Early Observations

- Some galaxies had been observed before 1900’s.
  - Distances were not known.
  - Some looked like faint spirals.
- Originally thought to be nearby star forming nebulas.

Hubble Classification

- Galaxies are classified by their appearance (morphology)
- Main types
  - Spirals
  - Ellipticals
  - Lenticulars
  - Irregulars
Spirals
- Flat disk, nuclear bulge, spiral arms
- Contain young and old stars, gas, and dust.
- Sub-classified by size of bulge and tightness of spiral arms.
  - Sa -- large bulge, tightly wound arms, less gas and dust.
  - Sb -- smaller bulge, more loosely wound arms
  - Sc -- small bulge, more loosely wound arms, more gas and dust.

Bars in Spirals
- Galaxies have bar type shapes near the center
- Labeled SBa, SBb, or SBc
Ellipticals

- Balls of stars with round or oval shape
- Classified E0 (round) to E7 (elliptical)
- Usually have less dust and gas.
- Contain older stars
- Large range of sizes

Lenticulars (S0 / SB0)

- Between elliptical and spiral galaxies
- Have disk and large bulge
- Labeled S0 or SB0 (barred)
- No spiral arms
- Usually little dust or gas

Irregulars

- Do not fall into other categories
- Often small
Hubble Tuning Fork Diagram

- Organizes classifications
- Possible evolutionary track? Not so simple

Distances to Galaxies

- Galaxies were first thought to be star forming regions.
- Proposed that the “spiral nebula” were “island universes”.
- Spectroscopic parallax is only good for distances up to 10,000 pc.

Using Cepheid Variable Stars to Measure Distances

- Variable stars are stars whose brightness varies in a very smooth, predictable way.
- Cepheid variables
  - periods vary from 1-100 days.
- RR Lyrae variables
  - periods are all less than 1 day.
• Cepheids are stars that have moved off of the MS.
  – Star is expanding and contracting.
  – Luminosity rises and falls.

Figure 23.6, Chaisson and McMillan, 6th ed. Astronomy Today, © 2008 Pearson Prentice Hall

Cepheid Variables

• Average luminosity is related to pulsation period.
• If luminosity and apparent brightness are known, distance can be determined

\[
\text{Apparent Brightness} = \frac{\text{Luminosity}}{4\pi d^2}
\]

Figure 23.7, Chaisson and McMillan, 6th ed. Astronomy Today, © 2008 Pearson Prentice Hall

Supernovae as Standard Candles

• Type Ia supernovae (exploding white dwarfs) all reach the same maximum luminosity, about \(3 \times 10^9\) solar luminosities
• If supernova is observed in another galaxy and the peak apparent brightness is measured, the distance can be calculated.

\[
\text{Apparent Brightness} = \frac{\text{Luminosity}}{4\pi d^2}
\]
Tully-Fisher Relation for Determining Distances

- Used to determine distances to galaxies where individual stars cannot be seen.
- Relates speed of rotation and luminosity of a galaxy.
  - The faster a galaxy rotates, the higher the luminosity.
- If apparent brightness and luminosity are known, distance can be determined

How is rotational speed measured?
  - Doppler Shift

Tully-Fisher calibrated using nearby galaxies with variable stars

The Distance Ladder
Distribution of Galaxies

- Most galaxies are clustered
  - Milky Way has 3 nearby companions (SMC, LMC, Sagittarius Dwarf)
  - Andromeda Galaxy (M31) is the largest in Local group
  - ~40 galaxies in Local Group (Size ~1 Mpc)

Clusters of Galaxies

- Galaxies often found in clusters
  - Rich cluster: many hundreds of galaxies
  - Poor cluster (or group): only a few dozen galaxies
- Held together by gravity
- Milky Way is near the Virgo Cluster of ~2500 galaxies (Size ~3Mpc across)
Clusters and Superclusters

- Large clusters
  - More ellipticals found near the center
  - More spirals found in outer regions
- Superclusters
  - Clusters of clusters of galaxies.
  - In between clusters -- no gas has been detected
    - Most must have been swept up during galaxy formation.
Abell 2218

Abell 2218 is a cluster of galaxies so dense that it warps spacetime and acts like a powerful lens, magnifying and distorting the galaxies that lie behind it.

Credit: NASA/ESA

Role of Interactions

- Small interactions may start formation of spiral structure.
- Strong interactions (collisions, cannibalism) may alter structure completely
  - Spirals lose structure, become ellipticals.
  - Large galaxies “eat” many other galaxies, become very large

Galaxy Merger