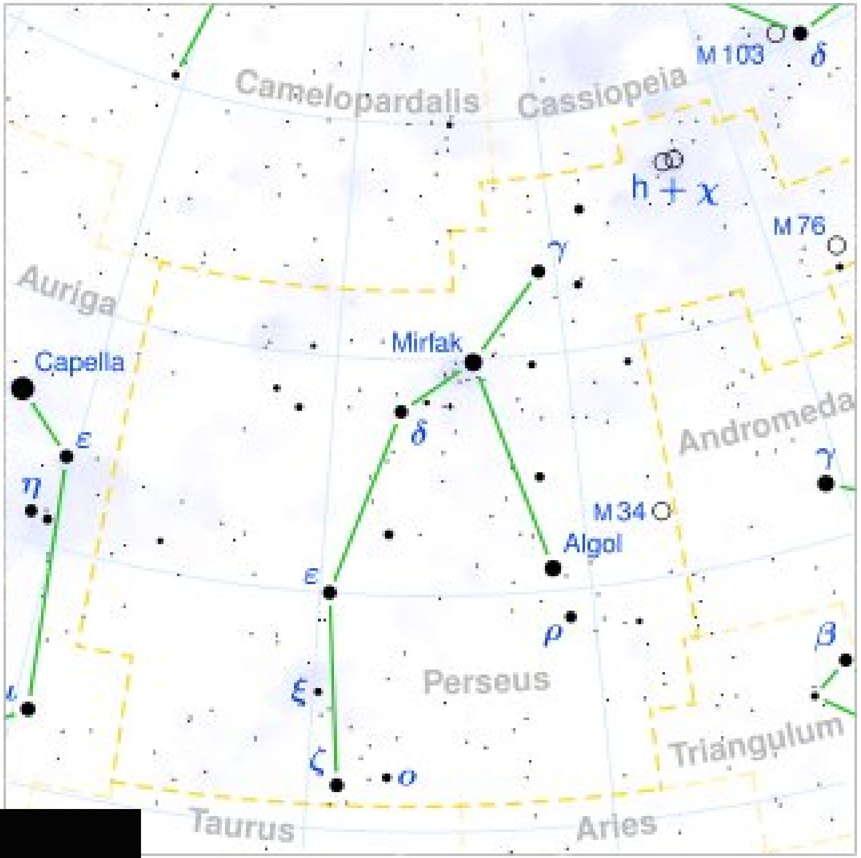
Mizar is a system of 4 stars.

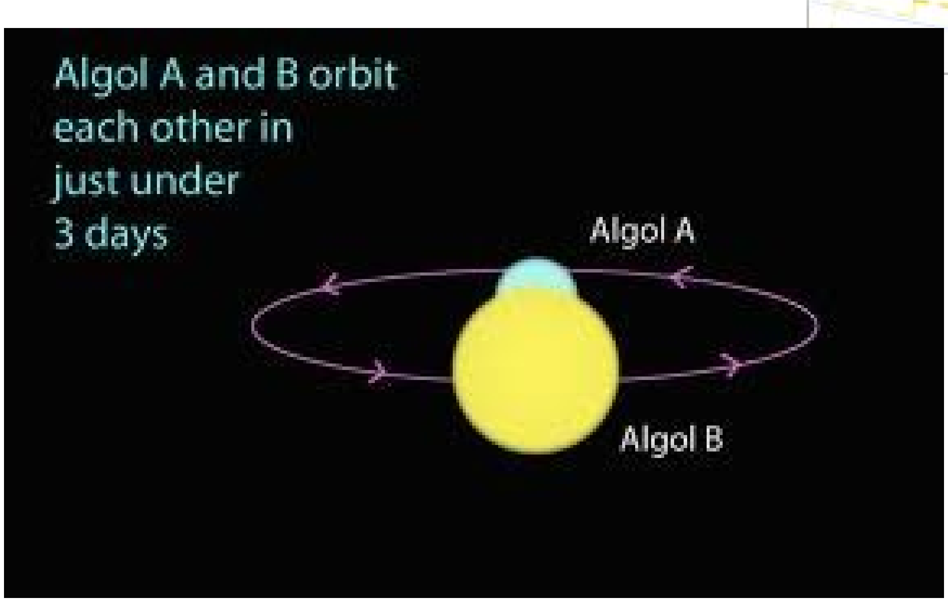
Through a telescope it looks like a visual binary, but each of the two "stars" is really a spectroscopic binary.

(One of these close pairs was in the group of the first spectroscopic binaries observed --- by William Pickering in 1889; the other was found to be a spectroscopic binary in 1908.)



Example: The star Algol in the constellation Perseus is an eclipsing binary with a period of about 3 days.

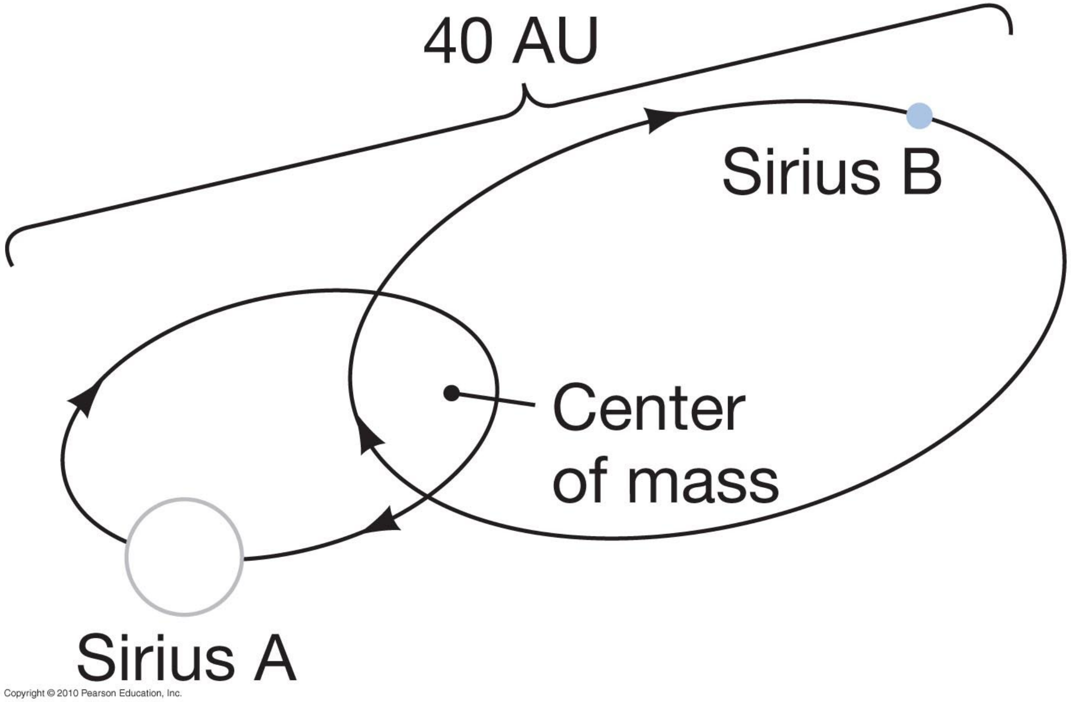



Algol A and B orbit each other in just under 3 days

Stellar masses from binaries

If one knows the period and the orbit of each star, one can find the mass of each star. By looking at the speed of each star in a binary system, one measures the mass of the two stars.

This is done with **Kepler’s third law**; binary stars orbiting each other follow the same laws as a planet orbiting a star.



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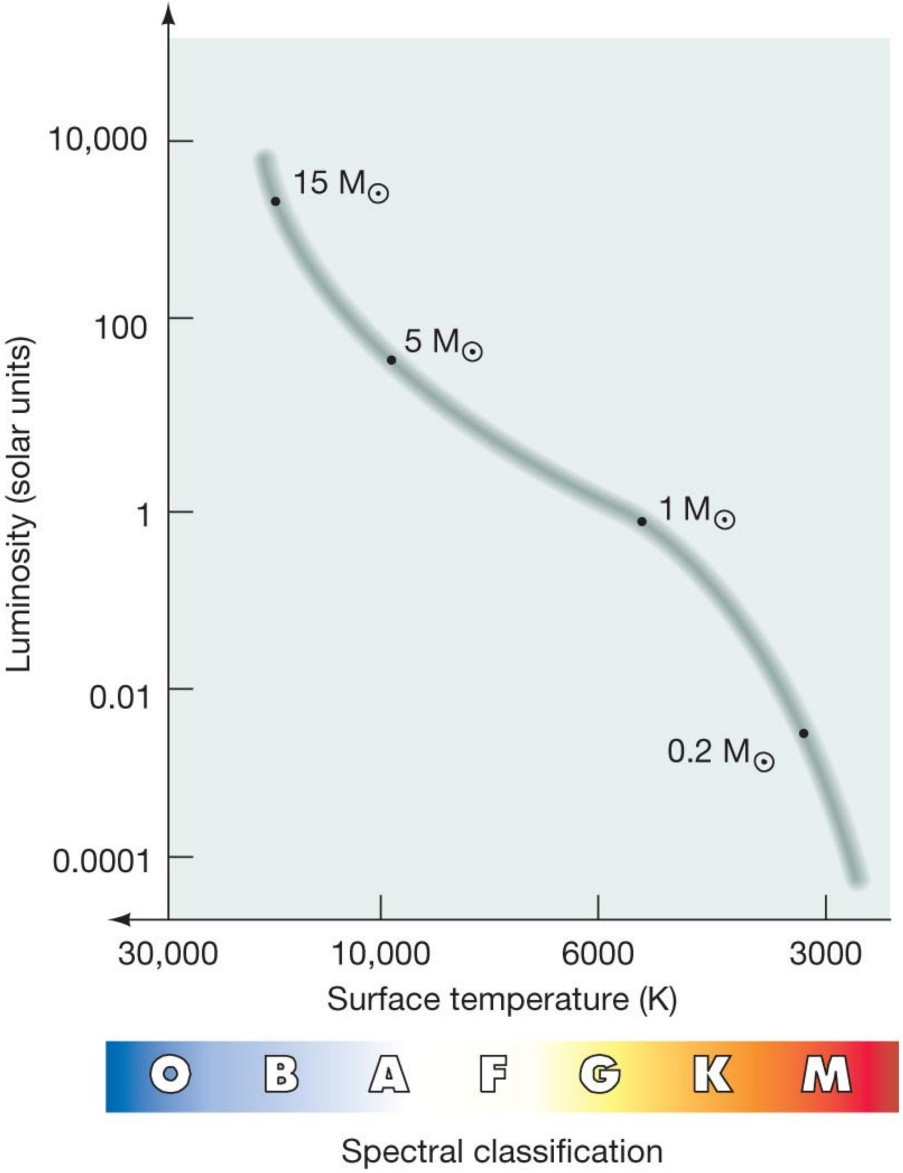
This is how we find the masses of stars.

From the masses of stars, one can understand the main sequence.

What determines where on the main sequence a star will be when it forms?

Stars on the main sequence are only distinguished by their mass

The Main Sequence



Stars with small masses are the stars that are low on the main sequence. They burn much more slowly, so they are much dimmer and their surfaces are cooler. Stars with larger masses burn much more quickly and have hotter surfaces (and hotter interiors).

The Main Sequence

Stars don’t move along the main sequence – that would require them to change their mass.

Instead they just sit on the main sequence until their time there is up.

The main sequence is a waystation, where stars spend MOST of their lives.

Summary

- The difference between stars on the main sequence is due to the difference in their **masses**.
- Low mass stars are low on the main sequence, and are much dimmer --- a star of 1/10 of a solar mass is only 1/1000 as bright as the Sun.
- Similarly, high mass stars are high on the main sequence, and are much brighter --- a star of 10 solar masses is 10,000 times brighter than the Sun

Topics for 2nd half of semester

- Stellar Evolution, star & planet formation; neutron stars, black holes
- **The solar system:** moons, asteroids, comets; planets around other stars
- **Galaxies:** Milky Way, Galaxy Structure, Quasars, Active Galaxies, Gravitational Lensing, Interactions
- **Cosmology:** Big Bang, Cosmic Microwave Background
- **Life in the Universe**