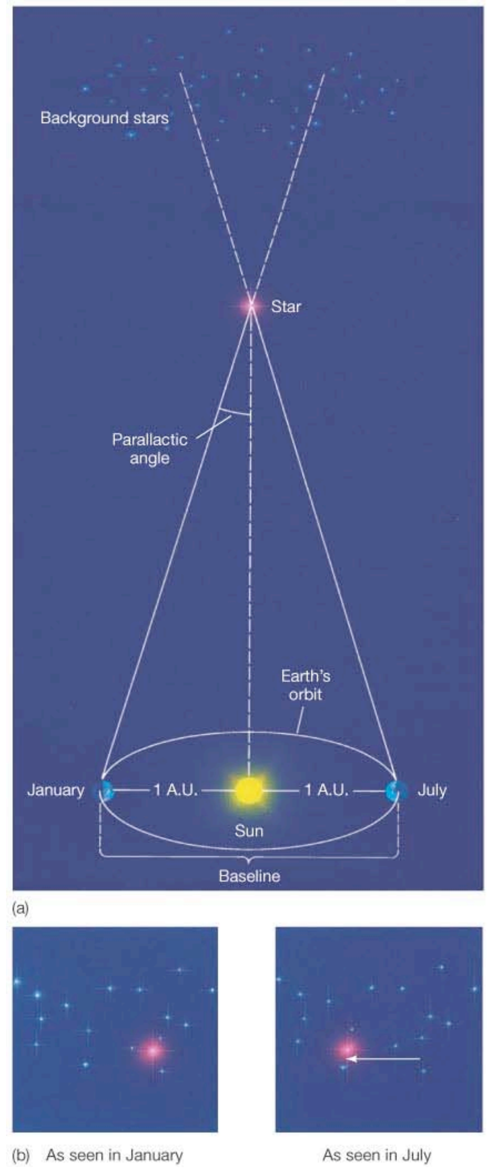
Chapter 17
Measuring the Stars

Units of Chapter 17

Units of Chapter 17 (cont.)

17.1 The Solar Neighborhood

Remember that stellar distances can be measured using parallax:



17.1 The Solar Neighborhood

Nearest star to the Sun: Proxima Centauri, which is a member of the three-star system Alpha Centauri complex

Model of distances:

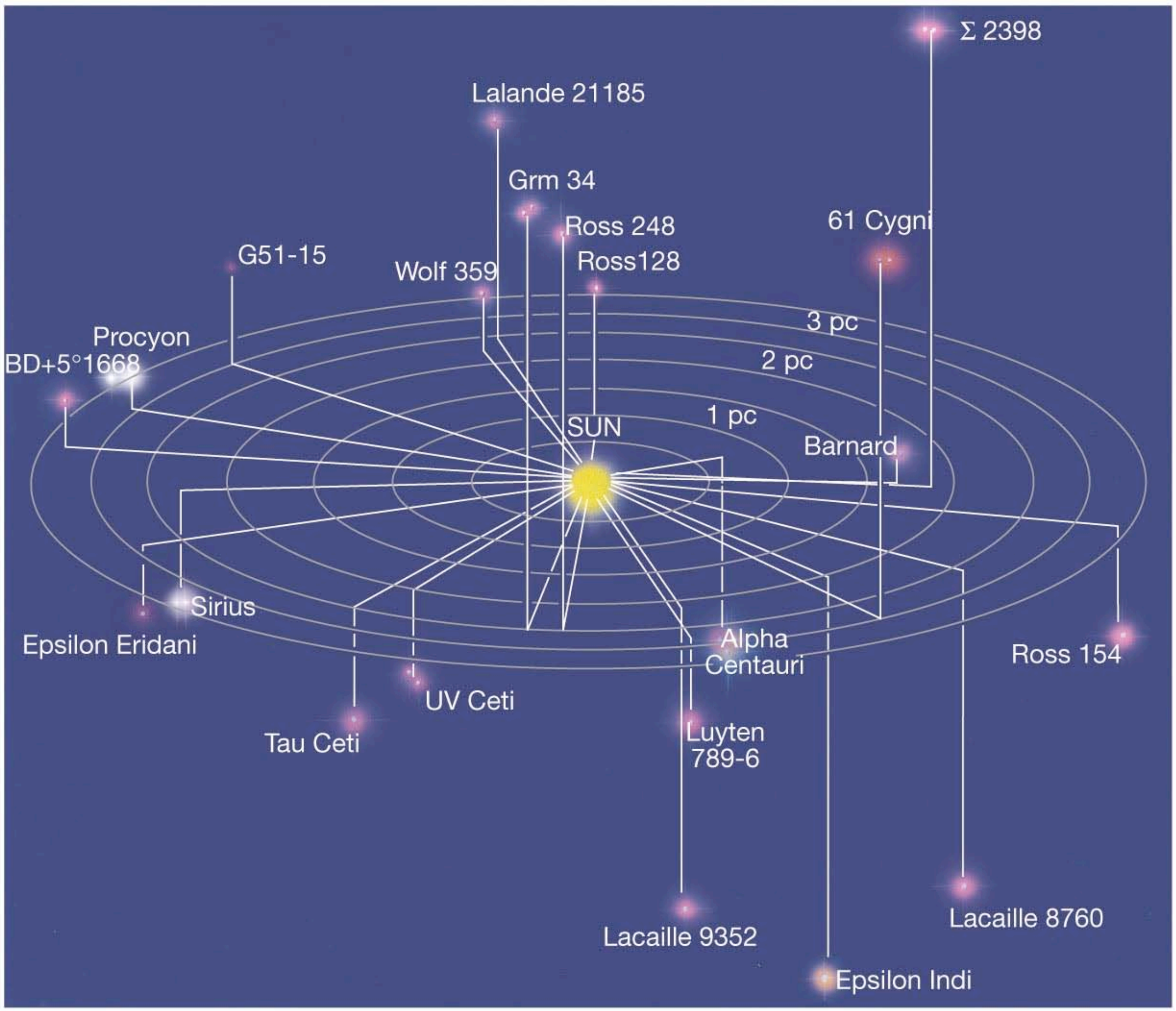
Sun is a marble, Earth is a grain of sand orbiting 1 m away

Nearest star is another marble 270 km away

Solar system extends about 50 m from Sun; rest of distance to nearest star is basically empty

17.1 The Solar Neighborhood

The **30 closest stars** to the Sun:

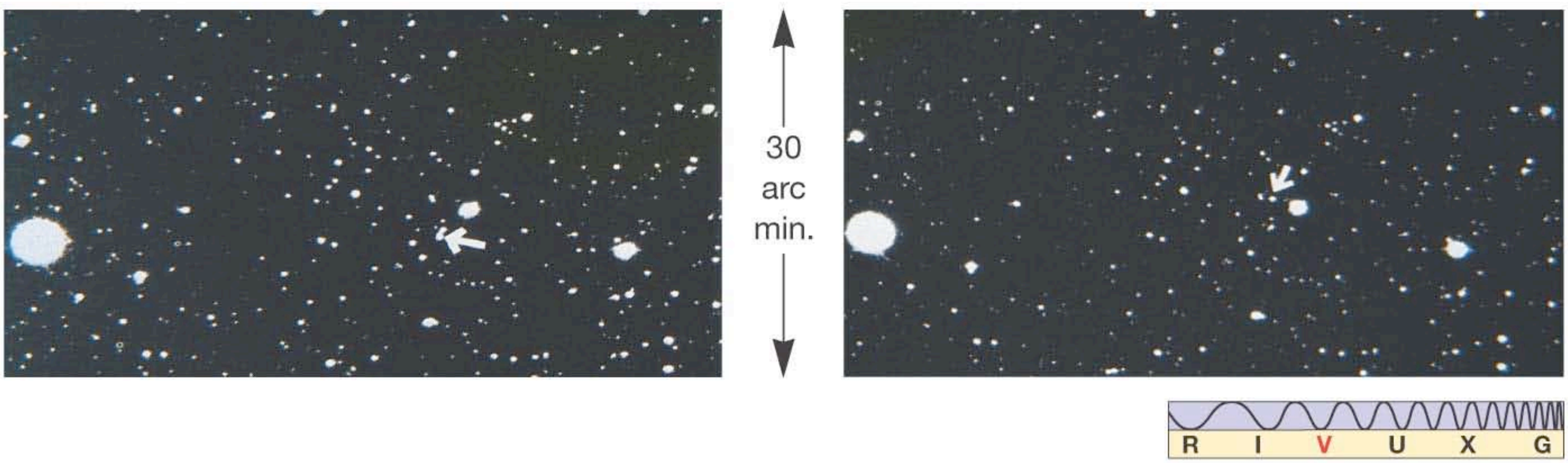


17.1 The Solar Neighborhood

Next nearest neighbor: **Barnard's Star**

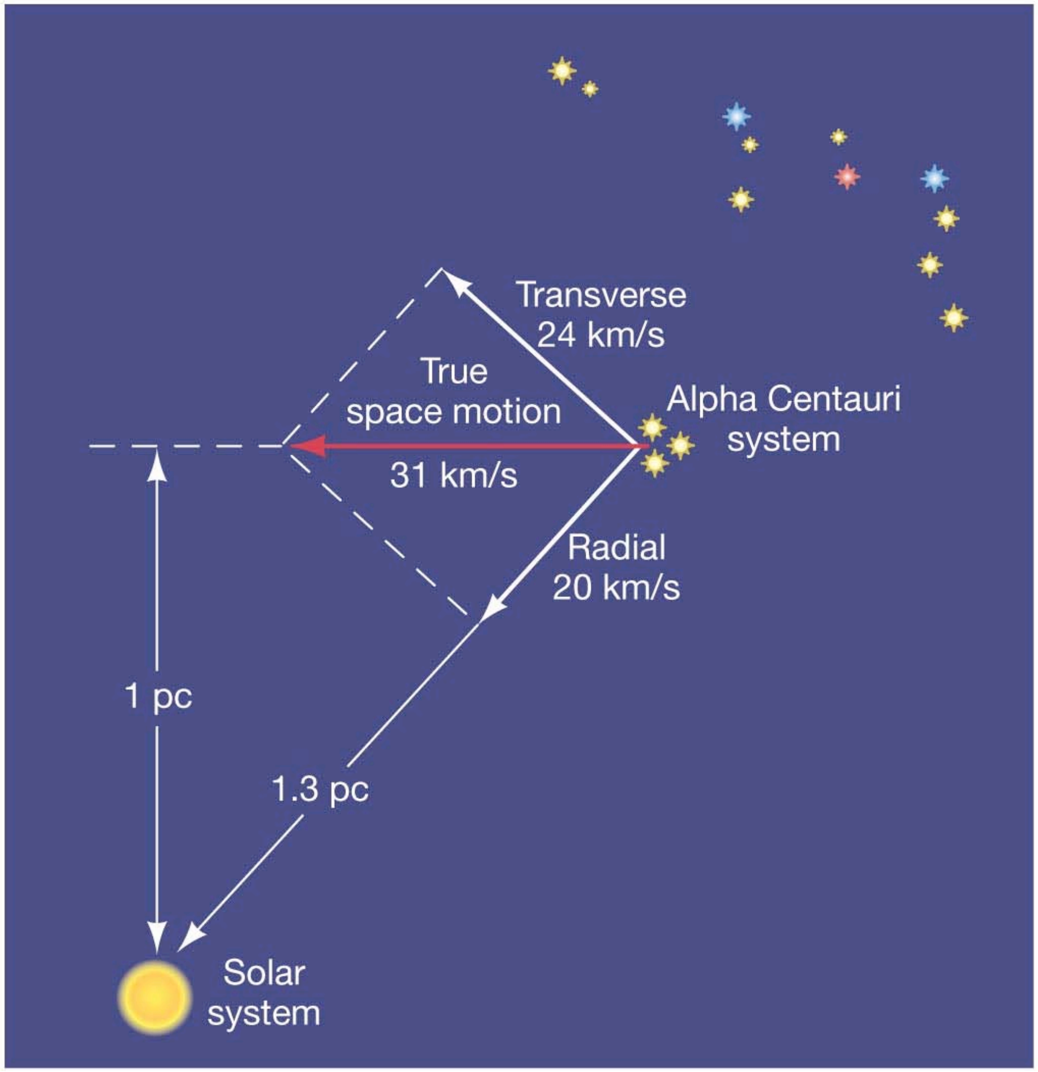
Barnard's Star has the largest **proper motion** of any star—proper motion is the actual shift of the star in the sky, after correcting for parallax

These pictures were taken 22 years apart:



17.1 The Solar Neighborhood

Actual motion of the **Alpha Centauri** complex:



17.2 Luminosity and Apparent Brightness

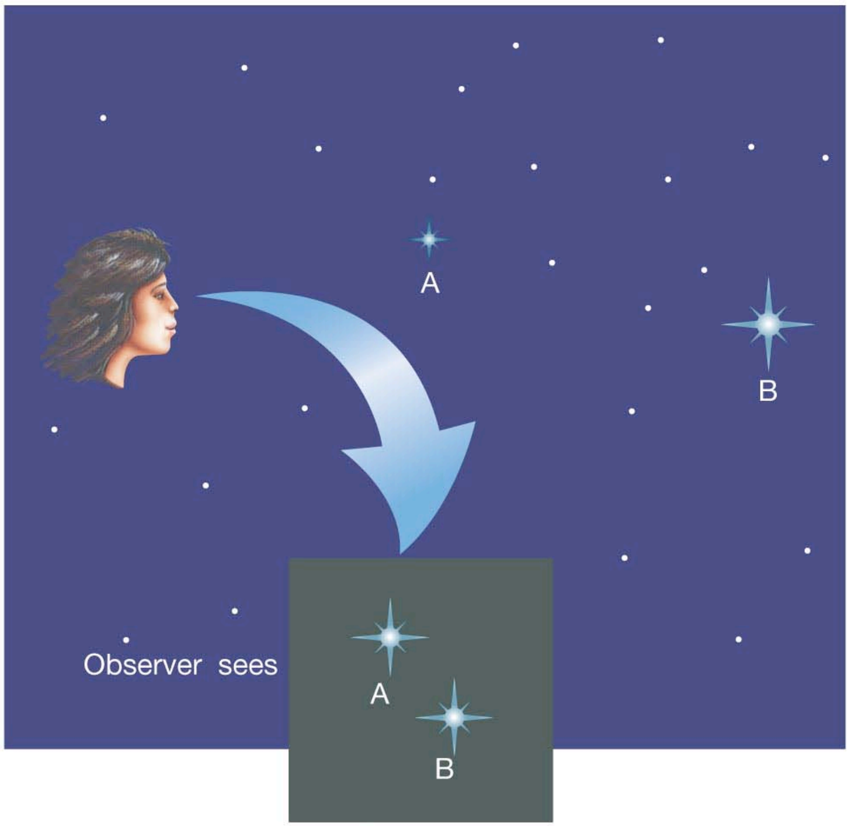
Luminosity, or absolute brightness, is a measure of the total **power** radiated by a star.

Apparent brightness is how bright a star appears when viewed from Earth; it depends on the **absolute brightness** but also on the **distance** of the star:

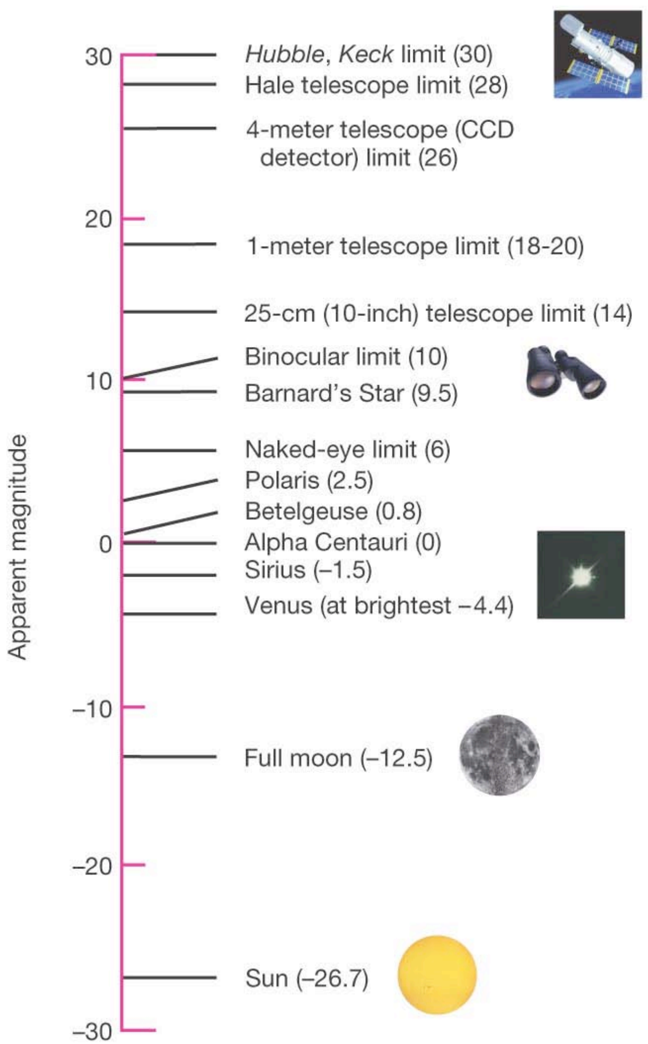
$$\text{apparent brightness (energy flux)} \propto \frac{\text{luminosity}}{\text{distance}^2}$$

17.2 Luminosity and Apparent Brightness

Therefore, two stars that appear equally bright might be a **closer, dimmer** star and a **farther, brighter** one:



17.2 Luminosity and Apparent Brightness



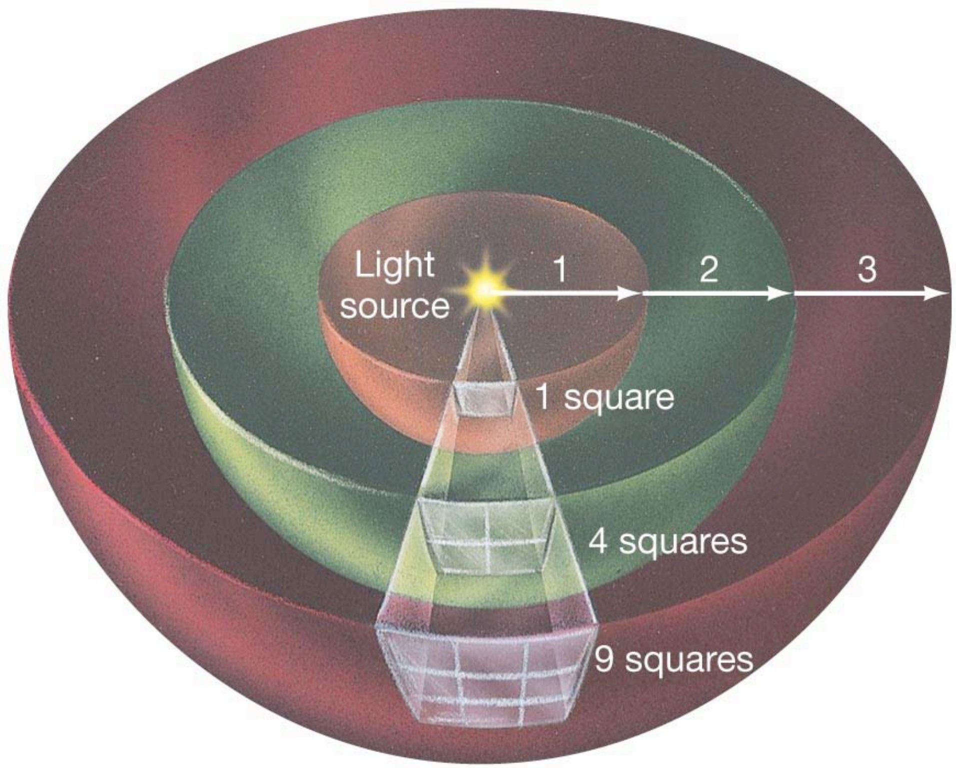
Apparent luminosity is measured using a **magnitude scale**, which is related to our perception.

It is a **logarithmic** scale; a change of 5 in magnitude corresponds to a change of a factor of 100 in apparent brightness.

It is also **inverted**—larger magnitudes are dimmer.

17.2 Luminosity and Apparent Brightness

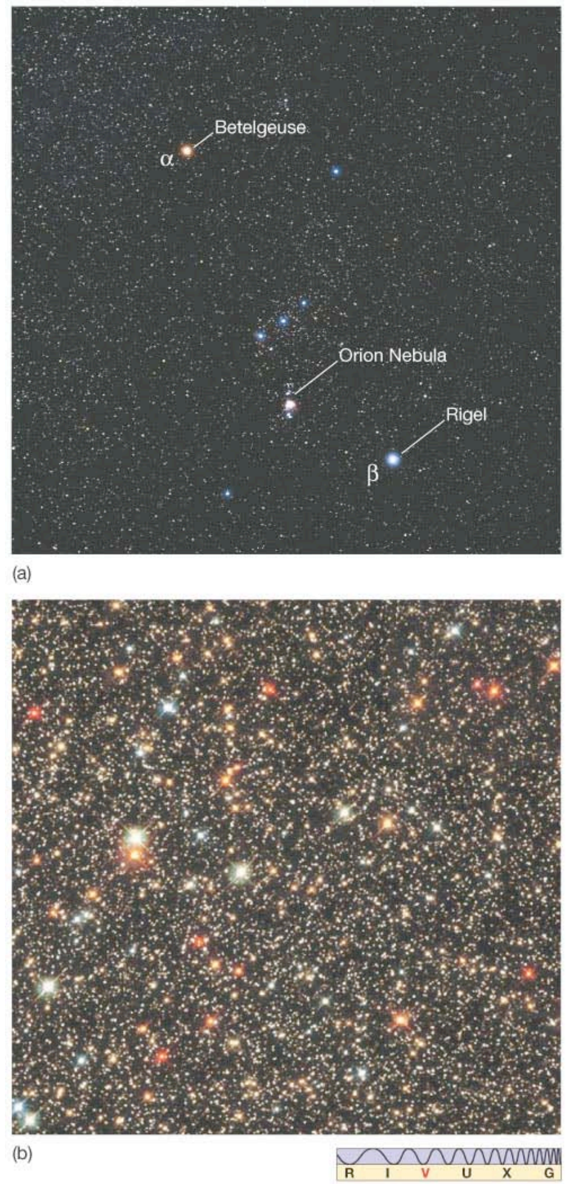
If we know a star's **apparent brightness** and its **distance** from us, we can calculate its **absolute luminosity**.



17.3 Stellar Temperatures

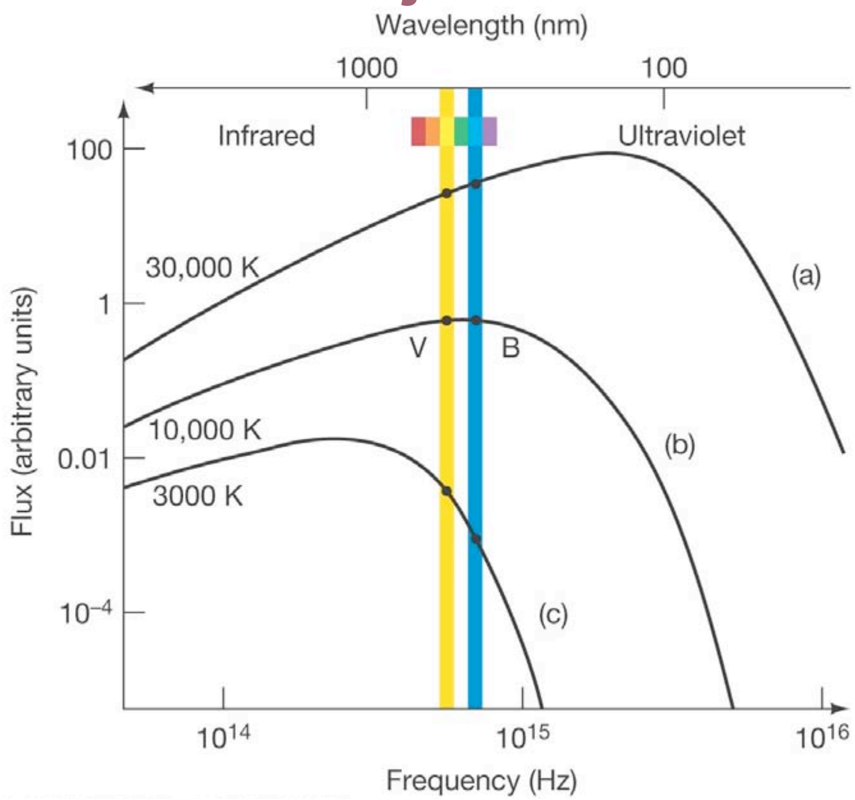
Recall Wein's Law for blackbodies:

The color of a star is indicative of its temperature. Red stars are relatively cool, while blue ones are hotter.



17.3 Stellar Temperatures

The **radiation** from stars is approximately **blackbody** radiation; as the blackbody curve is not symmetric, observations at two wavelengths are enough to define the temperature. The relative amount of light in two wavelength bands is an object's *color*.



17.3 Stellar Temperatures

Stellar spectra are much more informative than the blackbody curves (continuous part of the spectrum).

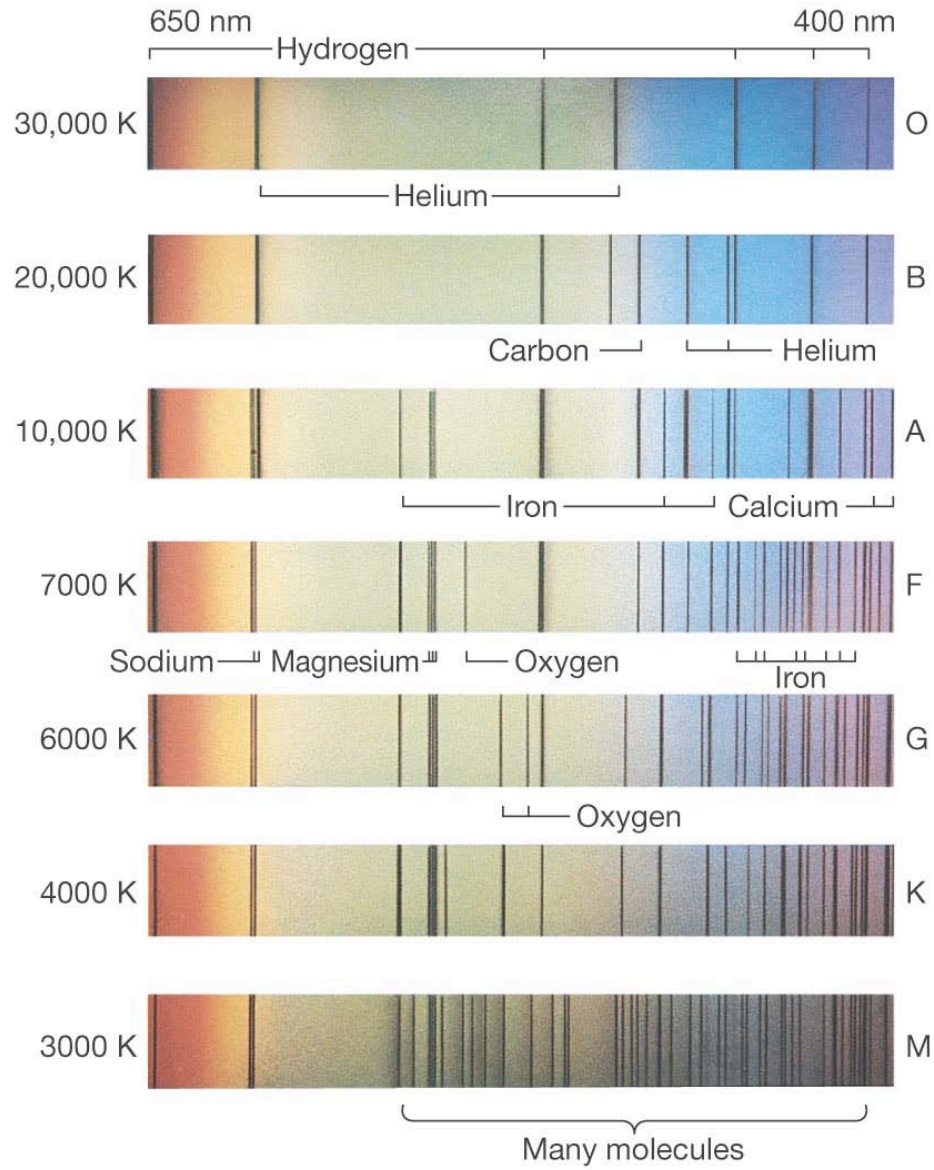
There are **seven** general categories of stellar spectra, corresponding to different **temperatures**.

From highest to lowest, those categories are:

O B A F G K M

17.3 Stellar Temperatures

Here are their spectra:



17.3 Stellar Temperatures

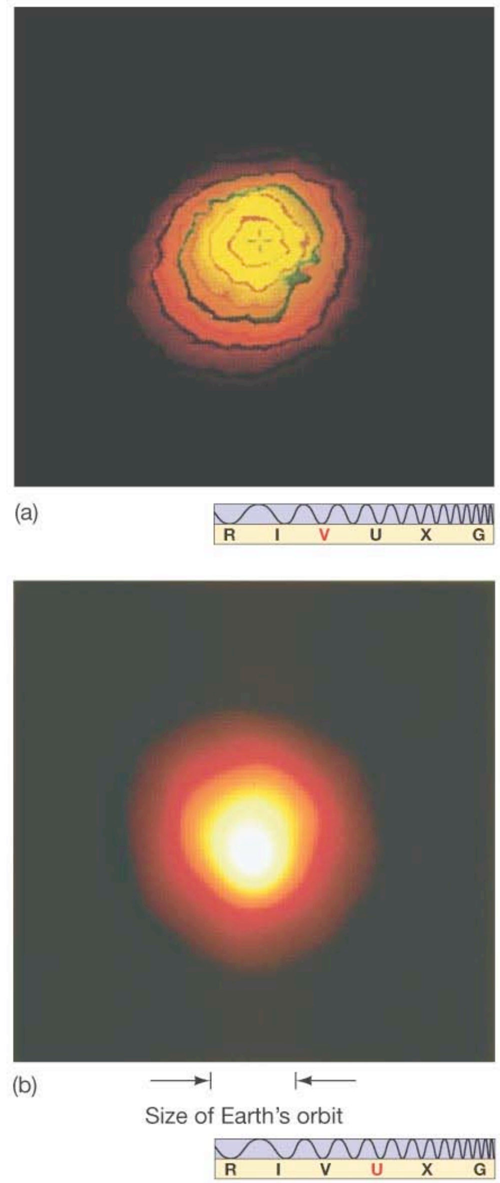
Characteristics of the spectral classifications:

TABLE 17.2 Stellar Spectral Classes

Spectral Class	Approximate Surface Temperature (K)	Noteworthy Absorption Line	Familiar Examples
O	30,000	Ionized helium strong; multiply ionized heavy elements; hydrogen faint	Mintaka (O9)
B	20,000	Neutral helium moderate; singly ionized heavy elements; hydrogen moderate	Rigel (B8)
A	10,000	Neutral helium very faint; singly ionized heavy elements; hydrogen strong	Vega (A0), Sirius (A1)
F	7000	Singly ionized heavy elements; neutral metals; hydrogen moderate	Canopus (F0)
G	6000	Singly ionized heavy elements; neutral metals; hydrogen relatively faint	Sun (G2), Alpha Centauri (G2)
K	4000	Singly ionized heavy elements; neutral metals strong; hydrogen faint	Arcturus (K2), Aldebaran (K5)
M	3000	Neutral atoms strong; molecules moderate; hydrogen very faint	Betelgeuse (M2), Barnard's Star (M5)

17.4 Stellar Sizes

A few very large, very close stars can be imaged directly using **speckle interferometry**. This is **Betelgeuse**.



17.4 Stellar Sizes

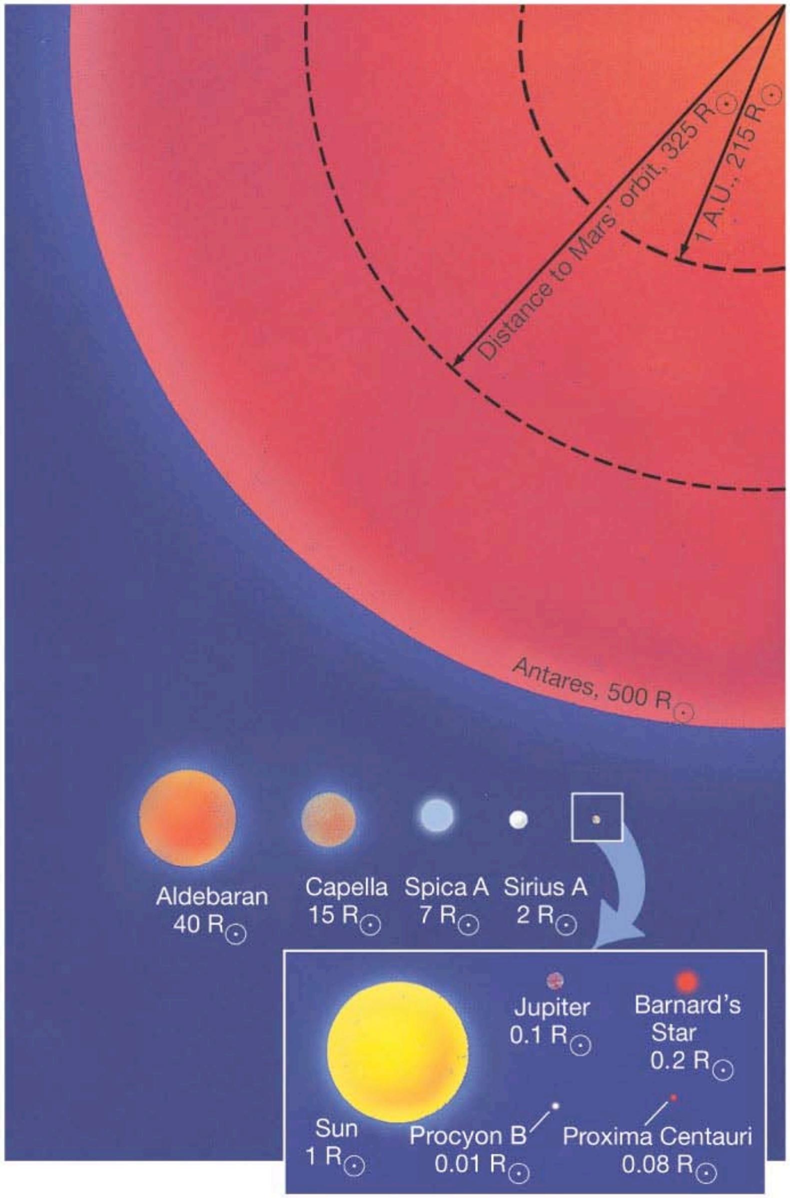
For the vast majority of stars that cannot be imaged directly, size must be calculated knowing the **luminosity** and **temperature**:

$$\text{luminosity} \propto \text{radius}^2 \times \text{temperature}^4$$

- **Giant stars** have radii between 10 and 100 times the Sun's
- **Dwarf stars** have radii equal to, or less than, the Sun's
- **Supergiant stars** have radii more than 100 times the Sun's

17.4 Stellar Sizes

Stellar radii **vary widely:**



More Precisely 17-2: Estimating Stellar Radii

Combining the Stefan-Boltzmann law for the power per unit area emitted by a blackbody as a function of temperature with the formula for the area of a sphere gives the total luminosity:

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

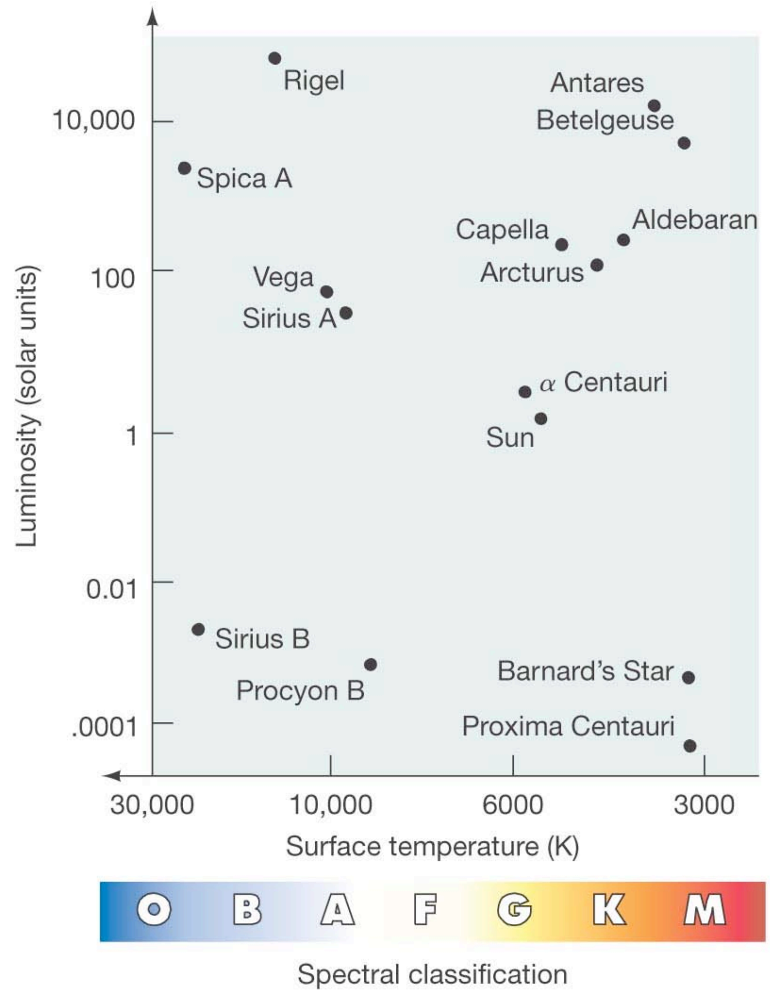
If we measure luminosity, radius, and temperature in solar units, we can write

$$L = R^2 T^4$$

17.5 The Hertzsprung-Russell Diagram

The H-R diagram plots stellar luminosity against surface temperature.

This is an H-R diagram of a few prominent stars:



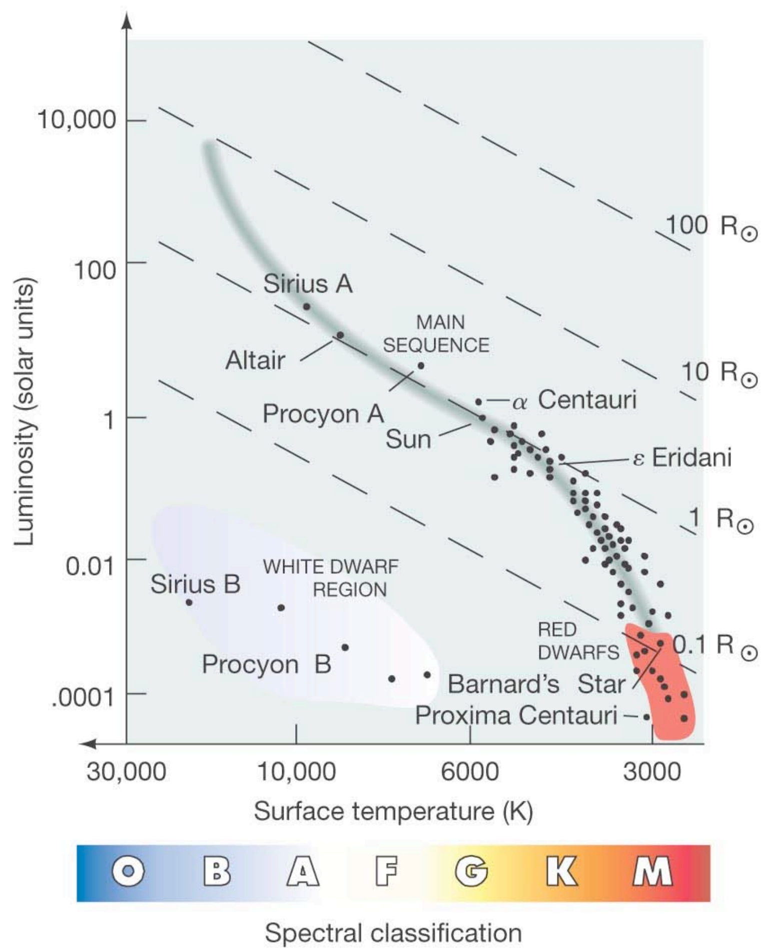
17.5 The Hertzsprung-Russell Diagram

Once many stars are plotted on an H-R diagram, a **pattern** begins to form:

These are the **80 closest stars** to us; note the dashed lines of **constant radius**.

The darkened curve is called the **main sequence**, as this is where most stars are.

Also indicated is the **white dwarf** region; these stars are hot but not very luminous, as they are quite small.

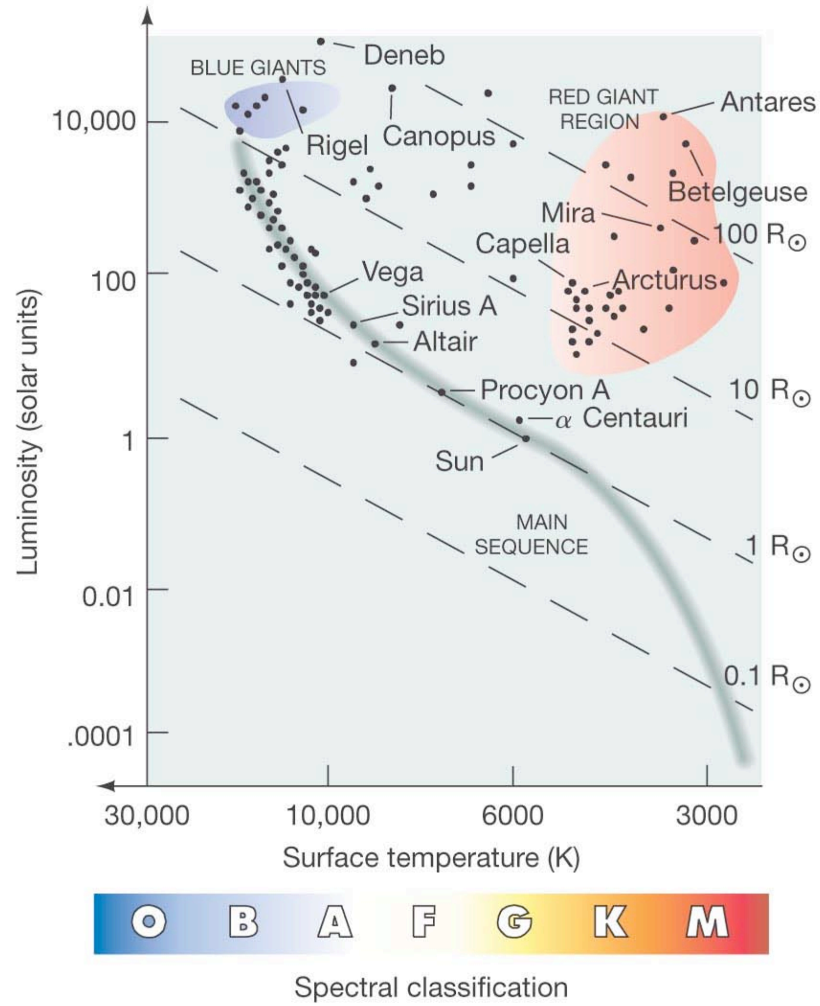


17.5 The Hertzsprung-Russell Diagram

An H-R diagram of the **100 brightest stars** looks quite different:

These stars are all **more luminous** than the Sun. Two new categories appear here—the **red giants** and the **blue giants**.

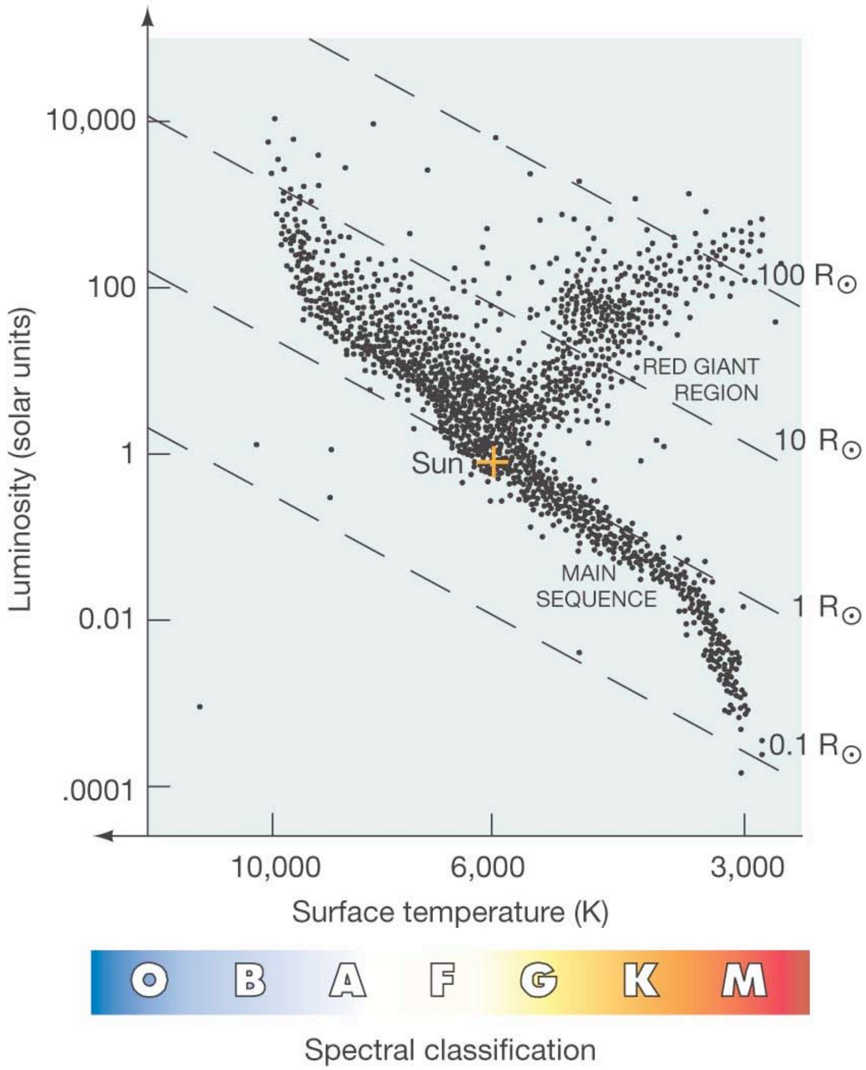
Clearly, the **brightest** stars in the sky appear bright because of their enormous **luminosities**, not their proximity.



17.5 The Hertzsprung-Russell Diagram

This is an H-R plot of about 20,000 stars. The **main sequence** is clear, as is the **red giant** region.

About **90%** of stars lie on the main sequence; **9%** are red giants and **1%** are white dwarfs.



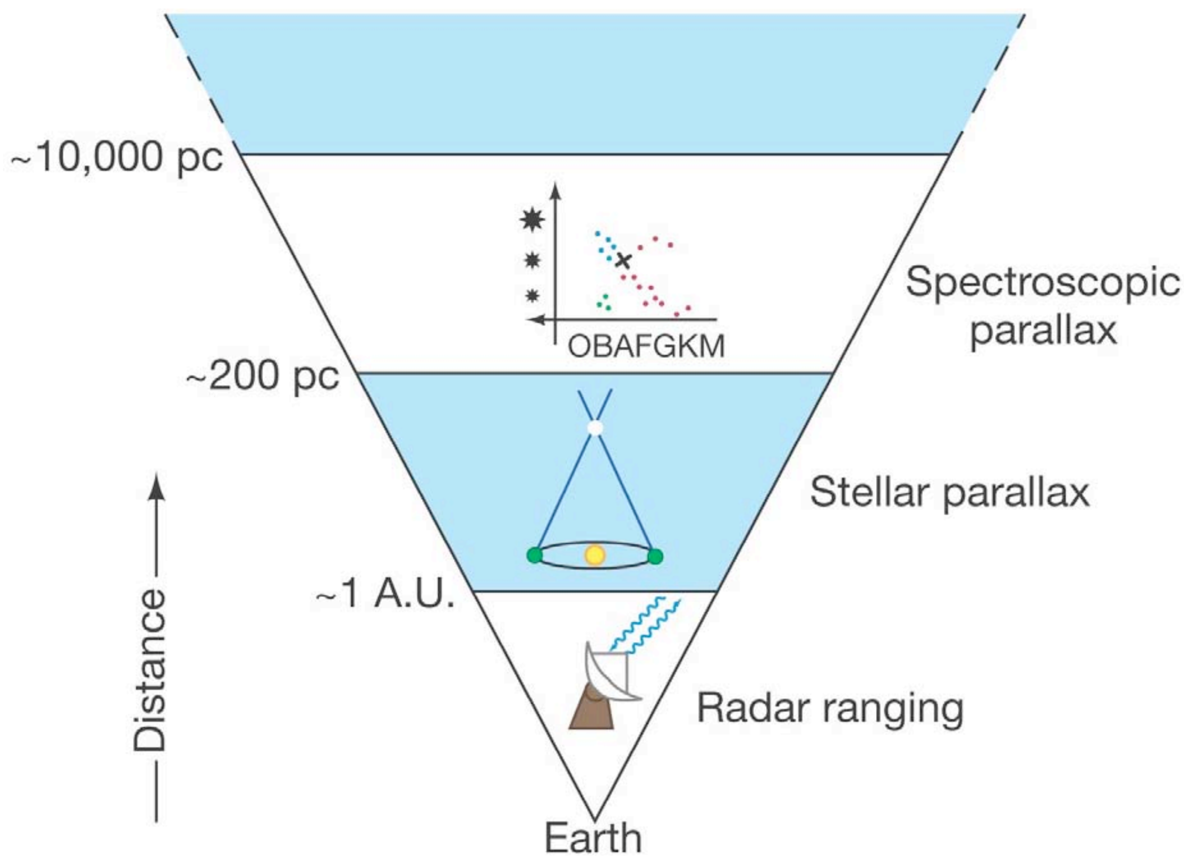
17.6 Extending the Cosmic Distance Scale

Spectroscopic parallax: Has nothing to do with parallax, but does use spectroscopy in finding the distance to a star.

1. Measure the star's **apparent magnitude** and **spectral class**
2. Use **spectral class** to estimate **luminosity**
3. Apply **inverse-square law** to find **distance**

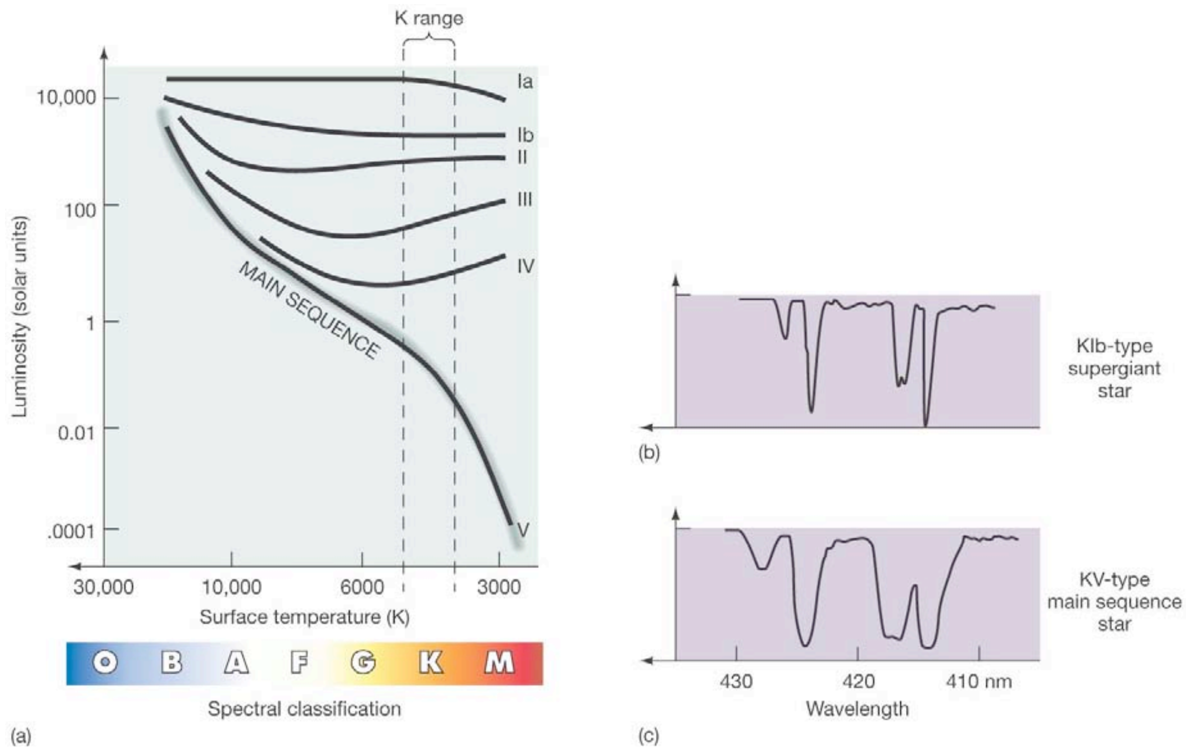
17.6 Extending the Cosmic Distance Scale

Spectroscopic parallax can extend the cosmic distance scale to several thousand parsecs:



17.6 Extending the Cosmic Distance Scale

The spectroscopic parallax calculation can be misleading if the star is not on the **main sequence**. The **width** of spectral lines can be used to define **luminosity classes**:



17.6 Extending the Cosmic Distance Scale

In this way, giants and supergiants can be distinguished from main-sequence stars

TABLE 17.4 Variation in Stellar Properties within a Spectral Class

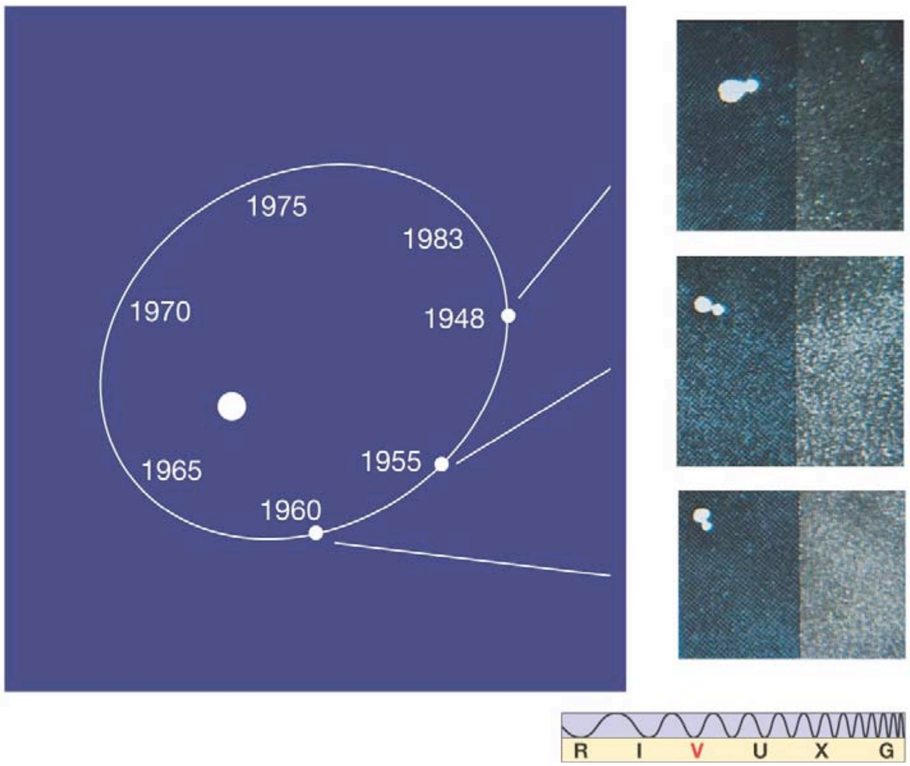
Approximate Surface Temperature (K)	Luminosity (solar luminosities)	Radius (solar radii)	Object	Example
4900	0.3	0.8	K2V main-sequence star	ε Eridani
4500	110	21	K2III red giant	Arcturus
4300	4000	140	K2Ib red supergiant	ε Pegasi

17.7 Stellar Masses

Determination of stellar **masses**:

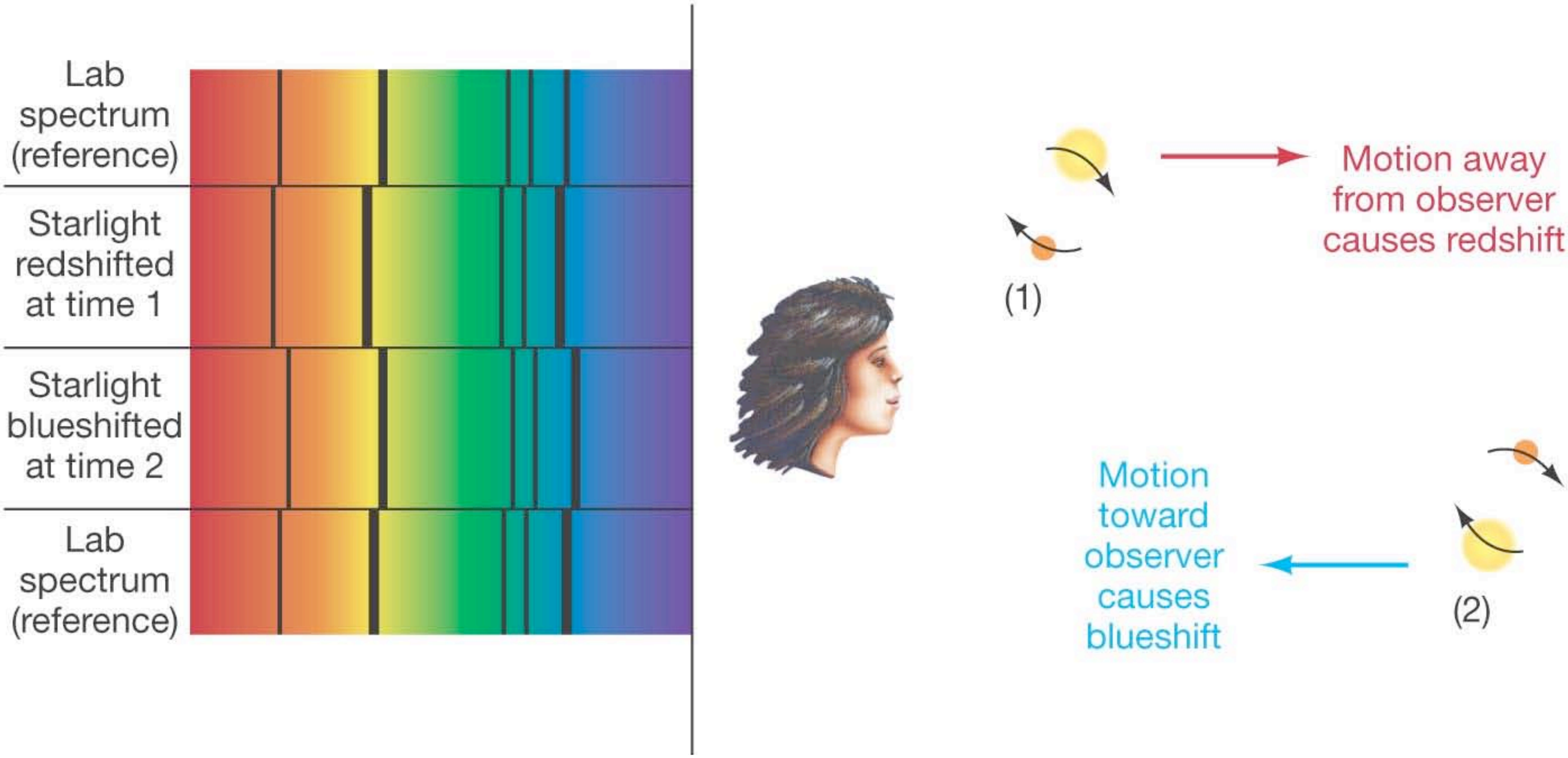
Many stars are in **binary pairs**; measurement of their orbital motion allows determination of the masses of the stars.

Visual binaries can be measured directly. This is Kruger 60:



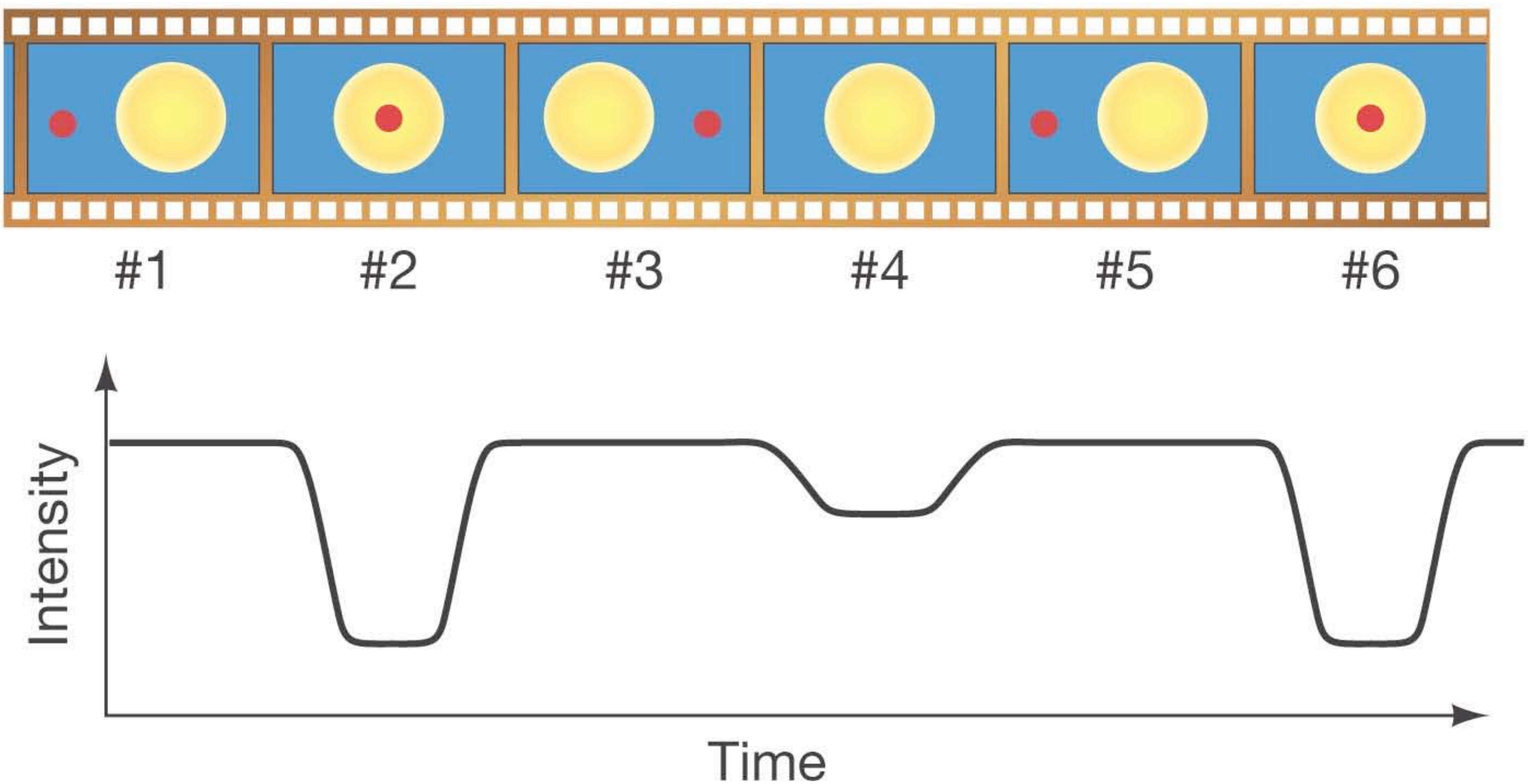
17.7 Stellar Masses

Spectroscopic binaries can be measured using their Doppler shifts:



17.7 Stellar Masses

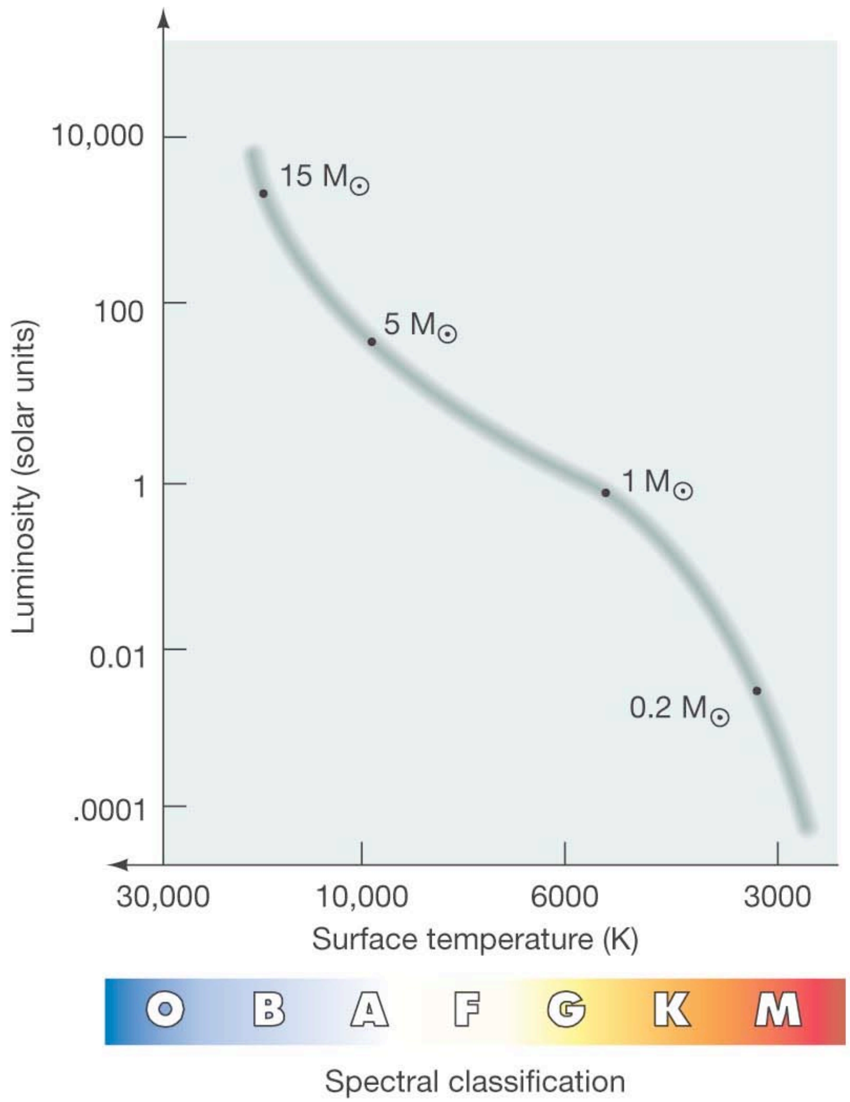
Finally, **eclipsing binaries** can be measured using the changes in luminosity.



17.7 Stellar Masses

Mass is the main determinant of where a star will be on the **Main Sequence**. Mass controls a star's lifetime, and the way in which it will die.

(We cover stellar evolution in ch.19-20, but we will get to lifetimes here.)

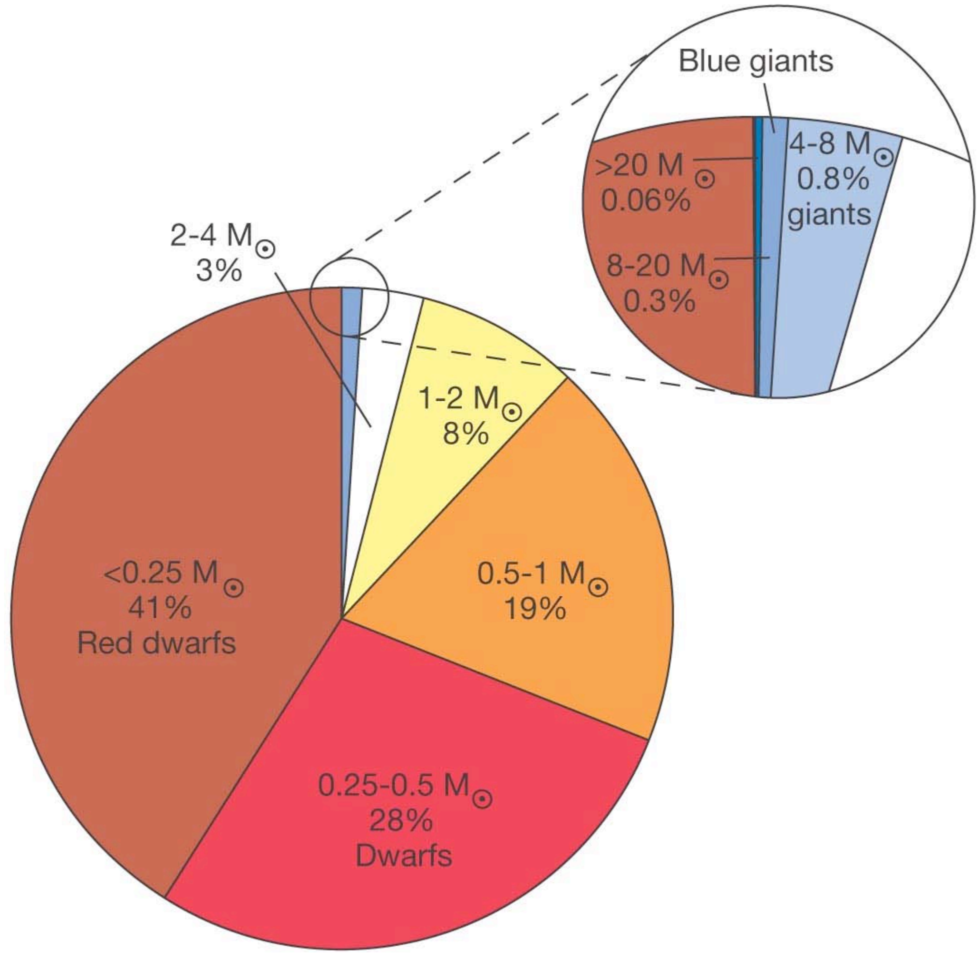


More Precisely 17-3: Measuring Stellar Masses in Binary Stars

In order to measure stellar masses in a binary star, the period and semimajor axis of the orbit must be measured. Once this is done, Kepler's third law gives the sum of the masses of the two stars. Then the relative speeds of the two stars can be measured using the Doppler effect; the speed will be inversely proportional to the mass. This allows us to calculate the mass of each star.

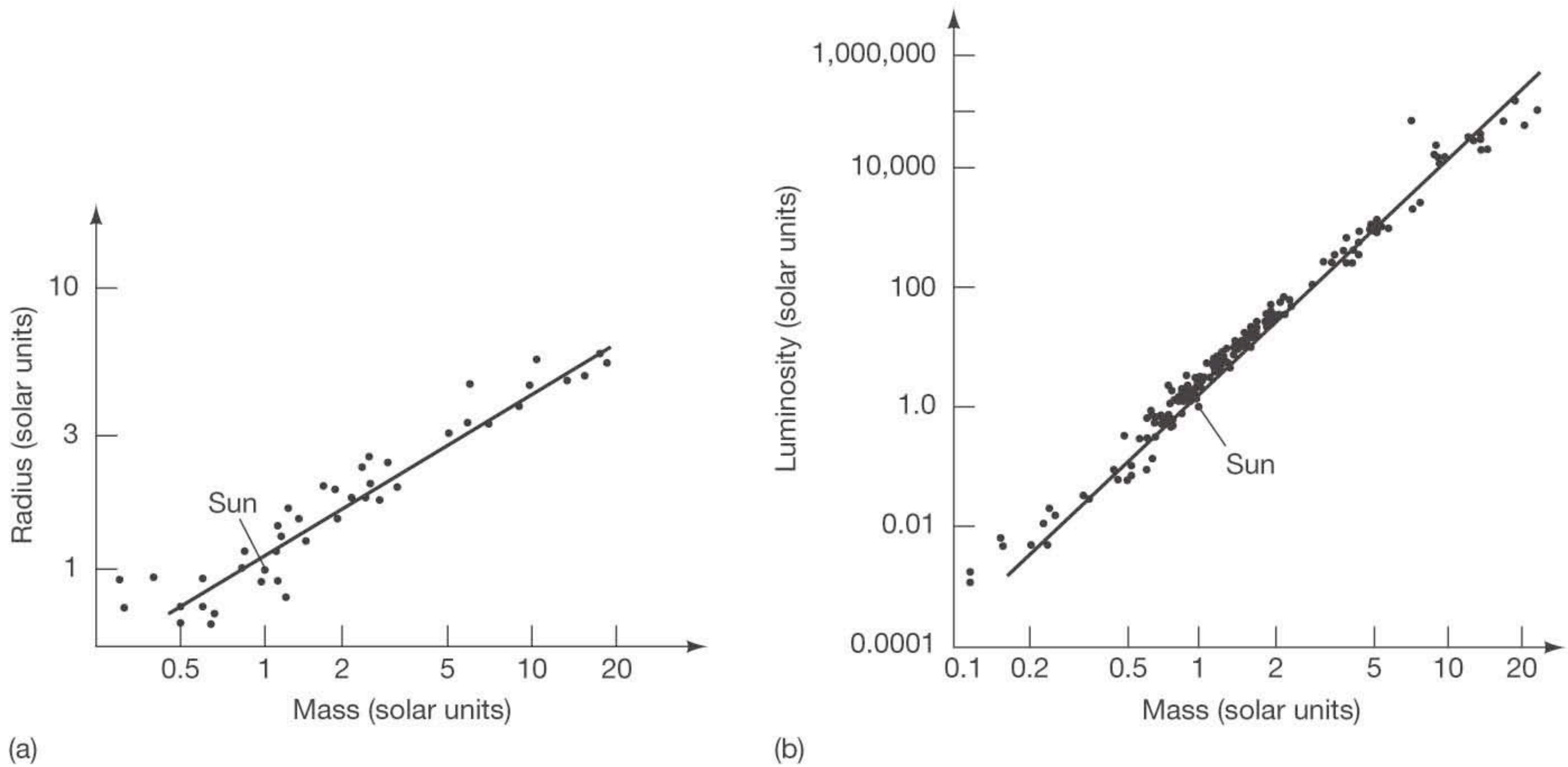
17.8 Mass and Other Stellar Properties

This pie chart shows the distribution of stellar masses. The more massive stars are much rarer than the least massive.



17.8 Mass and Other Stellar Properties

Mass is correlated with **radius** and is very strongly correlated with **luminosity**:



17.8 Mass and Other Stellar Properties

Mass is also related to **stellar lifetime**:

$$\text{stellar lifetime} \propto \frac{\text{stellar mass}}{\text{stellar luminosity}}$$

Using the **mass–luminosity relationship**:

$$\text{stellar lifetime} \propto \frac{1}{(\text{stellar mass})^3}$$

17.8 Mass and Other Stellar Properties

So the **most massive** stars have the **shortest lifetimes**—they have a lot of fuel but burn it at a very rapid pace.

On the other hand, **small red dwarfs** burn their fuel extremely slowly and can have **lifetimes** of a **trillion years** or more.

Summary of Chapter 17

• Can measure distances to nearby stars using parallax

• Apparent brightness is easy to measure, but tells us nothing about a star's intrinsic properties, only how bright it appears.

• Absolute luminosity L is a measure of the power output of the star. We can obtain L from the apparent brightness and *distance.*

• Spectral analysis has led to the defining of seven spectral classes of stars, which correspond to differences in temperature.

• Stellar radii can be calculated if distance and luminosity are known. (See if you can explain how.)

Summary of Chapter 17 (cont.)

- In addition to “normal” stars, there are also red giants, red supergiants, blue giants, blue supergiants, red dwarfs, and white dwarfs
- Luminosity class can distinguish giant star from main-sequence one in the same spectral class
- If spectrum is measured, can find luminosity; combining this with apparent brightness allows distance to be calculated
  - Measurements of binary-star systems allow stellar masses to be measured directly
  - Mass is well correlated with radius and luminosity
  - Stellar lifetimes depend on mass; the more the mass, the shorter the lifetime