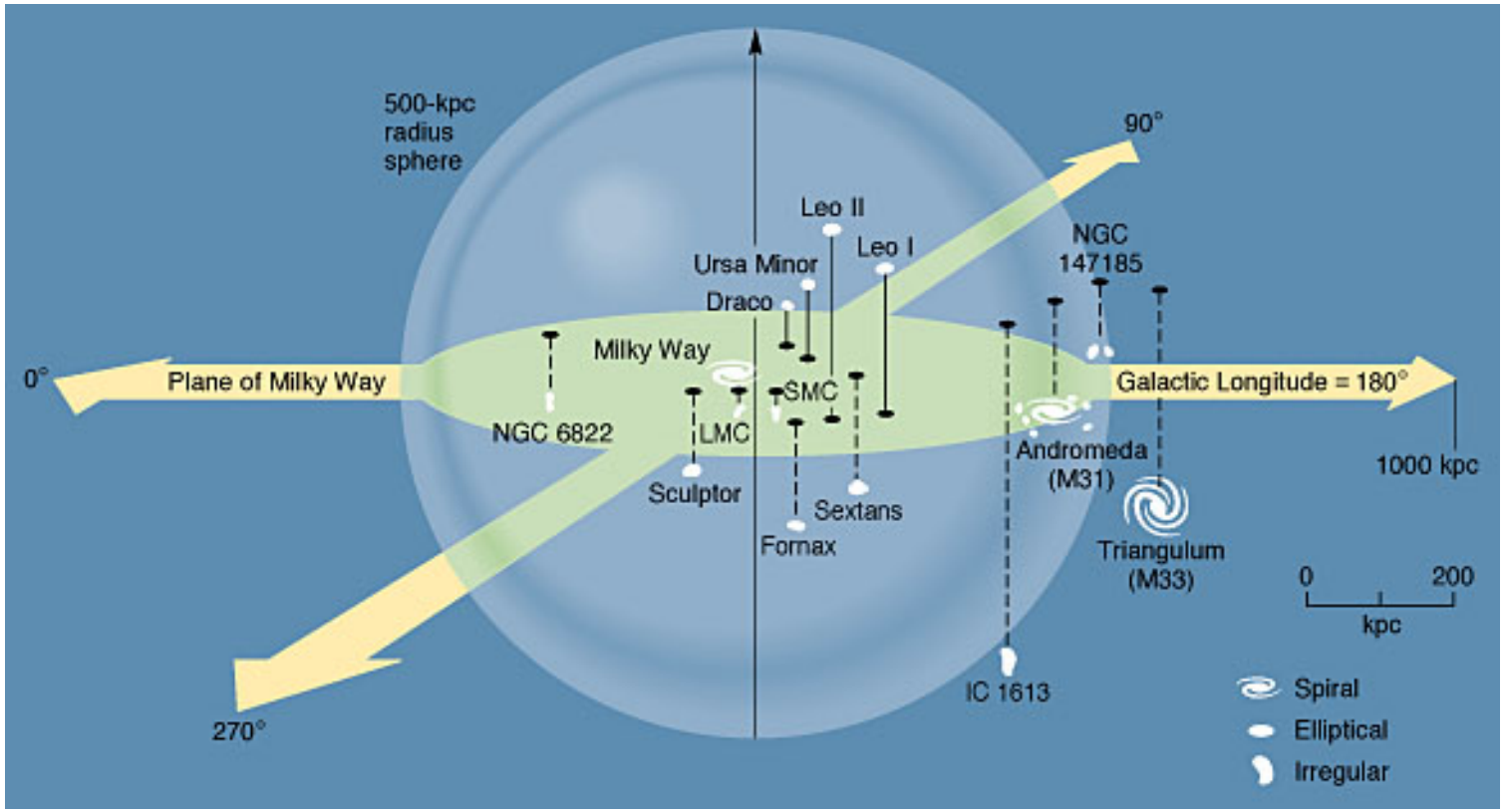

Galaxies!

The Local Group

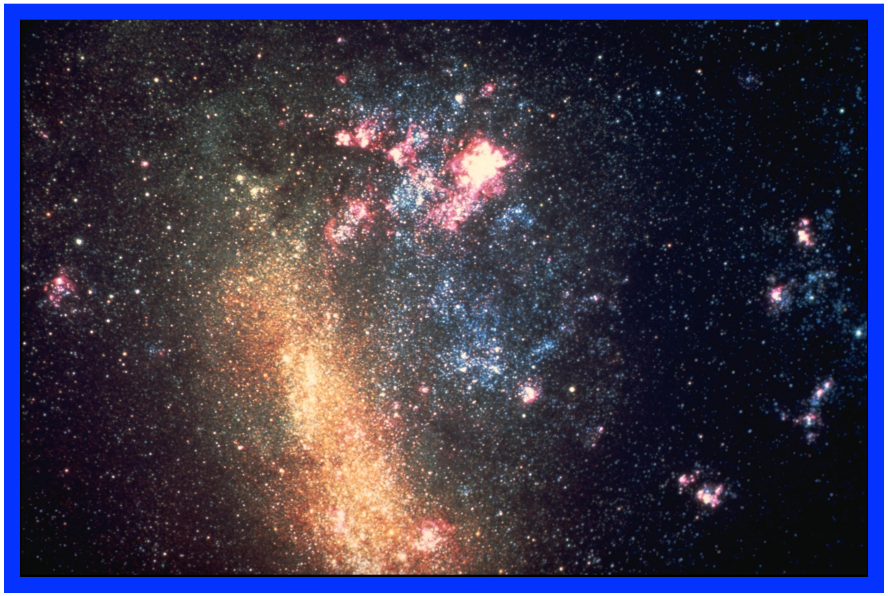
- Group of ~35 galaxies including Mw
- Large and Small Magellanic Clouds (LMC and SMC) are significant "satellite" galaxies to the MW
- MW and Andromeda are near twins and possibly the largest members



The Magellanic Clouds

Large Magellanic Cloud (LMC):

- 50 kpc distant with ~10^{10} M_o
- R136 – an outstanding active star forming region with at least 200 massive stars that will all go SN



The Magellanic Clouds

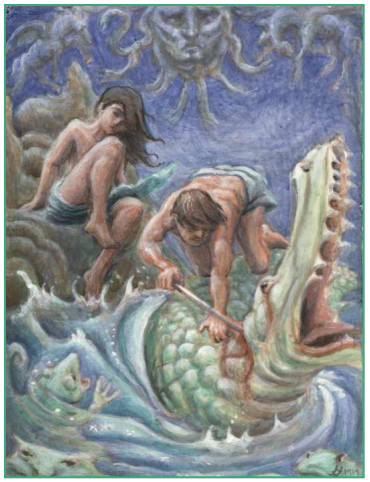
Small Magellanic Cloud (SMC):

- 60 kpc distant with ~10^9 M_o
- Extremely metal poor environment

  and little star formation activity

NGC602: Star Formation Region in the SMC

Andromeda



- Known as M31
- Nearest large spiral like our own Milky Way
- About 2.2 million LY away
- Has satellite galaxies
- Also a supermassive central black hole
- Also a dark matter halo!

Andromeda in the UV from Swift

Multi-wavelength View of M31

Galaxies

- Another subject with an interesting history
- Referred to as "nebulae" and "island universes", galaxies now known to be collections of stars and gas clouds that are bound by their mutual gravity
- Galaxies come is different types:
  - elliptical
  - spiral
  - irregular (also "peculiar")

Ellipticals

- Ellipticals are "roundish" (En)
- Mass, 10^6-10^{14} M_o
- Size, few kpc – 10^3 kpc
- Luminosity 10^5-10^{12} L_o
- Generally gas poor with old red stars

Spirals

- Spirals come in two types: normal (S) and barred (Sb)
- Contain gas and young stars

Irregulars

•Irregulars (Irr) appear "messy" or have patchy brightness

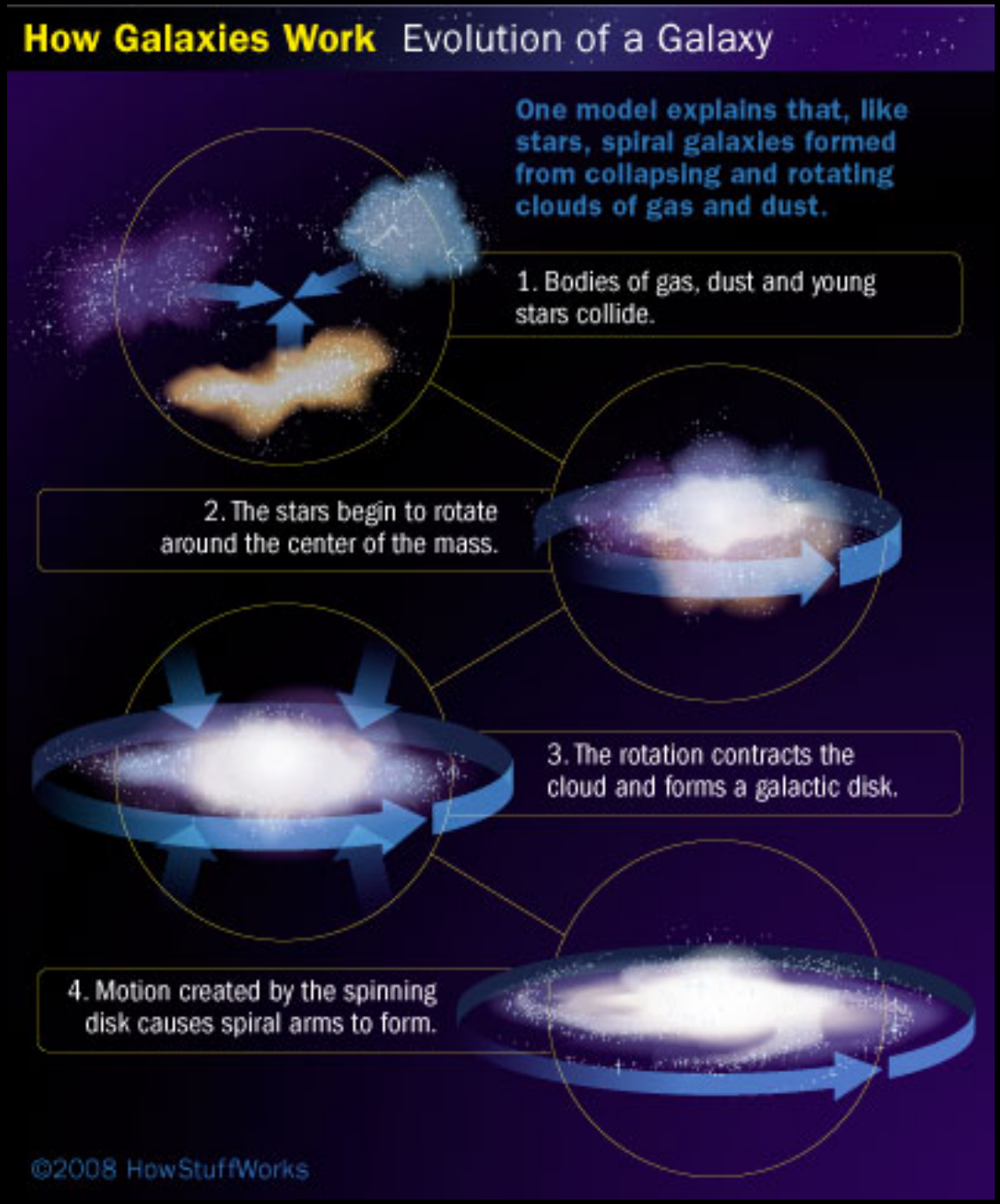
NGC 4622 - Face-On Spiral

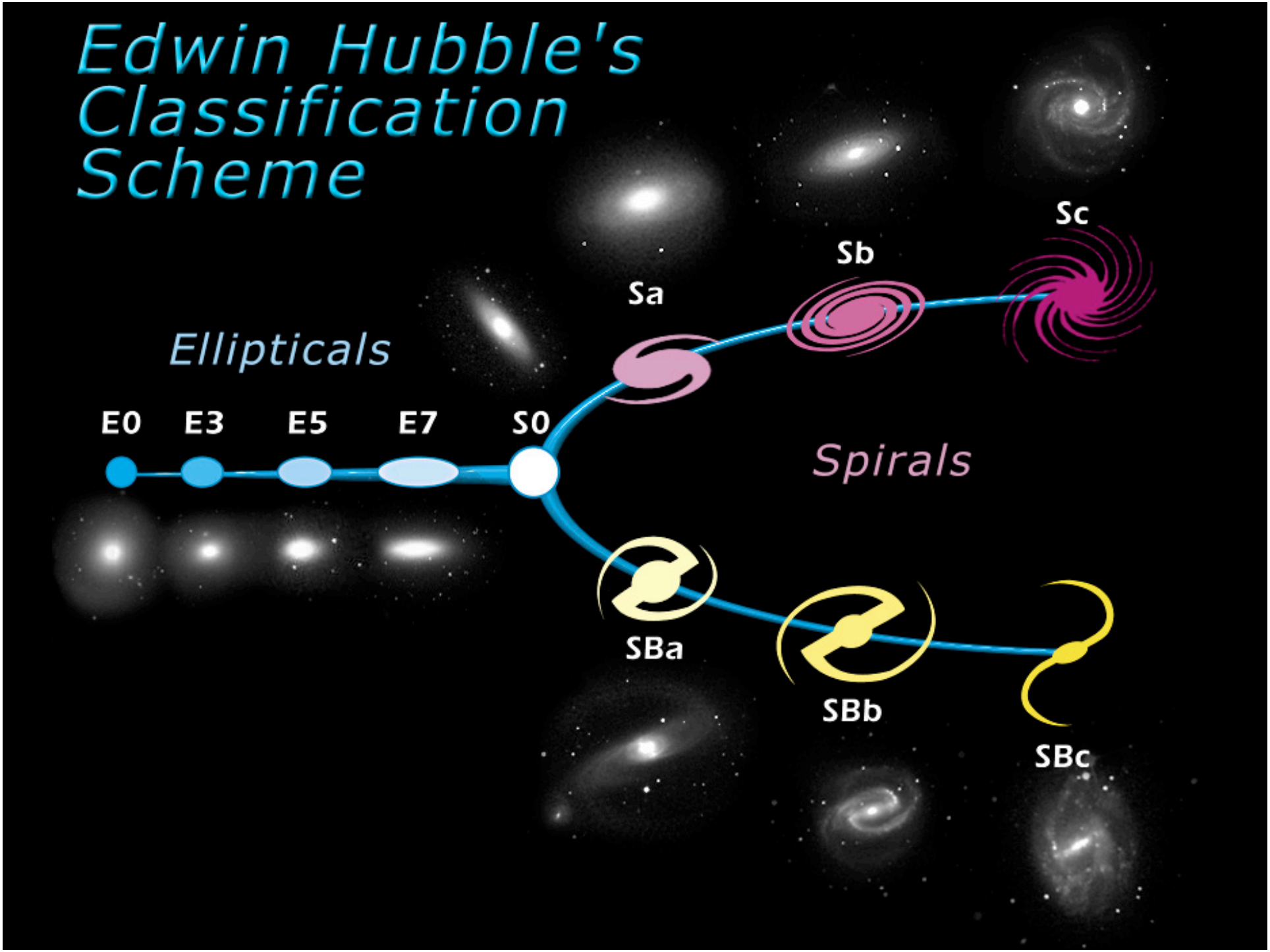
The Sombrero Galaxy

Understanding Galaxy Types

- Galaxy formation not well-understood, but types could result from different histories
- Ellipticals: proto-clusters form fast
- Spirals: cloud collapses first, then stars form
- *Collisions* are important – near hits, mergers, galactic cannibalism
- In "collision", gravity of 2 galaxies distort shapes
  - 2 ellipticals can make a spiral
  - Vice versa
- Large ellipticals (cD galaxies) are found at cluster centers

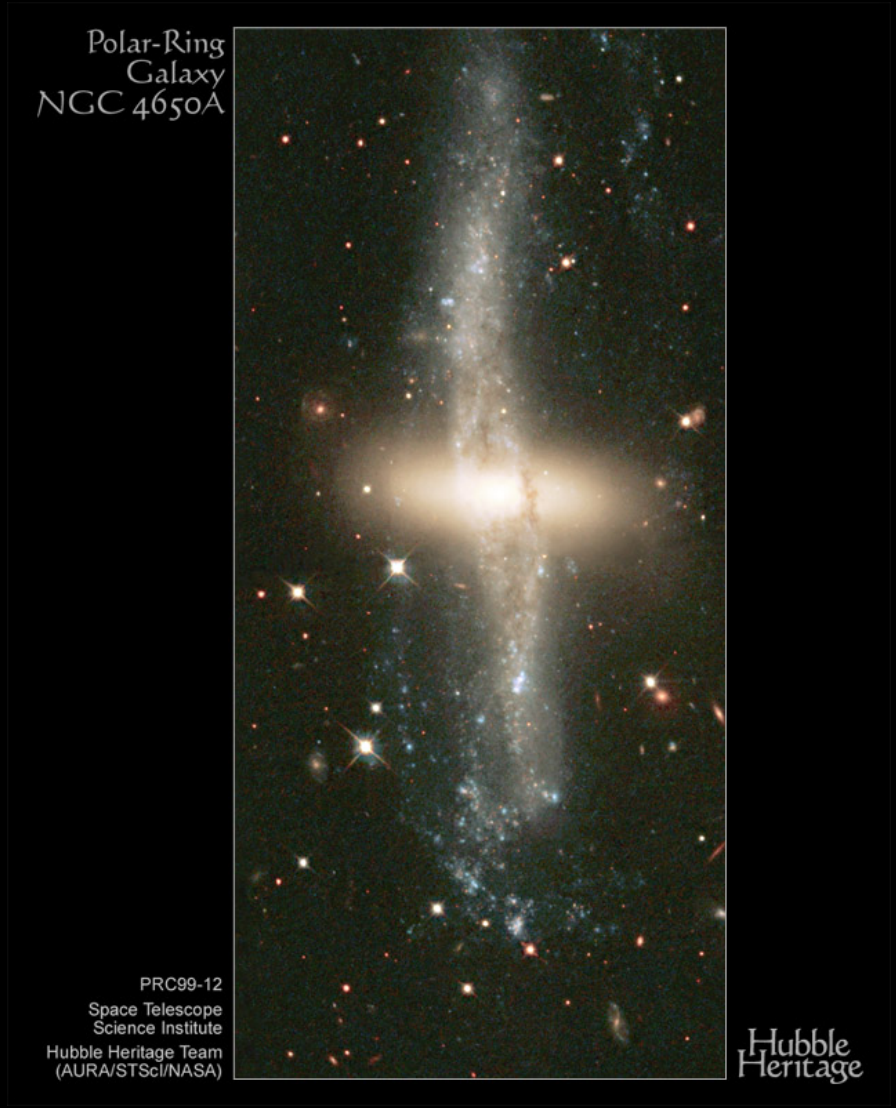
Sketch of Galaxy Formation




Edwin Hubble's Classification Scheme
Ellipticals
E0
E3
E5
E7
S0
Spirals
Sa
Sb
Sc
SBa
SBb
SBc

The Whirlpool Galaxy

A Polar Ring Galaxy



The Antennae

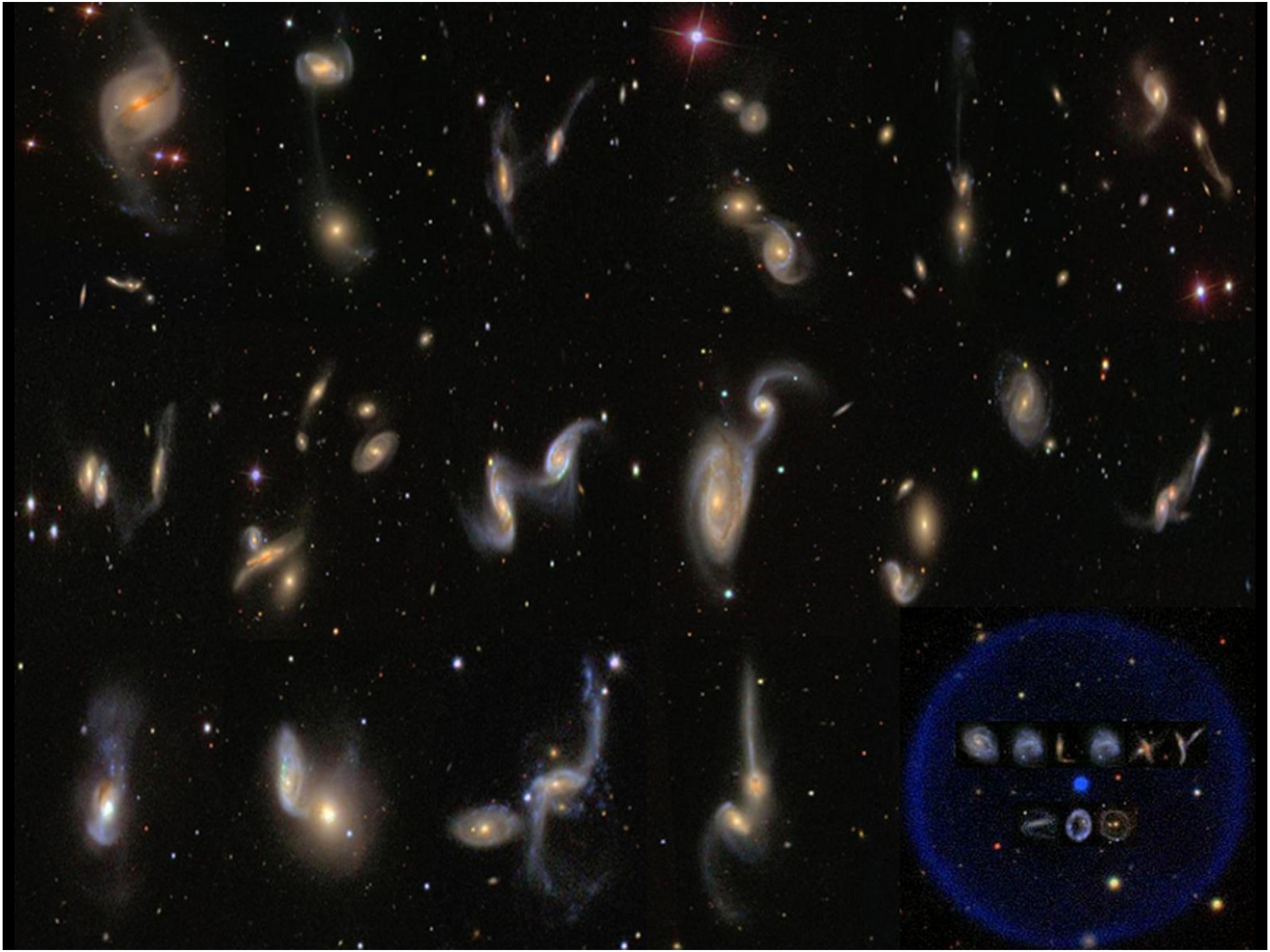
Colliding Galaxies NGC 4038 and NGC 4039 HST • WFPC2

PRC97-34a • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

The Antennae: IR View

Interactions Betrayed

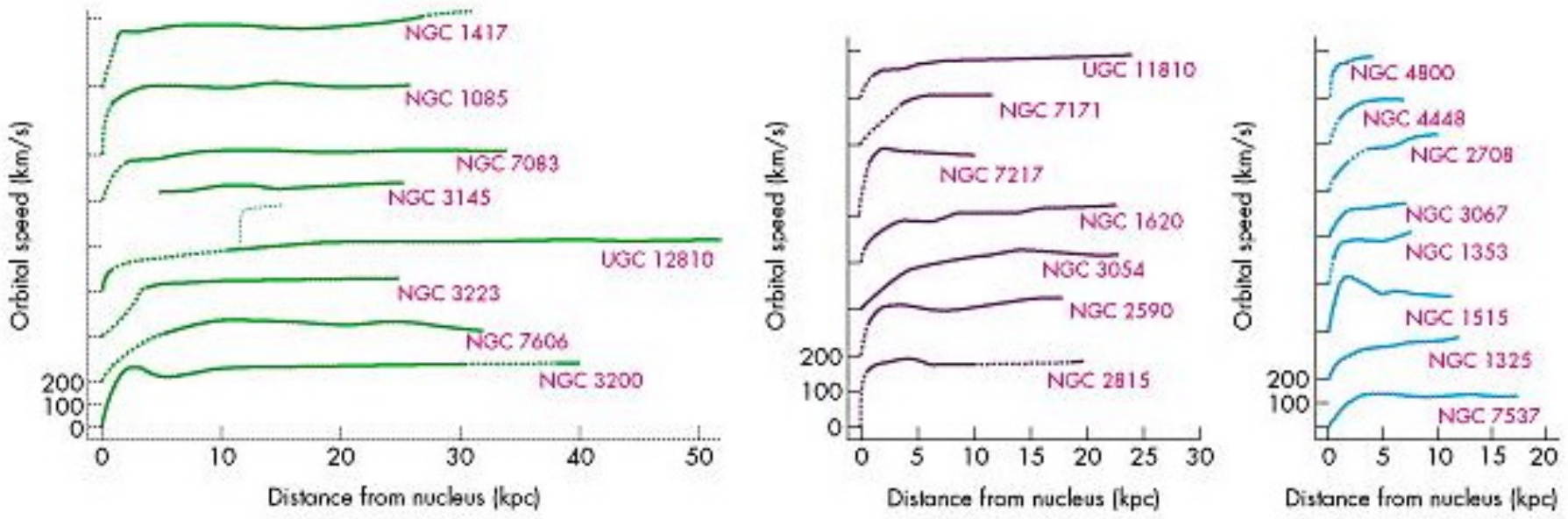
About 100 million LY distant, NGC 474 shows “shells” from past galaxy interactions


GALAXY

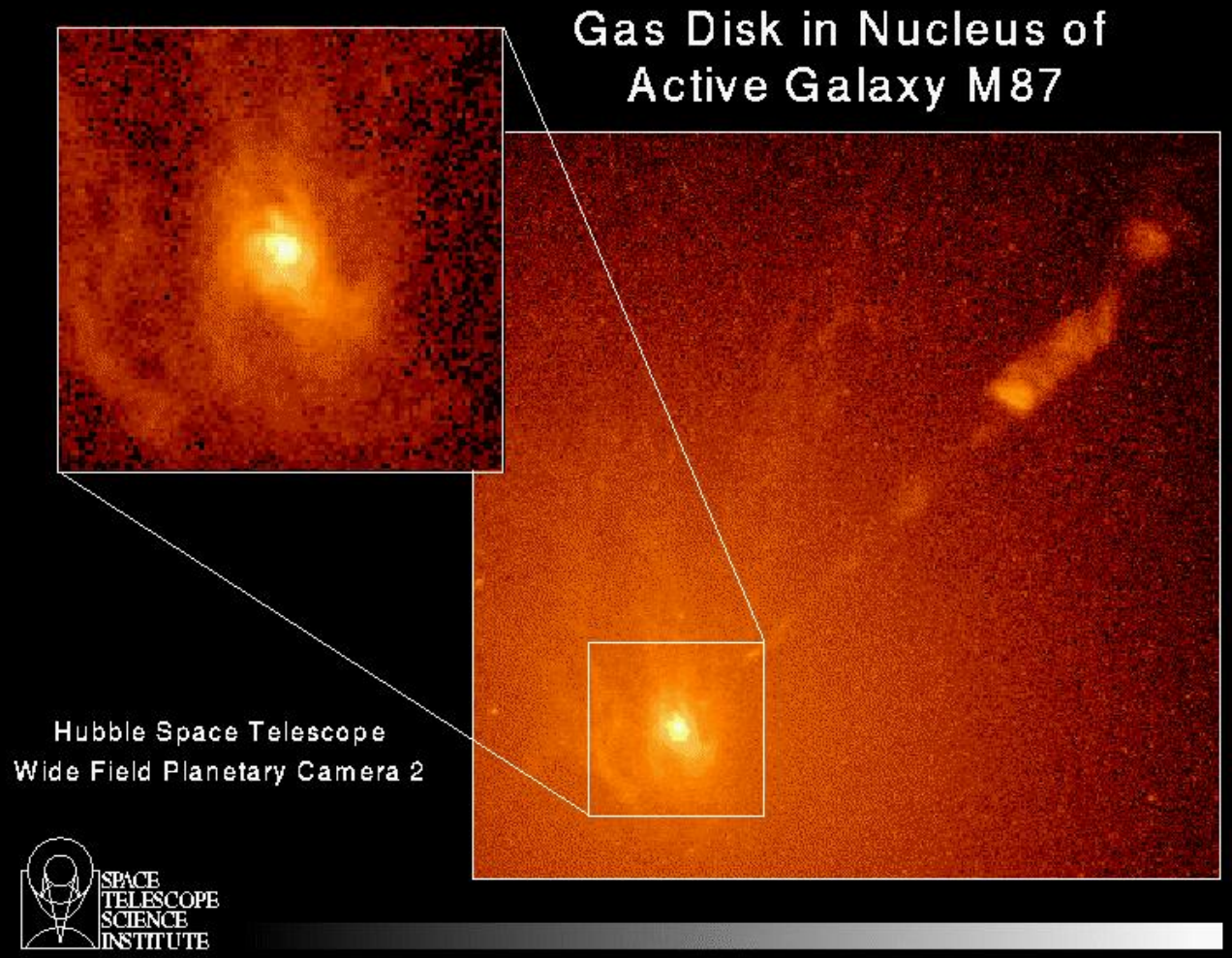
Dark Matter in Galaxies

- Many spirals are observed to have flat rotation curves like the MW
- Many galaxies thought to harbor central SBHs (of 10^6 to 10^9 M_o)
- Ellipticals also appear to possess substantial amounts of dark matter

Rotation Curves of Galaxies

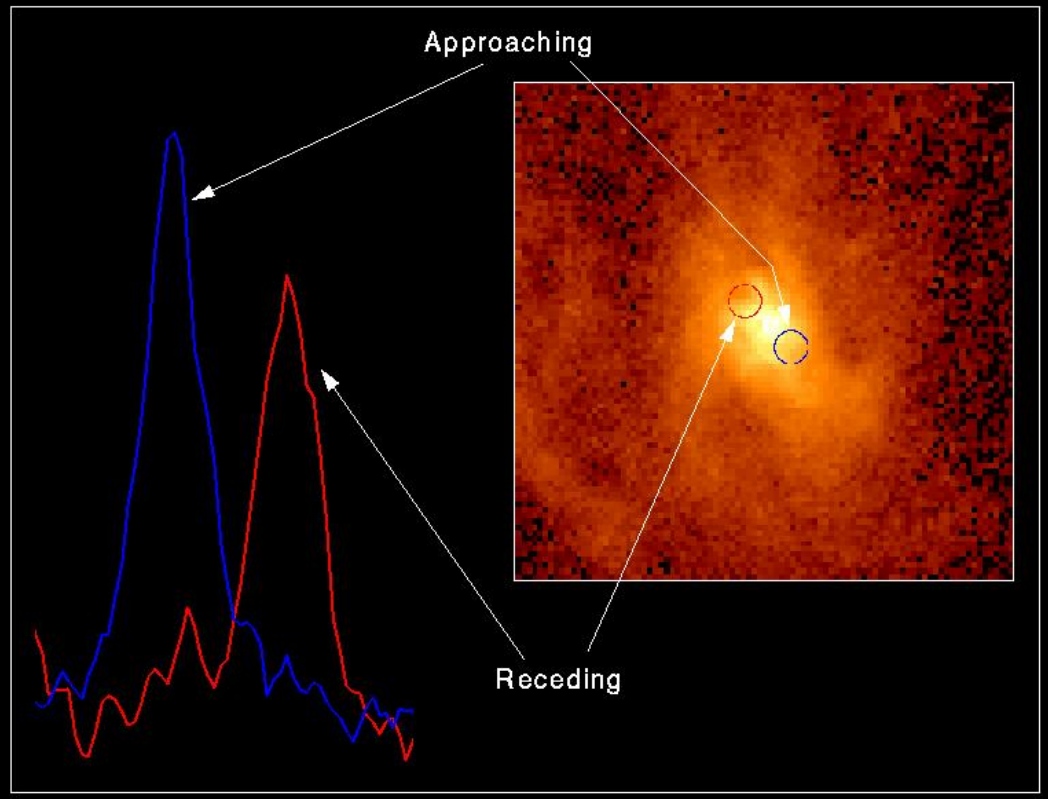


Close-up of M87's Center



M87's Central Black Hole

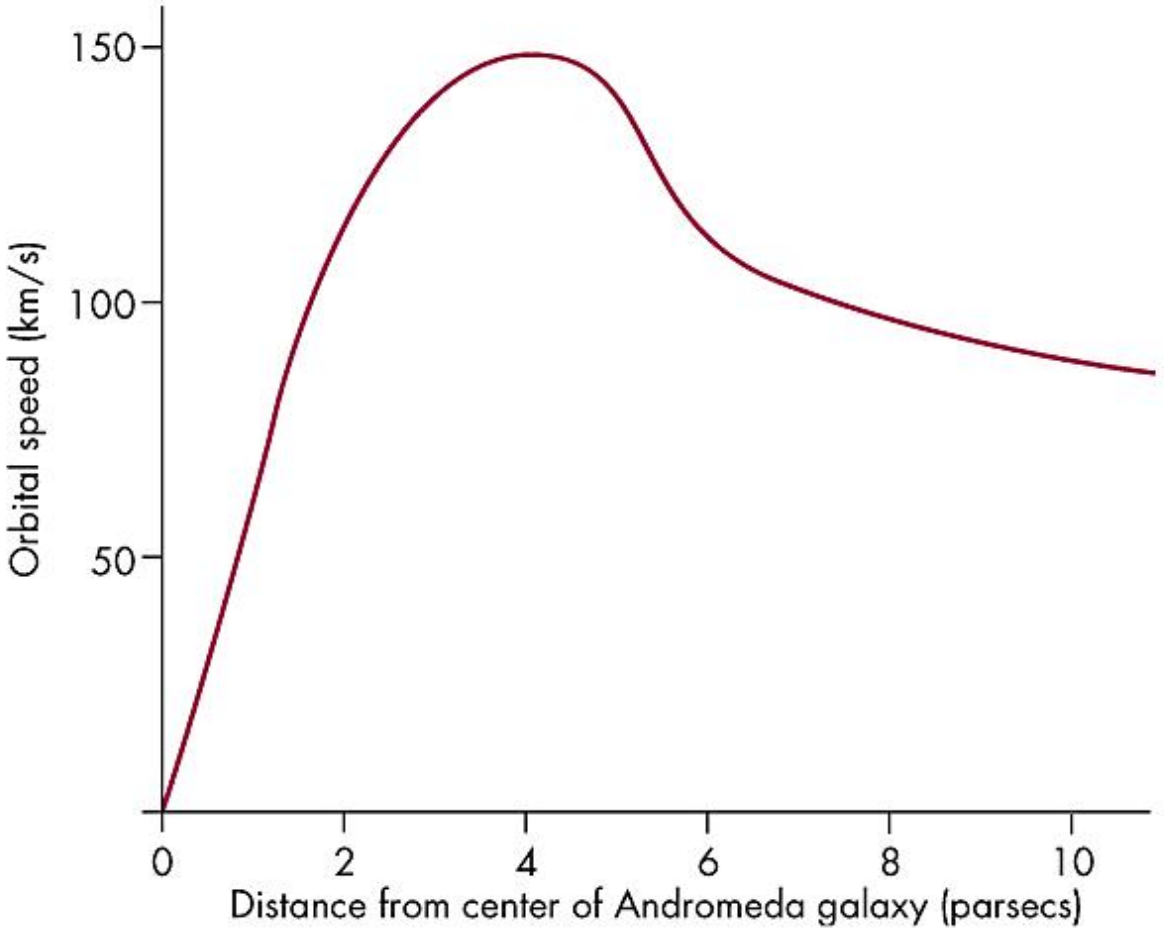
Spectrum of Gas Disk in Active Galaxy M87



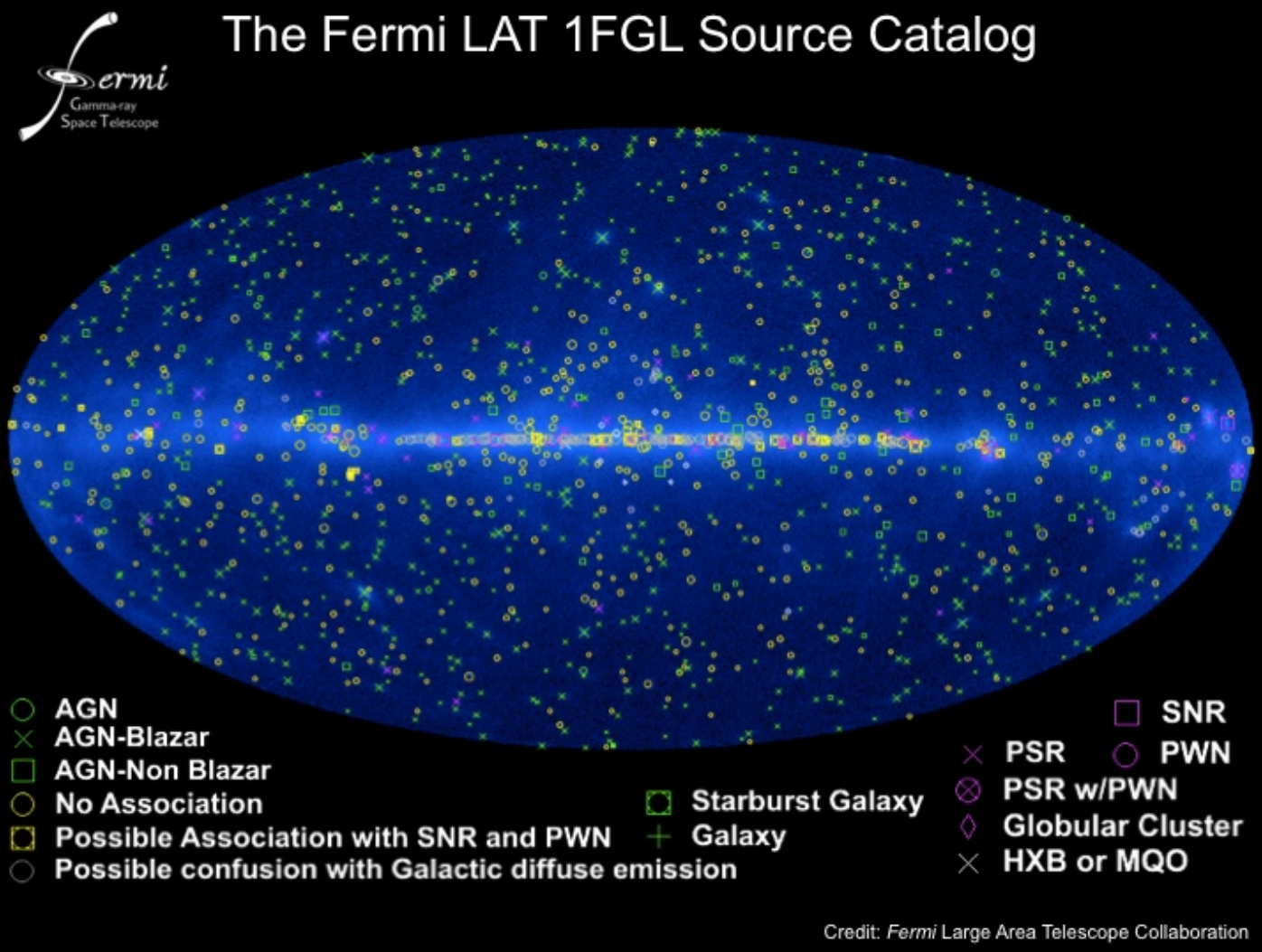
Hubble Space Telescope • Faint Object Spectrograph

SPACE TELESCOPE SCIENCE INSTITUTE

M31's Black Hole



Fermi's Map of the Gamma Ray Sky



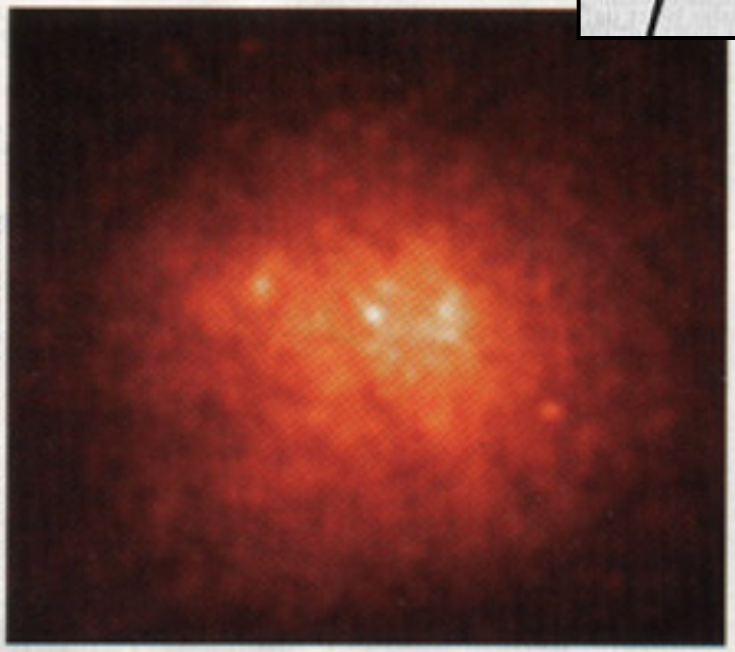
Gamma rays trace the highest energy events

Galaxy Clusters

- Stars come in clusters, and so do galaxies
  - Groups – few big galaxies
  - Clusters – about 1000 galaxies
  - Superclusters – clusters of clusters!
- Apparently even clusters possess dark matter, i.e., in the space between individual galaxies

The Virgo Cluster

The Coma Cluster



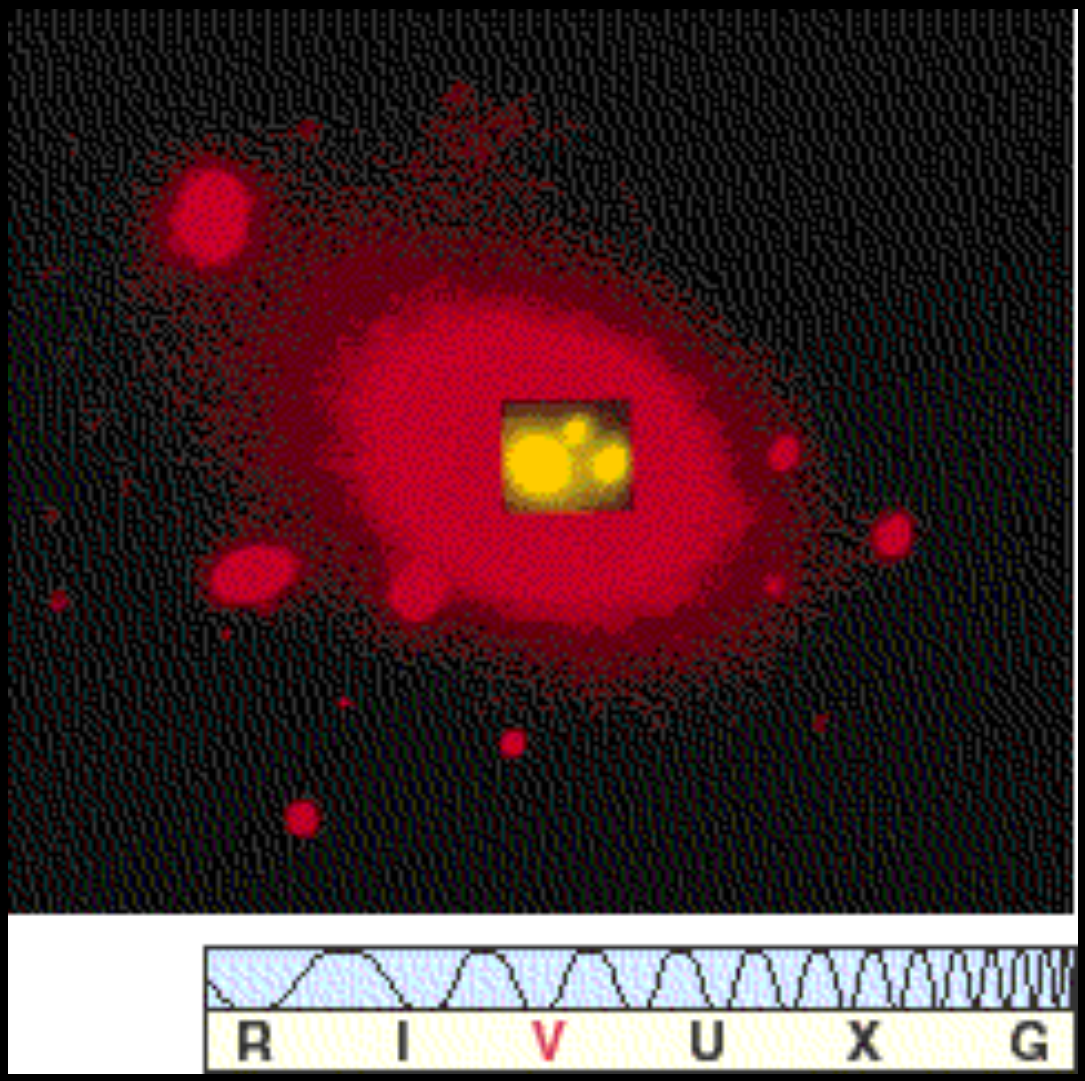
COMA CLUSTER looks different in visible light (*left*) and in x-rays (*right*). In visible light, it appears to be just an assemblage of galaxies. But in x-rays, it is a gargantuan ball of hot gas some five million light-years across.

The confinement of hot gas (right) indicates that dark matter exists even between galaxies!

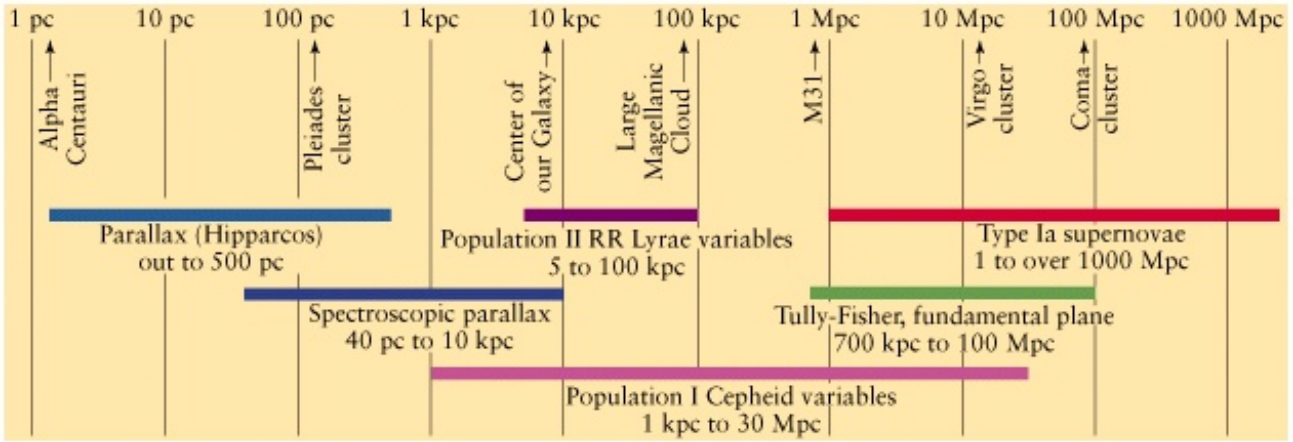
Abell 370

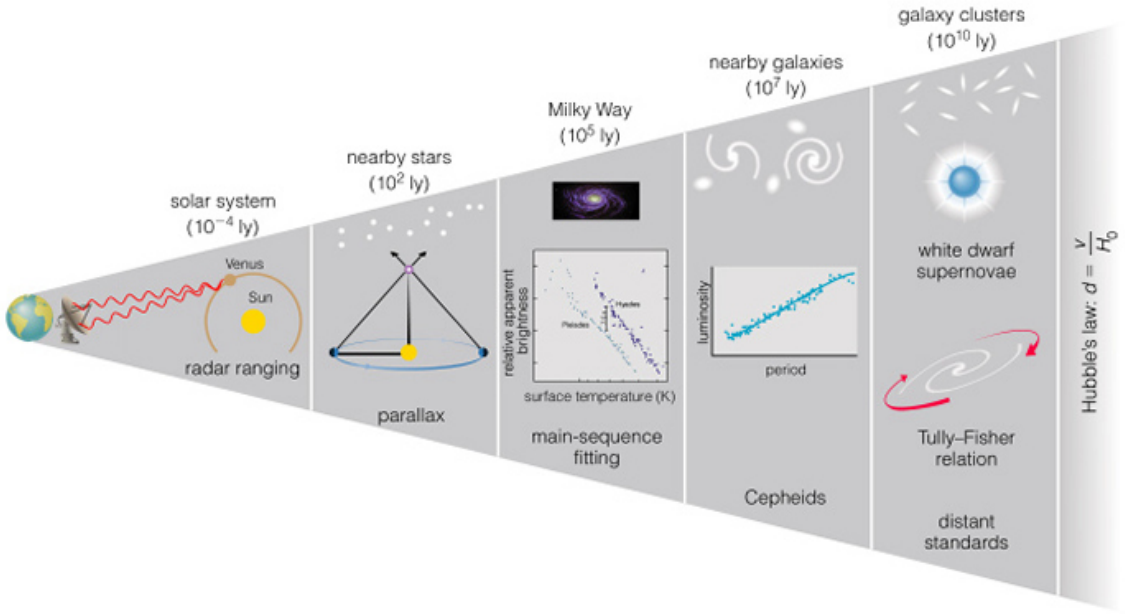
Cluster at 6 GLY distance. Arcs are from gravitational lensing of a more distant galaxy at 13 GLY away.

Galactic Cannibalism: Inside a cD Galaxy

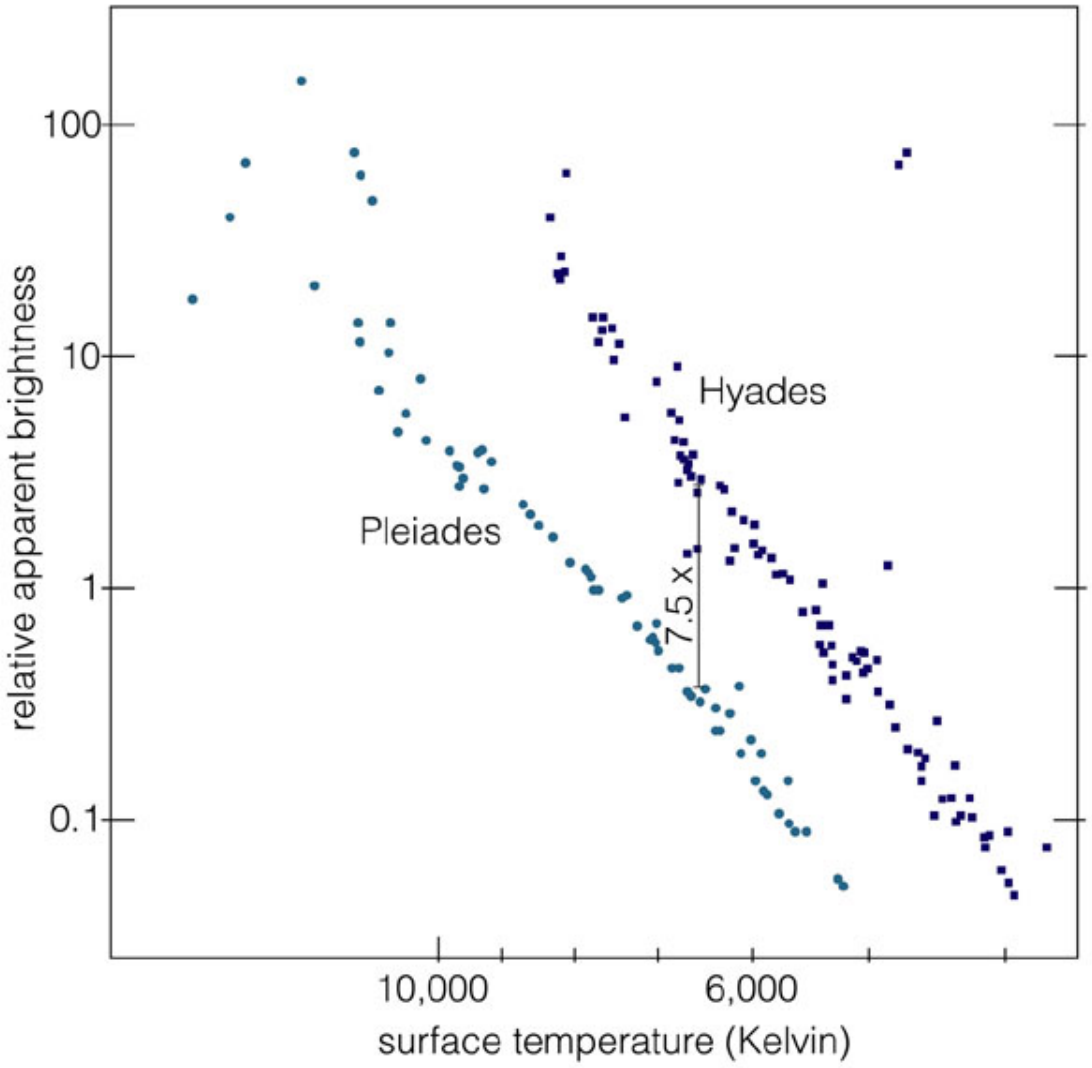


The Distance Ladder

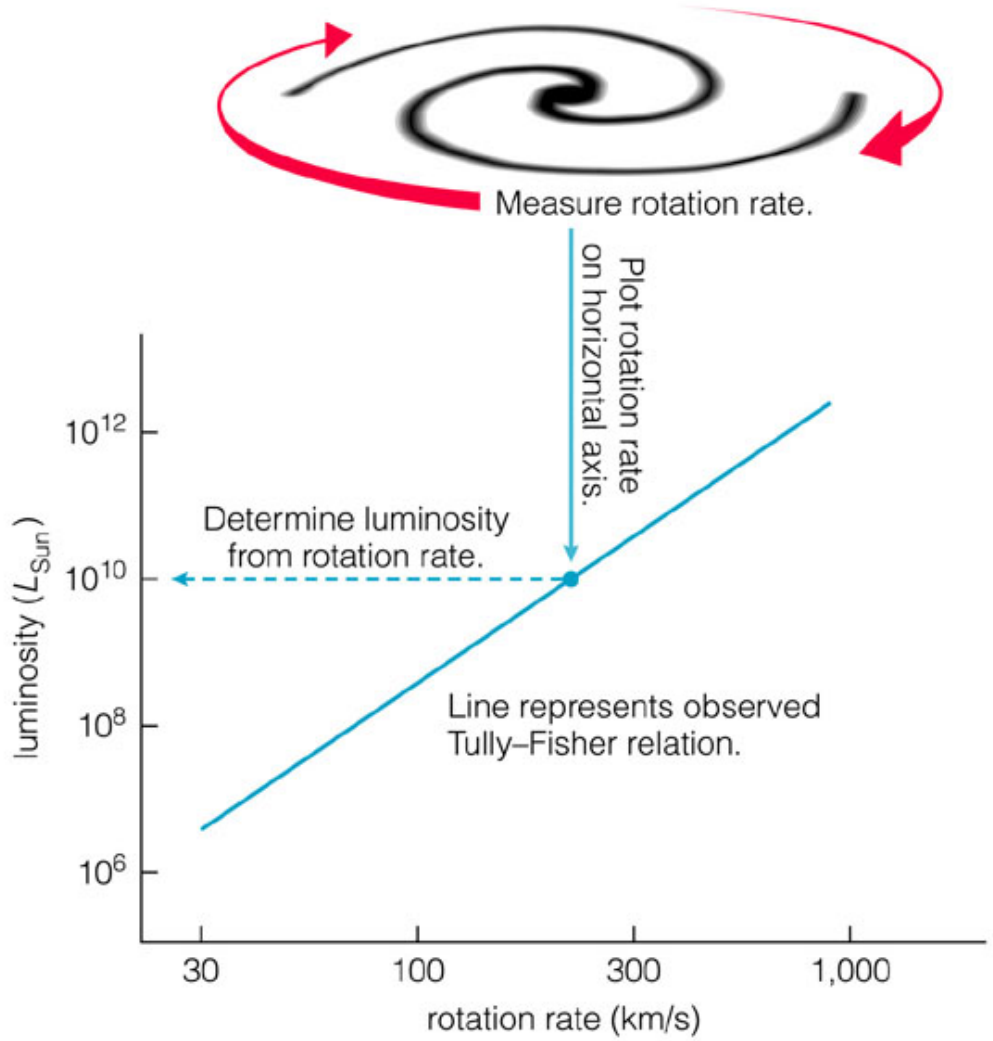




Main Sequence Fitting



The Tully-Fisher Method



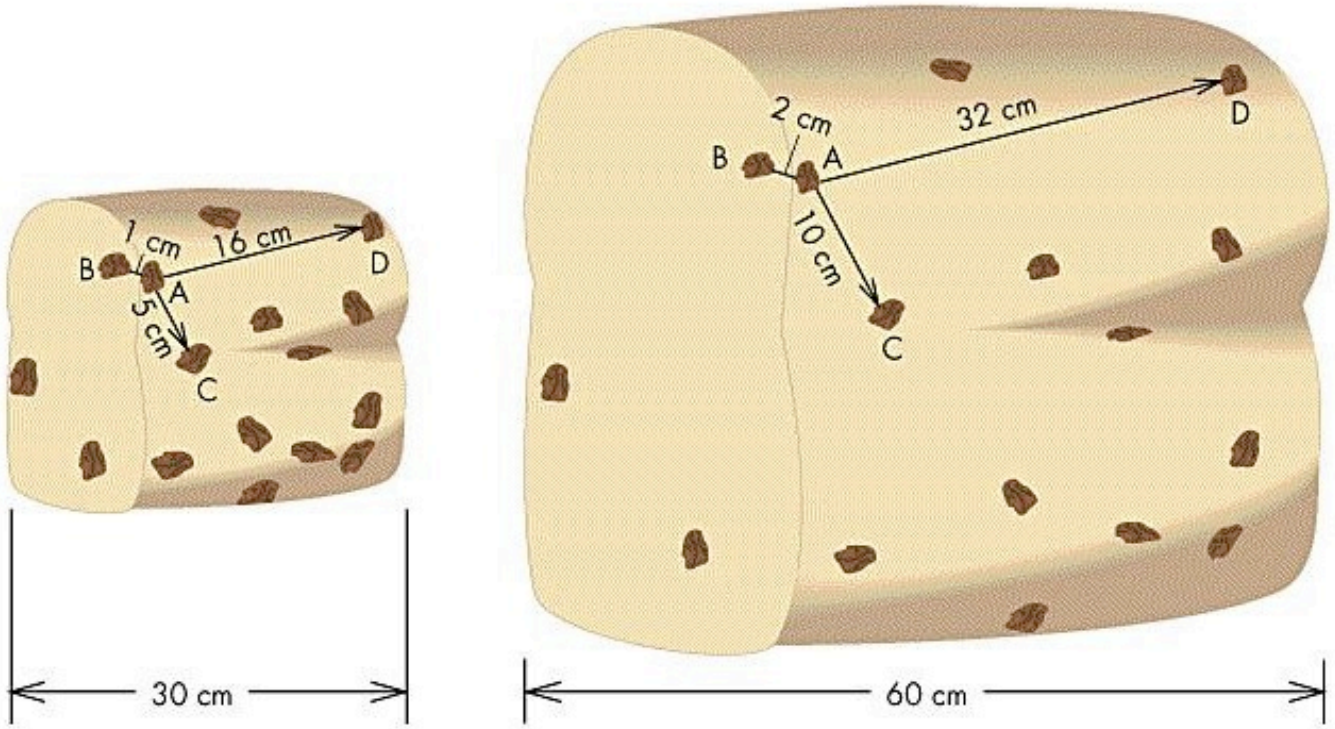
(Edwin) Hubble's Law

- 1868: 1st radial velocity measurement of a star
- 1913: 1st v_r for a galaxy, Slipher measured v_r=300 km/s for the Andromeda gal.
- 1917: Slipher finds that 21 of 25 galaxies show redshifts
- 1929: Hubble discovers that speed of recession is related to distance of galaxy

$$v \propto r$$

Are we are the Center?

- No, neither the Earth nor the Sun nor the Milky Way are at the center of the universe
- Instead, galaxies display redshifts (and the Hubble law) from every vantage throughout the universe



A Raisin bread dough before rising

B Raisin bread dough after rising