[02] Stellar Properties (1/30/18)

Upcoming Items

1. Homework #1 due in two weeks.
2. Read Ch. 15.2 and do the self-study quiz

APOD 1/30/17: Cat's Eye

LEARNING GOALS

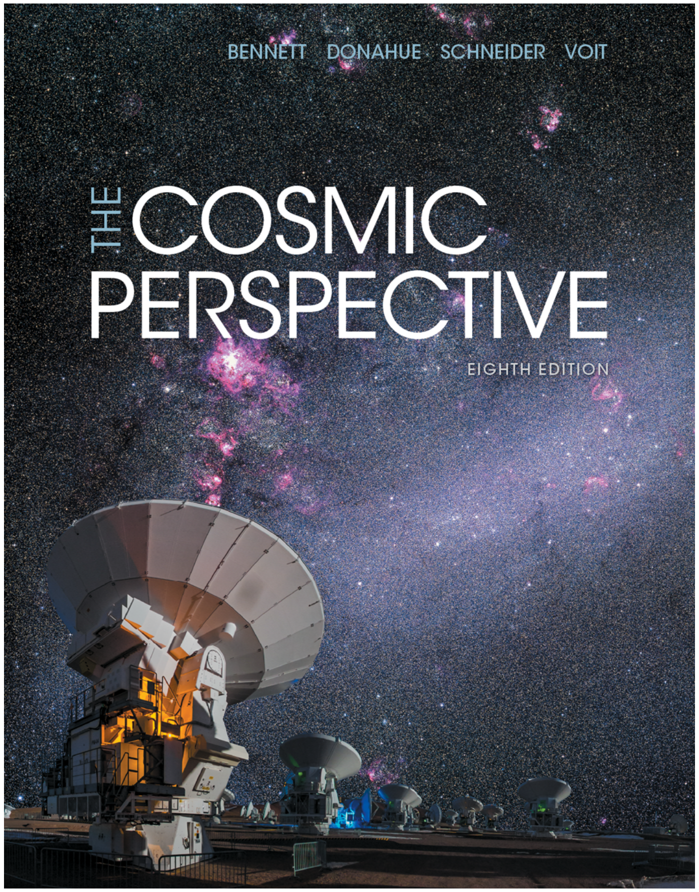
Ch. 15.1

For this class, you should be able to…

… *predict the relative distances of stars based on their apparent motion during a year, and calculate a star's distance from Earth given its parallax measurement;*

… *express a brightness (flux) ratio as a magnitude difference, and vice versa;*

… *use apparent and absolute magnitude to calculate a star's distance;*



ASTR121/320 Tutoring!

- As you recall, former ASTR121 and ASTR320 students have signed up for paid tutoring and are at your disposal!
- The tutors will help with course content, homework, and the lab.

Any astro questions?

Stellar Properties

- Distance
- Luminosity
- Temperature
- Radius
- Mass
- But how do we measure these? Think of as many *different* measurement methods as possible for each quantity. What uncertainties (statistical in nature) or errors (actual biases because our model isn't correct) might exist in such measurements?
- Please discuss this in your groups

Stellar Properties

- Distances to nearby stars from parallax.
  - $d = 1 / p$, d in pc, p in arcsec.
- Luminosities from distance and apparent brightness (flux).
  - $L = 4\pi d^2 F_{obs}$ (SI units). Stars range from 10^{-4} to 10^6 $L_\odot$.
  - Astronomers measure brightness using the magnitude system.
- Temperature from color or spectrum (spectral type).
  - Astronomers measure color using different filters, e.g., $B - V$.
  - Degree of ionization revealed in spectrum: gives *spectral type*—from hottest to coldest: O, B, A, F, G, K, M (50,000 to 3,000 K).
- Radius from luminosity and temperature.
  - $L = 4\pi R^2 \sigma T^4$.
- Mass from dynamics (binary stars etc., next lecture).

A star that is twice as far away from us as another star will have a parallax angle that is

A. twice as big.
B. half as big.
C. four times as big.
D. one quarter as big.

The reason astronomers typically take parallax measurements six months apart is that

A. the star is only visible once every six months.
B. it is quicker than waiting an entire year.
C. this gives the greatest change in apparent position.
D. it is not possible to track the star’s motion on timescales less than six months.

An Apology

- Astronomy is a science with an extremely long history
- Thus some astronomical conventions made sense to people decades, centuries, or even millennia ago
- They might not make sense now, but we use them because of long tradition
- I am ***so*** sorry ☹
- But this is the way that astronomers communicate to each other, so as budding astronomers you'll need to know those conventions
- One of those is that rather than using flux units (energy per area per time, as used for radio, X-ray, and gamma-ray), UV/optical/IR astronomers use ***magnitudes***

The Magnitude Scale

- 2000 years ago, Hipparcus ranked the apparent brightness of stars according to “magnitudes”…
  - 1st magnitude: brightest stars in night sky.
  - 2nd magnitude: bright but not brightest.
  - …
  - 6th magnitude: faintest stars visible to human eye.
- Based on logarithmic sensitivity of the human eye.
- Was a qualitative scale, but is now quantitative
  The magnitude scale is a ***logarithmic*** scale
  Notice that a *larger* magnitude means a *dimmer* object!

Apparent Magnitude

- Modern system:

$$\frac{F_1}{F_2} = (100^{1/5})^{(m_2 - m_1)} \quad \text{or} \quad m_2 - m_1 = 2.5\log_{10}\left(\frac{F_1}{F_2}\right).$$

- In one commonly used system, the star Vega is *defined* to have $m = 0$ in all bands. That's the system we'll use.
- The bad news is that other systems exist! Within a given system, the equation above holds
- The good news is that websites exist that allow you to convert from any magnitude system to more natural flux units (such as Watts per square meter)

Apparent Magnitudes

- Stars with *higher* apparent magnitudes are *fainter!*
- A difference of 5 mags is a factor of 100 in flux.
- Brightest night-sky star (Sirius) has $m = -1.4$.
- Faintest stars visible to human eye have $m = 6.0$.
- Sun has $m = -26.7$.
- Full moon has $m = -12.6$.
- Venus at its brightest has $m = -4.4$.
- Pluto has $m = 15.1$.
- Faintest object visible by Hubble Telescope: $m = 30$.

Absolute Magnitude

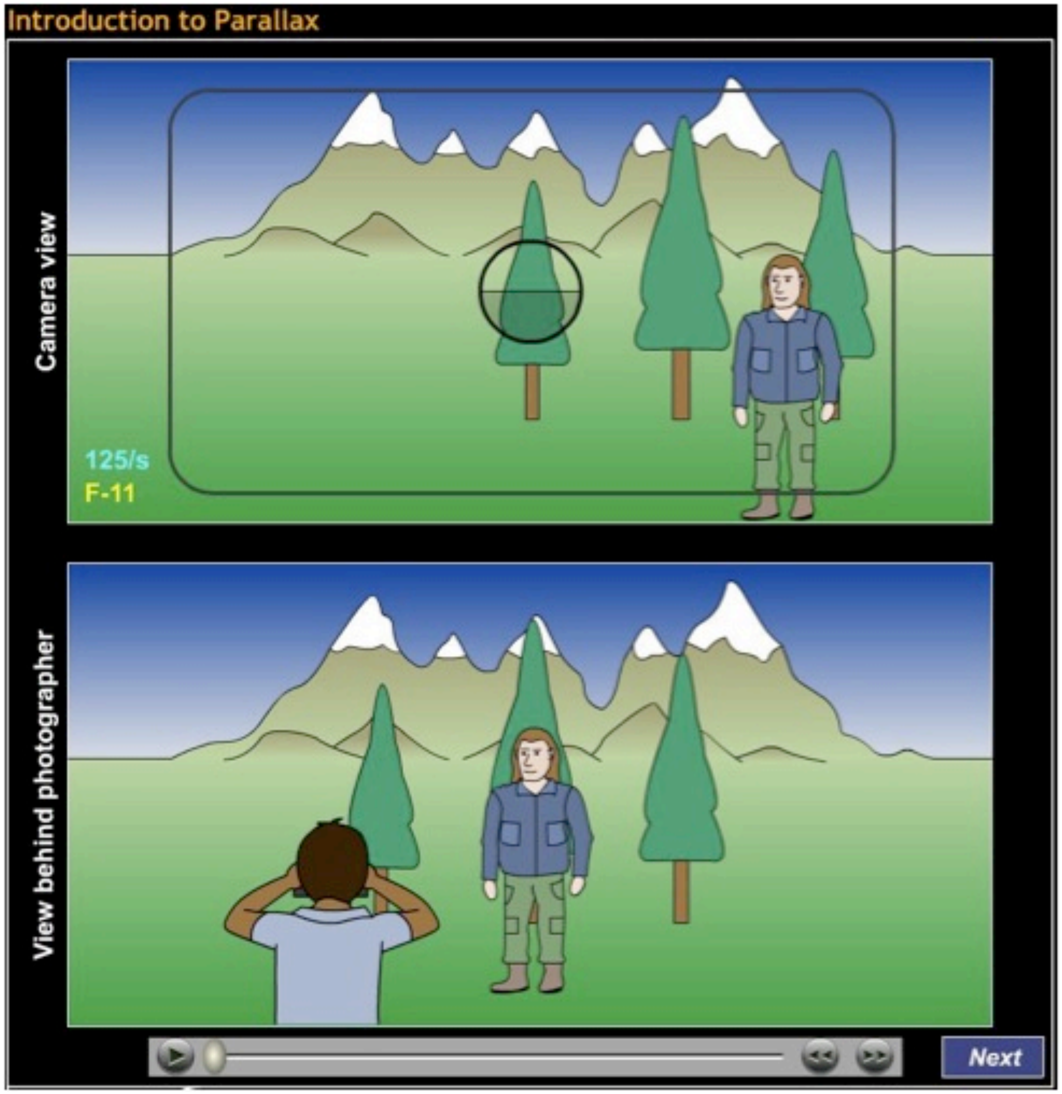
- The absolute magnitude (M) of an object is its apparent magnitude *if it were placed at a distance of 10 pc*:

$$m - M = 2.5\log_{10}\left(\frac{L/4\pi(10\text{ pc})^2}{L/4\pi d^2}\right)$$

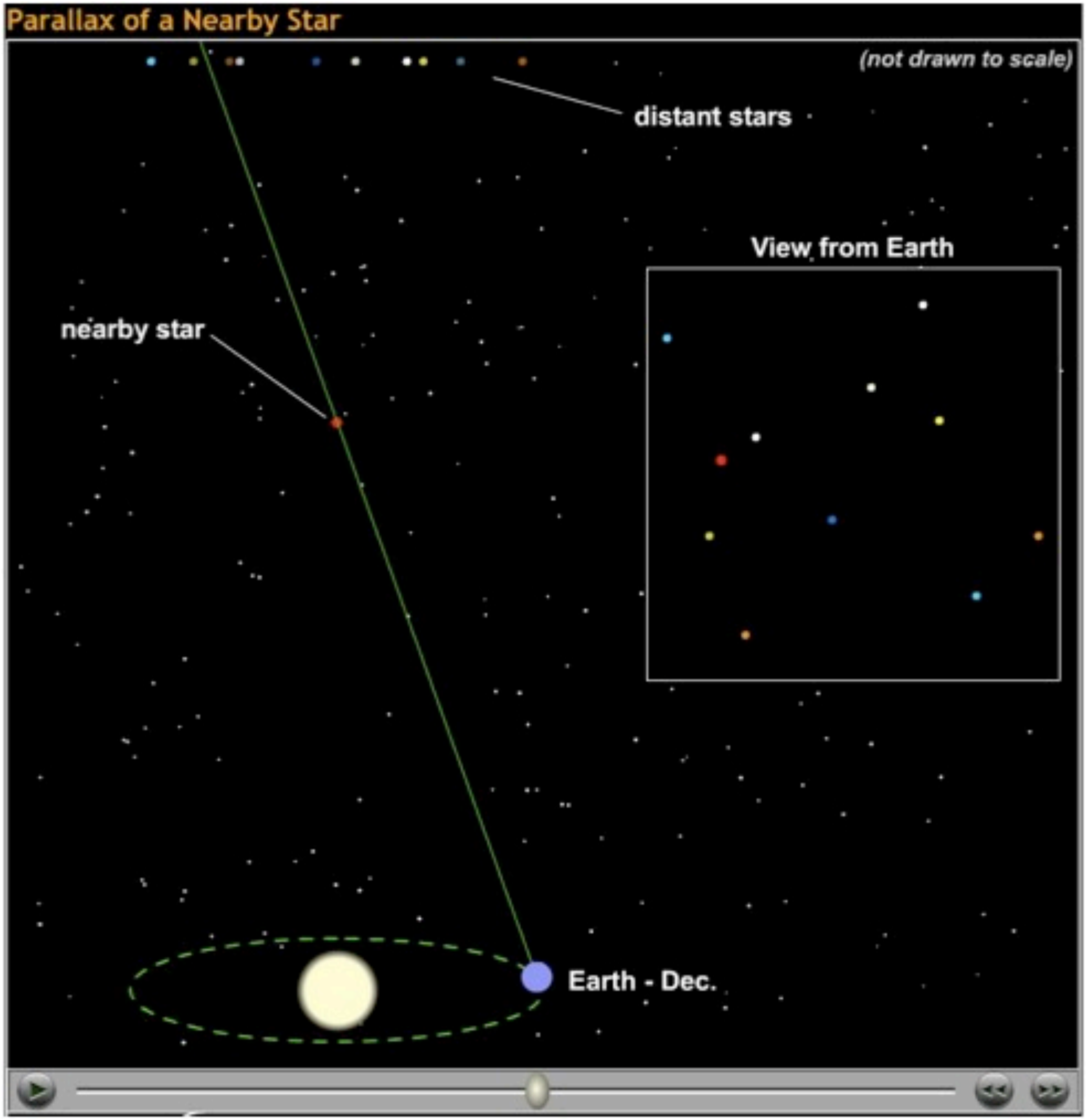
$$\text{or } m - M = 5\log_{10}\left(\frac{d}{10\text{ pc}}\right).$$

  - The quantity $m - M$ is called the **distance modulus**.
- All of this sounds complicated, but just keep in mind:
  - Apparent magnitude ⇔ observed flux.
  - Absolute magnitude ⇔ luminosity. (⇔ means "corresponds to")
  - Distance modulus ⇔ distance.
  - The magnitude system is logarithmic.

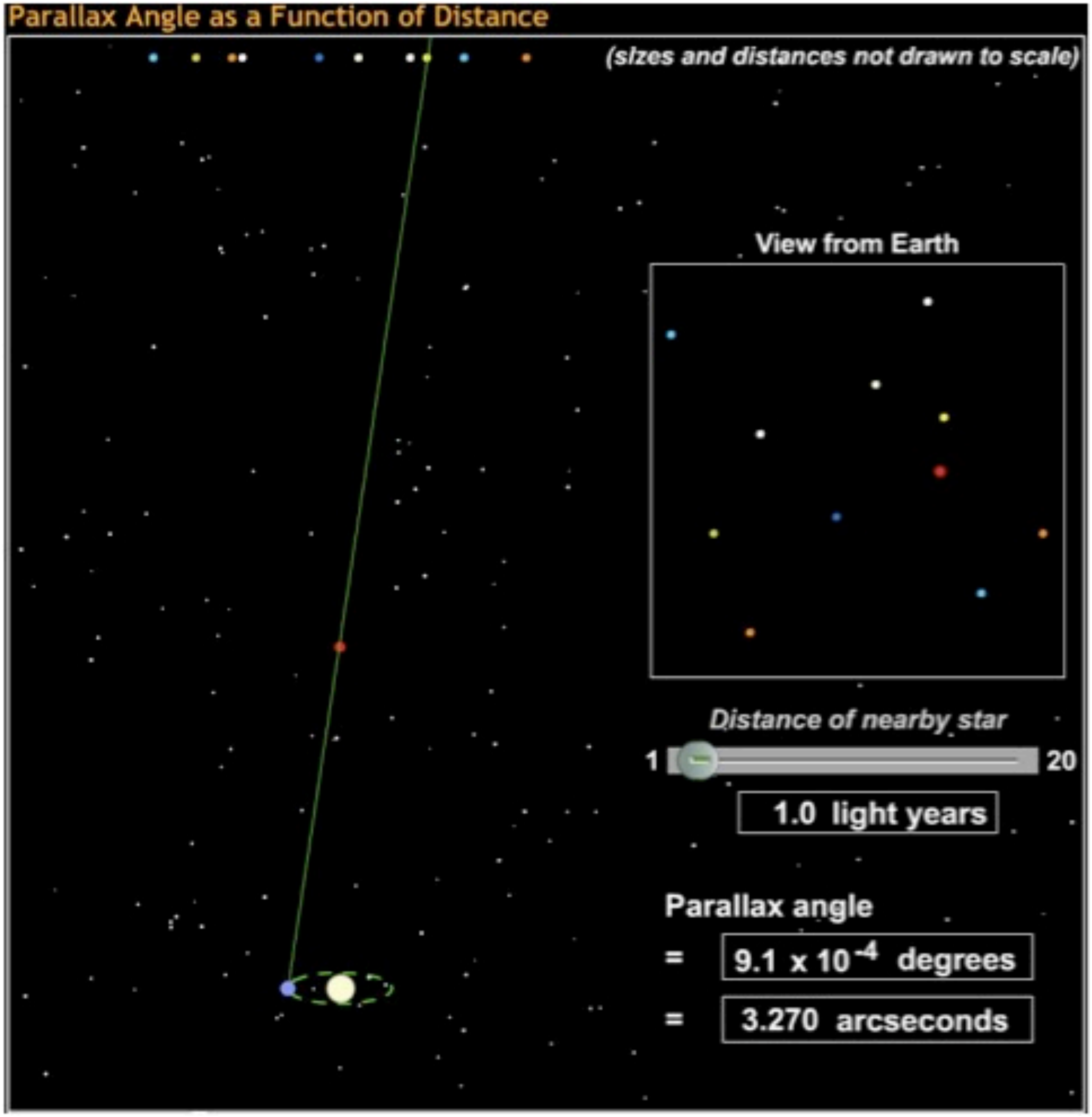
Parallax



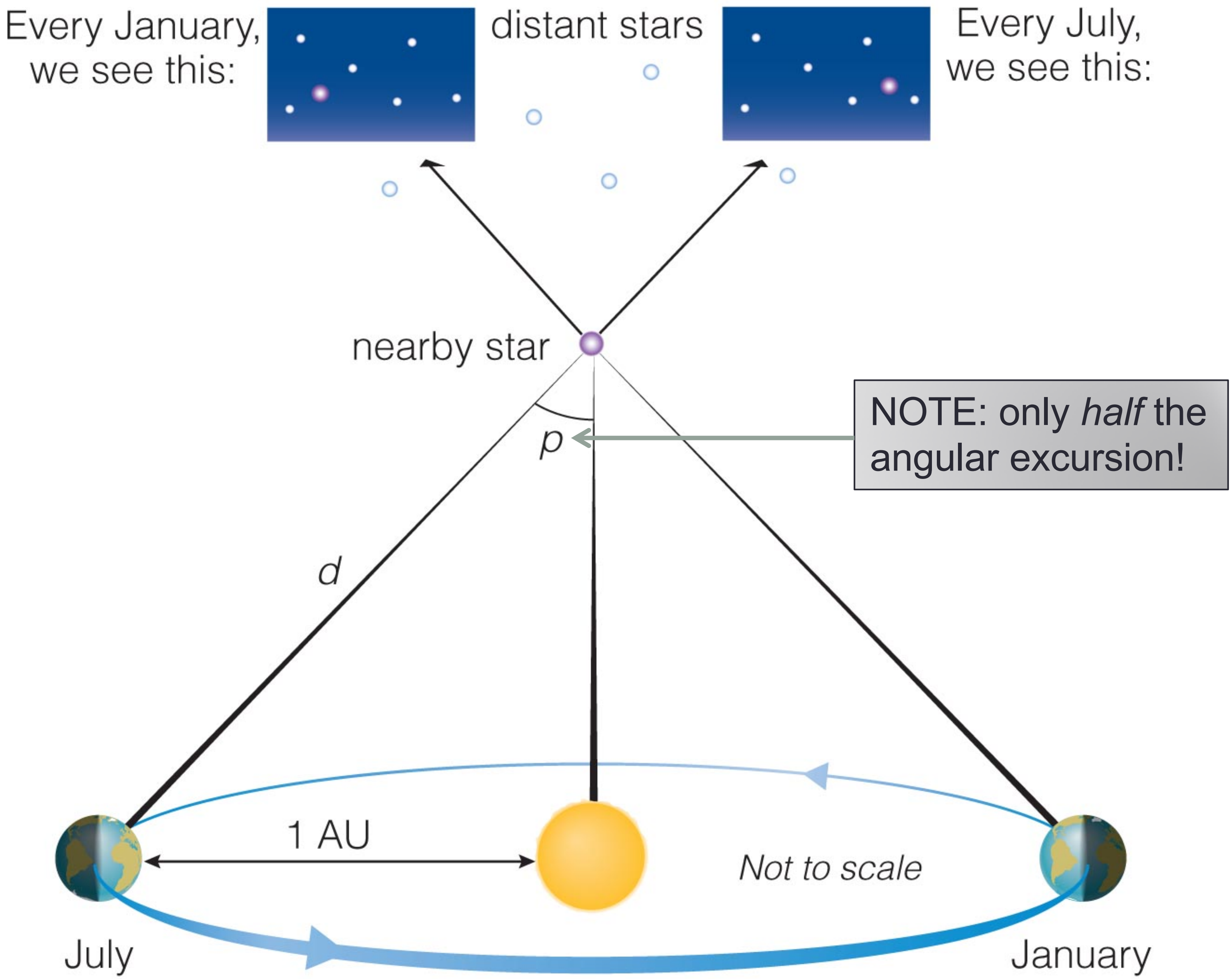
Parallax is the apparent shift in position of a nearby object against a background of more distant objects.



The apparent positions of the nearest stars shift by about an arcsecond as the Earth orbits the Sun.



The size of the shift (*parallax angle*) depends on distance.


Every January,
we see this:
distant stars
Every July,
we see this:
nearby star
p
d
NOTE: only *half* the
angular excursion!
1 AU
Not to scale
July
January

Parallax and Distance

$$p = \text{parallax angle}$$

$$d \text{ (in parsecs)} = \frac{1}{p \text{ (in arcseconds)}}$$

$$1 \text{ parsec (pc)} = 3.26 \text{ ly} = 206{,}265 \text{ AU}$$

The parsec is *defined* as the distance at which a length of 1 AU subtends an angle of 1 arcsec, i.e., $d = (1 \text{ AU})/(1 \text{ arcsec}) = 3.26 \text{ ly}$.

Group Exercise

Helpful hint:
1 pc = 206,265 AU

Perform the following calculations:

1. Knowing the Sun's distance of 1 AU and apparent magnitude of $m = -26.7$, what is its absolute magnitude?
2. What is the apparent magnitude of a star with absolute magnitude $+4.87$ and parallax angle 0.1 arcsec?

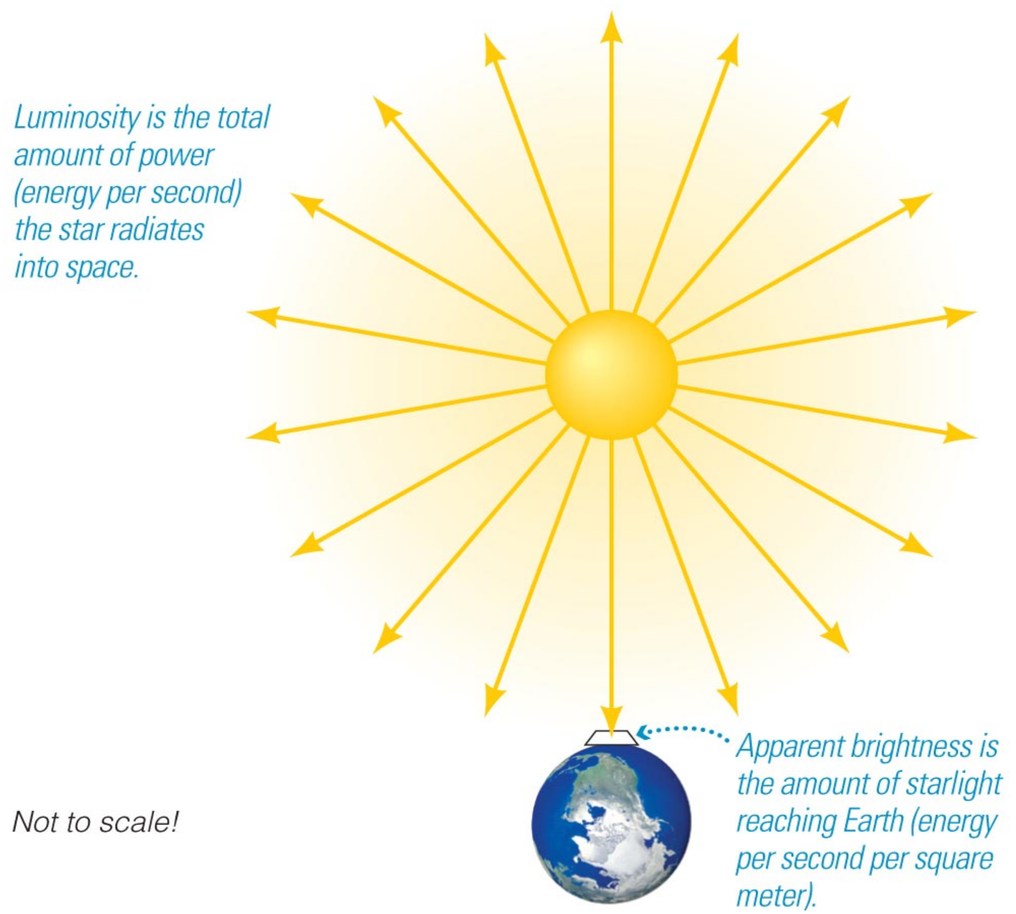
What can we learn about stars?

- We will start with the simplest *intrinsic* stellar properties to measure:
  - Distance
  - Luminosity
  - Temperature
  - Mass


How far away are these stars?

The brightness of a star depends on both *distance* and *luminosity*.

Luminosity *vs.* Apparent Brightness



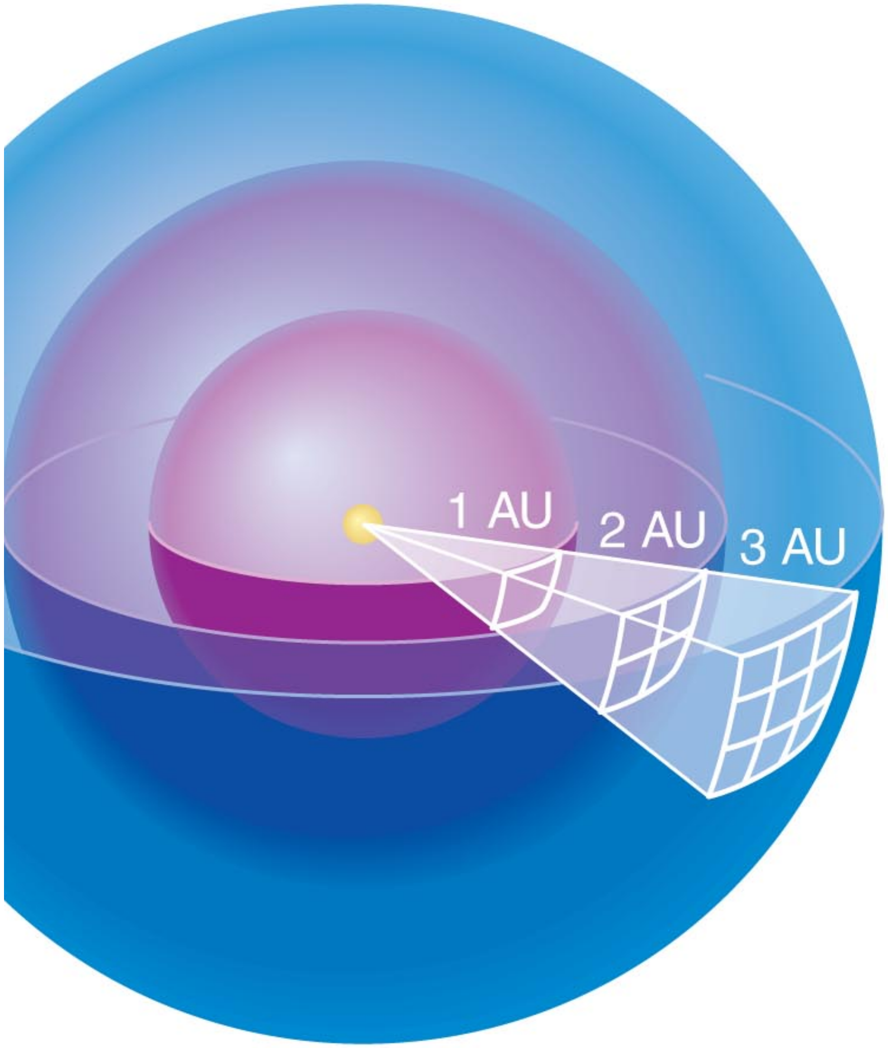
Luminosity:

- Amount of power a star radiates (energy per second, or Watts.)

Apparent Brightness (or ***Observed Flux***):

- Amount of starlight that reaches Earth (energy per second per square meter, or W/m^2.)

Inverse Square Law of Flux



- The amount of luminosity passing through each sphere shown here is the same.
- Area of sphere =

  $4\pi\ (\text{radius})^2$.
- Divide luminosity by area to get brightness.

Brightness, Luminosity, & Distance

- The relationship between apparent brightness (observed flux F_{obs}) and luminosity L depends on distance d:

$$F_{\mathrm{obs}} = \frac{L}{4\pi d^2}.$$

- We can determine a star's luminosity if we can measure its distance and apparent brightness:

$$L = 4\pi d^2 F_{\mathrm{obs}}.$$

Most luminous stars:

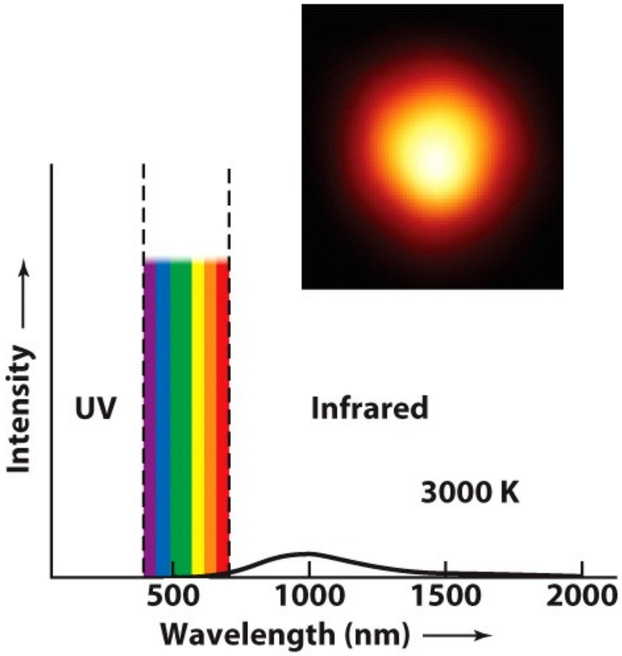
10^6 $L_\odot$

Least luminous stars:

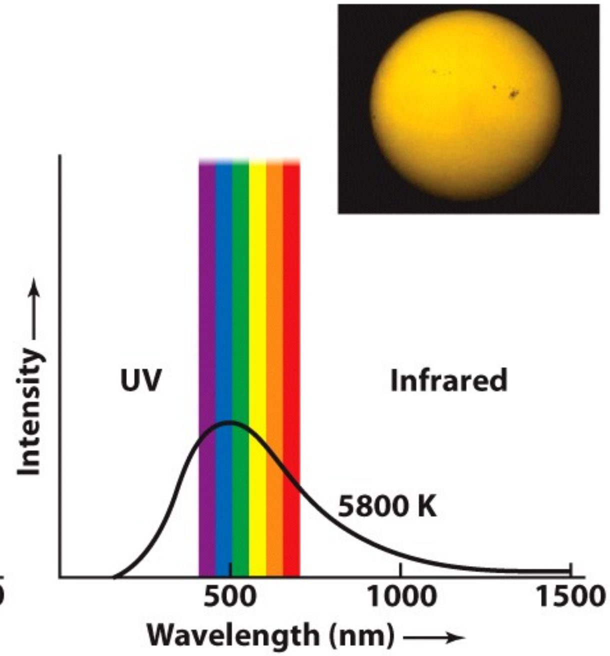
10^{-4} $L_\odot$

($L_\odot$ is luminosity of Sun)

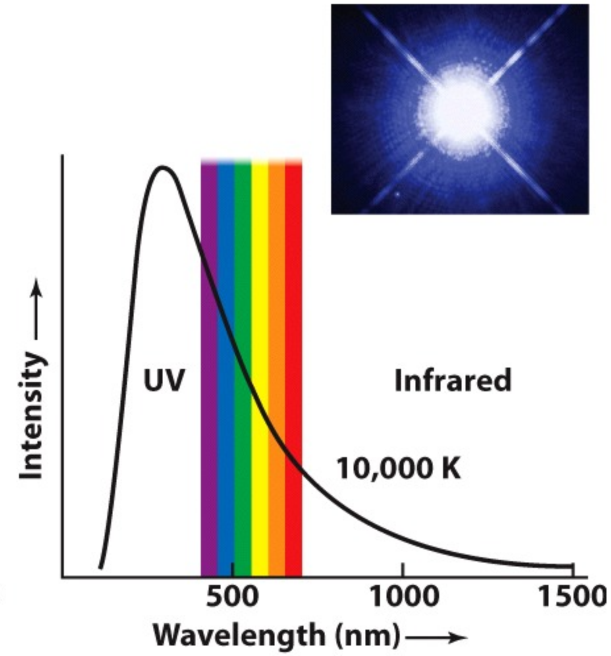
Recall how color relates to temperature…



(a) A cool star with surface temperature 3000 K emits much more red light than blue light, and so appears red.



(b) A warmer star with surface temperature 5800 K (like the Sun) emits similar amounts of all visible wavelengths, and so appears yellow-white.



(c) A hot star with surface temperature 10,000 K emits much more blue light than red light, and so appears blue.