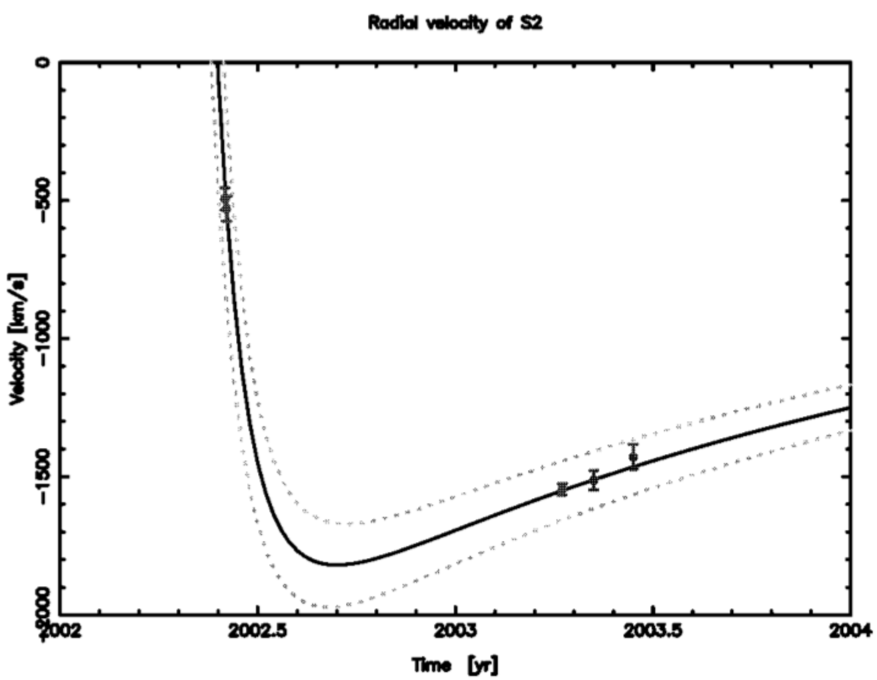
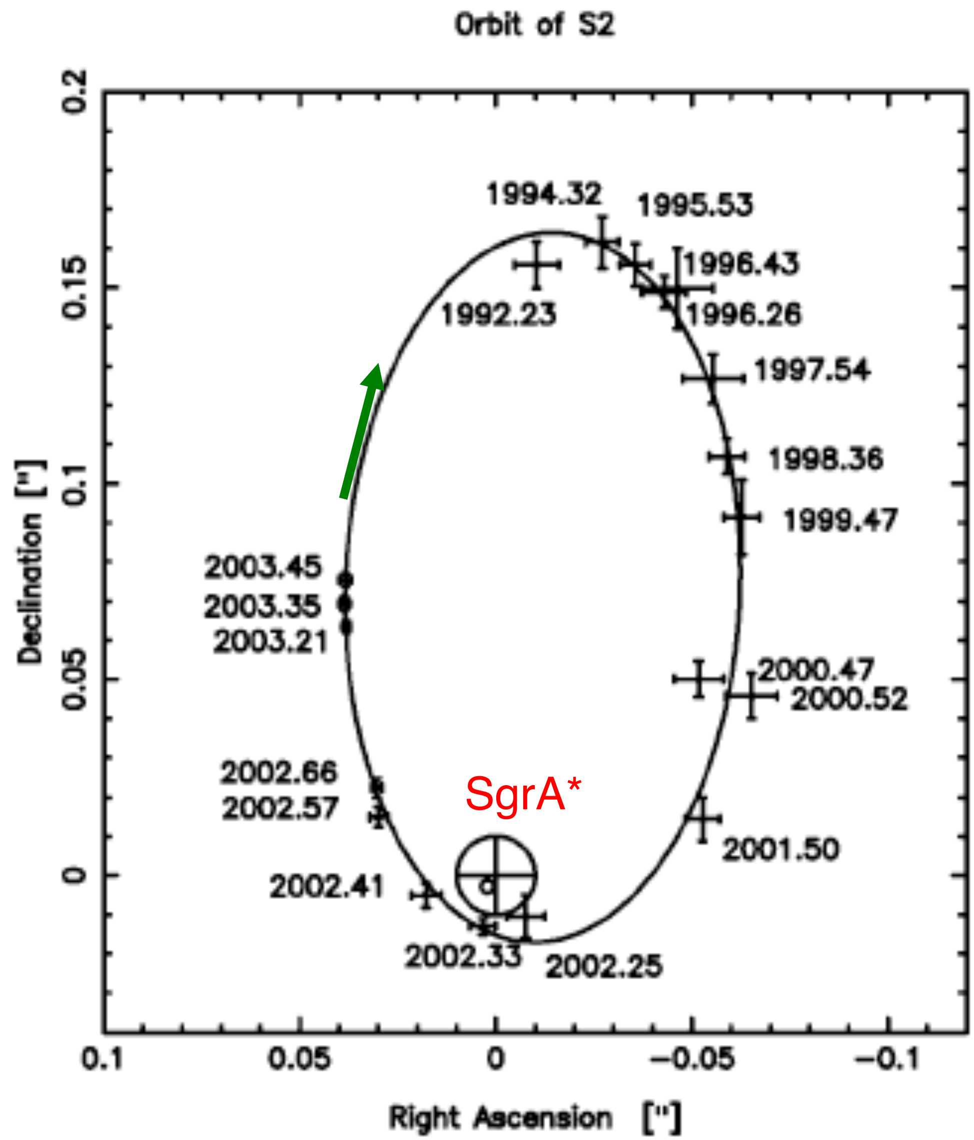
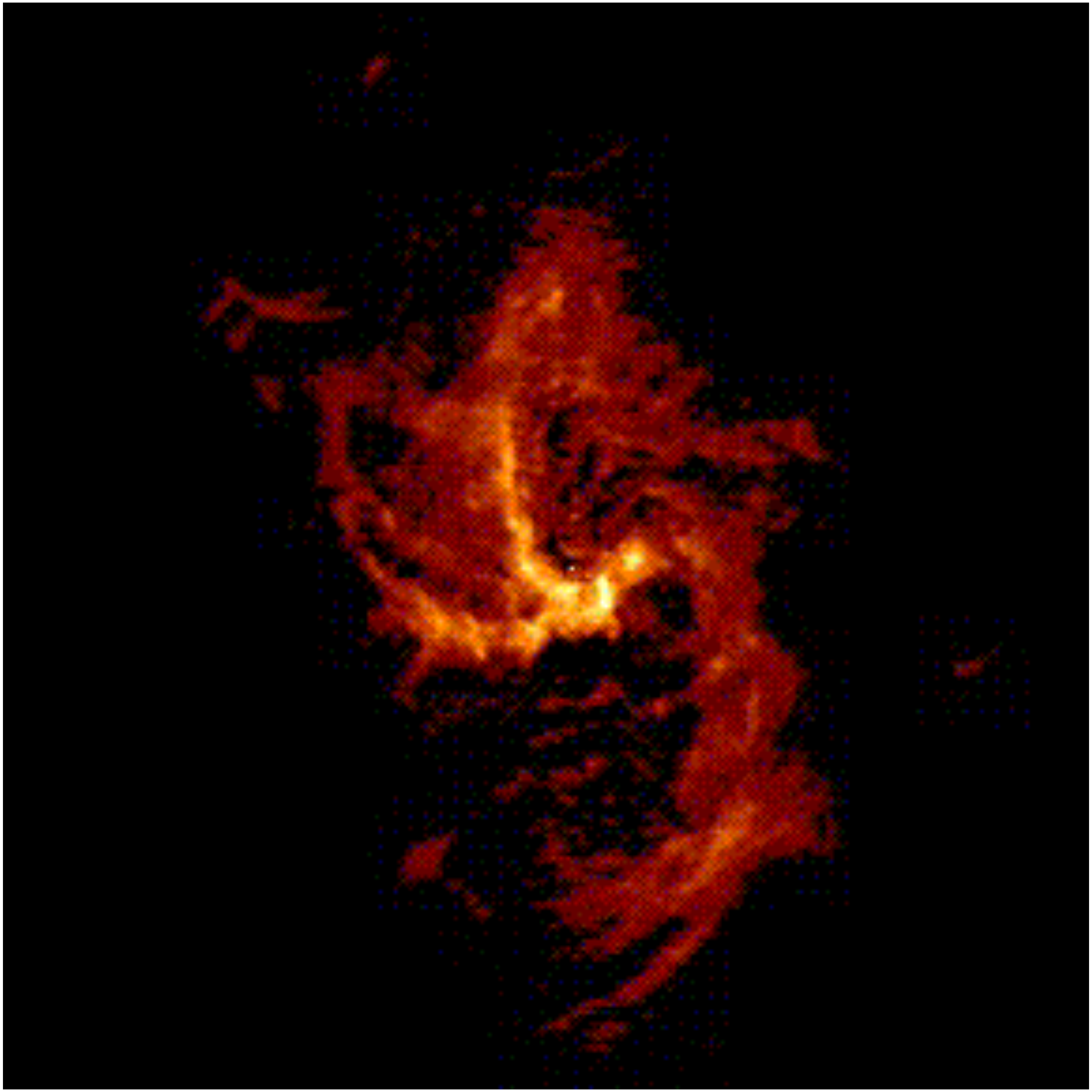
Precise Distance to Galactic Center

Distance = 7.94 +/- 0.42 kpc

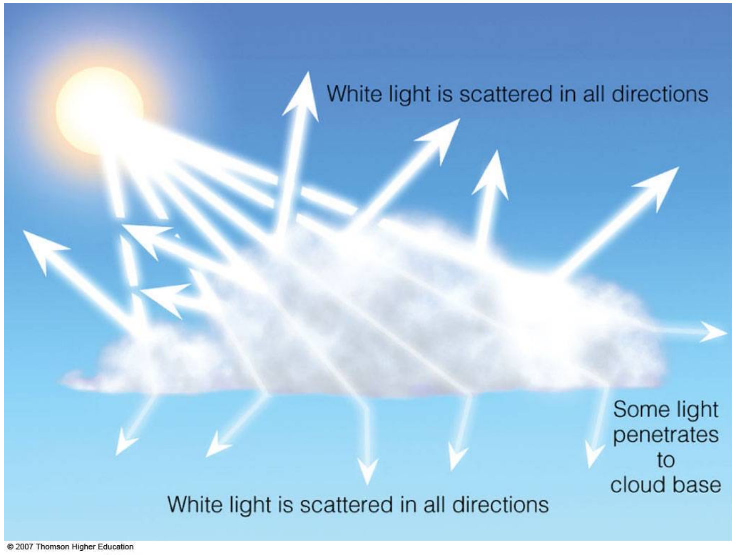
Eisenhauer et al. 2003

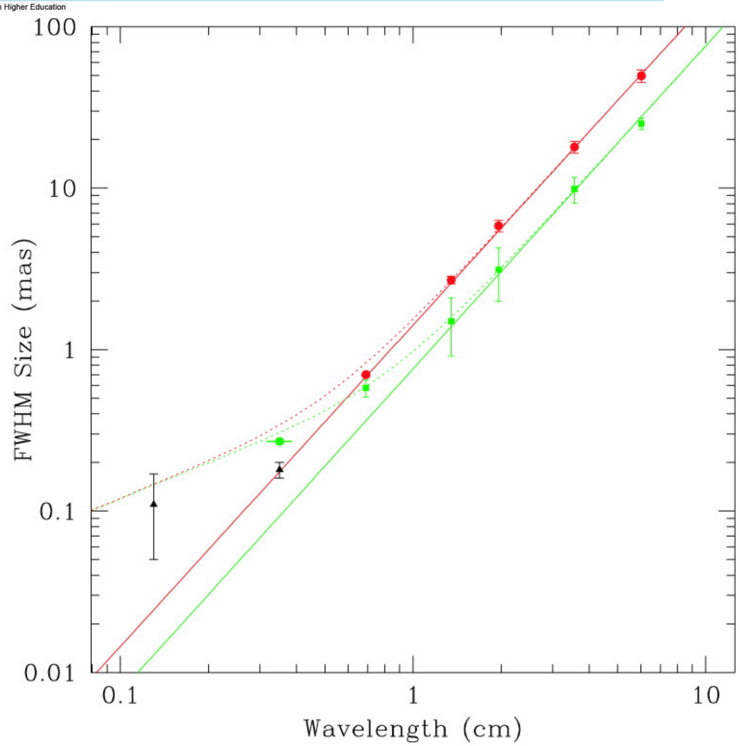


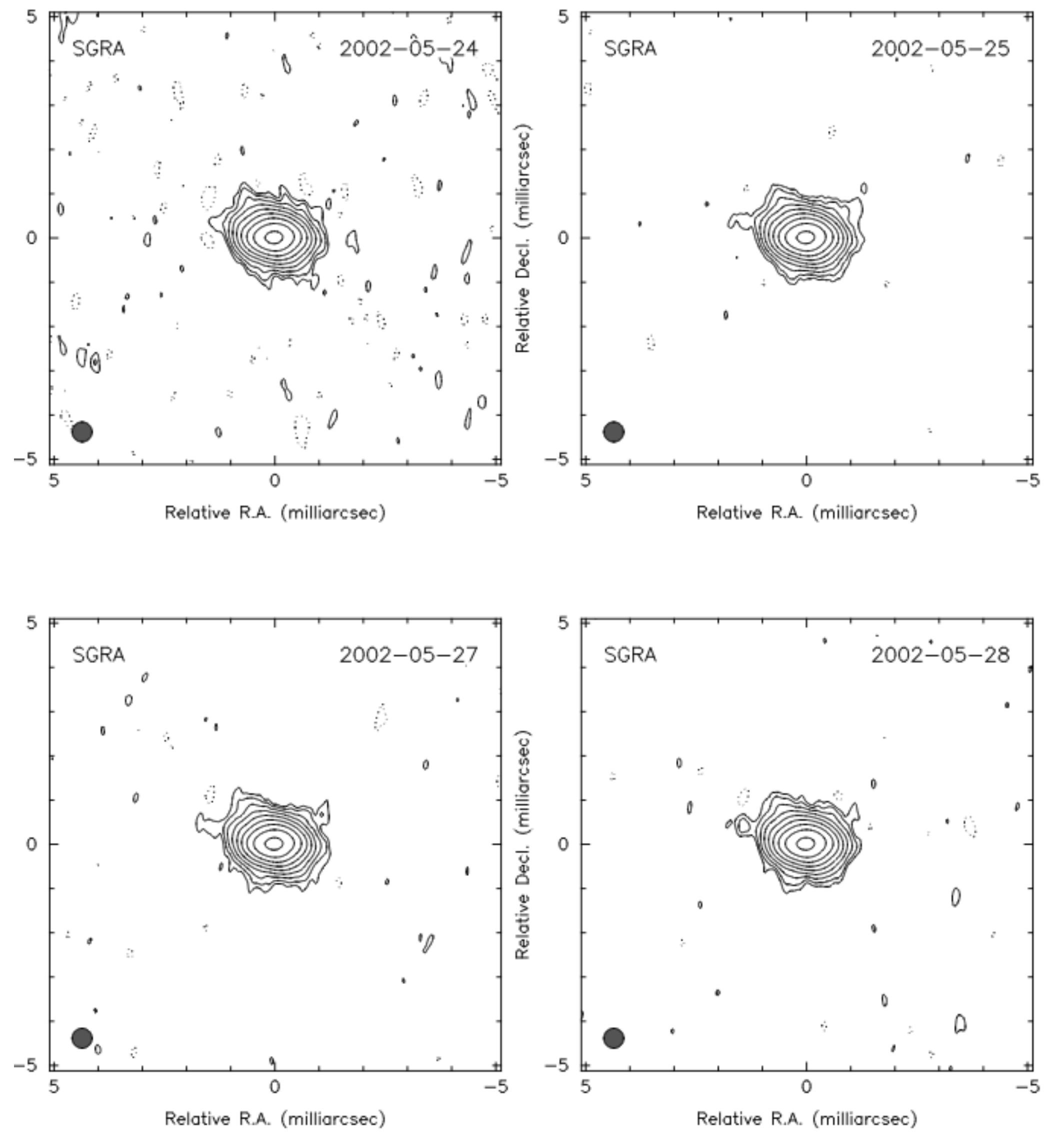




High Resolution Imaging of the Galactic Center







milliarcsec

Galaxies - Chapter 24

Until 1924, people did not know if "spiral nebulae" were in our Galaxy or not.

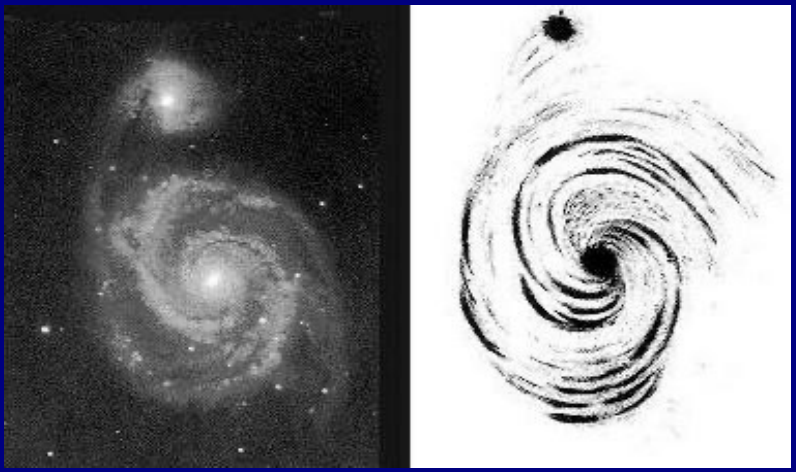
b

vs

a

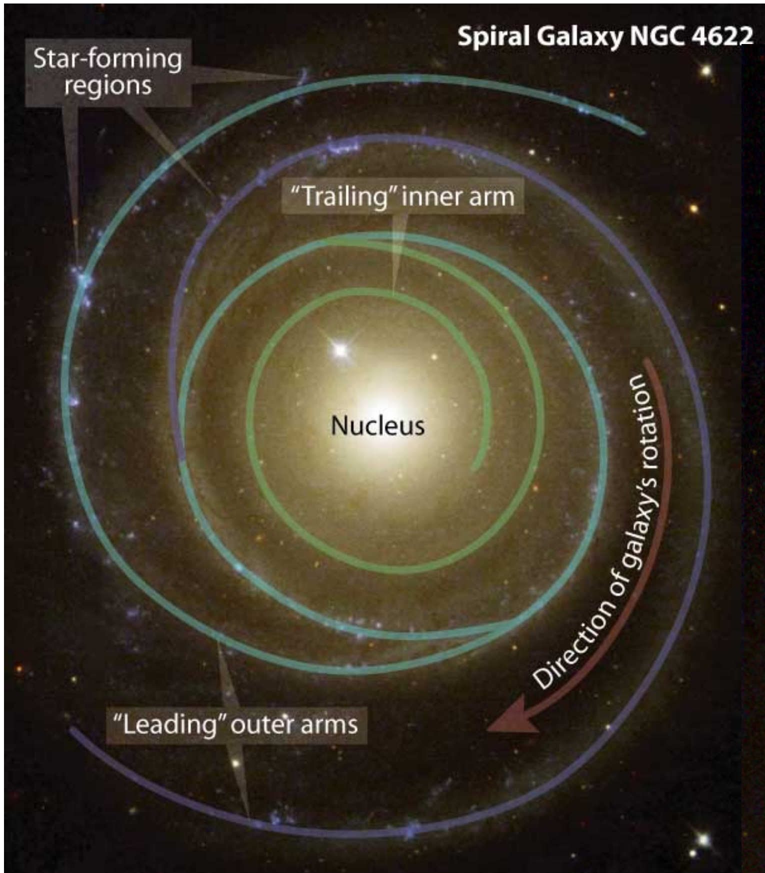
Galaxies

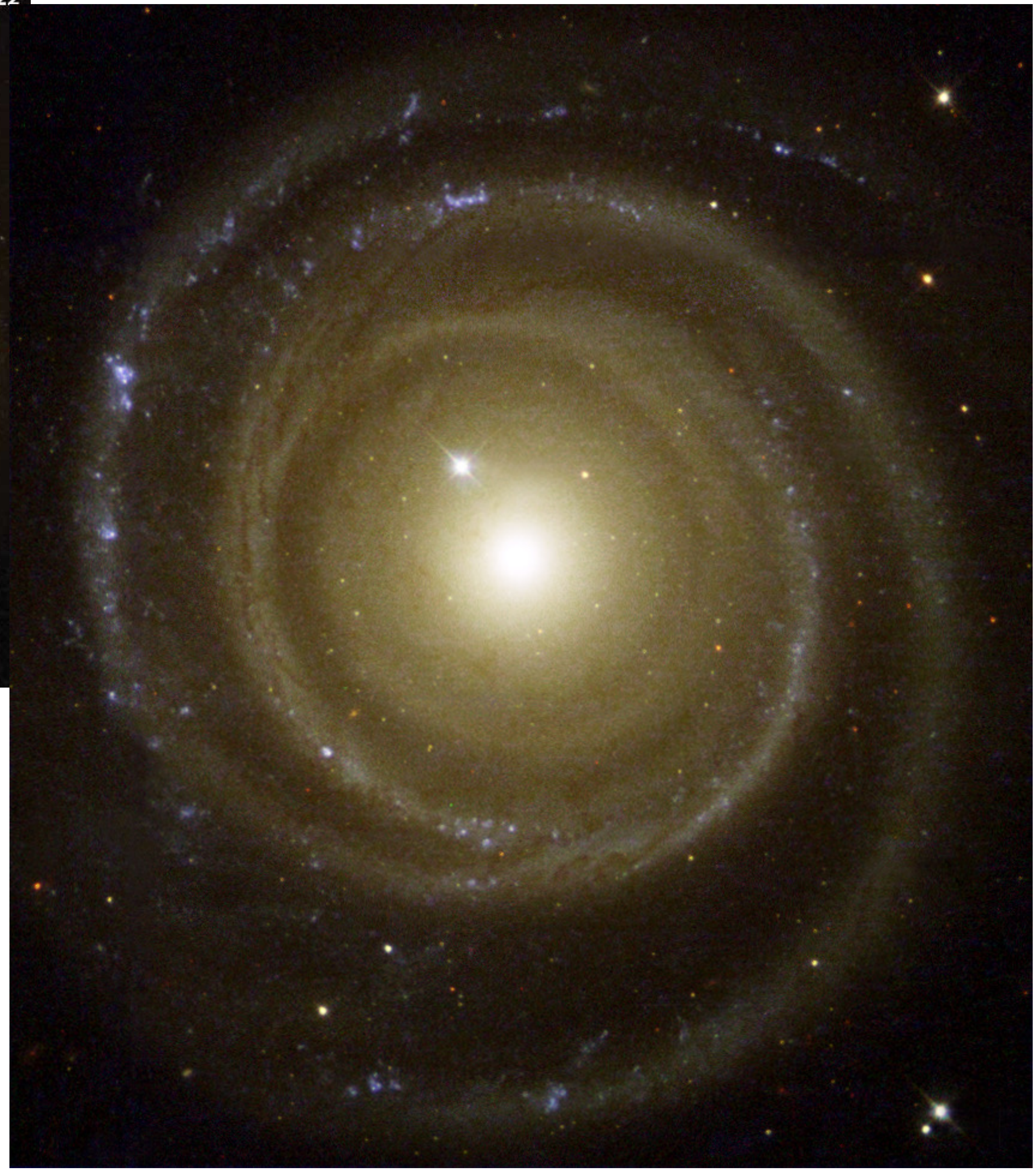
First spiral nebula found in 1845 by the Earl of Rosse.
Speculated it was beyond our Galaxy.



1920 - "Great Debate" between Shapley and Curtis on whether spiral nebulae were galaxies beyond our own. Settled in 1924 when Edwin Hubble observed individual stars in spiral nebulae.

NGC 4662 type SAab
A “backward” galaxy

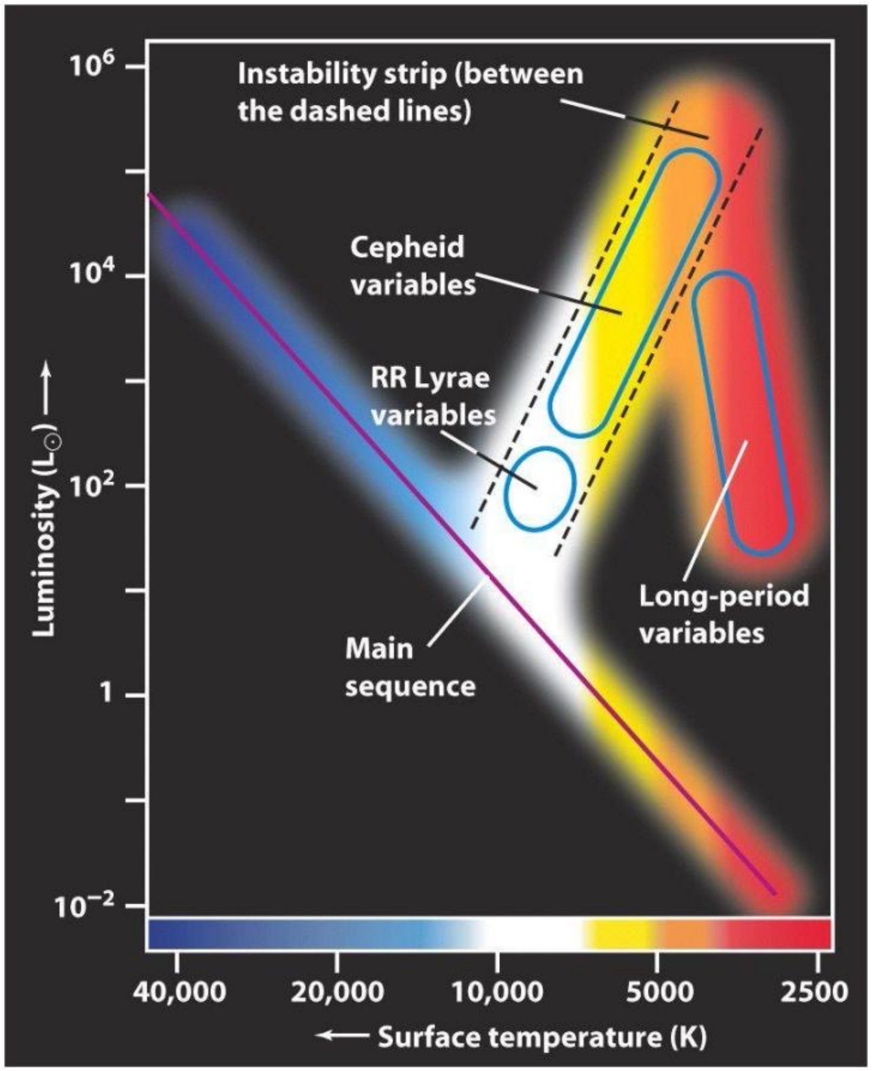

Spiral Galaxy NGC 4622
Star-forming regions
"Trailing" inner arm
Nucleus
Direction of galaxy's rotation
"Leading" outer arms



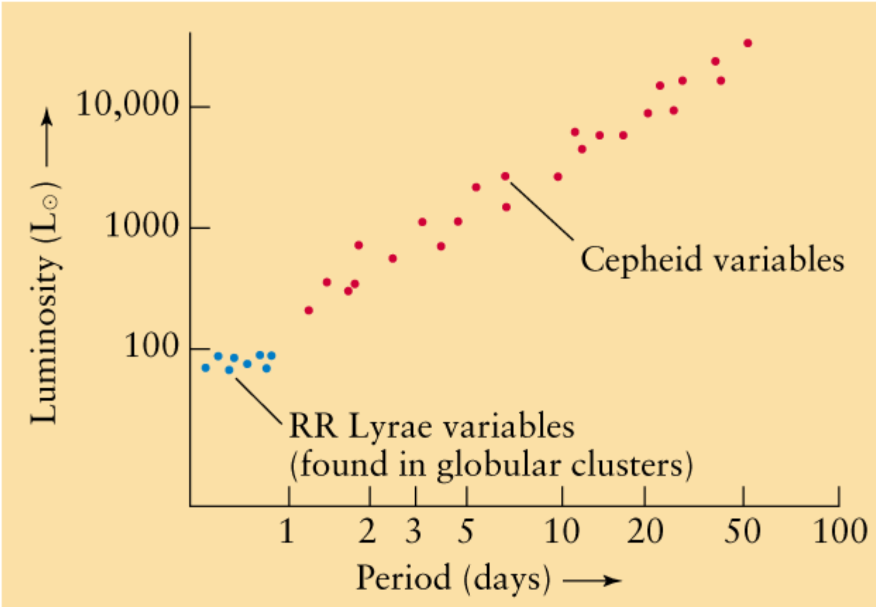

M31 – The Andromeda Galaxy


M51 – The Whirlpool Galaxy

Variable stars



- 1924 – Hubble used Cepheid variable stars to show that the Andromeda galaxy is too far away to be part of the Milky Way.
- Vary in brightness as a result of conditions within the star itself.



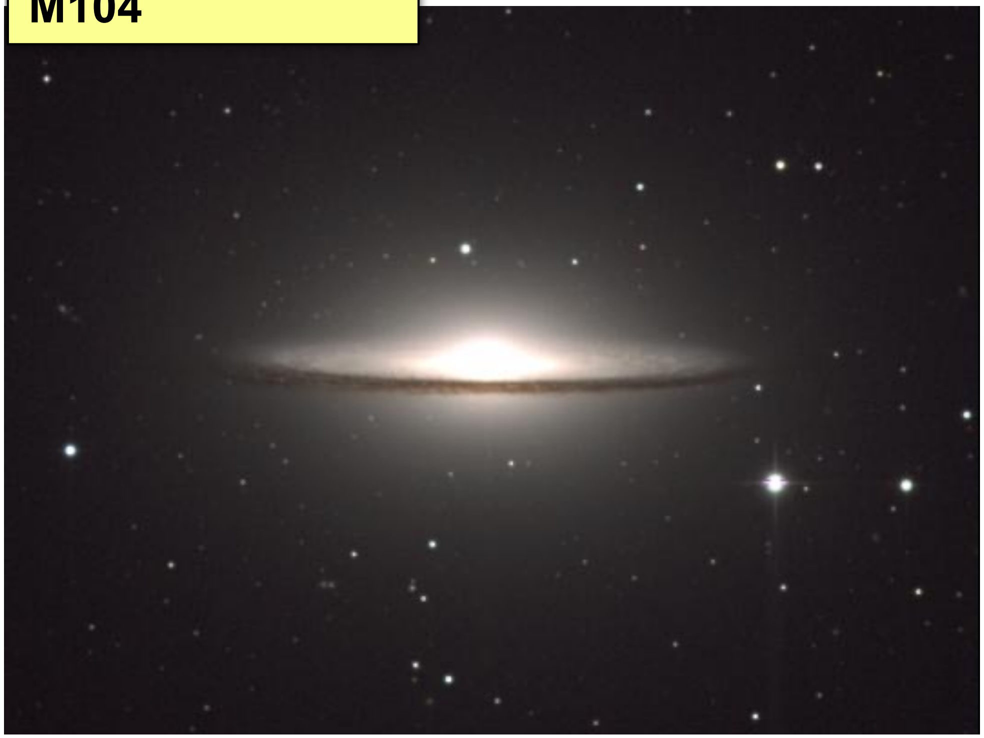
- The P/L relationship for Cepheids.
- Thus, the period will give us the luminosity *L* (or absolute magnitude *M*).
- The P/L relationship for RR Lyrae stars is easy - all have $L \approx 100 L_\odot$ (or $M = +0.5$).

- Knowing *m* and *M*, we can solve for *d:*

$$m - M = 5\log(d) - 5$$

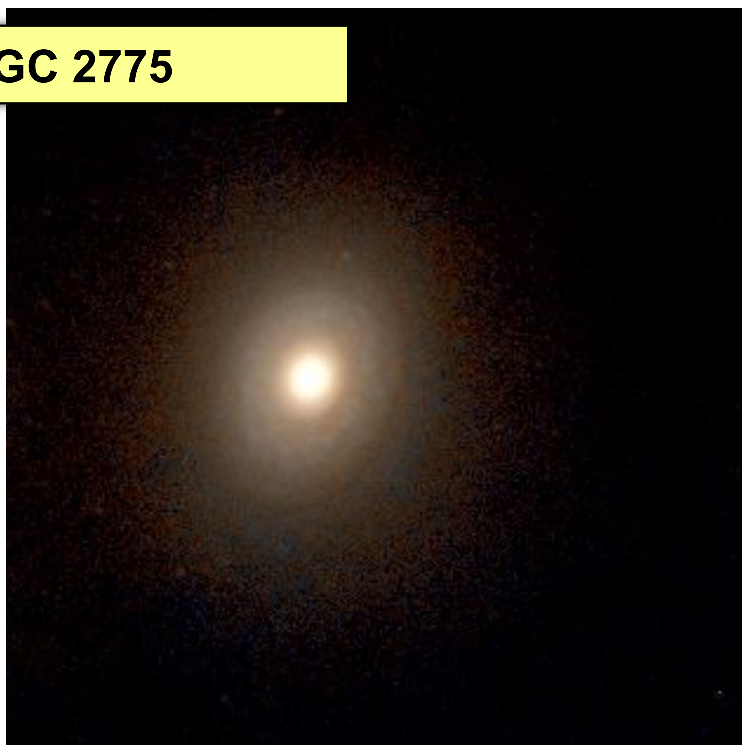
- Hubble showed that "spiral nebulae" are entire galaxies like the Milky Way!

M104

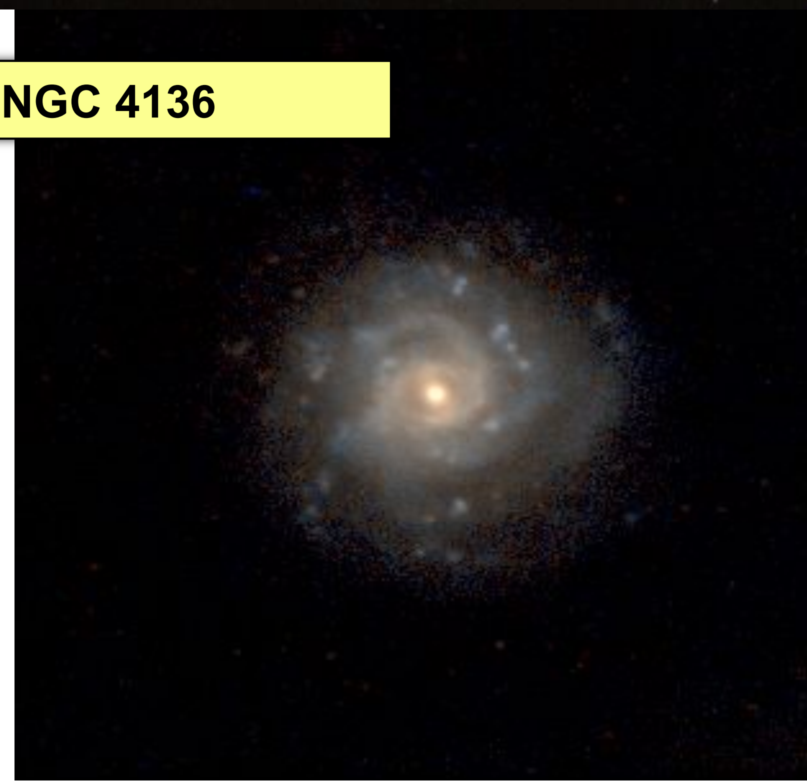


M82

NGC 2775



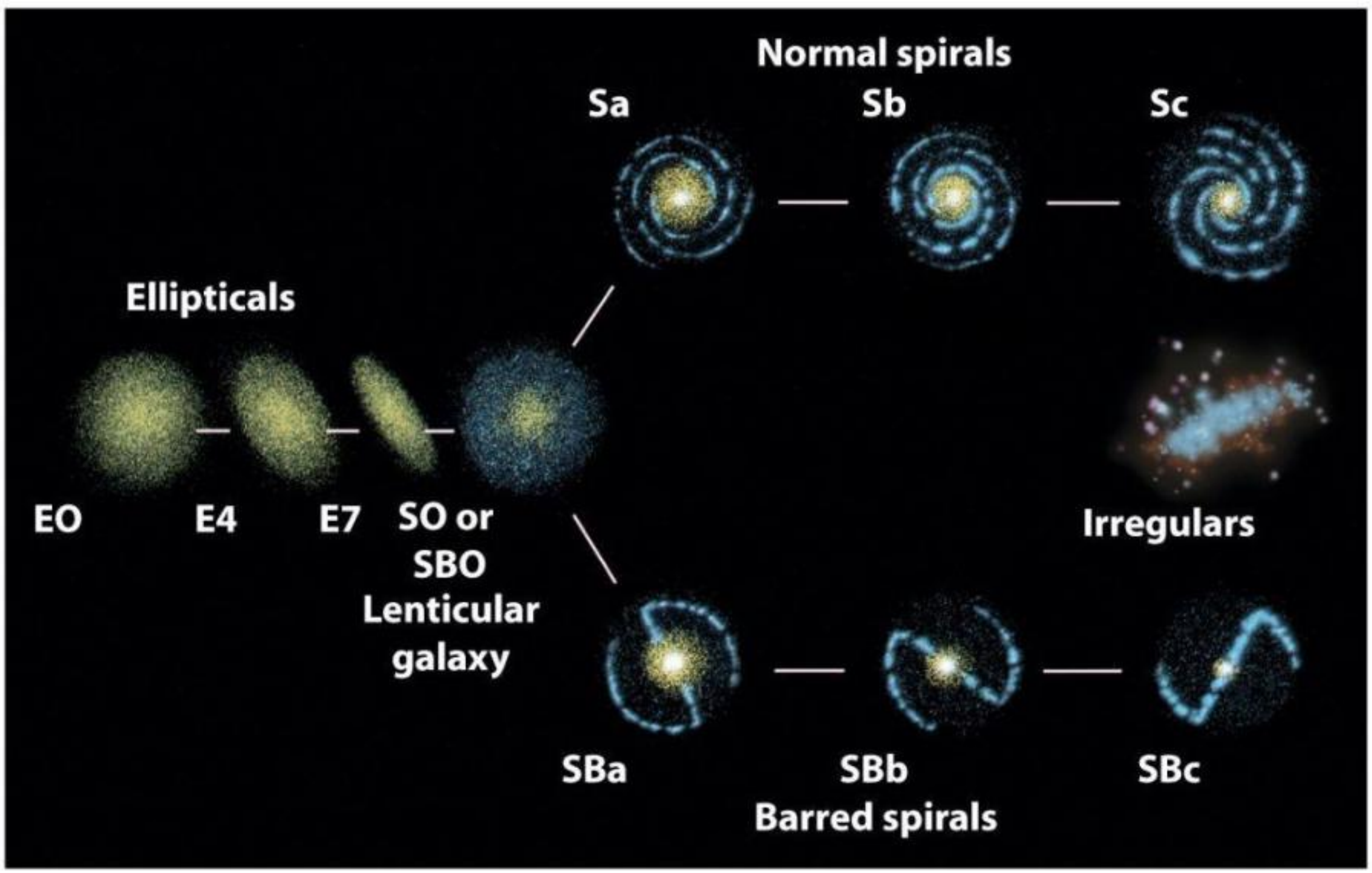
NGC 4136



Galaxy classification: morphology

- All bright galaxies fall into one of three main classes according to their shape:
- Spirals (77%), ellipticals (20%), irregulars (3%).

Hubble types: the *tuning fork* diagram

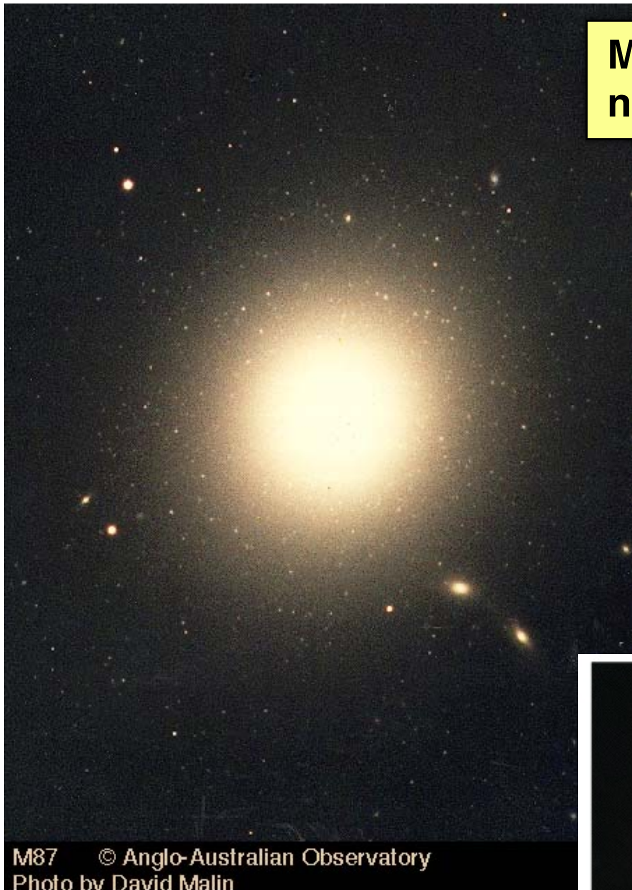


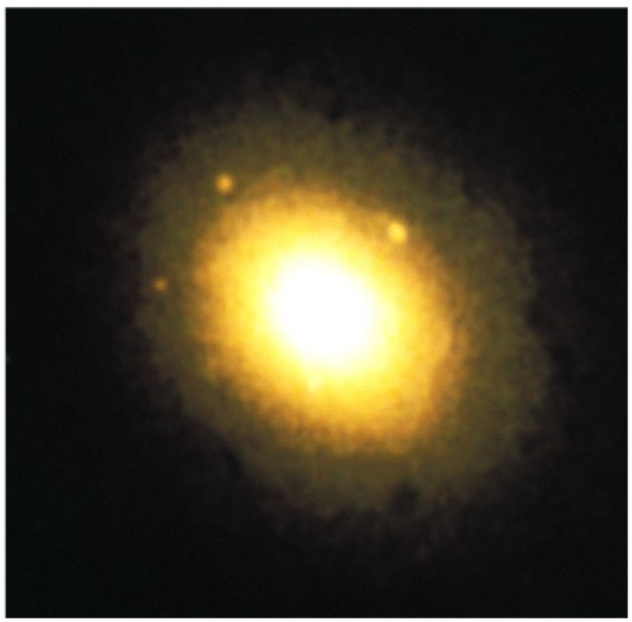
Type E: ellipticals

- Little internal structure, no spiral arms
- Very little cool gas and dust
- No O and B stars - brightest stars are red (old)
- Classify by degree of flattening, or ellipticity E0 $\rightarrow$ E7. In general, En where a=major (long) axis, b=minor (short) axis:

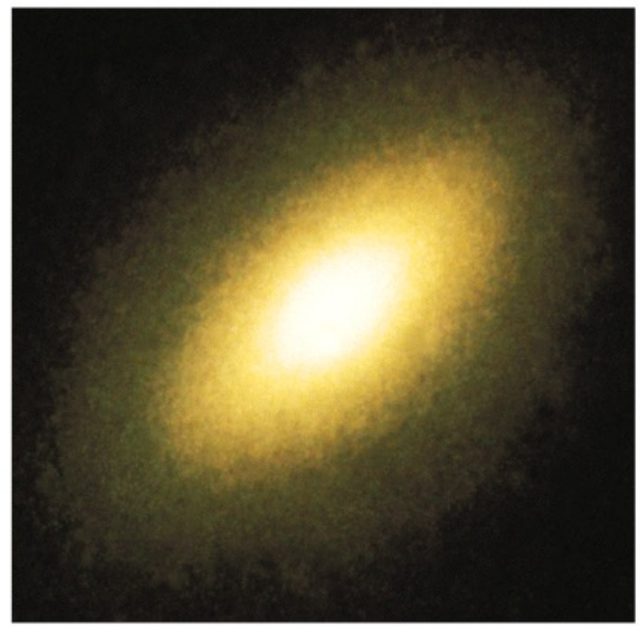
$$n = 10\left(1 - \frac{b}{a}\right)$$

M87 – classic giant E0 galaxy (also has active nucleus – more later).





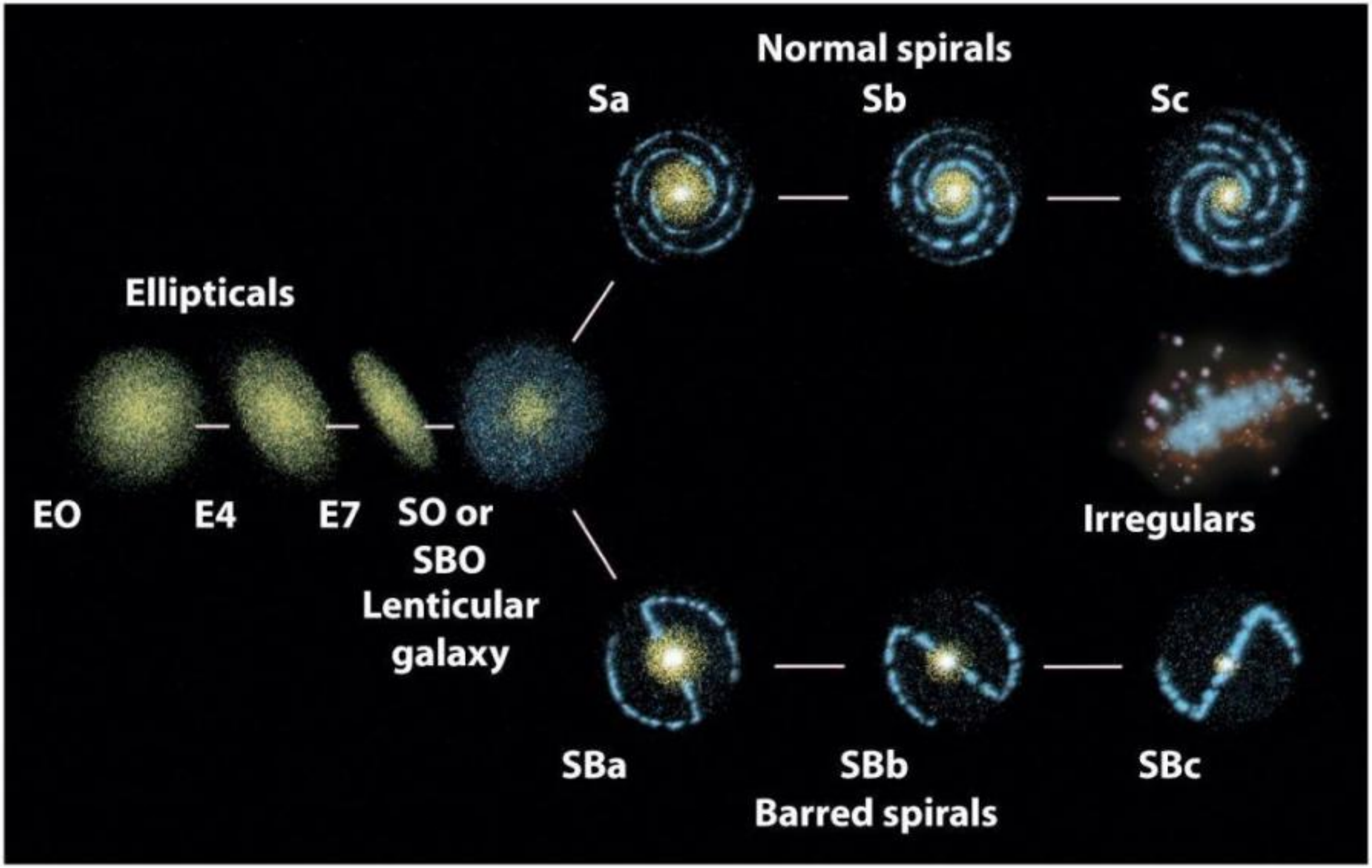
b E3 (NGC 4365)



c E6 (NGC 3377)

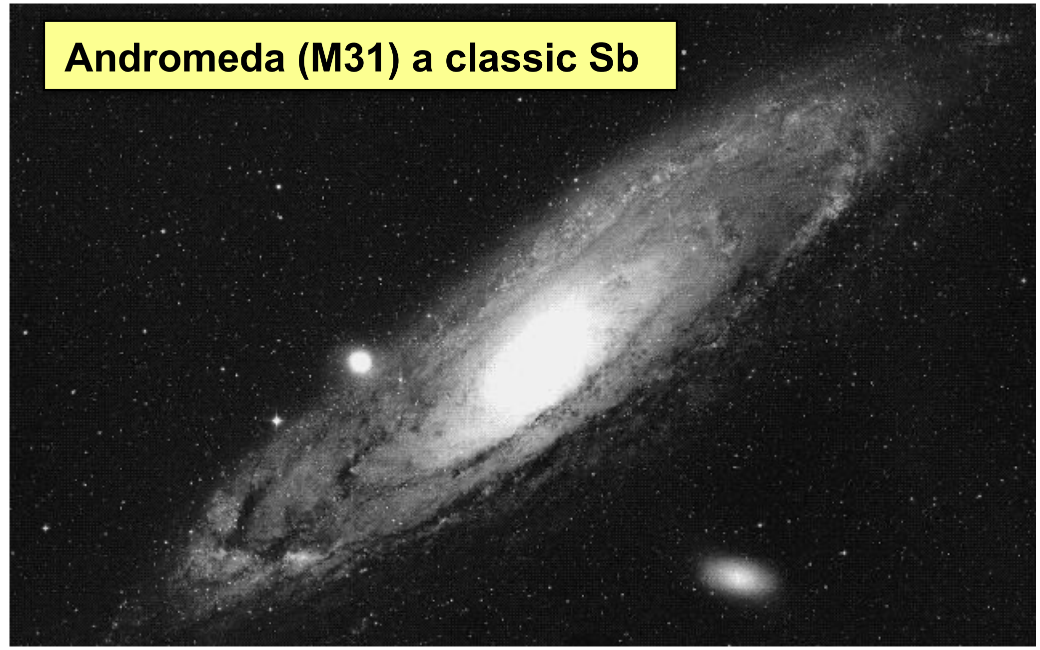
Type S: normal spirals

- Have (like the Milky Way):
  - Spiral arms, nucleus, disk and halo
- Emission nebulae present
- Often dusty (lots of cool dust and gas)
- The arms contain young stars
- Classified by relative strength of the central bulge is compared to the disk, and how tight the spiral arms are:
  - Sa: tight arms, large bulge/disk ratio
  - Sb: intermediate
  - Sc: most open arms, smallest bulge/disk

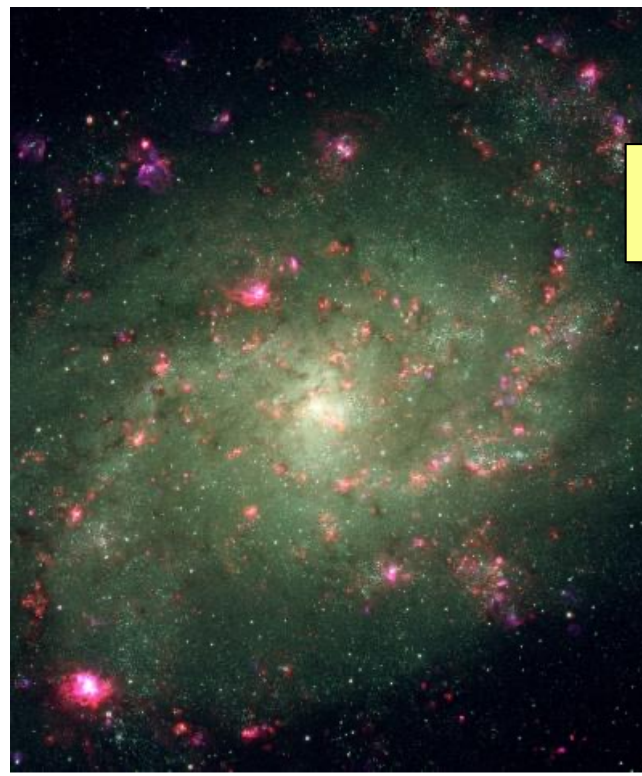


Normal spirals
Sa
Sb
Sc
Ellipticals
EO
E4
E7
SO or
SBO
Lenticular
galaxy
Irregulars
SBa
SBb
SBc
Barred spirals

a Sa (NGC 1357)



c Sc (NGC 4321)



M33 – an Sc galaxy

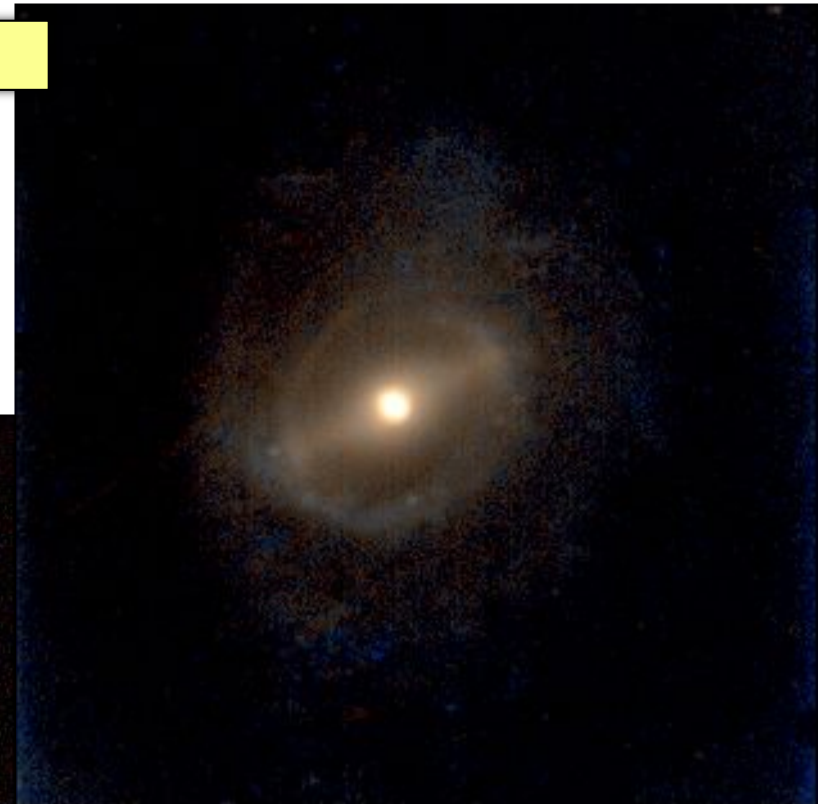
Type SB: barred spirals

- Parallel group to the normal spirals (about 2/3 of all spirals are barred).
- Features a strong, central stellar bar
  - Rotates as a unit (solid body rotation)
  - Spiral arms emerge from the ends of the bar
- Same subclasses as normal spirals: SBa, SBb and SBc.

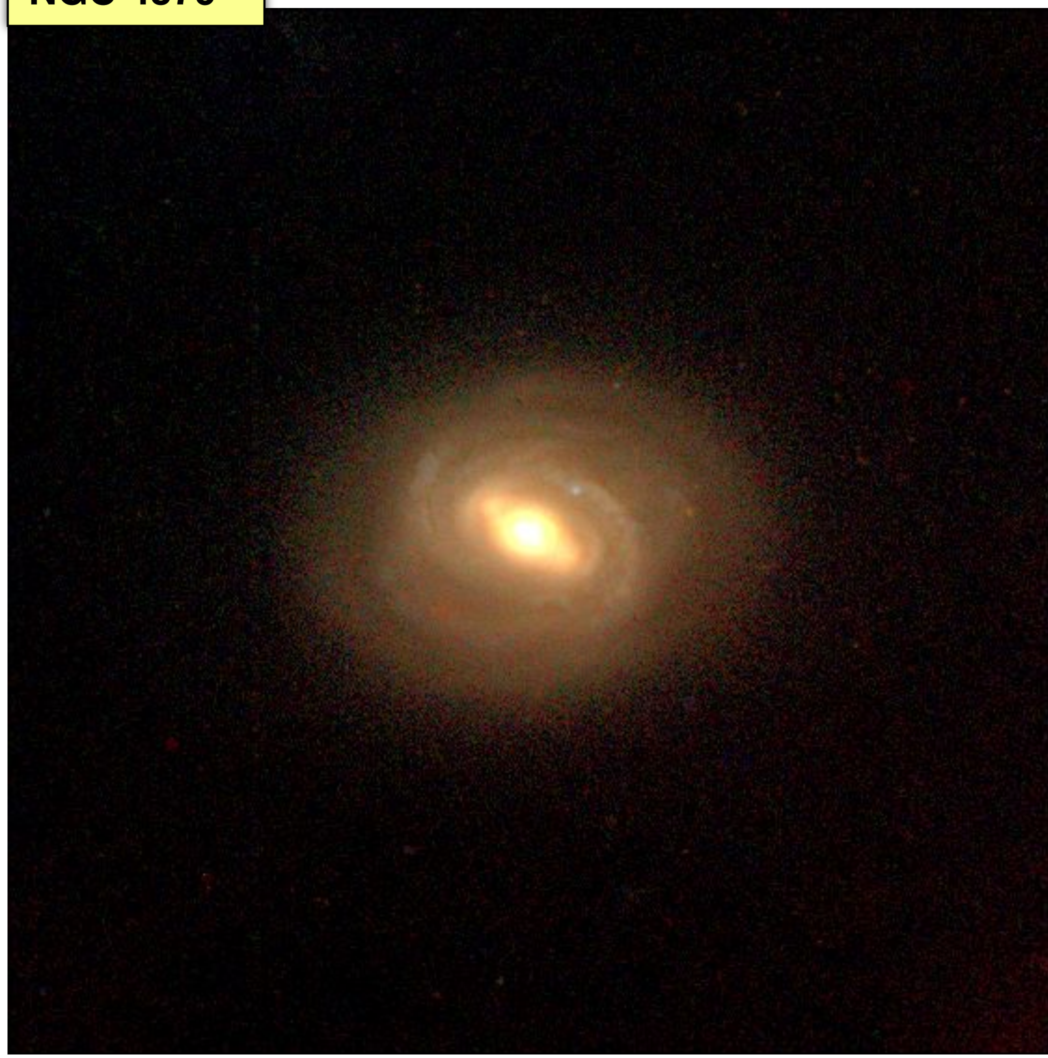
The MW is thought to have a weak bar: sometimes classified as a SBbc

Bars can be subtle or obvious

NGC 5850



NGC 4579



a SBa (NGC 4650)

b SBb (M83)

c SBc (NGC 1365)

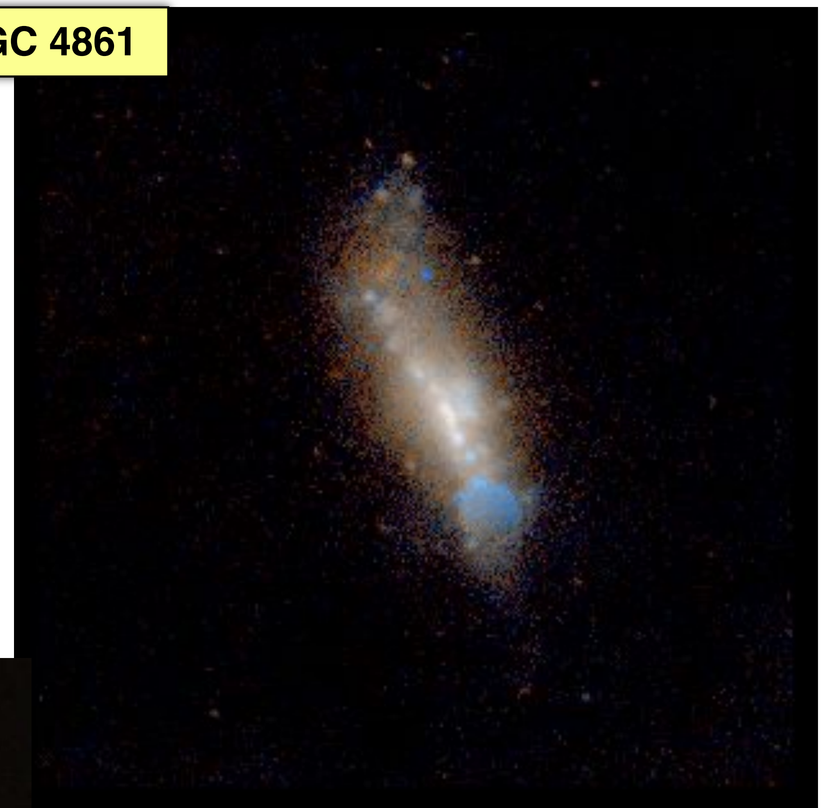
Sighting from Roswell? No, it is M104, an Sa or S0/a galaxy.

Type I: Irregulars

- Irregular, sometimes chaotic structure
- Little evidence of systematic rotation
- Catch-all class: many irregulars defy further classification
- Significant dwarf irregular population, dI.

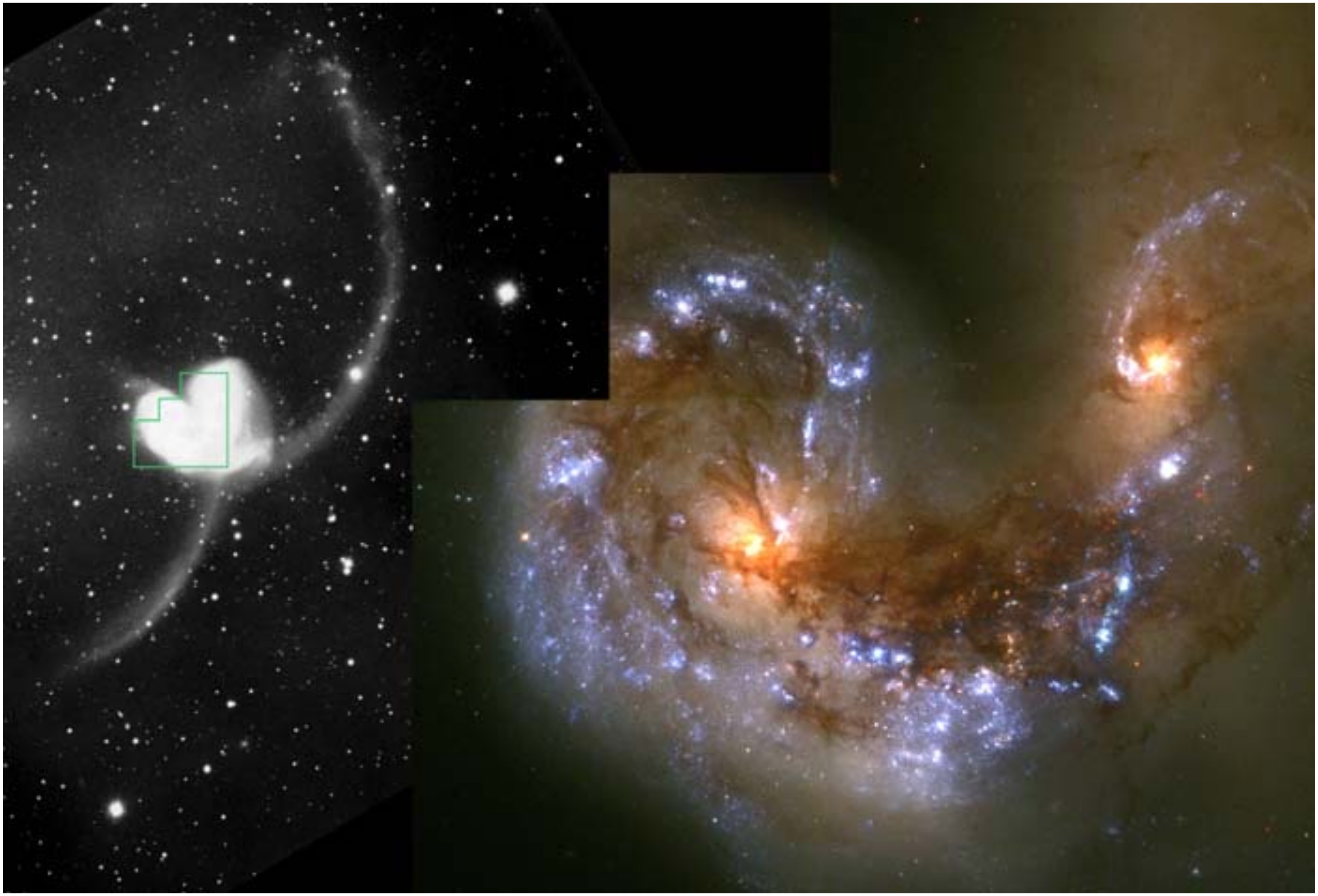
Irregular galaxies: examples

NGC 4861



M82

There are also pathologically shaped galaxies - *peculiars.*



Centaurus A (NGC5128), a collision between an E and an S galaxy.

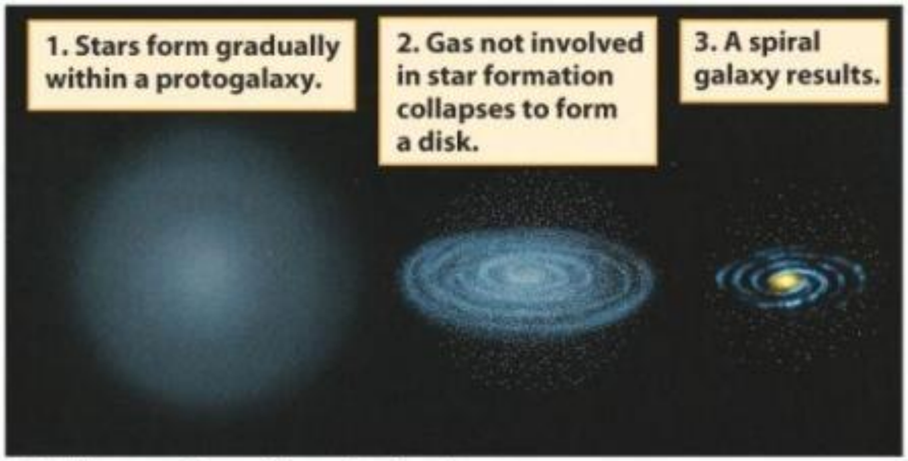
Physical differences

- Differ in terms of
  - relative stellar & gas content
  - star formation histories
  - internal motions

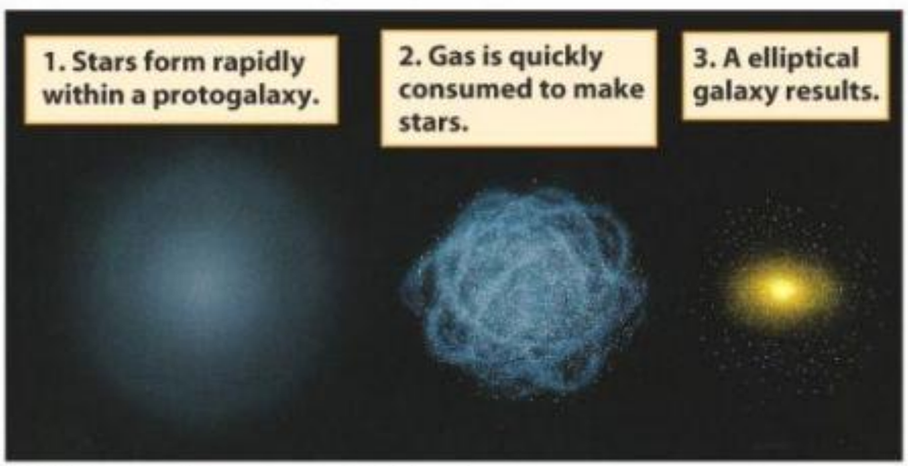
- E and S0 galaxies have no current star formation, little dust, little gas. Isotropic => anisotropic motion.

- S and irregular galaxies have dust, gas, and current star formation.

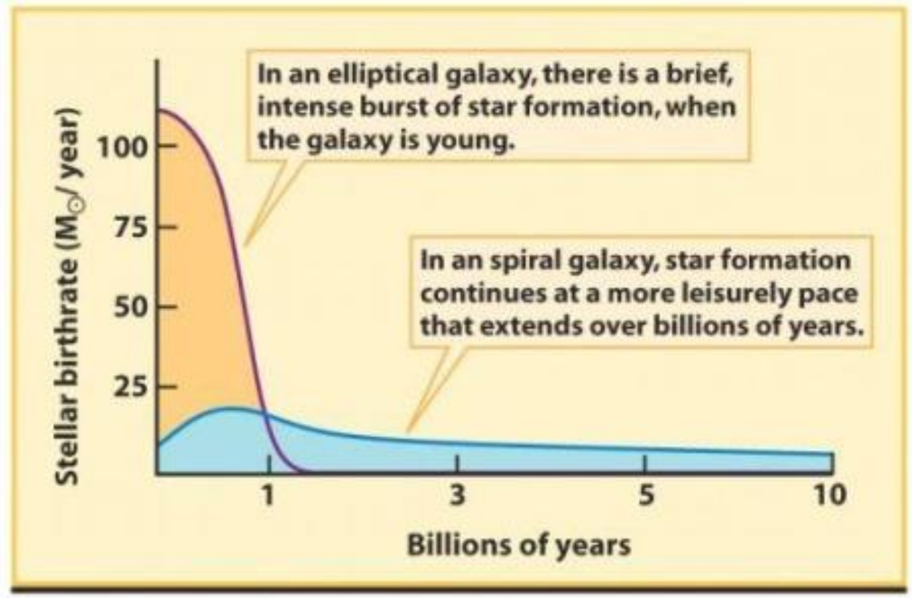
- Note that both E and S galaxies have similar ages – they both have old stars, but only the S have young stars and *current* star formation.



(a) Formation of a spiral galaxy



(b) Formation of an elliptical galaxy



(c) The stellar birthrate in galaxies

Dwarf galaxies

- The most common type: only a few 10^6 stars

The Leo I dwarf system, dE – a satellite of the Milky Way.

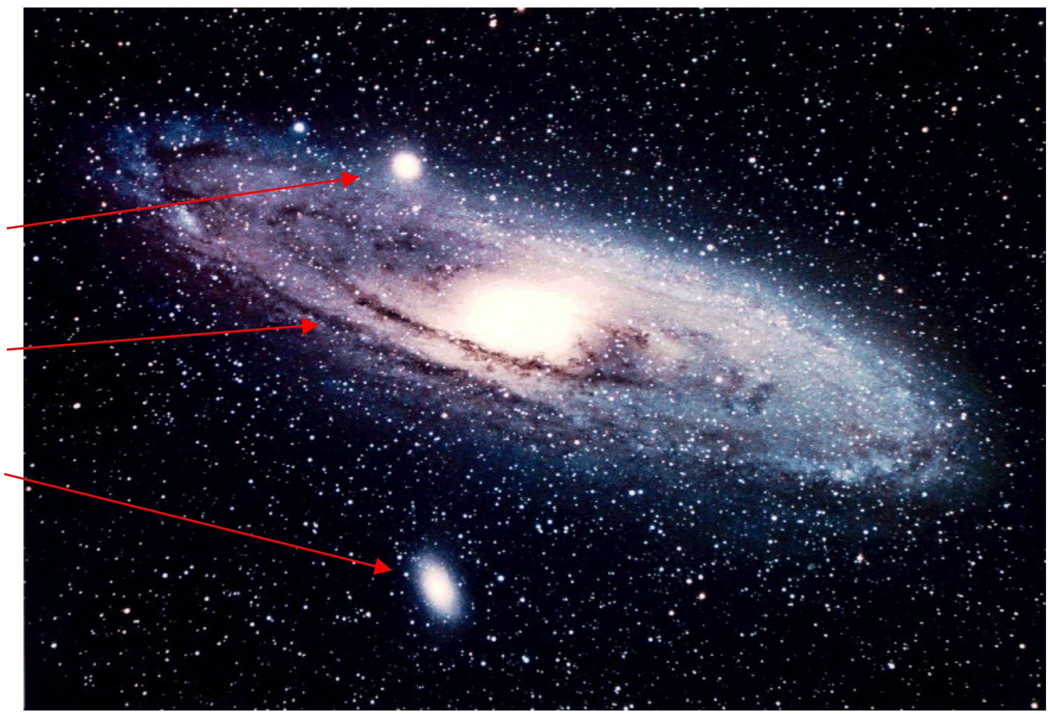
A further distinction for ellipticals and irregulars:

Giant	vs.	Dwarf
10^{10} - 10^{13} stars 10's of kpc across		10^{6} - 10^{8} stars few kpc across

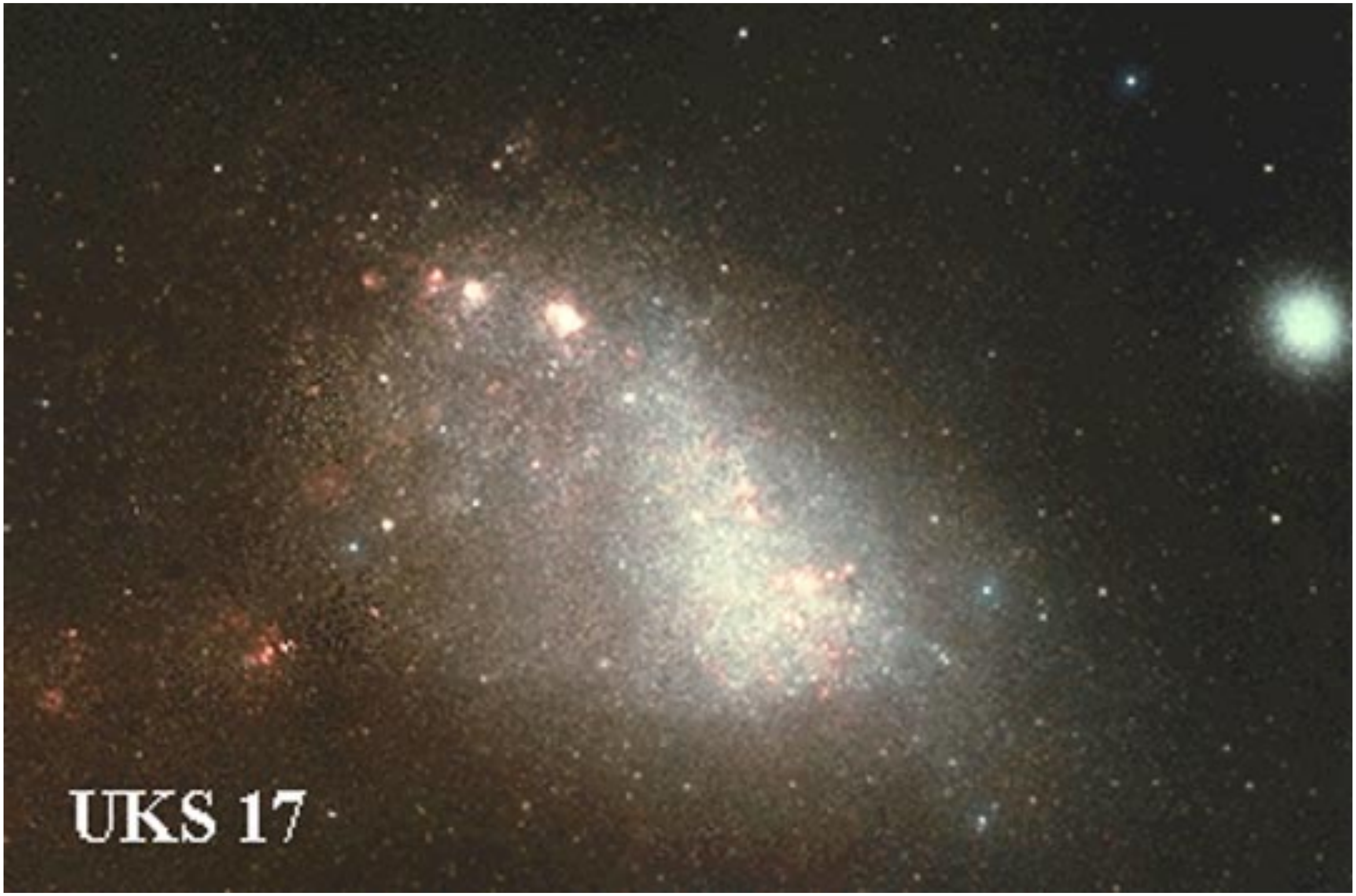
Dwarf Elliptical NGC 205

Spiral M31 (Andromeda)

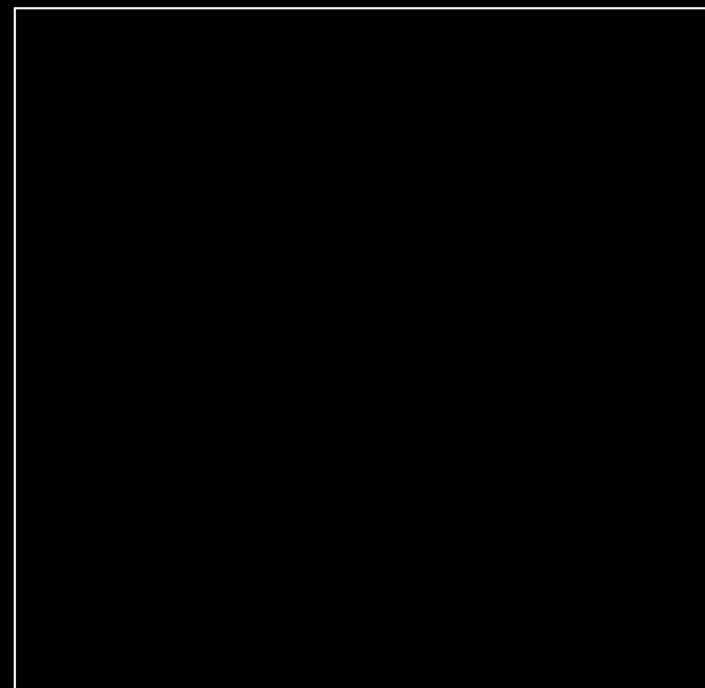
Dwarf Elliptical M32



The Small Magellanic Cloud, a dIrr galaxy.



UGCA285: Low surface brightness galaxy



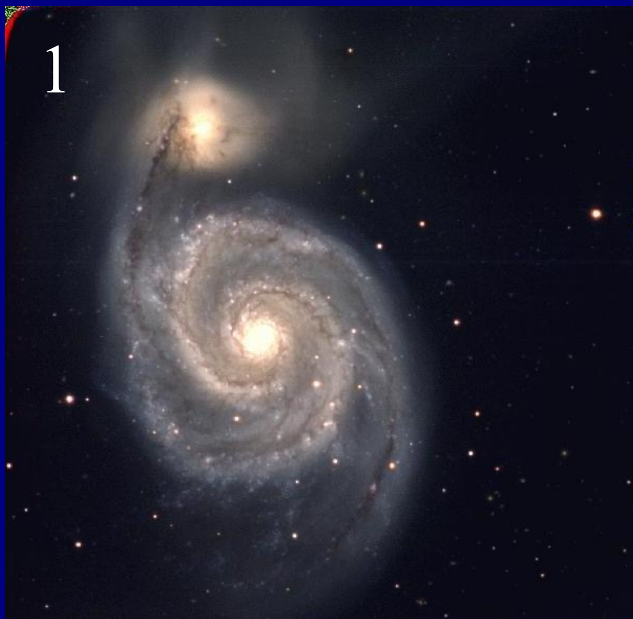
UGCNAN: Ultra Low surface brightness galaxy

table 26-1 Some Properties of Galaxies

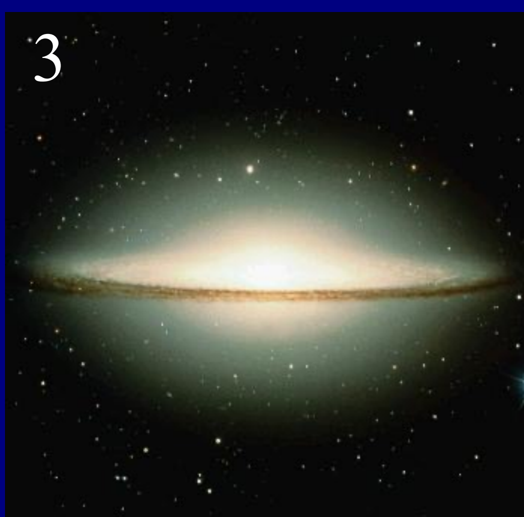
	Spiral (S) and barred spiral (SB) galaxies	Elliptical galaxies (E)	Irregular galaxies (Irr)
Mass ($M_\odot$)	10^9 to 4×10^{11}	10^5 to 10^{13}	10^8 to 3×10^{10}
Luminosity ($L_\odot$)	10^8 to 2×10^{10}	3×10^5 to 10^{11}	10^7 to 10^9
Diameter (kpc)	5 to 250	1 to 200	1 to 10
Stellar populations	Spiral arms: young Population I Nucleus and throughout disk: Population II and old Population I	Population II and old Population I	mostly Population I
Percentage of observed galaxies	77%	20%*	3%

**This percentage does not include dwarf elliptical galaxies that are as yet too dim and distant to detect. Hence, the actual percentage of galaxies that are ellipticals may be higher than shown here.*

The Variety of Galaxy Morphologies

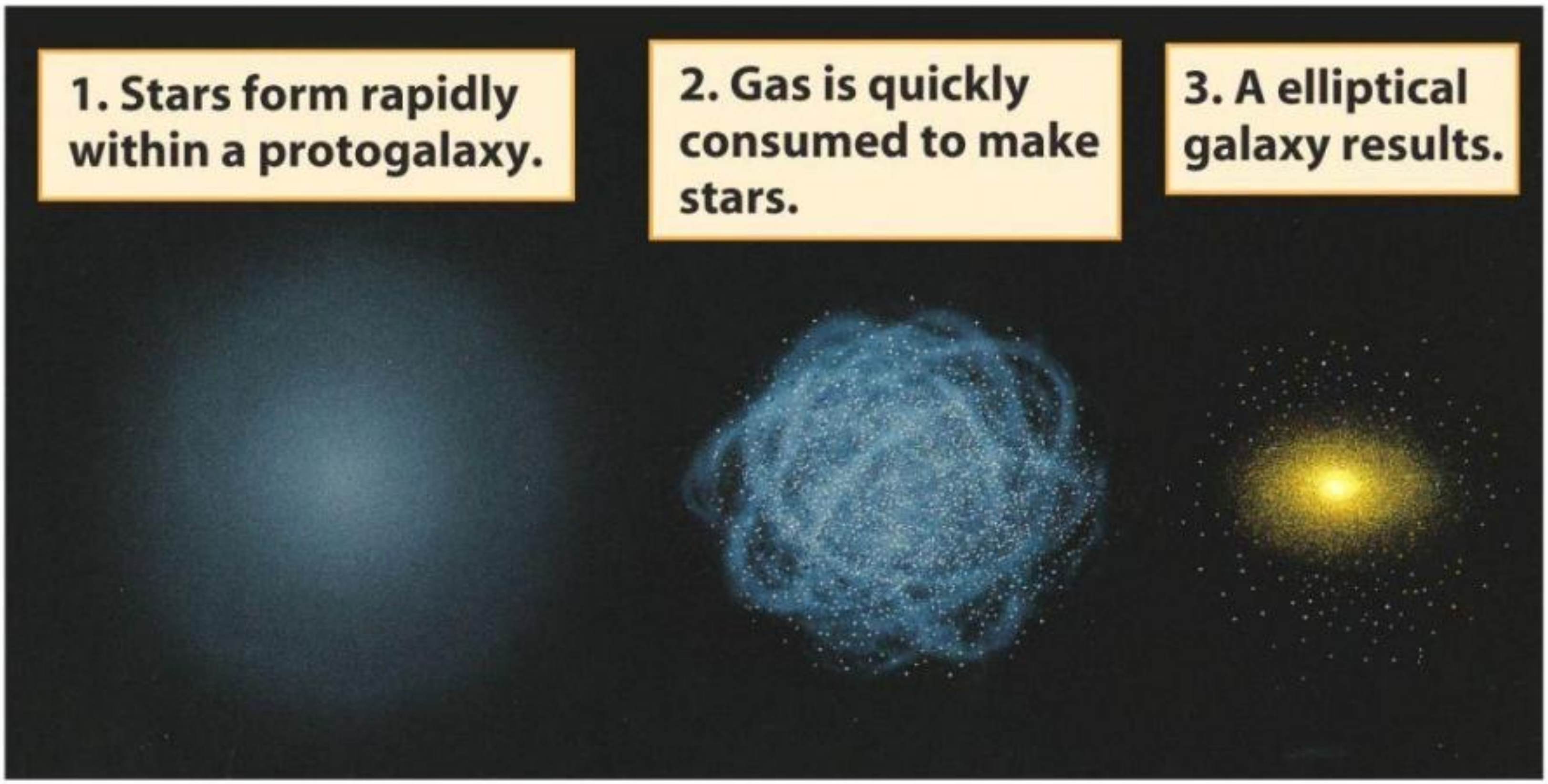


a) elliptical
b) spiral
c) barred spiral
d) dwarf
e) irregular



http://galaxyzoo.org/

- How do E galaxies form?
- One way is for the initial star formation burst to be 100% efficient $\Rightarrow$ no gas to dissipate into a disk and no material to build young stars.



Formation of an elliptical galaxy

Other ways to make **E galaxies**:

- Numerical simulations show that a *low speed* collision between spirals can totally disrupt their disks and remove their gas and dust.

- The remaining object will look like an E galaxy.

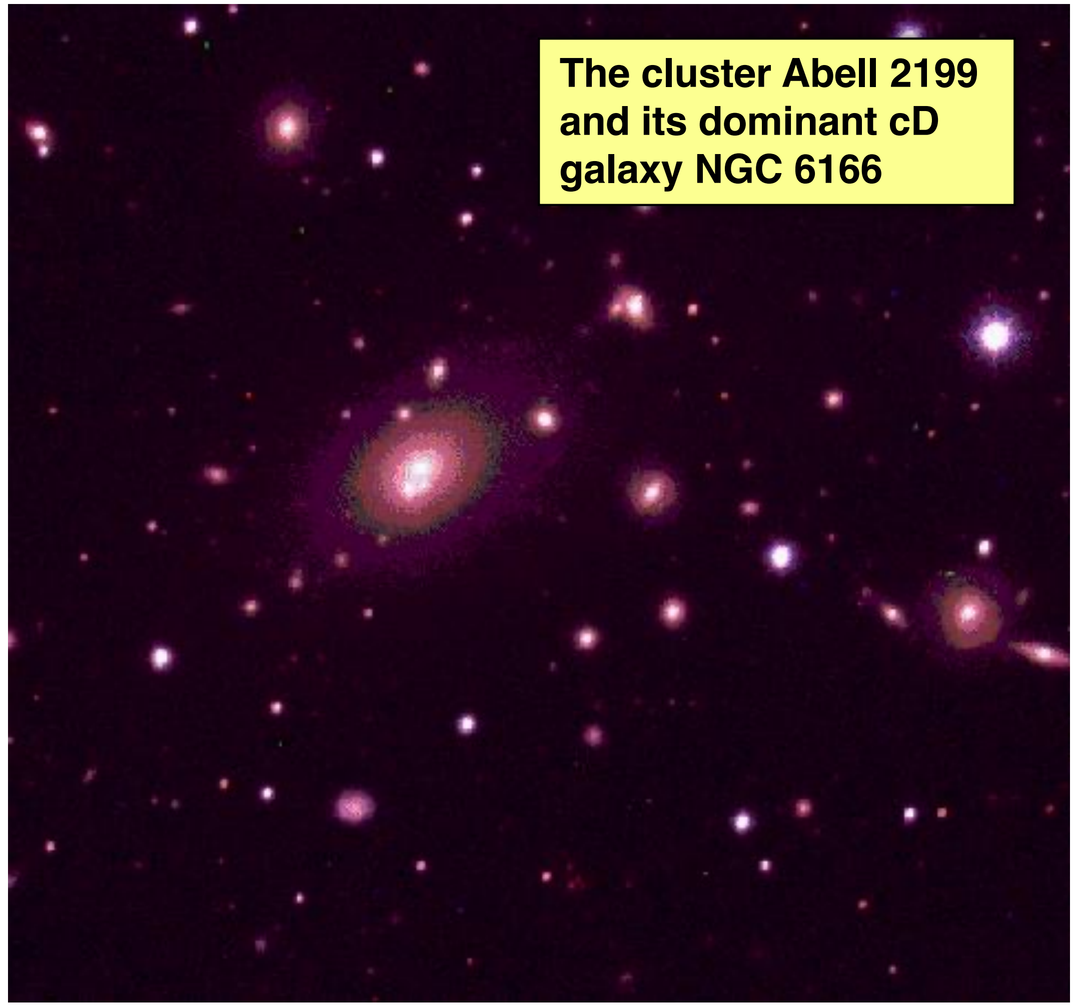
S0 galaxies:

- If a spiral suffers a *fast collision*, it might leave behind an object with all the assets of a spiral except for dust and gas.

- The disk might not be disrupted, but it wouldn’t have spiral arms or star formation.

Density effects

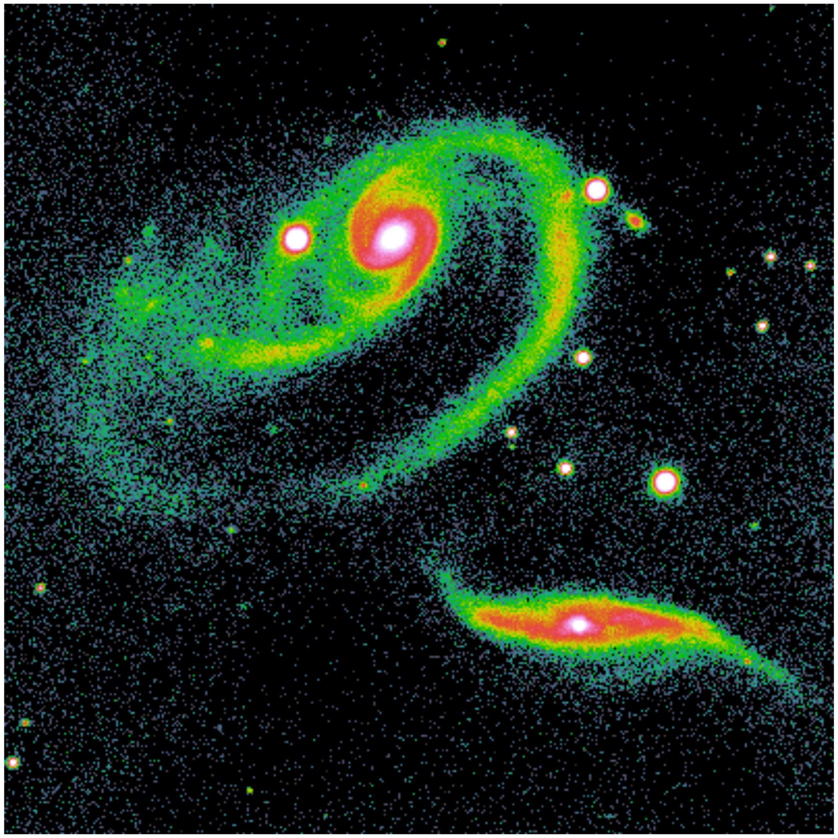
- E and S0 galaxies appear in the highest density regions - the cores of rich clusters.
- S galaxies are found in the outskirts.



Giant elliptical formed by mergers, D is for diffuse.

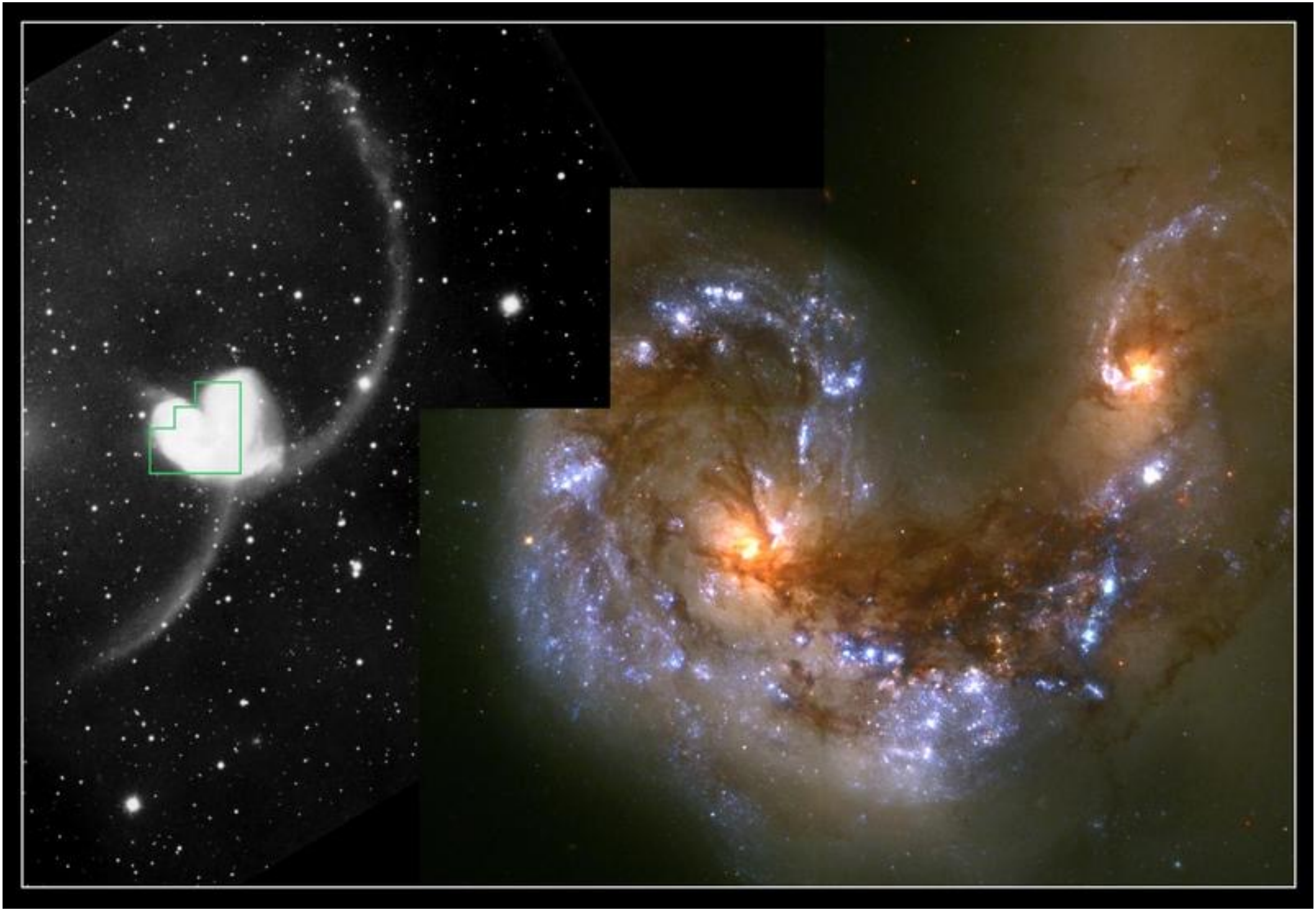
Colliding galaxies

- Collisions might distort shapes of galaxies involved in the collision, and thus impact the evolution of the galaxies



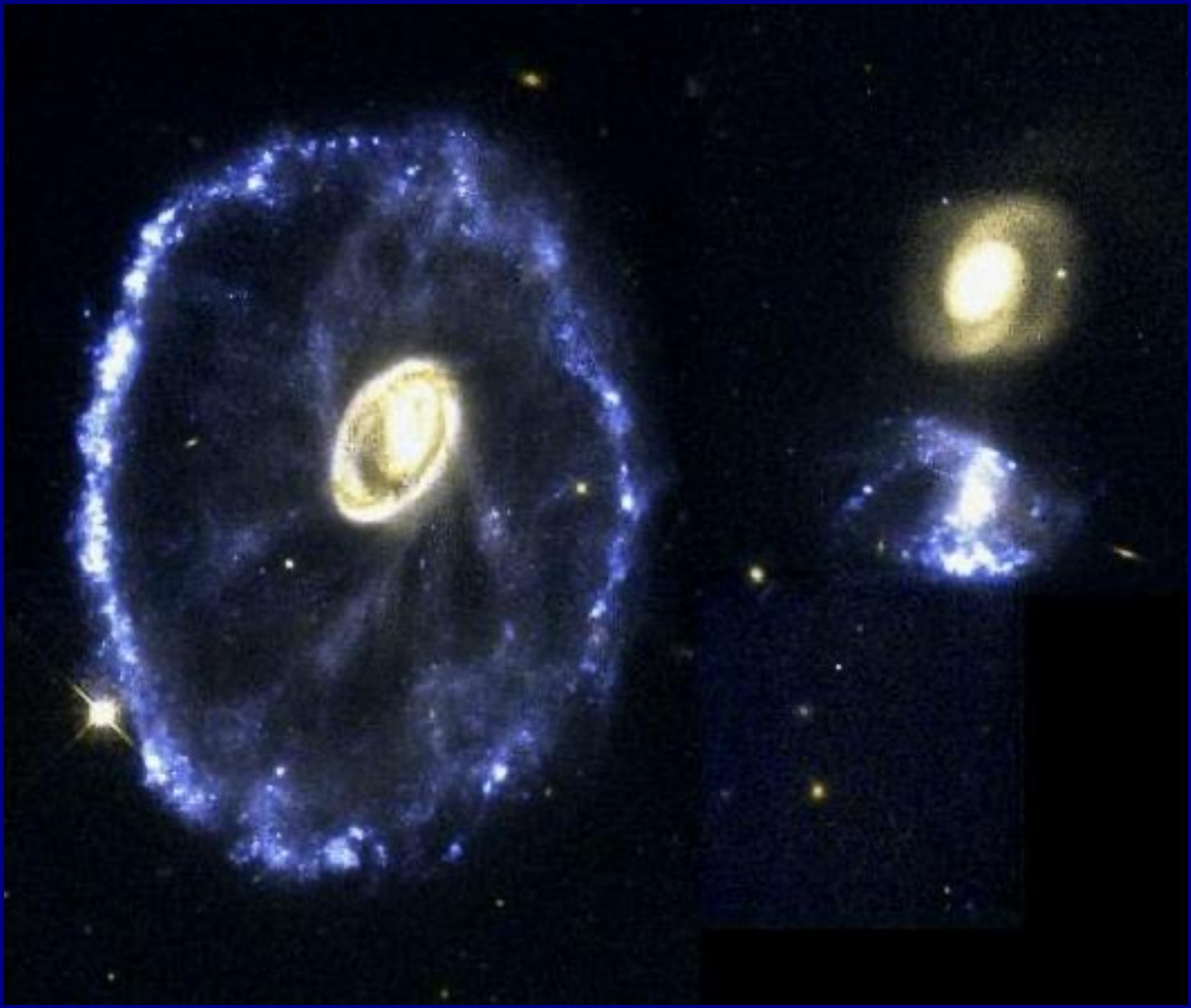
Arp273

Major mergers

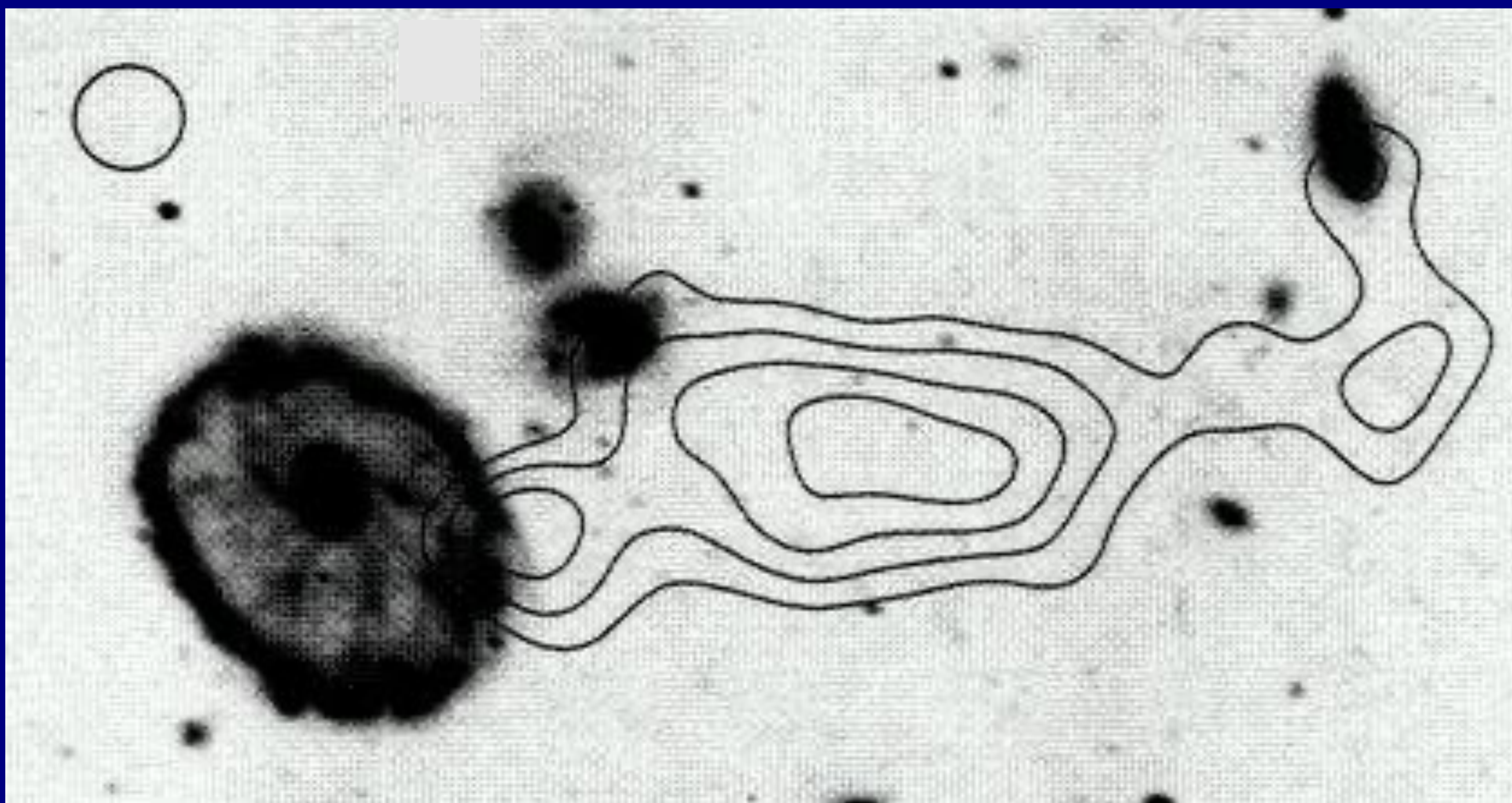


Sometimes a galaxy may pass right through another one, creating a ring galaxy.

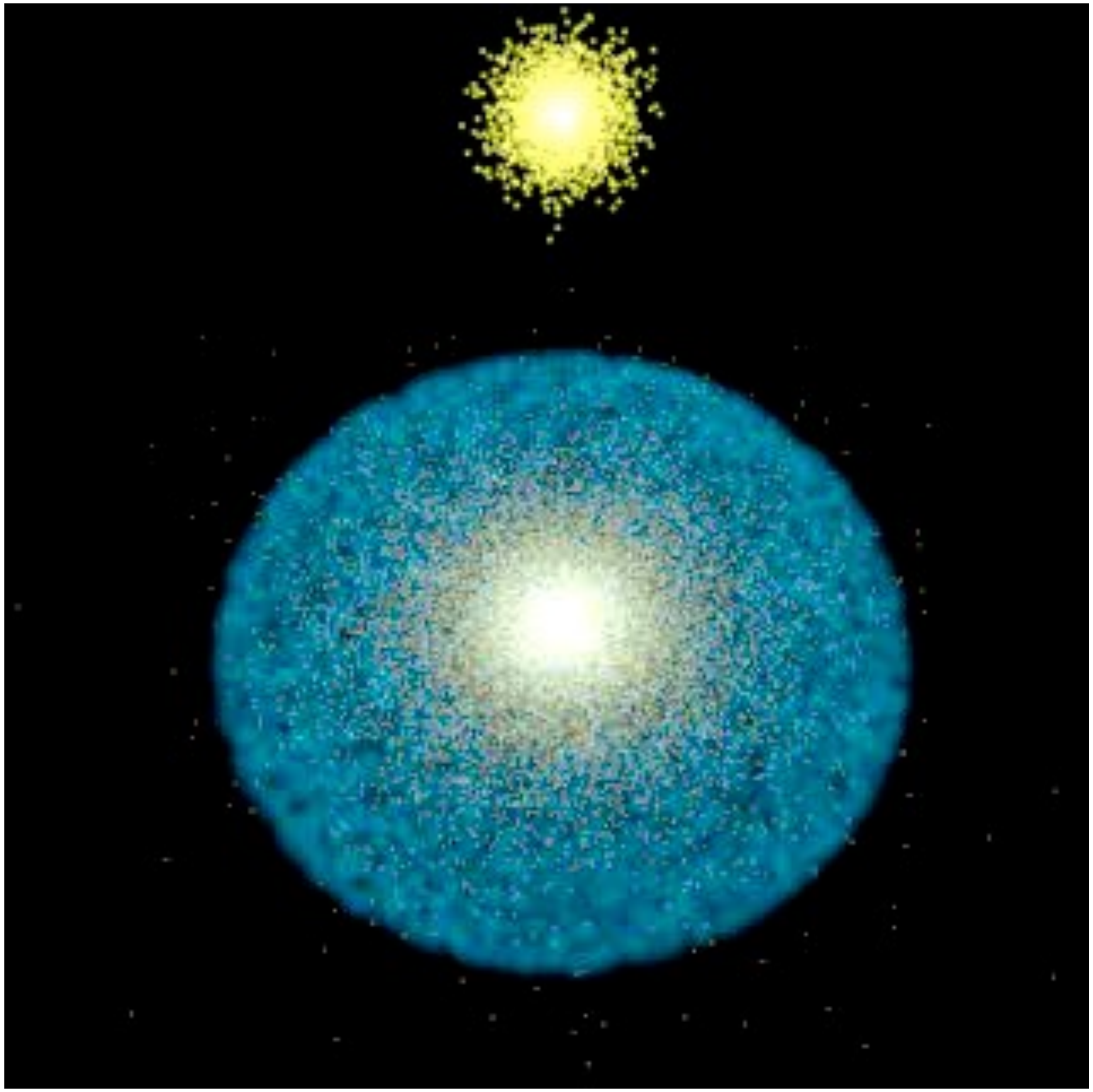
Hubble image of The "Cartwheel" galaxy



VLA observations show a bridge of atomic gas connecting Cartwheel and a more distant galaxy.



The Cartwheel collision



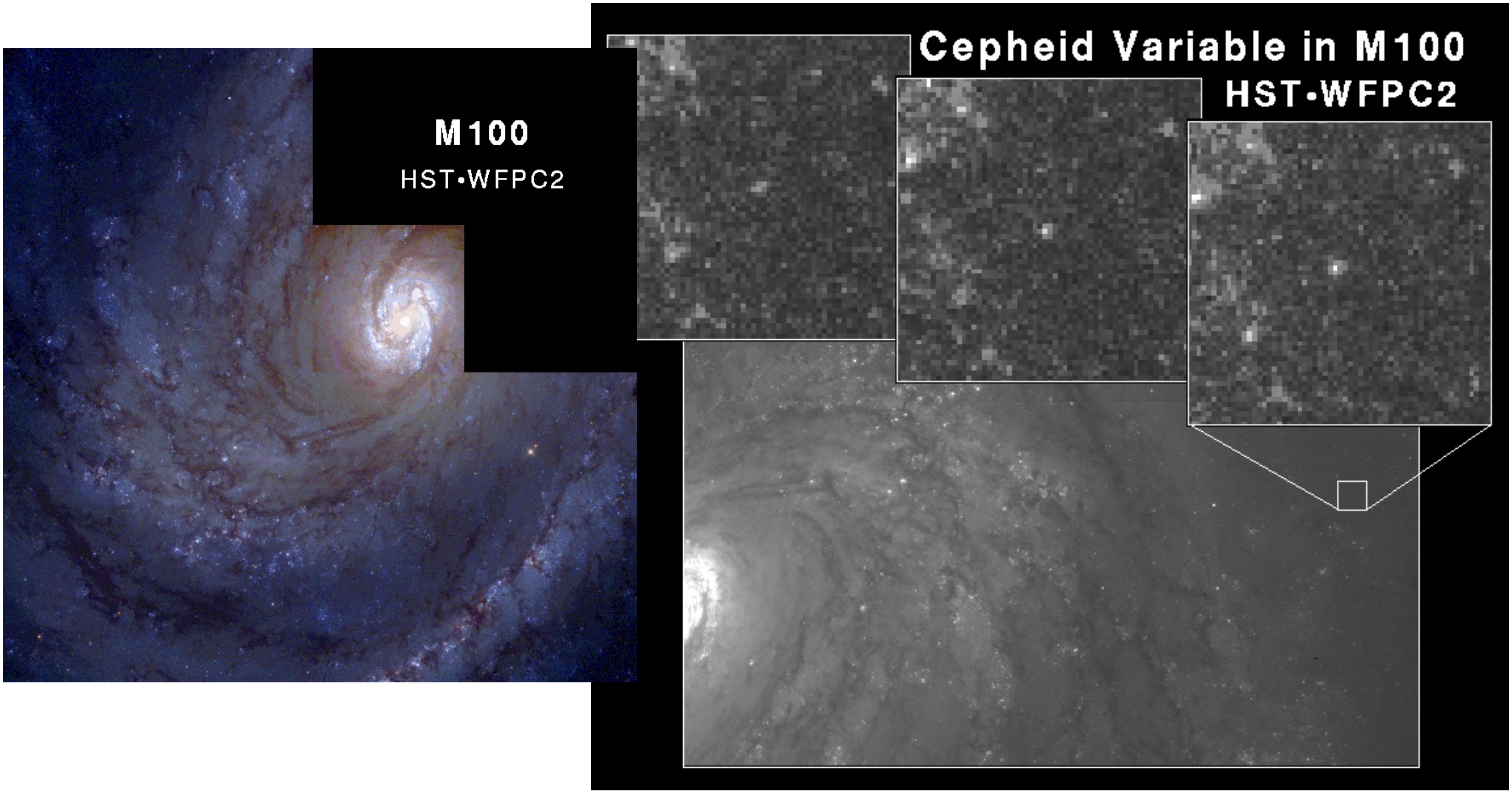
M31 and the Milky Way

- Dubinski 2006

Distances to galaxies

- Cepheids – used by Hubble, 1924 to show that nearby galaxies like M31 were farther from the Solar System than any part of the Milky Way, therefore separate systems.

- A key purpose of the Hubble Space Telescope was to measure Cepheids in more distant galaxies.

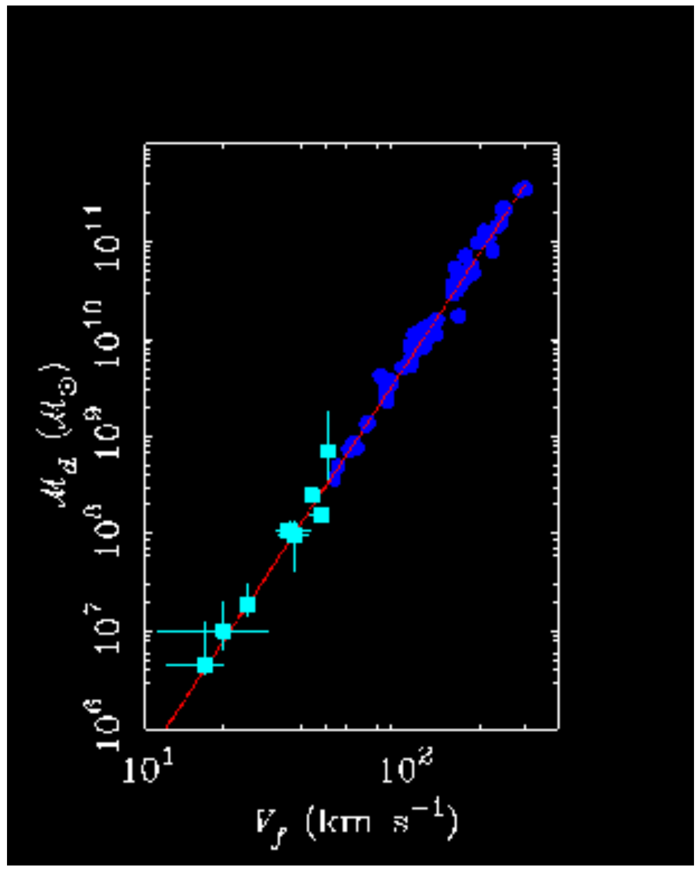


Are there other ways to estimate distances?

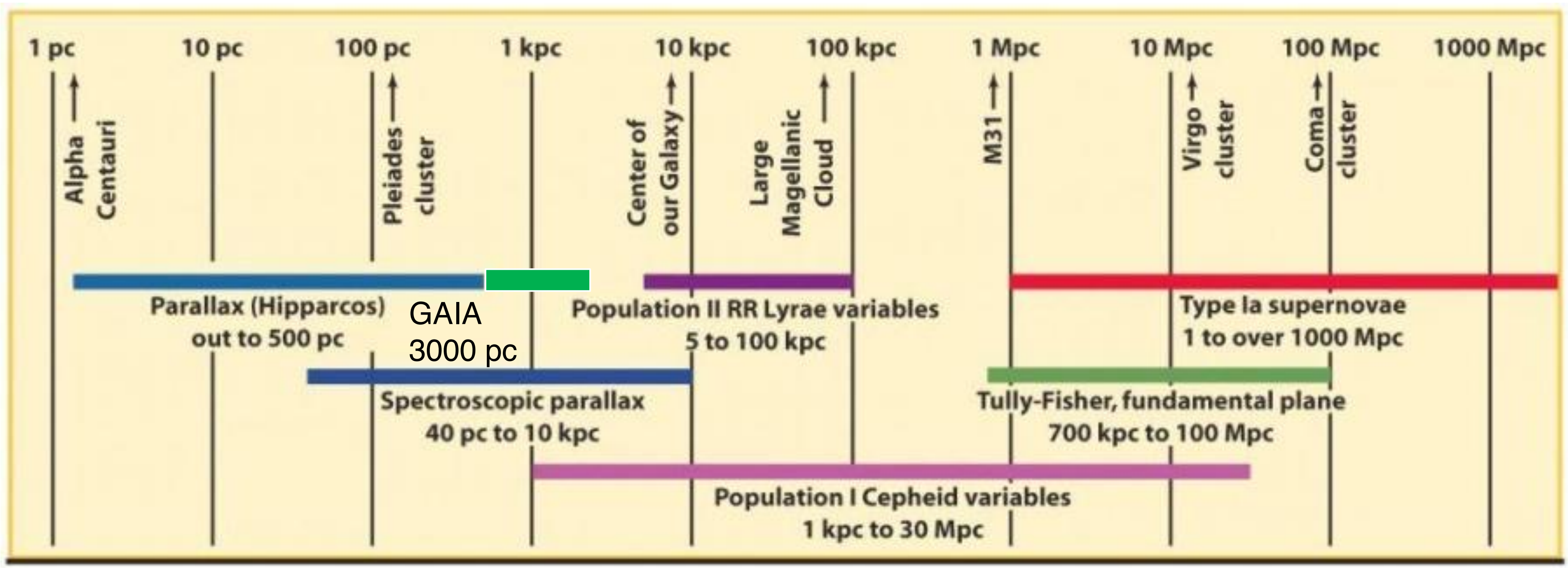
- Very useful: Type Ia supernovae.
- Peak brightness M = -19. Can use to find distances to galaxies more than 10^9 parsecs away!

Tully-Fisher relation

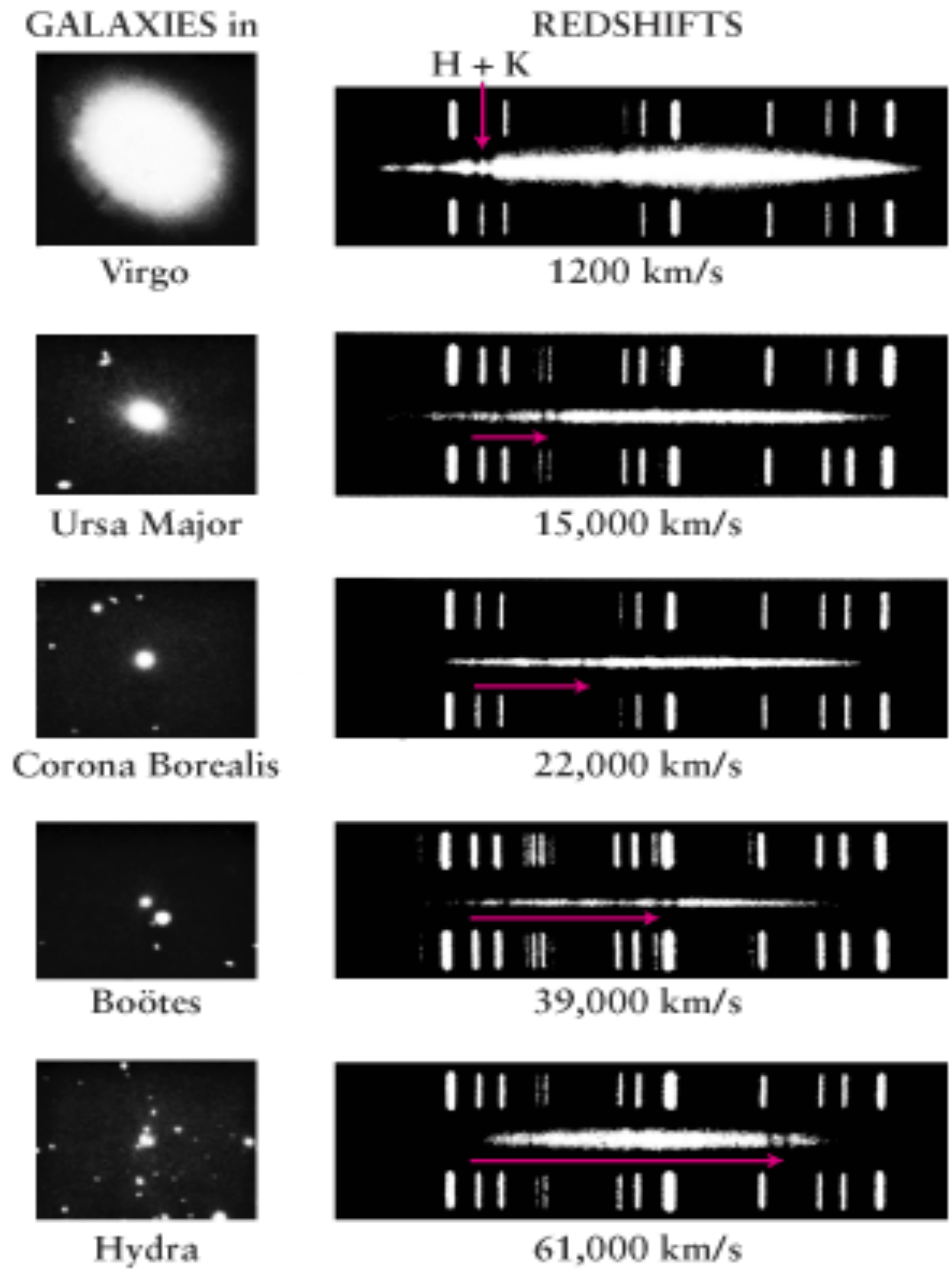
- Another way: the wider the 21cm line, the more massive the galaxy (Kepler's 3rd law).
- The more mass, the more luminosity.



The "Distance Ladder"



- Can rather easily find recession velocity of galaxies by measuring the shift of spectral lines.



Most galaxies exhibits redshifts

- The redshift is denoted by *z*

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0}$$

where z is the redshift, λ_0 is the rest wavelength of the spectral line, and λ is the observed (shifted) line from the galaxy.

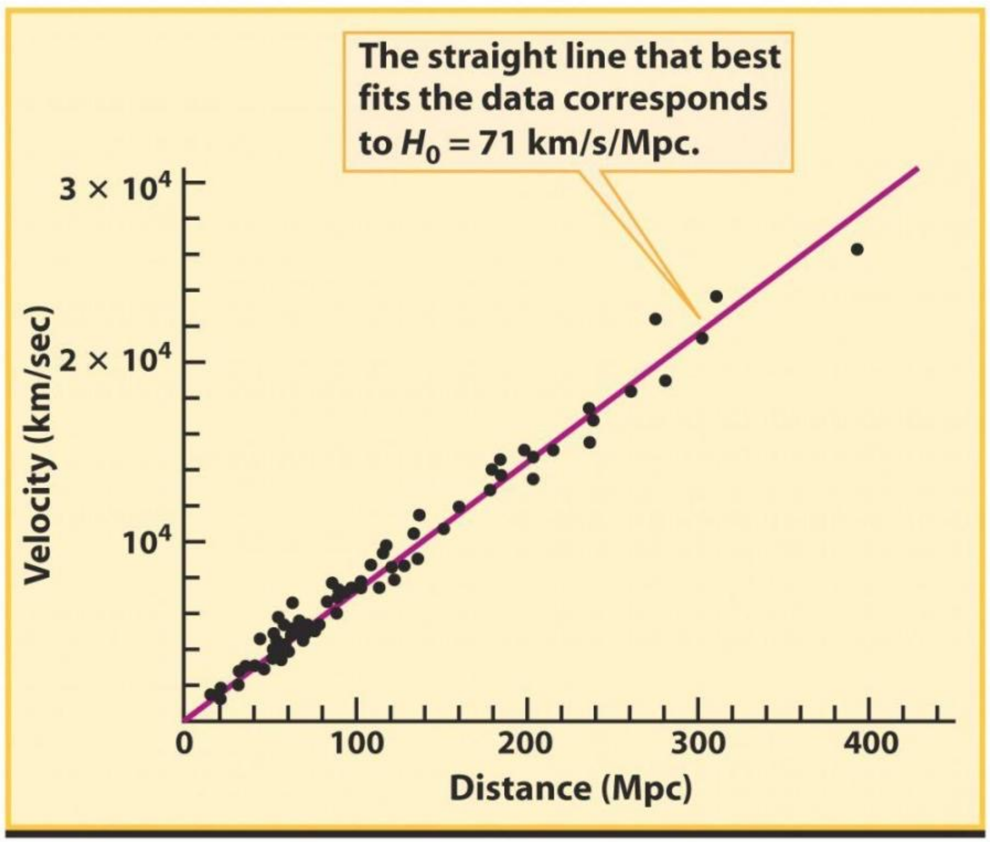
- The recession velocity is then taken as $V = cz$

(valid for low speeds – relativistic version Box 24.2)

The Hubble Law

- Plotting recession velocity *V*, versus distance *d*:

$V = H_0 d$ where the slope H_0 is Hubble's constant.



Implications from the Hubble Law

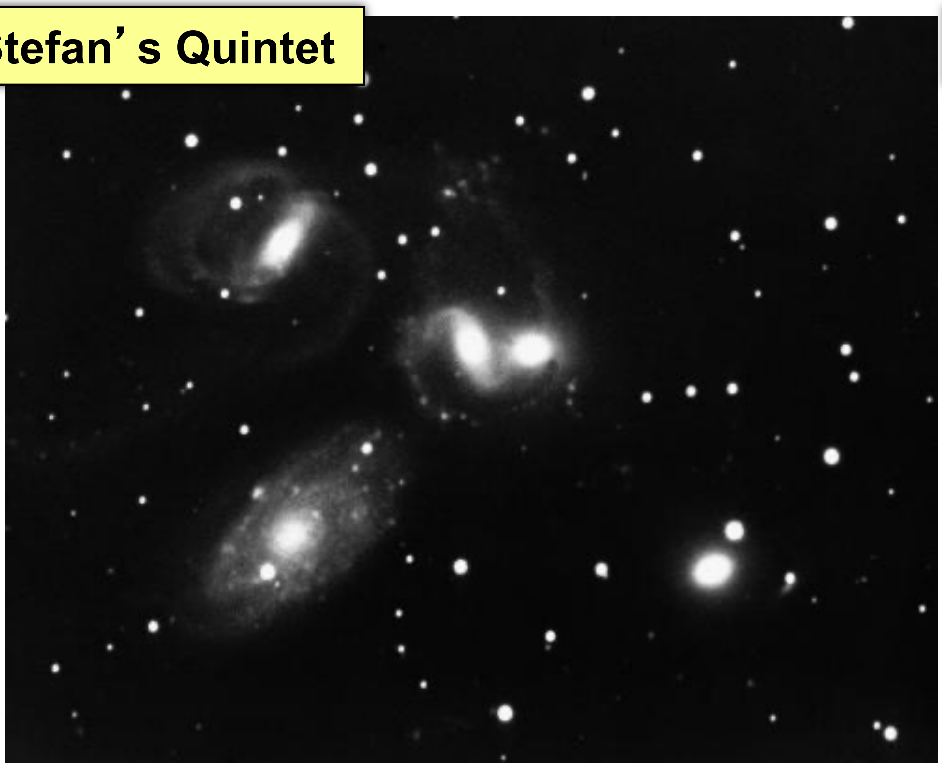
1. A new way to find distance.

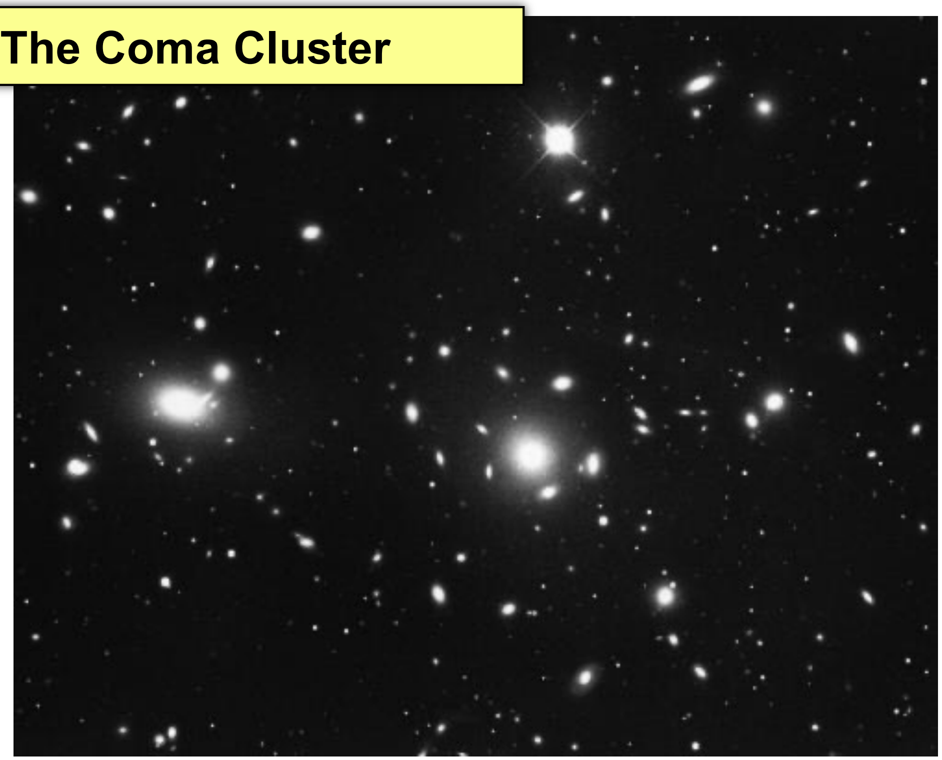
2. The Universe is expanding.

3. Long ago the Universe was compact – the Big Bang.

Clusters and groups

- Galaxies tend to form groups and clusters.


Stefan's Quintet

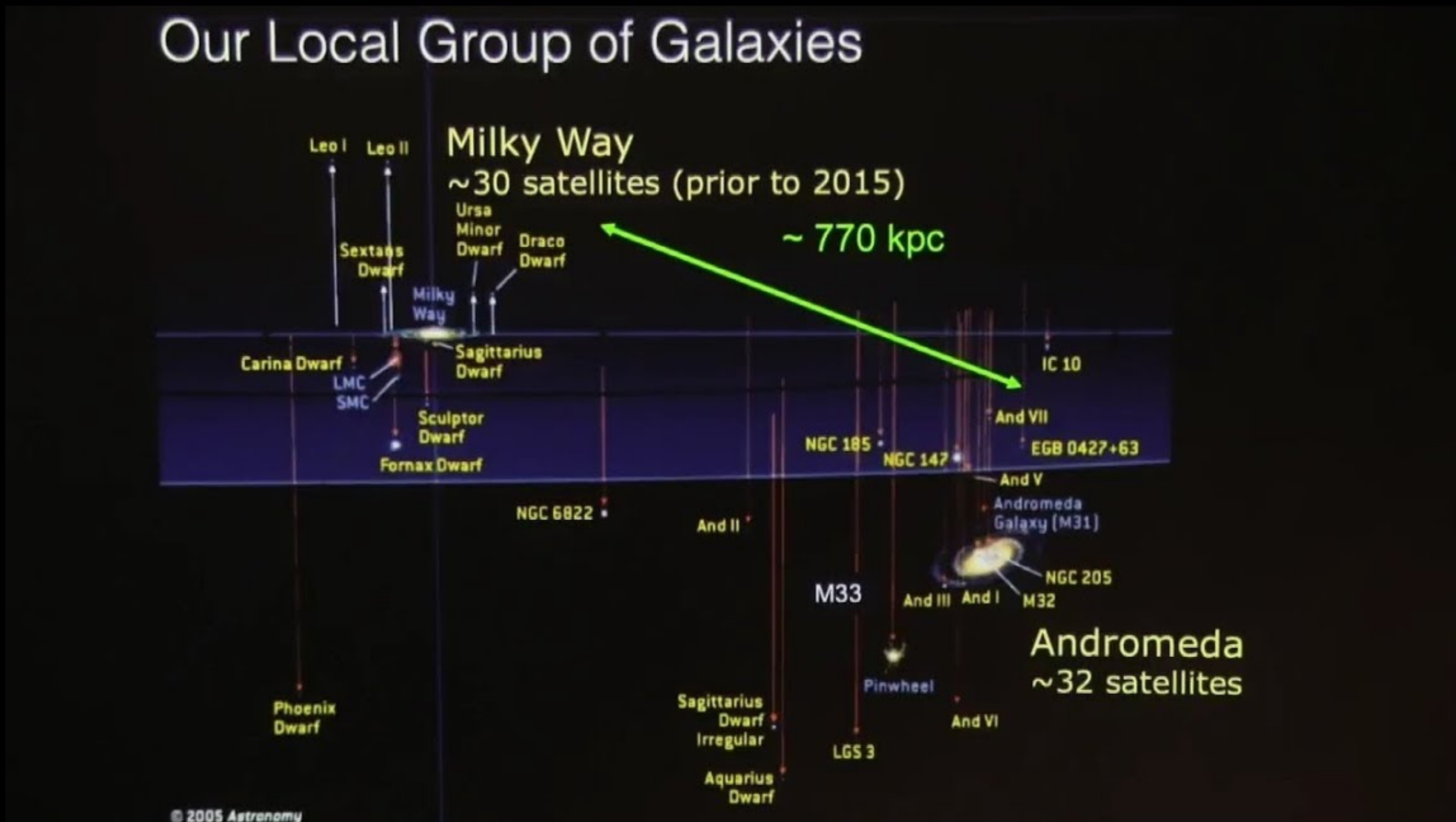

The Coma Cluster

Clusters and groups (cont.)

- Groups: 3 to 30 bright galaxies (also called *poor clusters*).
- Clusters: 30 to 300+ bright galaxies.
- Sizes: 1-10 Mpc across.
- Often contain many more dwarfs than bright galaxies.
- Total masses of 10^{12} to $>10^{15}$ $M_{\odot}$.
- About 3000 clusters have been cataloged to date.

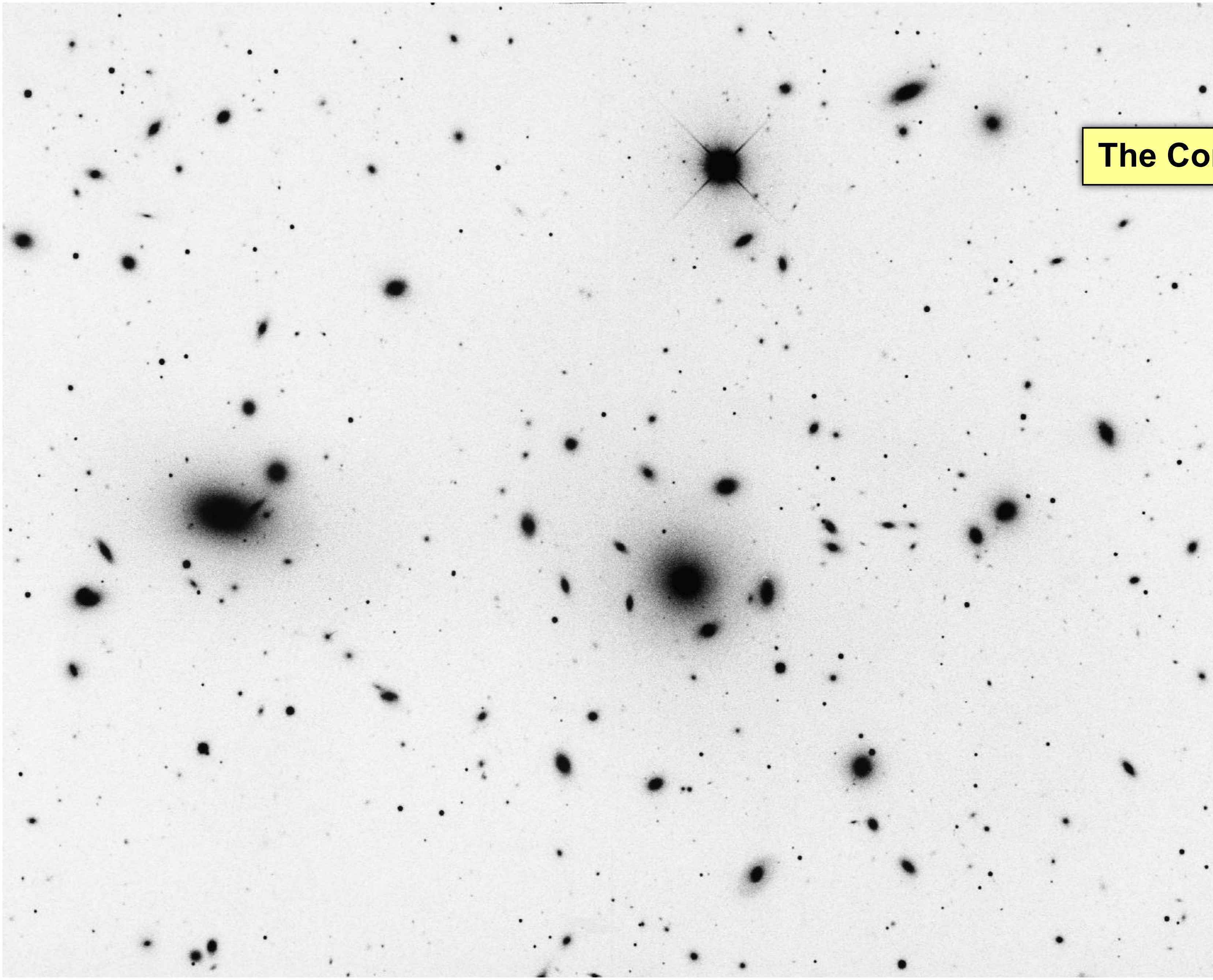
The Local Group

- The MW and Andromeda are the two giant galaxies in a loose collection of 60 [or more] galaxies.
- Several orbit the MW, and several orbit M31. The rest are in complex orbits around the center of mass.
- Most galaxies in the Local Group are dwarfs.


Our Local Group of Galaxies
Milky Way
~30 satellites (prior to 2015)
~ 770 kpc
Andromeda
~32 satellites
Leo I
Leo II
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
Milky Way
Carina Dwarf
LMC
SMC
Sagittarius Dwarf
Sculptor Dwarf
Fornax Dwarf
NGC 6822
And II
NGC 185
NGC 147
IC 10
And VII
EGB 0427+63
And V
Andromeda Galaxy (M31)
NGC 205
M32
And I
And III
M33
Pinwheel
And VI
LGS 3
Phoenix Dwarf
Sagittarius Dwarf Irregular
Aquarius Dwarf
© 2005 Astronomy

Rich clusters

- 10^3-10^4 galaxies.
- Extend 10-50 Mpc, masses up to 10^{15} $M_\odot$.
- The nearest are designated by the constellation that they lie in – Virgo, Coma Berenices, Perseus, Hercules, Hydra, Centaurus, etc.



The Coma cluster

The Hercules Cluster