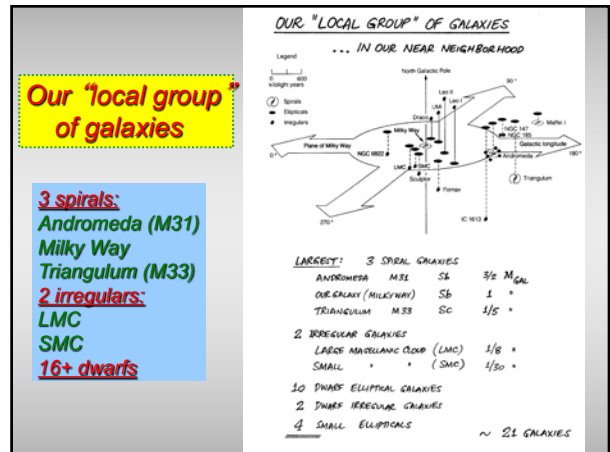
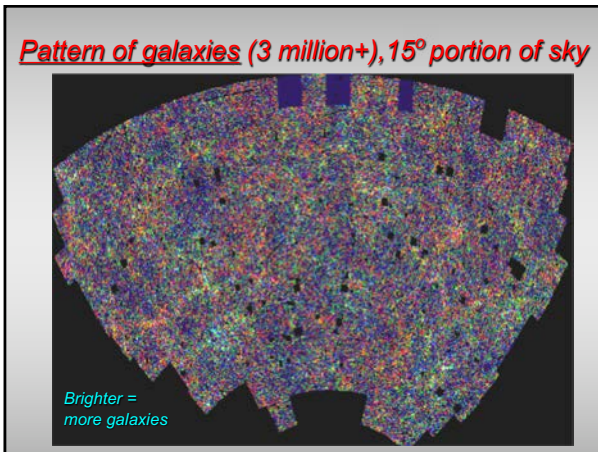
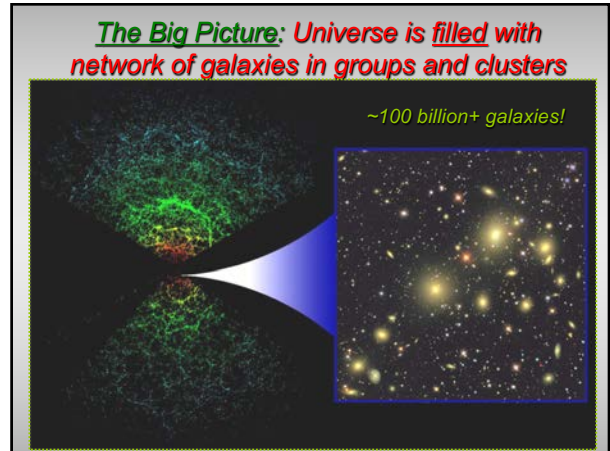
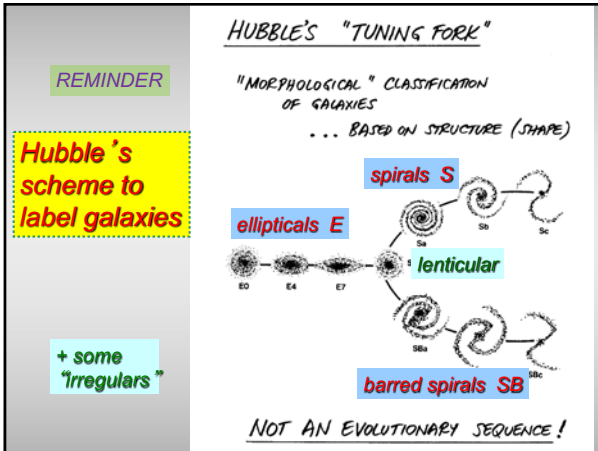




- Our wide world (universe) of Galaxies**
- **Expanding universe:** Hubble's discovery #2
  - Then turn with **planetarium** to the joys of galaxies and how **large-scale structure** emerged
  - Finish overview reading **Chap 21 "Galaxy Evolution"**
  - Observatory Night #9 **this Thur (Nov 15)** by signup (7pm onward)



### Biggest is Andromeda (Sb - M31)

- Andromeda is ~2.5 million light years away (780 kpc) (or ~35 MW diameters), has ~1.5 mass of MW
- We see her as "she" was 2.54 million years ago, not as she is today! – this is lookback time
- Oops! she may crash into MW in about 2+ billion years



### Andromeda: in IR + Xray views



### Triangulum (M33)

- 1/5 mass of MW, spiral classified as Sc
- Several bright (pink) star forming regions



### Large & Small Magellanic Clouds



LMC has 30 Doradus, home of SN 1987A



### Hubble: next showed universe appeared to be expanding!

- Vesto Slipher (1912) reported that most galaxies showed Doppler redshifts
- Edwin Hubble, using new 100" telescope, started busily measuring galaxy redshifts
- Hubble (1929) announced that redshifts of galaxies appear to increase with distance from us
- This was startling: suggests an EXPANDING UNIVERSE!

**Hubble and recession of galaxies: measured many redshifts**

Further away, greater redshift!

Hubble guessed their distances by size and brightness — underestimated by factor 10!

**HUBBLE'S DISCOVERY OF RECESSION OF GALAXIES**

Velocity (km/sec)

DISTANCE (MPC)

HUBBLE'S LAW:  
DOPPLER VELOCITY (RECESSION)  
= HUBBLE x DISTANCE CONSTANT

**Hubble showed universe appears to be expanding!**

**Hubble's Law:  $v = H_0 d$**

Velocity of Recession (Doppler Shift) (km/sec)

Hubble's Constant (km/sec/Mpc)

Distance (Mpc)

Hubble's (1929) original:

Scatter here from random velocities of nearby galaxies, unreliable distance estimates

**Clicker Question**

From Hubble's original plot, what is the Hubble Constant?

Velocity (km/s)

Distance (parsecs)

A. 100 km/s  
B. 500 km/s  
C. 500 km/s/Mpc  
D. 1000 km/s  
E. 1000 km/s/Mpc

**Best current values for expansion**

$H_0 = 71 \pm 4$  km/s/Mpc

"HUBBLE CONSTANT"

Hubble (1929) plot extended only to 2 Mpc,  $H_0$  was ~500!

recession velocity (km/s)

apparent distance (Mpc)

$H_0 = 79$  km/s/Mpc

$H_0 = 65$  km/s/Mpc

**UNIVERSE EXPANDS ON THE LARGE SCALE**

LIKE EXPANDING RAISIN BREAD!

UNiverse expands like raisin bread!

THIS COULD EXPLAIN HUBBLE'S VELOCITY-DISTANCE LAW

... CLUSTERS OF GALAXIES APPEAR TO BE MOVING AWAY FROM ALL OTHERS! (TRUE ON AVERAGE)

**Balloon analogy for expanding universe**

- On an expanding balloon, no galaxy is at the "center" of expansion; no edge
- Expansion happens into a higher dimension (2-D surface into a 3-D space)
- Is our 3-D space expanding through a 4<sup>th</sup> dimension?

*Clicker -- reading on galaxies*

• *How might you classify this galaxy?*

- **A.** Sa
- **B.** SBb
- **C.** E
- **D.** SO



*Now to our tour of  
Large-Scale Structure in our  
Universe*