Galaxies and Hubble's Law

Some Important History: Charles Messier (1730-1817)

- In the late 18th century, Charles Messier was hunting for comets, but in the telescopes of the time, identifying comets was difficult because there were many objects that looked like pre-tail comets.
- Objects seen in Messier's telescope fit into one of four categories:

Point

•

Star

Disk

Planet

Blob

If it moves relative to the stars,
Pre-tail comet

Blob

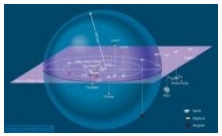
If it does not move relative to the stars,
"Nebula"

- To avoid confusion for himself (and other comet hunters), Messier made a a catalog of **Fixed Nebula** that we call the **Messier Catalog**.
- Today, we know what these things are: e.g. planetary nebulae, supernova remnants, clouds of gas, stellar clusters . . . and *Spiral Nebulae?*
- The nature of the **Spiral Nebulae** would be debated until the 1920's.
- In 1924, Edwin Hubble was able to identify a Cepheid variable in the Andromeda Nebula and – *using Henrietta Leavitt's technique* – determine its distance which put it beyond the Milky Way, i.e. it's another galaxy.

Nearby Galaxies

How far away are the nearest galaxies?

- Nearby galaxies form the **Local Group**, a region ~ 1 Mpc across that contains ~20 galaxies (not counting dwarf galaxies)



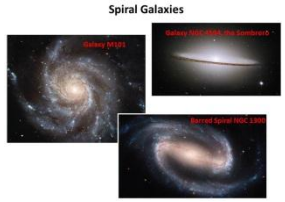
- The closest galaxies to the MW are the **Large (LMC) and Small (SMC) Magellanic Clouds** that are ~50 kpc away and are naked eye visible from the southern hemisphere.

- The nearest large spiral galaxy is **Messier Object 31** or the **Andromeda Galaxy at** ~600 kpc away. **This is the most distant object that you can see with the naked eye. It's apparent magnitude is +3.4.**

- **What about scales of sizes and distance?** If the MW and Andromeda are represented by paper plates (diameter ~ 50 kpc), **about how far apart are they? (LC)**

On this scale, about 10 feet.

Types of Galaxies



Spiral Galaxies:

- Spiral Galaxies have flat disks with central bulges, like the MW and Andromeda.
- Clouds of gas in the disk produce star forming regions
- Stars and clouds in the disk move in circular orbits around the center

Elliptical Galaxies:

- Ellipticals have no disk structure, they are ellipsoidal with some being rounder, some more elongated. Large ellipticals are believed to be the result of the merger of two spiral galaxies.
- No gas, so very little star formation.
- Stars move in randomly oriented flower-petal shaped orbits.
- Elliptical galaxies are both the largest (e.g. M87, ~300 kpc) and smallest galaxies (e.g. Dwarf Spheroidals, ~few kpc) in the Universe

Irregular Galaxies:

- Are not definitely spiral or elliptical, e.g. the Large Magellanic Cloud.
- Like the LMC, some may be being perturbed tidally by other galaxies.
- At great distances, and hence long ago, there were more irregular galaxies.

Galaxy Evolution

- The formation of galaxies appears to have happened very early in the life of the Universe. We can see this somewhat now, but the James Webb Telescope is revealing more, and it's been in the news.

- Galaxies likely formed from the gravitational collapse of gas in the early Universe; although, the details are very poorly understood, e.g. the roles of supermassive black holes and *Cold Dark Matter (*more about this next week).

- One thing we do know is that galaxies don't evolve in isolation, i.e. they can influence each other.

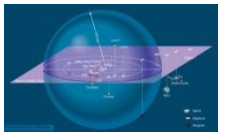
- If galaxies actually collide, this can trigger starbursts, i.e. rapid star formation.

- Our own galaxy is not immune to collisions with other galaxies; in particular, we're on a collision course with Andromeda.
  When will this happen? (LC)

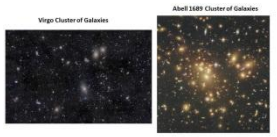
- Read the section in your text about **Active Galactic Nuclei** which we now know are powered by central supermassive black holes accreting material.

Groups of Galaxies

Galaxies interact gravitationally and form both small and large groups:



- e.g. the Local Group



- Large Clusters of thousands of galaxies, like the Virgo Cluster or Abell 1689

- Clusters of Clusters called Superclusters are the largest structures known in the Universe (~100 Mpc across). We belong to the Virgo Supercluster. (*we'll talk more about these in chapter 18*)

How many galaxies are there in the visible Universe? (LC)

The Hubble Space Telescope has taken several **Deep Field** images that reveal the enormous number of galaxies in our sky.

(Can you think of other images that have so profoundly affected our view of the Universe?)

Much of the Hubble Deep Field has been used in the extraordinary video called **Deep Field by Eric Whitacre**. Not showing all of it here, but it's good.

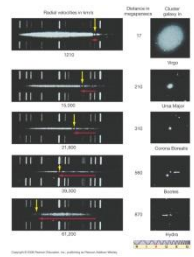
Hubble's Law

The Observations:

- In 1912, Vesto Slipher discovered that almost all galaxies had a red-shifted spectrum. *Remember the Doppler shift?*
  This means that almost all galaxies are moving away from us.

- But Slipher had no way of measuring the distances to the galaxies; in fact, he didn't even know what they were.

- In the 1920's, Edwin Hubble recorded the spectra of galaxies for which he could also get a distance either from Cepheid variables or by comparing the relative brightness of galaxies.



- When Hubble plotted his data, he found this relation:

Velocity = (a constant) X Distance

or $V = H_0 d$ where H_0 is Hubble's Constant

This is called **Hubble's Law**.

Hubble's Law

Interpretation of Hubble's Law:

- **The Problem:** all galaxies (except very near ones) are receding from us with more distant galaxies receding faster.

Does this mean that the MW is at the center of some kind of an expansion?

- No, the simplest explanation is that the entire Universe is undergoing a general expansion. All places in the Universe are the center of the expansion.
- **Any observer on any galaxy sees all other galaxies receding from their galaxy in accord with Hubble's Law.**

Hubble's Law

Does this interpretation of Hubble's Law make sense?

- **A very important idea: the galaxies are not expanding into a pre-existing empty space. It's the space between the galaxies that is expanding. The galaxies just ride along.** *(Note: because of gravity, the space within a galaxy or between nearby galaxies is not expanding. This begs the very confusing question: what is space anyway?)*

- For example: **raisins in a 3D expanding cake:**

- Visualizing this in 3D is difficult: **try the expanding space of a 2D balloon:**

- Or even simpler: **try the 1D Universe of tacks on a rubber band:**

What is the significance of Hubble's Law?

Hubble's Law shows that the Universe is dynamic and changing. In the 1920's, it was believed that the Universe was static: i.e. unchanging and eternal. Hubble showed this is not the case at all. *If the Universe is changing today, it had to be different in the past and it will be different in the future.* **This is one of the Foundations of Modern Cosmology – *our next topic*.**