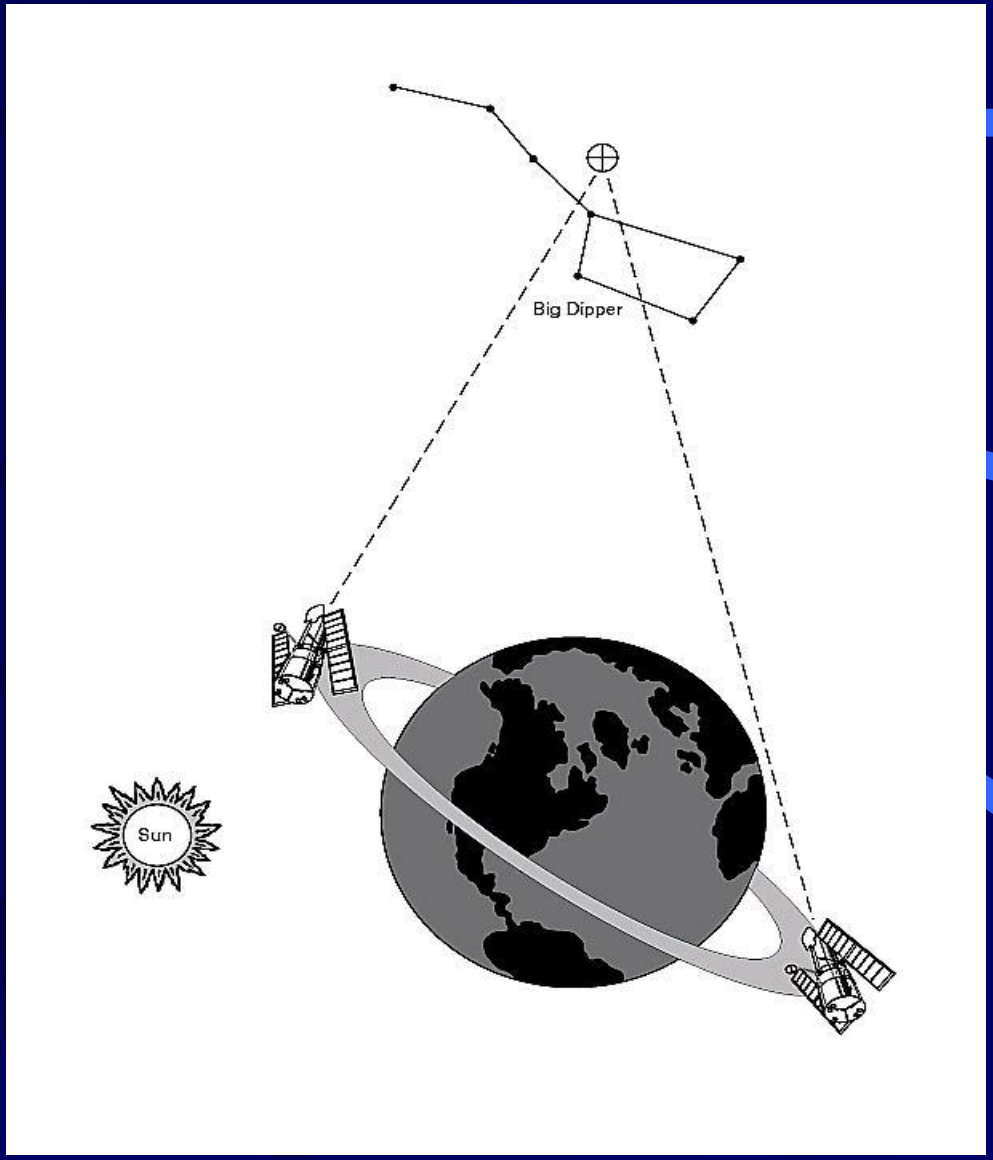
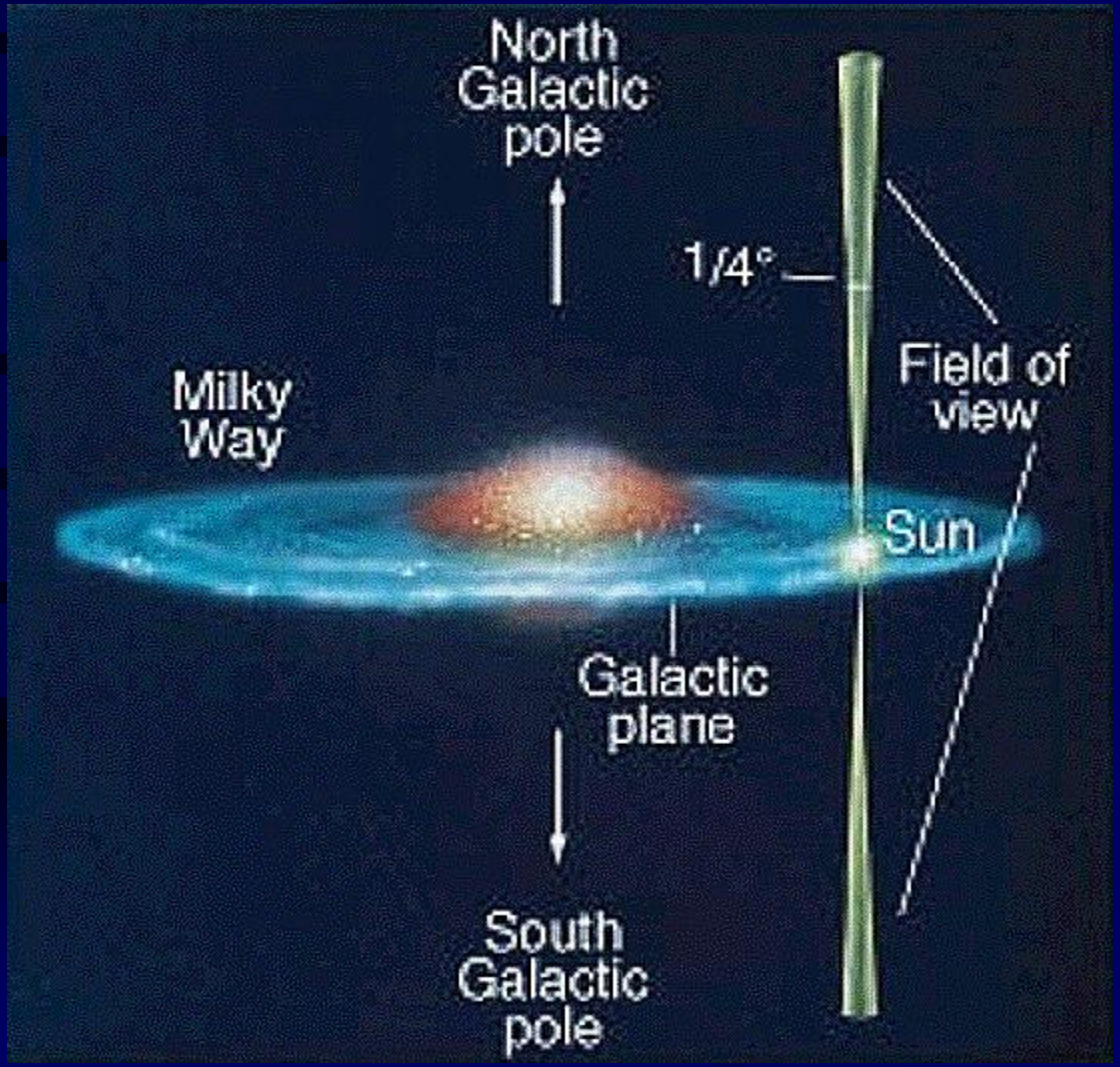
Galaxies & Introduction to Cosmology

Other Galaxies: How many are there?

- Hubble Deep Field Project
  - 100 hour exposures over 10 days
  - Covered an area of the sky about 1/100 the size of the full moon
- Probably about 100 billion galaxies visible to us!




North
Galactic
pole
1/4°
Field of
view
Milky
Way
Sun
Galactic
plane
South
Galactic
pole

- About 1,500 galaxies in this patch alone
- Angular size ~ 2 minutes of arc

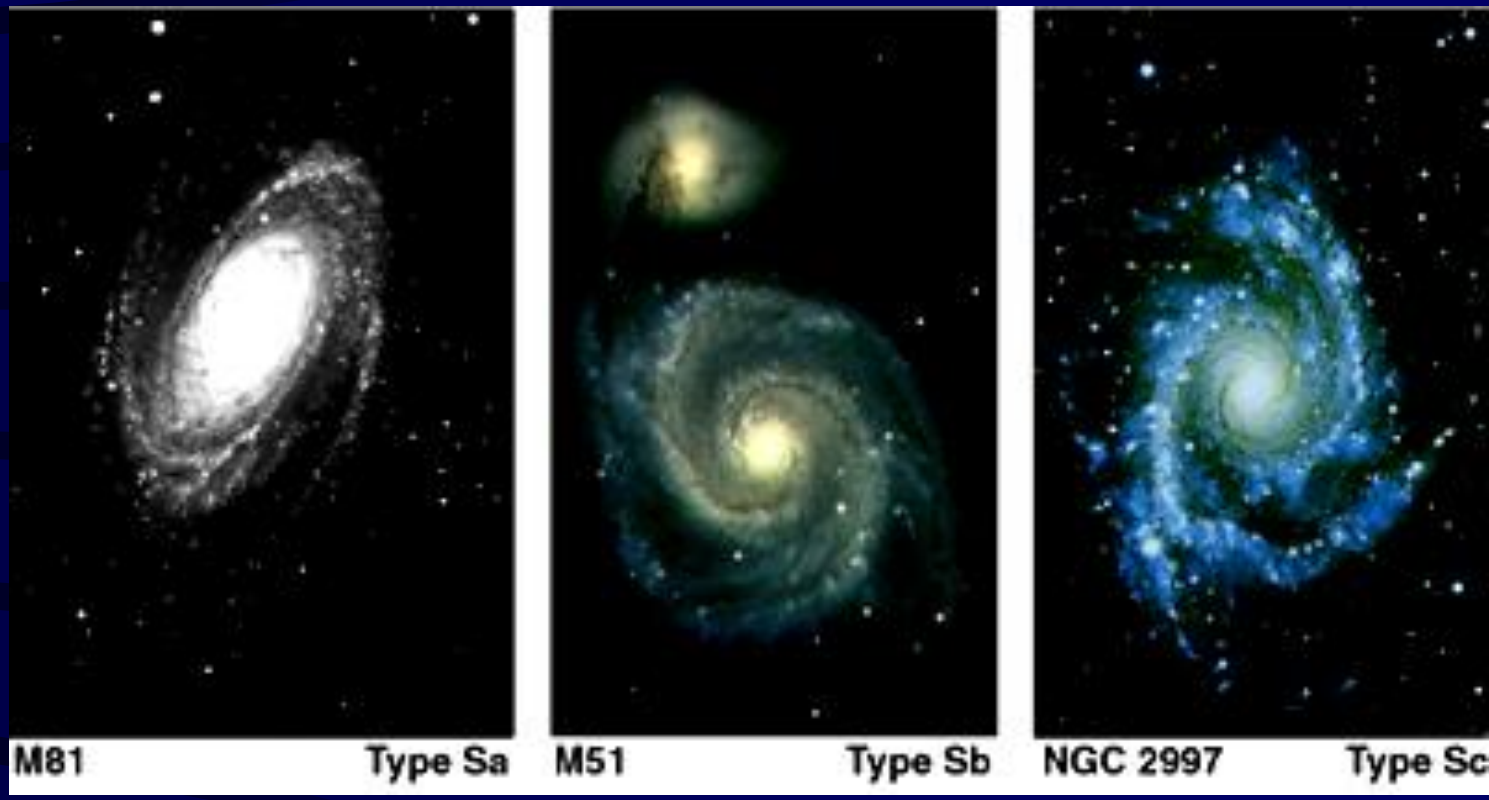
Other Galaxies

- there are ~ 100 billion galaxies in the observable Universe
- measure distances to other galaxies using the period-luminosity relationship for Cepheid variables
- Type I supernovae also used to measure distances
  - Predictable luminosity – a standard candle
- Other galaxies are quite distant
  - Andromeda (M31), a nearby (spiral) galaxy, is 2 million light-years away and comparable in size to Milky Way
- "Island universes" in their own right

Hubble Classification Scheme

- Edwin Hubble (~1924) grouped galaxies into four basic types:
  - Spiral
  - Barred spiral
  - Elliptical
  - Irregular
- There are sub-categories as well

Spirals (S)



- All have disks, bulges, and halos
- Type Sa: large bulge, tightly wrapped, almost circular spiral arms
- Type Sb: smaller bulge, more open spiral arms
- Type Sc: smallest bulge, loose, poorly defined spiral arms

Barred Spirals (SB)

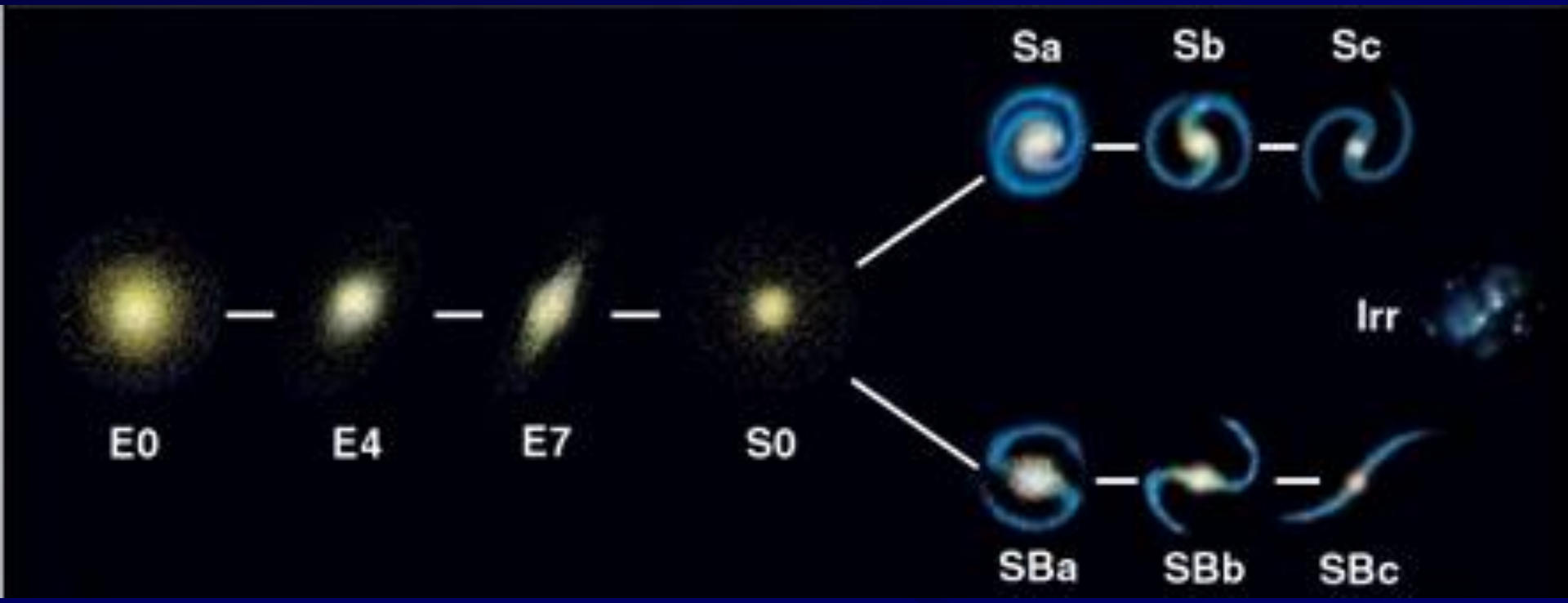
- Possess an elongated “bar” of stars and interstellar mater passing through the center

Elliptical (E)

- No spiral arms or clear internal structure
- Essentially all halo
- Vary in size from “giant” to “dwarf”
- Further classified according to how circular they are (E0–E7)

S0/SB0

- Intermediate between E7 and Sa
- Ellipticals with a bulge and thin disk, but no spiral arms

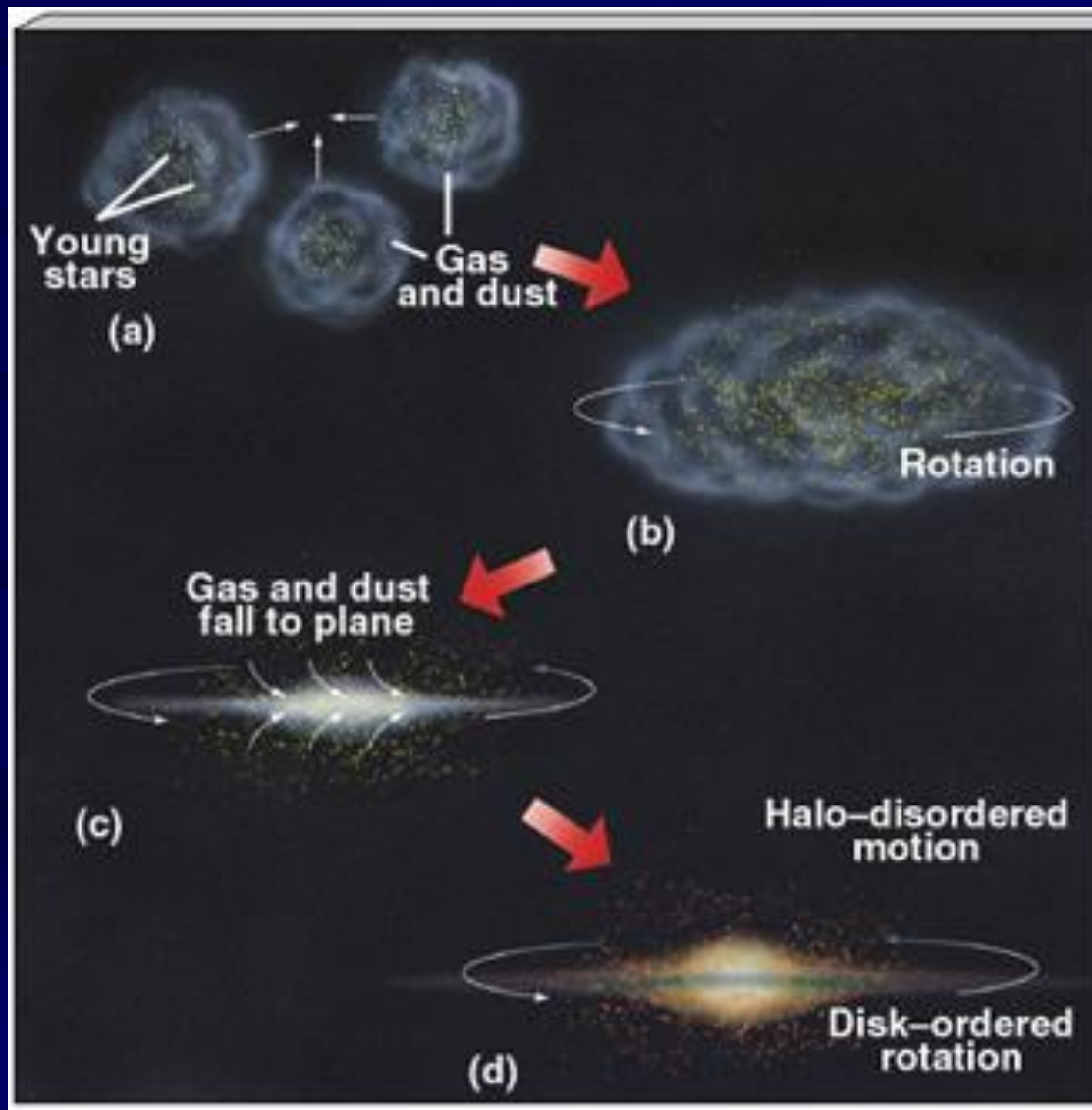


Galaxy Formation

- Not very well understood
  - More complicated than stellar formation, and harder to observe
- Formation of galaxies begins after Big Bang
- Different than star formation because galaxies may collide and merge

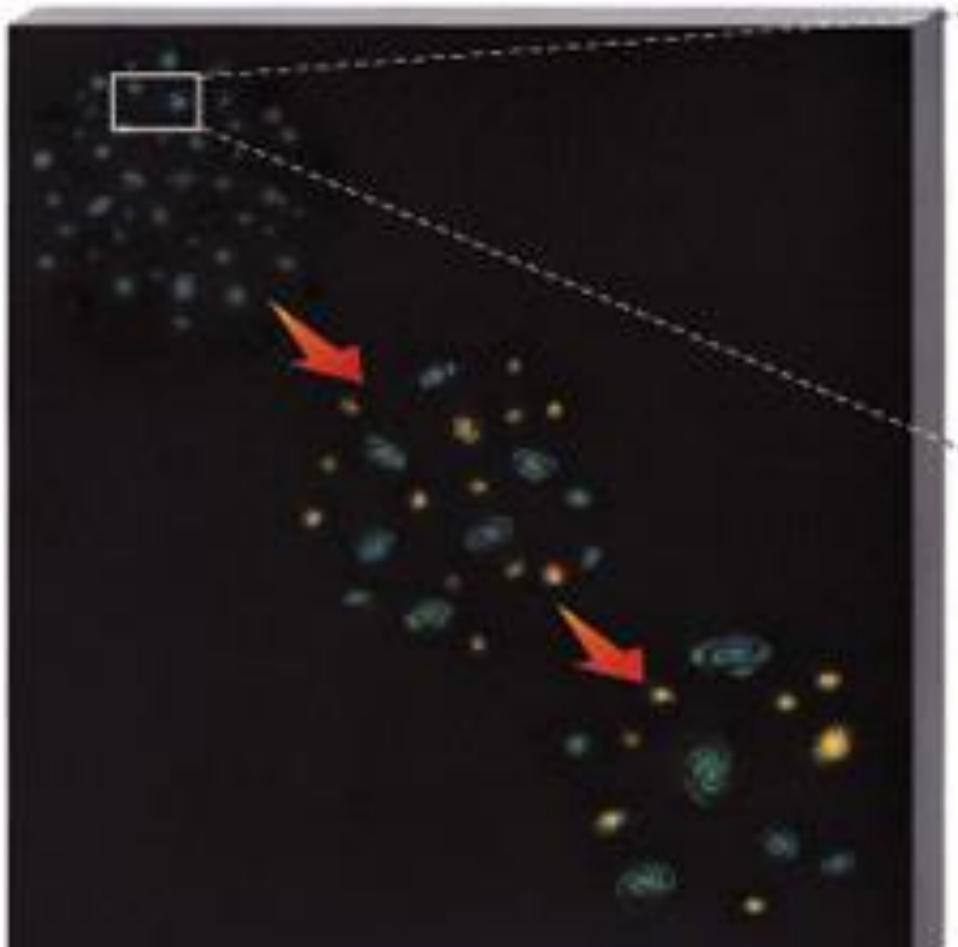
Galaxy Formation

- Galaxies are probably built up by mergers
  - Contrast to break up of clouds in star formation
- Our own Milky Way is eating up the neighboring Sagittarius Dwarf Galaxy



Galaxy Mergers

- Start with high density of small proto-galaxies
- Galaxies merge and turn into bigger galaxies



Actual photo (HST): lots of small galaxies

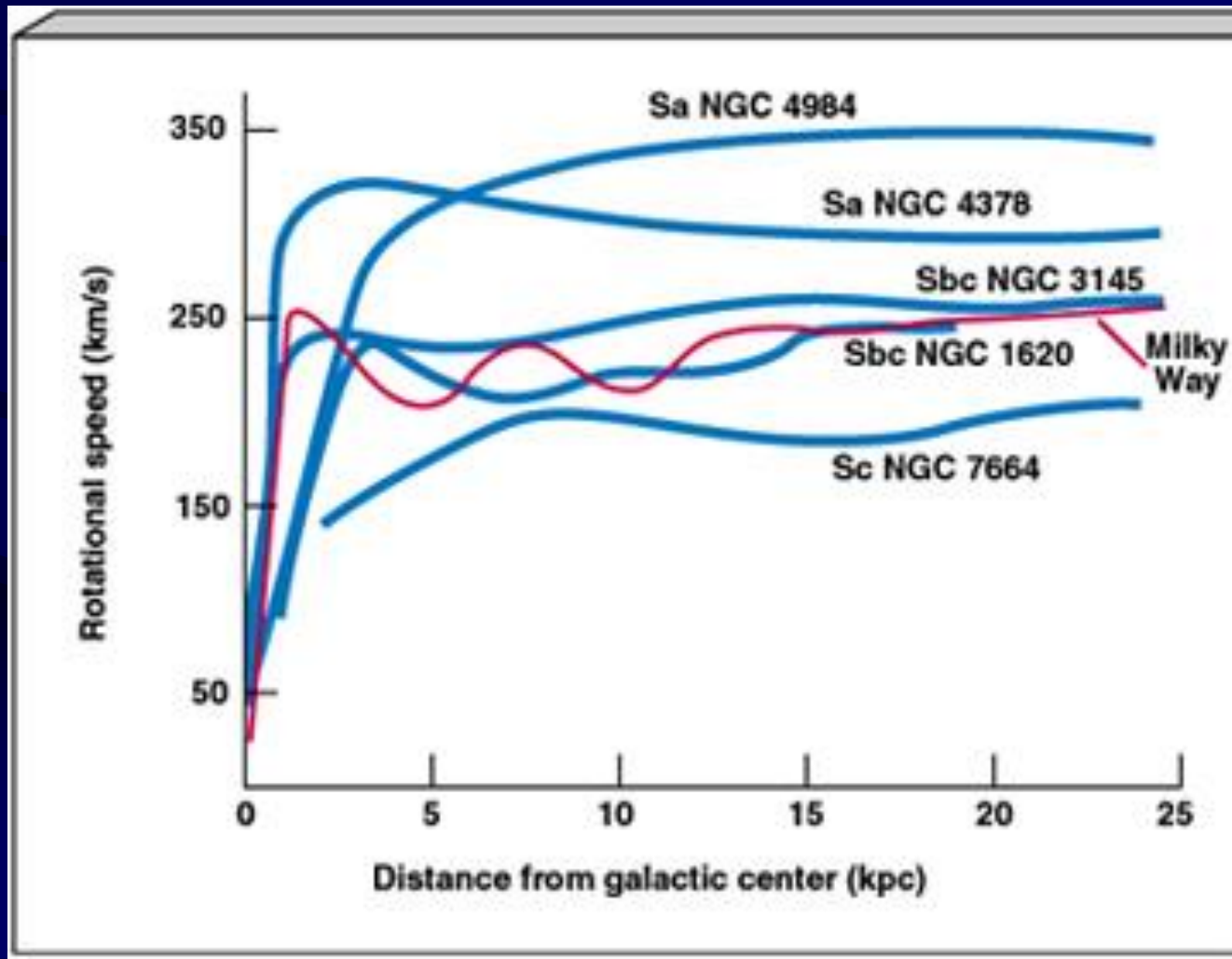
The Mass of the Galaxy

- Can be determined using Kepler's 3rd Law
  - Solar System: the orbital velocities of planets determined by mass of Sun
  - Galaxy: orbital velocities of stars are determined by total mass of the galaxy contained within that star's orbit

- Two key results:
  - large mass contained in a very small volume at center of our Galaxy
  - Much of the mass of the Galaxy is not observed
    - consists neither of stars, nor of gas or dust
    - extends far beyond visible part of our galaxy ("dark halo")

Galaxy Masses

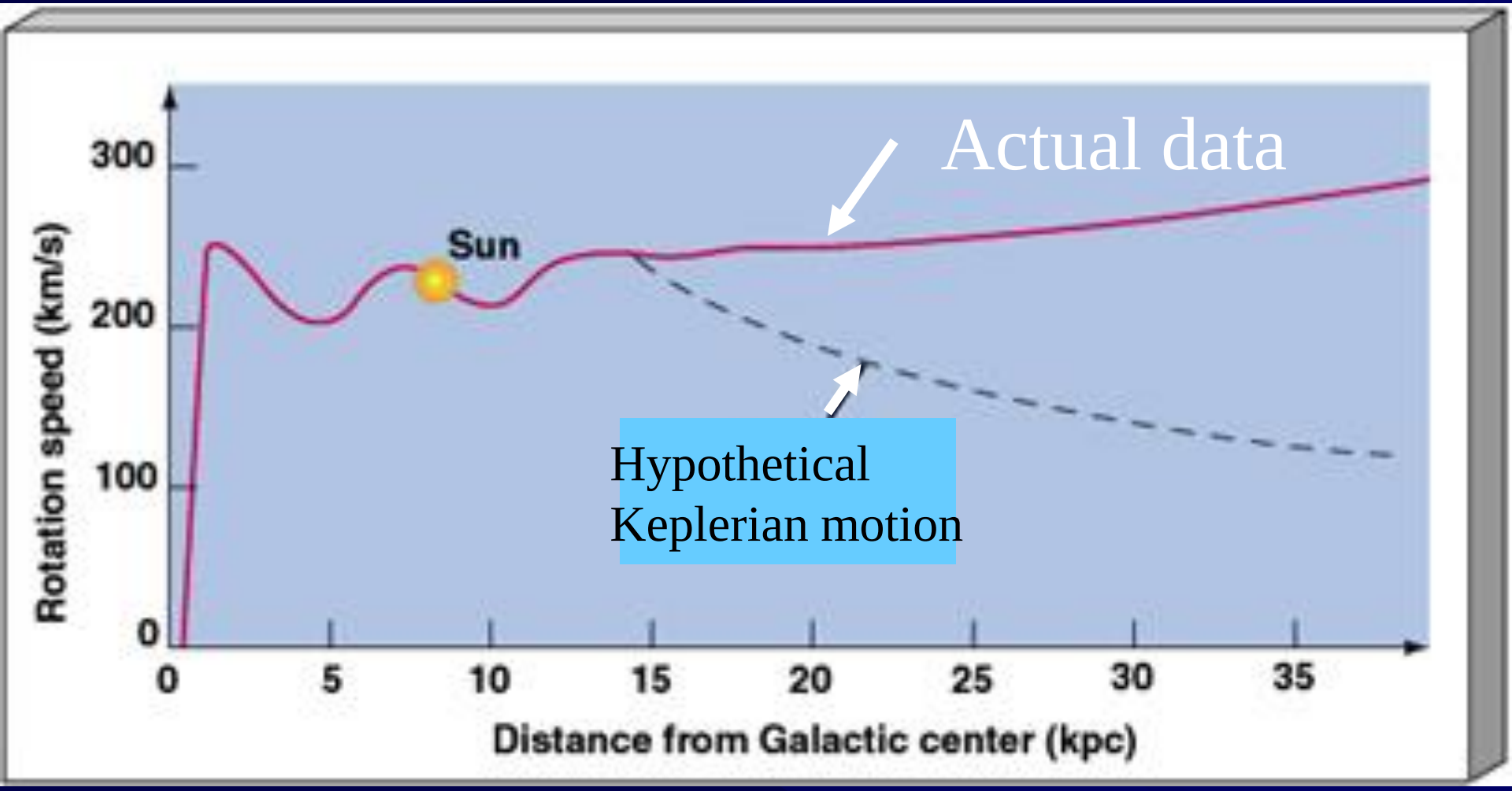
- Rotation curves of spiral galaxies comparable to milky way
- Masses vary greatly



The Missing Mass Problem

- Dark Matter is dark at all wavelengths, not just visible light
- The Universe as a whole consists of up to 25% of Dark Matter! → Strange!
- What is it?
  - Brown dwarfs?
  - Black dwarfs?
  - Black holes?
  - Neutrinos?
  - Other exotic subatomic particles?
- Actually: Most of the universe (70%) consists of Dark Energy → Even stranger!

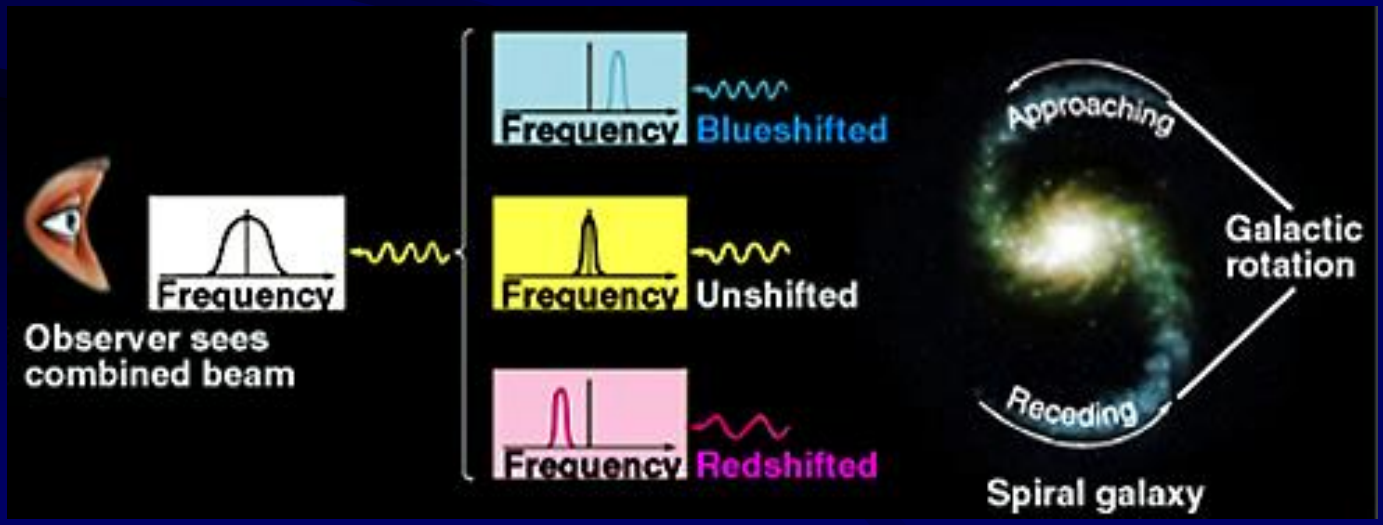
Missing Mass Problem



- Keplerian Motion: more distance from center → less gravitational pull → slower rotational speed

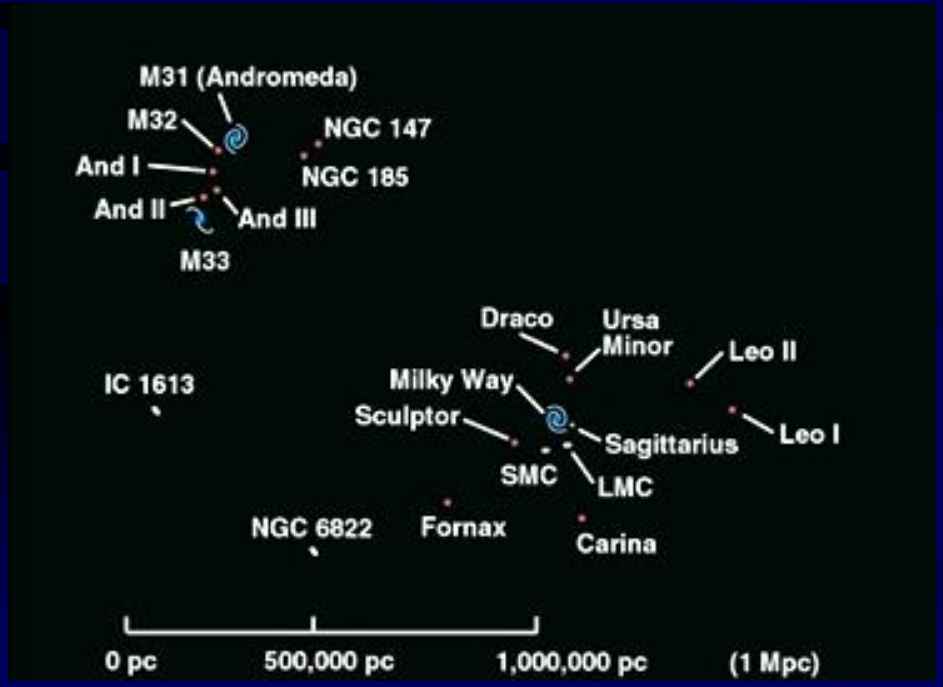
The Tully-Fisher Relation

- A relation between the rotation speed of a spiral galaxy and its luminosity
- The more mass a galaxy has ➔the brighter it is ➔ the faster it rotates ➔ the wider the spectral lines are
- Measuring rotation speed allows us to estimate luminosity; comparing to observed (apparent) brightness then tells us the distance

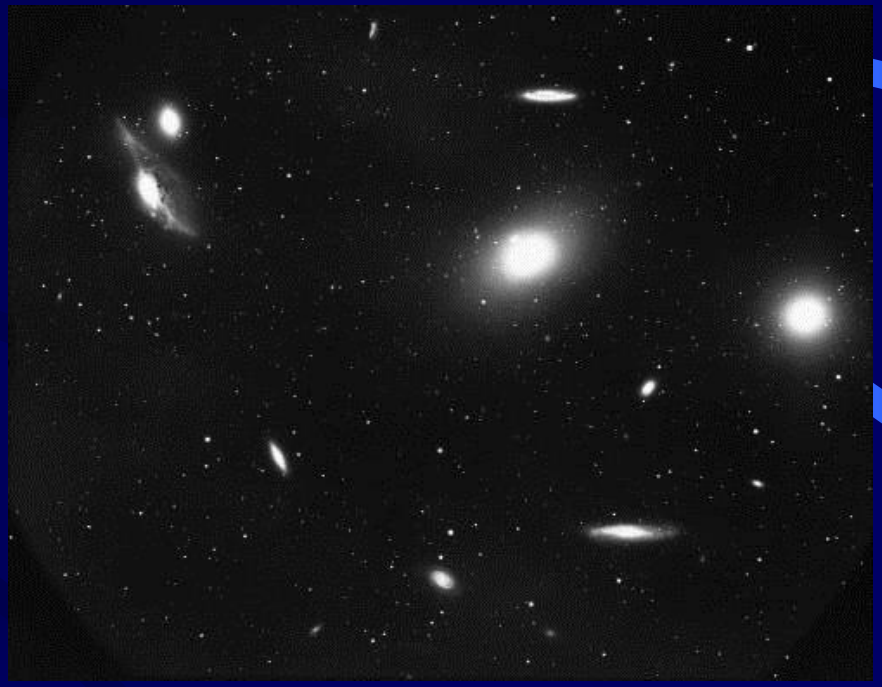


Beyond the Galactic Scale – Clusters of Galaxies

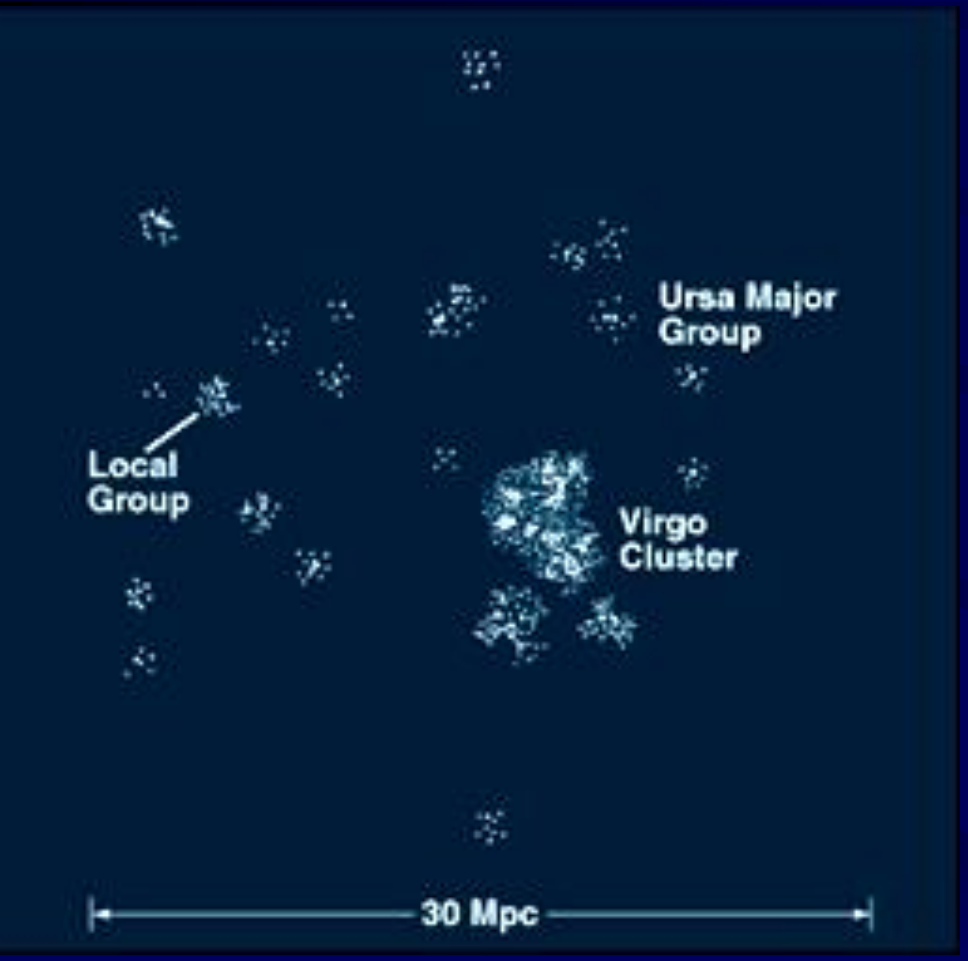
The Local Group

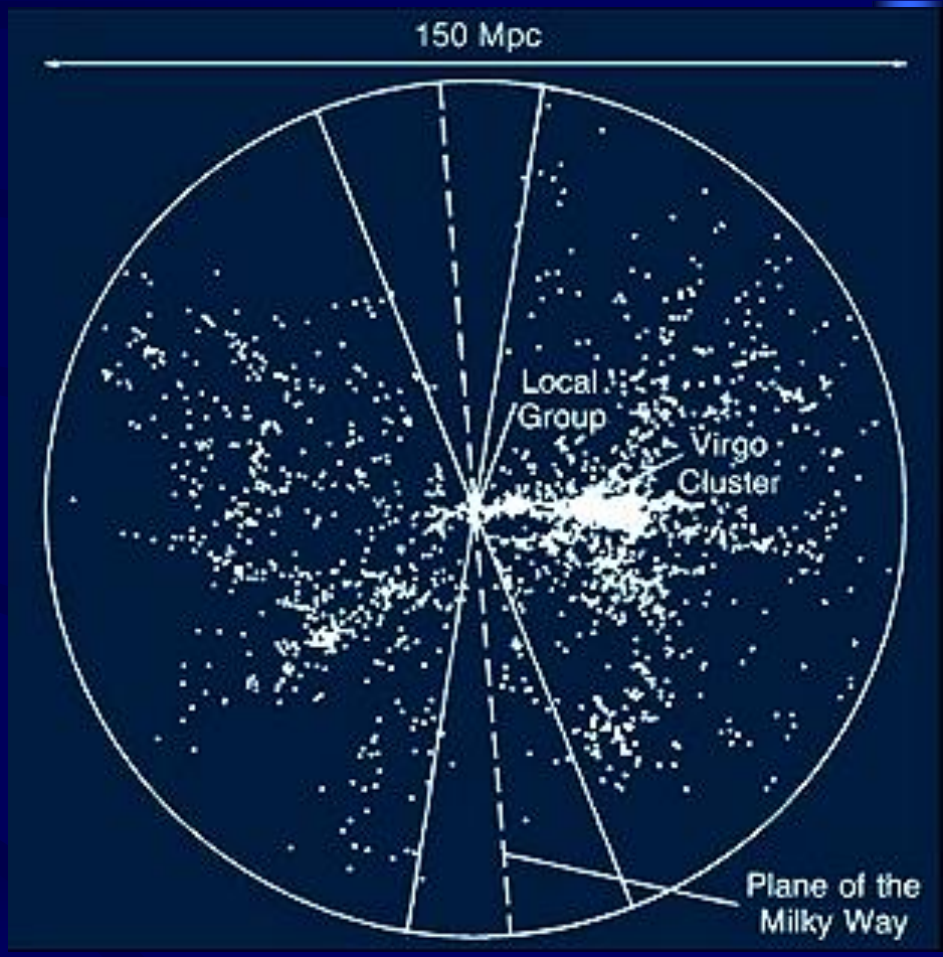


The Virgo Cluster



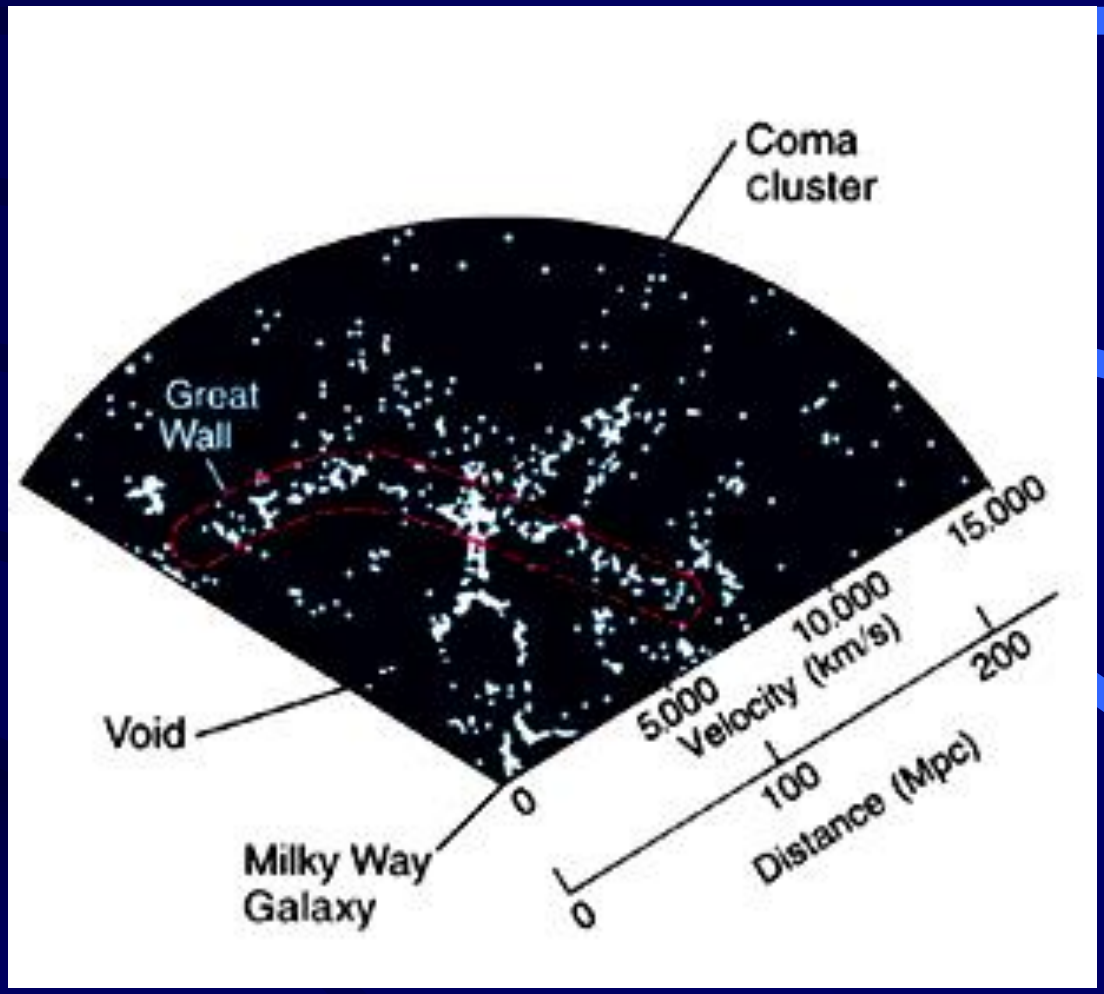
Superclusters: Clusters of Galaxy Clusters



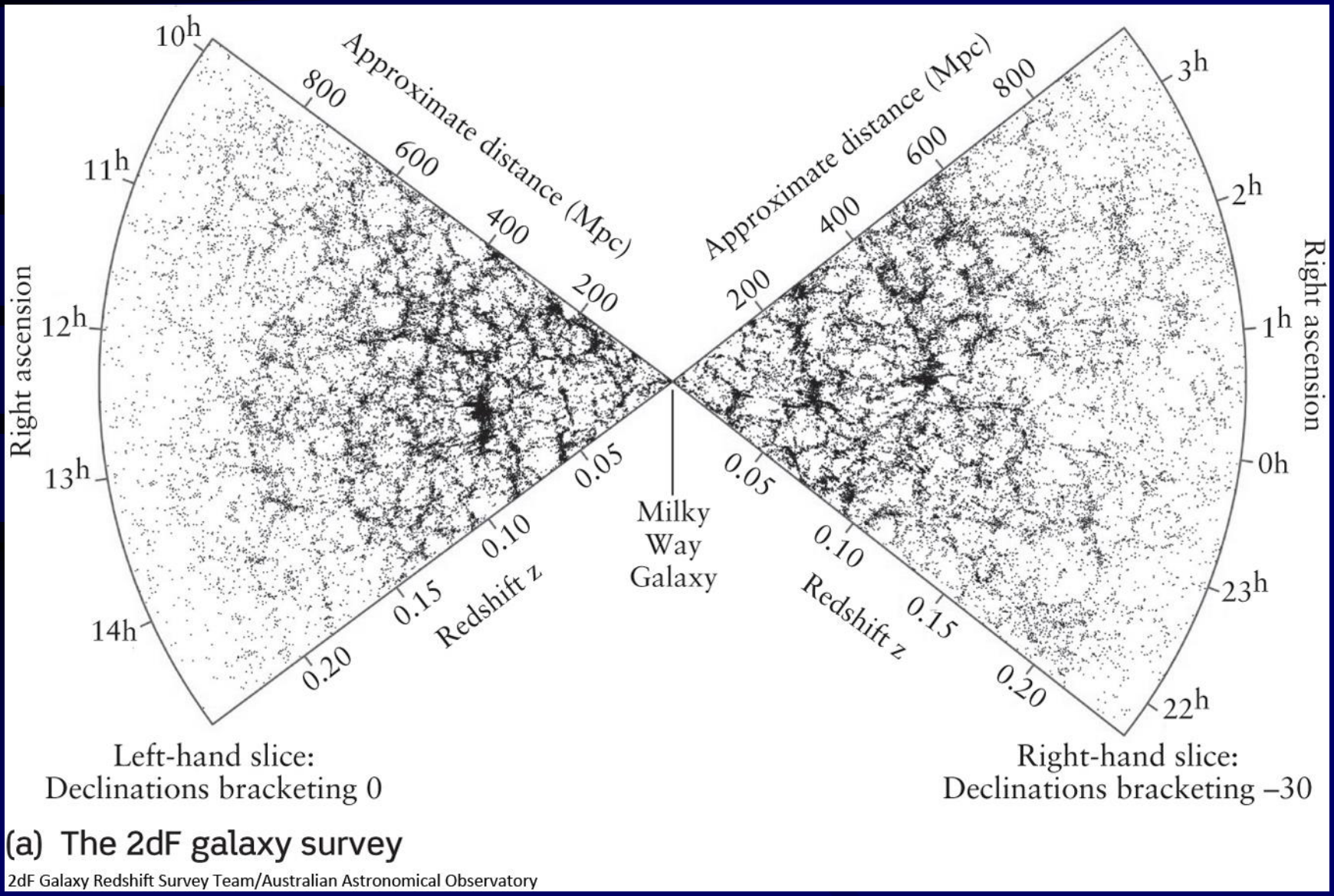


Beyond Superclusters

- Strings, filaments, voids
- Reflect structure of the universe close to the Big Bang
- Largest known structure: the Great Wall (70 Mpc × 200 Mpc!)



Latest Results from the 2dF Survey



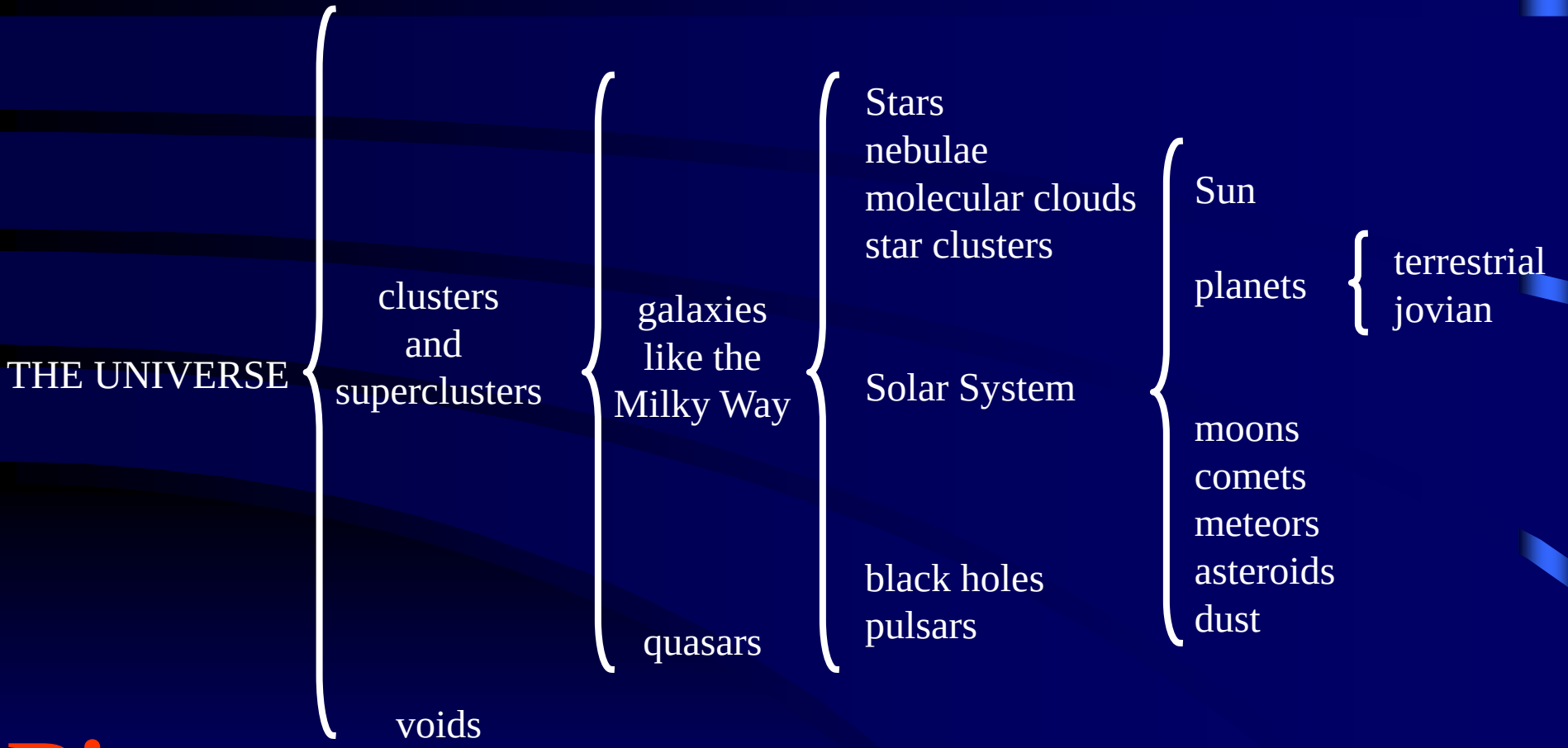
Cosmology

- The part of astronomy (and astrophysics) that deals with the greatest structures in the universe – and the evolution of the universe itself!

Cosmological Questions

- What is in the universe?
- How do these things interact?
- How does the universe change in time?
  - Is there a beginning?
  - Is there an end?

What's in the Universe?

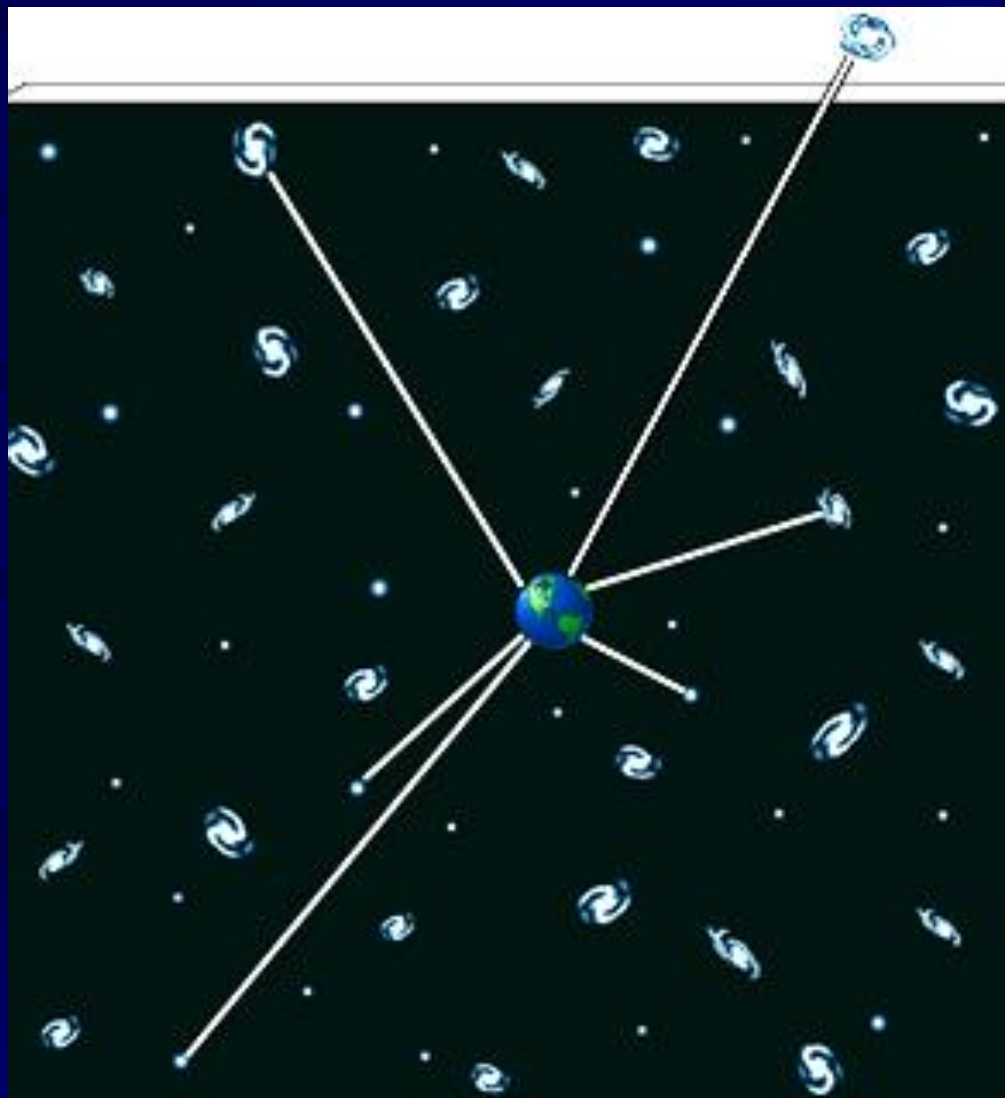


Big . . . . . small

So, why is the night sky dark?

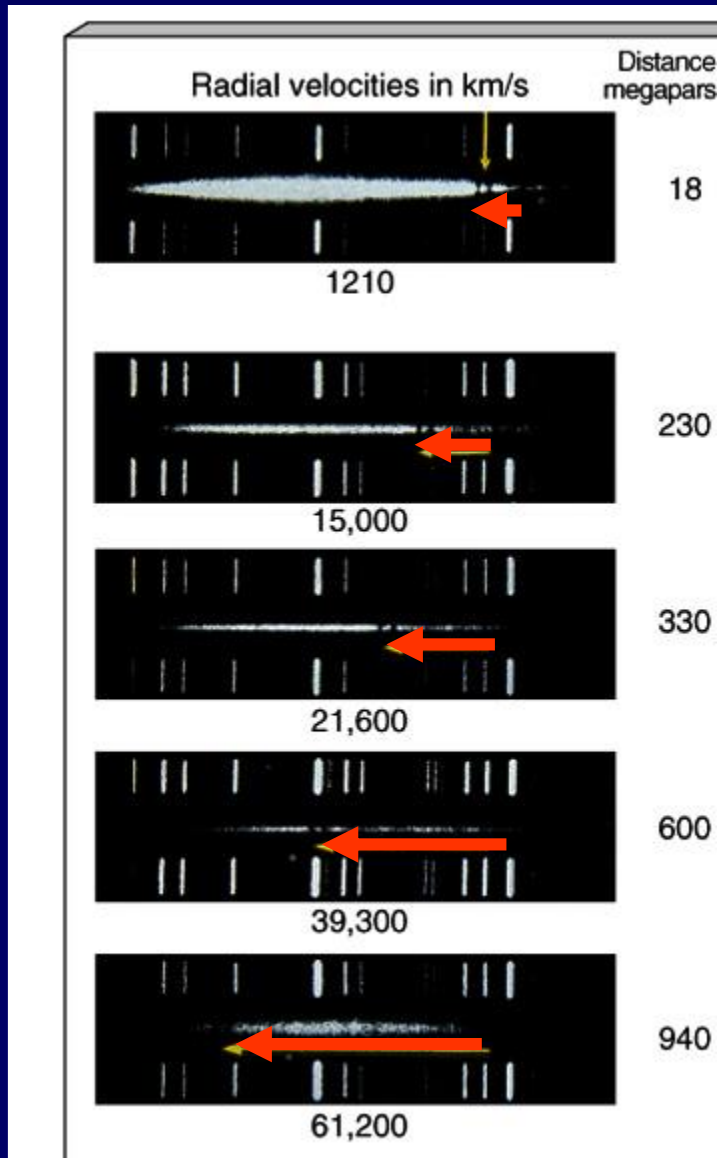
(Olbers' Paradox)

- Conclusion: either
  - Universe is **not infinite** or
  - Universe **changes** in time



Observation III: Everything is moving away from us!

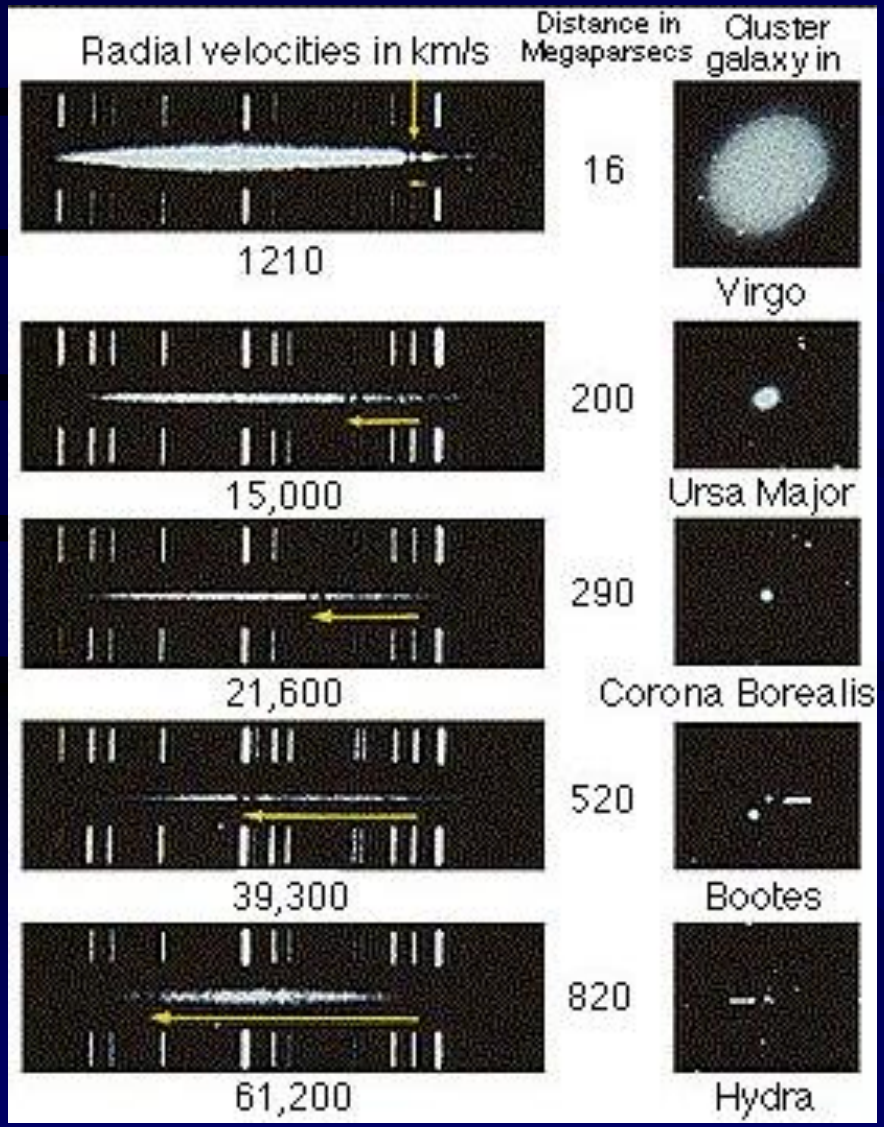
- Measure spectrum of galaxies and compare to laboratory measurement
- lines are shifted towards red
- This is the Doppler effect: Red-shifted objects are moving away from us



Hubble's Law

- The final rung on the cosmic distance ladder
- Hubble's observations (1920's):
  - Light from distant galaxies is red-shifted
  - The more distant the galaxy, the greater the red-shift
- Interpretation:
  - Galaxies are moving away from us
  - More distant galaxies are moving faster
- The universe is expanding, carrying the galaxies with it!

Doppler Shifts of Galaxies



Hubble, 1929

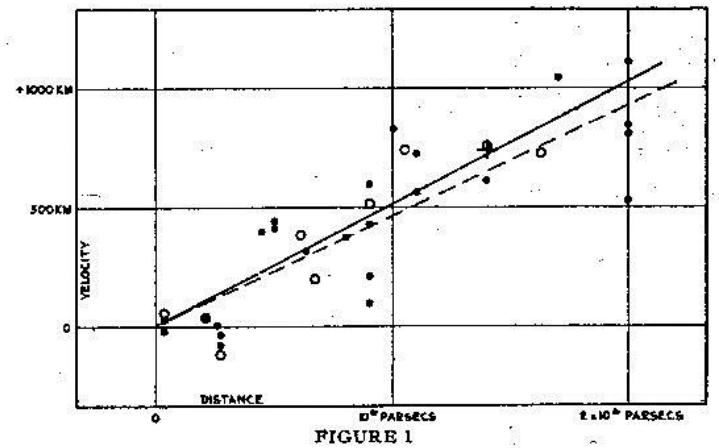
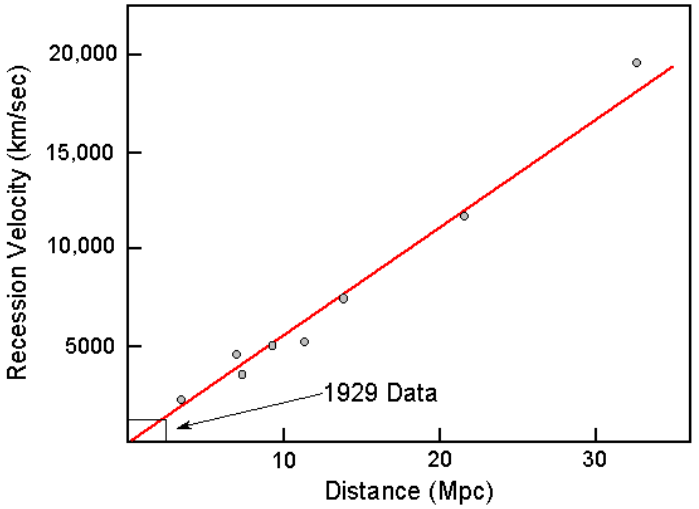


FIGURE 1

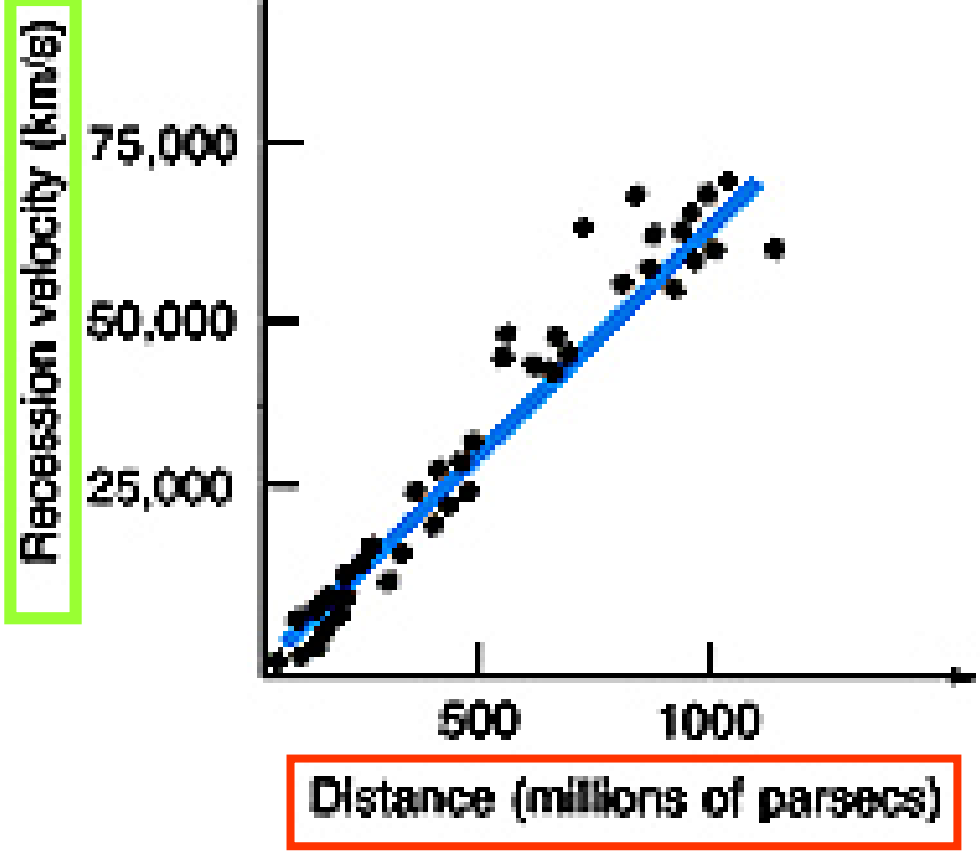
Hubble & Humason (1931)



Hubble's Law

Velocity = $H_0 \times$ Distance

Distance = Velocity /H_0



- H_0 = (68 ± 1) km/sec/Mpc is Hubble's constant
- Compare to distance = velocity × time
- Appears the universe "exploded" from a single point in the past – the Big Bang
- **Age** of the universe is $1/H_0$ or about 14 billion years

Example

- Object that is 2 Mpc away recesses with

  $v = H\,d = (68\ km/s/Mpc)\ (2Mpc) = 136\ km/s$

- Object that is receding with 27,200 km/s has distance

  $d = v/H = (27{,}200\ km/s)/\ (68\ km/s/Mpc)$

  $= 400\ Mpc$