Killer Skies

- **Homework 10** due Dec 2nd (Monday after break)
- Solar Obs due Friday
- Moon report due Dec 2nd
- Last time: Dark Matter
- Today: Galaxies

Music: *Glorious Dawn* – Colorpulse

Iclickers

- 4 students have STILL not registered their iclickers!
- This is a problem
- Fix it!

Galaxies

Back to the idea of galaxies…

The Milky Way Galaxy (not a surprise) is not special.

There are other galaxies out there.

"Spiral Nebulae"

All stars you can see by eye or with small telescopes are in Milky Way

- as are stellar remains:

  white dwarfs, neutron stars, black holes and planetary nebulae

But by 1800's, other dim, diffuse "nebulae" seen

- with spiral patterns
- Spiral structures catalogued mid-1800s by Lord Rosse (Ireland)

Modern M51 picture

"Leviathan"
1.8 m telescope

Edwin Hubble

Finally solved, as it often is in astronomy, with a BIGGER telescope!

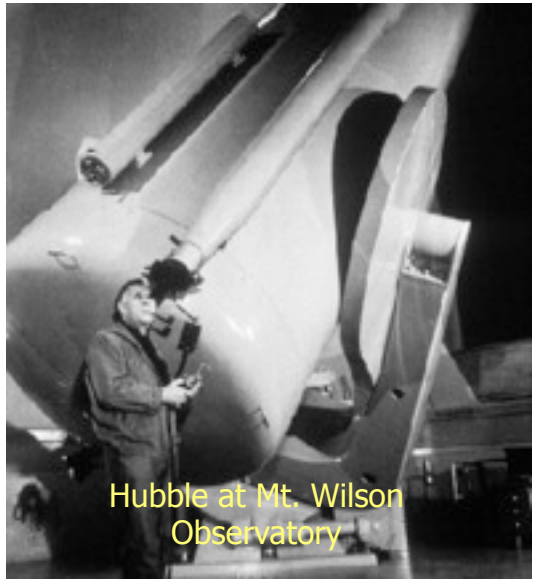
- The old 100 inch trick! (2.5 meter)

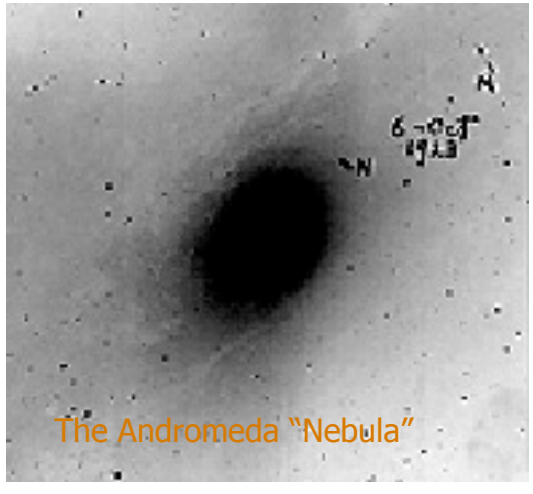
In 1923, Hubble resolved M31, the Andromeda "Nebula", into stars

If these stars were like the stars in our Galaxy, then M31 must be far away!

Estimated the distance to M31 to be 1 million lightyears (modern estimate is 2.54 Mlyrs)

Andromeda is an "island universe" like our own Galaxy.

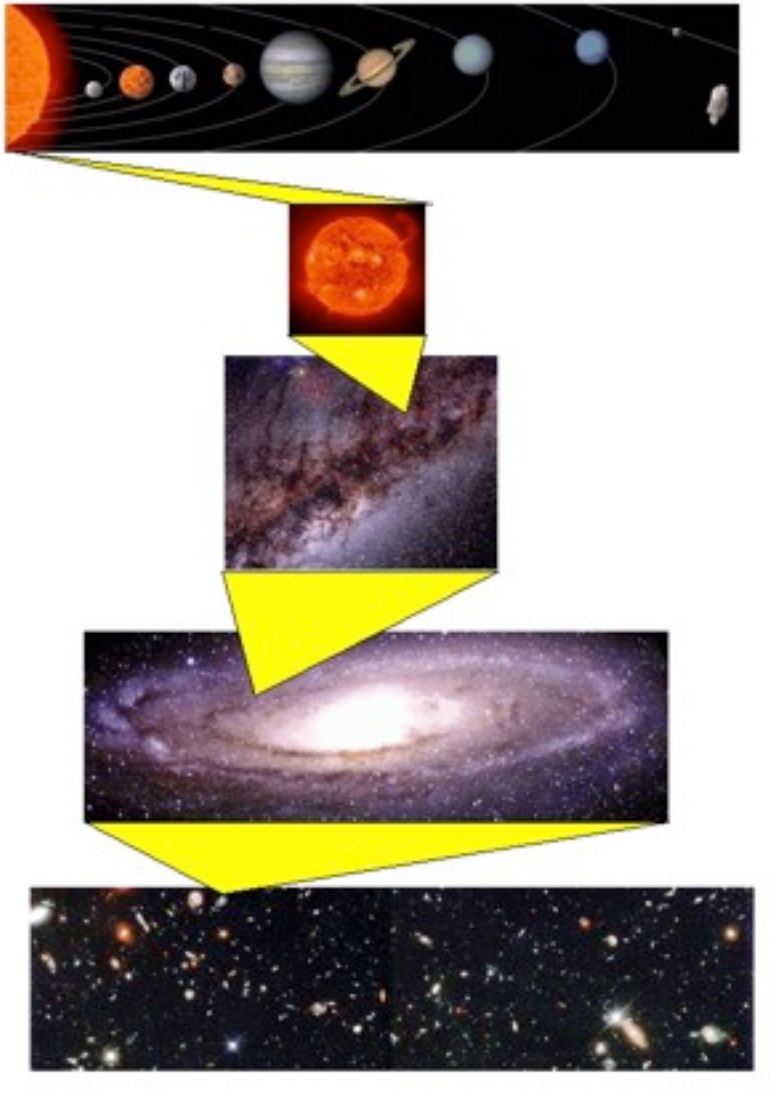

Hubble at Mt. Wilson Observatory


The Andromeda "Nebula"

One of

We are:

- 1 planet out of ~~9~~ 8 in our solar system.
- 1 stellar system of 100 billion stars in our Milky Way
- 1 galaxy of the 100 billion galaxies in the observable Universe.



Galaxies – Fundamental "Ecosystems" of the Universe

Galaxies "fill" universe.

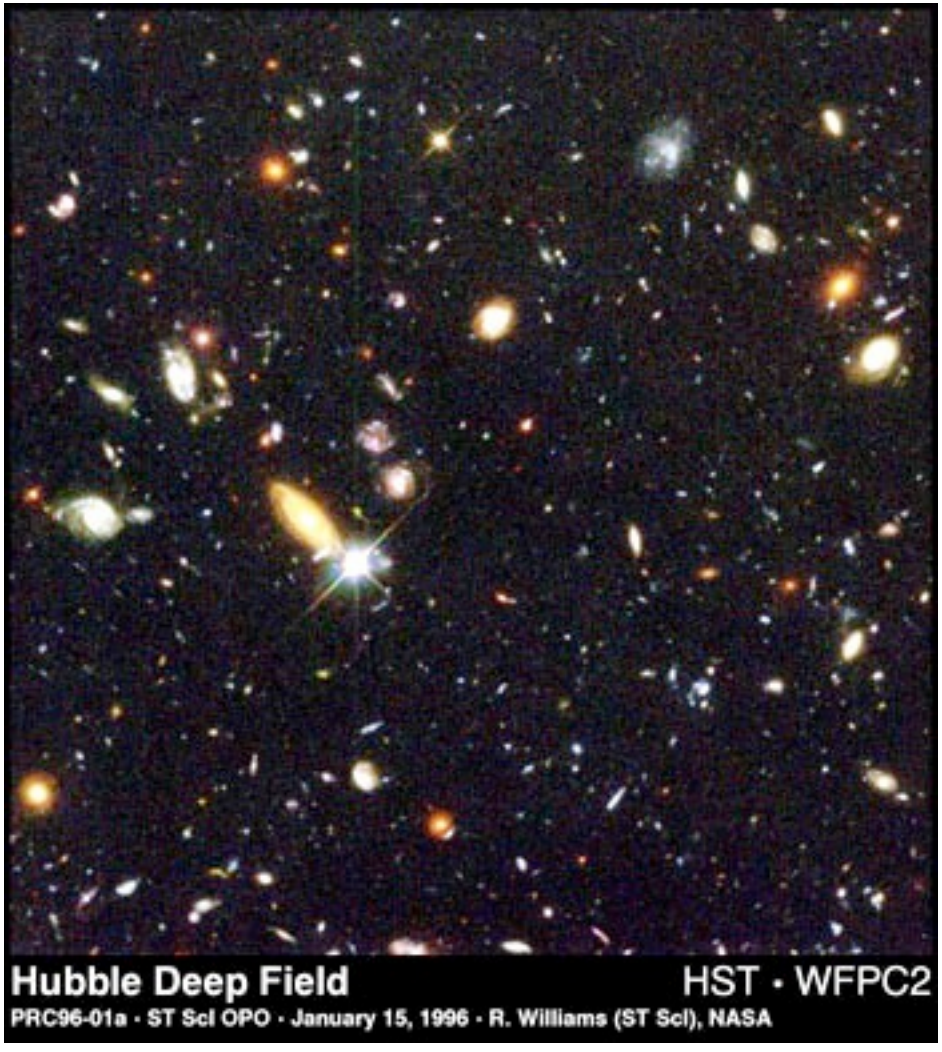
Typical separation
~ 3.2 million light years!

Most distant we can see are nearly 13 billion light years away

Galaxies are huge masses of stars

Range in size from large (MW-like) to small "Dwarf"

- 1 billion to 500's billions of stars

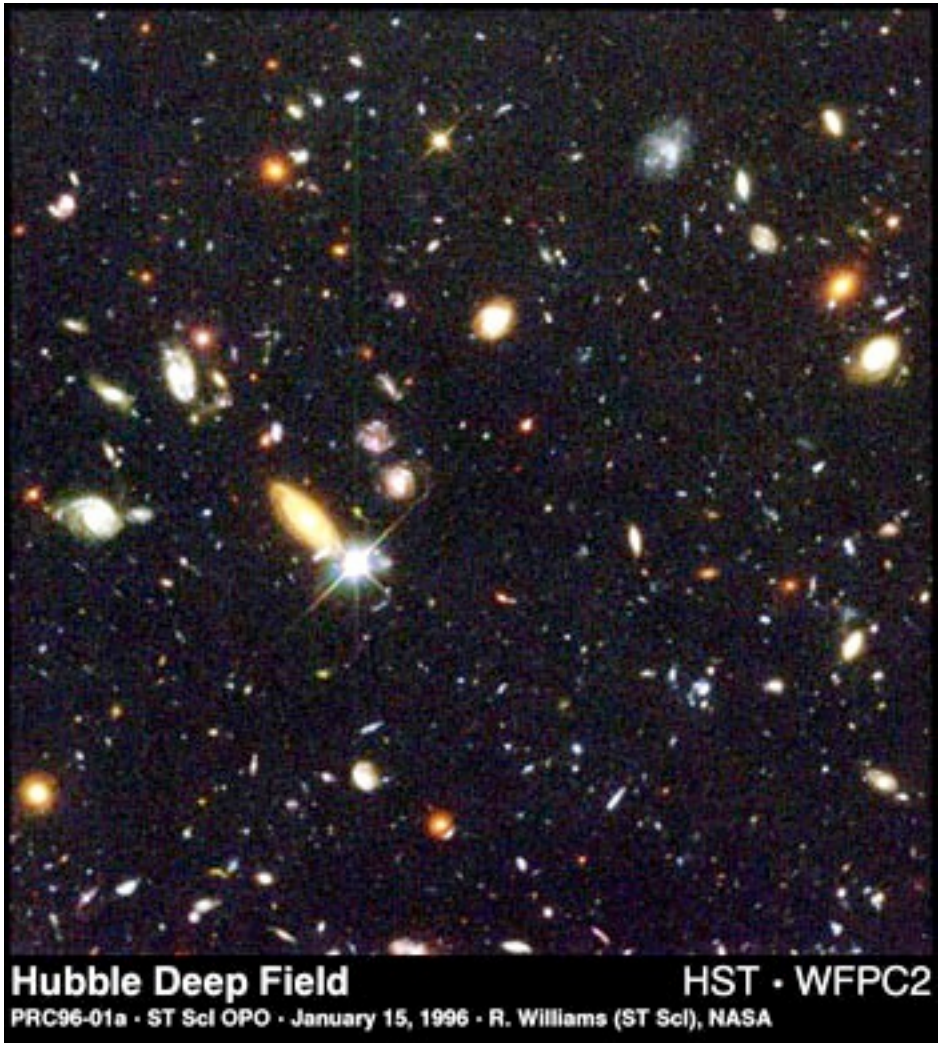


Galaxies – Fundamental "Ecosystems" of the Universe

Galaxies are the cosmic engines that turn gas into stars, then recycles the gas the stars eject back into stars, around and around.

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

- Caveat is galaxy clusters

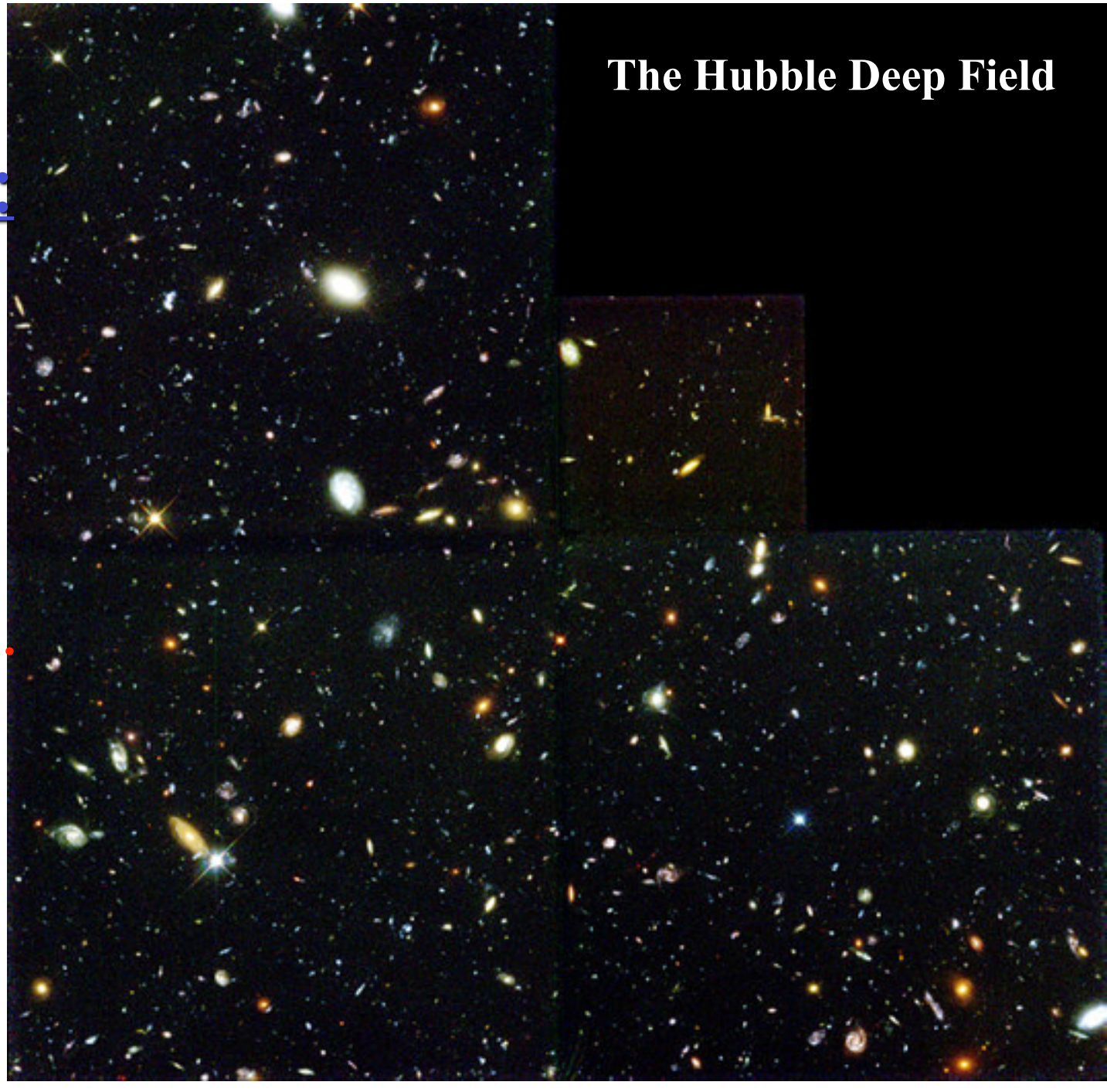


Distant galaxies:

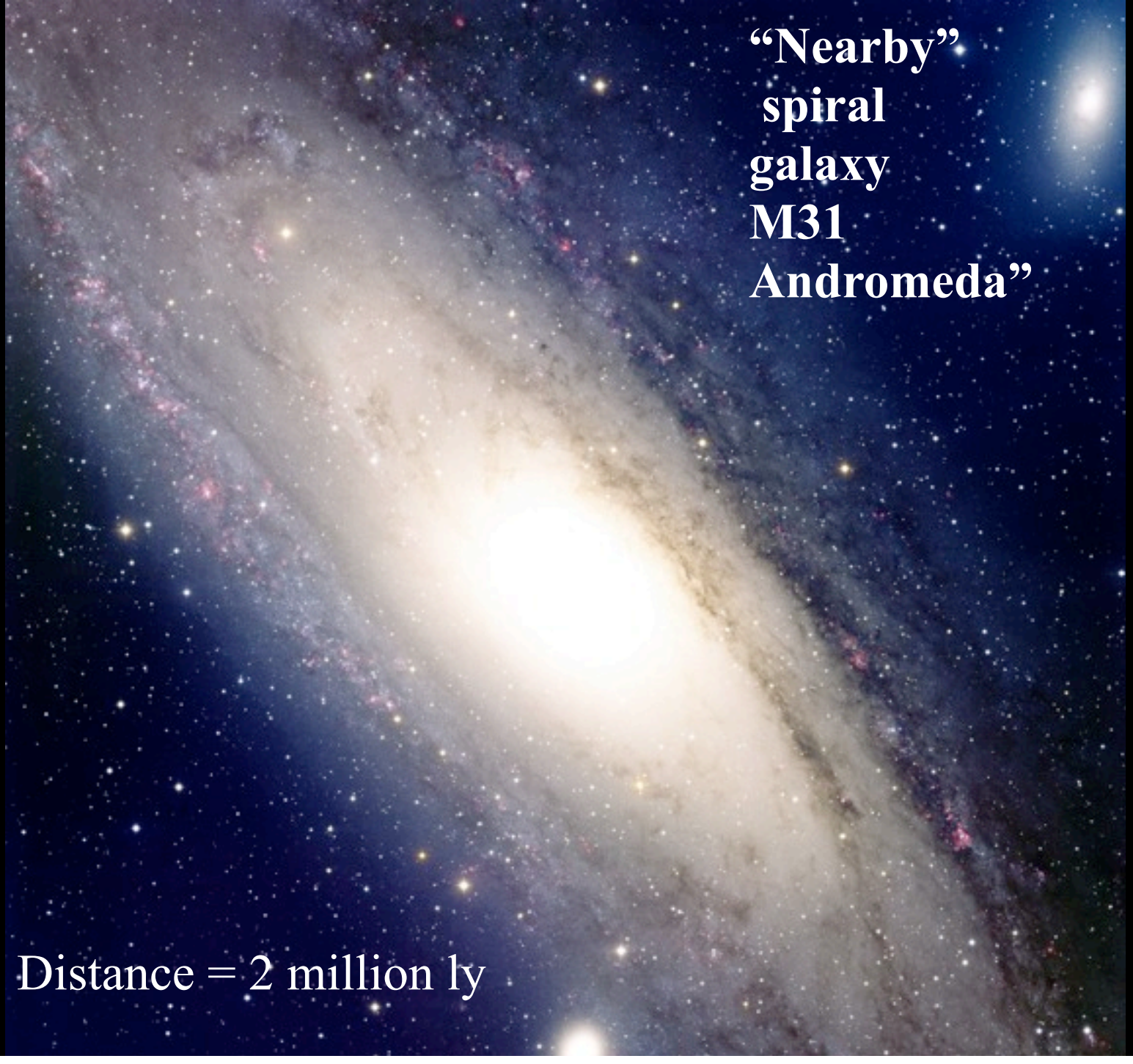
The deepest optical image of a patch of sky

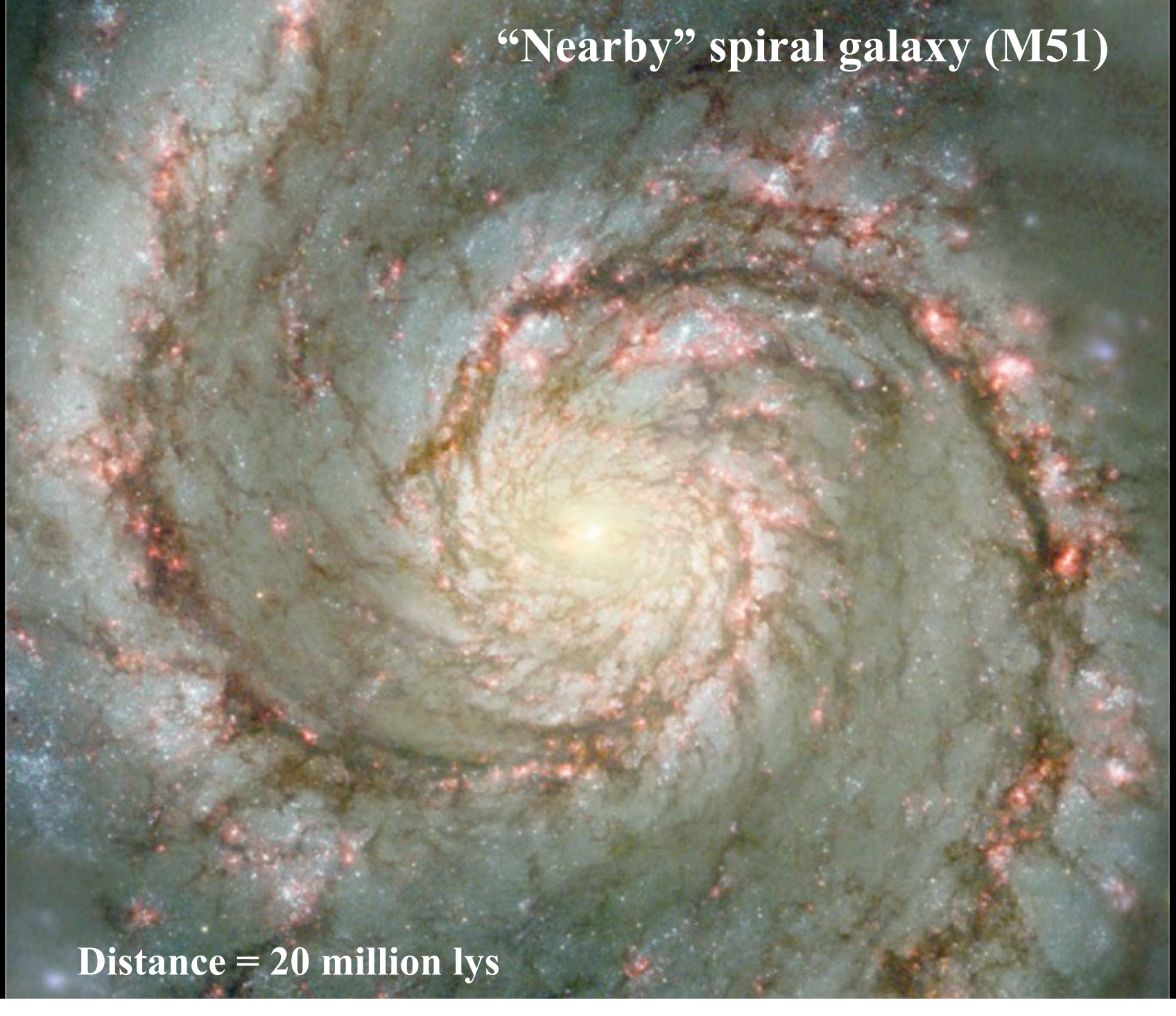
Like looking back in time …

Galaxies as they were, 1 to 10 billion years ago.



The Hubble Deep Field


“Nearby”
spiral
galaxy
M31
Andromeda”
Distance = 2 million ly


"Nearby" spiral galaxy (M51)
Distance = 20 million lys


Sombrero Galaxy: ~10^12 stars (20 million lyrs)

Question

The Hubble Deep Field looked at a nearly blank patch of sky with high sensitivity. What did it see?

a) Dark Matter
b) Many spiral galaxies
c) Many low luminosity stars
d) Nothing
e) Many galaxies with different shapes, sizes, and colors

Answer: E

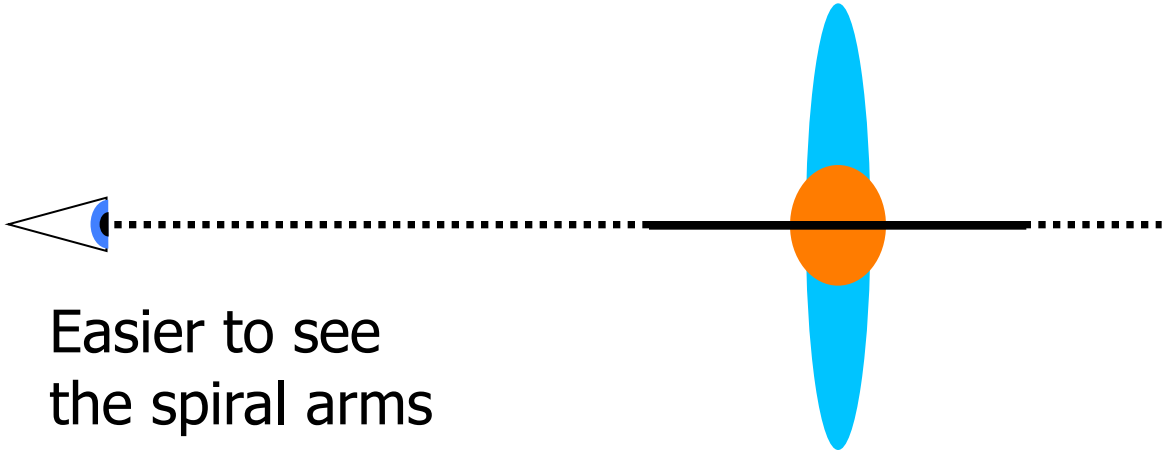
Galaxies are the Fundamental "Ecosystems" of the Universe

Three Main Types of Galaxies:

- Spirals (77%)
- Ellipticals (20%)
- Irregulars (3%)

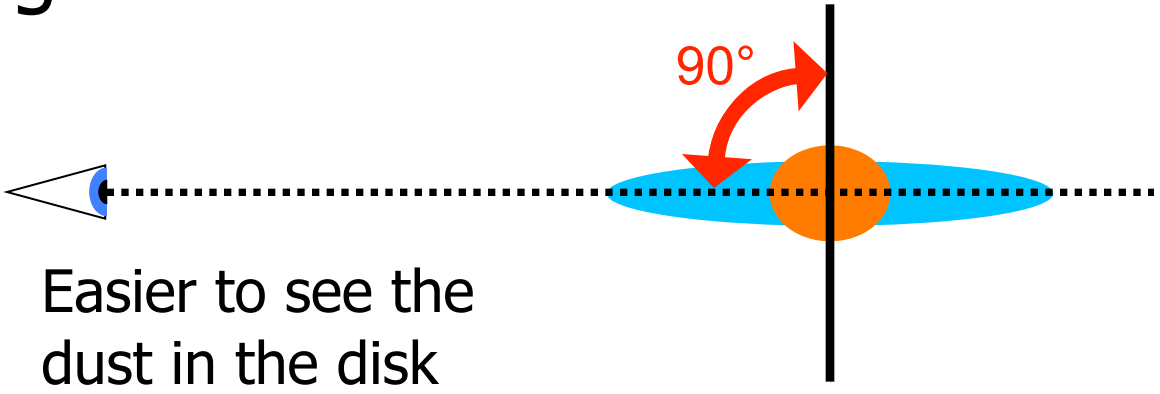
Effect of Viewing Angle

Face-on



Easier to see
the spiral arms

Edge-on



Easier to see the
dust in the disk

Classes of Galaxies

Spirals (S)

- Basic structure: disk and bulge
- Medium to large galaxies
- The disk has the young blue stars, while the bulge has older red stars

Ellipticals (E)

- Pure bulge, no disk component
- Large range in sizes
- All older red stars

Irregulars (Ir)

- Well… odd, irregular structure
- Smaller galaxies
- Mostly young blue stars

Question

What does the color of the galaxy tell us about the age of the stellar population?

a) Nothing.
b) If blue-ish, then recent star formation.
c) If red-ish, then recent star formation.
d) If X-ray bright, then recent stellar deaths.

Answer: B

Measure other Galaxies Rotation Curves

What do you think we find?

a) No other galaxies have dark matter

b) Some other galaxies have dark matter

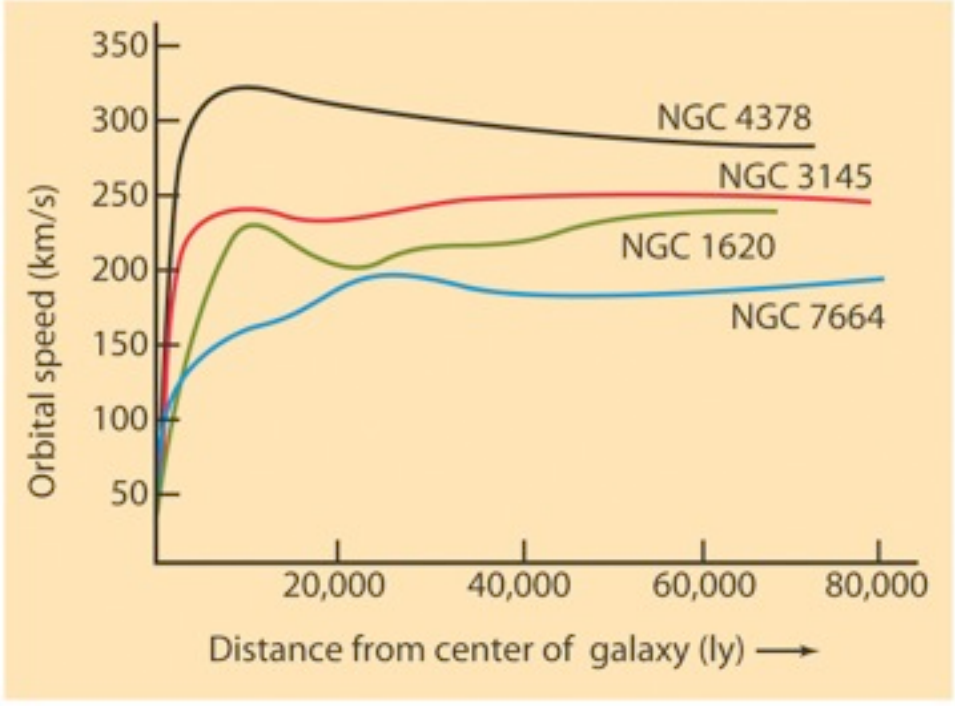
c) All other galaxies have dark matter

Answer: C

Masses of Galaxies

As with the Milky Way, we measure the speed of a galaxy's rotation

Like the Milky Way, other galaxies have a flat rotation curve



Indicates a halo of dark matter

We aren't special that way either.

Dark matter fills the Universe!

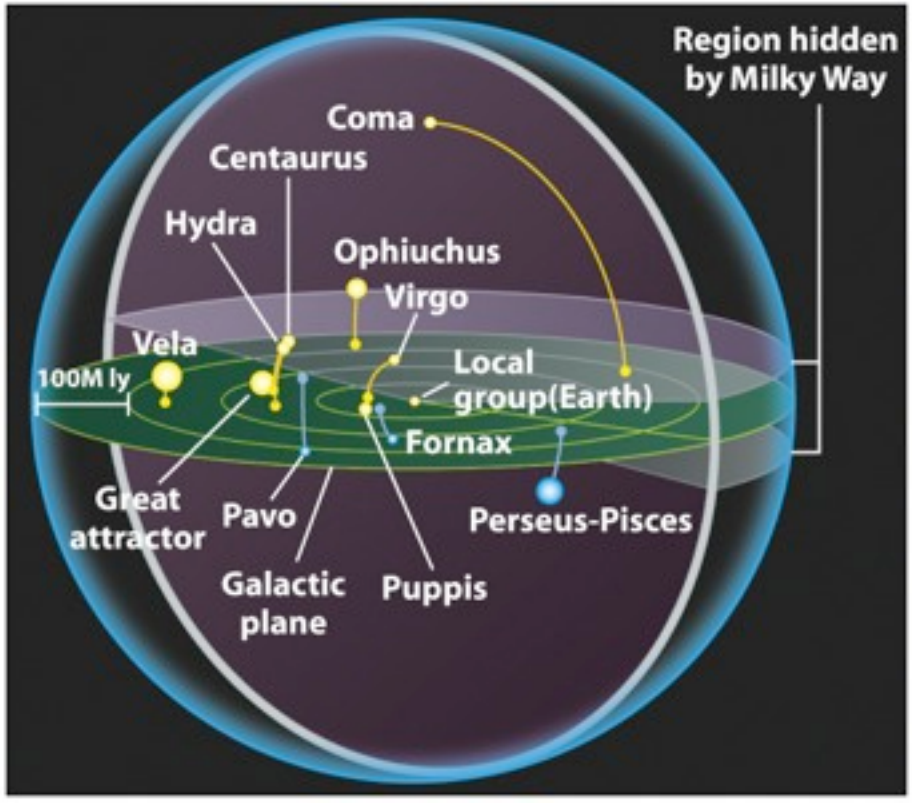
Galaxies Are Not Alone

Galaxies are not scattered randomly throughout the Universe

Galaxies are found in clusters

Like clusters of stars, clusters of galaxies come in a wide variety

- Poor or rich?
  Dozens or thousands of members?
- Regular or irregular?
  Is the cluster concentrated towards the center?



800 Mly sphere, centered on Earth

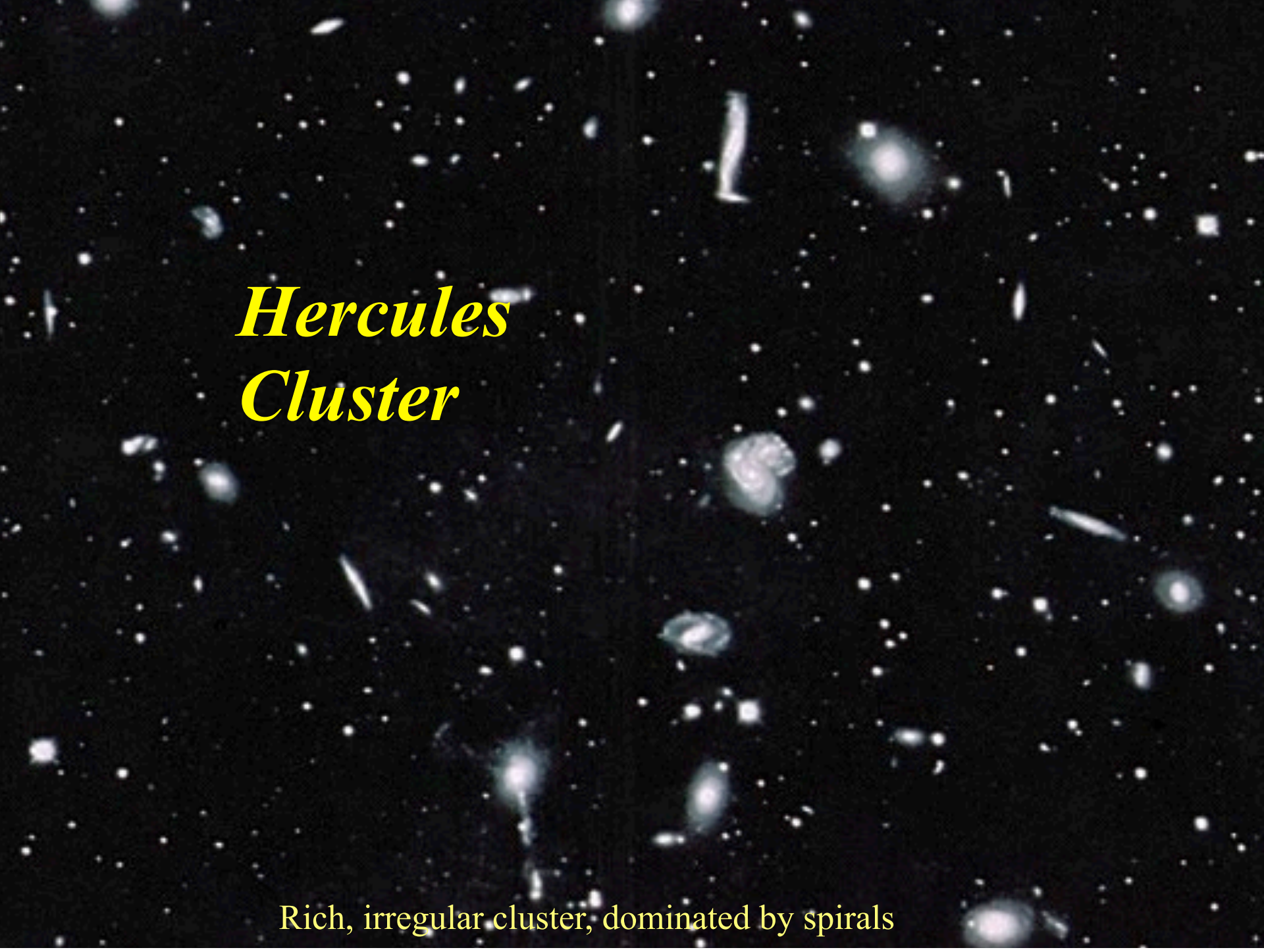
Galaxy Clusters

- Large, rich clusters often contain **giant elliptical galaxies** at their centers

Abell 2218, a large galaxy cluster

Deep photos made with the largest telescopes reveal clusters of galaxies scattered out to the limits of visibility.
In general, large clusters tend to contain 80 to 90 percent elliptical galaxies and few spirals.
Small clusters contain a larger percentage of spirals.
Among isolated galaxies that are not in clusters, 80 to 90 percent are spirals.
This suggests that a galaxy's environment is important in determining its structure.


Fornax Cluster



Rich, irregular cluster, dominated by spirals

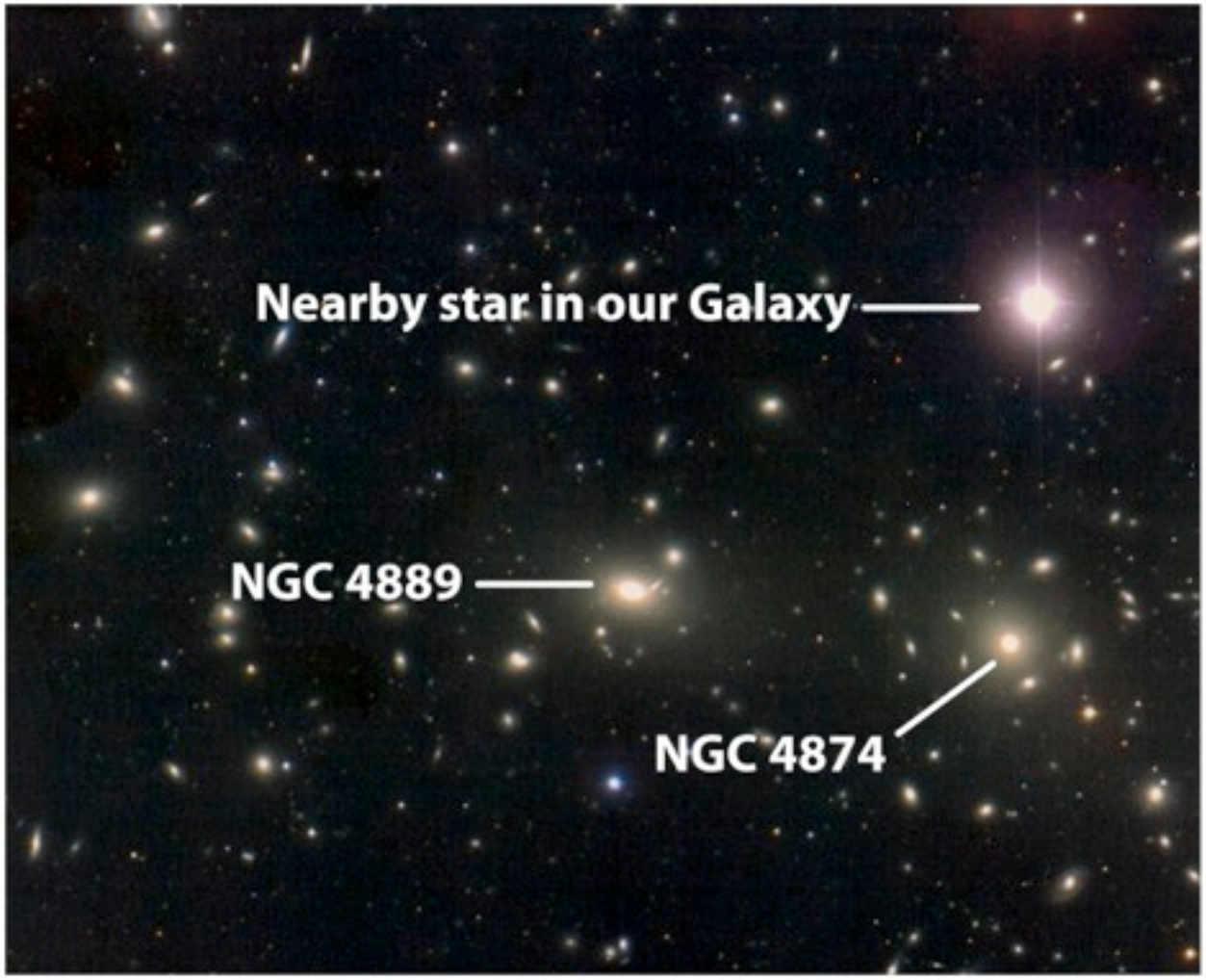
The Coma Cluster

Rich, regular cluster

d = 300 million lyrs.

Over 2000 galaxies.

Dominated by two ellipticals



Coma Cluster

A zoom near one of the ellipticals

Contains many spirals, but more ellipticals the closer to the center


Virgo Cluster

The Virgo Cluster

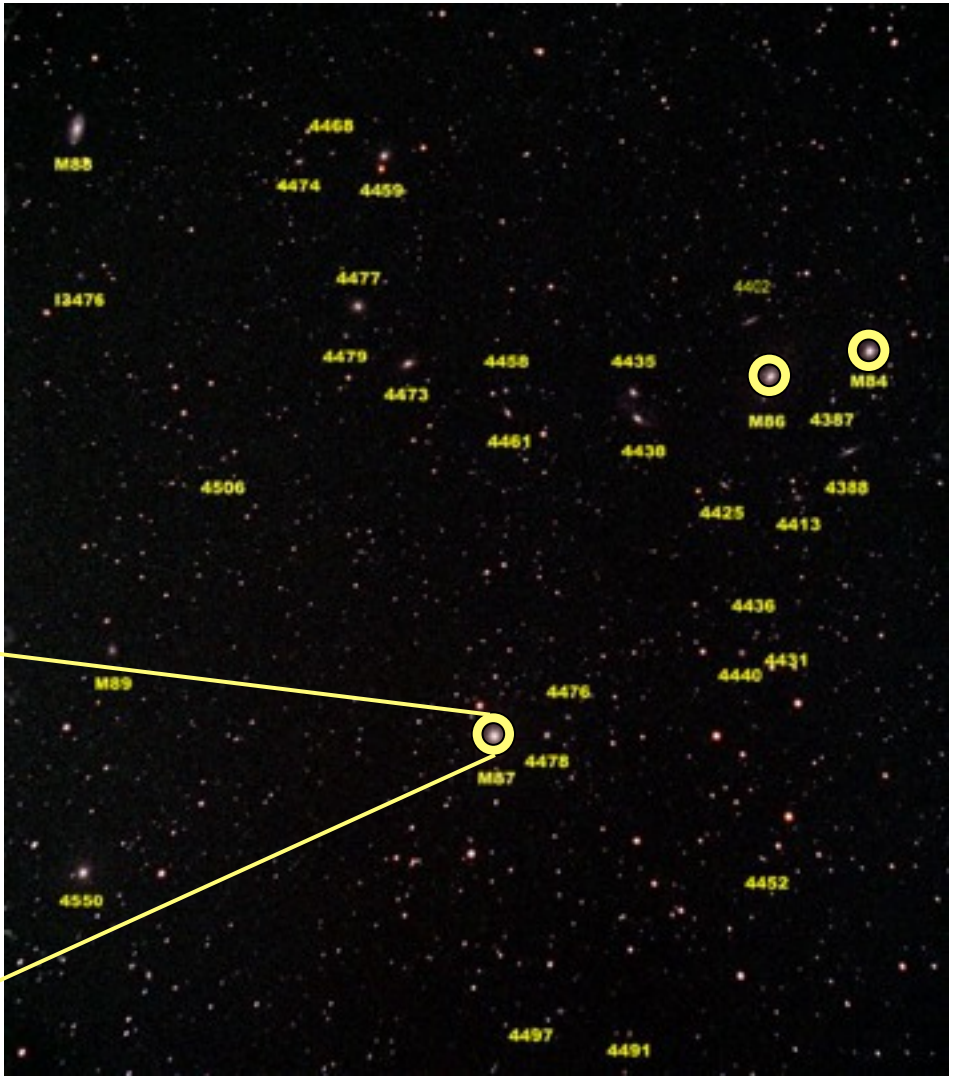
More than 1,000 galaxies

52 Mlyrs away from the Milky Way

About 13 Mlyrs across

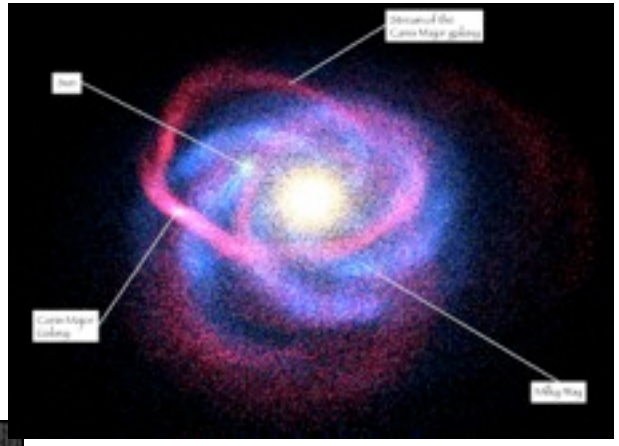
Dominated by three giant elliptical galaxies

Our cluster is headed right for it.



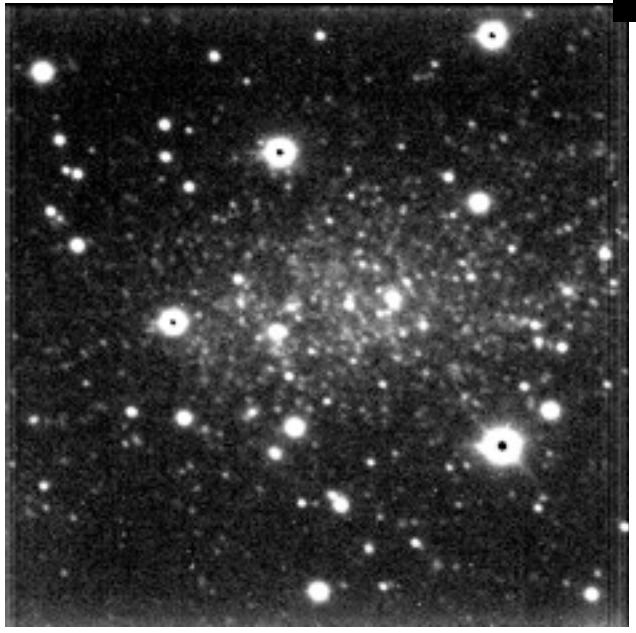
Is the Milky Way Alone?

We have lots of neighbor galaxies

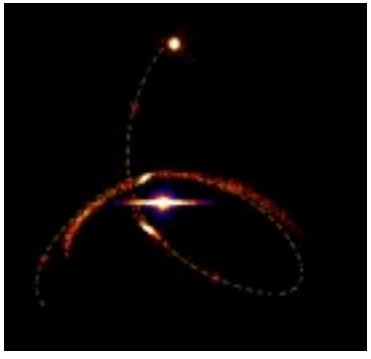


Canis Major
(42,000 ly away)

Large Magellanic Cloud
(180,000 ly away)



Sagittarius Dwarf Elliptical
(80,000 ly away)



Small Magellanic Cloud
(250,000 ly away)

The Local Group

Our Galaxy is in a "group"

- a poor, irregular cluster
- Called the **Local Group**

Dominated by two large spirals

- The Milky Way = us
- The Andromeda Galaxy (M31)

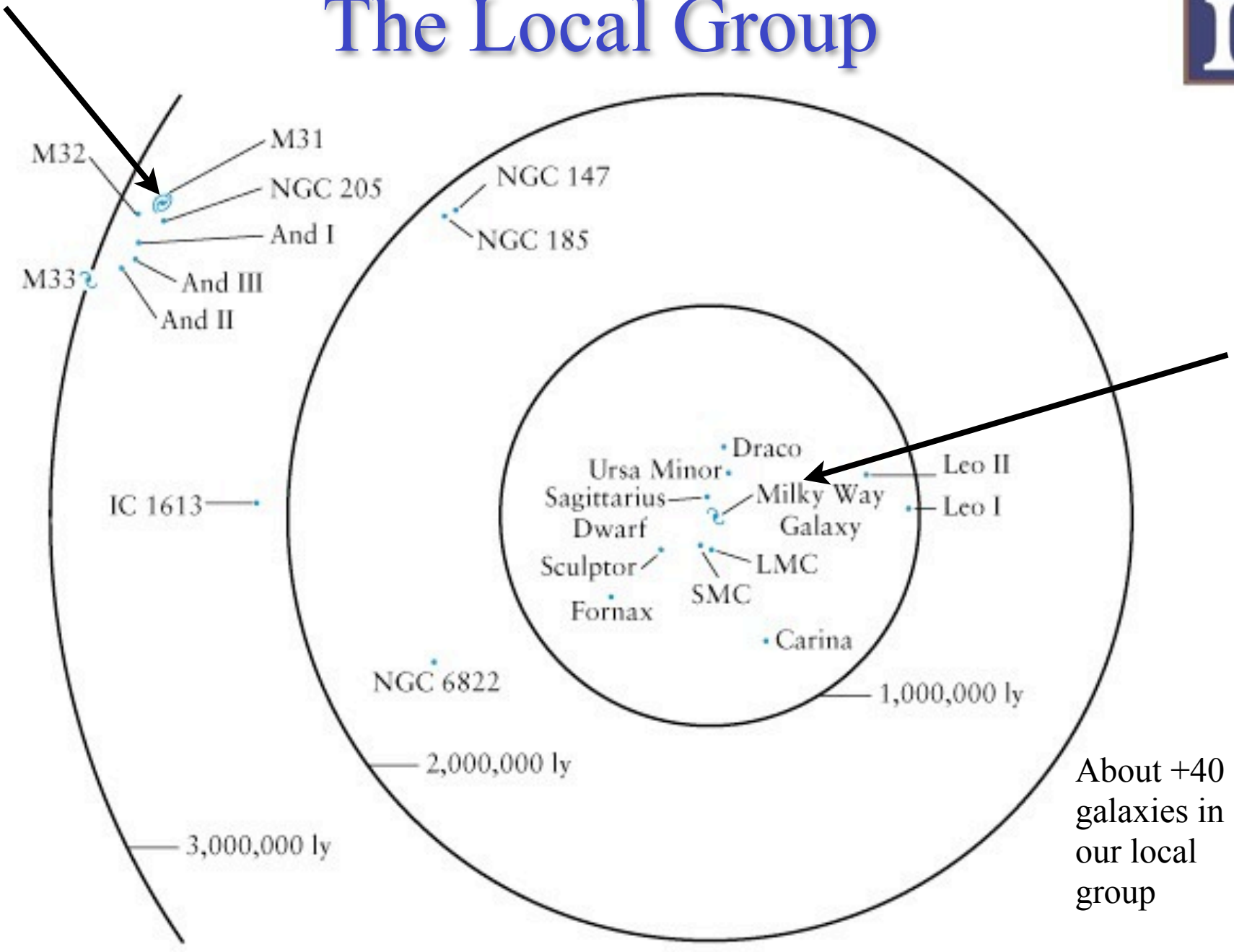
About 40 smaller galaxies

- Some satellites of the big two
- M33 (small spiral)
- Lots of dwarfs ellipticals and irregulars

Triangulum (M33)

Local Group dwarf galaxies

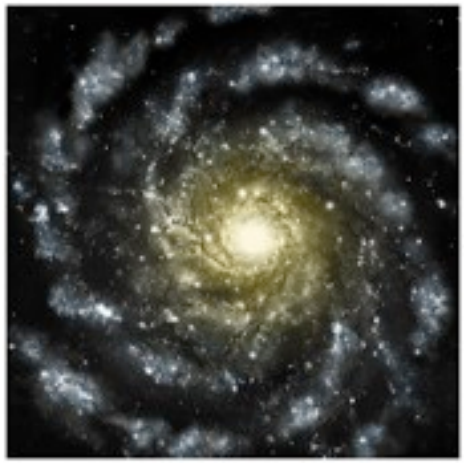
The Local Group



About +40 galaxies in our local group

Andromeda is still very far away from us!

The Local Group: Many Galaxies in the Same Town



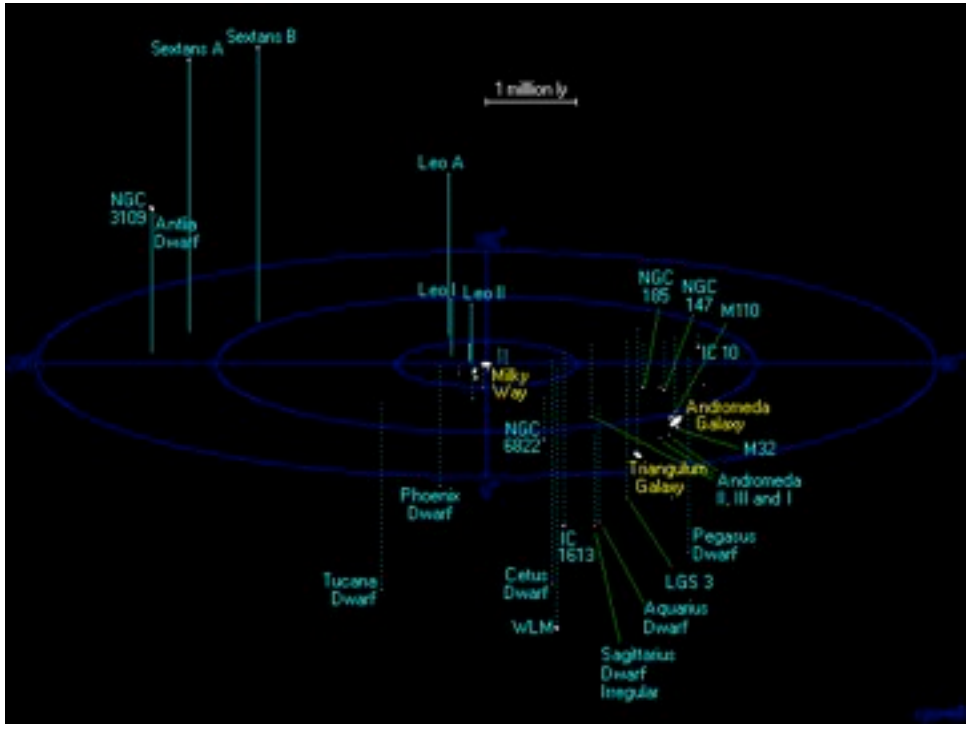
Milky Way

2.3 Mlyrs

Andromeda (M31)

Triangulum (M33)

Local Group Dwarf galaxies



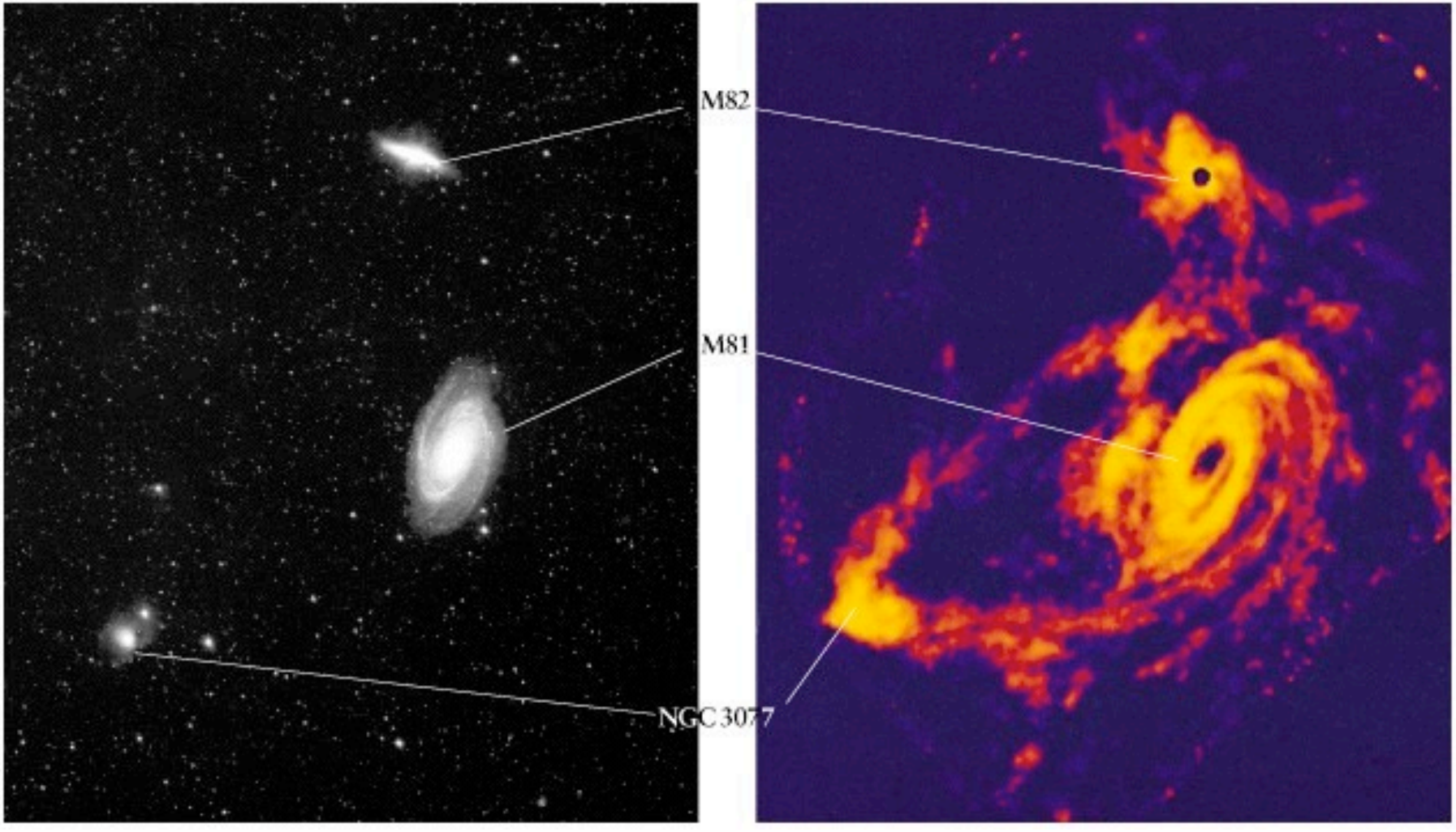
Galaxies evolve by collision and merger

Arp 148: The aftermath of a galactic encounter

NGC 6050: A collision between two spiral galaxies

Astronomers are finding more and more evidence to show that galaxies collide, interact, and merge.
In fact, collisions among galaxies may dominate their evolution.
Arp 148 is the staggering aftermath of an encounter between two galaxies, resulting in a ring-shaped galaxy and a long-tailed companion. The collision between the two parent galaxies produced a shockwave effect that first drew matter into the centre and then caused it to propagate outwards in a ring.
The two spiral galaxies of NGC 6050 are linked by their swirling arms

“Normal” galaxies show evidence of past interactions



Even among “normal galaxies”, we can see evidence of past interactions between galaxies by looking for trails of gas & dust in radio waves

You should not be surprised that galaxies collide with each other.

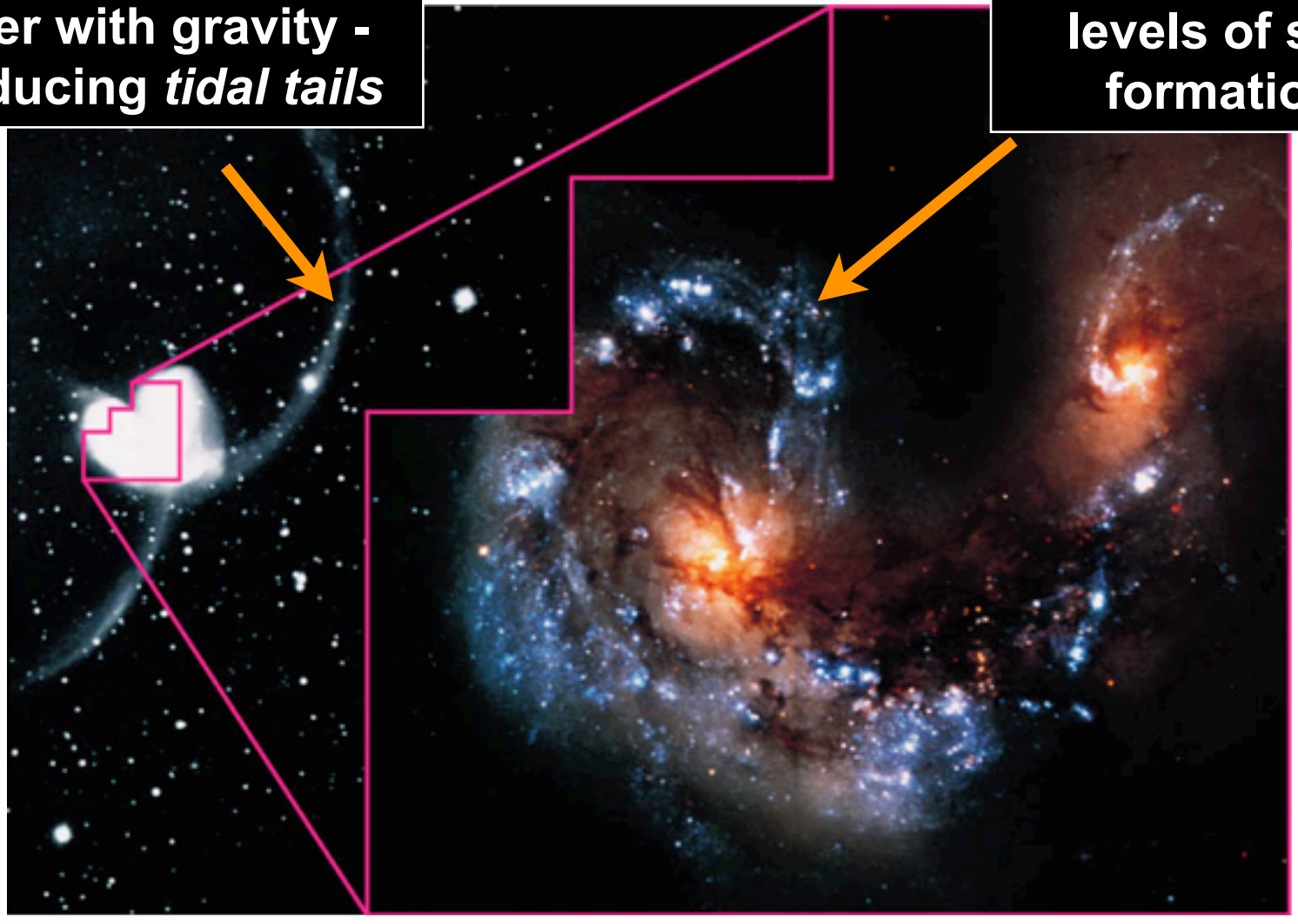
The average separation between galaxies is only about 20 times their diameter.

So, astronomically speaking, galaxies should bump into each other fairly often.

What happens when galaxies collide?

Can distort each other with gravity - producing *tidal tails*

Can trigger *starbursts* - high levels of star formation



When spiral galaxies collide, their bulges eventually merge, while the disks are turned into tidal tails
The collisions we observe also trigger bursts of star formation - Called “starbursts”
100 times the star formation rate of a galaxy like the Milky Way

Large ellipticals are the result of galaxy mergers

Swarm

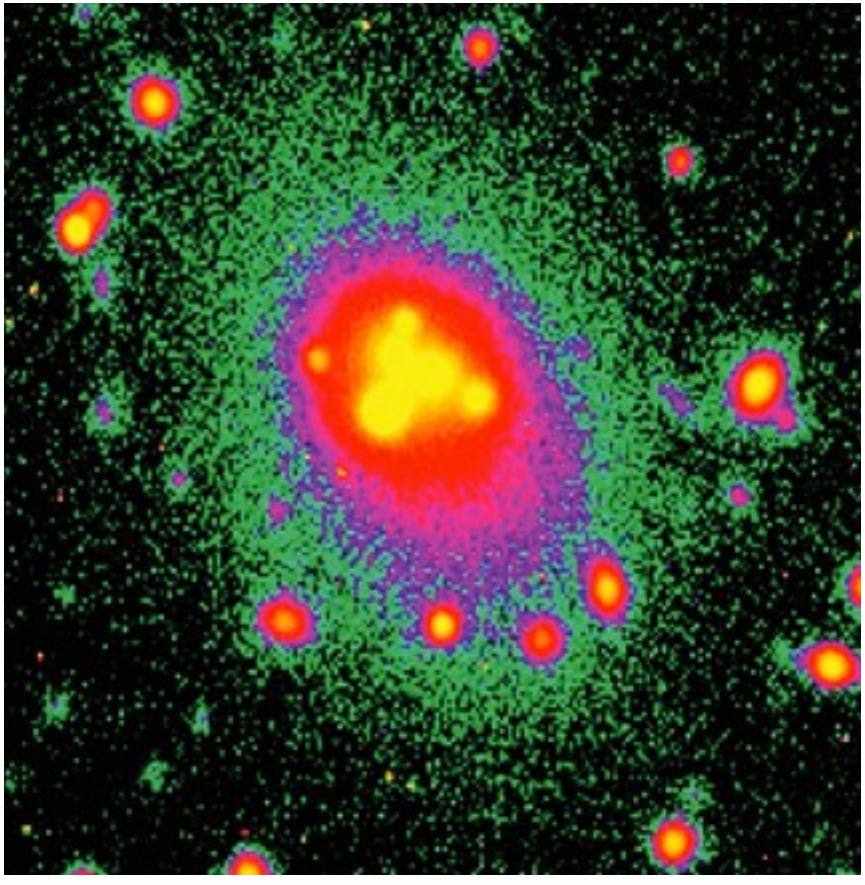
"A process somewhat analogous to that of the alleged formations of the universe, time and times ago, was observable. The bustling swarm had swept the sky in a scattered and uniform haze, which now thickened to a nebulous centre... till it formed a solid black spot upon the light."

- Thomas Hardy, *Hiving the Bees,*
Far From the Madding Crowd 1874

Modeling galaxy collisions shows that spiral galaxies can merge to make an elliptical
Elliptical galaxies appear to be the product of galaxy mergers
Mergers trigger star formation, uses up gas and dust
Gravitational forces in a collision between massive galaxies collapses structure to a ‘blob’
The animation shows the result of 6 spiral galaxies merging into 1 giant elltipcal

Giant Ellipticals: Evidence of galactic cannibalism

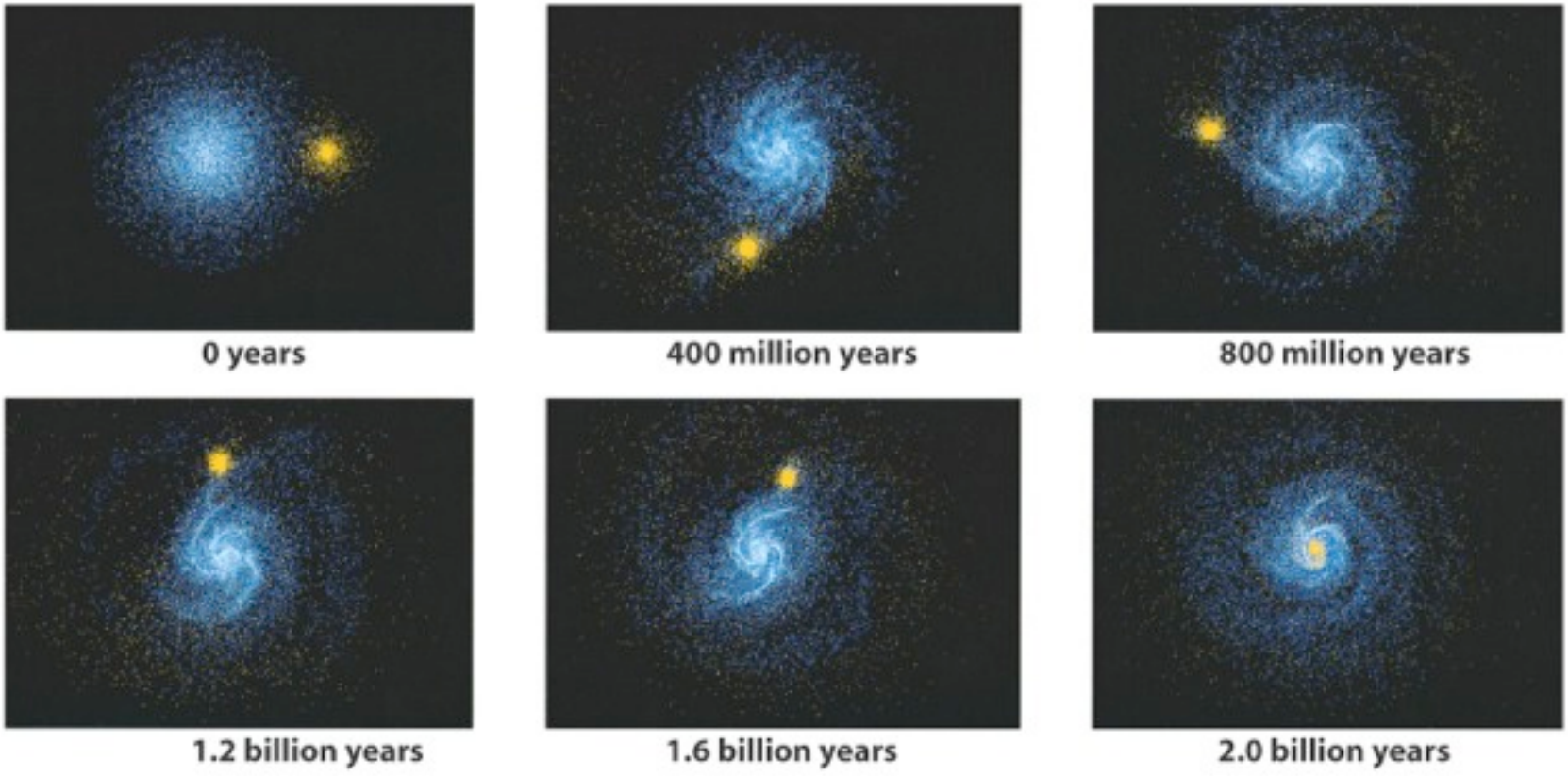
- Giant elliptical galaxies at the centers of clusters often have multiple nuclei
- Remains of smaller galaxies only partly disgested!
- Evidence they formed from multiple mergers



Central galaxy of cluster Abell 3827

Collisions may explain why elliptical galaxies tend to be found in rich clusters, where galaxies are closer together
Leads to giant ellipticals

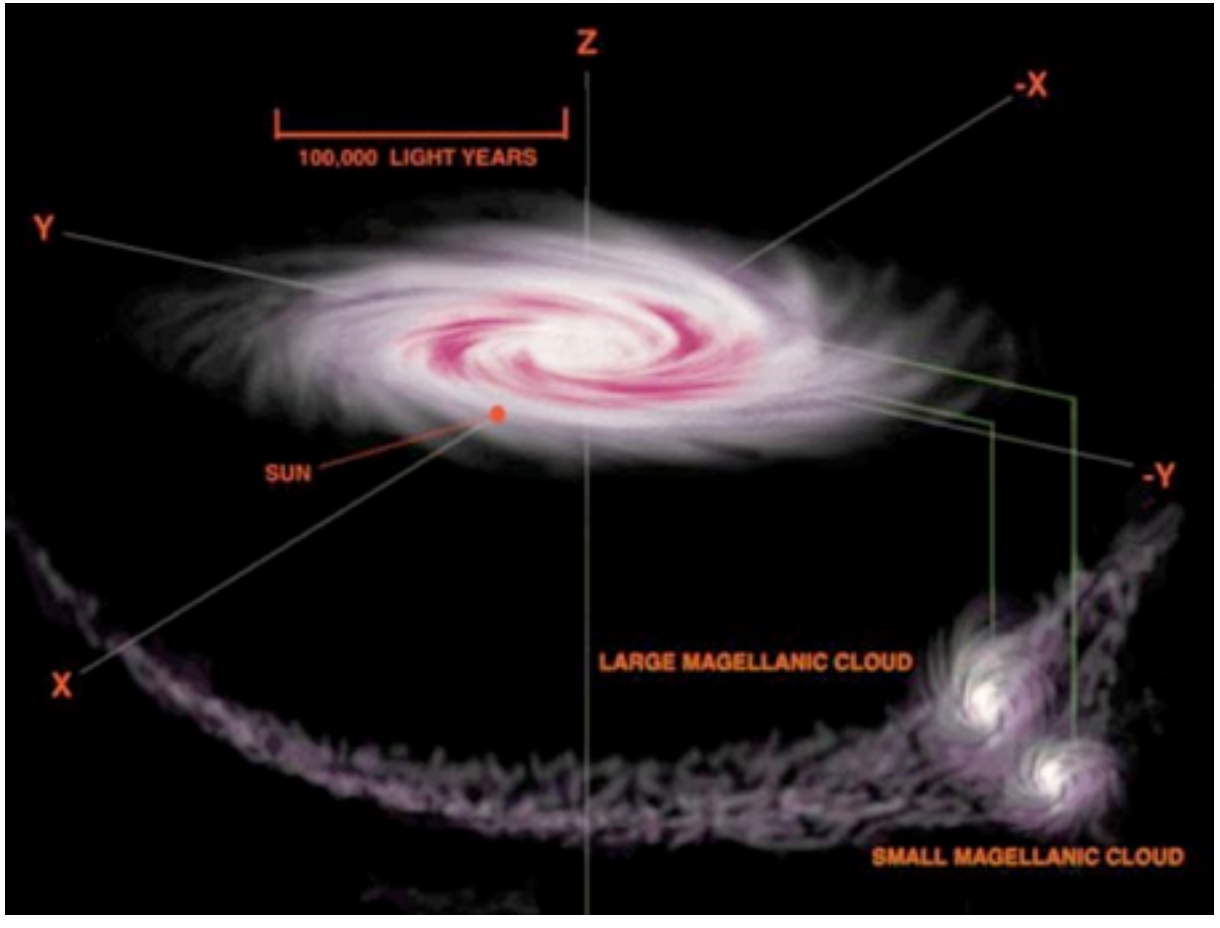
Spirals seem not to have suffered recent major collisions



Mergers with small galaxies add to a spiral's bulge, but do not destroy its disk

Disks would be destroyed by tidal forces in a collision with a massive galaxy
Also, they retain plenty of gas and dust and continue making stars
Large spirals can survive mergers with small galaxies
Spirals tend to be found isolated or in poor clusters, where collisions are less frequent!

Is our Galaxy undergoing galactic interactions?

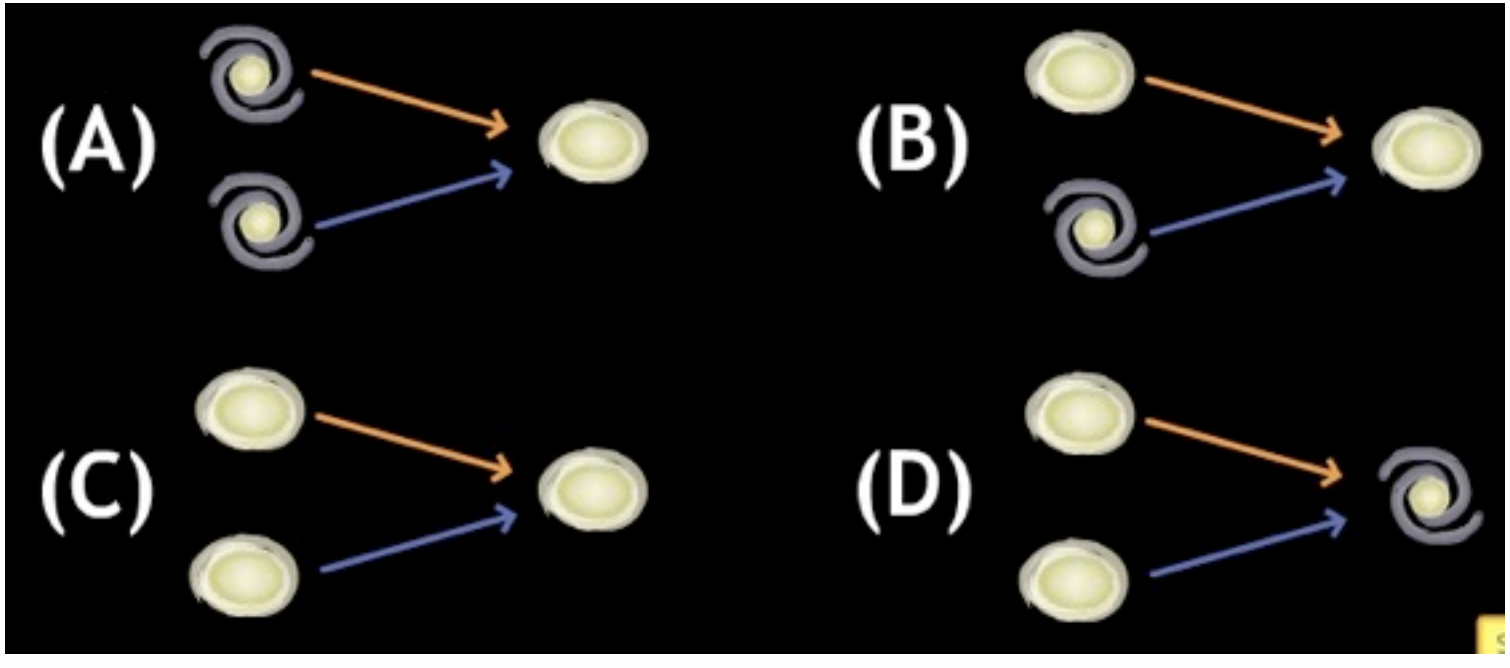


As the Magellanic Clouds orbit the Galaxy, a stream of gas is stripped off by its gravity

Yes! Our Galaxy is "consuming" some of its satellites

iClicker Question

The outcomes for four galactic mergers are shown below for different combinations of elliptical and spiral galaxies. Which merger shown is inconsistent with galactic evolutionary theory?



Answer D – mergers of large galaxies produce ellipticals, not spirals

The Andromeda Galaxy

- 2.5 million light years away
- About the same size/mass as our Galaxy
- Also a spiral galaxy, like our own
- On a collision course with the Milky Way!

Currently, Andromeda is about 2.5 million light years away
24 million trillion km away
The Andromeda galaxy is on a collision course– 300 km/s.
In about 2 billion years, it starts.