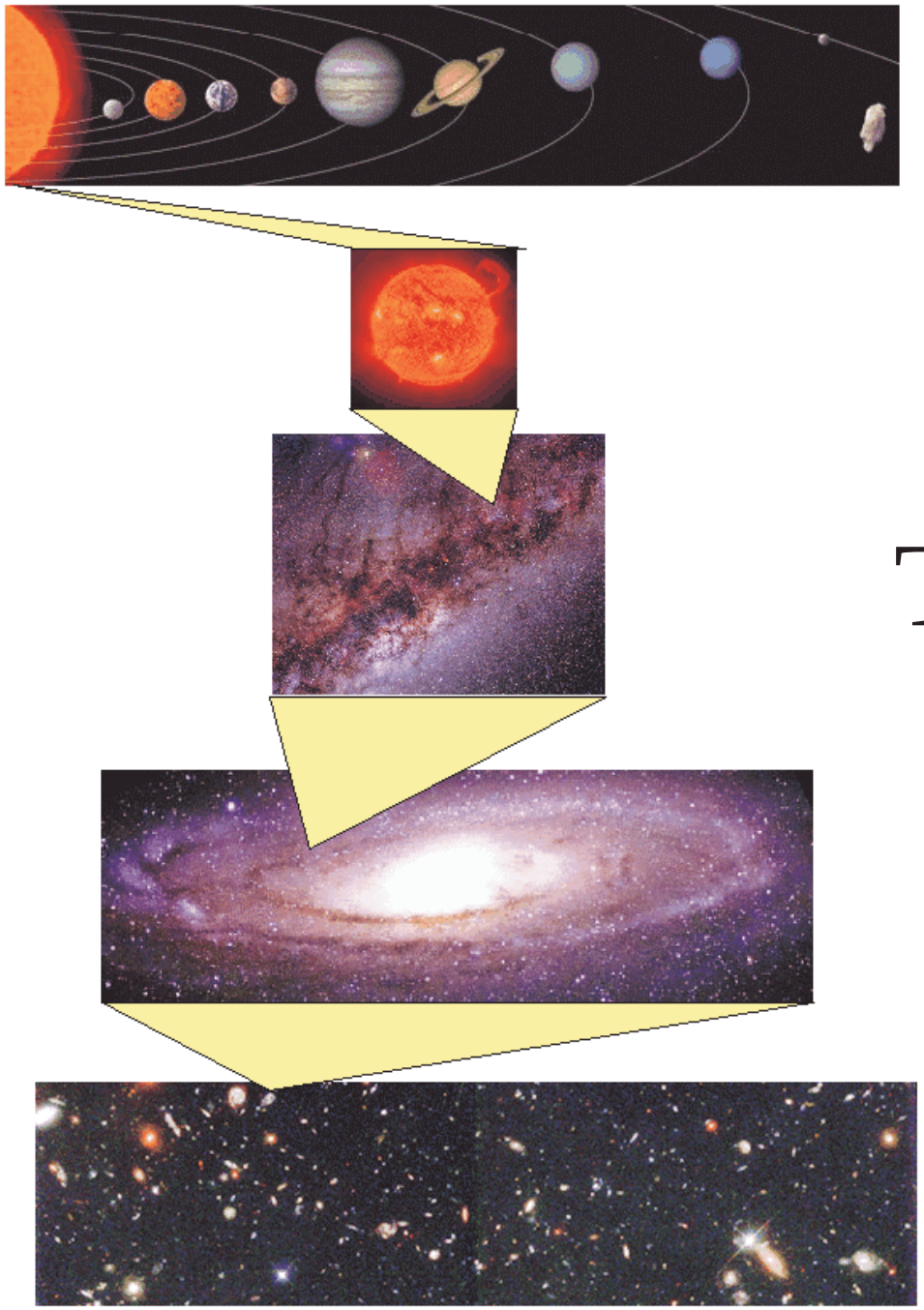
- Homework due on Friday– 11:50 am
- Honor credit– need to have those papers soon!
- Exam 2 Grades are posted.
- THE FINAL IS DECEMBER 15th: 7-10pm!
  - Style…

Outline

- Galaxies are the Fundamental “Ecosystems” of the Universe.
- Hubble’s Classification Scheme.
- Galaxies tend to cluster and supercluster– structures of the Universe.
- The Local Group.
- The Local Cluster.
- Dark Matter in Clusters.
- Collisions
- Hubble’s Law



Astronomy: The Big Picture

Galaxies are the Fundamental "Ecosystems" of the Universe

• The cosmic engines that turn gas into stars and stars back into gas.

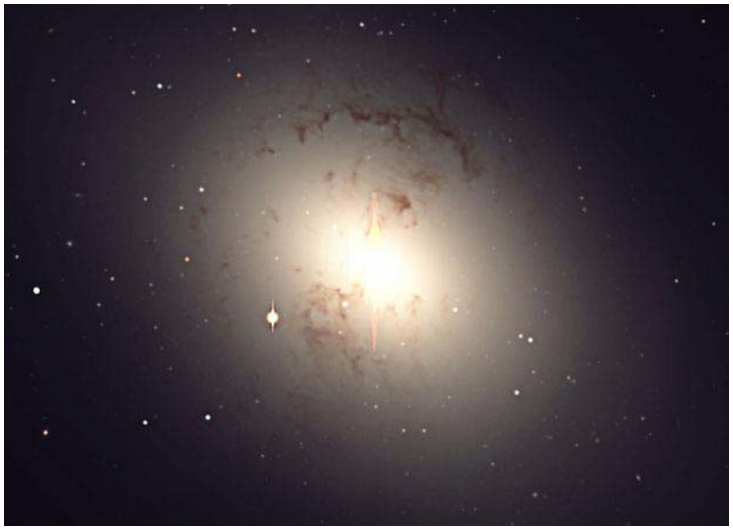
• In between no star formation occurs– "nothing happens" in intergalactic space.

• Are recently discovered (by Edwin Hubble in late 1920's)

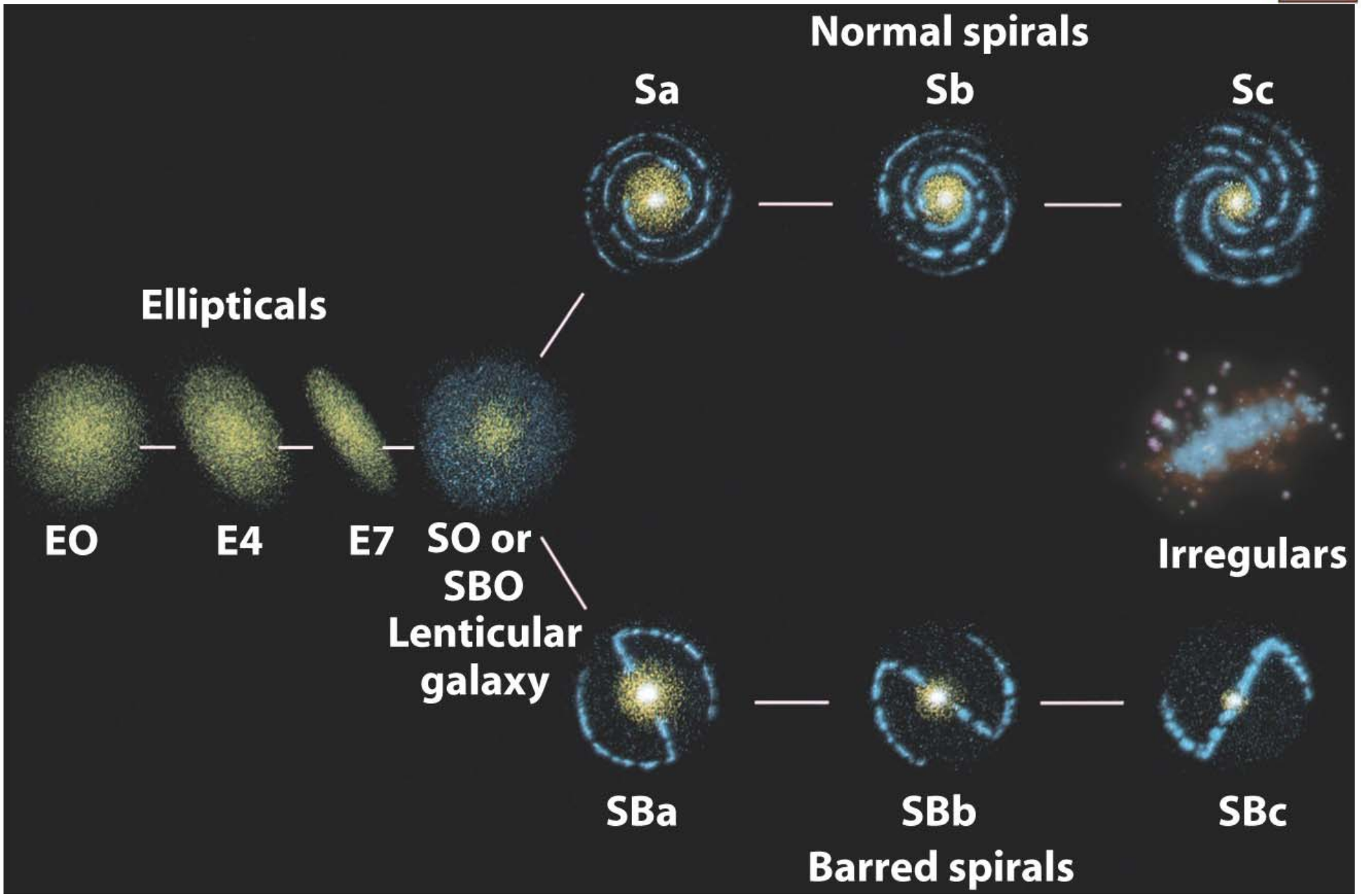
• Can be classified by morphology (shapes and sizes).

Types of Galaxies

- Spiral: < 20%
- Barred Spiral: > 57%
- Elliptical: >20%
- Irregular: < 3%



Hubble's Tuning Fork Diagram



Galaxies Are not Alone

- Galaxies are not scattered randomly throughout the Universe
- Galaxies are found in ***clusters***
  - The Milky Way is part of the *Local Group* of about 40 galaxies
- Clusters of galaxies are clustered as well in groups called ***superclusters***
  - Our Local Group is part of the *Local Supercluster*
- The majority of space is empty - called ***voids***.

The Local Group of Galaxies

Milky Way

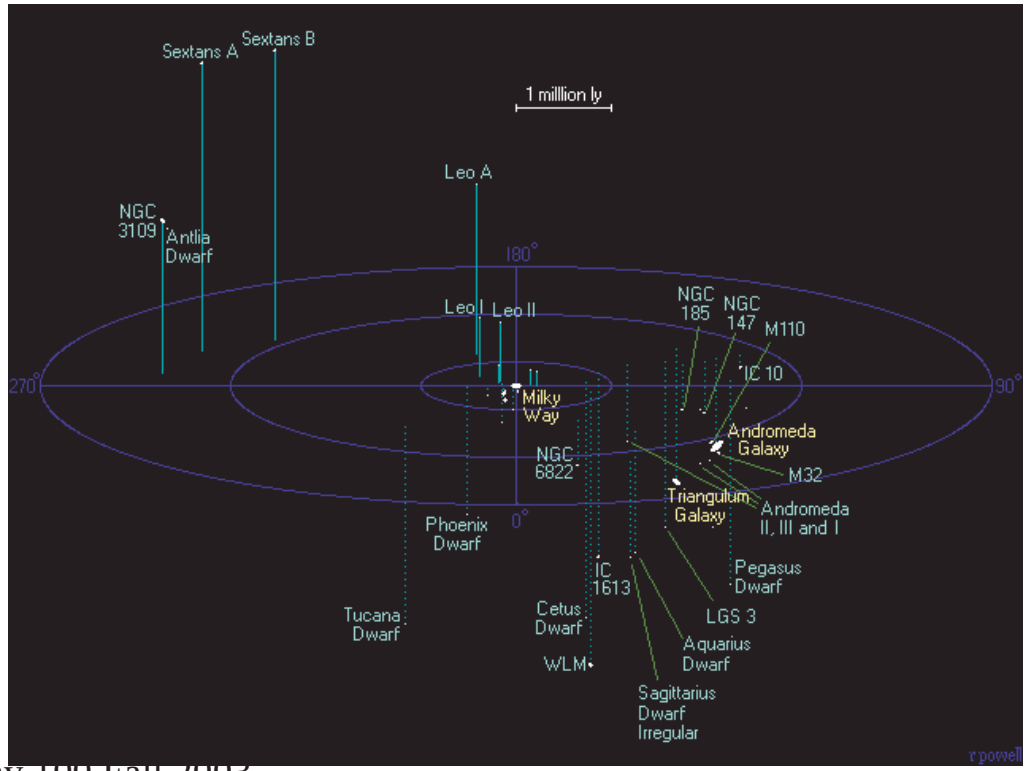
About 40 galaxies– a poor cluster.

Triangulum (M33)

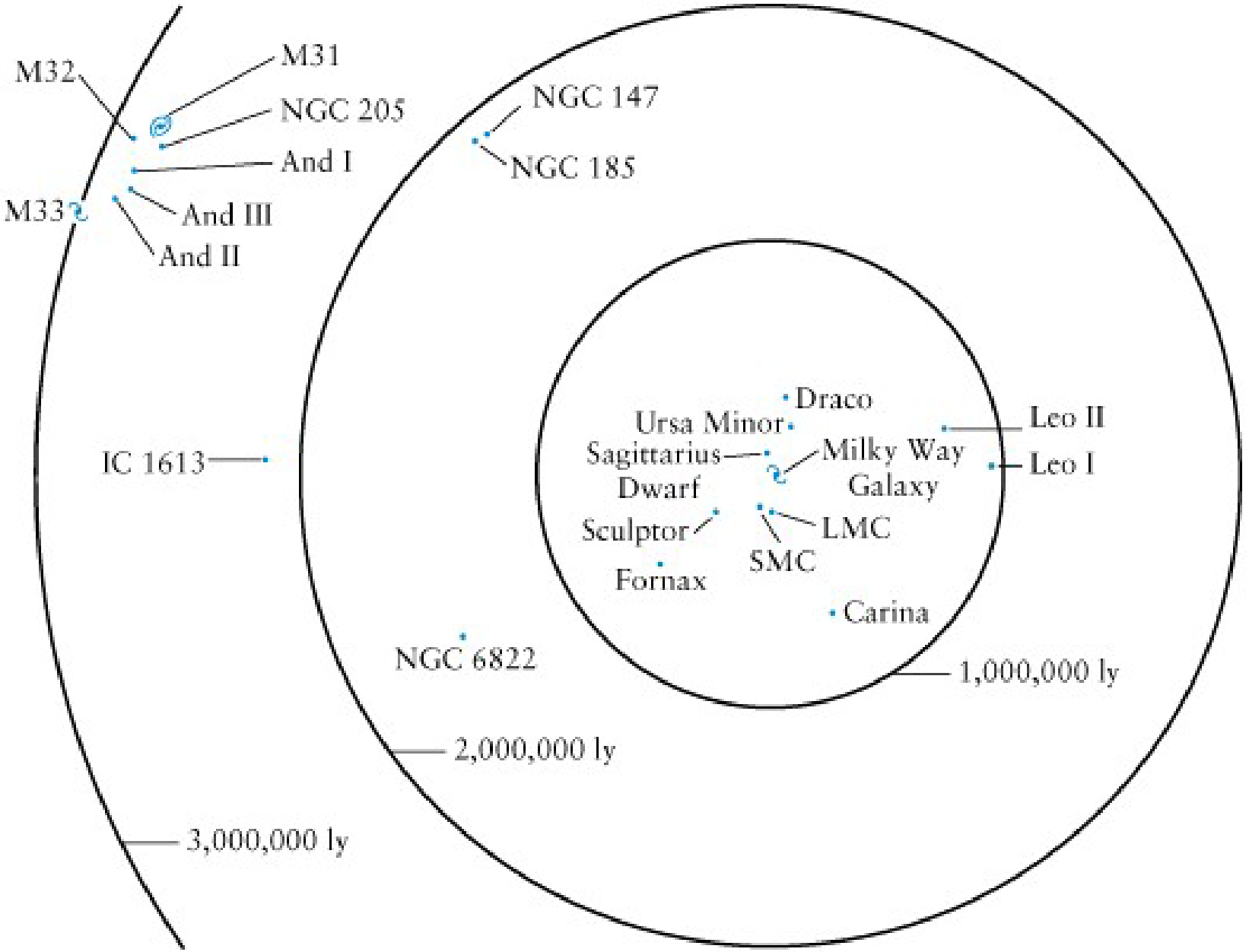
Local Group Dwarf galaxies

0.7 Mpc

Andromeda (M31)

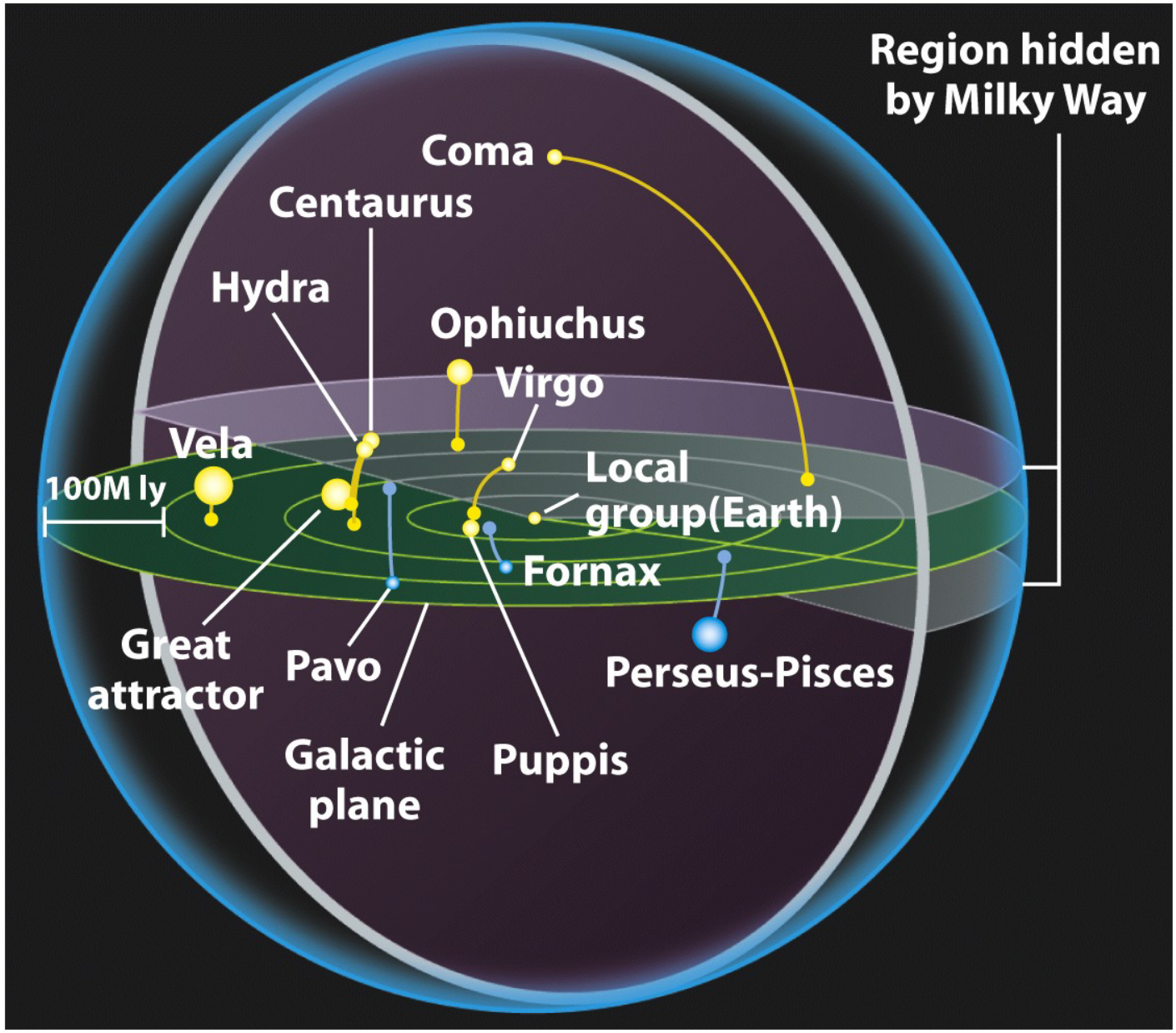


The Local Group of Galaxies



The Local Galaxy Clusters

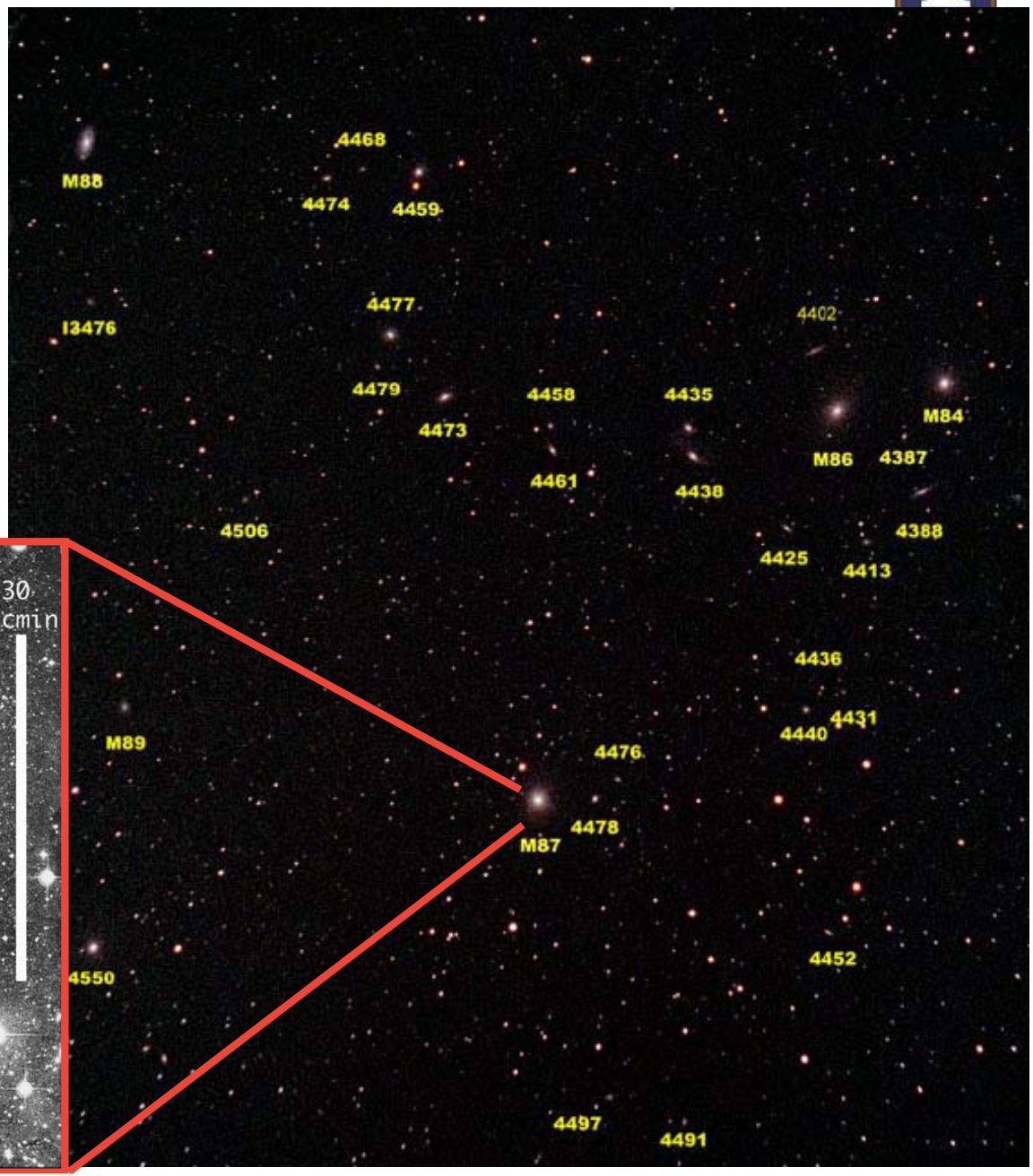
- 800 Mly sphere, centered on the Earth
- Galaxies live in clumps called clusters, which are in clumps called superclusters



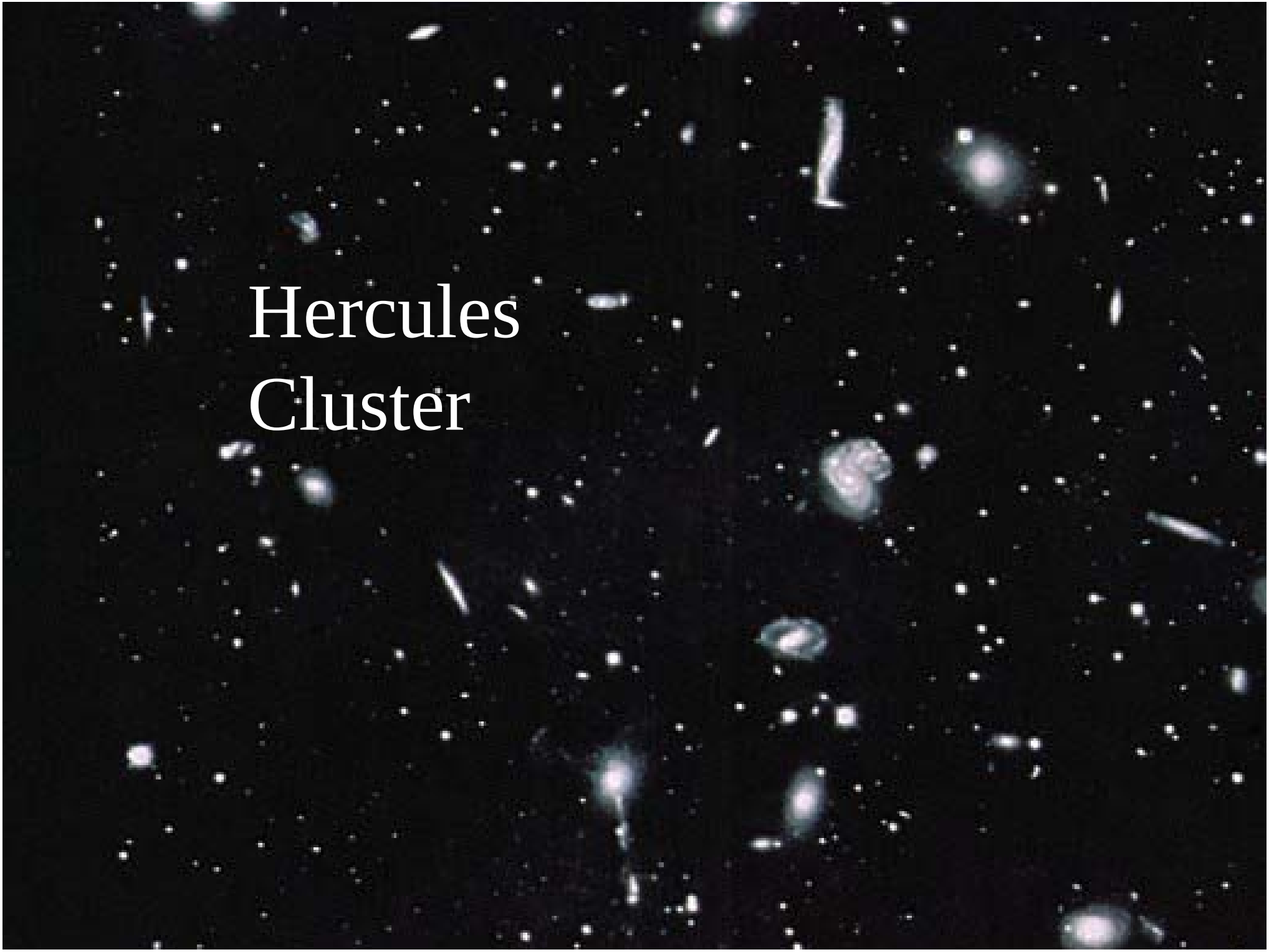

Virgo Cluster

The Virgo Cluster

- Part of our supercluster
- More than 2000 galaxies
- 15 Mpc away from us
- Bigger than 1 Mpc in size
- Our cluster is headed right for it.

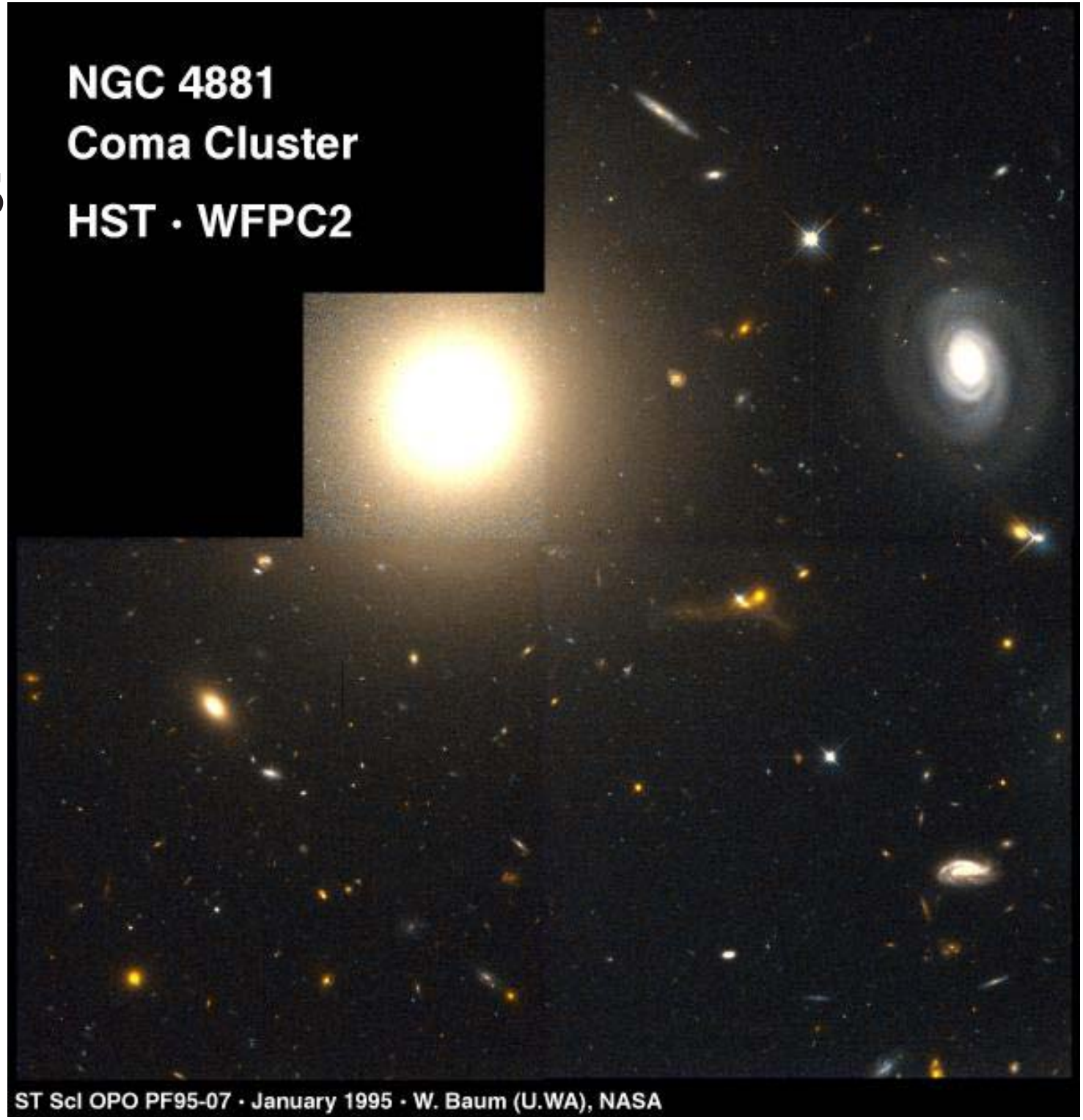



Fornax Cluster


Hercules
Cluster

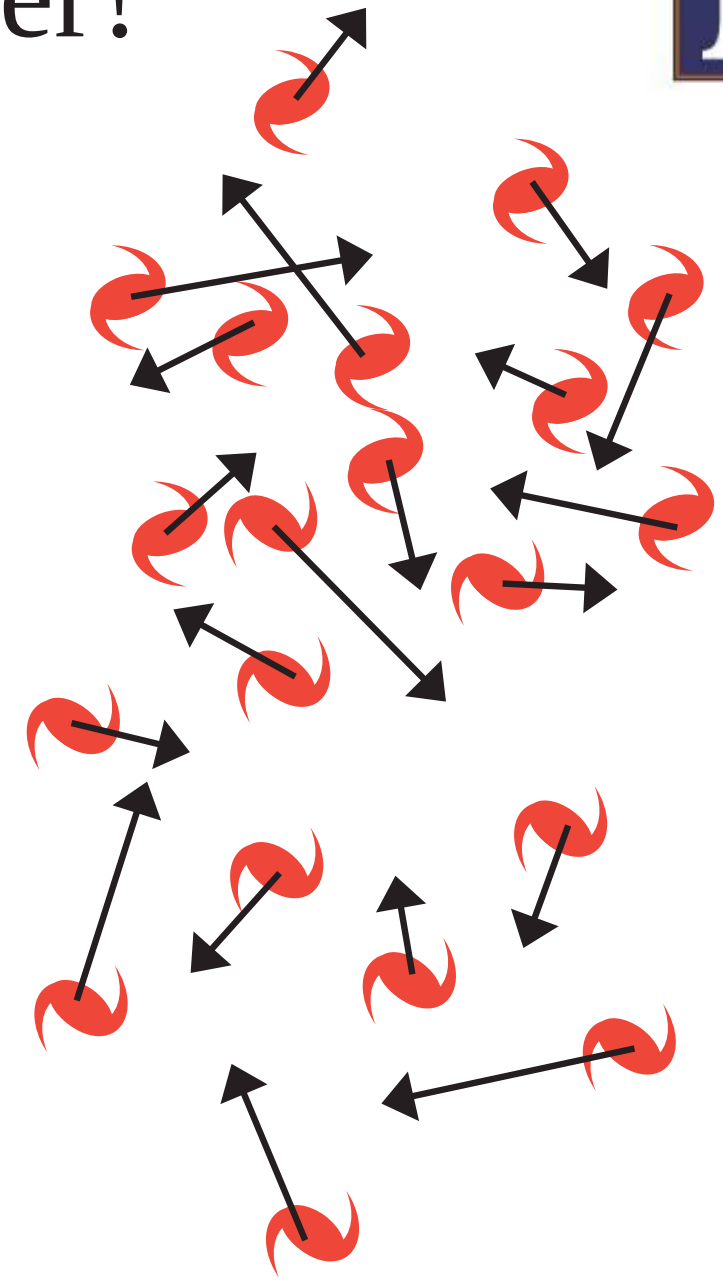
Giant Ellipticals

- Often 1 or 2 in a large cluster
- More ellipticals in general in clusters.
- Grow by accretion.
- How are they formed?
- Nature or Nurture?

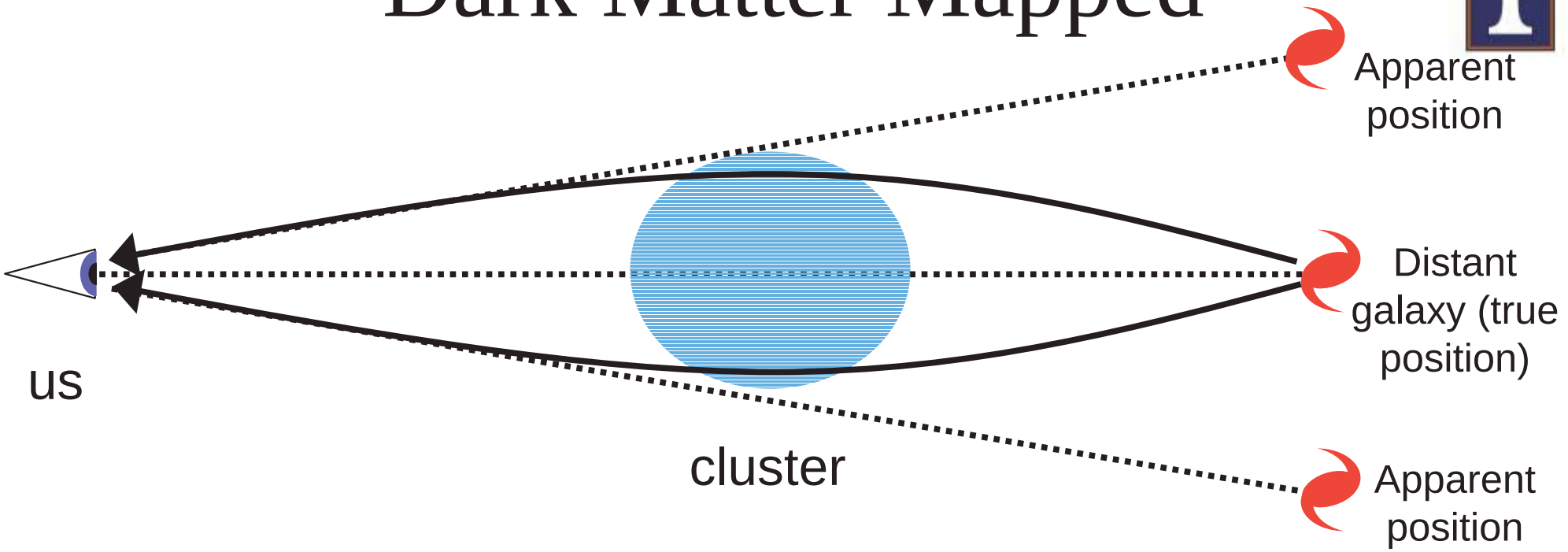


Dark Matter?

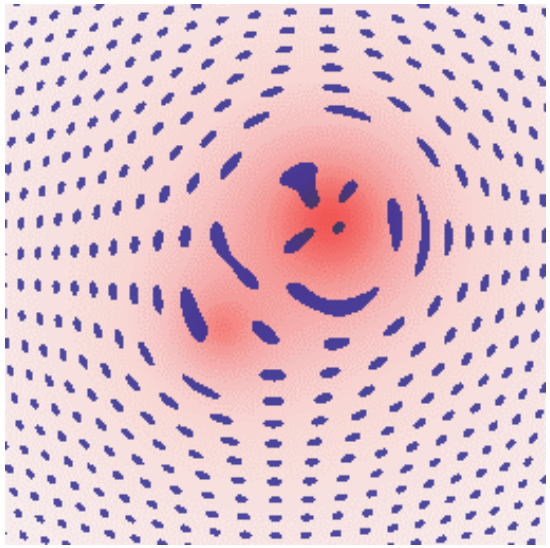
- If the clusters only have the visible mass in the cluster, then the cluster should dissipate.
- Not enough mass to hold the cluster together.
- Visible matter must only be about 1% of the total mass.
- Dark Matter.



Dark Matter Mapped



- Mass causes gravity lensing.
- Can use the warping of light to estimate the mass distribution in the cluster.



N. Wright (UCLA)

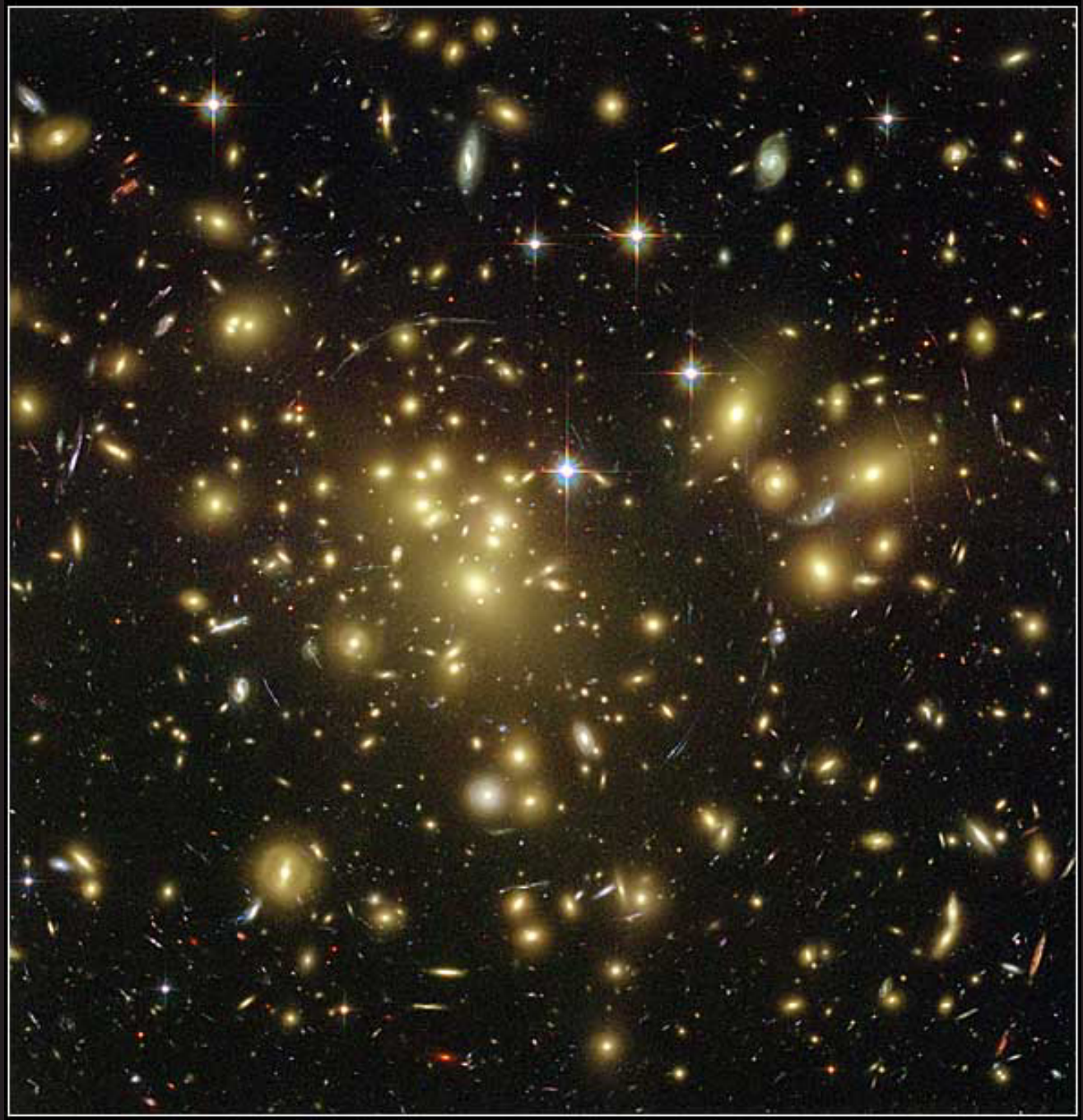
Gravitational Lens
Galaxy Cluster 0024+1654

HST • WFPC2

PRC96-10 · ST ScI OPO · April 24, 1996

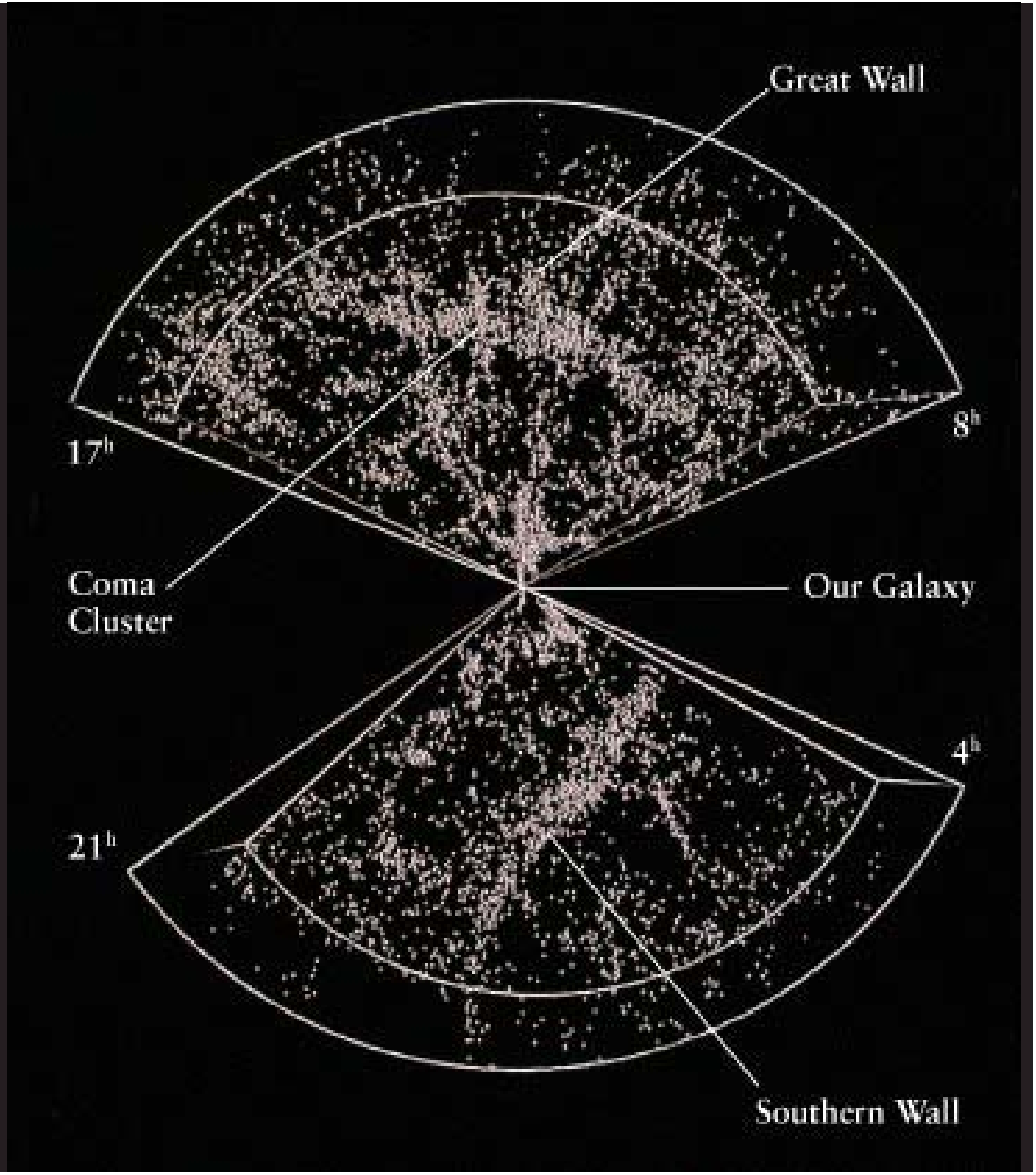
W.N. Colley (Princeton University), E. Turner (Princeton University),
J.A. Tyson (AT&T Bell Labs) and NASA

Galaxy Cluster Abell 1689 **HST ▪ ACS**



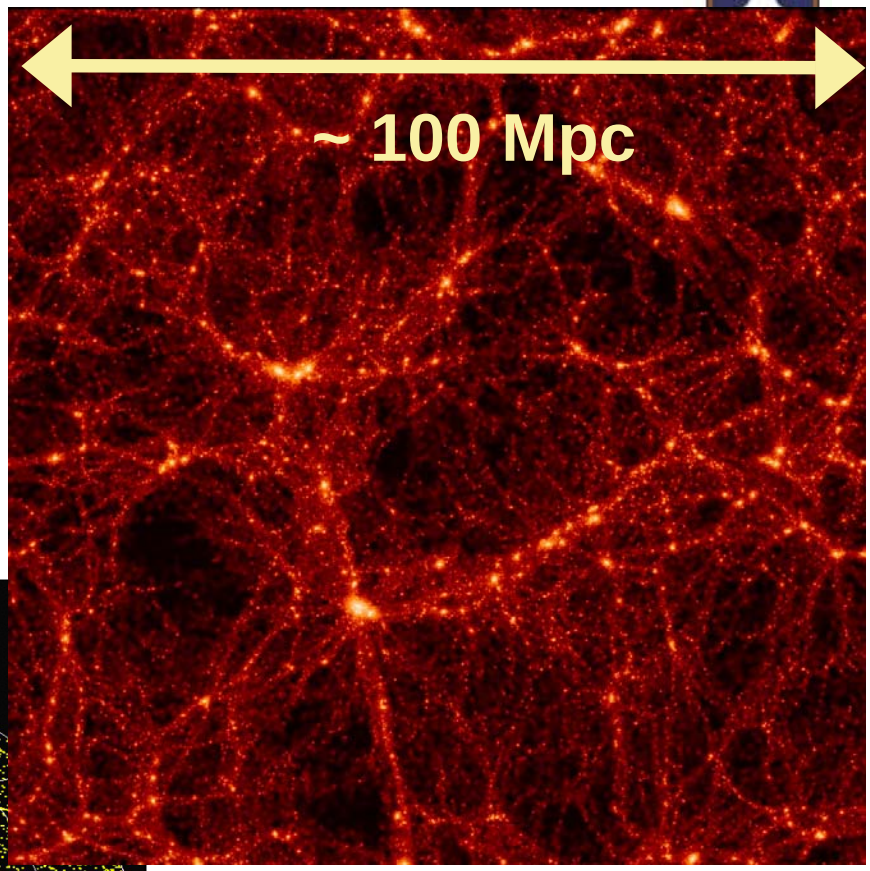
NASA, N. Benitez (JHU), T. Broadhurst (Hebrew Univ.), H. Ford (JHU),
M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory),
the ACS Science Team and ESA STScI-PRC03-01a

Each dot represents a single galaxy

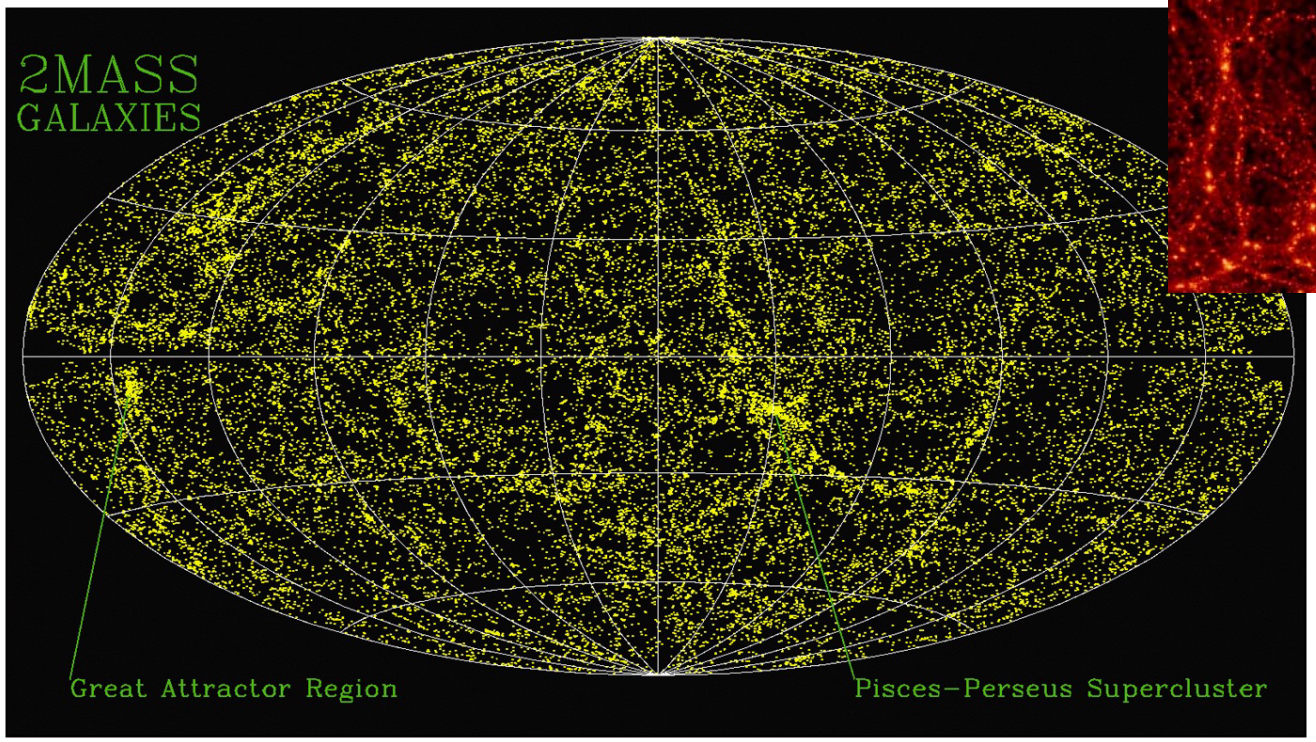


Structure of Universe

- Superclusters are distributed in Universe.
- Filamentary structure.
- Voids of nothing between them.

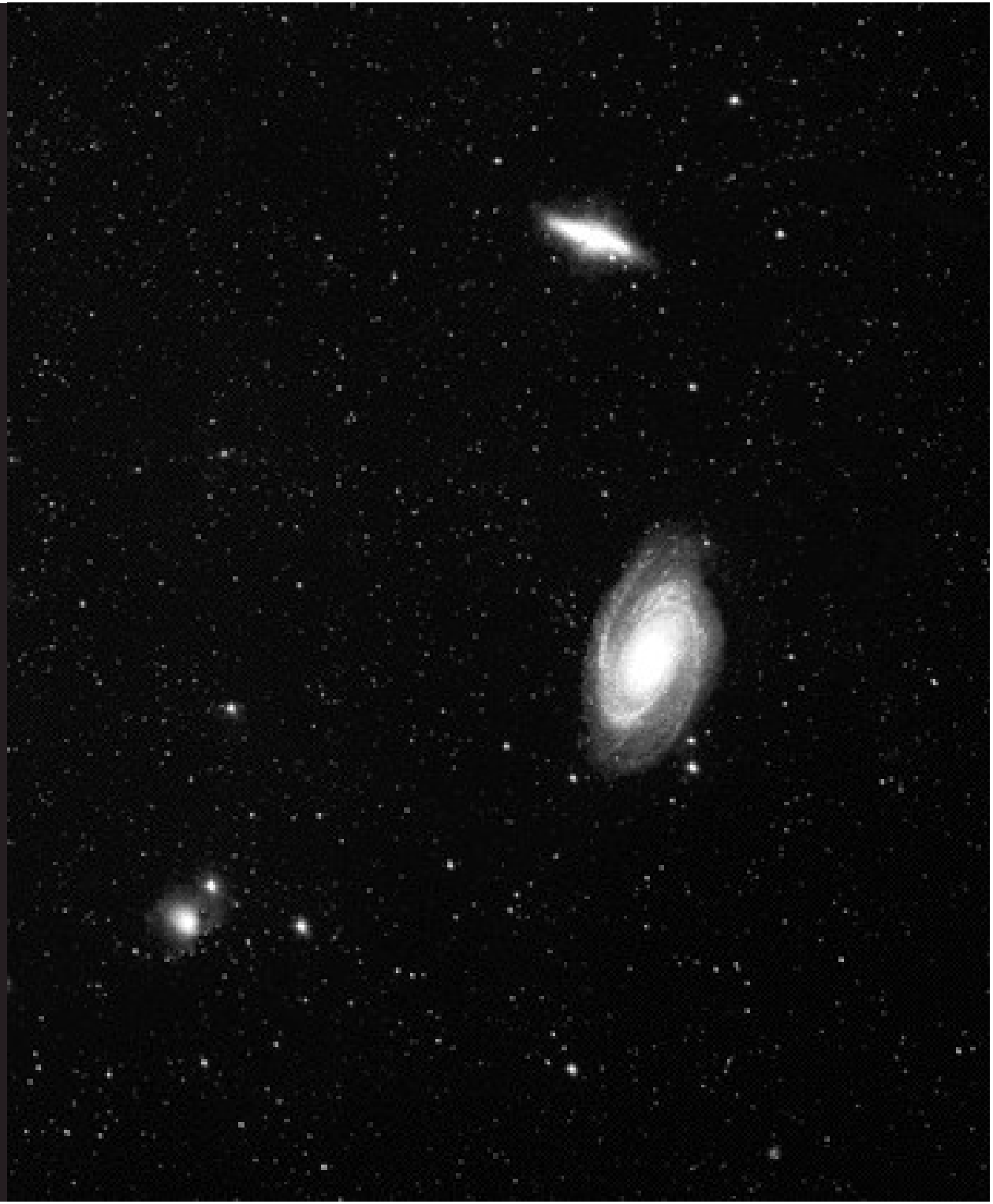


Computer simulation (A. Jenkins)

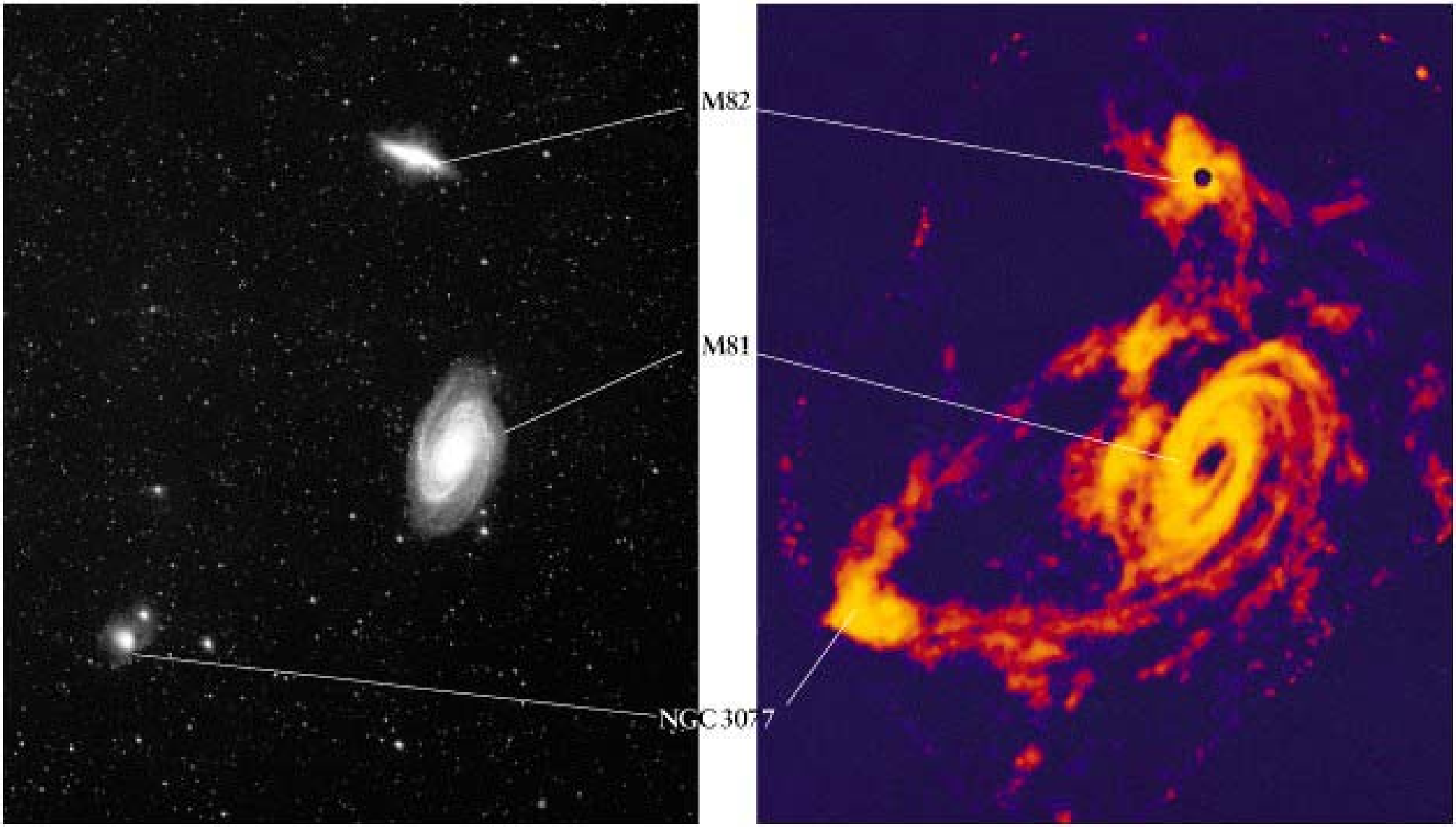


Three galaxies, M81 (big), M82 (medium), and NGC 3077 (small).

Are they related to one another?



Collisions



Galaxies Collide

NGC 2207 &
IC 2163

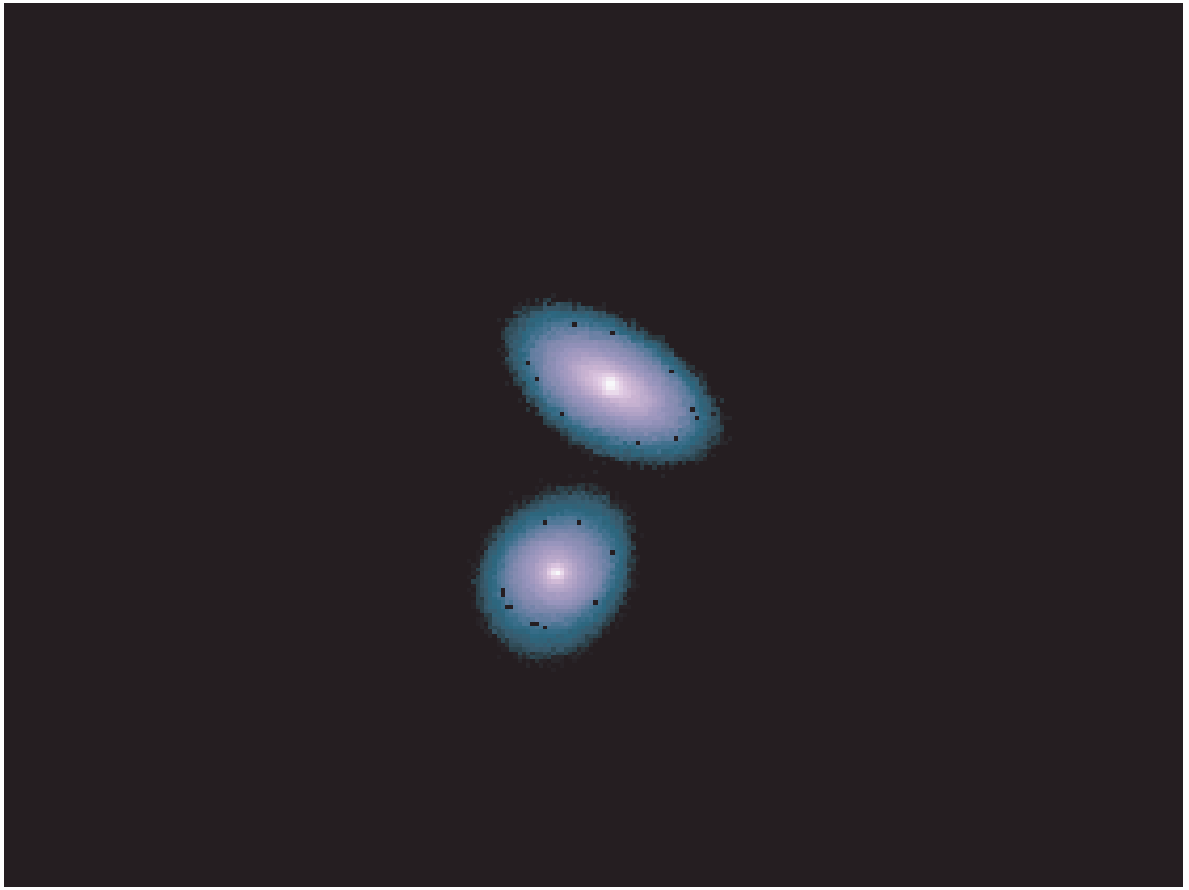
NGC 7676
“The Mice”

Collisions

- They do not involve colliding stars– but rather gravitational fields
- Might form hot intergalactic gas
- Could initiate rapid star formation - called *Starburst Galaxies*
- Collision causes stars to be scattered into “tails”
- Causes galaxy mergers called “galactic cannibalism”

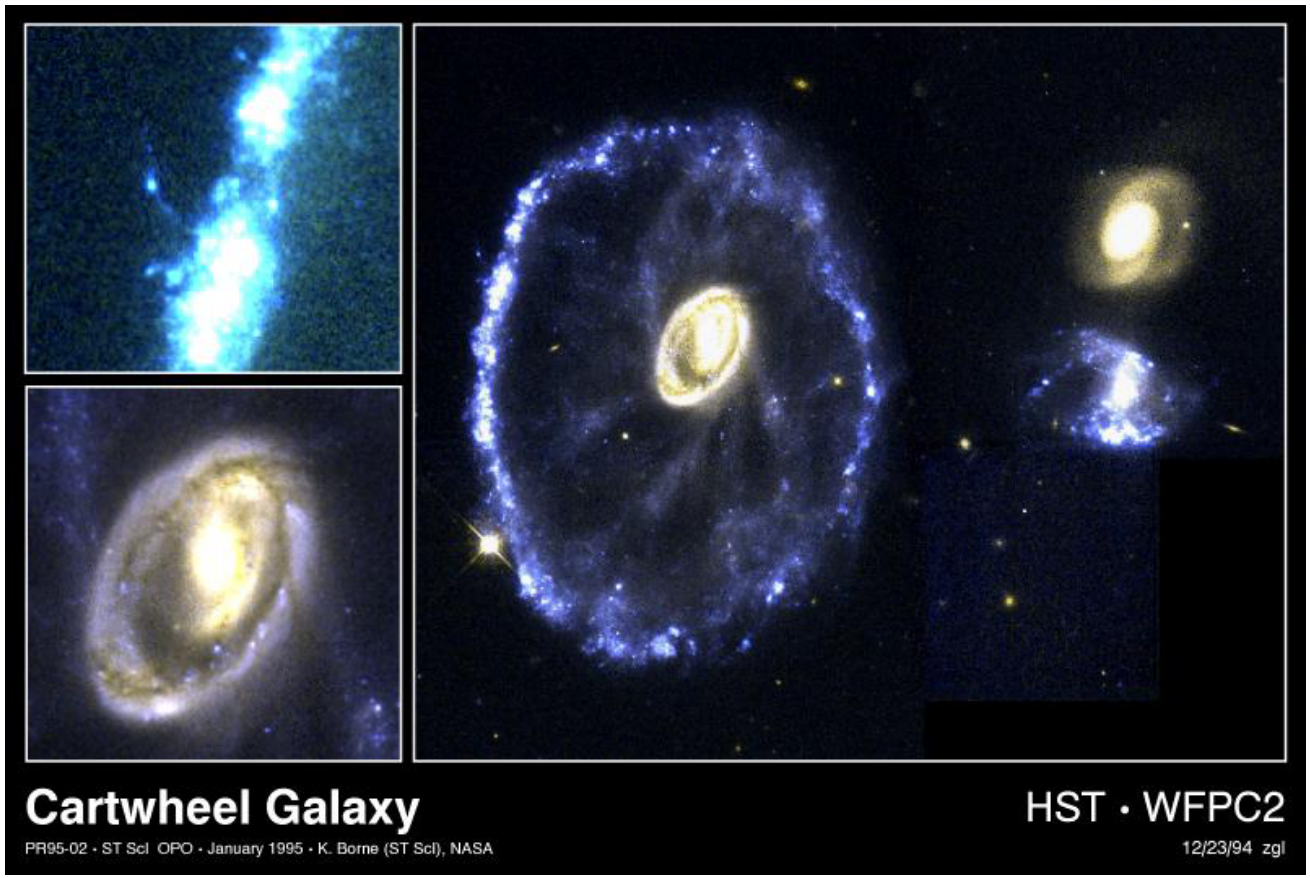
Galaxy Collisions

Computer simulation of two galaxies colliding by John Dubinski and Lars Hernquist



Starburst Galaxies

- Galaxies with enhanced rates of star formation
- Usually forming massive stars for a short period (few Myr).
- Probably due to collisions



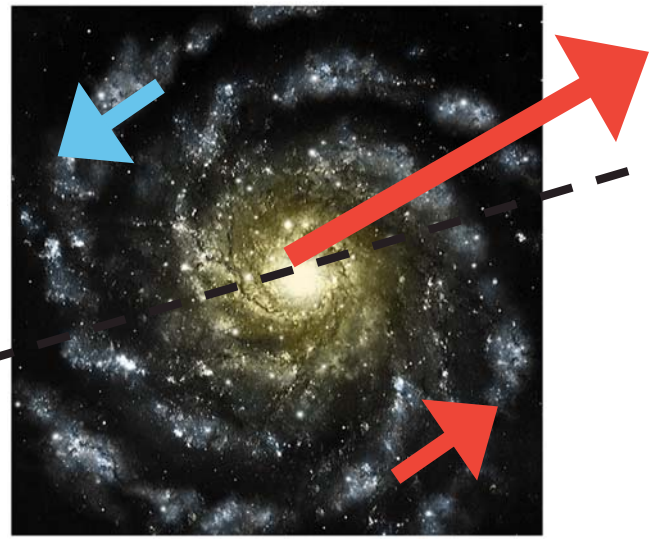
How are Galaxies Moving?

It's 1928, and Edwin Hubble is measuring how galaxies move. What does he find?

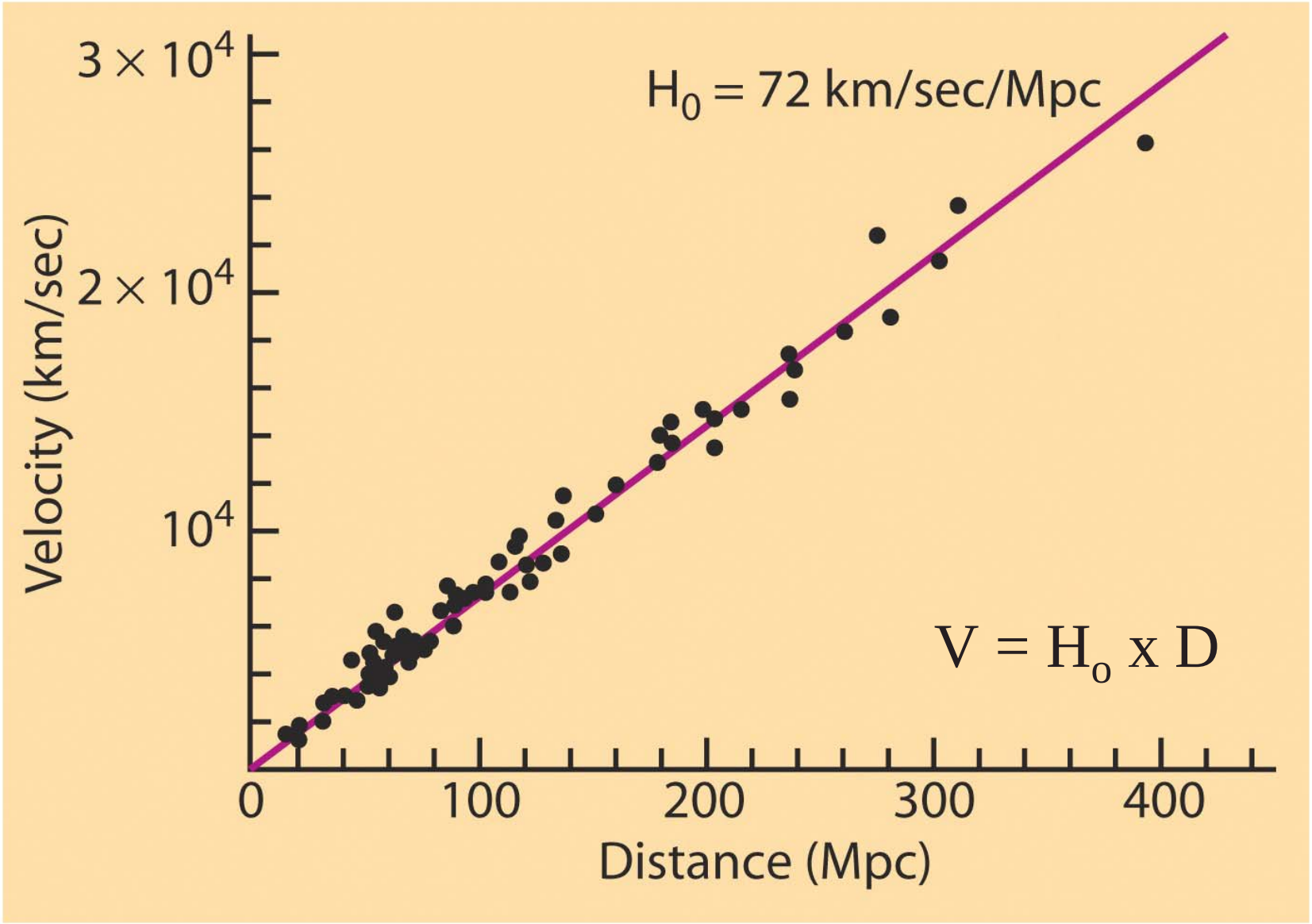
a) More galaxies receding than approaching.
b) More galaxies approaching than receding.
c) About equal numbers of each.

Run Away

- Most Galaxies are moving away from us.
  - Did you bathe today?
- The farther away, the faster they are moving away.
- Or $V \propto D$
- The overall spectrum is the sum of all the emission.
- The rotation speeds are small wrt recession speed



Hubble's Law


H_0 = 72 km/sec/Mpc
$V = H_o$ x D
Velocity (km/sec)
3×10^4
2×10^4
10^4
0
100
200
300
400
Distance (Mpc)