

# Astronomy

Semester 2

Weeks 14 – 15

Begin 6<sup>th</sup> six-weeks

# Monday / Tuesday (April 13 & 14)

- Bio STAAR on April 14

- **T:** (G) illustrate how astronomers use geometric parallax to determine stellar distances and intrinsic luminosities; and
- (H) describe how stellar distances are determined by comparing apparent brightness and intrinsic luminosity when using spectroscopic parallax and the Leavitt relation for variable stars.
- **O:** I will be able to explain the luminosity of stars and their magnitudes
- **D:** by participating in a class lecture and watching a video with questions.
- **A:** luminosity
- **Y:** How does distance and temperature relate to the brightness of a star?

# Light, the Astronomer's Tool

- Astronomers want to know the motions, sizes, colors, and structures of stars.
- This information helps to understand the nature of stars as well as their life cycle.
- The light from stars received at Earth is all that is available for this analysis.

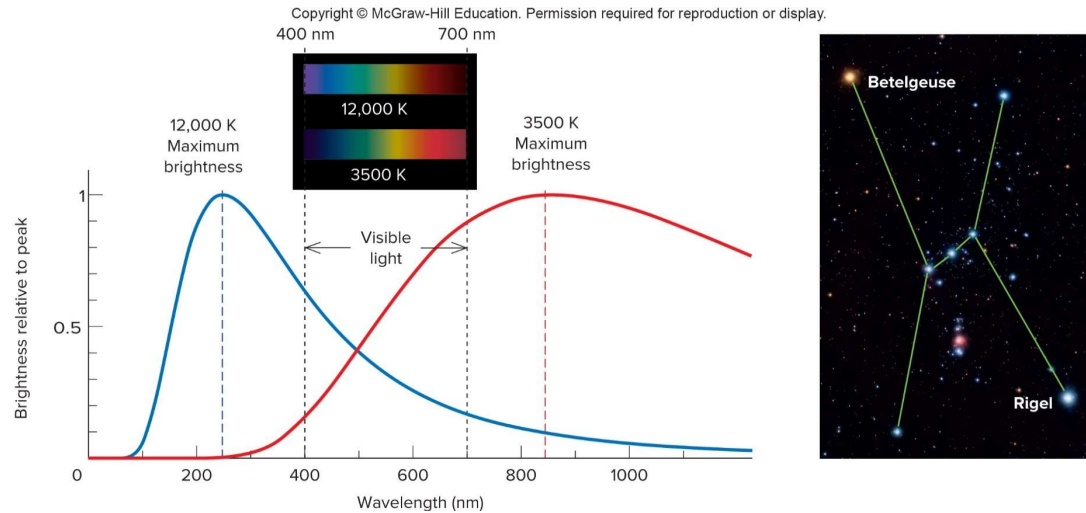
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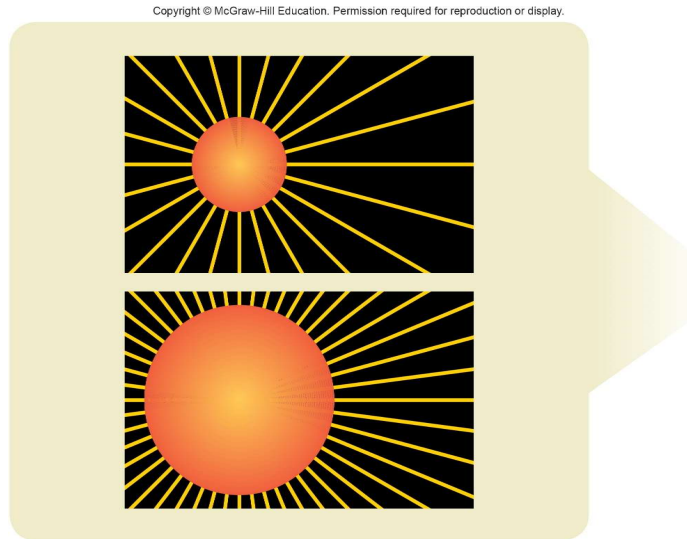


# Temperature



- The color of a star indicates its relative temperature – blue stars are hotter than red stars.
- More precisely, a star's surface temperature (in Kelvin) is given by the wavelength in nanometers (nm) at which the star radiates most strongly.

# Key Measurement: Luminosity

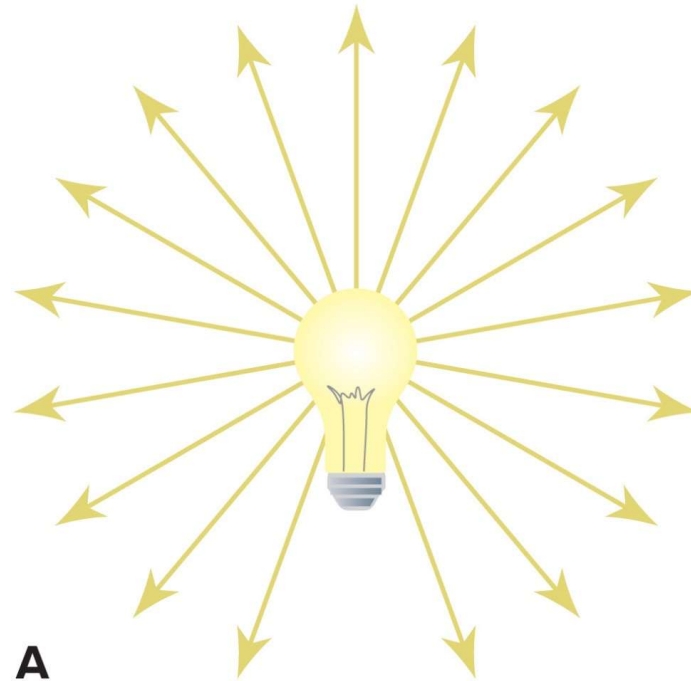


- Luminosity is a measure of a star's energy production (or hydrogen fuel consumption).
- Knowing a star's luminosity will allow a determination of a star's distance and radius.

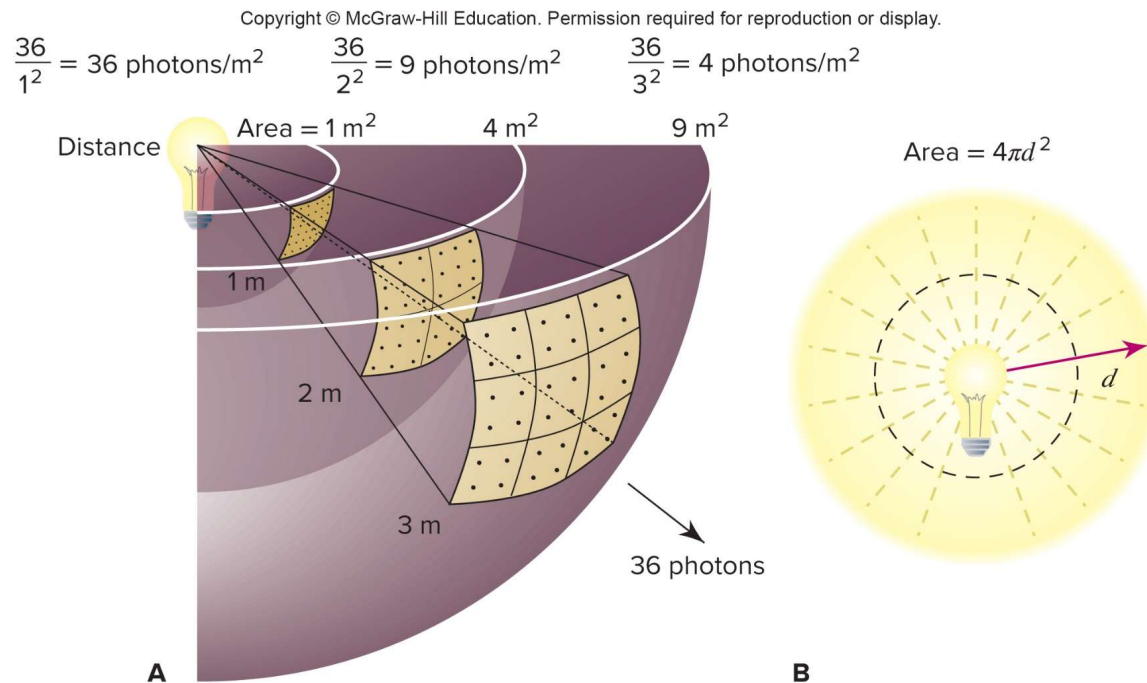
# Luminosity

- The amount of energy a star emits each second is its ***luminosity*** (usually abbreviated as *L*).
- A typical unit of measurement for luminosity is the watt.
- Compare a 100-watt bulb to the Sun's luminosity,  $4 \times 10^{26}$  watts.

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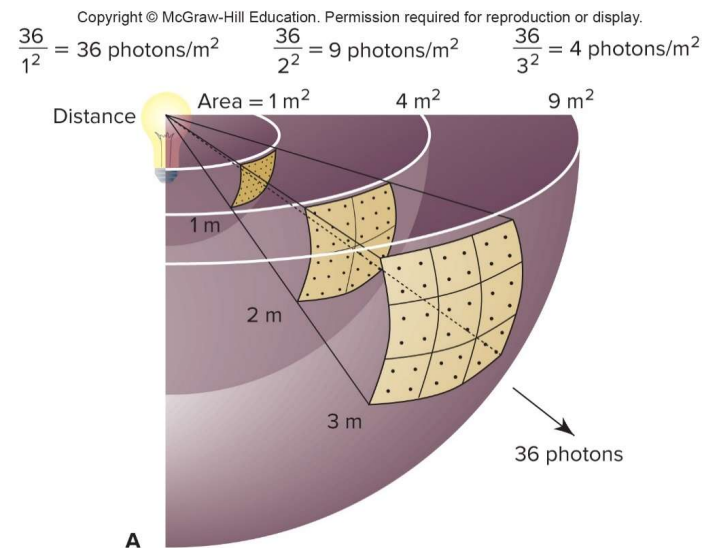
# The Inverse-Square Law



- The ***inverse-square law*** relates an object's luminosity to its distance and its apparent brightness (how bright it appears to us).

# Why Distant Objects Appear Dim!

- This law can be thought of as the result of a fixed number of photons, spreading out evenly in all directions as they leave the source.
- The photons have to cross larger and larger concentric spherical shells.
- For a given shell, the number of photons crossing it decreases per unit area.

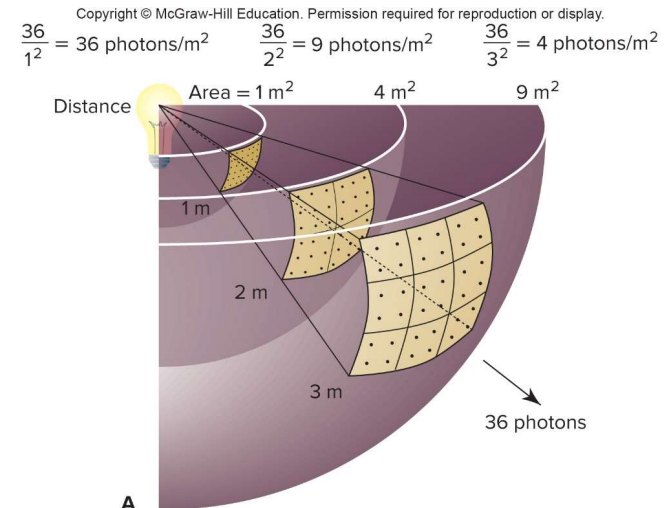


# Brightness

- The inverse-square law (IS) is:

$$B = \frac{L}{4\pi d^2}$$

- $B$  is the brightness at a distance  $d$  from a source of luminosity  $L$ .
- This relationship is called the inverse-square law because the distance appears in the denominator as a square.



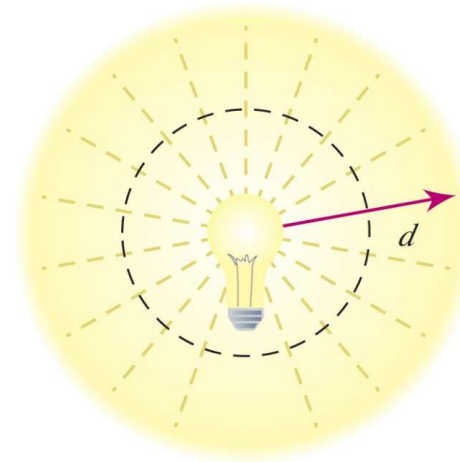
# Inferring Luminosity

- The inverse-square law is one of the most important mathematical tools available to astronomers:
- Given  $d$  from parallax measurements, a star's  $L$  can be found (A star's  $B$  can easily be measured by an electronic device, called a photometer, connected to a telescope.).
- Or if  $L$  is known in advance, a star's distance can be found.

$$B = \frac{L}{4\pi d^2}$$

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$$\text{Area} = 4\pi d^2$$

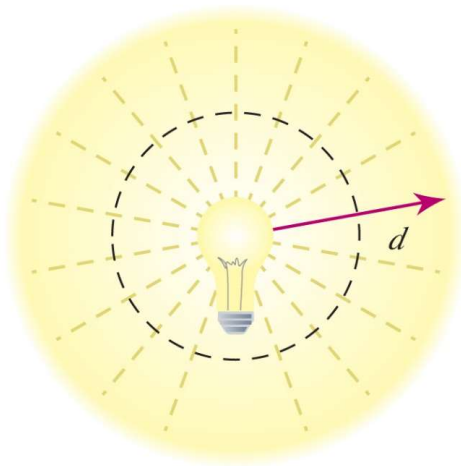


**B**

# The “Standard Candle” Method

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$$\text{Area} = 4\pi d^2$$



B

- If an object’s *intrinsic* brightness is known, its distance can be determined from its *observed* brightness.
- Astronomers call this method of distance determination the *method of standard candles*.
- This method is the principle manner in which astronomers determine distances in the universe.

# Method of Standard Candles

- Step 1: Measure a star's brightness (B) with a photometer.
- Step 2: Determine star's Luminosity, L.
- Some kinds of stars (variable stars, for example) or supernovae (Type 1a supernova) have a known luminosity.
- Use combined formula to calculate d, the distance to the star.

$$d = \sqrt{\frac{L}{4\pi B}}$$

# The Magnitude Scale

- About 150 B.C., the Greek astronomer Hipparchus measured apparent brightness of stars using units called *magnitudes*.
- Brightest stars had magnitude 1 and dimmest had magnitude 6.
- The system is still used today and units of measurement are called apparent magnitudes to emphasize how bright a star looks to an observer.
- A star's apparent magnitude depends on the star's luminosity and distance – a star may appear dim because it is very far away or it does not emit much energy.

# Magnitude differences

- The apparent magnitude can be confusing.

Scale runs “backward”: high magnitude = low brightness.

Modern calibrations of the scale create negative magnitudes.

Magnitude differences equate to brightness ratios:

- A difference of 5 magnitudes = a brightness ratio of 100.
- 1 magnitude difference = brightness ratio of  $100^{1/5} = 2.512$ .

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# Absolute Magnitude

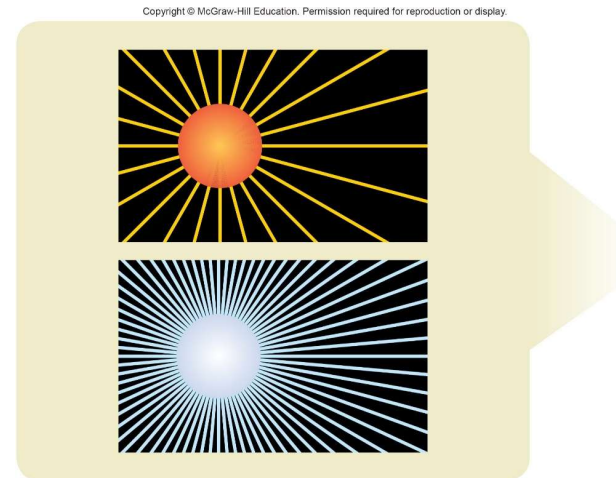
- Astronomers use ***absolute magnitude*** to measure a star's luminosity.
- The absolute magnitude of a star is the apparent magnitude that same star would have if it were 10 parsecs from us.
- The sun's absolute magnitude is about 5, therefore if the sun were 10 parsecs away, it would have an apparent magnitude of 5.
- A comparison of absolute magnitudes is now a comparison of luminosities, no distance dependence.
- An absolute magnitude of 0 approximately equates to a luminosity of  $100L_{\odot}$ .

# Stefan-Boltzmann Law

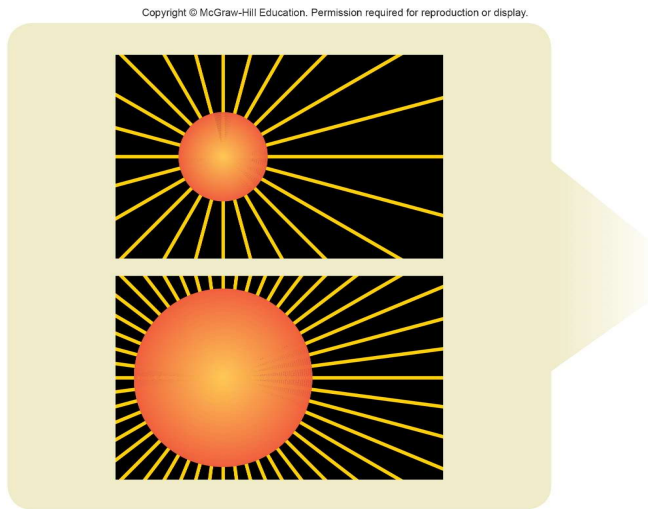
- If two stars have the same size but the surface of one is hotter than the other, the hotter star will have a greater luminosity.
- The Stefan-Boltzmann (SB) Law gives this:

$$B = \sigma T^4$$

- Here  $\sigma$  is the Stefan-Boltzmann constant ( $5.67 \times 10^{-8}$  watts  $\text{m}^{-2}\text{K}^{-4}$ ).



# Radius



- If two stars have the same temperature but one is more luminous than the other, the more-luminous star must have a larger surface area, therefore a larger radius than the dimmer star.

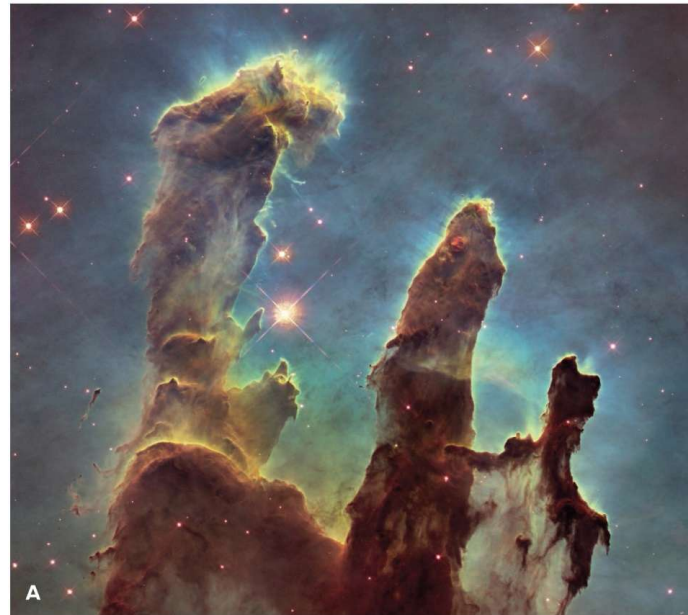
# Tying It All Together

- The Stefan-Boltzmann law only applies to stars, but not hot, low-density gases.
- We can combine SB and IS to get:

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

- $R$  is the radius of the star.
- Given  $L$  and  $T$ , we can then find a star's radius!

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# Finding Luminosity

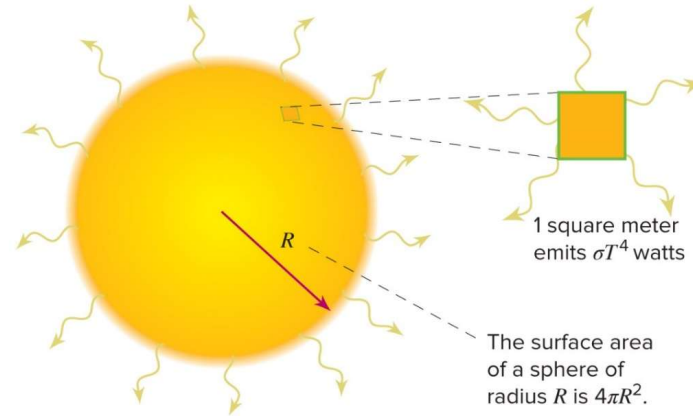
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$$L = \sigma T^4 \times 4\pi R^2$$

Luminosity—total energy radiated per second by the star

Energy emitted per second by 1 square meter

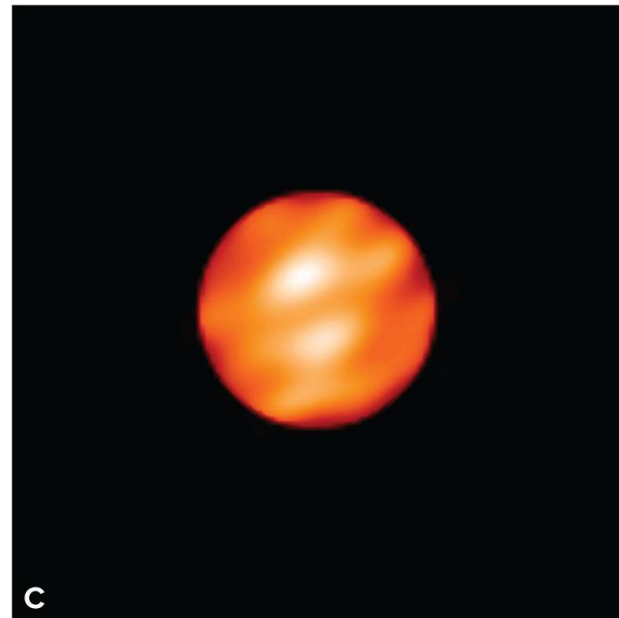
Number of square meters in surface area of the star



# Large Range in Stellar Radii

- The methods using the Stefan-Boltzmann law and interferometer observations show that stars differ enormously in radius.
- Some stars are hundreds of times larger than the Sun and are referred to as *giants*.
- Stars smaller than the giants are called *dwarfs*.

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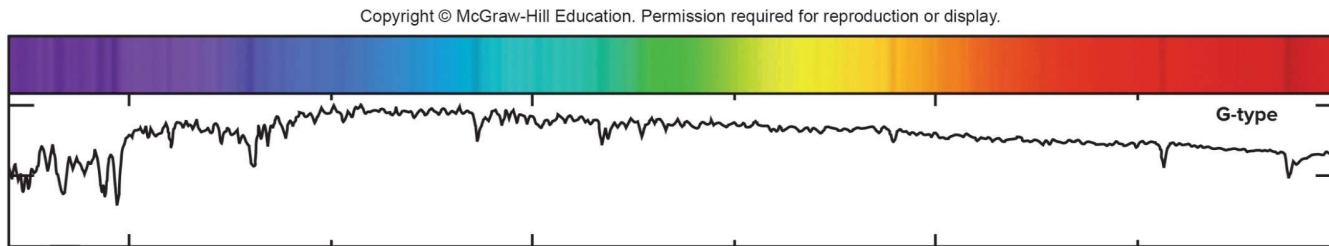
Wednesday / Thursday (April 15 & 16)

## Journal 6.1

- What are your plans the first week after the school year is over?

- **T: 13** (A) identify the characteristics of main sequence stars, including surface temperature, age, relative size, and composition;
- (E) describe the use of spectroscopy in obtaining physical data on celestial objects such as temperature, chemical composition, and relative motion;
- **O:** I will begin to understand how scientist learn about the composition of stars
- **D:** by taking notes, discussing the concepts with my peers, and completing a Gizmos activity.
- **A:** spectra, absorption, emission
- **Y:** How are stars classified?

# The Spectra of Stars



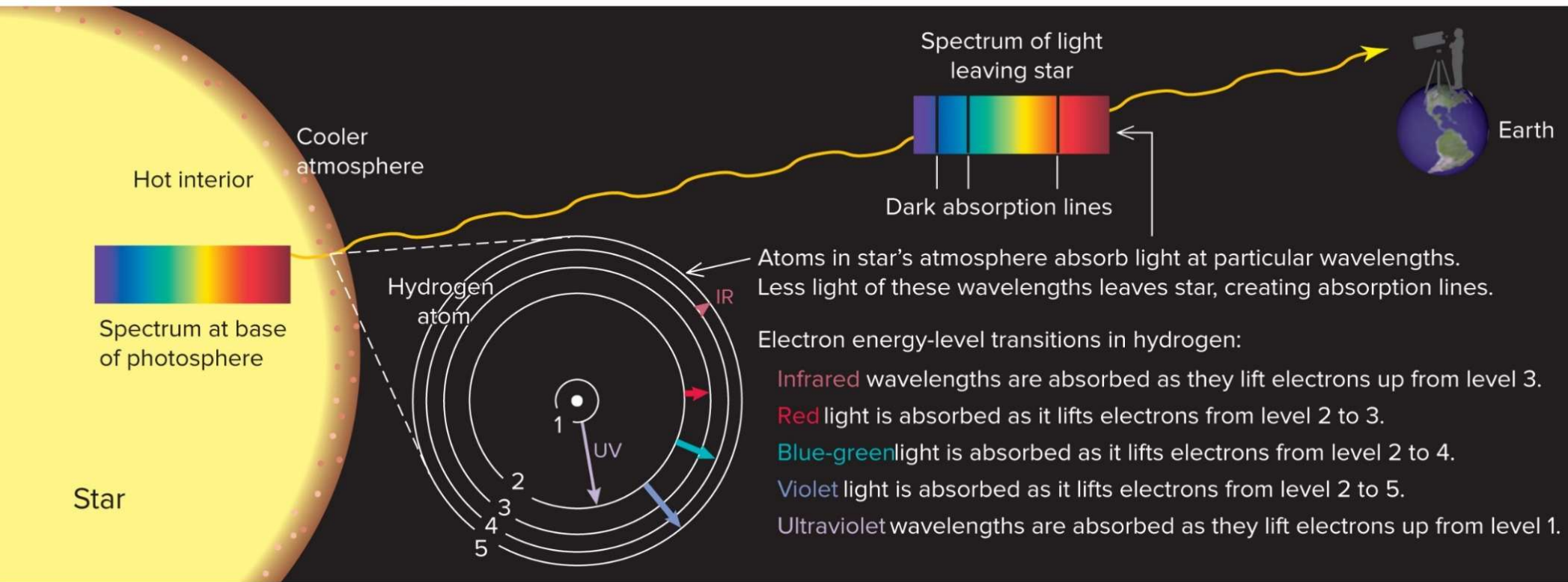
- A star's spectrum typically depicts the energy it emits at each wavelength.
- A spectrum also can reveal a star's composition, temperature, luminosity, velocity in space, rotation speed, and other properties.

# Measuring a Star's Composition

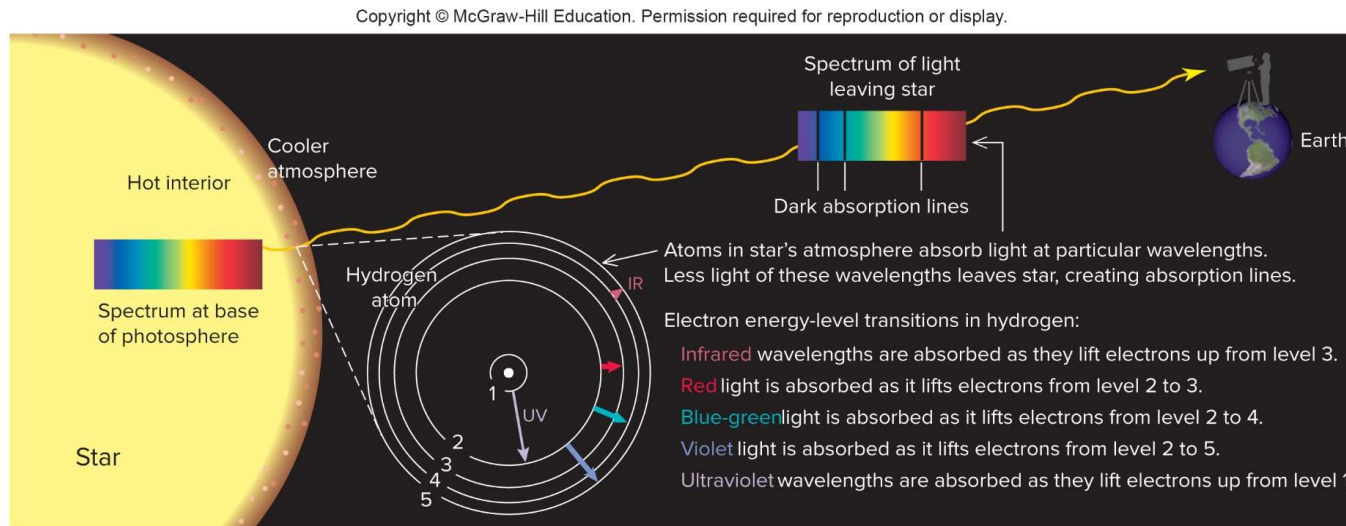
- As light moves through the gas of a star's surface layers, atoms absorb radiation at some wavelengths, creating dark absorption lines in the star's spectrum.
- Every atom creates its own unique set of absorption lines.

# Strength of Absorption Line

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# Temperature's Effect



- Possible overlap of absorption lines from several varieties of atoms being present.
- Temperature can also affect how strong (dark) an absorption line is.

# Temperature's Effect on Spectra

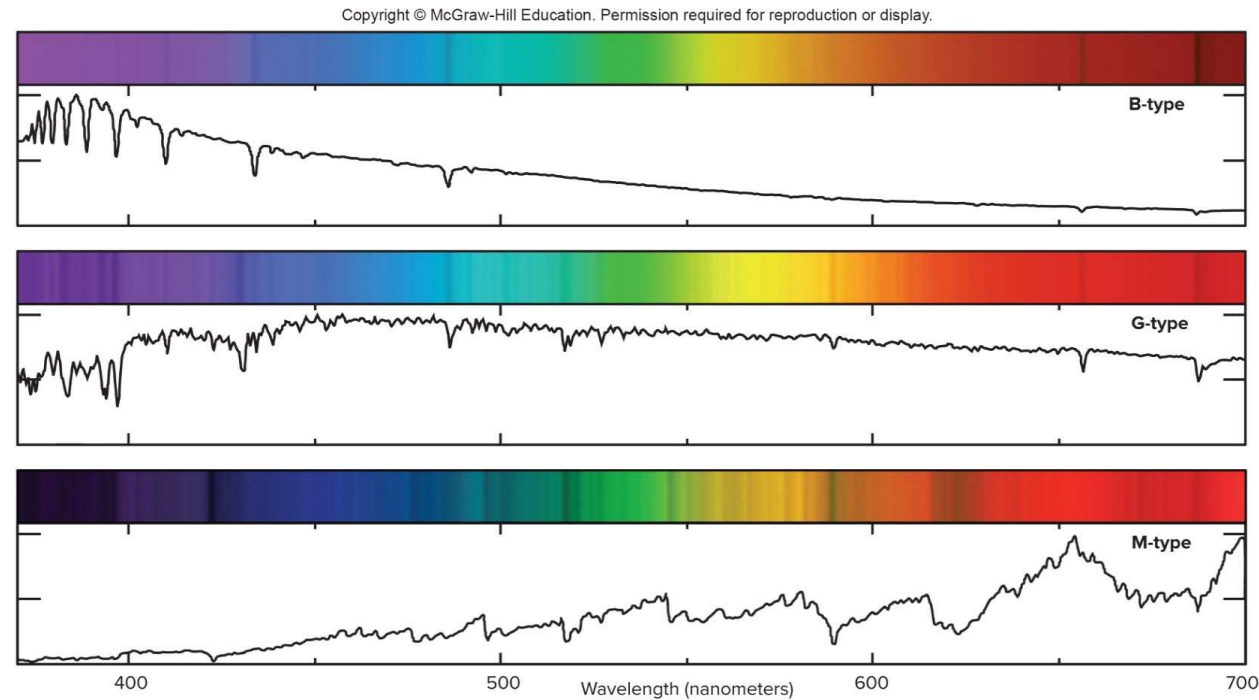
- Higher temperatures, through collisions and energy exchange, will force electrons, on average, to occupy higher electron levels – lower temperatures, lower electron levels.

# Temperature's Can Erase Lines

- An atom may be abundant but create only weak lines because the gas is too hot or too cold—its electrons are in the “wrong” energy level to absorb that wavelength of light.
- Adjusting for temperature, a star's composition can be found – interestingly, virtually all stars have compositions very similar to the Sun's: 71% H, 27% He, and a 2% mix of the remaining elements.

# Early Classification of Stars

- Historically, stars were first classified into four groups according to their color (white, yellow, red, and deep red)



# Modern Classification of Stars

- Cecilia Payne:
  - Found connection between temperature and the resulting absorption lines.
  - Proved that stars are composed mainly of hydrogen

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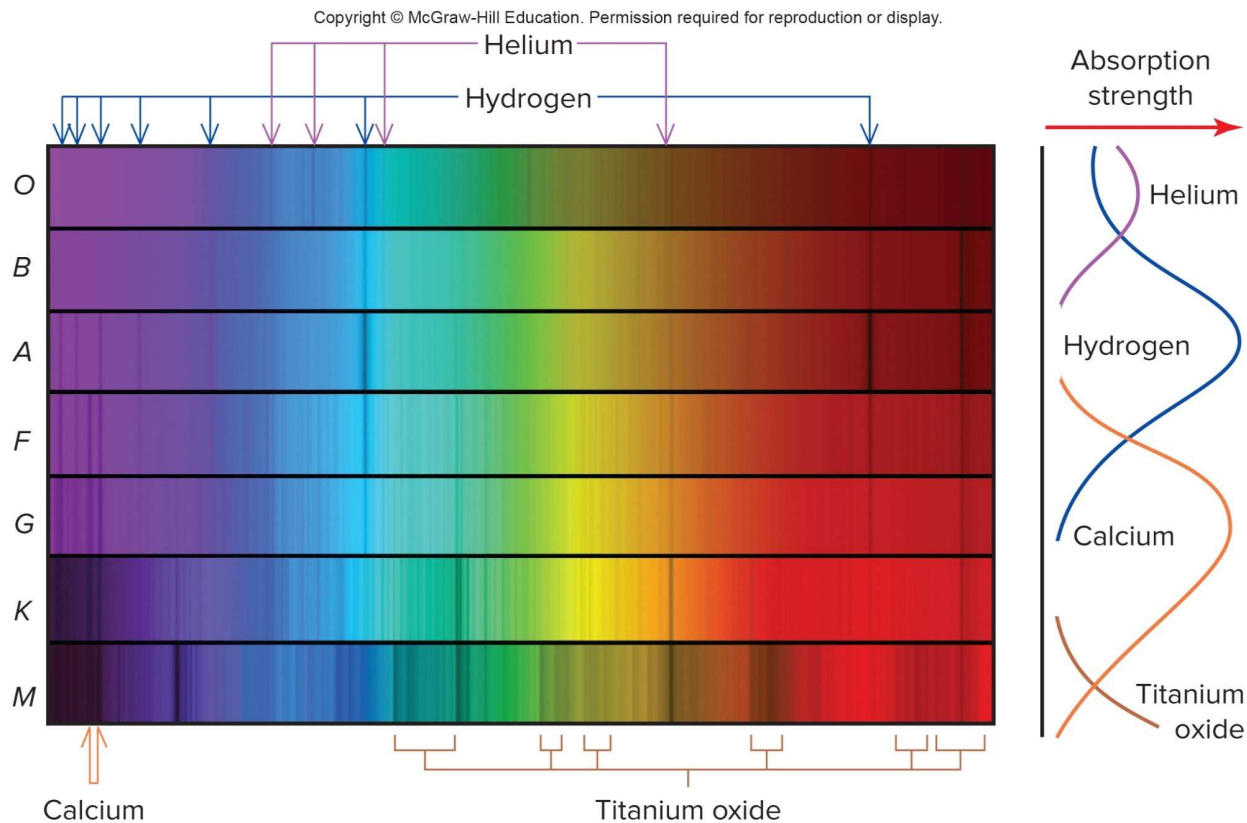
# Spectral Types

- Annie Jump Cannon arranged stars by temperature (hottest to coldest): O, B, A, F, G, K, M
- Called *spectral types*.

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# Absorption Lines Changing with Temperature



# New Spectral Types

- Temperature range: more than 25,000 K for O (blue) stars and less than 3500 K for M (red) stars.
- New spectral types L, T and Y have been added, even cooler than M stars.
- Spectral classes subdivided with numbers - the Sun is G2.

# Measuring a Star's Motion

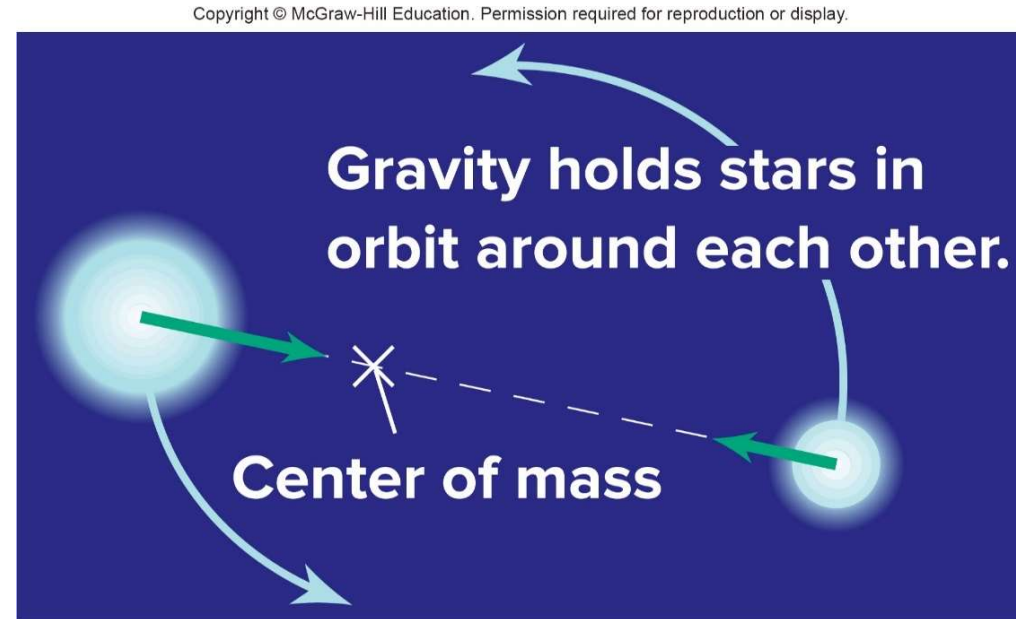
- A star's motion is determined from the Doppler shift of its spectral lines (Red shift).

# Binary Stars

- Two stars that revolve around each other as a result of their mutual gravitational attraction are called ***binary stars***.
- Of O and B type stars, 80% have orbiting companions (some more than one).
- Of Sun-like stars, roughly half are in binary systems.
- Most binary stars are only a few AU apart – a few are even close enough to touch.

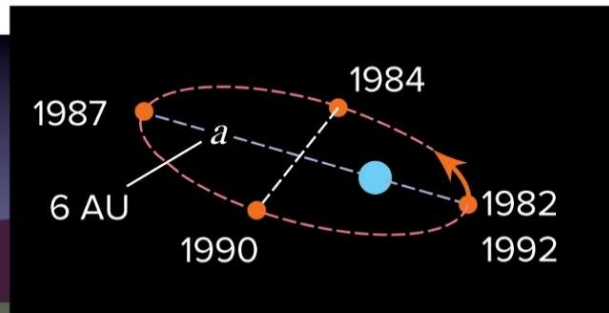
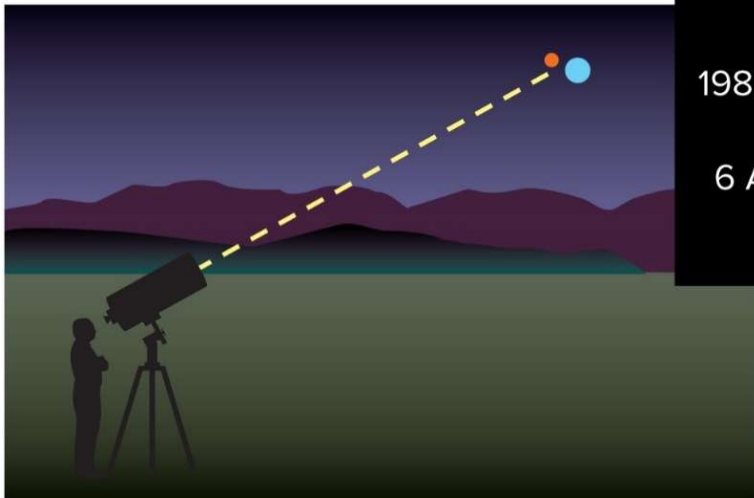
# Visual Binary Stars

- **Visual binaries** are binary systems where we can directly see the orbital motion of the stars about each other by comparing images made several years apart.



# Newton's Form of Kepler's 3rd Law

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Plot of star positions → Period of 10 years

Measure semi-major axis =  $a = 6$  AU

Use modified form of Kepler's third law

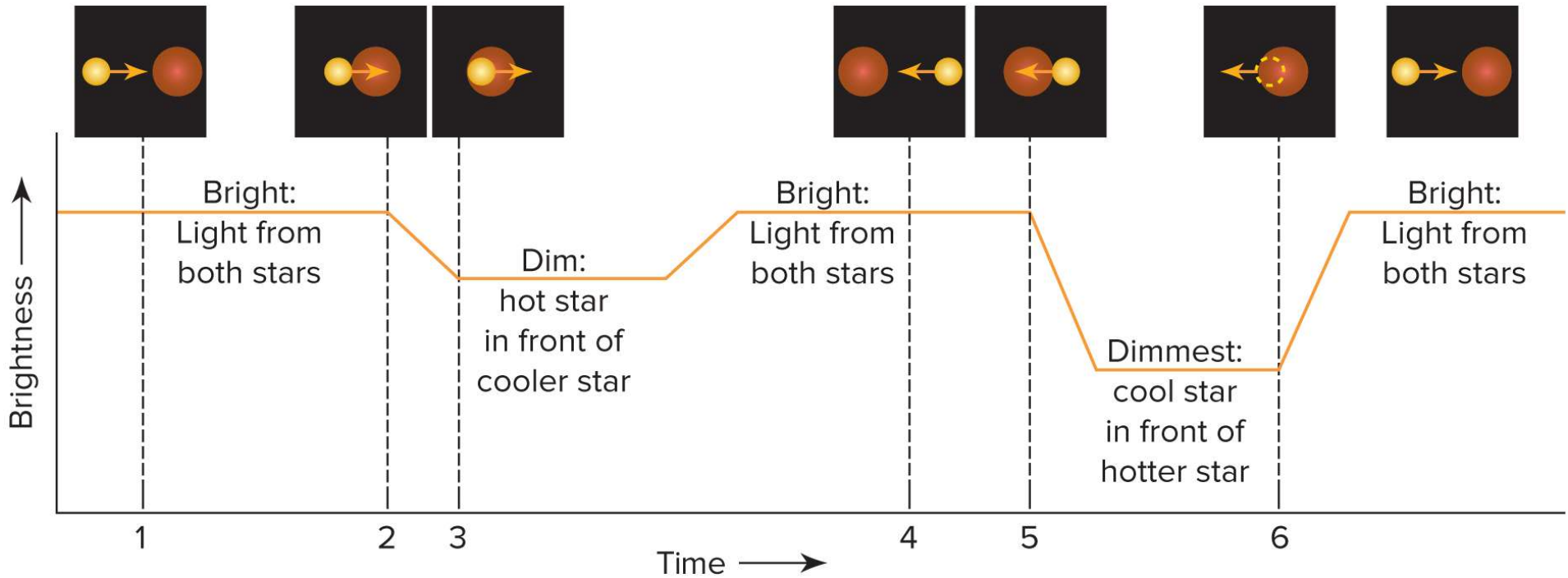
$$\begin{aligned}M_A + M_B &= \frac{a_{\text{AU}}^3}{P_{\text{yr}}^2} \\ &= \frac{6^3}{10^2} \\ &= 2.16 M_{\odot}\end{aligned}$$

# Stellar Masses

- $P$  and  $a$  are determined from observations (may take a few years) and the above equation gives the combined mass ( $m + M$ ).
- Further observations of the stars' orbit will allow the determination of each star's individual mass.
- Most stars have masses that fall in the narrow range 0.1 to  $30 M_{\odot}$ .

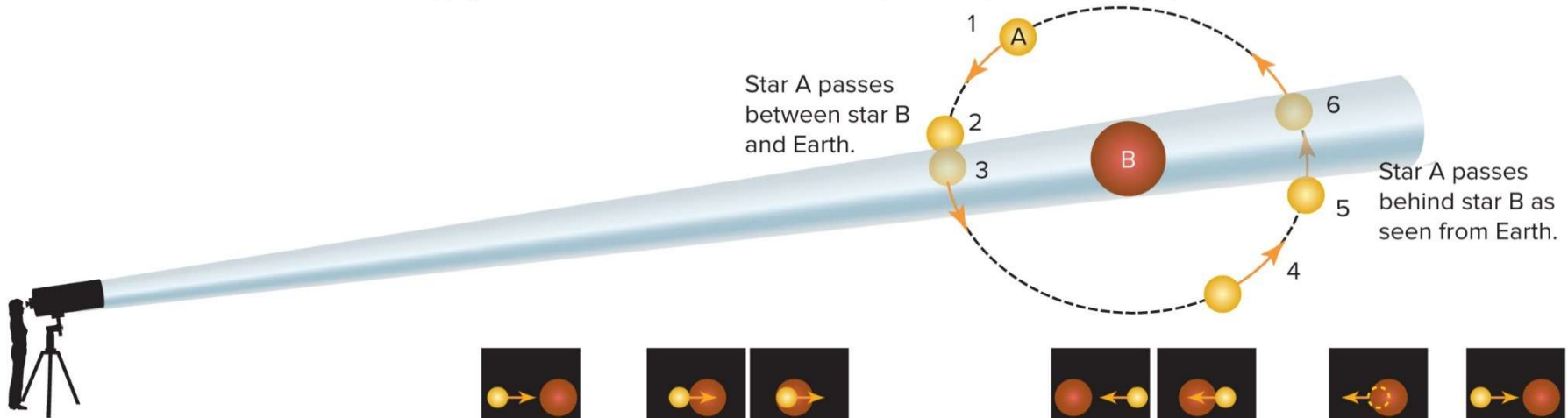
# Eclipsing Binaries

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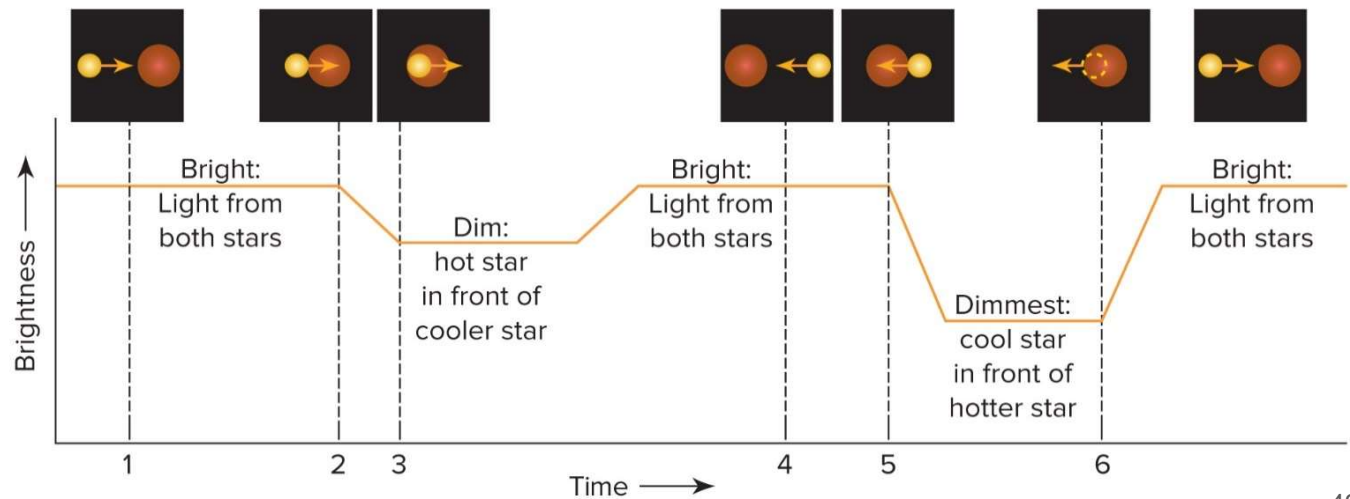


# Stellar Transits

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If we imagine star B at rest, star A moves a distance equal to its own diameter between the times 2 and 3. That time interval, when multiplied by star A's orbital speed, gives its diameter. Similarly, the time between points 5 and 6 multiplied by star A's orbital speed will give star B's diameter.



# Summary of Stellar Properties

- Distance.
  - Parallax (triangulation) for nearby stars ( $d$  less than 250 pc).
  - Standard-candle method for more distant stars.
- Temperature.
  - Wien's law (color-temperature relation).
  - Spectral class (O hot; M cool).
- Luminosity.
  - Measure star's apparent brightness and distance and then calculate with inverse square law.
  - Luminosity class of spectrum (to be discussed).
- Composition.
  - Spectral lines observed in a star.

# More Stellar Properties

- Radius.
  - Stefan-Boltzmann law (measure  $L$  and  $T$ , solve for  $R$ ).
  - Interferometer (gives angular size of star; from distance and angular size, calculate radius).
  - Eclipsing binary light curve (duration of eclipse phases).
- Mass
  - Modified form of Kepler's third law applied to binary stars.
- Radial Velocity.
  - Doppler shift of spectrum lines.

## Friday (April 17)

- C-day
- Students not in class due to STAAR will complete assignment from that day.

Monday / Tuesday (April 20 & 21)

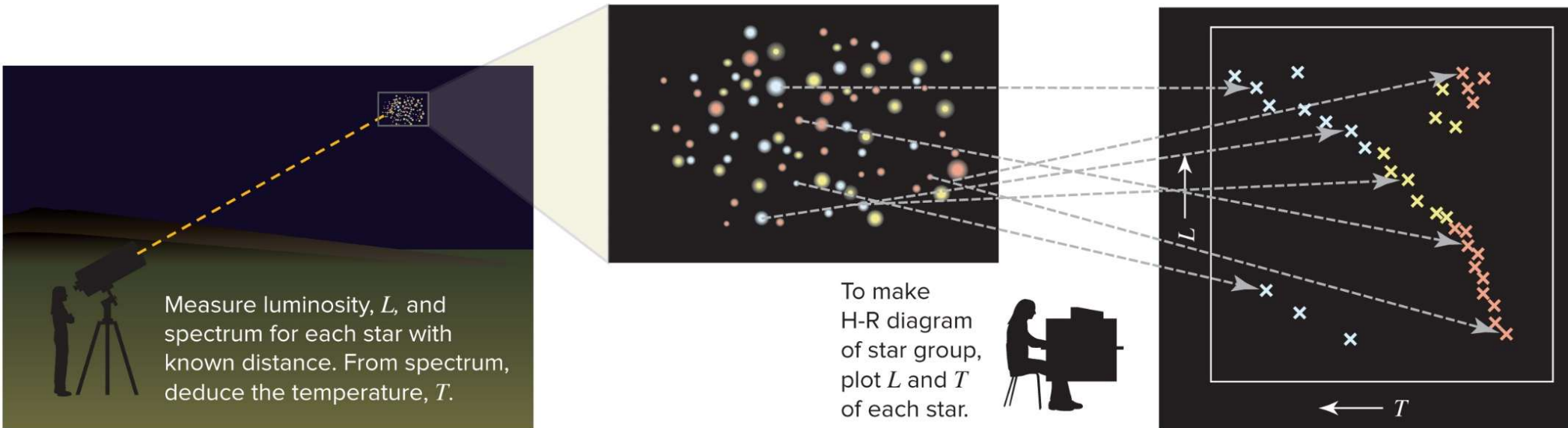
- T: 13 (F) use the Hertzsprung-Russell diagram to classify stars and plot and examine the life cycle of stars from birth to death;
- O: I will be able to understand an H-R diagram
- D: by taking notes, participating in a class discussion, and creating my own H-R diagram
- A: H-R diagram
- Y: What are main sequence stars?

# The Hertzsprung – Russell Diagram

- H-R diagram, developed independently by Ejnar Hertzsprung and Henry Norris Russell in 1912.

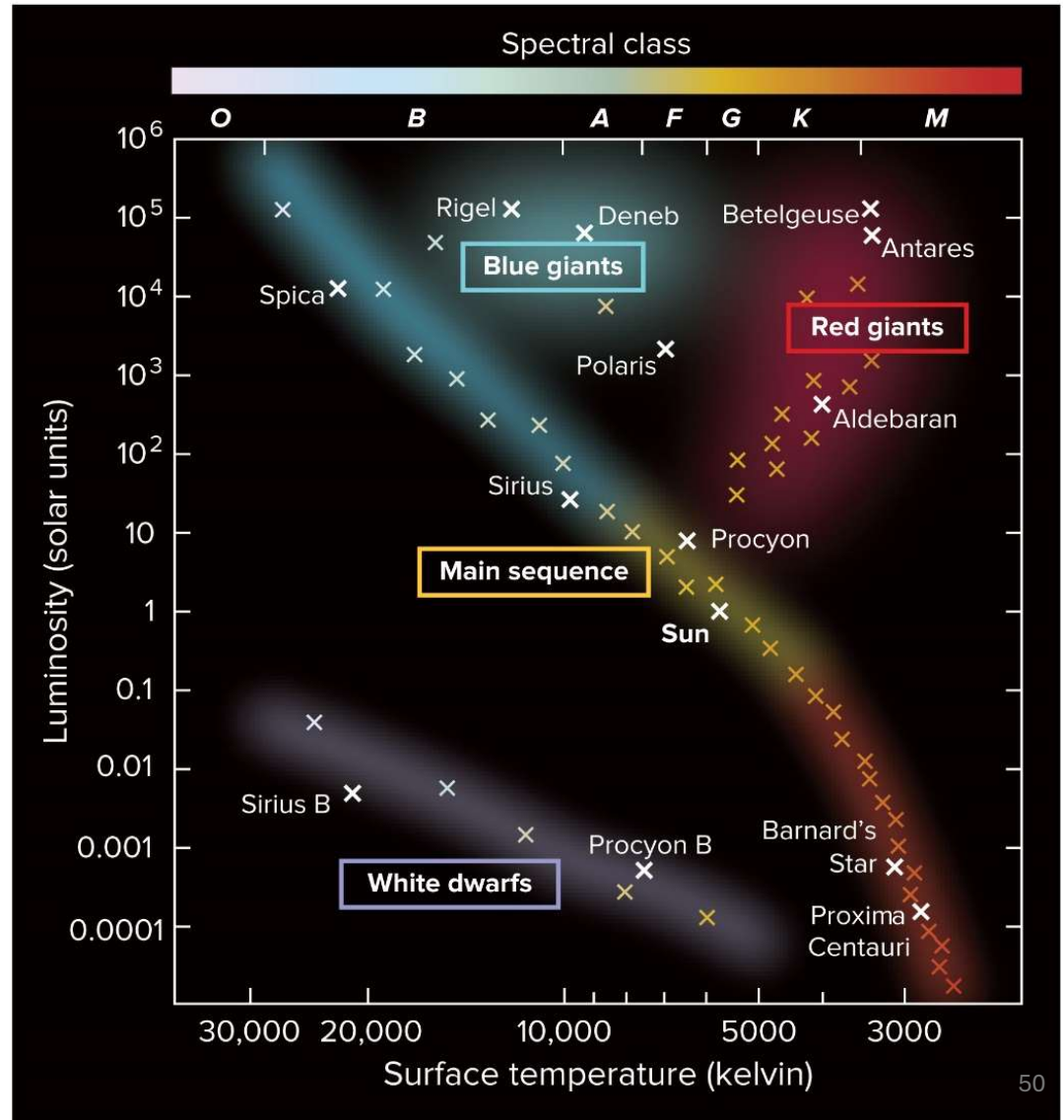
# Constructing the HR Diagram

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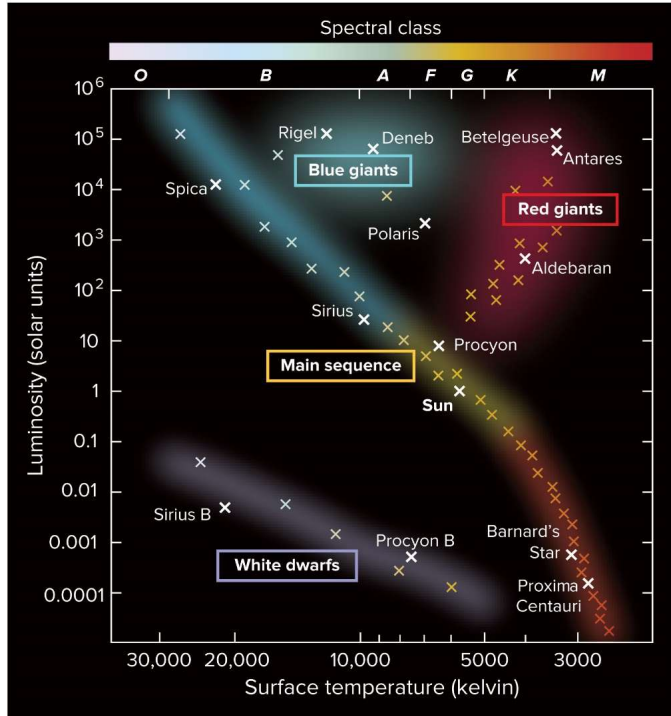
# The HR Diagram

- The *H-R diagram* is a plot of stellar temperature vs. luminosity.



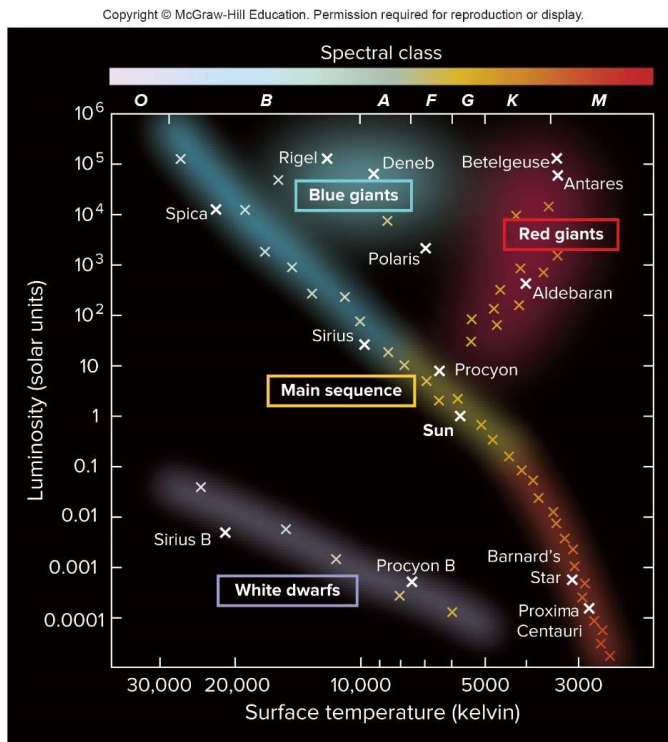
# Axes of the HR Diagram

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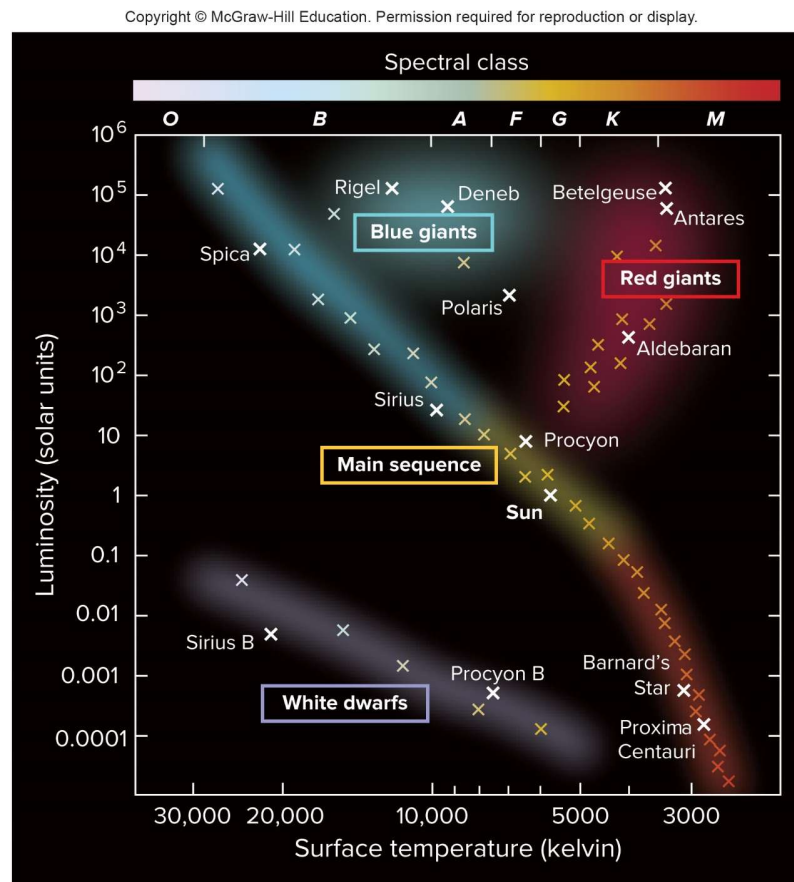
- Bright stars are placed at the top; dim ones at the bottom
- High-temperature (blue) stars are on the left; cool (red) stars on the right.
  - Note: temperature does not run in a traditional direction, it goes from hot to cold (left to right)

# The Main Sequence



- The diagonally running group of stars on the H-R diagram is referred to as the ***main sequence***.
- 90% of a group of stars will be on the main sequence
  - a few stars will be cool but very luminous (upper right part of H-R diagram)
  - others will be hot and dim (lower left part of H-R diagram).

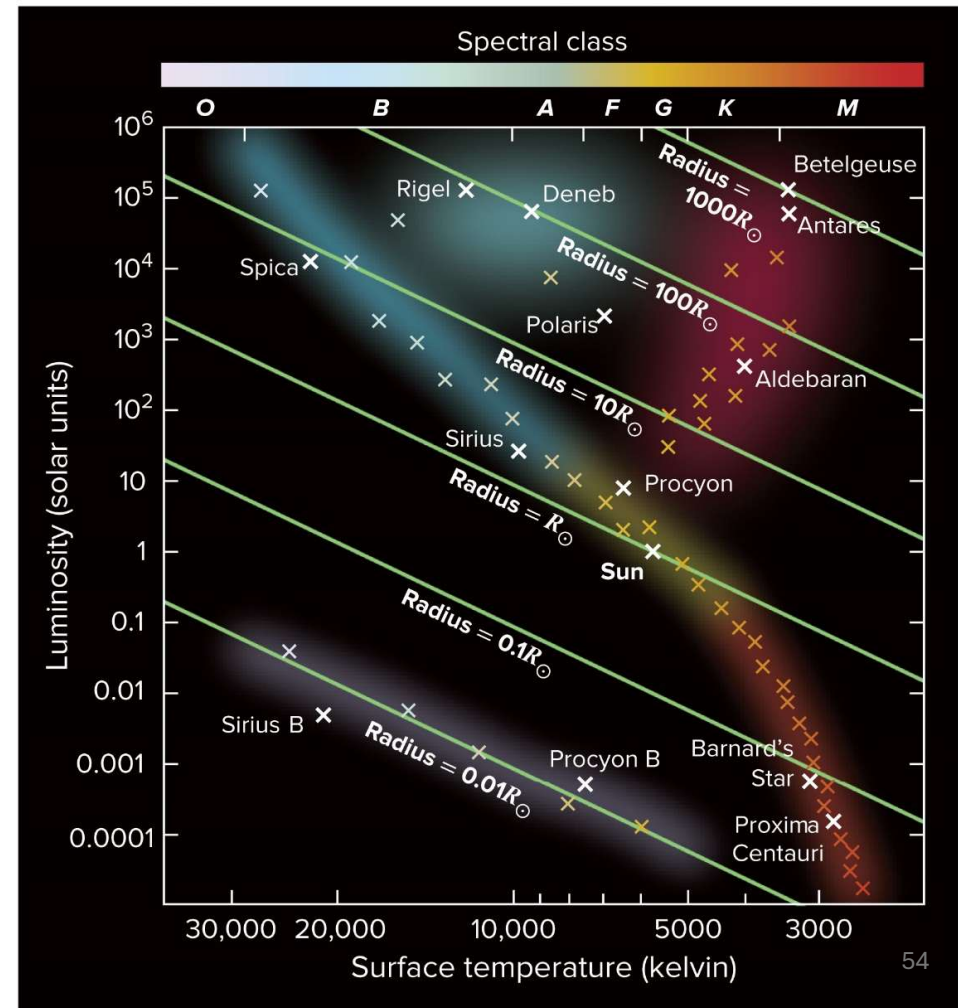
# Interpreting the HR Diagram



# Giants and Dwarfs

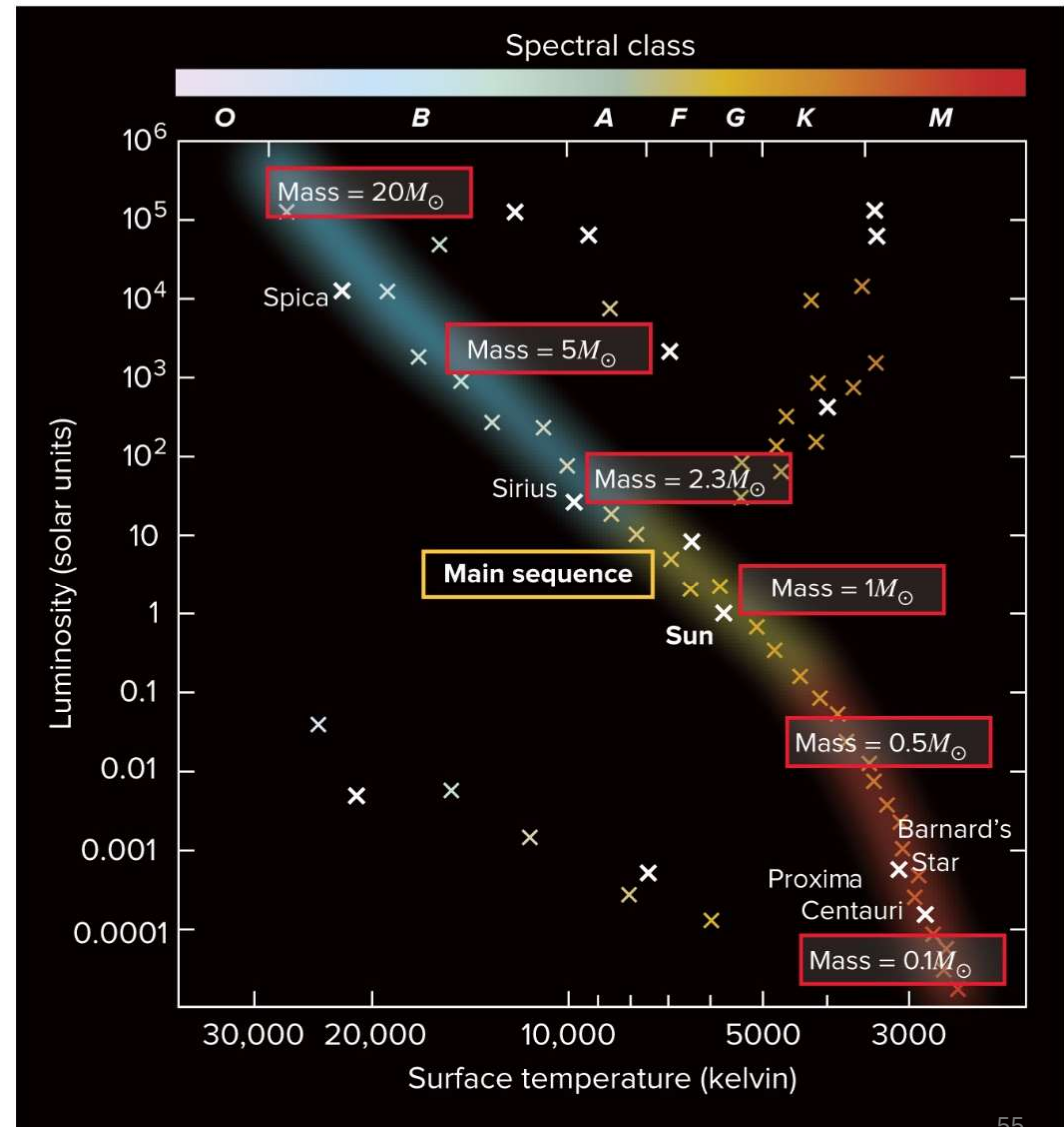
- Stars in the upper left are called **red giants** (red because of the low temperatures there).
- Stars in the lower right are **white dwarfs**.
- Three stellar types: main sequence, red giants, and white dwarfs.

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# Mass and Density

- Giants, dwarfs, and main sequence stars also differ in average density, not just diameter.
- Typical density of main-sequence star is  $1 \text{ g/cm}^3$ , while a giant is  $10^{-6} \text{ g/cm}^3$ .

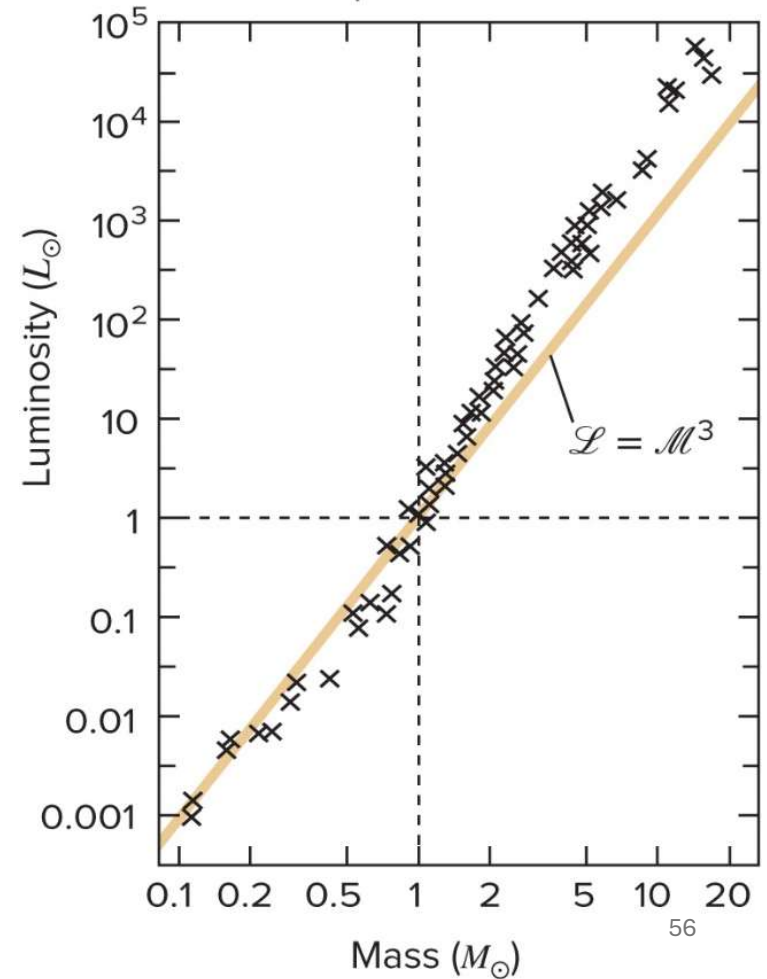


# The Mass-Luminosity Relation

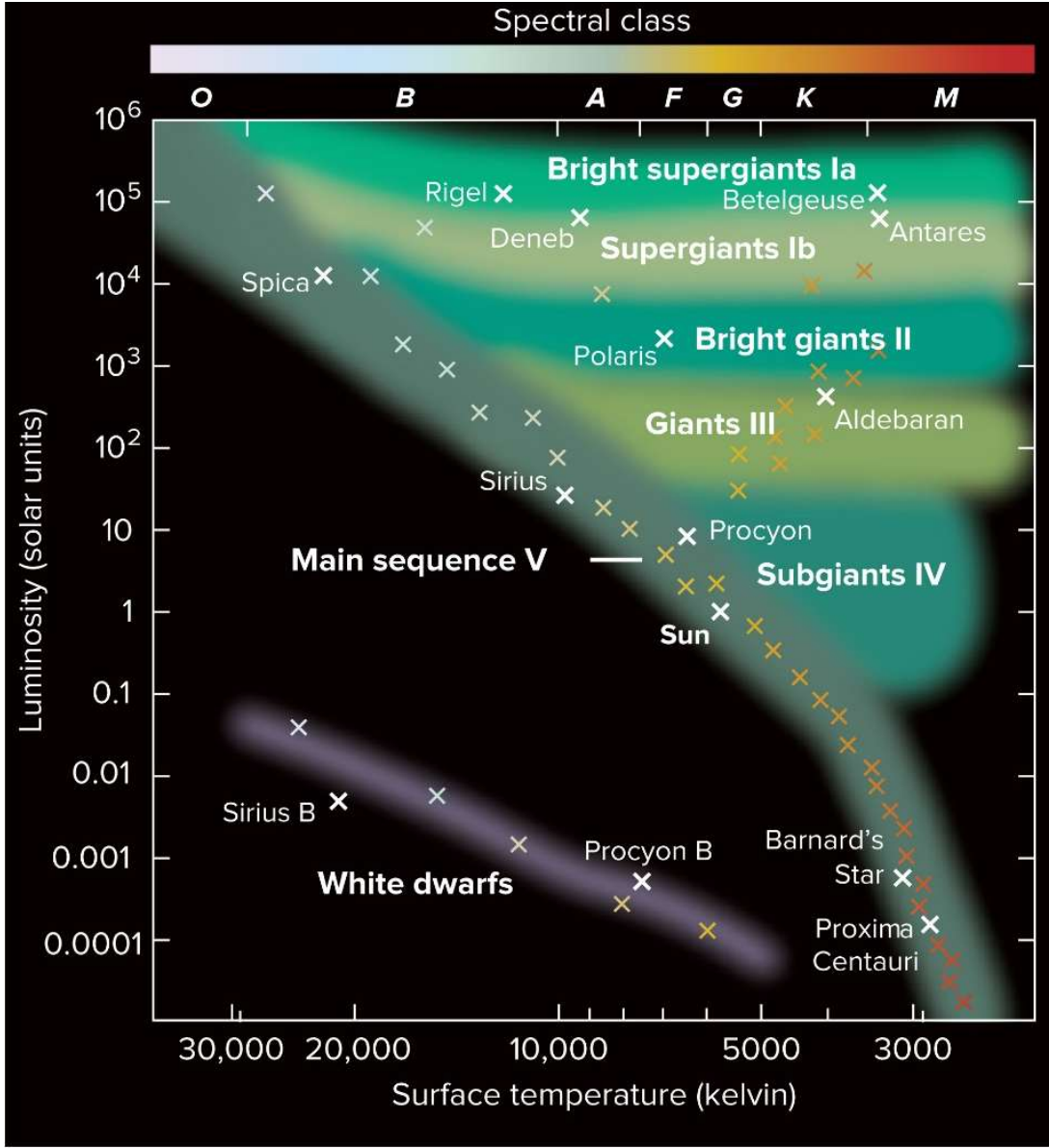
$$L = M^3$$

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For main sequence stars only, plotting their luminosities versus their masses shows the following relationship:

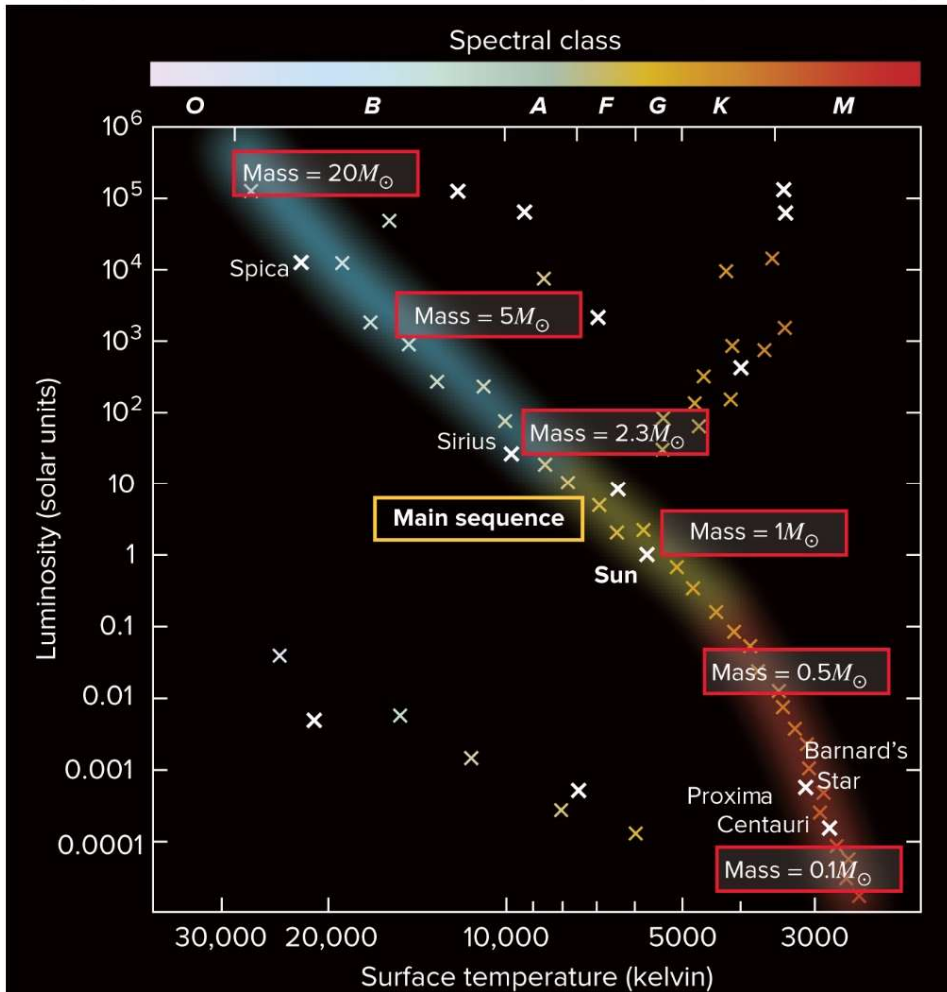


# Classes of Stars on the HR Diagram



# Summary of the HR Diagram

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- Most stars lie on the main sequence
- Of these, the hottest stars are blue and more luminous, while the coolest stars are red and dim.
- Star's position on sequence determines its mass, being more near the top of the sequence.

- Three classes of stars:
- Main-sequence.
- Giants.
- White dwarfs.



Wednesday / Thursday (April 22 & 23)

- T: 13 (F) use the Hertzsprung-Russell diagram to classify stars and plot and examine the life cycle of stars from birth to death;
- O: I will complete my understanding of the properties of stars
- D: by completing the Chapter 13 SmartBook as a test review.
- A: stars
- Y: How will finishing the test review help me with my test next class?

# Friday (April 24)

- C-day
- Finish the test review, work on any missing assignments, take notes for the next unit.