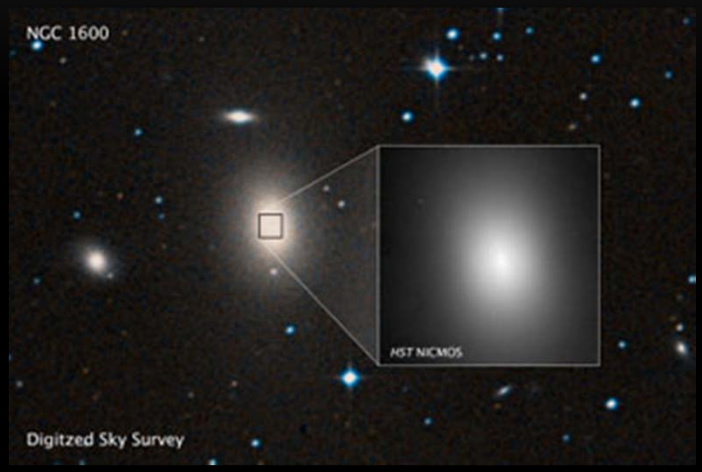
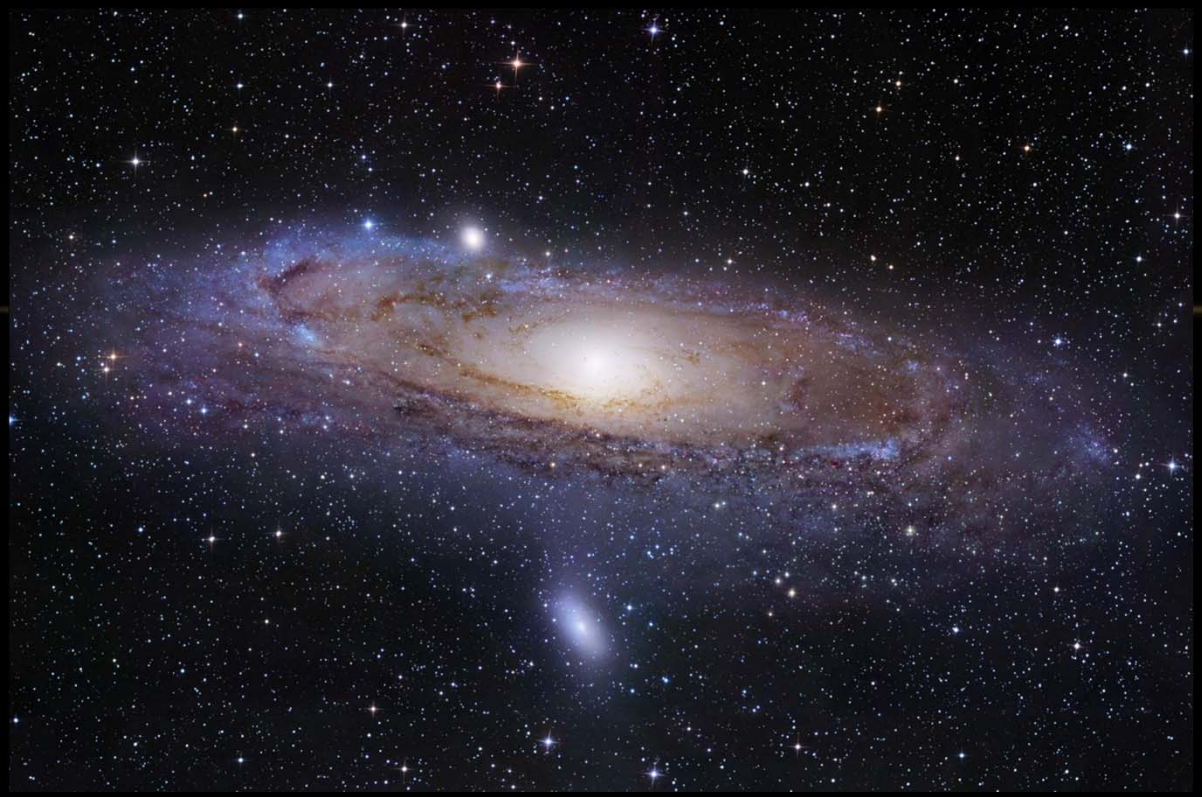
TURNS OUT MOST ALL GALAXIES HAVE A SUPERMASSIVE BLACK HOLE

- One example In the news last year:
  - 17-billion solar mass black hole discovered in galaxy NGC-1600



- Possibly largest ever seen
  - Odd that it's in a fairly normal galaxy group, not in a huge cluster, where the biggest black holes usually live
- Likely the leftover remnant of a quasar (*more later*)

GALAXIES
Ch.16



Andromeda (M31)
Photo by Robert Gendler

SPIRAL NEBULAE

- Up until 1924, other galaxies were thought to be nebula
- Edwin Hubble found Cepheid variables in several of these “spiral nebula”
  - Timed their light curves
  - Found their absolute magnitudes
  - Compared to apparent magnitudes, found they were very far away

GALAXIES GALORE

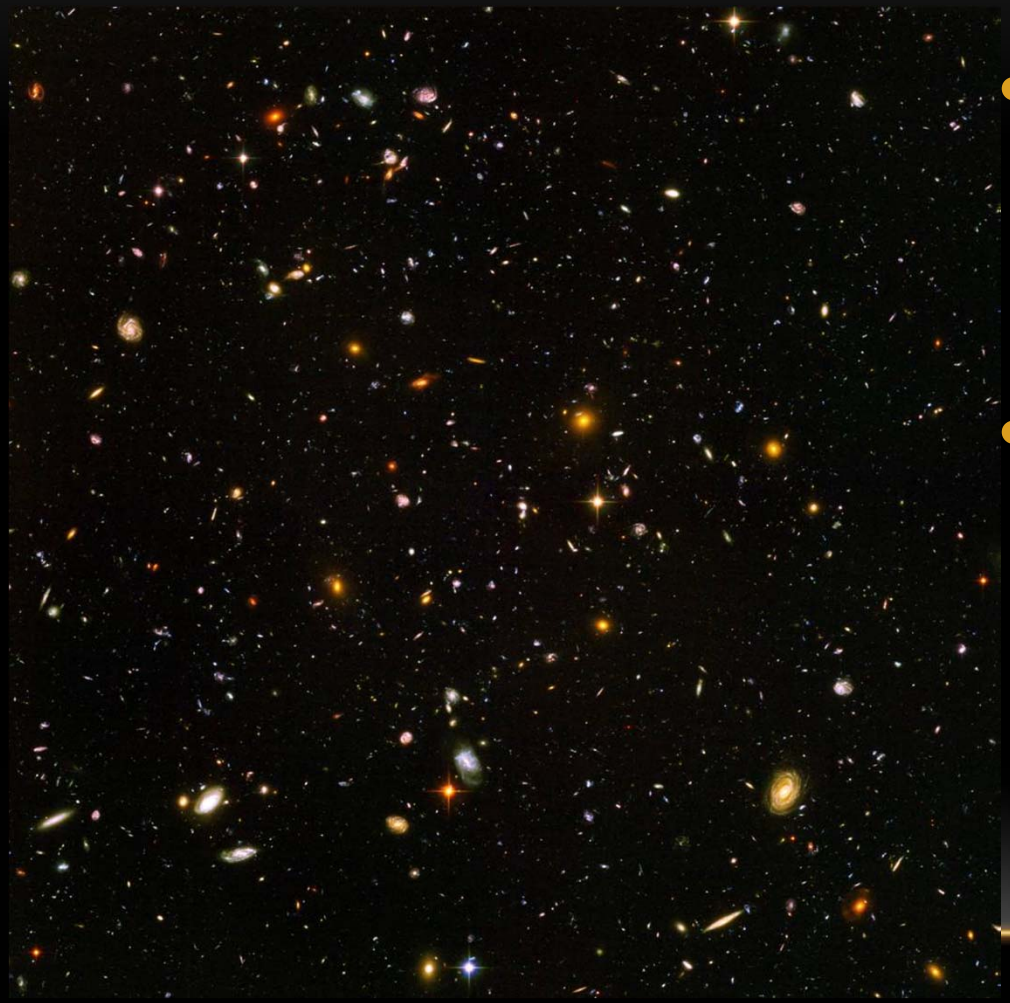
- Like looking at the Milky Way reveals many many faint stars…
- Looking out of our galaxy reveals many many faint galaxies

Part of the Hubble Deep-Field South

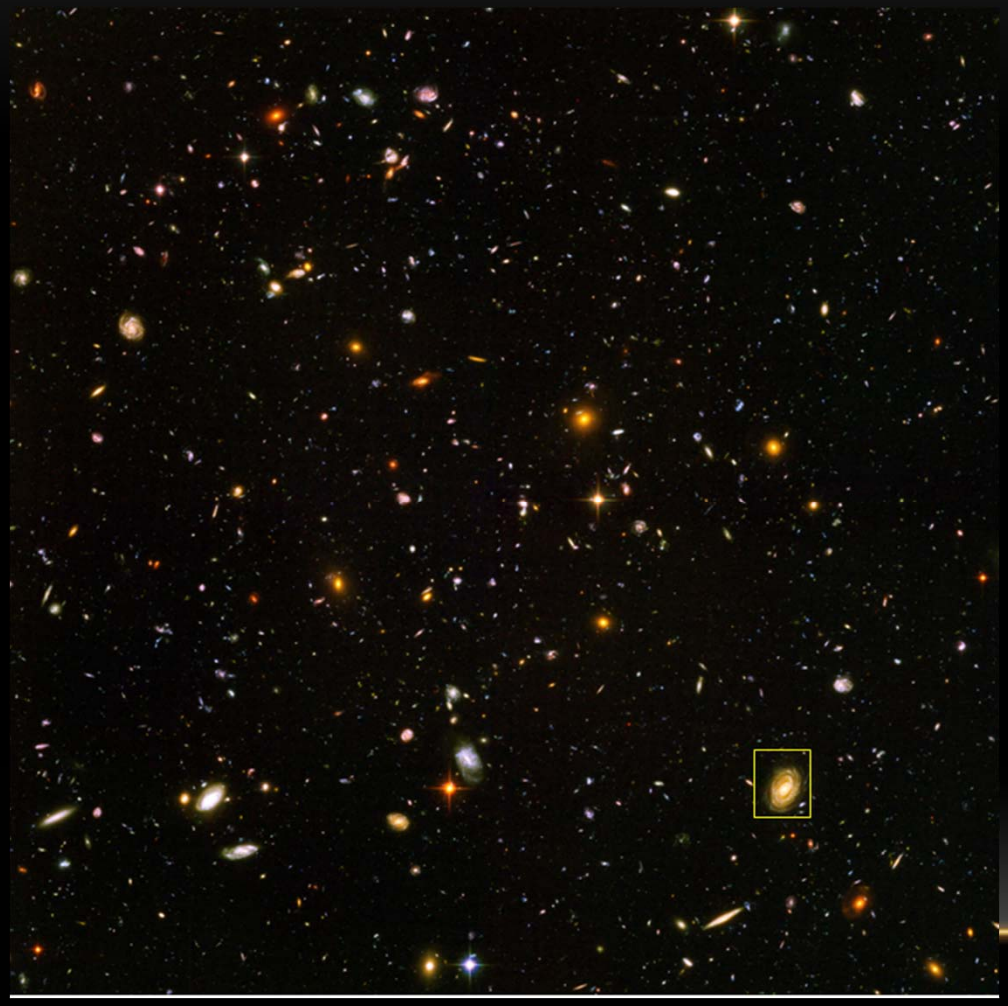
HUBBLE DEEP-FIELD

- ~100 hour exposure (took 10 days or orbits) made in 1995
- Pictures of faint stuff (30th mag) near the Big Dipper
  - A second one done in the south in 1998
- Sees ordinary galaxies out to 10 billion light years
- Allows calculation that there are some 40 billion galaxies in the observable universe
  - If one were to take these pictures everywhere and count things all up

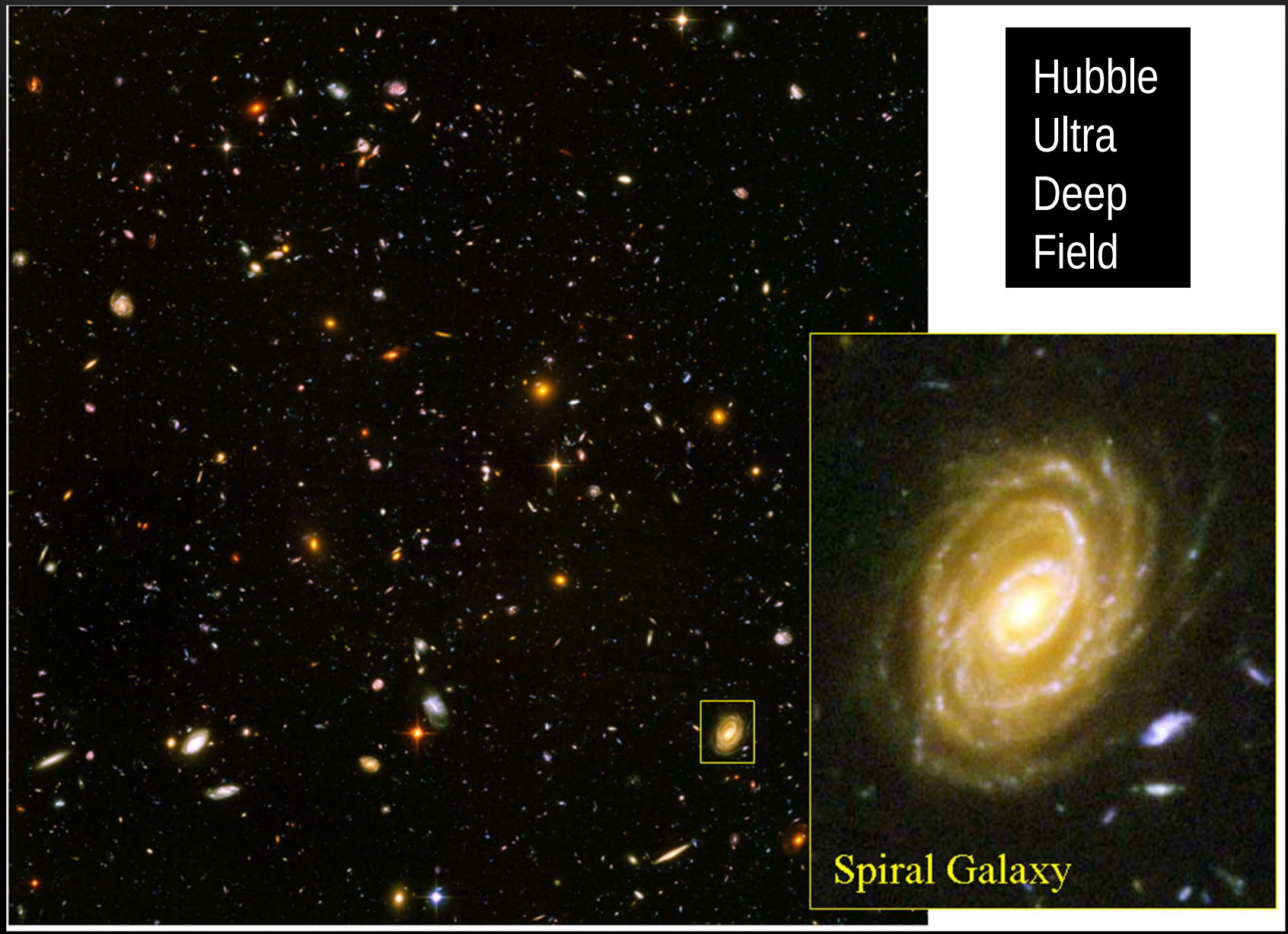
HUBBLE ULTRA DEEP FIELD

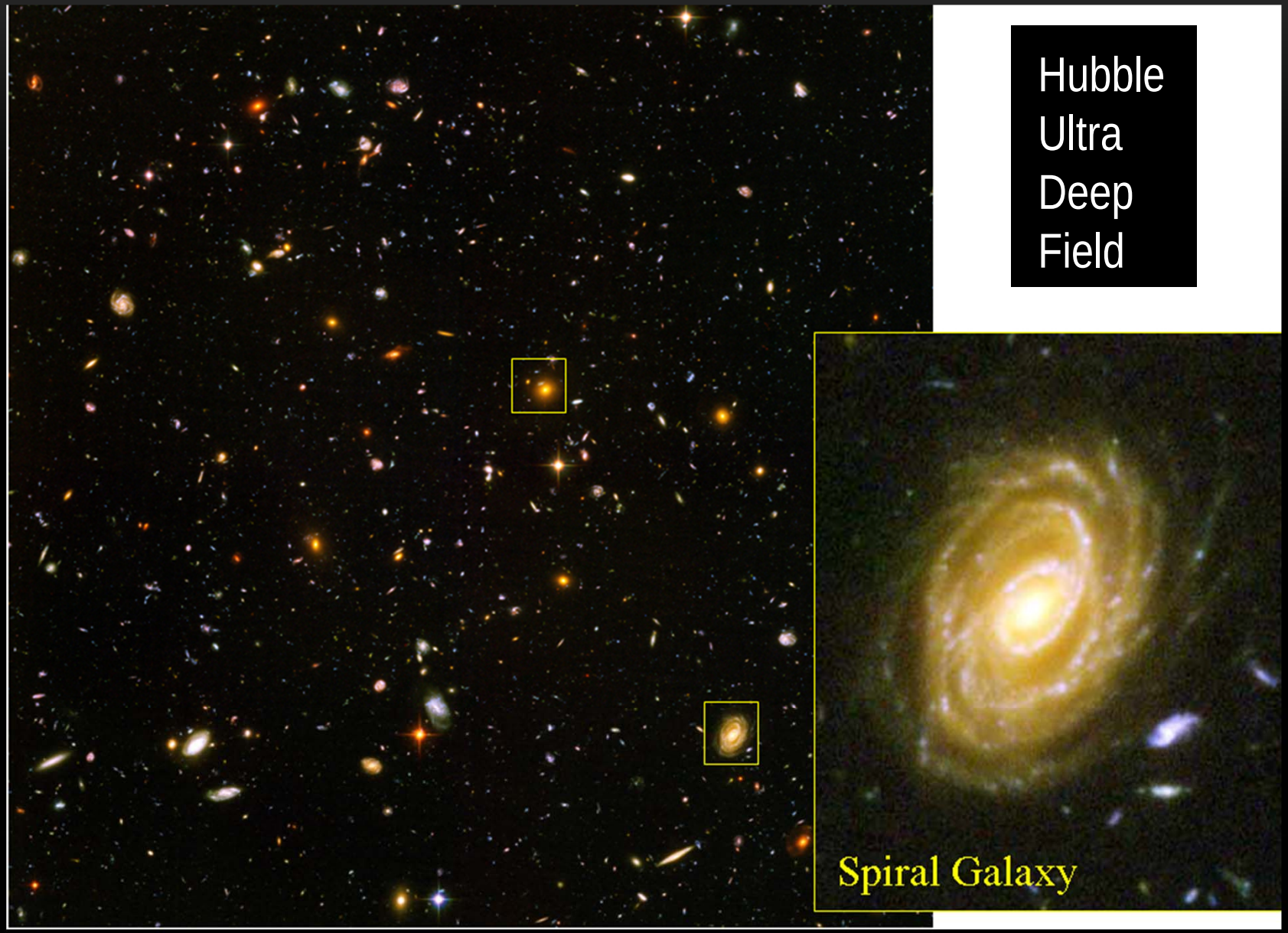


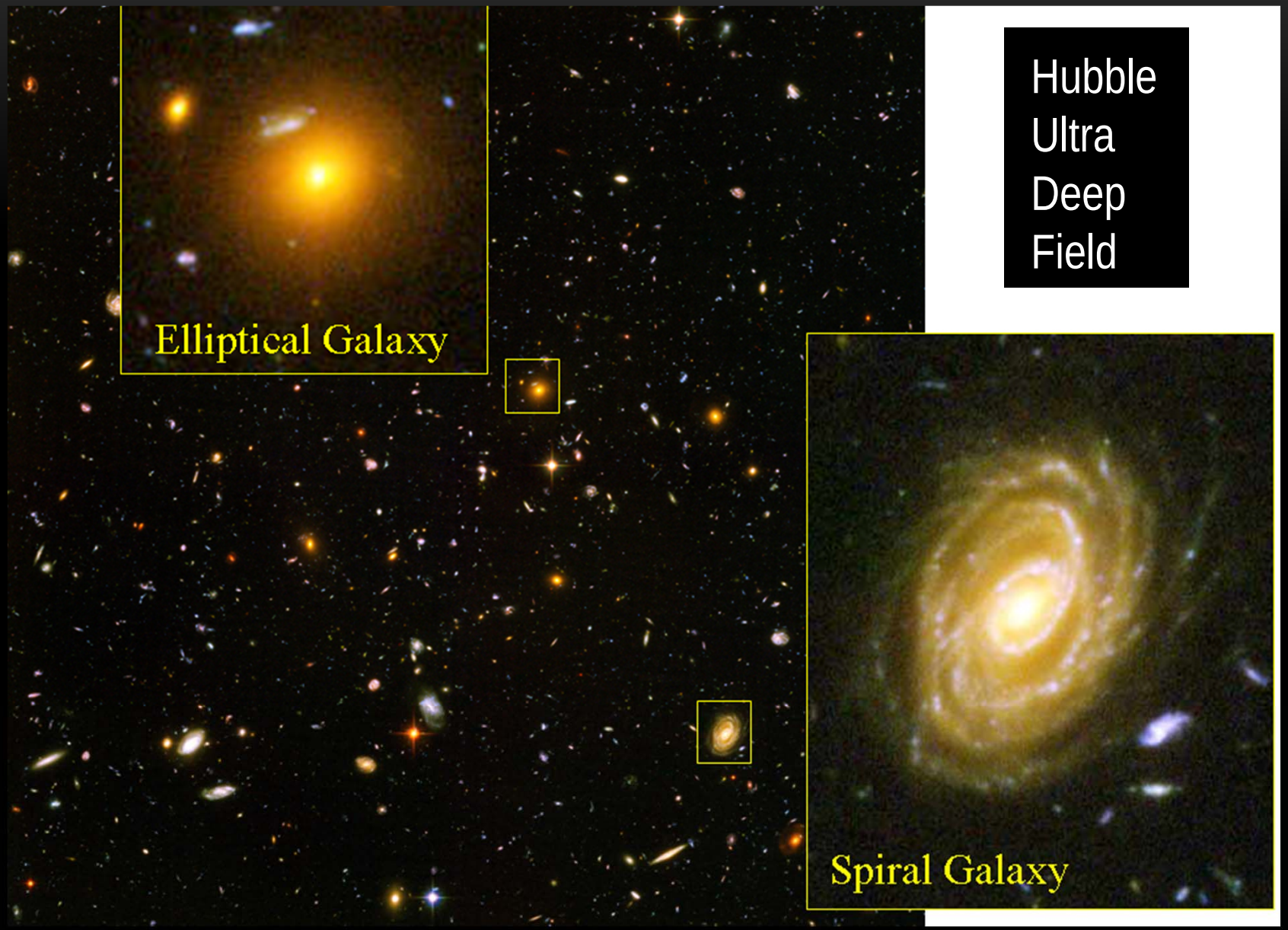
- Same idea, done in 2004 from months of exposure
- (*in 2012, this was one-upped by the Extreme Deep Field*)

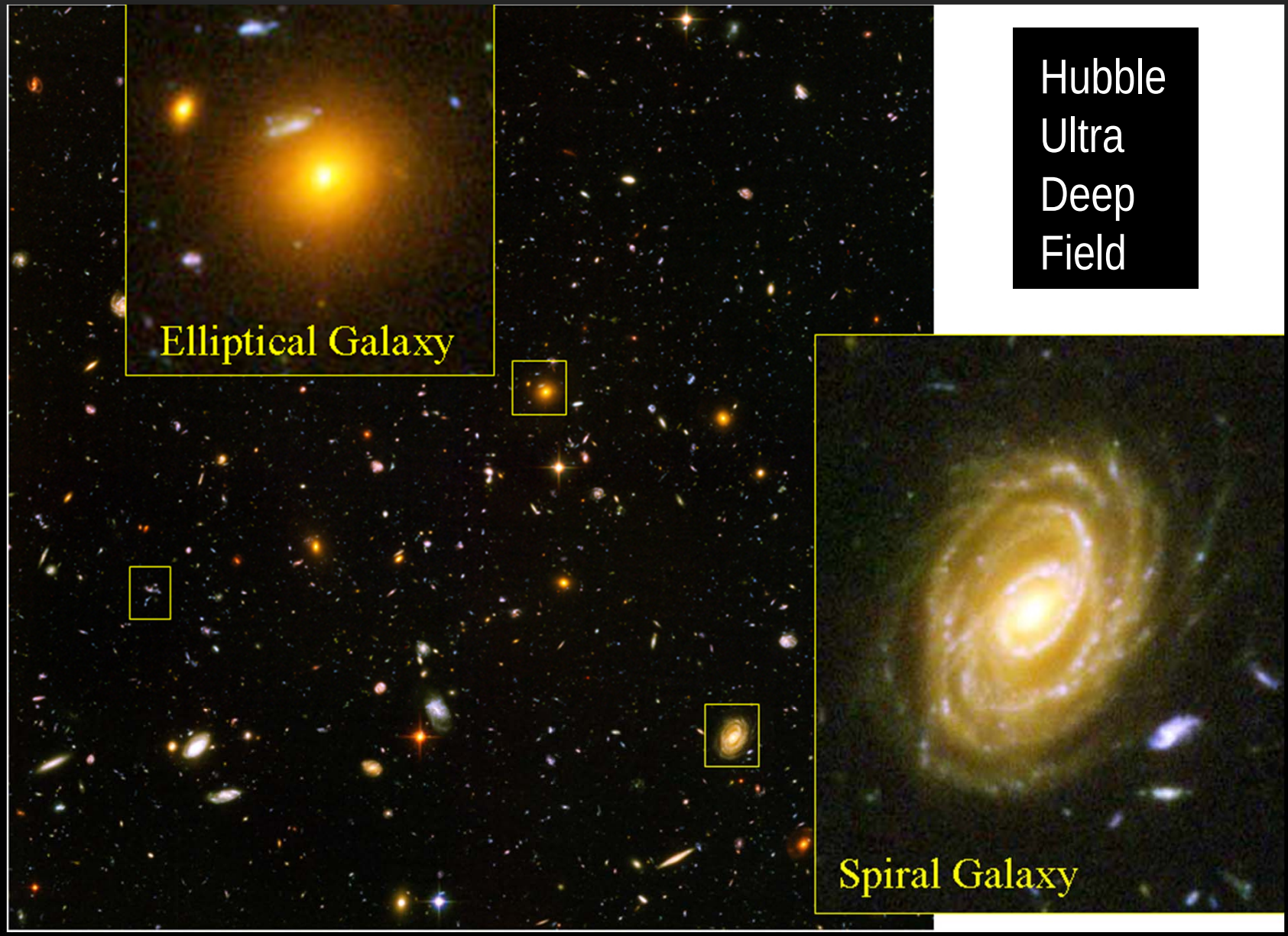


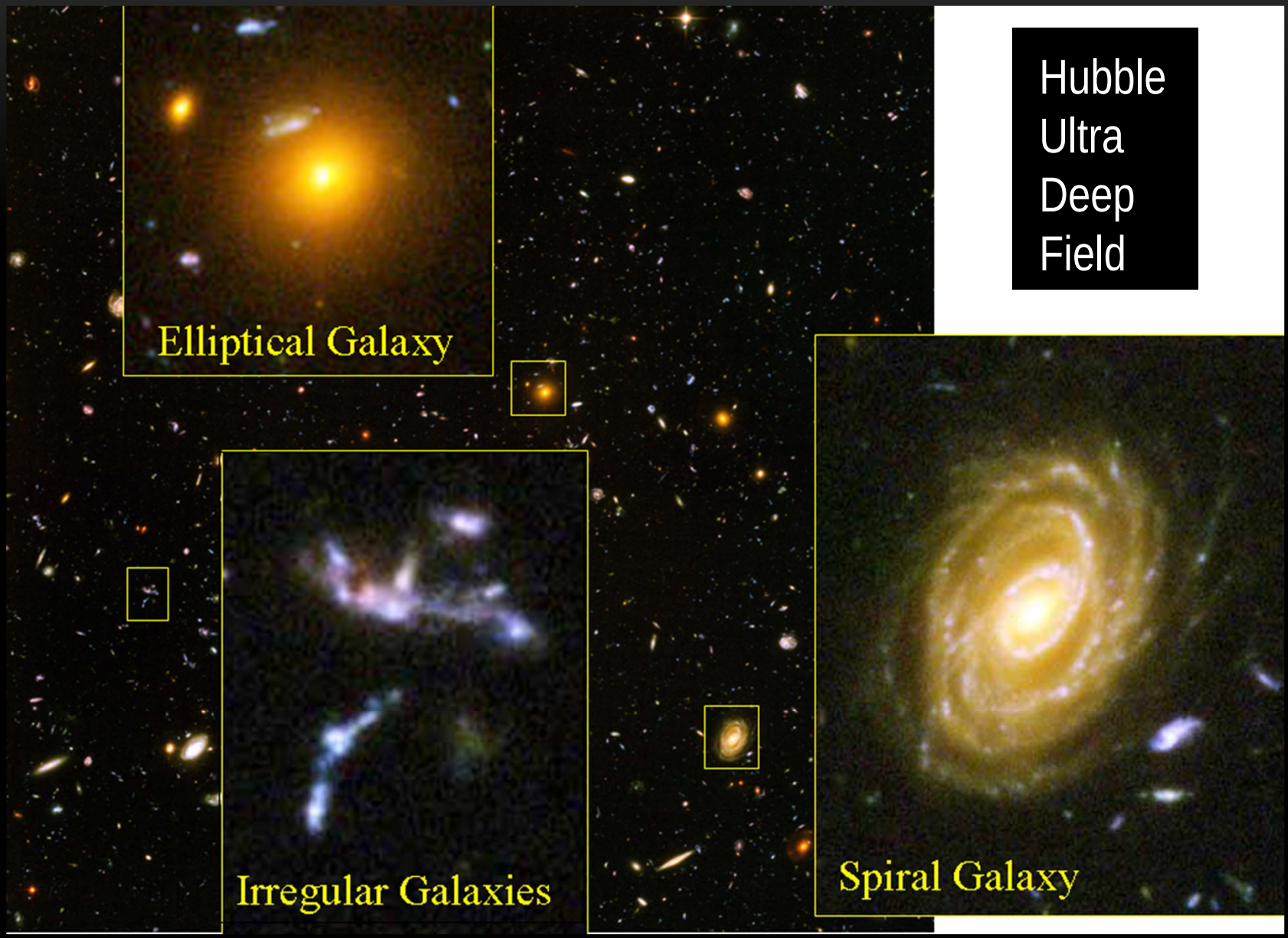
Hubble Ultra Deep Field


Hubble
Ultra
Deep
Field
Spiral Galaxy


Hubble
Ultra
Deep
Field
Spiral Galaxy


Hubble
Ultra
Deep
Field
Elliptical Galaxy
Spiral Galaxy


Hubble
Ultra
Deep
Field
Elliptical Galaxy
Spiral Galaxy


Hubble
Ultra
Deep
Field
Elliptical Galaxy
Irregular Galaxies
Spiral Galaxy

DIFFERENT TYPES OF GALAXIES

M100 © Anglo-Australian Observatory
Photo by David Malin

- In addition to seeing them at different angles, they come in different shapes
- M100 has a small nucleus and big arms

BARRED SPIRALS

- Some spirals have a central “bar” structure
- The Milky Way is probably similar to this

NGC 1300
by S. Lee
& D. Malin

BIG NUCLEI

- Some have more nucleus than arms

"Sombrero" galaxy
M104 VLT image
by P. Barthel *et al*

SAME CONSTRUCTION AS THE MILKY WAY

Fig.16.2

Blue-white color indicates ongoing star formation.

Disk Component: stars of all ages, many gas clouds

Spheroidal Component: bulge and halo, old stars, few gas clouds

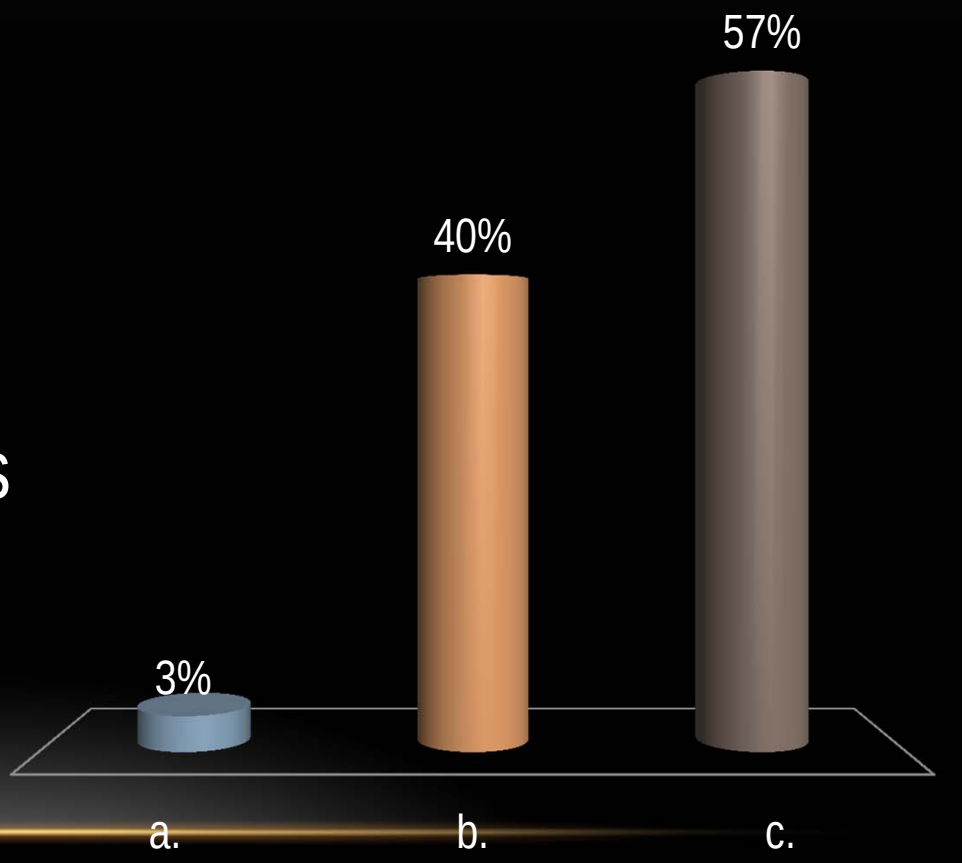
Red-yellow color indicates older star population.

WHY DOES ONGOING STAR FORMATION LEAD TO A BLUE-WHITE APPEARANCE?

a. There aren't any red or yellow stars.

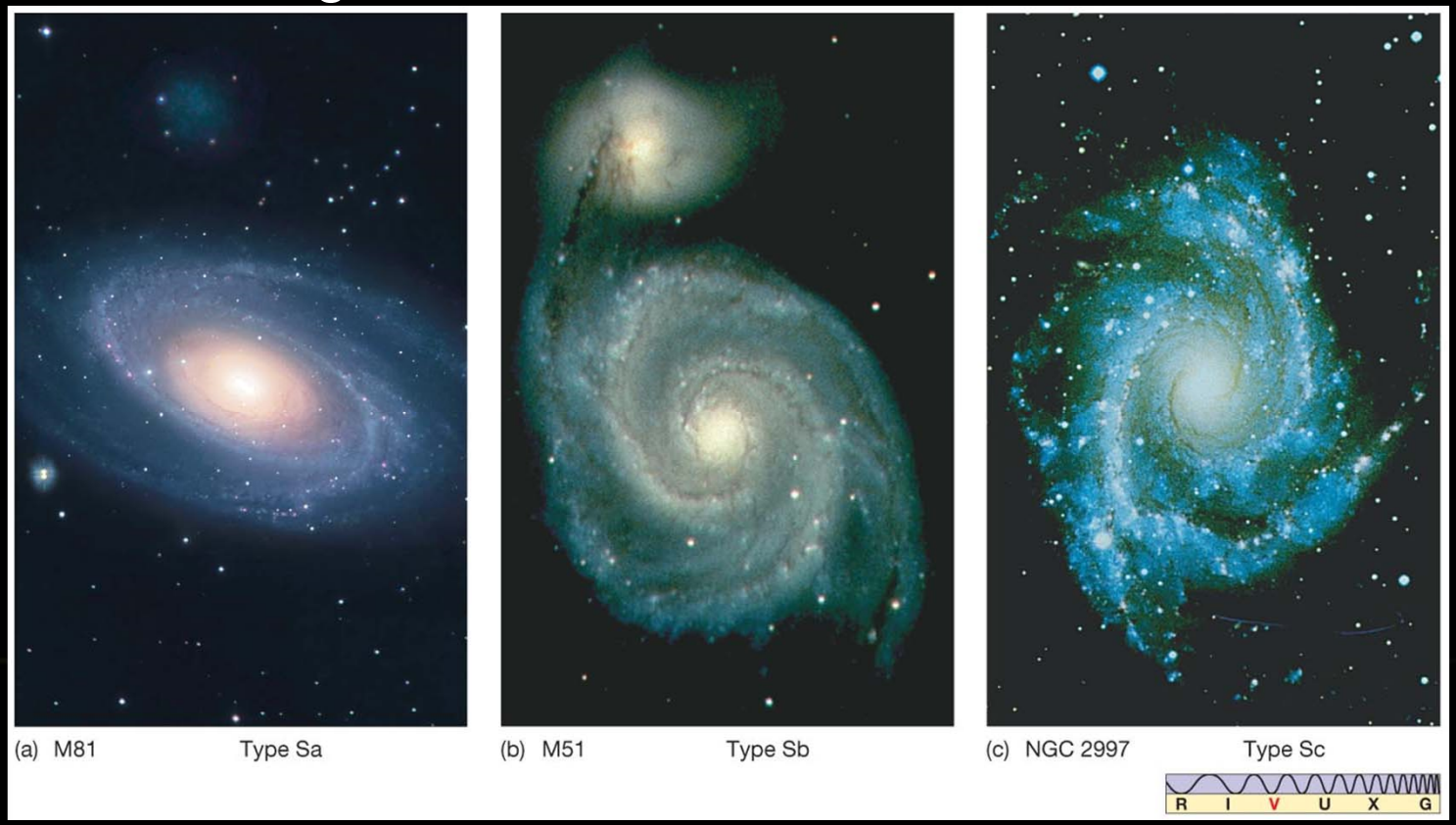
b. Short-lived blue stars outshine others.

c. Gas in the disk scatters blue light.



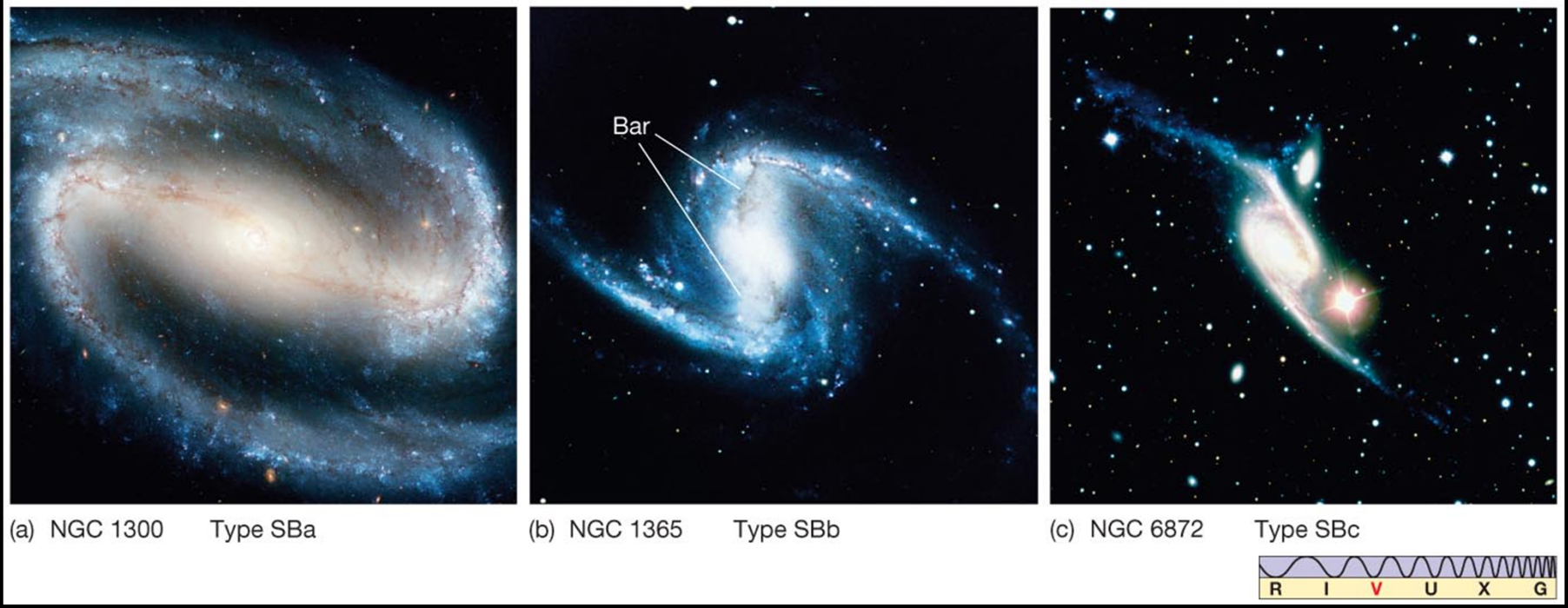
CLASSIFY THEM

- Spiral galaxies are classified by the size of their central bulge



BARRED SPIRALS

- Some have an elongated bulge



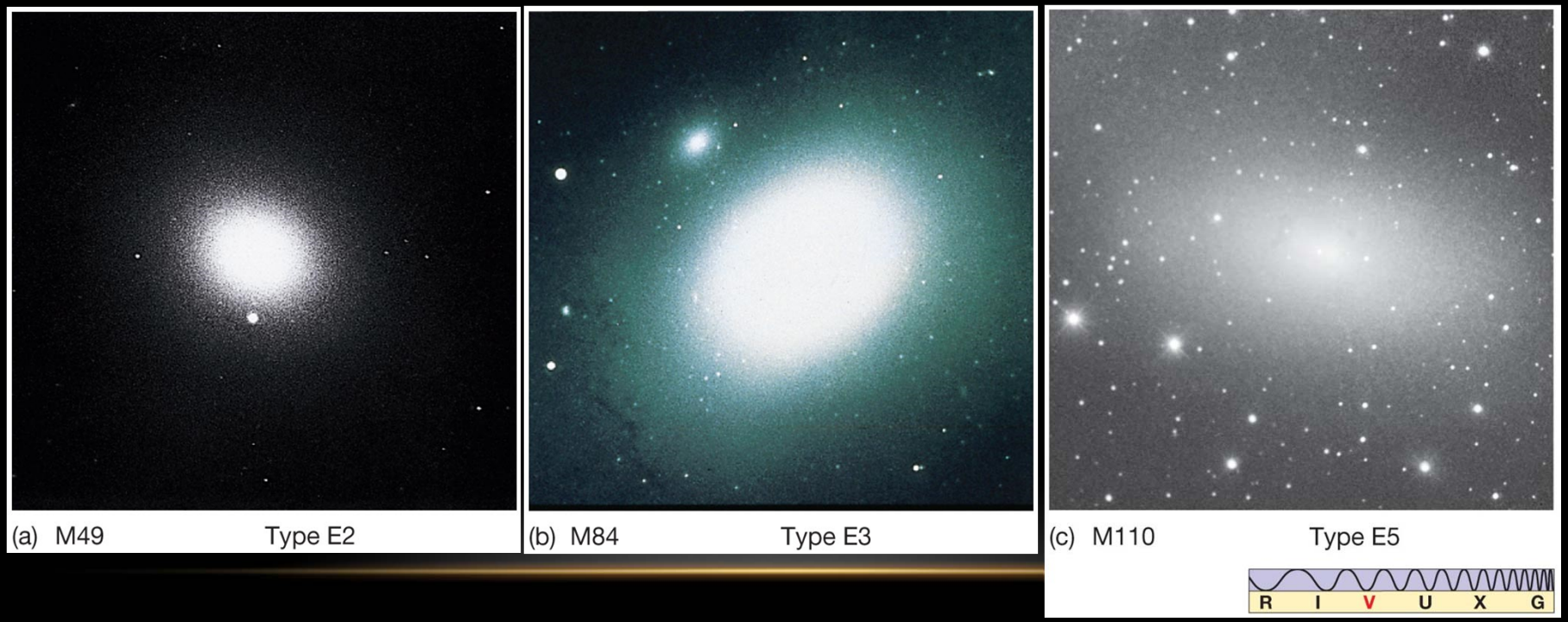
ELLIPTICAL

M87 © Anglo-Australian Observatory
Photo by David Malin

- Some galaxies have no arms
- Just big ellipsoids
- This is M87 (it's huge, too – many times the mass of the Milky Way)
  - Also has thousands instead of hundreds of globular clusters

ELLIPTICAL

- Classify by how squashed



IRREGULAR

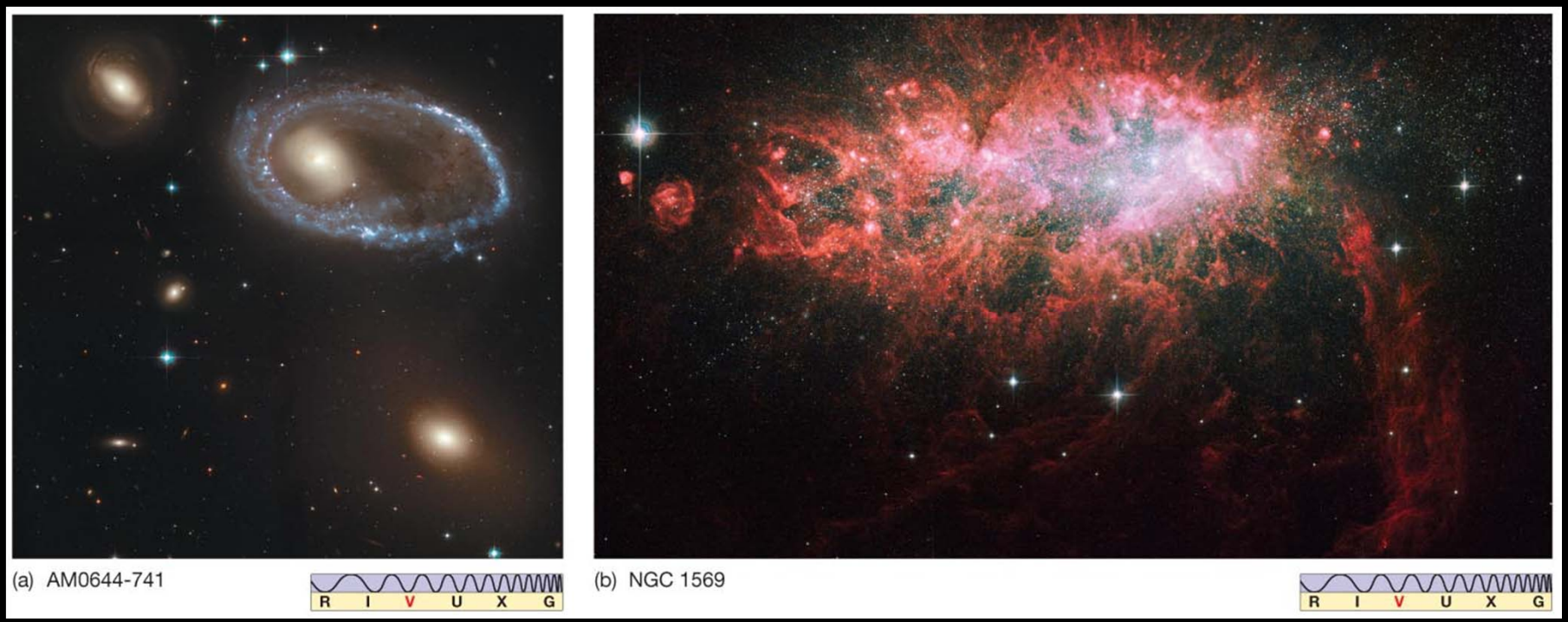
- Some are all messed up
- “Barnard’s Galaxy” NGC6822
  - Only 1.5 million ly away
  - Note the emission nebulae

LARGE MAGELLENIC CLOUD

- Satellite galaxy of our own
  - Only 180,000 ly away
- Irregular
- Note nebulae

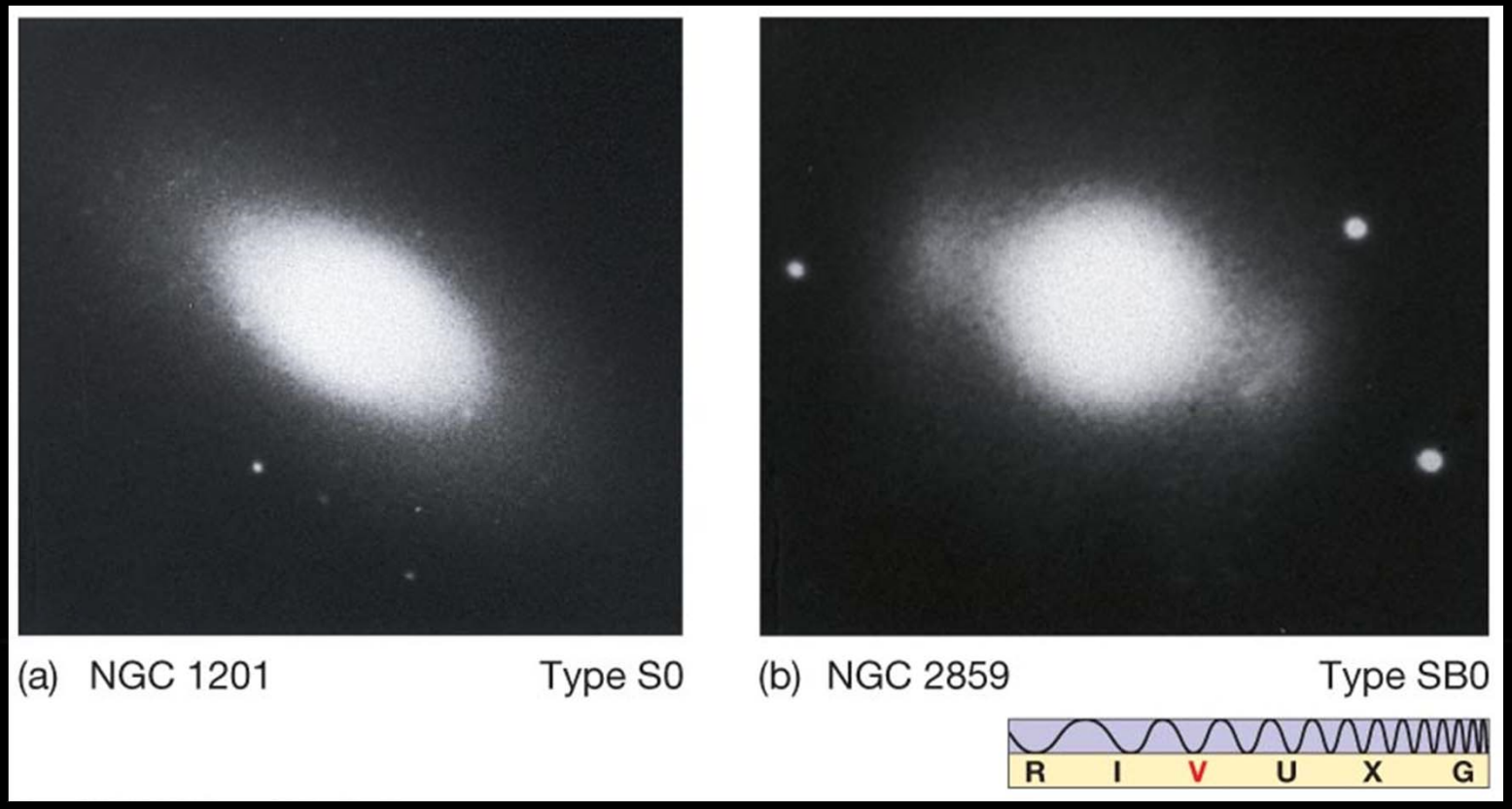
IRREGULAR

- Often appear to be in the midst of collisions with other galaxies
  - What do all those emission nebulae and blue light tell us?



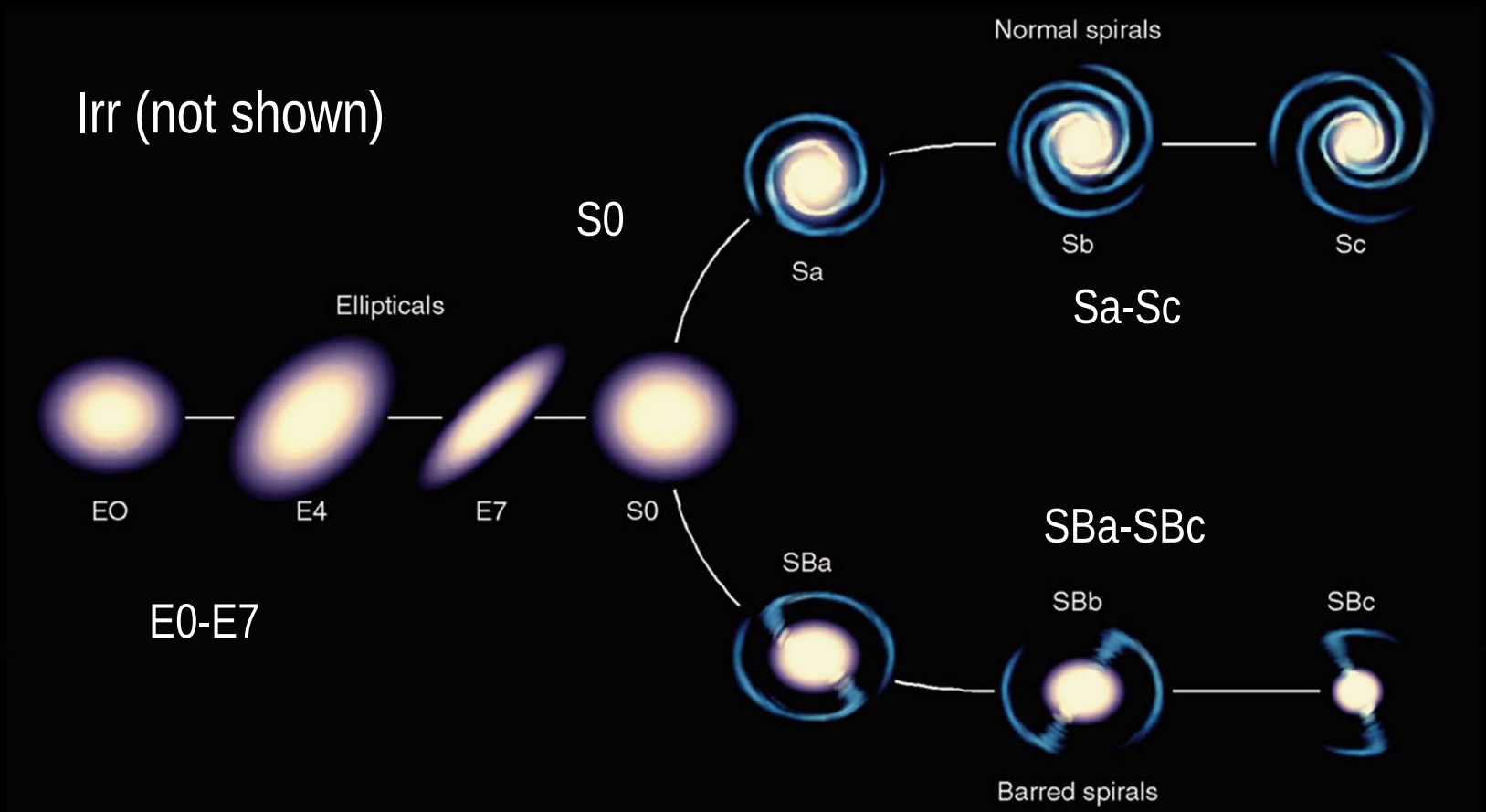
LENTICULAR

- Have disk but no arms (and no gas & dust)



HUBBLE CLASSIFICATION

- Edwin Hubble sorts galaxies by type



TUNING FORK

- That is known as the “Tuning Fork” diagram
- Just a classification scheme – one galaxy type does not grow into the next

SPIRAL GALAXIES

- Like the Milky Way
- Classified Sa, Sb, Sc
  - From large nuclei with tightly wound arms to small nuclei with loosely wound arms
- S0 have disk, no arms, large nucleus
- Pop II + old Pop I stars in nucleus, disk
- Pop I stars in arms
  - Where star formation is happening
- Much gas, dust in disk

BARRED SPIRALS

- Like normal Spirals only they have a rectangular bar structure
- Milky way probably is one of these
- Classified SBa, SBb, SBc
  - Similarly to normal spirals
- Same general size & stellar population as normal spirals

ELLIPTICALS

- Classified E0 (round) through E7 (stretched out)
- The very hugest galaxies are all elliptical
- Most galaxies in the universe are small dwarf elliptical galaxies
  - Almost like glorified globular clusters
- Mostly Pop II and old Pop I stars
  - Little star formation seen
- Little dust or cool gas
  - But often have a very diffuse, very hot gas in x-rays

IRREGULARS

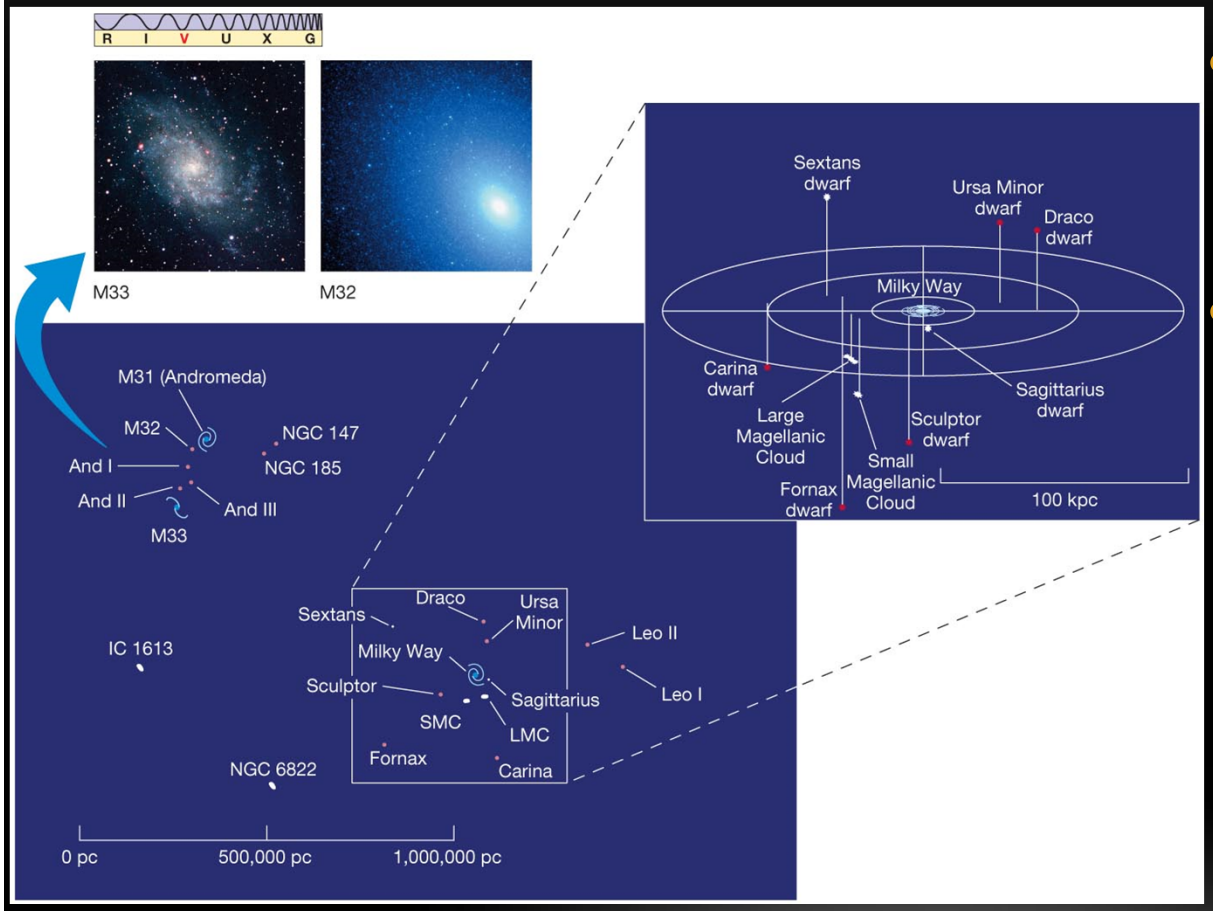
- Whatever is doesn’t fit into one of the other categories
- Usually small
- Mostly Pop I stars
- Often associated with colliding galaxies

HOW ARE GALAXIES GROUPED TOGETHER IN SPACE?

Fig.16.8

- Spiral galaxies are often found in “groups” of galaxies
  - Up to a few dozen galaxies per group

THE LOCAL GROUP



- Galaxies in a group orbit its common center of mass
- Milky Way and Andromeda are the two biggest members of the “Local Group” cluster
  - 45 galaxies, three are big spirals

CLUSTERS

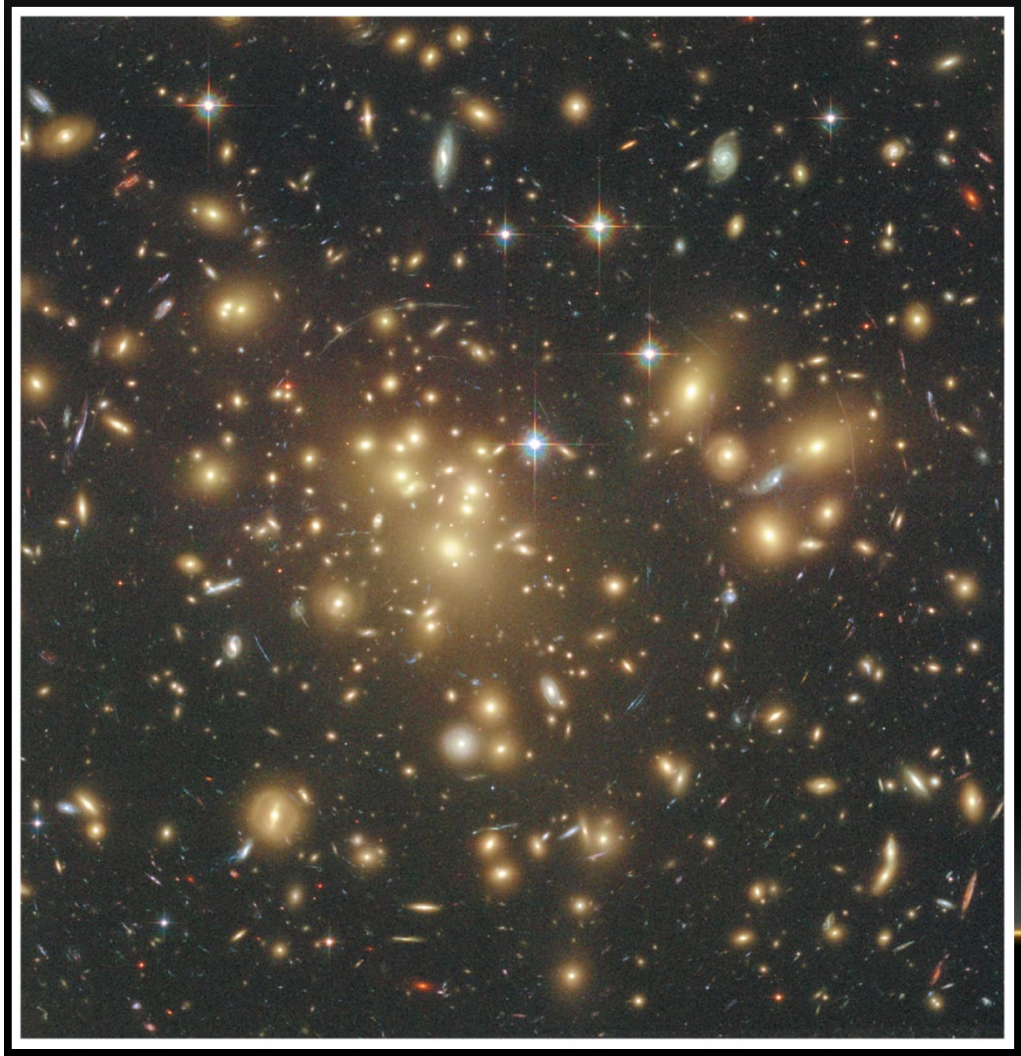
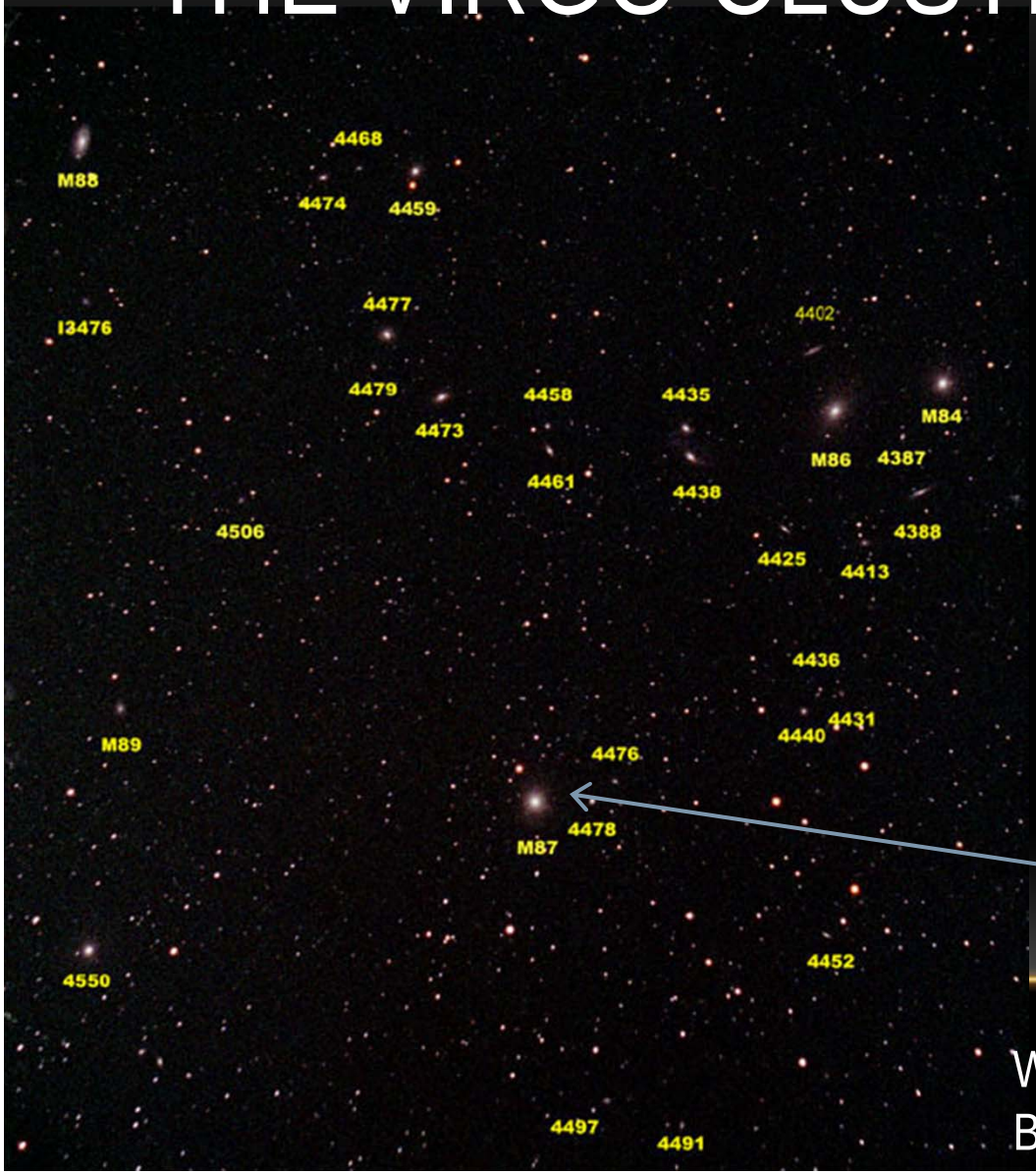


Fig.16.9

- Elliptical galaxies are more common in “clusters” of galaxies
  - Hundreds to thousands of galaxies
  - All orbiting its center of mass

THE VIRGO CLUSTER

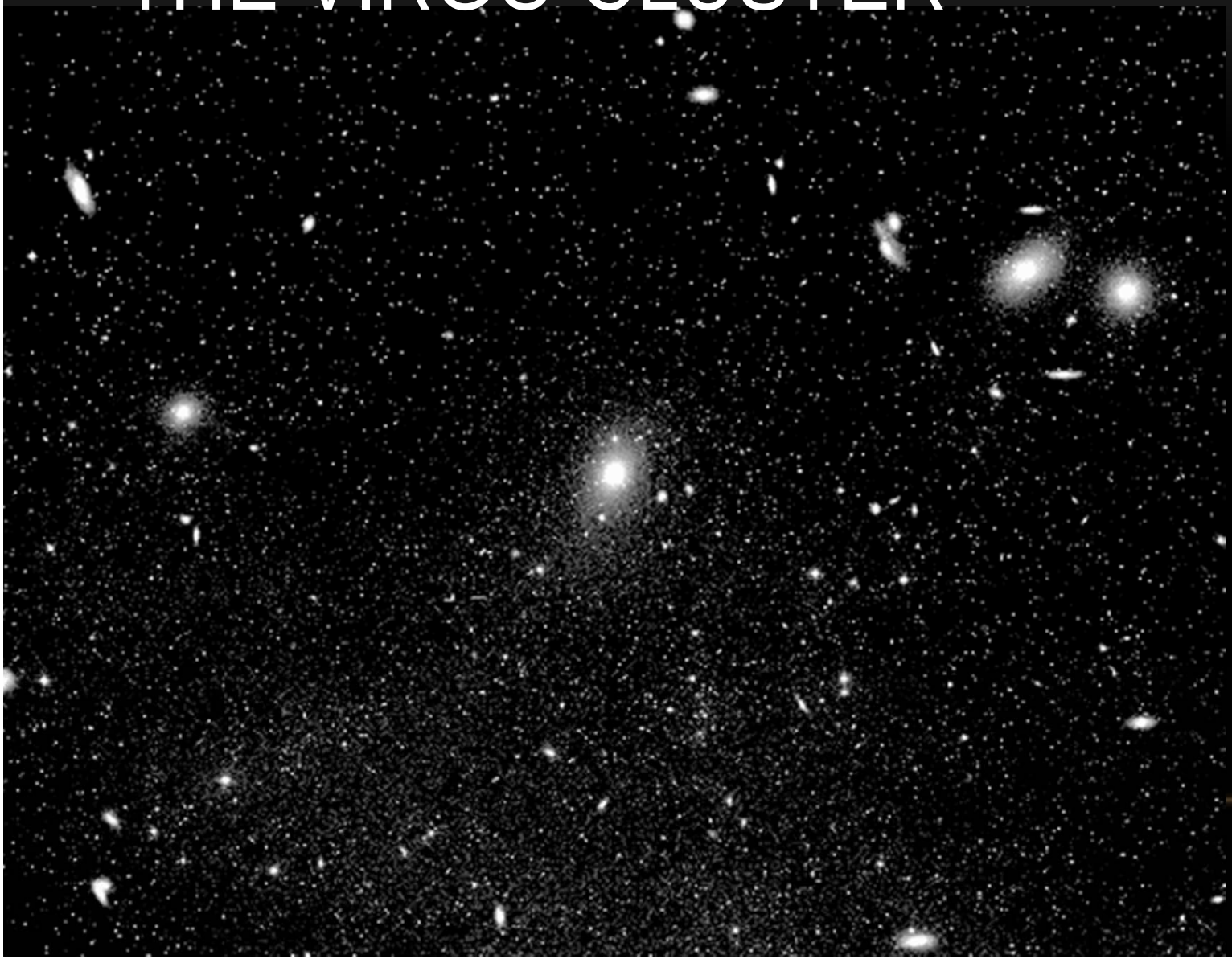


- A much larger nearby galaxy cluster
- About 17 Mpc away
- 3500 galaxies
- About 3 Mpc wide

M87, a huge elliptical galaxy in the Virgo Cluster

Wide-field image of Virgo Cluster
By Matt BenDaniel

THE VIRGO CLUSTER



A close-up of M87 and surrounding Virgo Cluster Galaxies

(*from the Palomar Sky Survey*)

PROPERTIES TO MEASURE

- We would like to know about Galaxies:
  - Distance
  - Mass
  - Velocity
  - Composition
- “Composition” in this case is what sort of stars are in there (all that Pop I, II stuff)

DISTANCE

PLAY

- Can just radar around our solar system PLAY
- With Stars, we saw:
  - Close by: parallax: knowing size of Earth's orbit, compare apparent motion of stars as we orbit