Lecture 21
Distance Ladder

Reminders/Announcements
• Midterm corrections are due in class TOMORROW
• More Extra Credit: Mars Rover Landing on Aug. 5 (Sunday) at IFA from 6-8 pm.
• Homework due tomorrow at 5 pm.

Astronomical Distances
• Understanding the distances to astronomical objects is crucial for understanding the universe.
• Needed to determine the SIZE and SCALE of astronomical objects.
• Are objects in the Milky Way or in separate galaxies?
• Is our Universe expanding?
How do we measure distance?

• We have many techniques that work better for different distance scales.
  • For nearby objects (in our solar system):
    – Radar
  • For nearby stars (in our galaxy):
    – Parallax
  • For nearby galaxies (in the Local Group):
    – Cepheid Variables
  • For the distant universe:
    – Type Ia Supernovae
Radar Astronomy

- RADio Detection And Flanging
- Bounce microwave signals off object and analyze the echoes.
- Strength of return signal is $1/r^4$
  - Two factors of $1/r^2$
- First used in 1946 to measure distance to the moon
- Determined the size of an astronomical unit (1 AU) in 1961 by measuring distance to Venus.

Parallax

We can measure distances to objects by seeing how they move relative to a background set of stars as the Earth orbits around the Sun.

Does your thumb appear to move more or less when you moved it farther from your eyes?

Parallax

As the Earth moves around the sun over the course of a year, our perspective changes.

Relative to a set of background stars (that are too far away to move), a foreground star will change where it appears.
Parallax - Angles

Time:
60 minutes = 1 hour
60 seconds = 1 minute
3600 seconds = 1 hour

Angles:
60 arcminutes = 1 degree
60 arcseconds = 1 arcmin
3600 arcsec = 1 degree

Parallax – Angles to Distance

So how do we go from angles to actual distances?

Need to know at least 1 distance – the distance from the Earth to the Sun!

D = 1/p

P is angle in arcseconds (half of theta), called “parallax”
D is distance in “parsecs”

1 Parsec = 3.09 x 10^{13} km
Class Action!

If a star has a parallax of 0.1 arcseconds, it must be at a distance of _____.

A) 10 parsecs  
B) 20 parsecs  
C) 5 parsecs  
D) 100 parsecs

Class Action!

The distances (in parsecs) for four stars are given below. Which has the smallest parallax?

<table>
<thead>
<tr>
<th>Star</th>
<th>Distance (parsecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capella</td>
<td>12.6</td>
</tr>
<tr>
<td>Polaris</td>
<td>132</td>
</tr>
<tr>
<td>Rigel</td>
<td>237</td>
</tr>
<tr>
<td>Sirius</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Cepheid Variables

- Henrietta Leavitt
- 1893 – 1921 worked as a human computer at Harvard College Observatory
  (women weren’t allowed to operate telescopes or get PhDs in astronomy at that time).

She discovered thousands of variable stars in images of the Magellanic Clouds (our neighbor galaxies). She found that the brighter ones had longer periods, now called the period-luminosity relation.
Cepheid Variable Stars

- Large, hot giant-branch (helium fusing) stars that have pulsating luminosities.
- 5-20 times more massive than the sun
- 30 000 times more luminous than the sun
- Why do they pulsate?
Cepheid Variable Stars

* When a Cepheid is compressed, it becomes opaque.
* Light photons are trapped inside, heating the gas and increasing its pressure.
* The high-pressure gas expands, becoming transparent.
* Photons escape, the gas cools, the pressure drops.
* As the pressure drops, the Cepheid is compressed by gravity.

Opacity = how much light can escape.
High opacity = little or no light can escape (opaque)

Recall: Hertzsprung-Russell Diagram

This Cycle repeats over and over again
Cepheid Variable Stars

- Recall: Hertzsprung-Russell Diagram

![H-R Diagram with Cepheids highlighted]

- Cepheids with periods of days
- Variable stars with periods of hours (called RR Lyrae Variables)

Calibrating Cepheids

- Although there was a well-established relationship between pulsation period and luminosity, we still didn’t know the real luminosities or distances.
- Harlow Shapley was the first to calibrate the luminosities of Cepheids by measuring the parallax of Cepheid variable stars in our own galaxy.
- Cepheid Variable Stars could then be used as “standard candles.”

Measuring Distance

Apparent Brightness = \# of photons arriving / Area
\sim \# photons / d^2
Class Action!

The graph of apparent magnitude versus time for a Cepheid variable star is shown below. The pulsational period of the star is approximately ...

(A) 8.7 days  
(B) 6.7 days  
(C) 9.7 days  
(D) 7.7 days

Type Ia Supernovae

Recall: White Dwarfs

3. Runs out of Helium  
Becomes a White Dwarf

Image of white dwarf Sirius A, taken with the Hubble Space Telescope
**Binary star systems**

- Binary star systems can form with a red giant and a white dwarf
- The outer layers of the red giant can accrete onto the white dwarf

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**The White Dwarf Limit**

- Electrons move faster as they are squeezed into a smaller space
- As a white dwarf’s mass approaches 1.4 solar masses, its electrons move at nearly the speed of light!
- This speed creates a pressure called electron degeneracy pressure
- Because nothing can move faster than light, a white dwarf cannot be more massive than 1.4\(M_{\text{Sun}}\), the white dwarf limit (or Chandrasekhar limit)

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**Supernovae Type Ia**

- When the mass of the White Dwarf exceeds 1.4\(M_{\text{Sun}}\), the electron degeneracy pressure can no longer hold up against gravity.
- The White Dwarf suddenly collapses, releasing huge amounts of energy and causing runaway fusion of Carbon & Oxygen into heavier elements.
- The energy release causes a massive supernova explosion.
Supernovae as Standard Candles

• Since Type Ia Supernovae all explode at the exact same mass (Chandrasekhar limit), the brightness of the explosion is the same every time!
• The luminosity of a single supernova can exceed the luminosity of an entire galaxy, so we can see these candles at extremely large distances.

Acceleration of the Universe

• The universe is expanding.
• In 1998, researchers Adam Reiss, Brian Schmidt, and Saul Perlmutter studied Type Ia Supernovae and discovered that the universe is not only expanding, it is accelerating!
• Won the 2011 Nobel Prize in Physics for this groundbreaking discovery.

Distance Ladder
Lecture Tutorial

• Break up into groups of 2:3
  – NO MORE THAN 3
• In your group, work through the following:
  – The Parsec (pages 35-37)
  – Discuss the answers – don’t be silent!
• I will be roaming around if you need help...
• If your group finishes, check your answers with another group and start Parallax and Distance (pages 39-41)