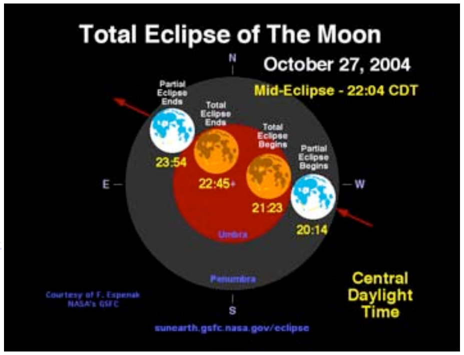
Announcements

- Please pick up homework#3 as you leave the lecture hall today.
- Mid-term exam next Tuesday.
  - Prof. Gebhardt and a graduate student will be there. (I will be out of town.)
- Schedule of TA
  - She will be gone to observing, so…
    - No help session next Tuesday
    - No office hours on Oct 25 (Mon.), 27 (Wed.), and Nov 1 (Mon.)
    - She will be back on normal schedule from Nov 2.
- Any questions about mid-term?
  - I will take questions after this lecture.
  - Make an appointment with either TA or me and see us BY FRIDAY. Both of us will be out of town on Monday and Tuesday.

Don't Miss It!

- Watch the total lunar eclipse!! Next Wednesday!
  - **Oct 27:8pm to 12am.**
- Wednesday Night Public Viewing at RLM
  - http://outreach.as.utexas.edu/public/parties.html



http://sunearth.gsfc.nasa.gov/eclipse/LEmono/TLE2004Oct28/image/TLE2004Oct-CDT.GIF

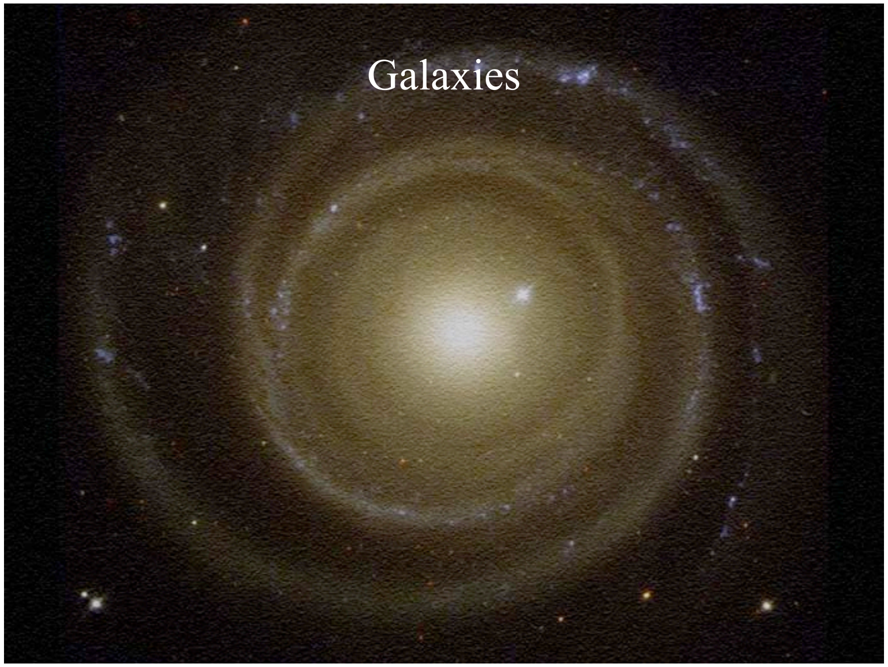
Station #5, "Galaxies"

Lecture 16 (October 21): Galaxies

Lecture 17 (October 28): Galaxy Evolution

Lecture 16
Galaxies

Reading: Chapter 20



A Universe of Galaxies

- In 1995, the Hubble Space Telescope observed a patch of sky in the Big Dipper for 10 days.
  - many galaxies, each one an island of stars like our own Milky Way, were detected
  - by counting them and correcting for the entire sky, we estimate that there are over 80 billion galaxies in the observable Universe


Movie. Click to play.

Classification of Galaxies

- Using a system invented by Edwin Hubble, astronomers classify galaxies into three major types:
  - Spiral
  - Elliptical
  - Irregular



- The sizes of all three types span a wide range, from
  - dwarf galaxies
    - which contain 100 million (10^8) stars
- to
  - giant galaxies
    - which contain 1 trillion (10^{12}) stars

Spiral Galaxies



- have a *disk component* and bulge & halo (*spheroidal component*)
- disk contains an ISM of gas & dust
- relative sizes of bulge/disk & amount of ISM vary among galaxies
- appear white because they contain both blue & red stars

Spiral Galaxies

- Some spiral galaxies have a bar of stars cutting through their centers.
  - spiral arms are attached to the ends of the bar
  - we call them **barred spiral galaxies**
- Some astronomers have suggested that the Milky Way is a barred spiral.
  - its bulge appears elongated

- Some galaxies have disks with *no* spiral arms.
  - we call then **lenticular galaxies**
  - they look like a lens seen edge-on
- They contain less cool gas than normal spirals.

Elliptical Galaxies

- only have a *spheroidal component;* no *disk component*
- very little ISM, which is mostly low-density and ionized
- appear red because they contain mostly red stars

Irregular Galaxies

- “none of the above” category; neither spiral nor elliptical
- appear white & dusty with ISM
  - have more in common with the disk component of spirals
- distant galaxies are more likely to be irregular
  - they were more common when the Universe was young
  - Galaxies just formed?

Groups and Clusters

- Among large galaxies…
  - most (75–85%) are spirals
  - they tend to associate in loose **groups** of several galaxies
- Our Local Group is an example
  - dominated by two large spirals
    - the Milky Way
    - Great Galaxy in *Andromeda*

- Some galaxies associate in tightly bound **clusters**.
  - contain hundreds of galaxies
  - half of all large galaxies are elliptical
- Outside of clusters…
  - large ellipticals are rare (15%)
  - most dwarfs are elliptical

Edwin Hubble
(1889-1953)

- He calculated the distance to the *Andromeda* galaxy.
  - 2 million light years
  - it was **not** in the Milky Way
- He developed a classification scheme for galaxies.
- He has a space telescope named after him!

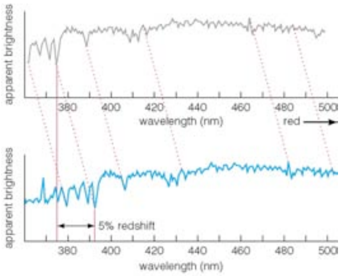
Milton Humason
(1891-1972)

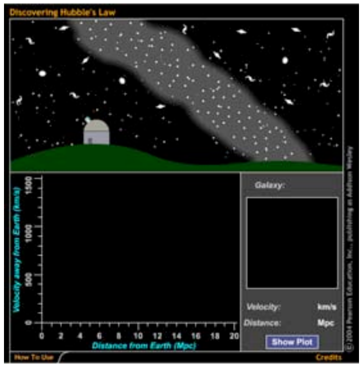
- He took spectra and measured the redshifts of many galaxies.
- He worked with Hubble, who measured the distances to those same galaxies.
- They plotted distance vs. velocity and formulated :

Hubble's Law: $v = H_o d$

Hubble's Law

- Hubble supplied the distance to a galaxy.
  - using Cepheid or "brightest star" standard candles
- Humason measured the shift to longer wavelengths of absorption lines in the galaxy's spectrum.
  - used Doppler formula to calculate velocity

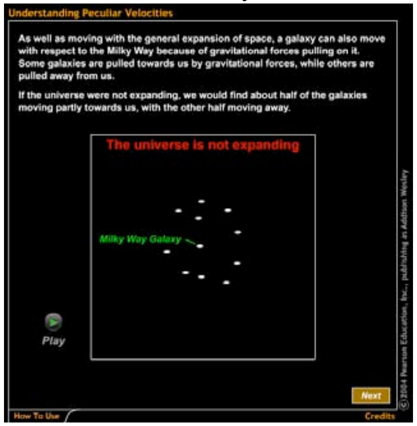




- Plot resulted in a straight line.
  - the farther away a galaxy was, the faster it was moving away from us
  - velocity increased *linearly* with distance
- $v = H_o d$
- H_o, the slope of the line, is called Hubble's constant [km/s per Mpc]

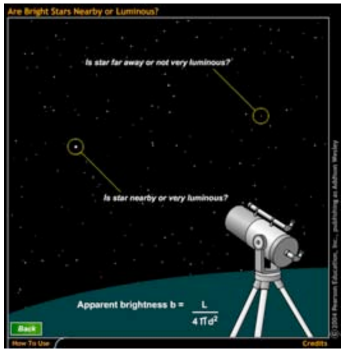
Where Hubble's Law Applies

- Hubble's Law does not apply to the nearest galaxies.
  - gravitational tugs from nearby galaxies cause velocities greater than the Hubble velocity



Standard Candles

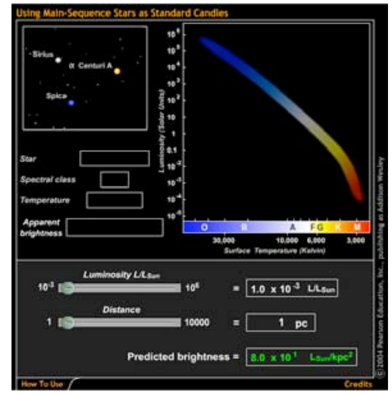
Are these lights at the same distance?



- Obviously not!
  - have the <u>same</u> apparent brightness, but <u>very</u> <u>different</u> luminosities
- If you knew the luminosity of…
  - a standard lighthouse beacon
  - or a *standard candle*
- you could measure the distance to each given their apparent brightness
- Astronomers call any astronomical object whose luminosity can be determined without knowledge of its distance a **standard candle**.
- We can then calculate the distance to any standard candle by…
  - measuring its apparent brightness and using the luminosity/distance formula

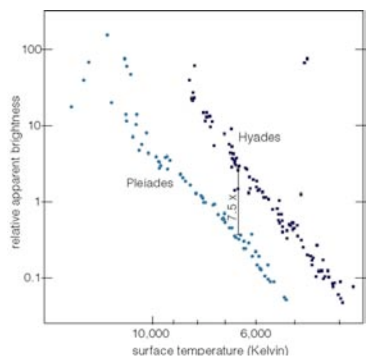
What Makes a Good Standard Candle?

- Well, we know the luminosity of our Sun, as well as all stars on the main sequence.
  - we know this by using the parallax method on nearby stars
  - we can measure the distance to stars of the same type which are far away



What Makes a Good Standard Candle?

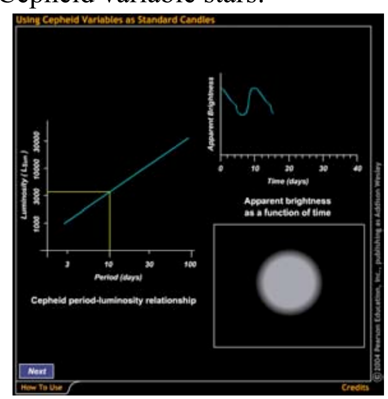
- For a cluster of stars, we can compare the entire main sequence.
  - we know distance to *Hyades* from parallax
  - by measuring how much fainter Pleiades' MS is, we can calculate its distance
- This is called **main-sequence fitting**.



- The problem with main-sequence fitting is that…
  - most main sequence stars are too faint to observe in other galaxies!
- So we need a more luminous standard candle to measure distances to galaxies.
  - we have already studied such a candle…**Cepheid variable stars**

What Makes a Good Standard Candle?

- Review of Cepheid variable stars:

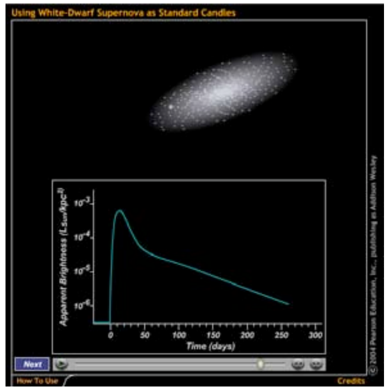


- Cepheid variables make good standard candles because:
  - they follow a well-defined period-luminosity relationship
  - they are bright giants…luminous enough to see at great distances

Distant Standard Candles

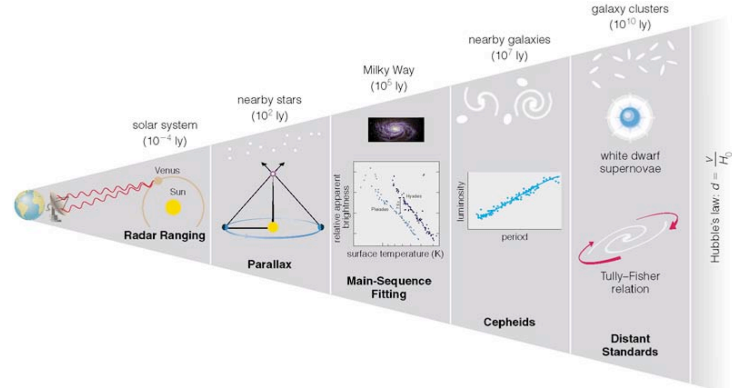
- When galaxies do obey Hubble's Law, the distances we calculate from redshifts are only as accurate as our measurement of H_o.
- To obtain a more accurate value of H_o, we need standard candles which allow us to measure even greater distances.

- White Dwarf Supernovae
  - all have the same peak luminosity
  - 10 billion Suns
  - we calibrate them in nearby galaxies which contain Cepheids
  - can be observed in galaxies billions of light years away
- One problem:
  - must be lucky to be observing a galaxy when one explodes



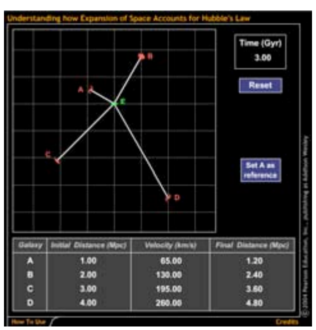
The Distance Chain

- The most accurate methods for measuring distance…
  - have the shortest range of applicability, so…
  - we use them to calibrate the next-most accurate method, and so on until…
  - we have built up a chain of methods for measuring the size of the Universe!



An Expanding Universe

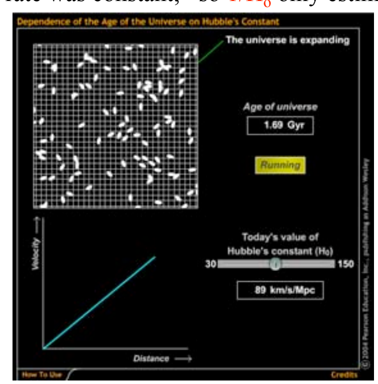
- The consequence of Hubble's Law is
  - most galaxies are moving away from us
  - if all galaxies swarm out through a void
  - then the Milky Way is at the center of the Universe
- NO! We've learned that lesson already!



- The Universe <u>itself</u> is expanding.
  - the galaxies expand with it
  - there is no center or edge to the Universe
- From any galaxy's point of view, other galaxies are all moving away from it.

The Age of the Universe

- In the context of an expanding Universe…
  - H_o tells us the rate at which galaxies are moving apart from one another
  - so if we run the clock backward to when the galaxies were all at one point
  - then $1/H_o$ tells us how long it took the Universe to expand to its current size
  - *if* the expansion rate was constant; so $1/H_o$ only estimates age of Universe



The Age of the Universe

- Our best measurement of the Hubble Constant…
  - comes from the *Wilkinson Microwave Anisotropy Probe*
  - announced by NASA in February 2003
- H_o = 71 km/s per Mpc
- The WMAP measured the age to be 13.7 billion years

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