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…
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    • No office hours on Oct 25 (Mon.), 27 (Wed.), and Nov 1 (Mon.)
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Don’t Miss It!

• Watch the total lunar eclipse!! Next Wednesday!
  – Oct 27:8pm to 12am.
• Wednesday Night Public Viewing at RLM
  – [Link](http://outreach.as.utexas.edu/public/parties.html)

[Image of total lunar eclipse]


Station #5, “Galaxies”

Lecture 16 (October 21): Galaxies
Lecture 17 (October 28): Galaxy Evolution

Lecture 16
Galaxies

Reading: Chapter 20
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.

Using a system invented by Edwin Hubble, astronomers classify galaxies into three major types: Spiral, Elliptical, and 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. They 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 them 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:
  \[ v = H_0 d \]

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

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

Hubble’s Law

- 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
  - \[ v = H_0 d \]
  - \( H_0 \), the slope of the line, is called Hubble’s constant [km/s per Mpc]
Standard Candles

Are these lights at the same distance?

- Obviously not!
  - have the same apparent brightness, but very different 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?

- 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 $H_0$.
- To obtain a more accurate value of $H_0$, 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 Age of the Universe

- In the context of an expanding Universe…
  - $H_0$ 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 $1/H_0$ tells us how long it took the Universe to expand to its current size
  - if the expansion rate was constant; so $1/H_0$ only estimates age of Universe

- The Universe itself 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

- Our best measurement of the Hubble Constant...
  - comes from the *Wilkinson Microwave Anisotropy Probe*
  - announced by NASA in February 2003
- $H_0 = 71 \text{ km/s per Mpc}$
- The WMAP measured the age to be 13.7 billion years

Tuesday, Oct 26: Mid-Term!

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