Introduction to Galaxies

Chapter 9

Earth and Space Science Class

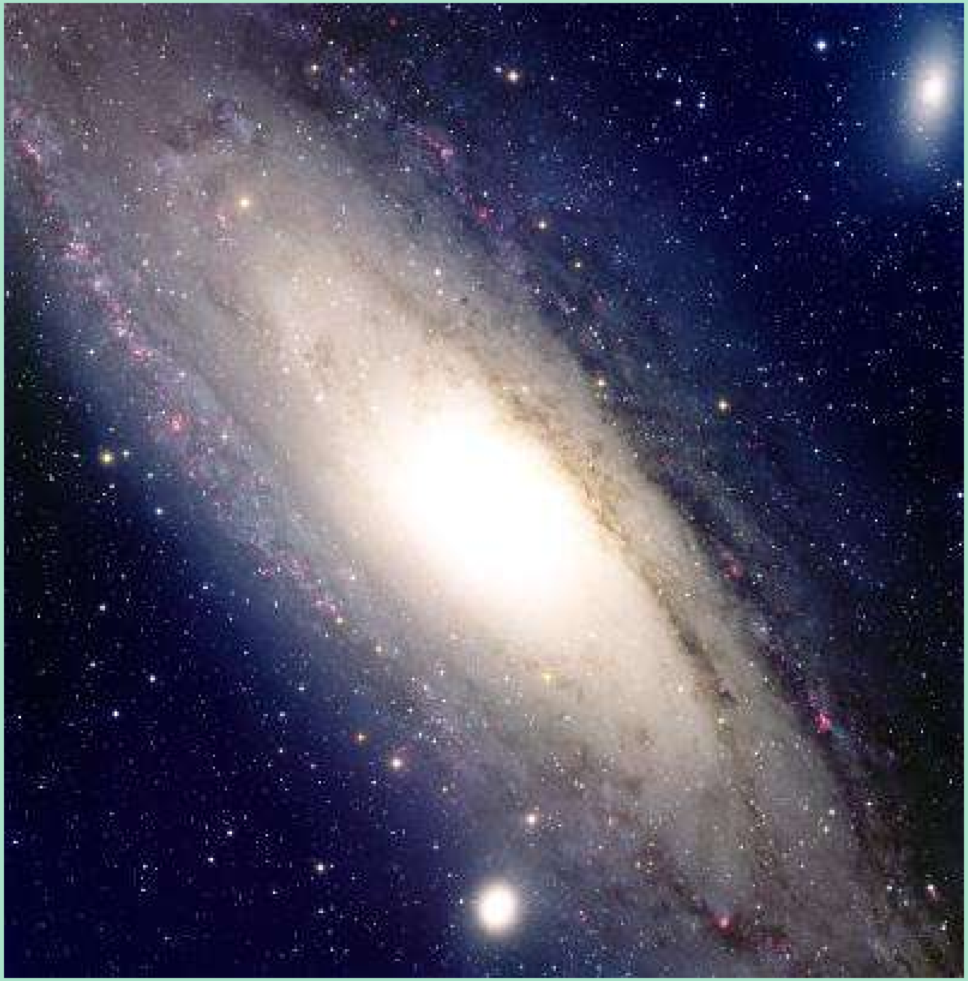
What are Galaxies?

- Galaxy - a group of billions of stars and their planets, gas, and dust that extends over many thousands of light-years and forms a unit within the universe.

Held together by gravitational forces, most of the estimated 50 billion galaxies are shaped as spirals and ellipses, with the remainder being asymmetric.

The "Discovery" of Galaxies

At the beginning of the 20th century, what we now call spiral galaxies were referred to as "spiral nebulae" and most astronomers believed them to be clouds of gas and stars associated with our own Milky Way.

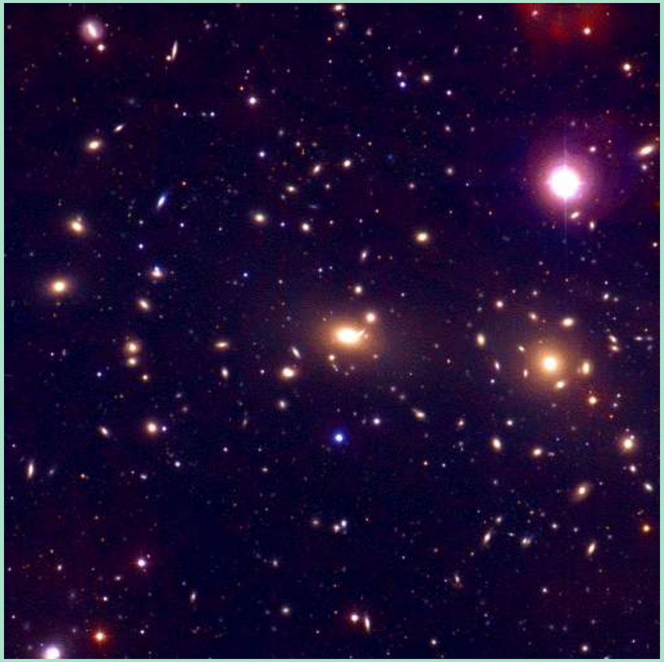


(NOAO/AURA Photo)

Edwin P. Hubble (1889-1953)

The breakthrough came in 1924 when Edwin Hubble was able to measure the distance to the "Great Nebula in Andromeda" (M 31, previous slide) and found its distance to be much larger than the diameter of the Milky Way. This meant that M 31, and by extension other spiral nebulae, were galaxies in their own right, comparable to or even larger than the Milky Way.

Galaxy Classification



In 1924, Edwin Hubble divided galaxies into different “classes” based on their appearance.

Why begin here?

- Hubble classification serves as the basic language of the field.
- The morphological sequence reflects a fundamental physical and, in some ways, evolutionary sequence, which offers important clues to galactic structure, formation and evolution.

GALAXIES, GALAXIES, GALAXIES!

A dime a dozen… just one of a 100,000,000,000!

1. Galaxy Classification

    Ellipticals
    Dwarf Ellipticals
    Spirals
    Barred Spirals

Irregulars

2. Measuring Properties of Galaxies

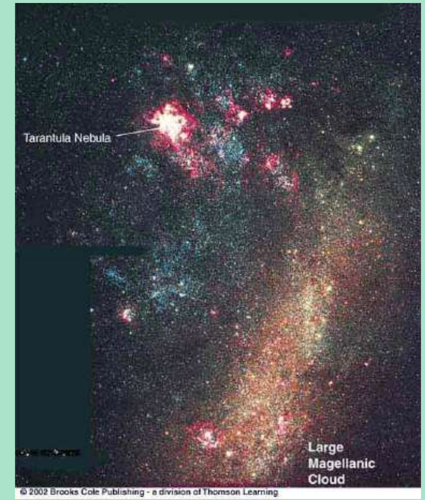
Distances
Sizes
Luminosities
Masses
Dark Matter?

Examples of Three Main Morphological Galaxy Types

Elliptical

Spiral

Irregular



The Hubble Tuning Fork

Spiral Galaxies

(a) Sa (NGC 1302) (b) Sb (NGC 4450) (c) Sc (NGC 4303)

- Disk + spiral arms + bulge (usually)
- Subtype a b c defined by 3 criteria:

- Bulge/disk luminosity ratio
- Sa: B/D>1   Sc: B/D<0.2
- Spiral pitch angle
- Sa: tightly wound arms Sc: loosely wound arms
- Degree of resolution into knots, HII regions, etc.

Spiral Galaxies

Comprise about 2/3rds of bright galaxies
Grand Design Spiral - well defined spiral structure
Flocculent - less organized spiral design

Spirals clearly contain much gas and dust
Most starlight is from young, blue stars - ongoing star formation

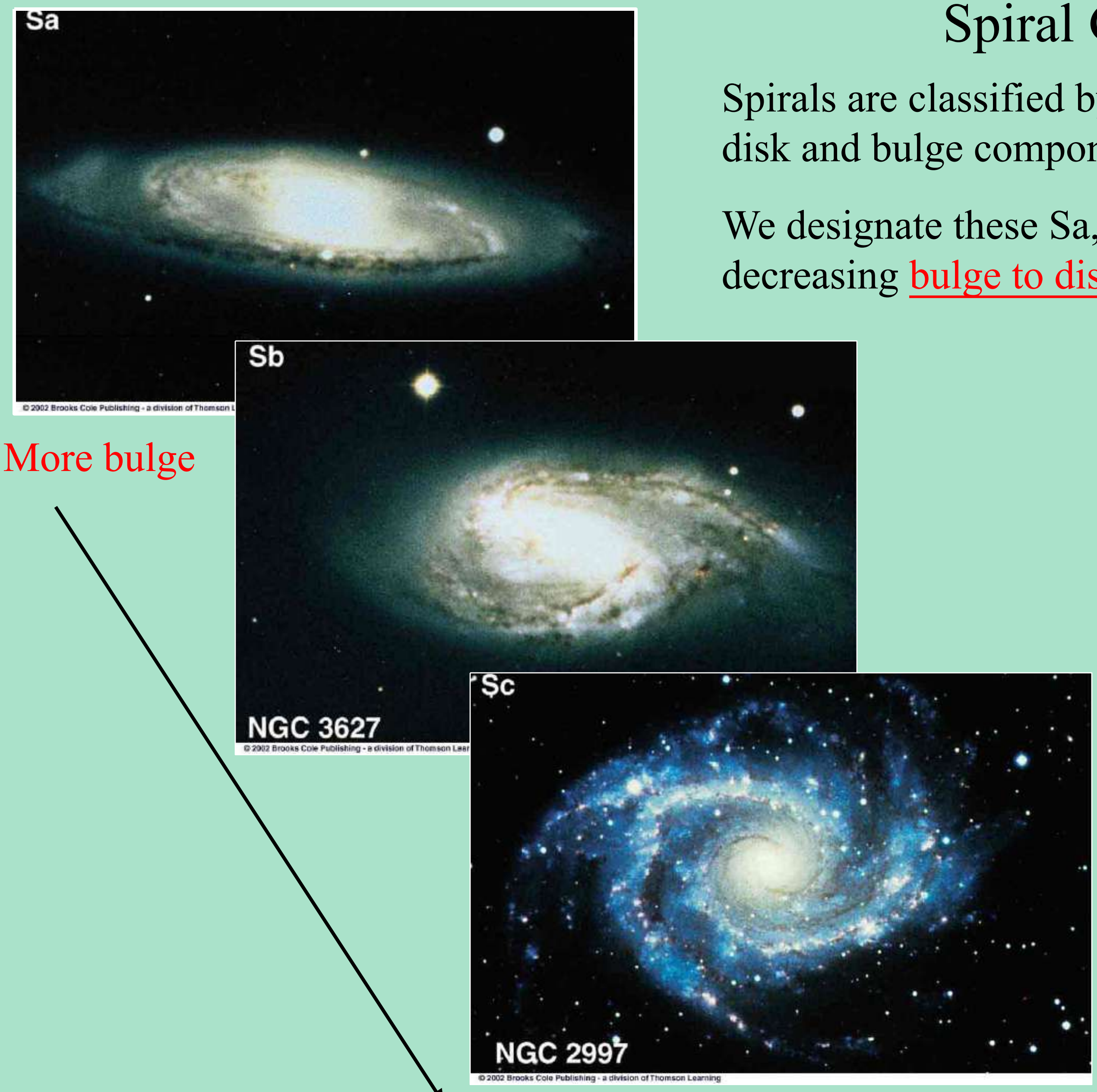
Sizes - radius = 10 to 30 kpc
Masses - M = 10^7 to 10^{11} M_{sun}

Milky Way and Andromeda are both bright, spirals
M_V ~ -21 or L_V ~ 2 x 10^{10} $L_{V,sun}$

Spiral Galaxies

Spirals are classified by their relative amount of disk and bulge components.

We designate these Sa, Sb, Sc, in order of decreasing bulge to disk ratio.



More bulge

More disk

More disk means more star formation!

Barred spirals are called SBa, SBb, SBc

Elliptical Galaxies

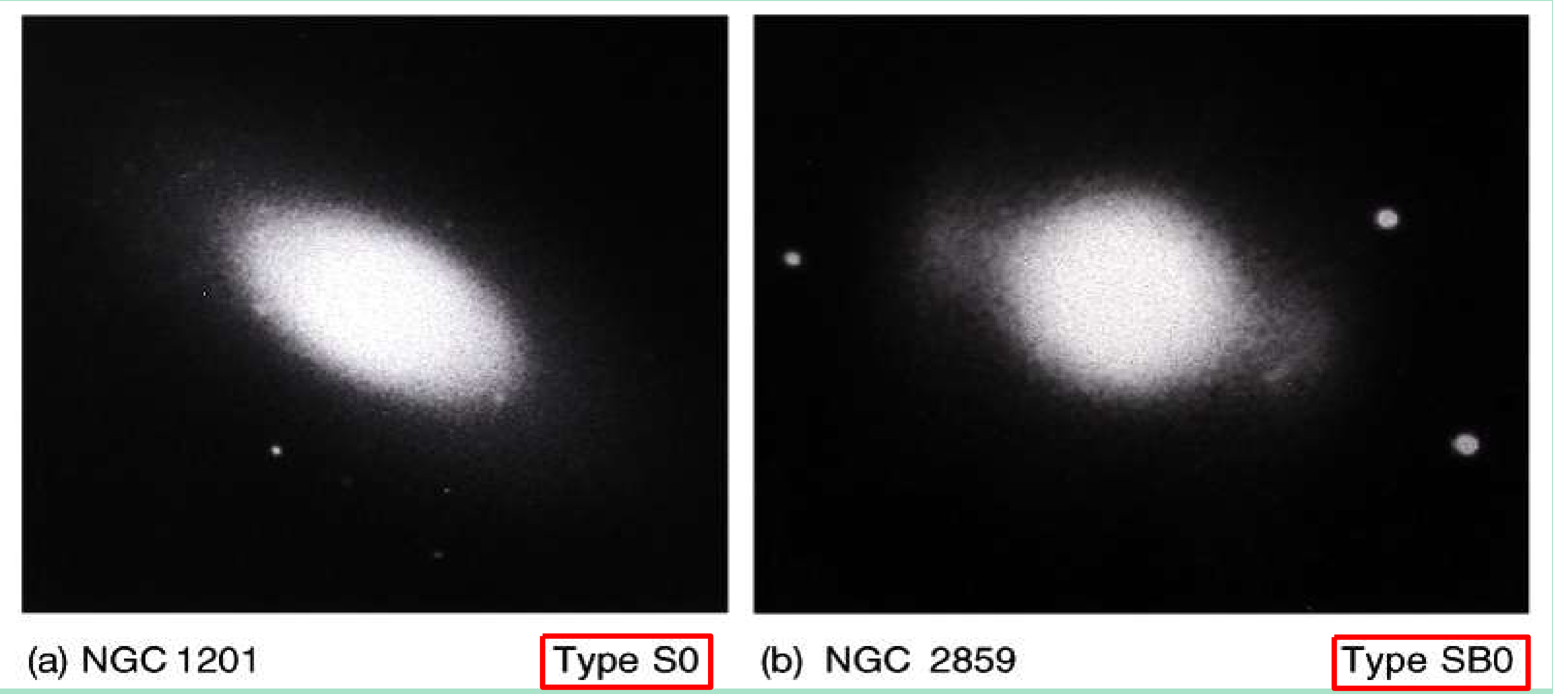
(a) E0 (NGC 4486) (b) E3 (NGC 4365) (c) E6 (NGC 4564)

- Smooth structure and symmetric, elliptical contours
- Subtype E0 - E7 defined by flattening

- En where n = 10(a-b)/a

a and b are the projected major and minor axes
(not necessarily a good indicator of the true 3-D shape)

S0 Galaxies (Lenticulars)

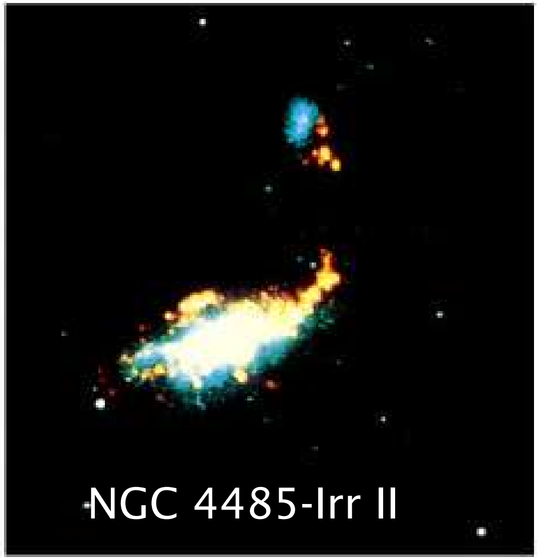


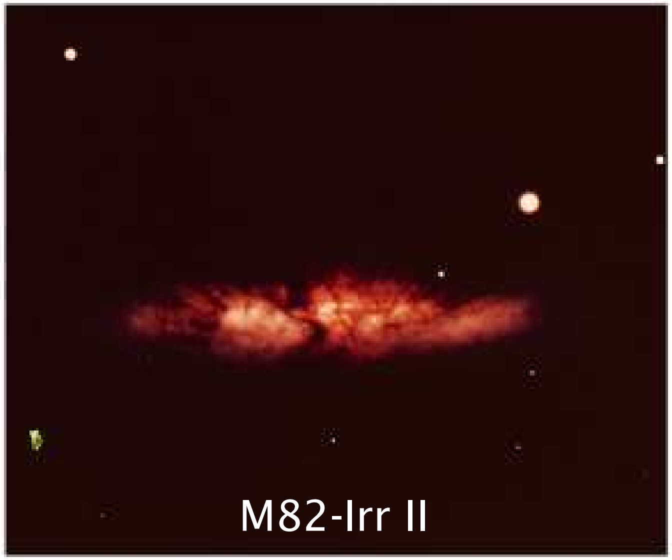
•Smooth, central brightness concentration (bulge similar to E) surrounded by a large region of less steeply declining brightness (similar to a disk)

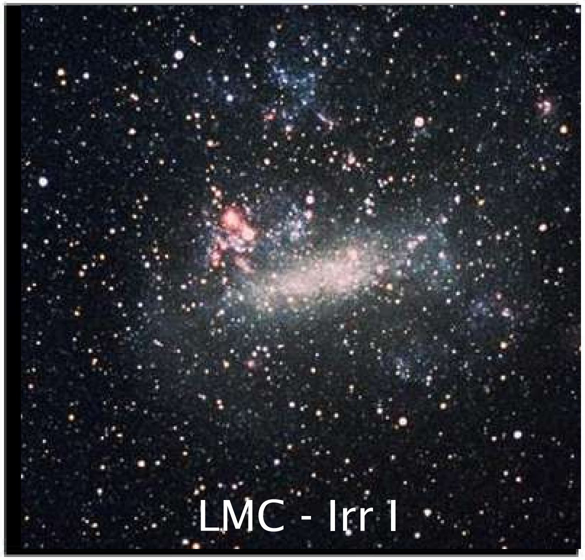
•No spiral arm structure but some contain dust and gas

•Originally thought to be transition objects between Sa and E but typical S0 is 1-2 mags fainter than typical Sa, E (van den Bergh 1998)

Irregular Galaxies







- No morphological symmetry

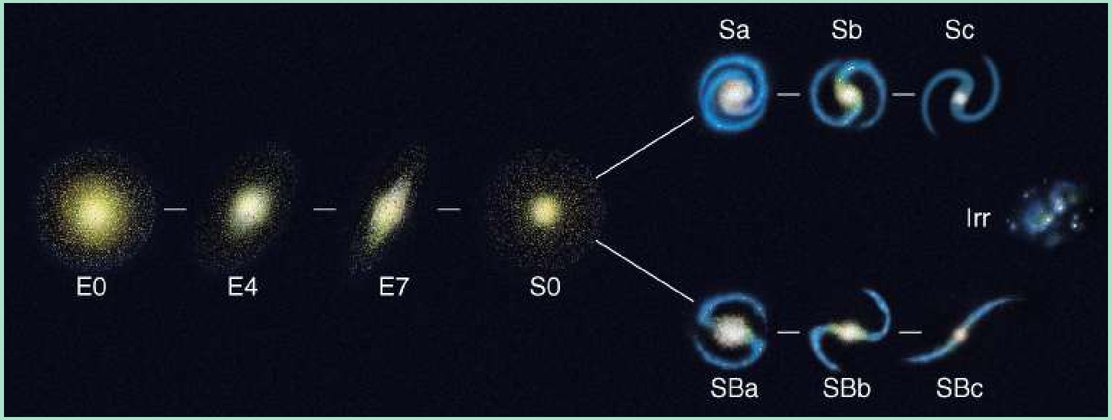
- Lots of young, blue stars and interstellar material

- Smaller than most spirals and elliptical galaxies

- Two major subtypes:
- Irr I: spiral-like but without defined arms, show bright knots with O,B stars
- Irr II: contain many dust lanes and gas filaments (e.g. M82) - explosive

General trends within Hubble sequence E → Sc:

- Decreasing Bulge/Disk
- Decreasing stellar age
- Increasing fractional gas content
- Increasing ongoing star formation



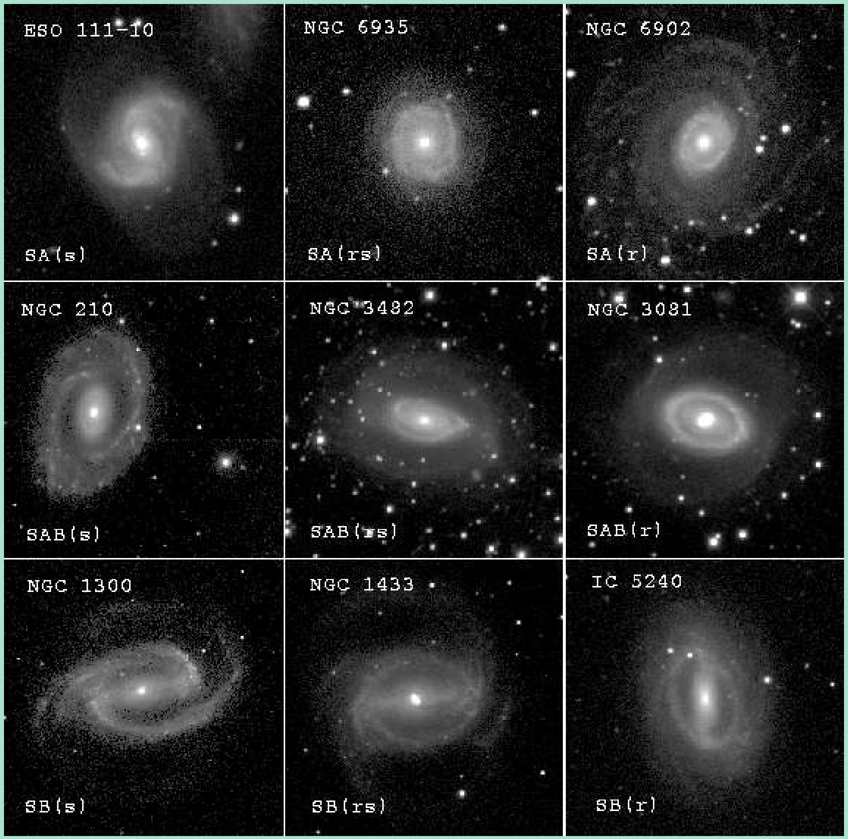
Limitations of the (original) Hubble Classification Scheme

1. Only includes massive galaxies (doesn't include dwarf spheroidals, dwarf irregulars, blue compact dwarfs)
2. Three different parameters for classifying spirals is unsatisfactory because the parameters are not perfectly correlated.
3. Bars are not all-or-nothing. There is a continuum of bar strengths.

de Vaucouleurs' Revised Hubble Classification System

(de Vaucouleurs 1958, Handbuch der Phys. 53, 275)
(de Vaucouleurs^2 1964, Reference Catalog of Bright Galaxies)

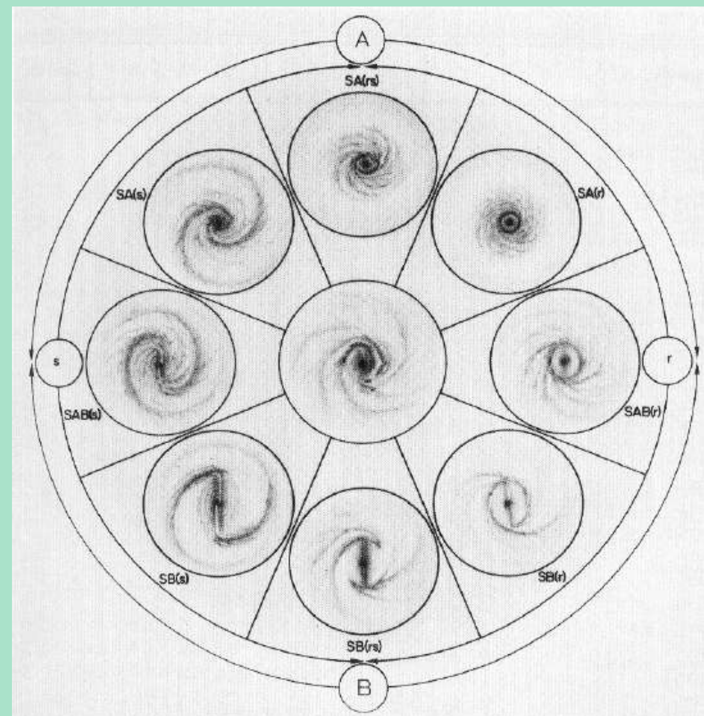
Basic idea: retain Hubble system, but add lots of additional options:
Rings (inner and outer), range of bar-like structures….



Spiral shaped

Cross section of diagram

No Bar



Ring shaped

Bar

Limitations:
Rings and bars are not independent
Does not take into consideration mass or other important parameters.

Barred Spiral Galaxies

(a) SBa (NGC 4314) (b) SBb (NGC 4548) (c) SBc (NGC 613)

- Contain a linear feature of nearly uniform brightness centered on nucleus

- Subclasses follow those of spirals with subtypes a b and c

MW may be SBb, depending on prominence of the bar.

The Hubble Deep Field

From this image, we can estimate the number of galaxies in the universe!

1. Count the number of galaxies in this image
2. Measure angular area on the sky of this image
3. Figure out how many images of this size needed to cover entire sky
4. Multiply that number (from 3.) by the number of galaxies in this image (from 1.)

The longest, deepest exposure ever taken. Was an empty piece of sky!

Galaxies are the Fundamental "Ecosystems" of the Universe

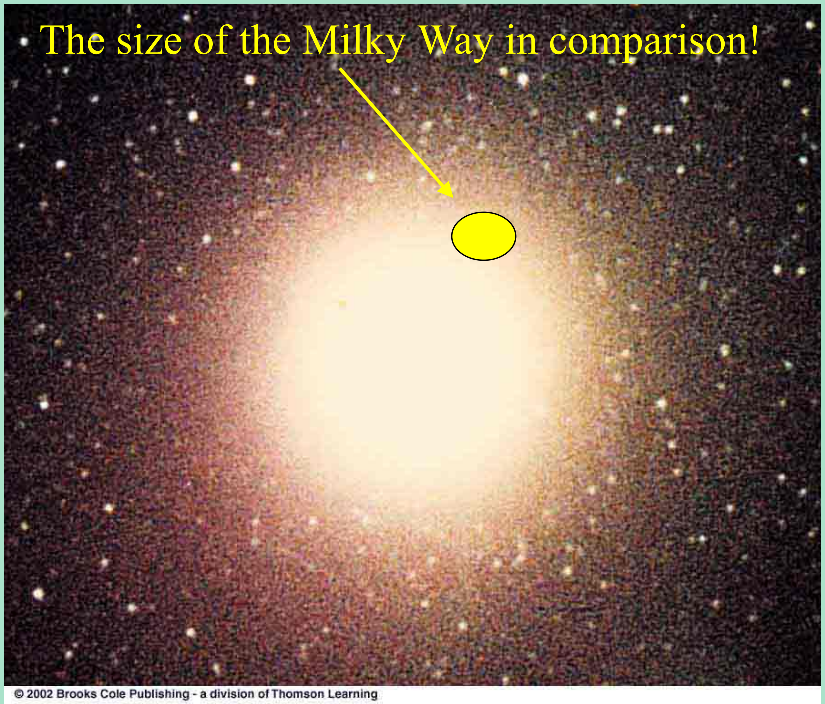
- are cosmic engines that turn gas into stars and stars into gas
- between them no star formation occurs; "nothing happens" in intergalactic space
- are recent discovery (by Edwin Hubble in late 1920's)
- can be classified my morphology (shapes and sizes)

<u>Three Main Types of Galaxies</u>:

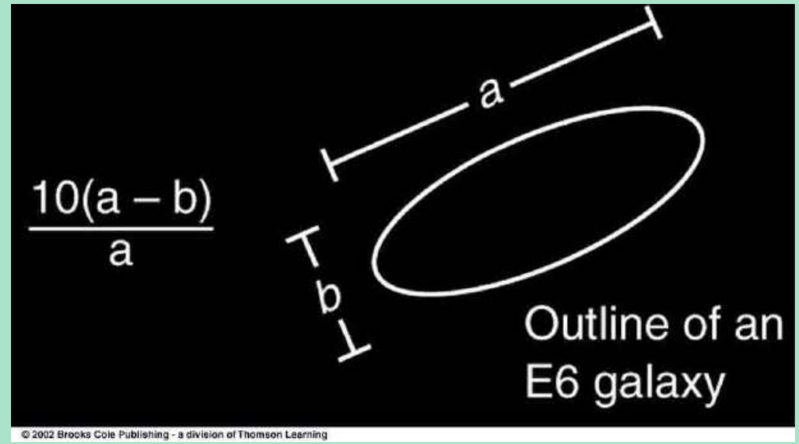
- Ellipticals - *galaxies are pure bulge, no disk component*
- Spirals - *galaxies contain varying amounts of disk component from mostly bulge with barely detectable disks to those totally dominated by their disks*
- Irregulars - *galaxies are… well. Odd.*

Elliptical Galaxies

Elliptical galaxies are affectionately called "E" galaxies. They can be extremely large and massive. This galaxy is 2 million light years across.



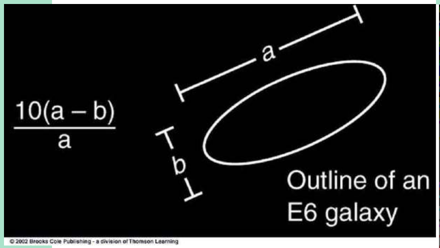
An Example of an E0 galaxy. The bright objects surrounding it are its own globular clusters.



Names of E galaxies give their shape. E0 is round. E6 is elongated.

The way you name an E galaxy is to measure its "major" and "minor" axis and plug it into the formula above.

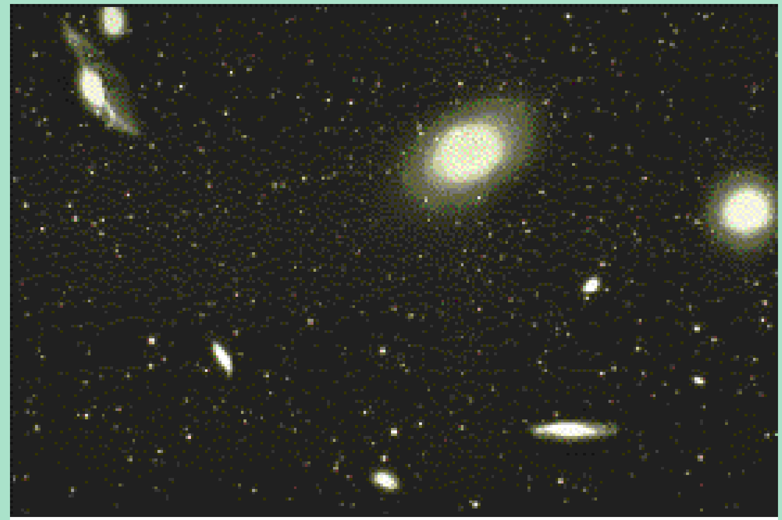
More E Galaxies



Note how this little formula is used simply by looking at the photograph. We use computers to make these measurements.

Here is an example of an E6 galaxy. Note how well it fits the definition of an E6.

Note that it has smooth brightness profile, that there are no features due to dust and gas.



Many E galaxies reside in center of groups or clusters of galaxies.

Note the E0 (to the right) and the E3 near the center of the cluster.

Disks vs. Bulges

Disks:

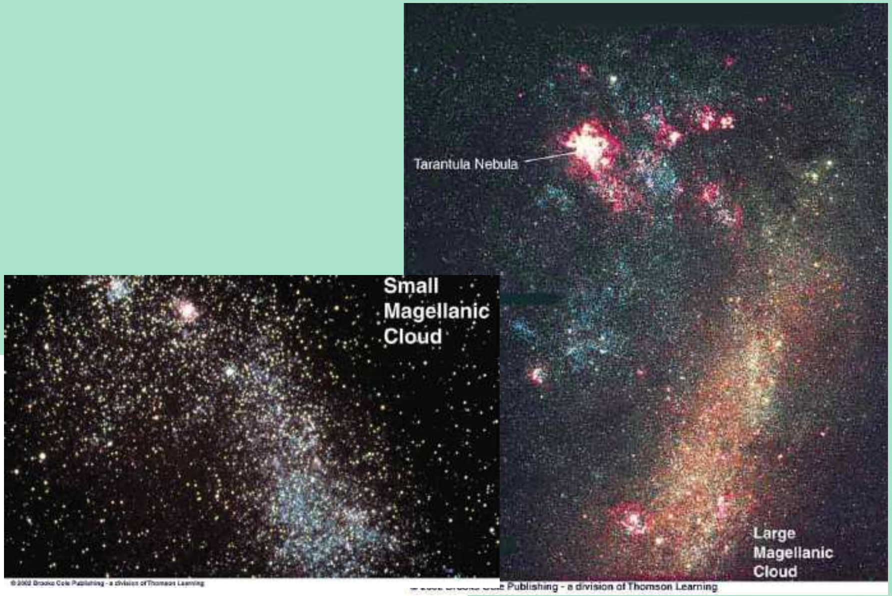
- flattened systems that rotate
- orbits of stars and gas are “circular”, rotating about disk axis
- star formation is on-going; it is can be fairly constant over the age of the galaxy
- gas and dust mass fraction is roughly 10-50% of full disk
- due on-going star formation, ages of stars widely range from age of galaxy to new
- spiral arms form as sustained density waves; where majority of star formation occurs

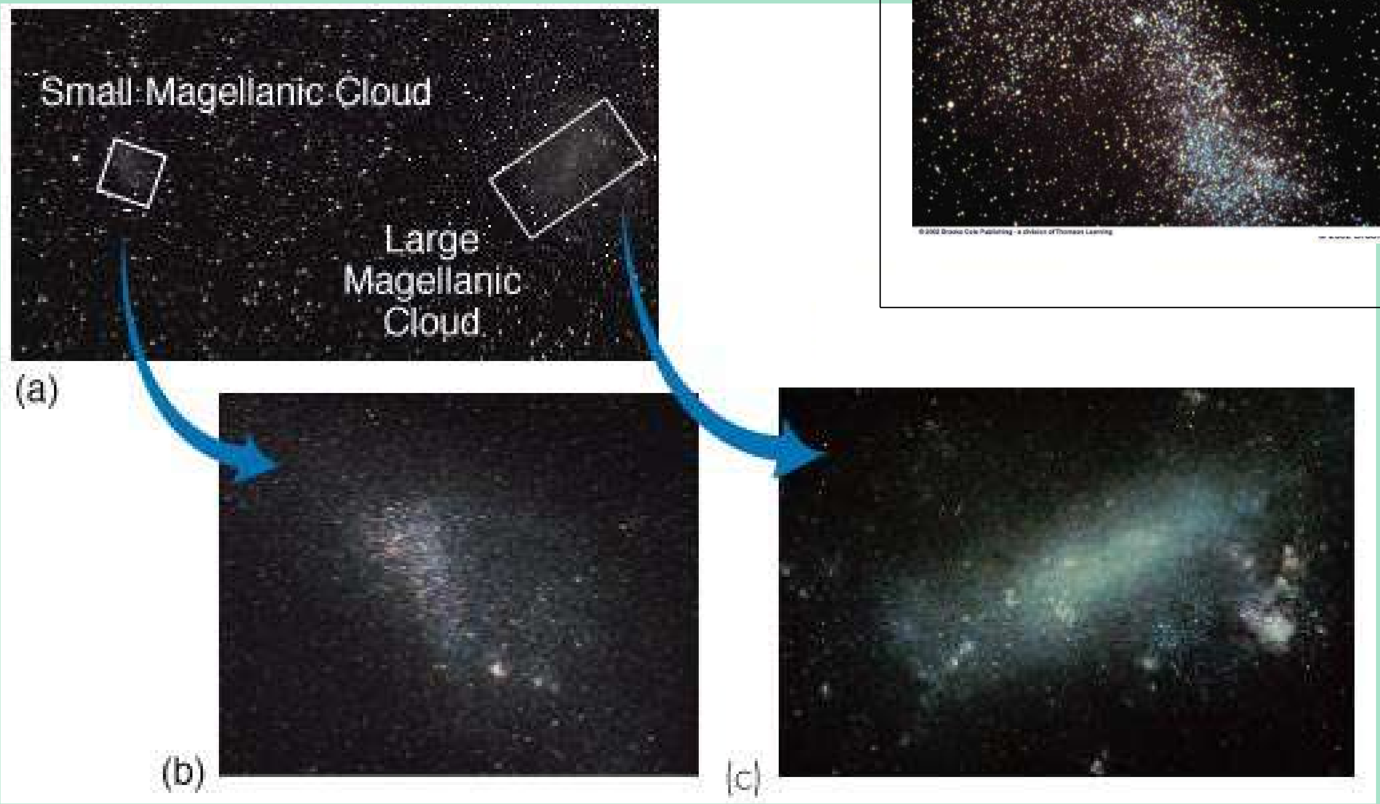
Bulges:

- spheriodal systems with little or no rotation
- orbits of stars are randomly oriented and highly eccentric (some are radial)
- star formation complete long ago; gas consumed efficiently long ago
- ages of stars are mainly old; most as old as the galaxy
- very little to know gas; it has been converted to stars already
- overall structure is smooth- no clumpy areas like analogous to spiral arms in disks

The Large and Small Magellanic "Clouds"

The SMC and LMC are small Irregular galaxies that are satellites of the Milky Way Galaxy.





The LMC is still forming stars.

The SMC is not forming new stars.

The Garbage Can of Galaxy Classification

Dwarf Elliptical

Dwarf Irregular

… and there are more of these types of galaxies than any other type!

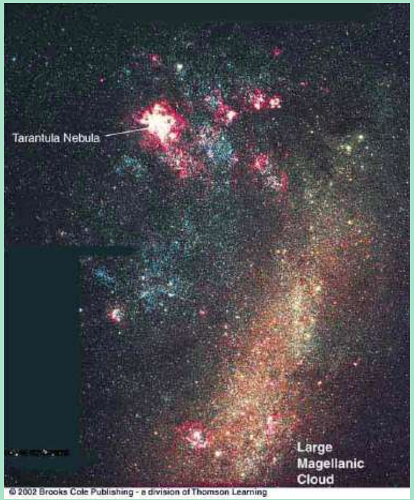
There may be lots of them, but they are not very luminous or very massive, so they do not contribute to the total integrated galaxy luminosity or mass in the universe.

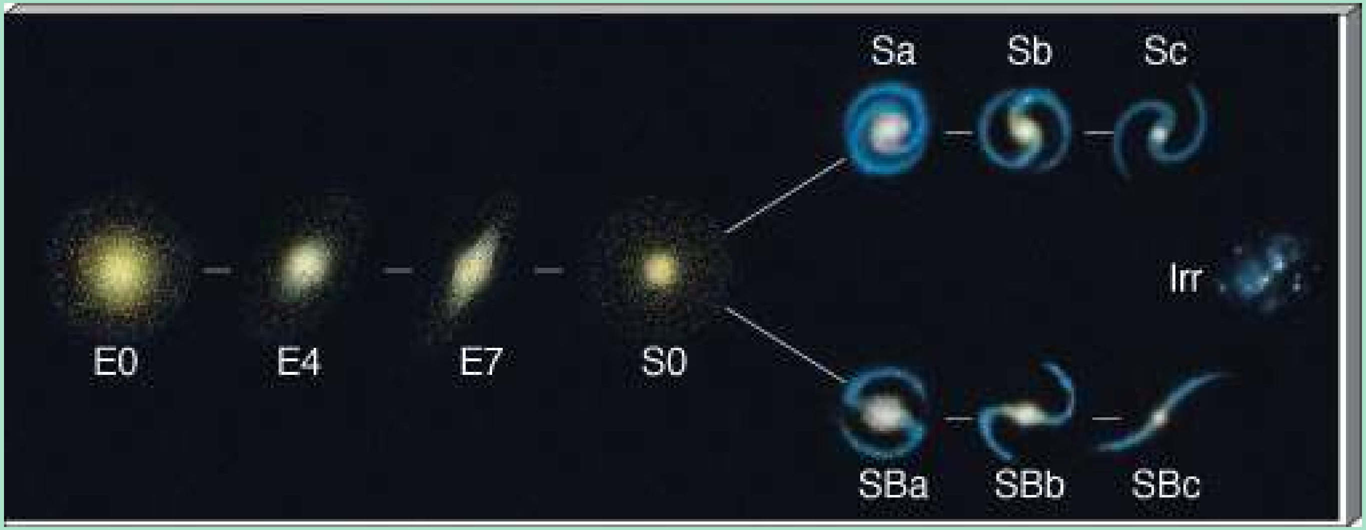
Galaxy Morphological Revisted

Elliptical

Spiral

Irregular



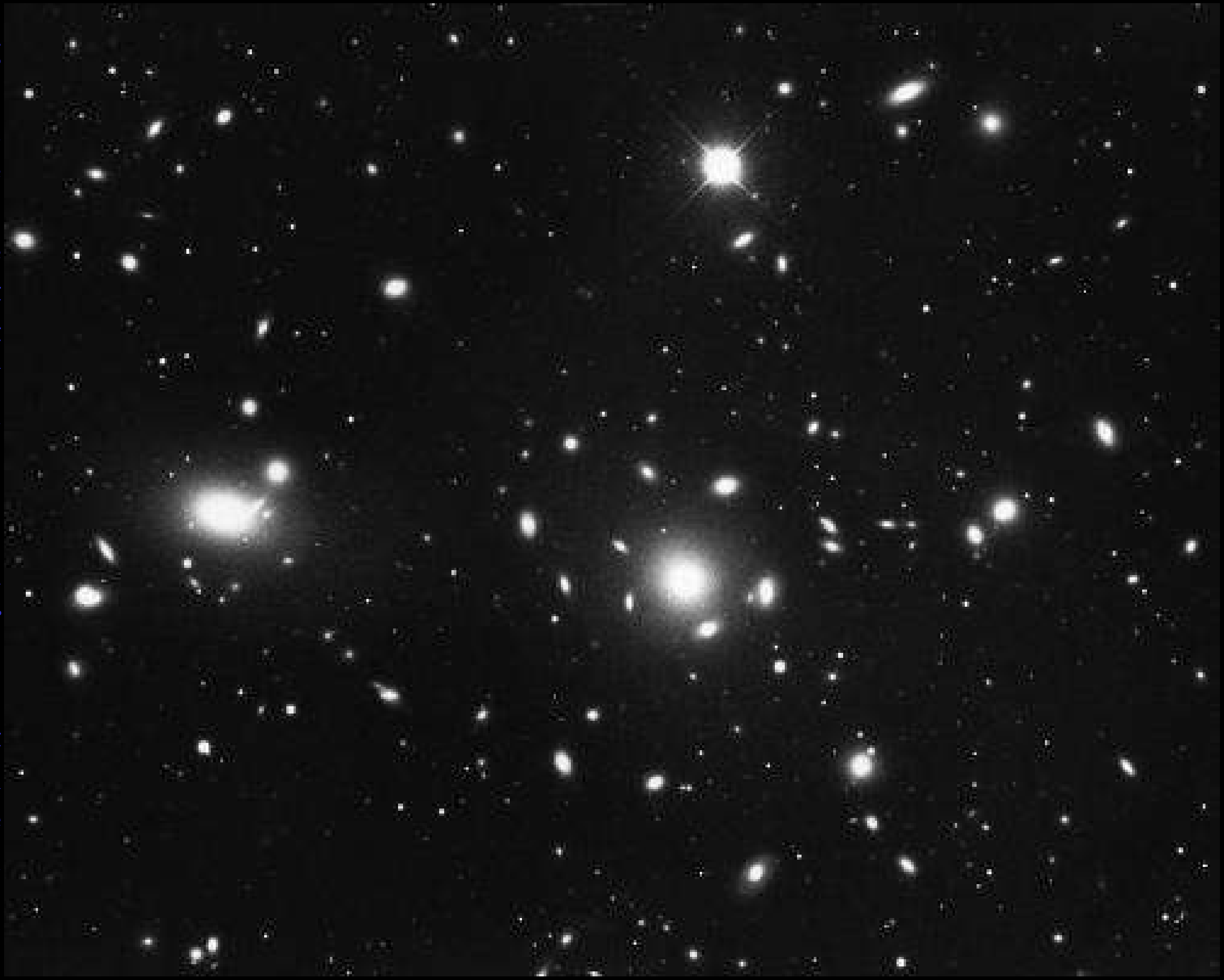


The Hubble Tuning Fork

Clusters of Galaxies

Rather than occurring individually in space, galaxies are grouped in clusters ranging in size from a few dozens to thousands of galaxies. The Coma Cluster, shown at right, is 300 million light years from the Milky Way and contains more than 1,000 (and possibly as many as 10,000) galaxies.

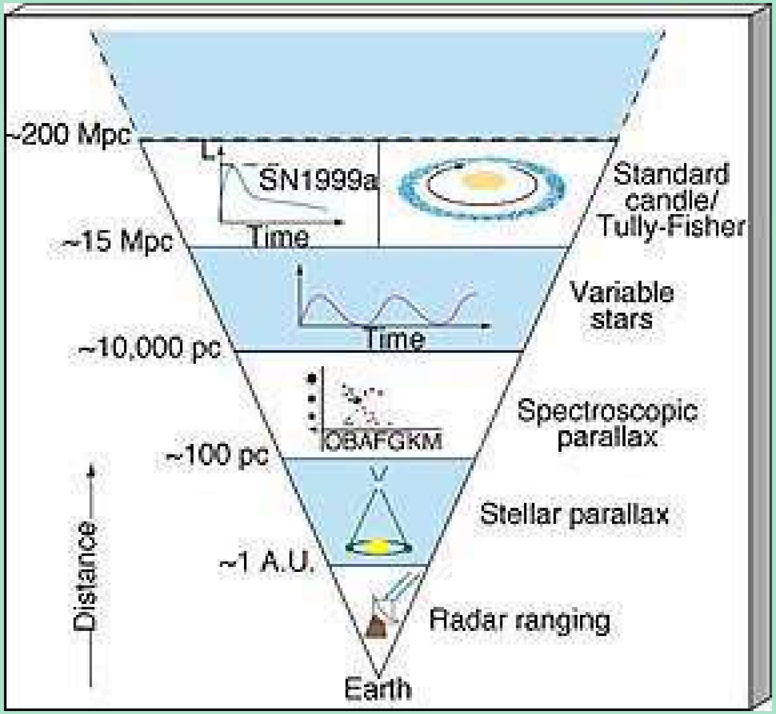
The Milky Way is a member of a small cluster called the Local Group which contains about 40 galaxies. The largest member of the Local Group is M 31, with the Milky Way coming in second in size.



(NOAO/AURA Photo)

Getting the Distances to Galaxies is a "Big Industry"

$d = \text{constant} \times (L/B)^{1/2}$



1 Mpc = 1 million parsecs

The Distance Ladder

Location	Distance	Method
solar system	10 A.U.	radar ranging
Local Galaxy	100 pc	stellar parallax
Across Galaxy	10,000 pc	spectroscopic "parallax"
Nearby galaxies	15 Mpc	Variable stars
Distant galaxies	200 Mpc	Standard candle and "Tully-Fisher"

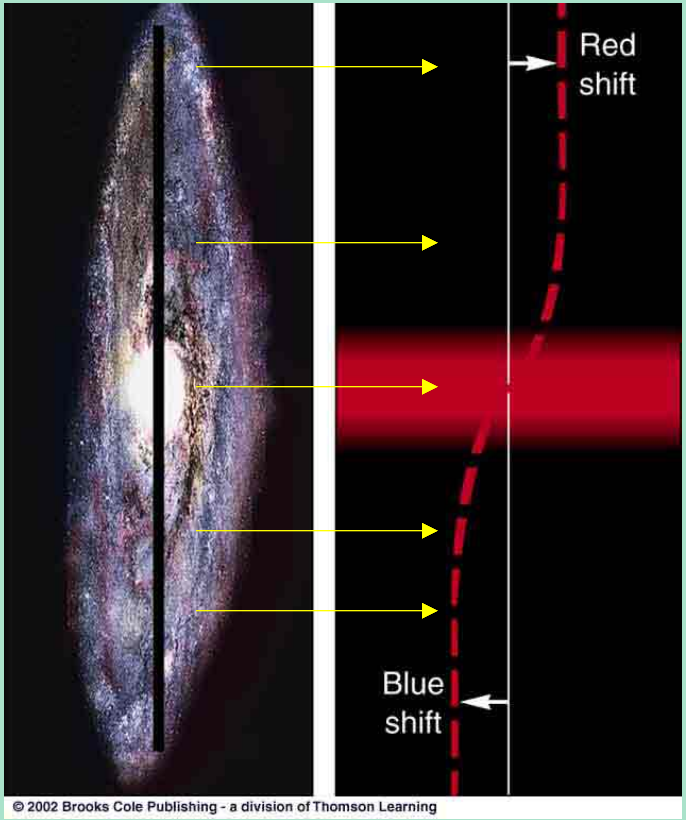
We have studied stellar parallax, and variable stars.

Spectroscopic parallax is simply comparison of brightness of identical stars.
Standard candle is comparison of brightness of identical supernovae explosions.
Tully-Fisher is a way to measure galaxy luminosity from its rotations speed. *More ...*

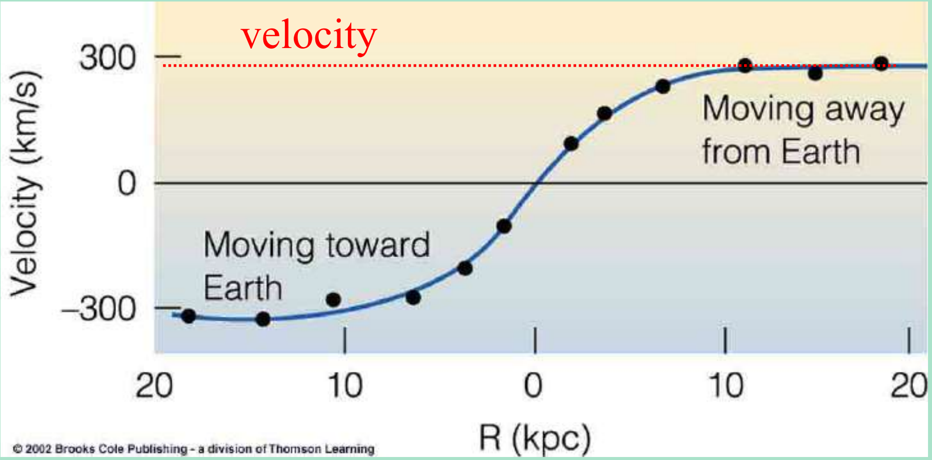
Tully-Fisher Distance Indicator

Recall, luminosity of stars scales with mass of stars… therefore, luminosity of galaxy scales with number of stars (and thus, mass of stars). Thus, luminosity of galaxy gives mass of galaxy.

Going backwards… measure the velocity to "weigh" the galaxy to obtain luminosity.



Doppler velocity map of galaxy.



$$L = \text{constant x } (\text{velocity})^4$$

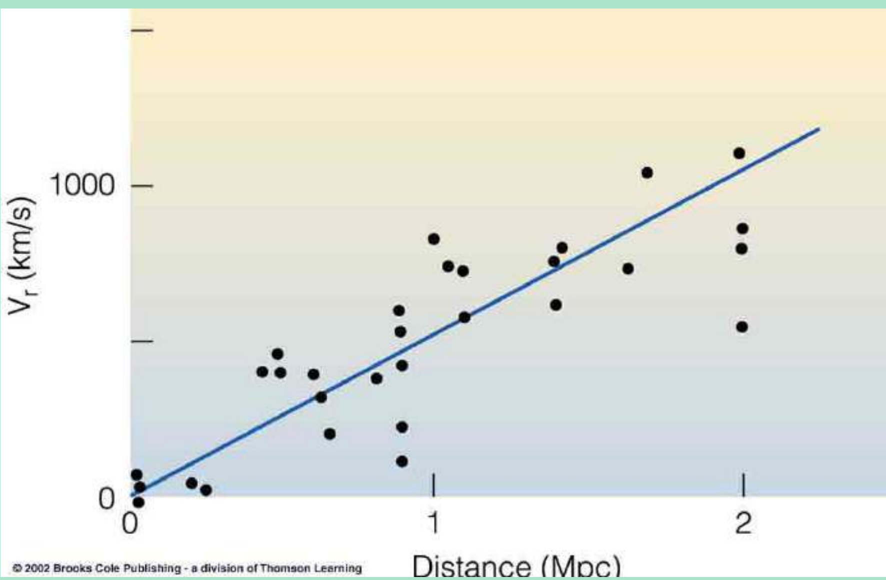
$$d = \text{constant x } (L/B)^{1/2}$$

The Hubble Law

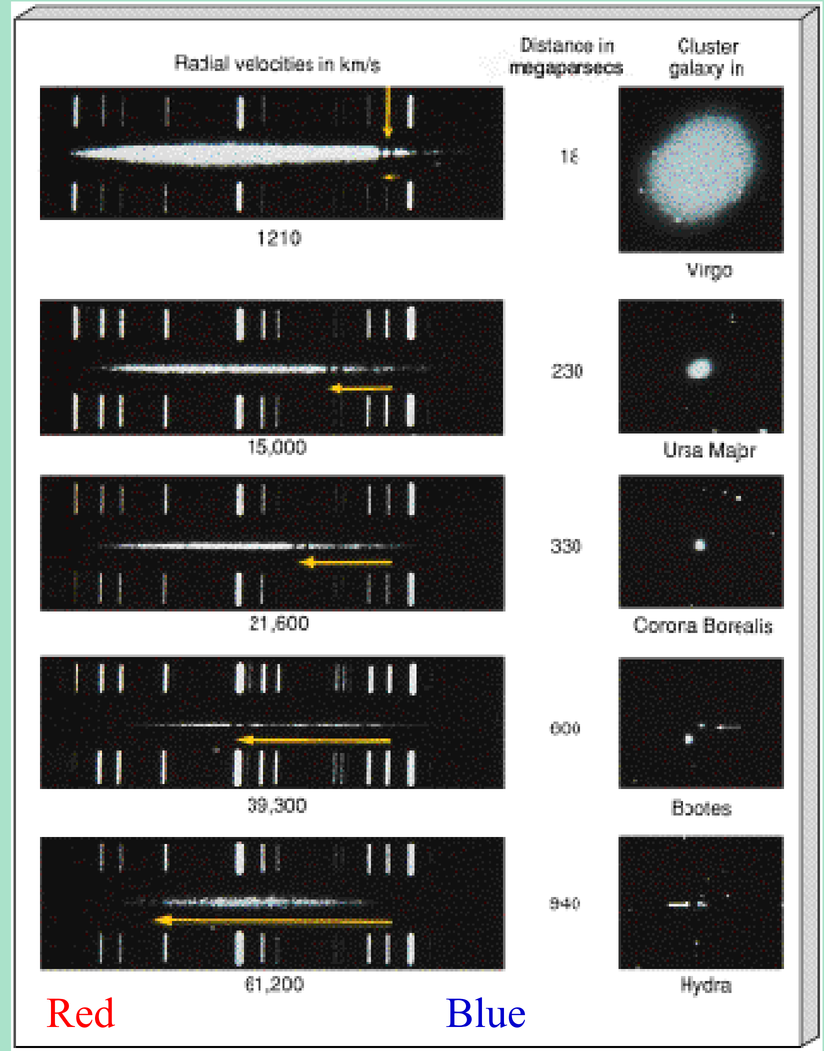
The problem is that 200 Mpc is nothing!

Well, it turns out that there is another indicator for extreme distances.

The Hubble Law
The further away a galaxy is, the greater is its redshift.

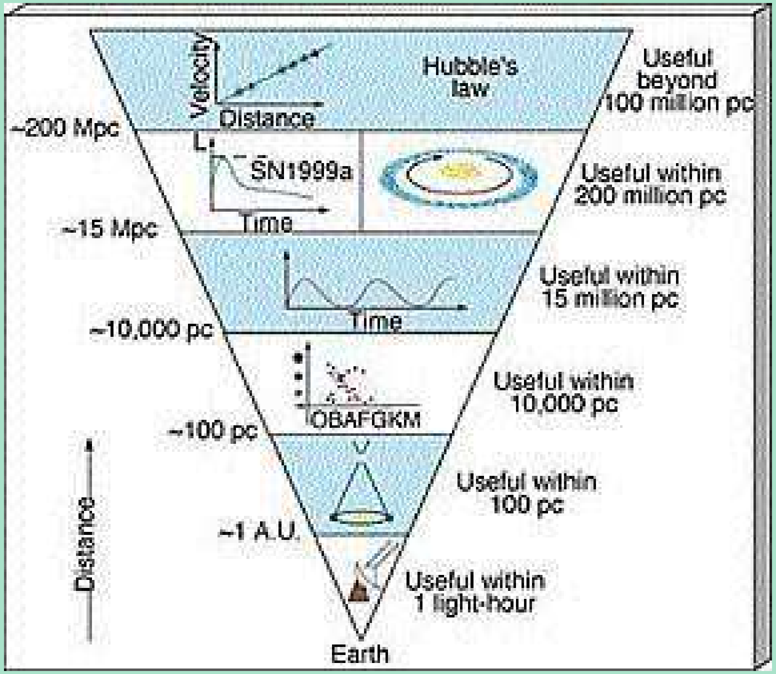


(As you can see, it is not perfect.)



Hubble Law Takes us All the Way Out

The distance scale revisited.



Implies that Galaxies are "flying away" and that the speed with which they are moving away is proportional to there distance away.

The further away the galaxy, the faster it is receding from us. (more on this later…)

velocity = constant x distance

The constant is called Hubble's constant. It is designated as **H_0**. Pronounced "H not".

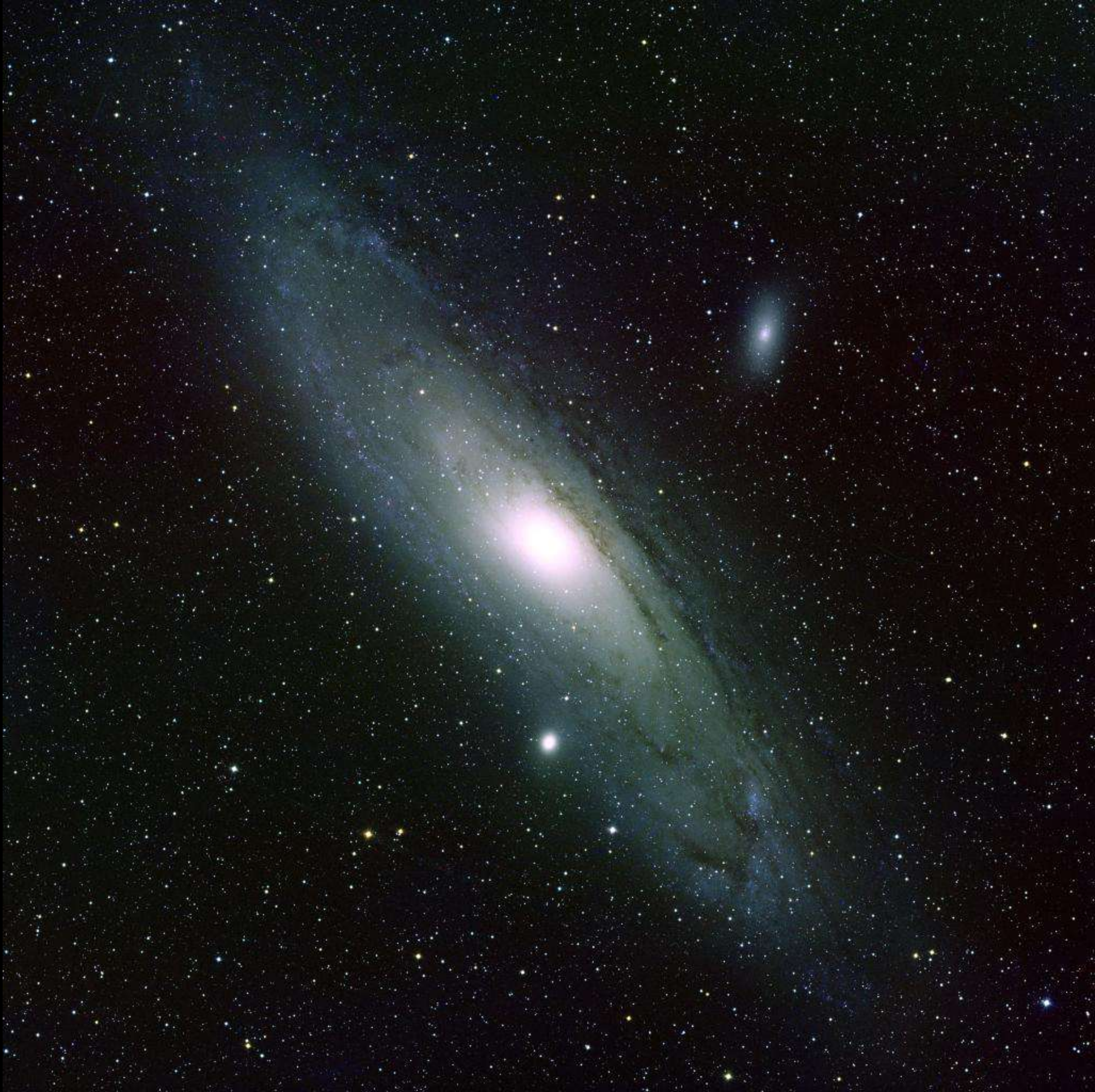
velocity = H_0 x distance

Examples of Galaxies

M31 - The Great Spiral Galaxy in Andromeda

This nearby galaxy in the Local Group of galaxies, of which the Milky Way is a member, is 2.5 million light years away.

(NOAO/AURA Photos)



The Nuclear Bulge of M31

Young stars have formed along the foreground spiral arm. M31's two satellite galaxies M32 and NGC 205, both dwarf elliptical galaxies, are in the bottom center and upper right.

(NOAO/AURA Photos)

The Outer Disk of M31

(NOAO/AURA Photos)

Central Region of the Spiral Galaxy M 51

(Hubble Space Telescope Image)

Barred Spiral Galaxies

The spiral galaxies M 91 (left) and M 109 (right) have bars across their nuclei from which spiral arms unwind. In virtually all spirals (barred or not) the galaxies rotate such that the spiral arms trail behind in the rotation. The Milky Way is thought to be a barred spiral galaxy. (NOAO/AURA Photos)

Types of Galaxies II. Ellipticals

Elliptical galaxies lack spiral arms and dust and contain stars that are generally identified as being old. The elliptical galaxies M 32 (below) and M 110 (right) show varying degrees of ellipticity.

(NOAO/AURA Photos)

Types of Galaxies III. Irregulars

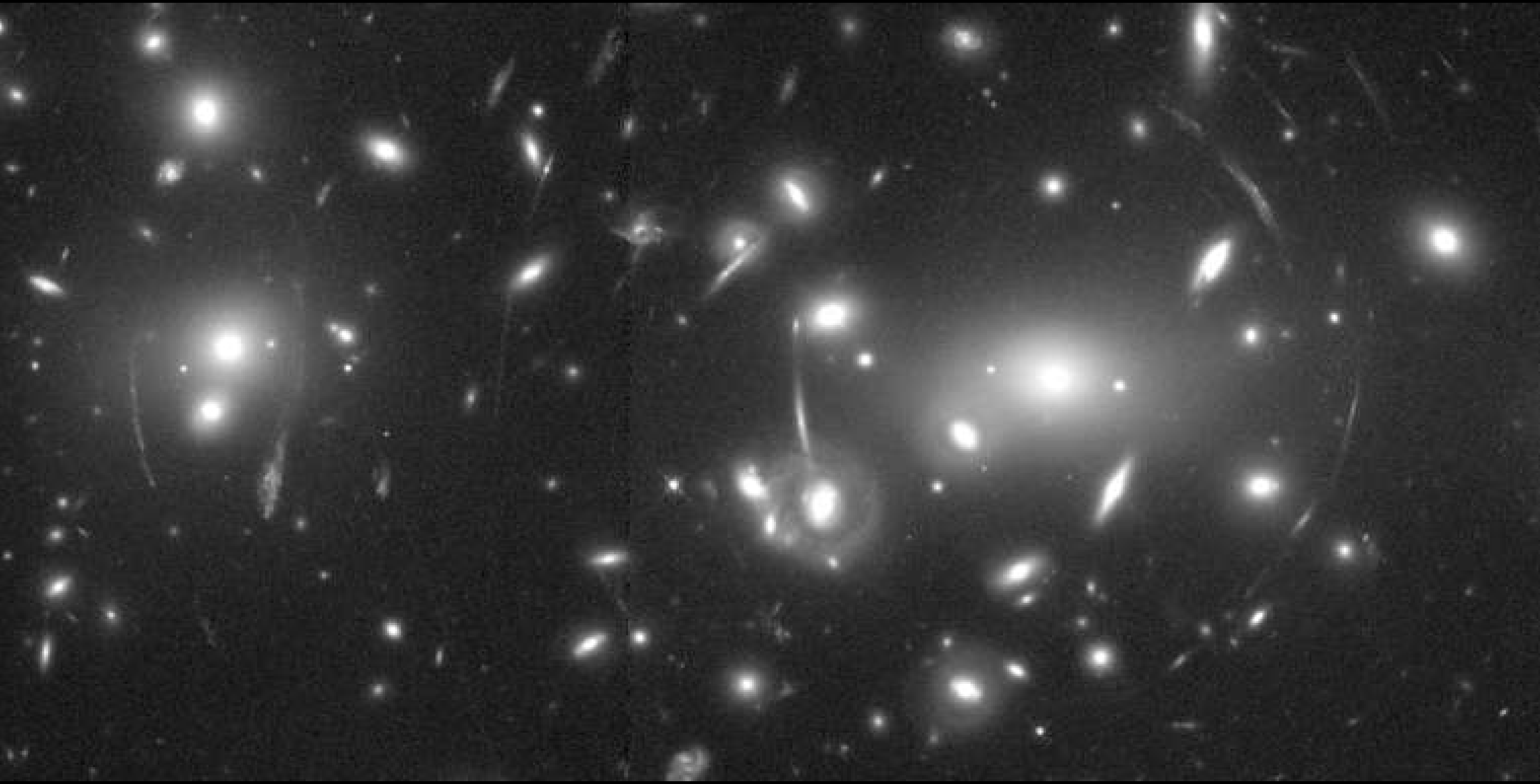
Irregular galaxies lack any specific form and contain stars, gas and dust generally associated with a youth. The irregular galaxy at right is the Large Magellanic Cloud, a satellite of the Milky Way located about 180,000 light years from the sun. The LMC is about 60,000 light years across. The bright reddish feature in the upper right is the “Tarantula Nebula” a region of star formation in the LMC. (NOAO/AURA Photo)

Dwarf Irregular Galaxy in Sagittarius

Hubble Space Telescope Image

Gravitational Lensing in Abell 2218 Cluster

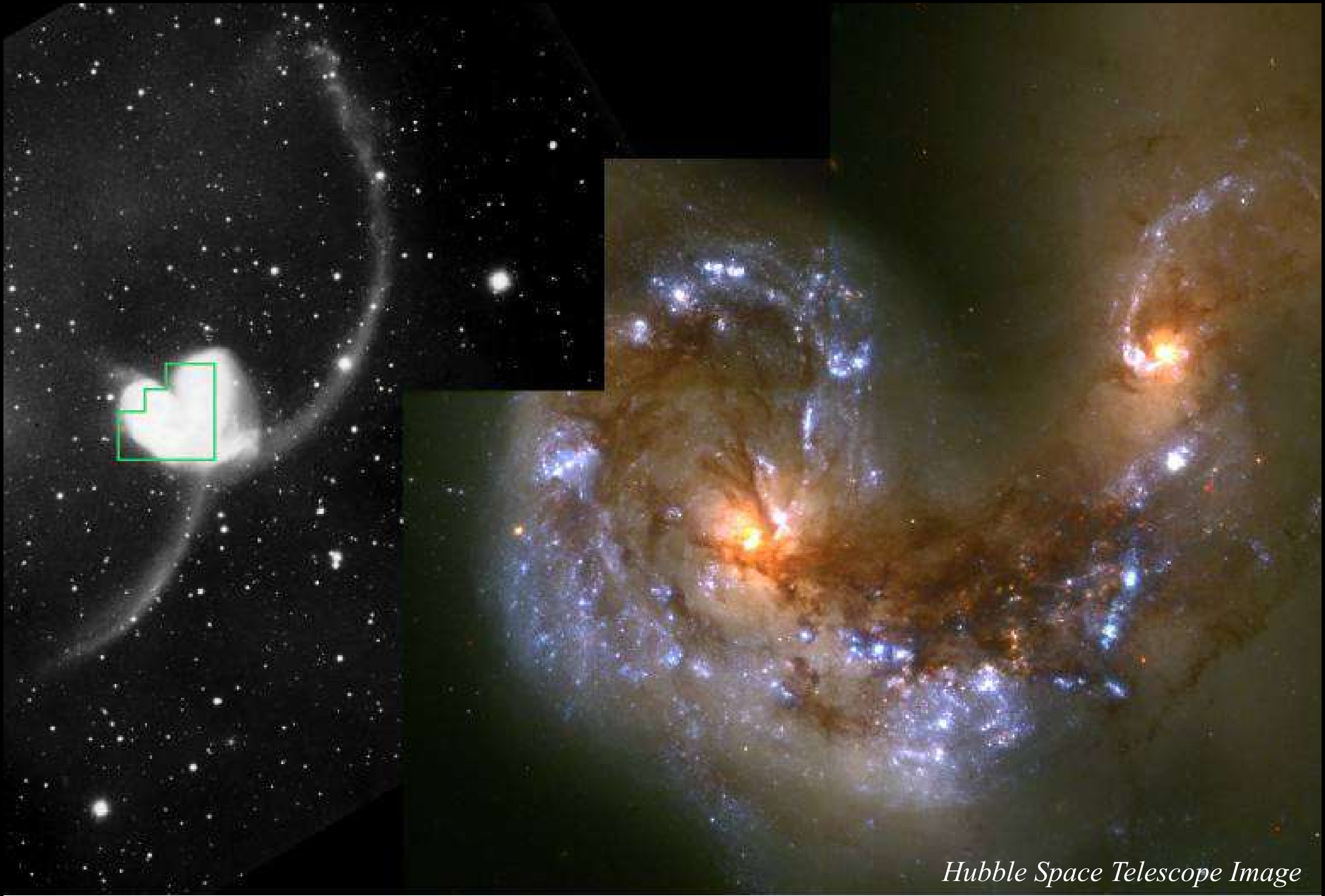
As predicted by Einstein's General Theory of Relativity, a compact intervening object is bending and distorting light from individual members of this cluster so that we see a halo effect.



Hubble Space Telescope Image

Galaxies in Collision

In this close encounter between two spiral galaxies, their arms are dramatically warped and massive star formation is triggered when the hydrogen gas clouds in the two collide. It is believed the Milky Way may have "cannibalized" small galaxies in the past through collision.



The Disrupted Galaxy NGC 5128

Active Galaxies I.

The galaxy NGC 7742 is an otherwise normal spiral galaxy except for its extraordinarily bright nucleus that outshines the rest of the galaxy. Such galaxies, i.e. spirals with extremely bright nuclei, form a class of active galaxies known as Seyfert galaxies.

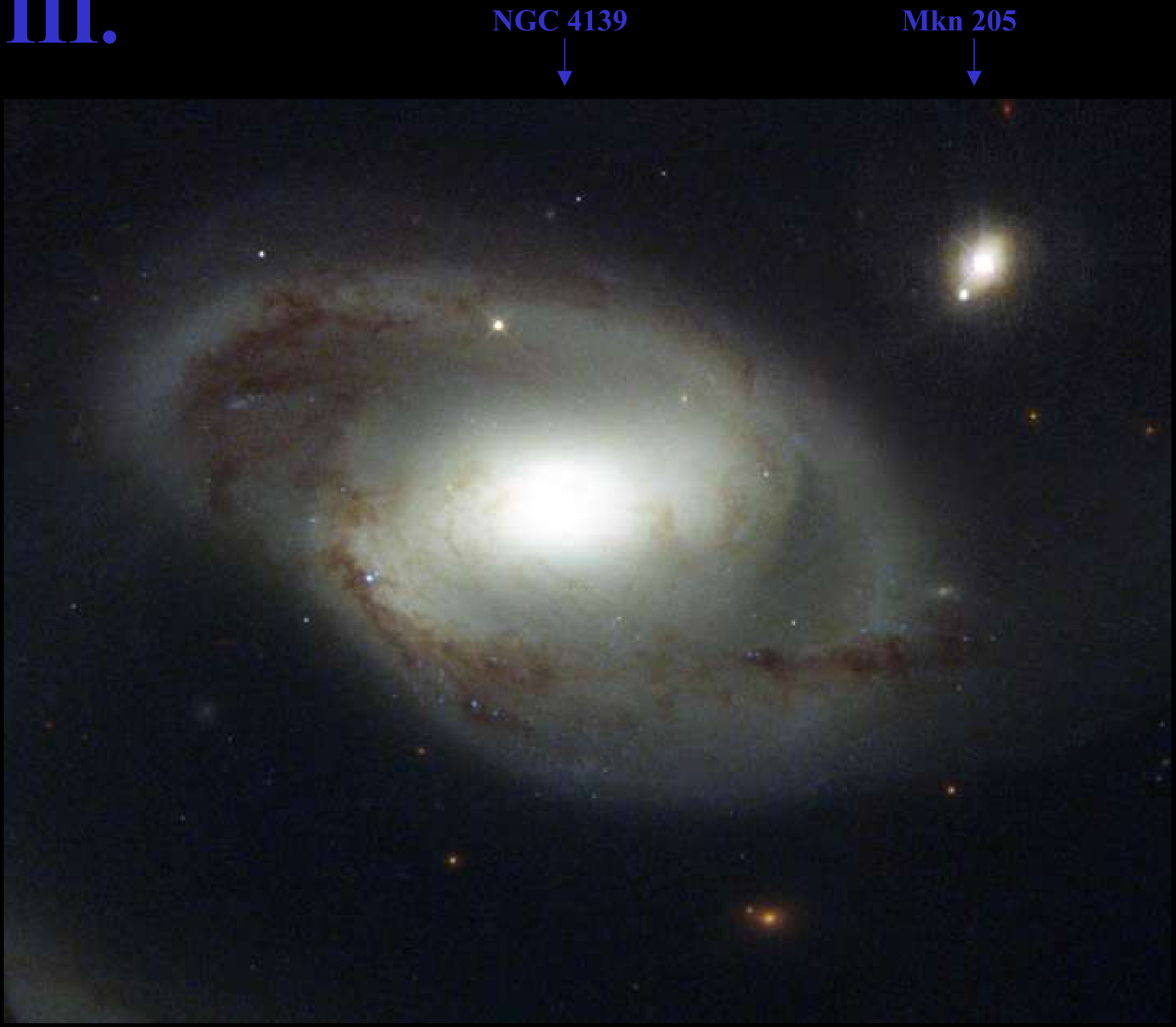
Active Galaxies II.

The elliptical galaxy M87, shown below in a wide-field ground-based image, has a very bright, point-like nucleus from which a jet of material emanates. The jet is seen in great detail from an HST image at right.

Hubble Space Telescope Image

Active Galaxies III.

This image shows the spiral galaxy NGC 4319 and the quasar Markarian 205. The distance to NGC is 80 million light years, which Mkn 205 is 14 times farther away at a distance of 1 billion light year.
The very distant quasar is nearly as bright as the much closer galaxy. The extraordinary brightness of quasars, which is a blending of the term quasi-stellar radio source, indicates that some incredibly powerful mechanism must be producing enormous amounts of energy from a small volume of space.



Hubble Space Telescope Image

A Lensed Quasar

An intervening galaxy between us and this distant quasar is causing light from the quasar to be bent along curved paths that give rise to an Einstein cross, a phenomenon predicted by Einstein's General Theory of Relativity.

National Optical Astronomy Observatories Image