Galaxies, Hubble, and the Expanding Universe

Typical spiral galaxies

Elliptical galaxies

Irregular galaxies
Using the New Astronomy Tools

- **Doppler Shift**
  - Observed frequency depends on relative motion of source and observer.

- **Cepheid Variables**
  - A class of yellow-giant pulsating stars.
  - Can be used to calculate distances.

- **Big Telescopes** - Smaller place for amateurs!

- **Photography**
  - Large photographic plates

Distances to Galaxies

- For nearby galaxies - use inverse-square law and method of standard candles
  - \[ B = \text{constant} \times \frac{L}{D^2} \]
  - Pick an object of known brightness (Cepheid variable, planetary nebula, supernova).
  - Measure how bright it looks
  - Compare to known brightness to get distance

- Harlow Shapley (1917) calibrated the period-luminosity relationship.
The Hubble Law

- Edwin Hubble, in the early 1900's, found galaxies to be receding from the Milky Way
  - Deduced from spectra which show redshift, implying motion away from observer
  - Redshift observed in all but a very few nearby galaxies
  - Redshift larger for dimmer galaxies
  - Dimmer galaxies must be farther away
  - Recession is faster for more distant galaxies

Hubble's Law - Continued

- Recession velocity related to distance by
  - Velocity = constant \times \text{distance}
  - The Hubble law - now written as
    \[ V = H \cdot D \]

- For nearby galaxies
  - Measure \( D \) using standard candles
  - Measure \( V \) using spectra
  - Calculate \( H \)
  - If \( V \) measured in km/sec and \( D \) in Mpc, then \( H \) is in km/sec/Mpc.

Hubble's Law - Continued

- Value of \( H \) is uncertain
  - \( H = 50 \) km/sec/Mpc or
  - \( 100 \) km/sec/Mpc
  - Law implies Universe is expanding
  - Distance to galaxy - found from its velocity
  - Example:
    - Suppose measured \( V = 3000 \) km/sec
    - \( V = H \cdot D \)
    - Therefore, \( D = \frac{V}{H} = 3000/50 = 60 \) Mpc.

Galaxies Farther Away Recede Faster: Hubble’s Law

Quasars

Accretion disk
Jets formed by accretion disk

Gravitational lens effect

The Local Group

The Local Supercluster
The Great Wall

Courtesy M. J. Geller and J.P. Huchra; Smithsonian Astrophysical Observatory