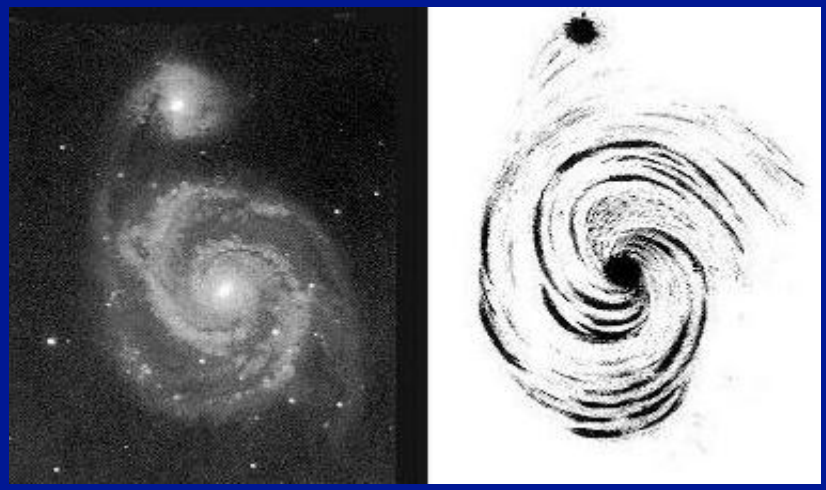
Galaxies

Reminder: Homework #8 is due today

Galaxies

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

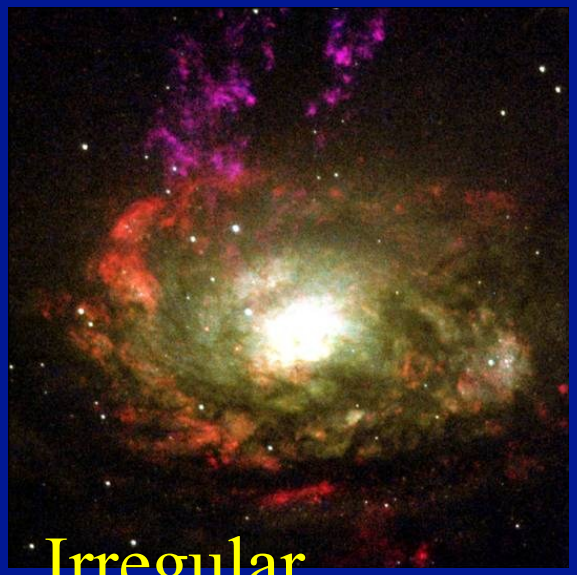


1920 - "Great Debate" between Shapley and Curtis on whether spiral nebulae were galaxies beyond our own. Settled in 1924 when Edwin Hubble observed individual stars in spiral nebulae.

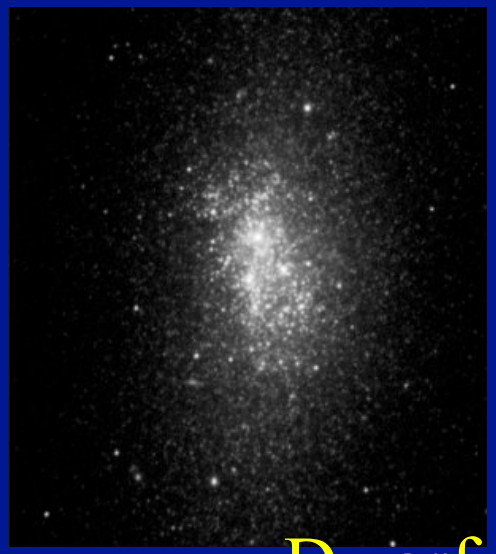
Sample of Galaxies


Spiral


Barred Spiral


Irregular


Elliptical


Dwarf

Milky Way schematic
showing bar

A barred spiral galaxy

A bar is a pattern too,
like a spiral

Galaxy Classification

Spirals

barred SBa-SBc

unbarred Sa-Sc

Ellipticals

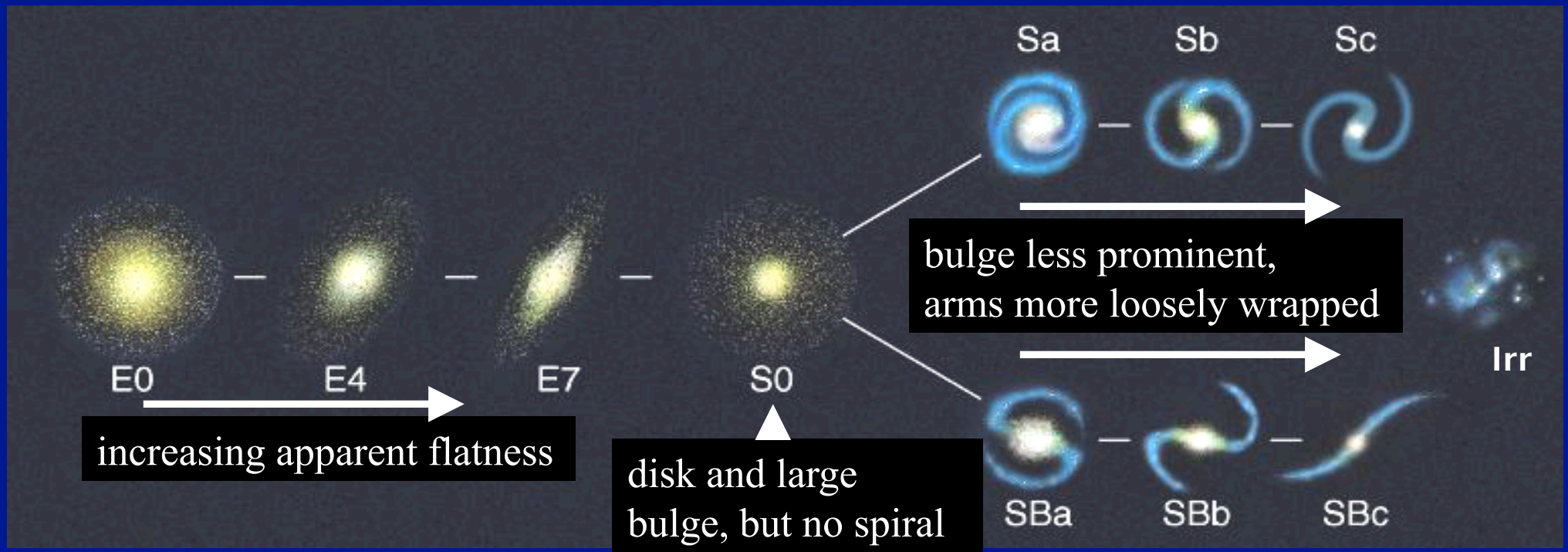
E0 - E7

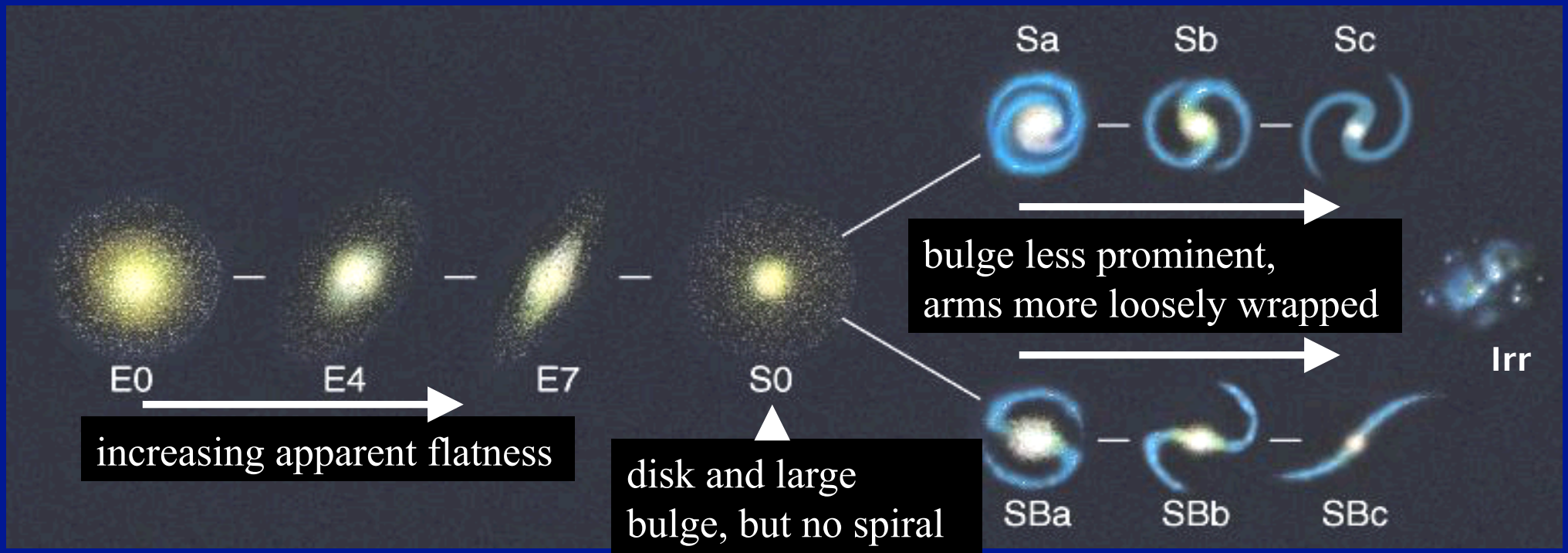
Irregulars

Irr I "misshapen spirals"

Irr II truly irregular

First classified by Hubble in 1924 => "tuning fork diagram"





Still used today. We talk of a galaxy's "Hubble type"

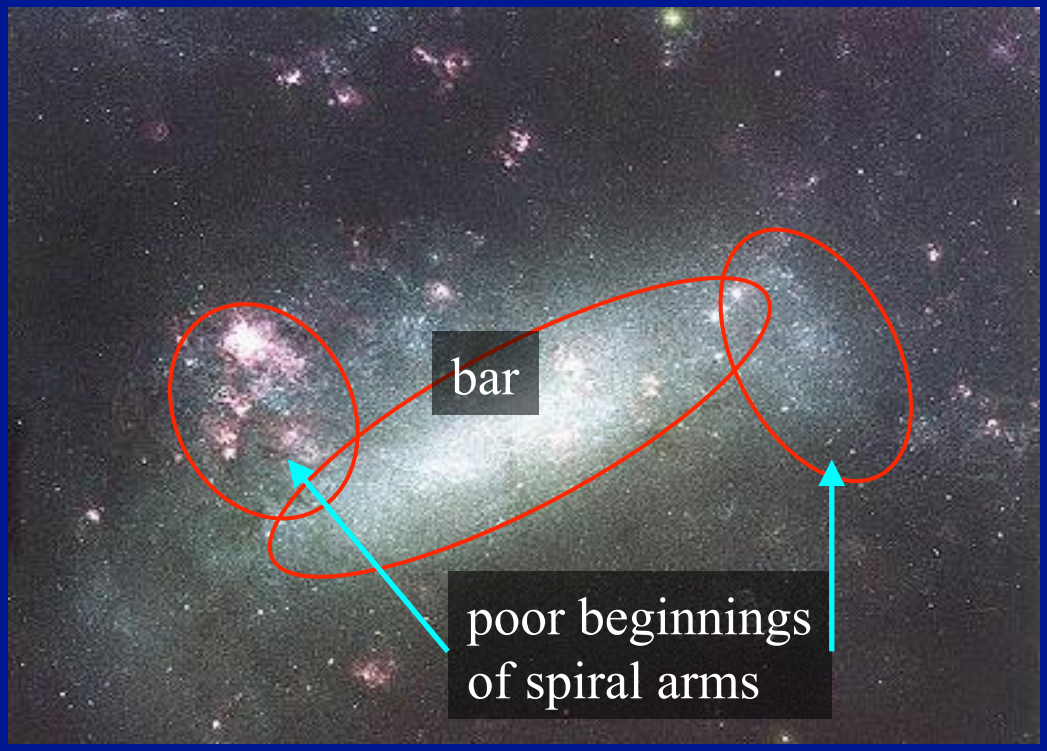
Milky Way is an SBbc, between SBb and SBc.

Later shown to be related to other galaxy structural properties and galaxy evolution.

Ignores some notable features, e.g. viewing angle for ellipticals, number of spiral arms for spirals.

Irr I vs. Irr II

Irr I ("misshapen spirals")



Large Magellanic Cloud

Irr II (truly irregular)

Small Magellanic Cloud

These are both companion galaxies of the Milky Way.

The Variety of Galaxy Morphologies

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

http://galaxyzoo.org/

Clicker Question:

What type of galaxy do we live in?

A: Elliptical

B: Dwarf Elliptical

C: Spiral

D: Irregular

Clicker Question:

What type of galaxy is the Large Magellanic Cloud?

A: Elliptical

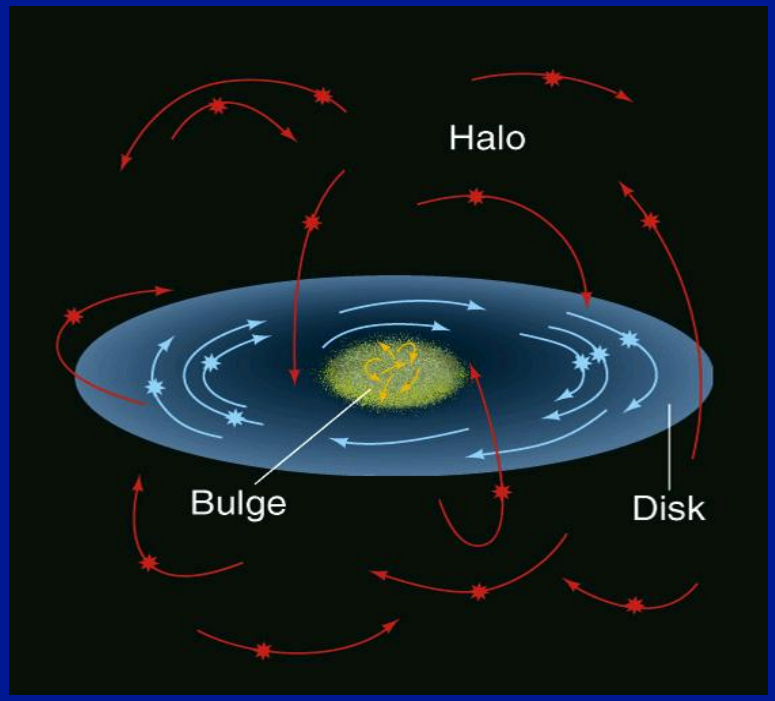
B: Dwarf Elliptical

C: Spiral

D: Irregular

Ellipticals are similar to halos of spirals, but generally larger, with many more stars. Stellar orbits are like halo star orbits in spirals. Stars in ellipticals also very old, like halo stars.

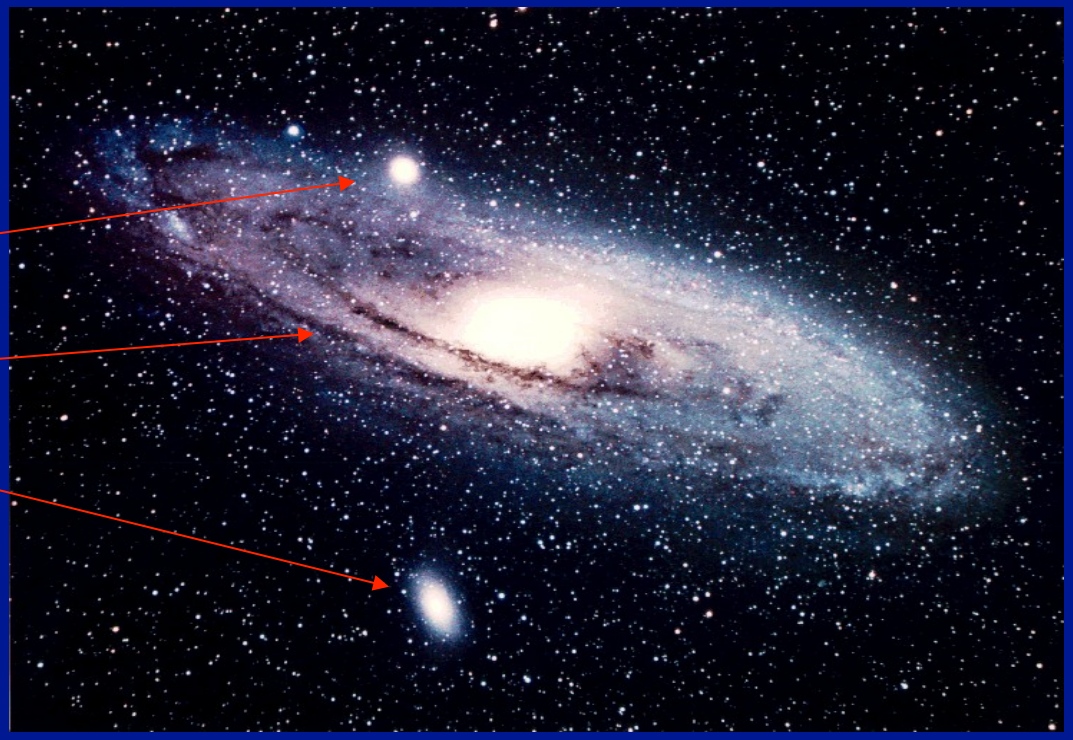
Orbits in a spiral



An elliptical

A further distinction for ellipticals and irregulars:

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



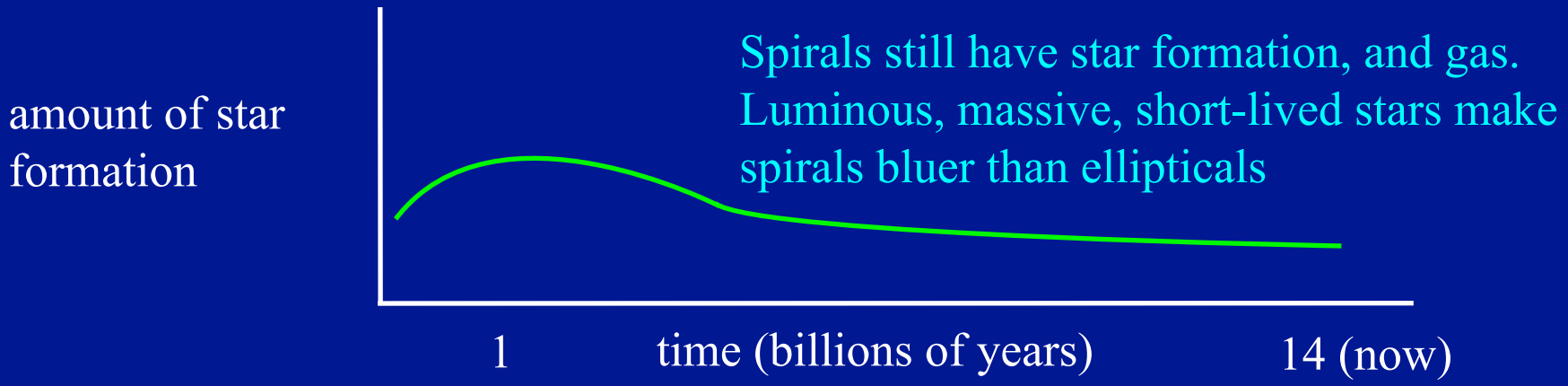
In giant galaxies, the average elliptical has more stars than the average spiral, which has more than the average irregular.

What kind of giant galaxy is most common?

Spirals - about 77%
Ellipticals - 20%
Irregulars - 3%

But dwarfs are much more common than giants.

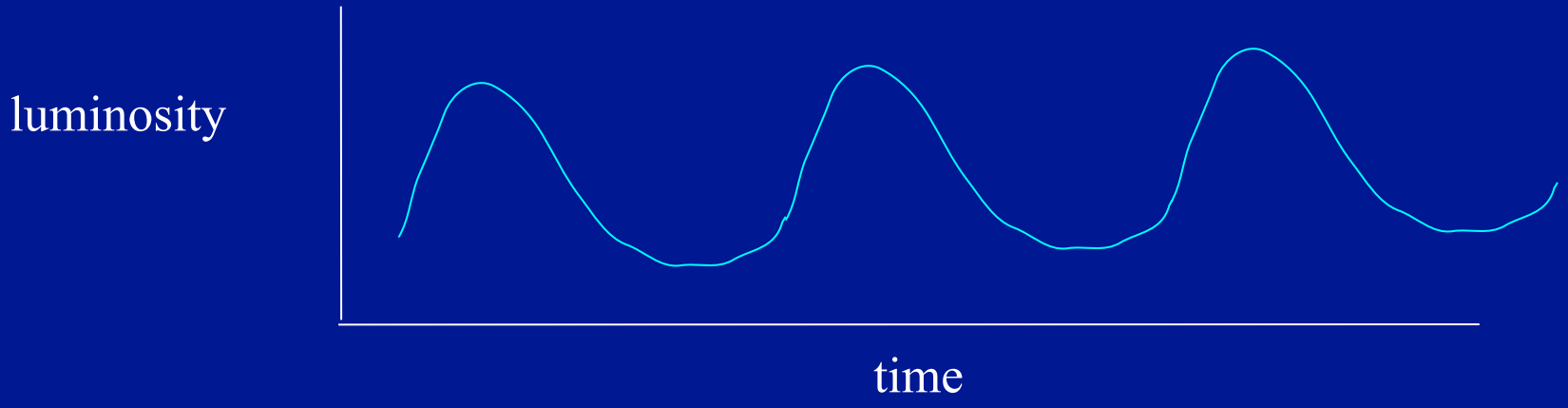
"Star formation history" also related to Hubble type:

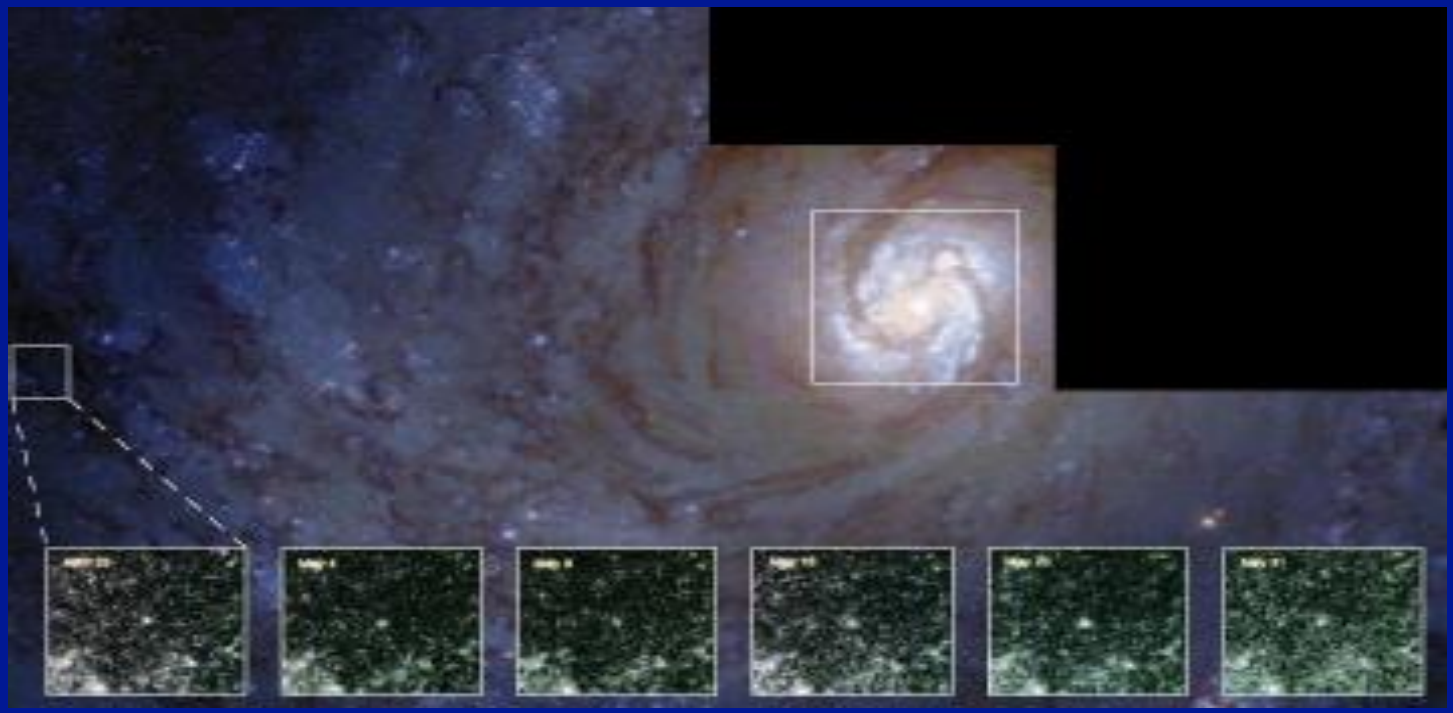


Irregulars have a variety of star formation histories.

Distances to Galaxies

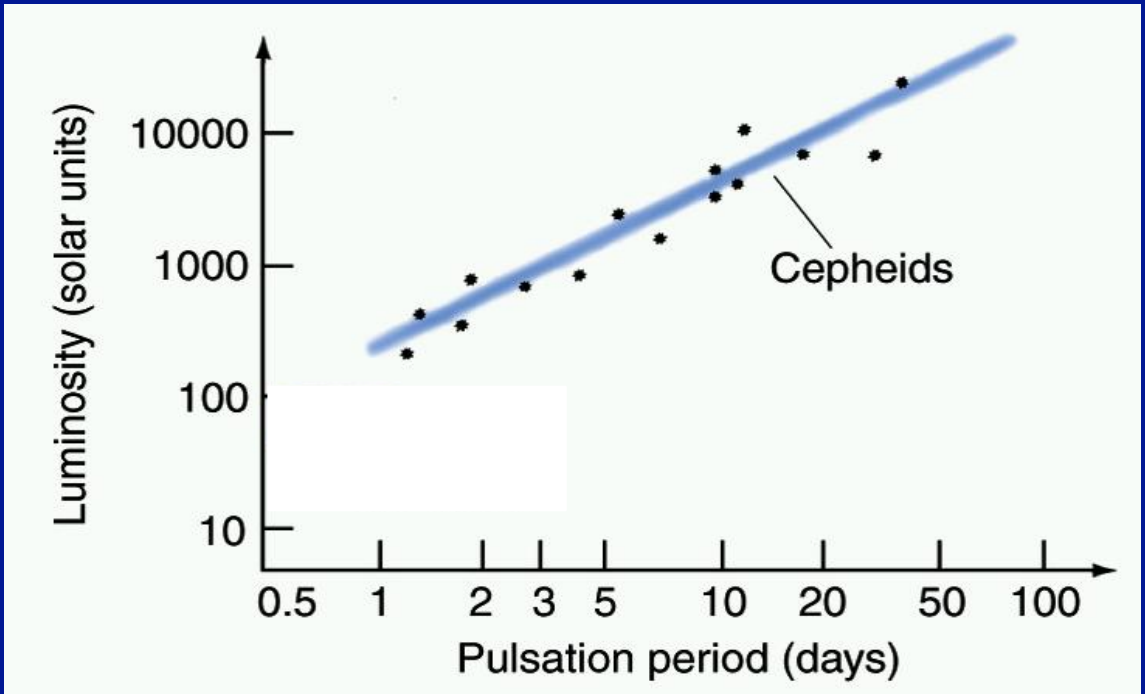
For "nearby" (out to 20 Mpc or so) galaxies, use a very bright class of variable star called a "Cepheid".





Cepheid star in galaxy M100 with Hubble. Brightness varies over a few weeks.

From Cepheids in Milky Way star clusters (with known distances), it was found that period (days to weeks) is related to luminosity (averaged over period).

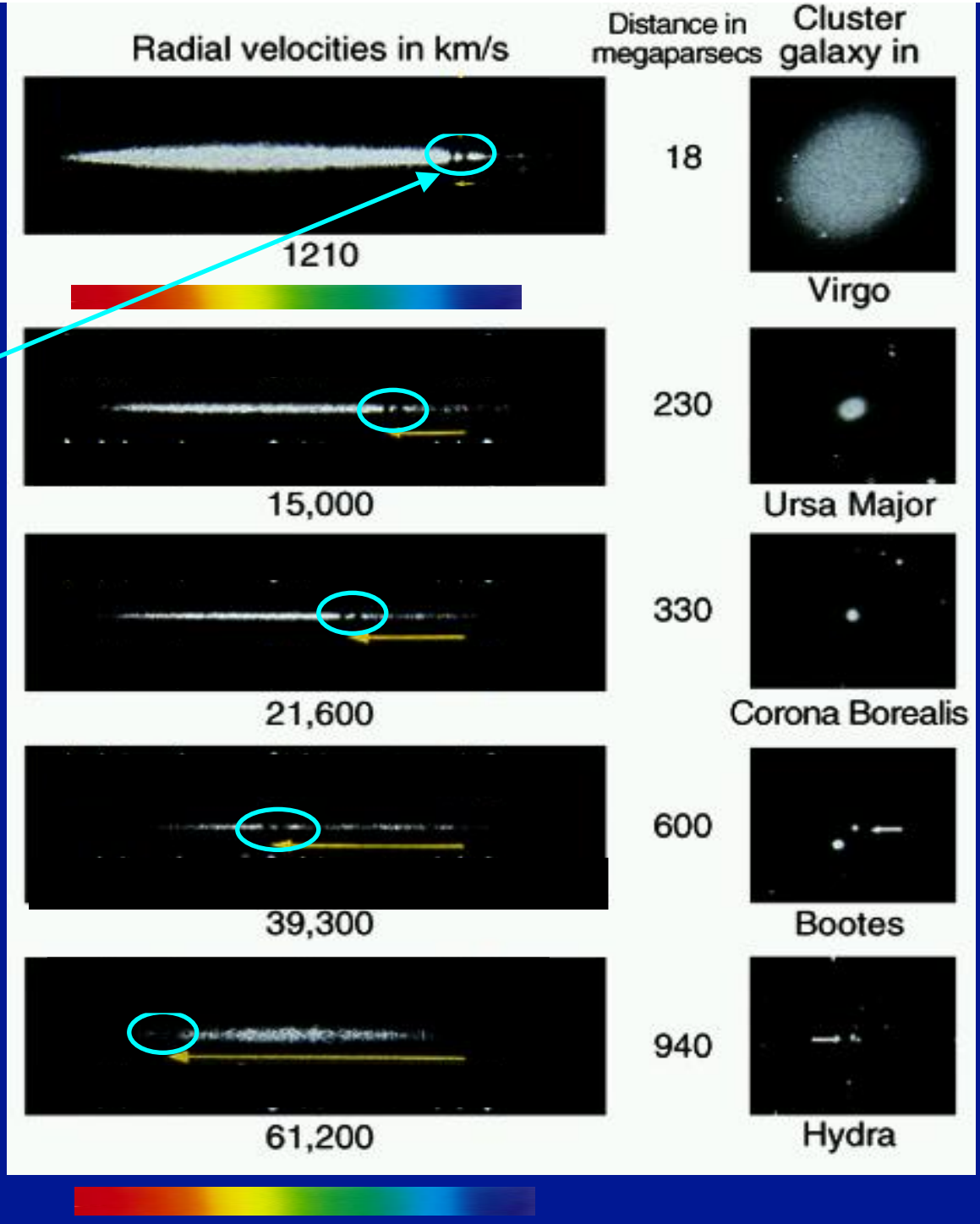


So measure period of Cepheid in nearby galaxy, this gives star's luminosity. Measure apparent brightness. Now can determine distance to star and galaxy.

Has been used to find distances to galaxies up to 25 Mpc.

Spectra of galaxies in clusters of increasing distance

prominent pair of absorption lines



In 1920's, Hubble used Cepheids to find distances to some of these receding galaxies. Showed that redshift or recessional velocity is proportional to distance:

$$V = H_0 \times D \quad \text{(Hubble's Law)}$$

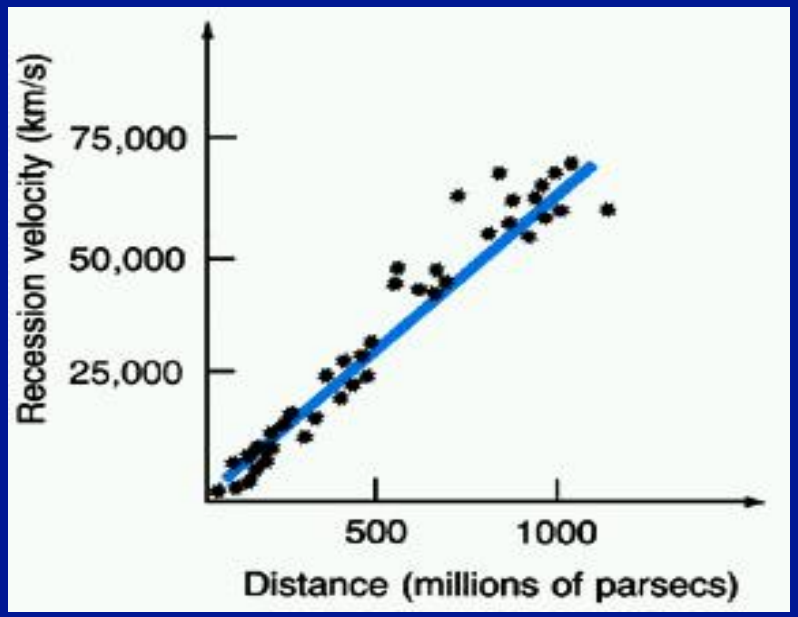
velocity (km / sec)

Hubble's Constant (km / sec / Mpc)

Distance (Mpc)

DEMO

Or graphically. . .



Current estimate:

$H_0 = 73$ +/- 2 km/sec/Mpc

If $H_0 = 75$ km/sec/Mpc, a galaxy at 1 Mpc moves away from us at 75 km/sec, etc.

Clicker Question:

Suppose we see a galaxy moving away from us at 300 km/s. How far away is it?

A: 1 AU

B: 8 kpc

C: 4 Mpc

D: 1 Gpc

Clicker Question:

What type of galaxy contains the most stars?

A: Elliptical

B: Dwarf Elliptical

C: Spiral

D: Irregular

Getting used to these huge distances!

Milky Way

30 kpc

Milky Way to Andromeda

700 kpc

Milky Way to Virgo Cluster

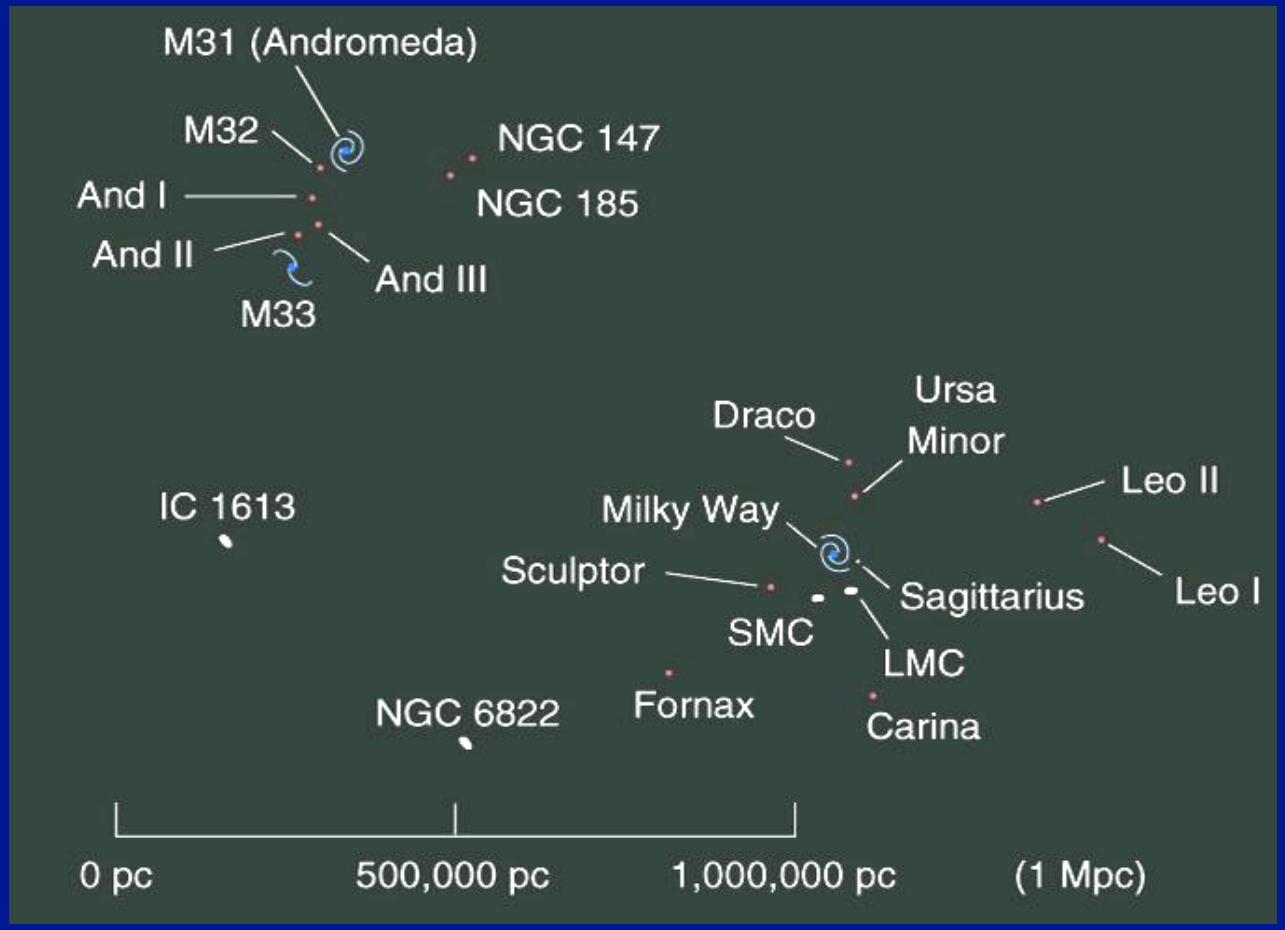
17 Mpc

Structures of Galaxies

Groups

A few to a few dozen galaxies bound together by their combined gravity.

No regular structure to them.



The Milky Way is part of the Local Group of about 30 galaxies, including Andromeda.

Another group

Clusters

Larger structures typically containing thousands of galaxies.

The Virgo Cluster of about 2500 galaxies (central part shown).

The center of the Hercules Cluster

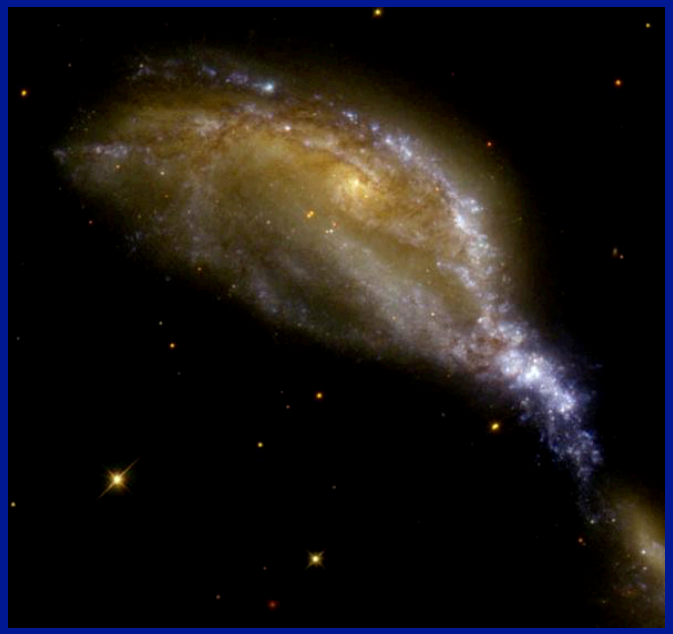
Galaxies orbit in groups or clusters just like stars in a stellar cluster.

Most galaxies are in groups or clusters.

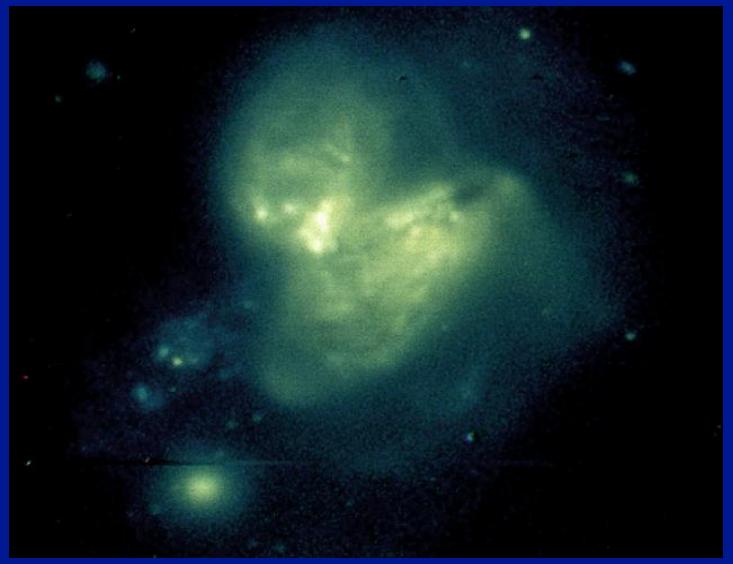
Galaxy Interactions and Mergers

Galaxies sometimes come near each other, especially in groups and clusters.

Large tidal force can draw stars and gas out of them => tidal tails.
Galaxy shapes can become badly distorted.



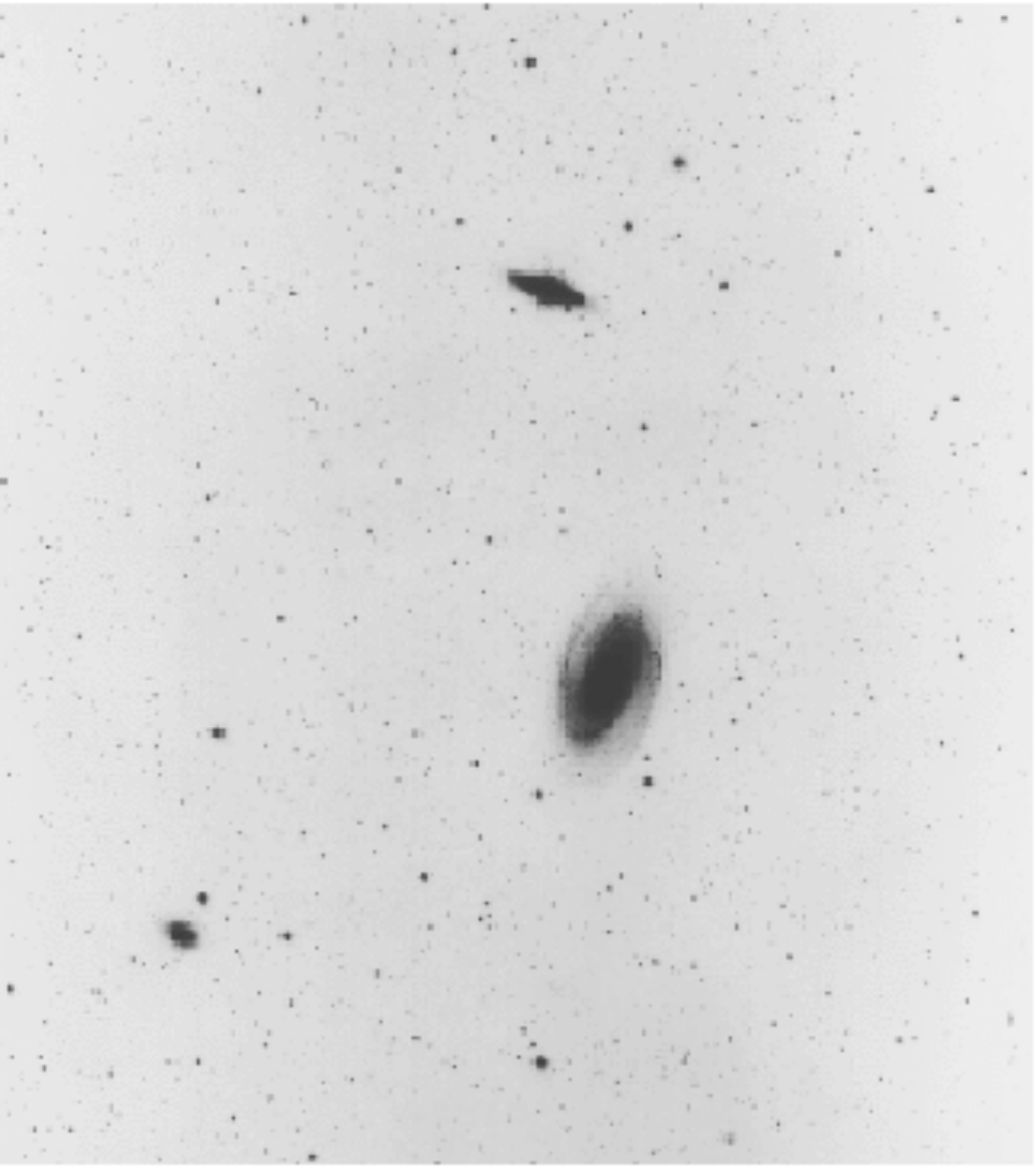
Galaxies may merge.



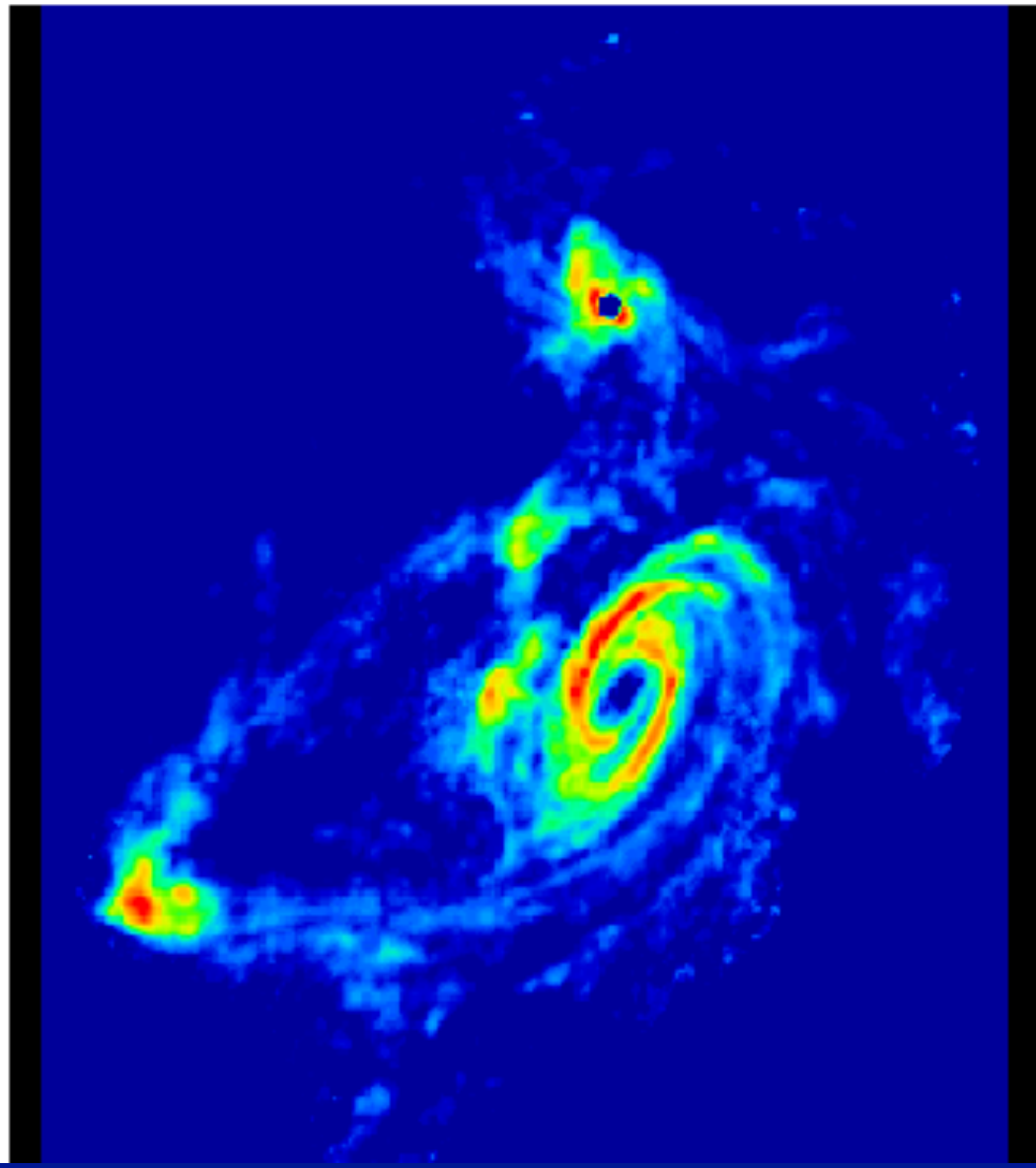
Ellipticals may be mergers of two or more spirals. Since they have old stars, most mergers must have occurred long ago.

TIDAL INTERACTIONS IN M81 GROUP

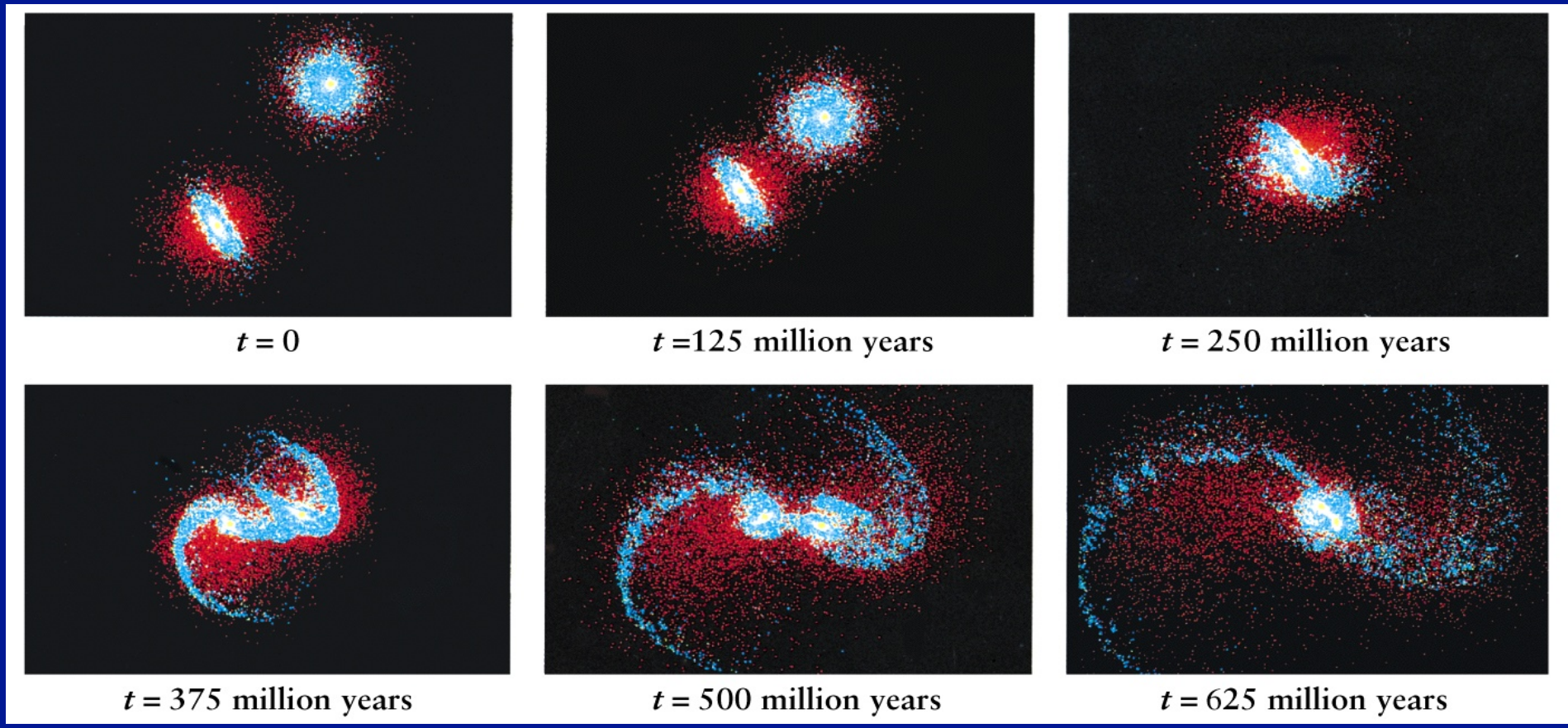
Stellar Light Distribution



21cm HI Distribution

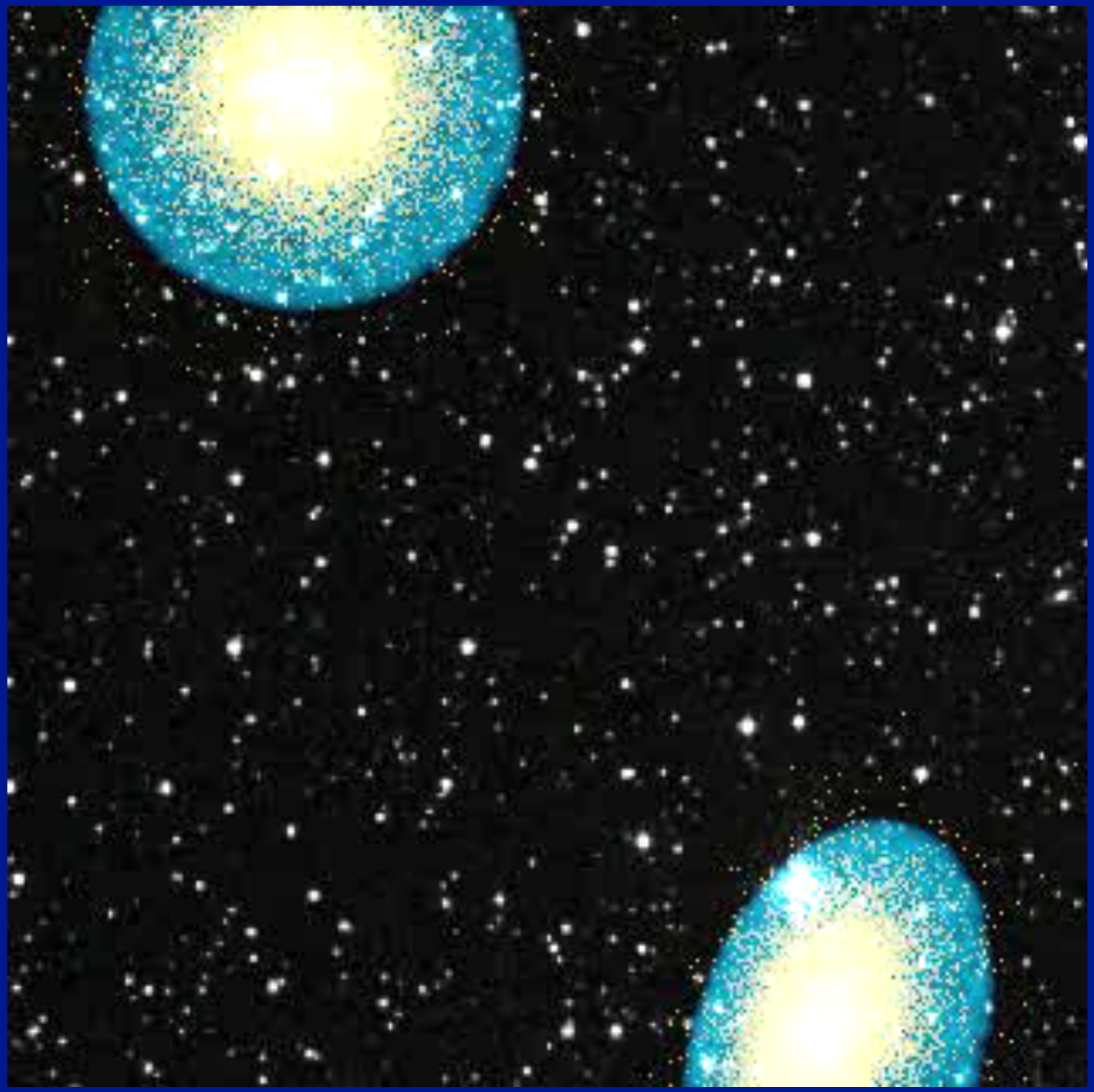


Interactions and mergers are simulated by computers.



Simulations of interacting and merging galaxies

Interactions and mergers can be simulated by computers.



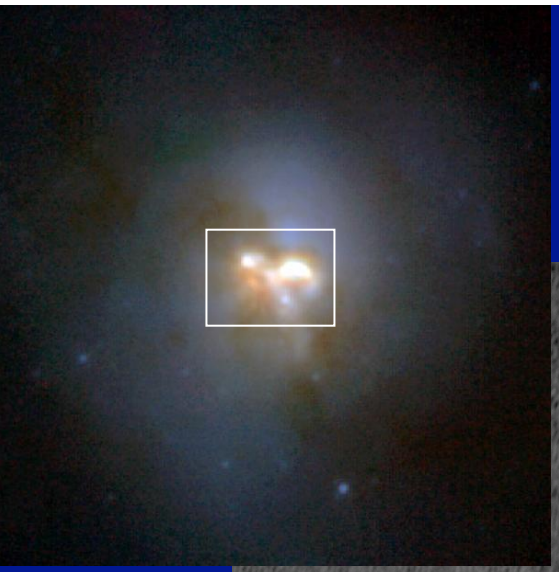
Yellow = stars
Blue = gas

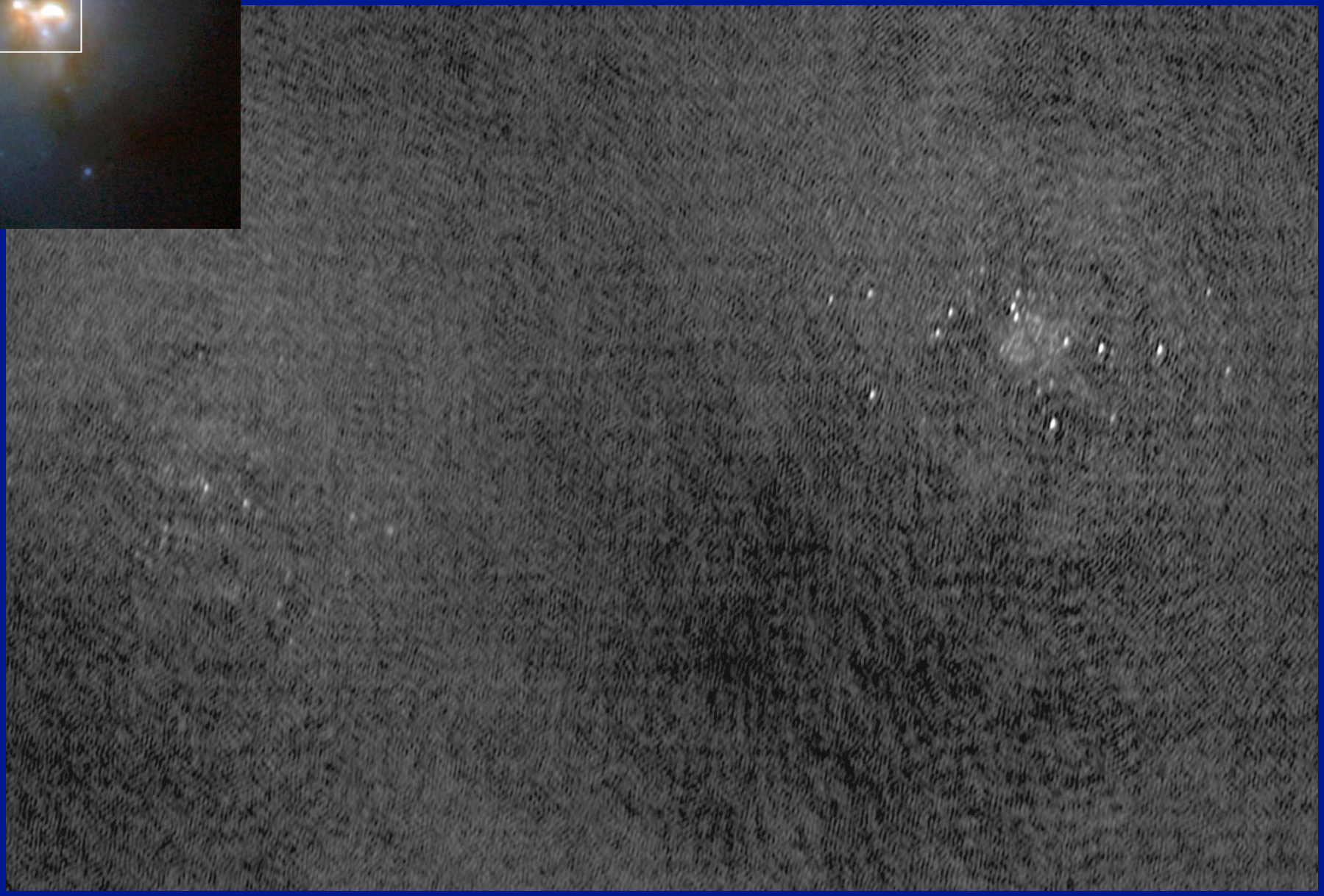
Mihos et al.

Interactions and mergers also lead to "starbursts": unusually high rates of star formation. Cause is the disruption of orbits of star forming clouds in the galaxies. They often sink to the center of each galaxy or the merged pair. Resulting high density of clouds => squeezed together, many start to collapse and form stars.

M82

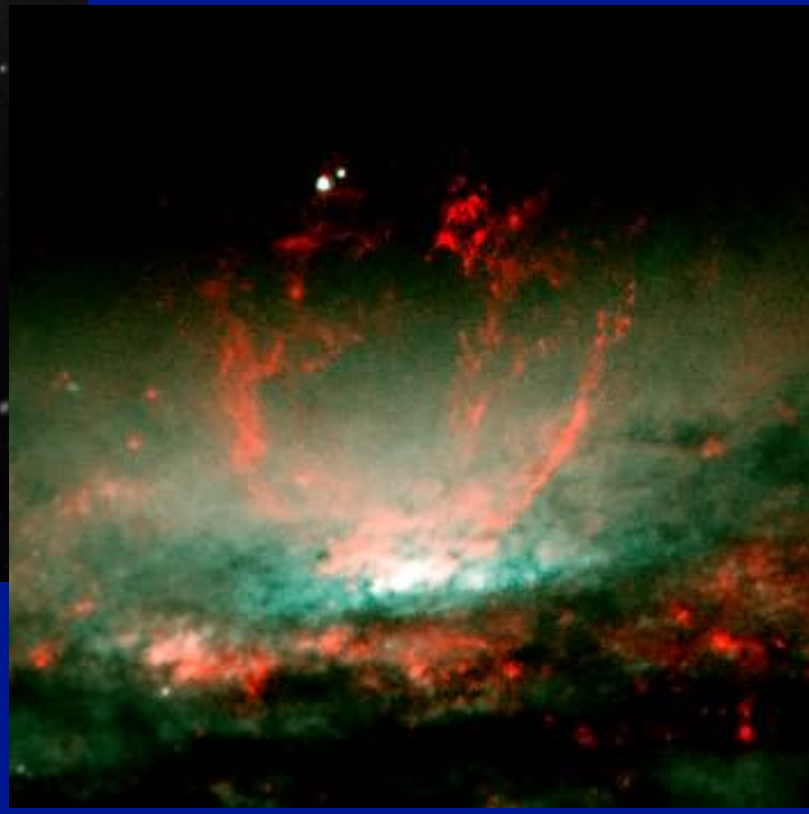
Arp 220 - A starburst Galaxy





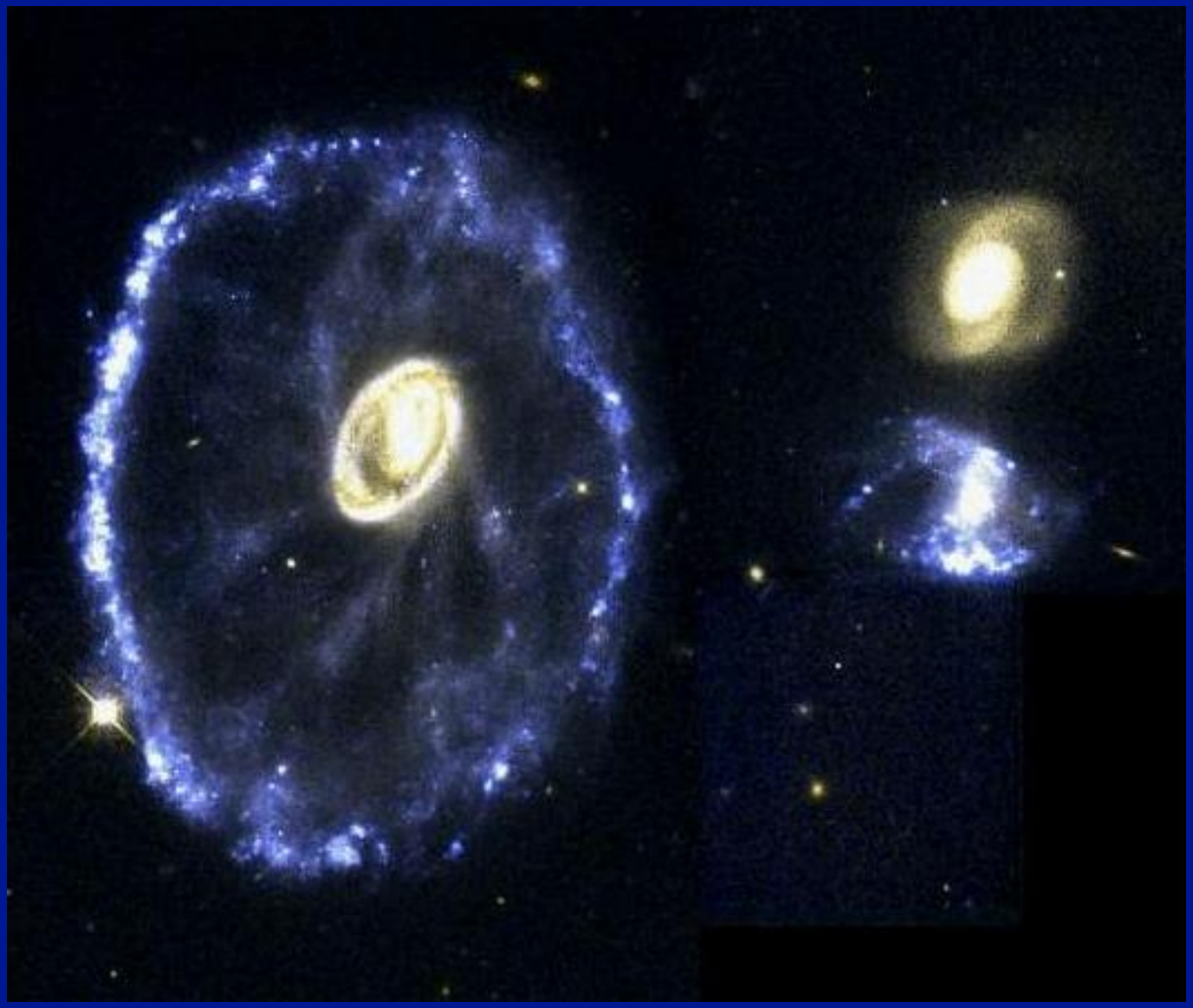
VLBA Image of the core of Arp 220 at 1.4 GHz - Lonsdale et al. in prep

In some starbursts, supernova rate so high that the exploded gas combines to form outflow from disk.

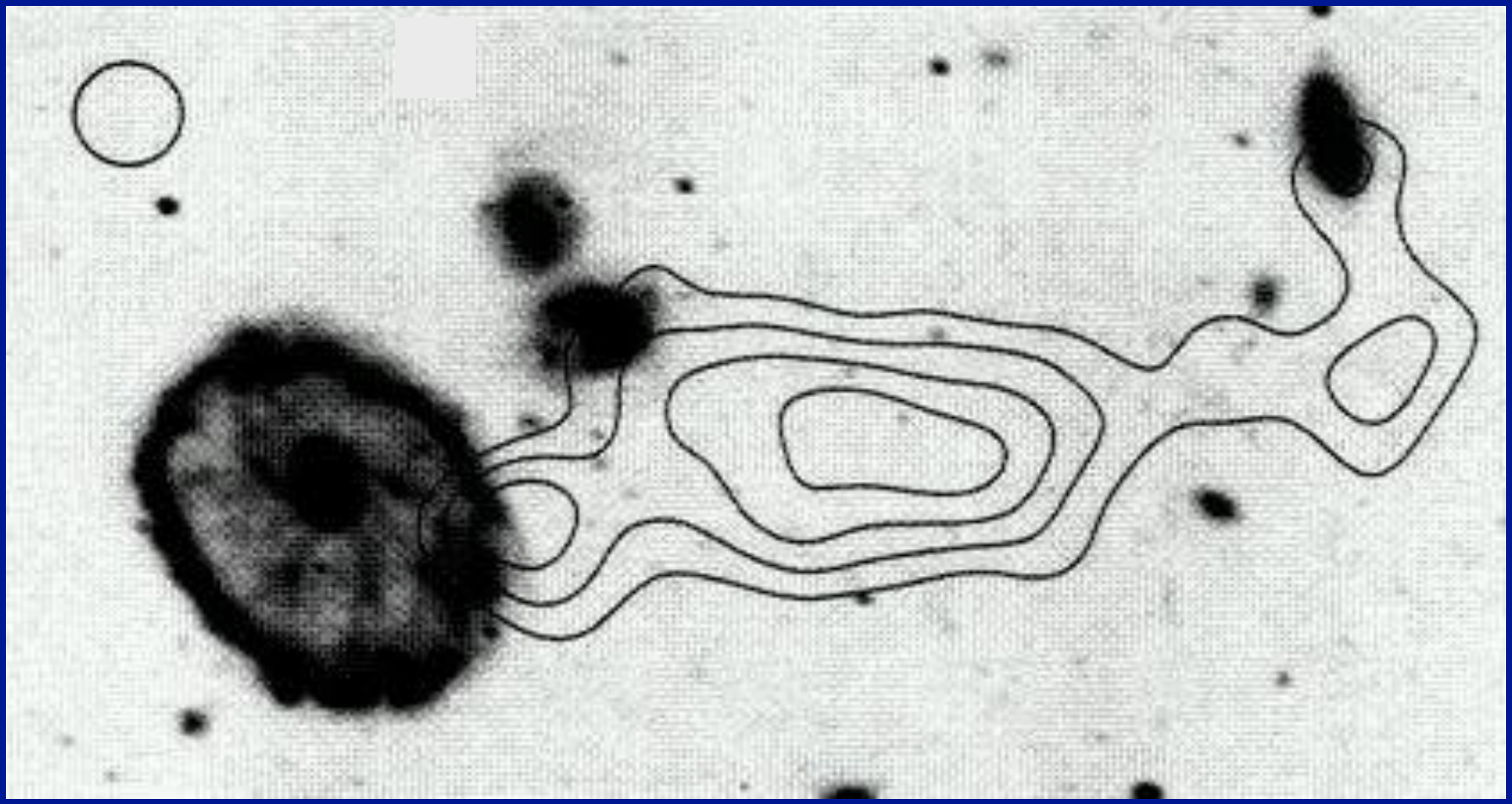


Sometimes a galaxy may pass right through another one, creating a ring galaxy.

Hubble image of The “Cartwheel” galaxy



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

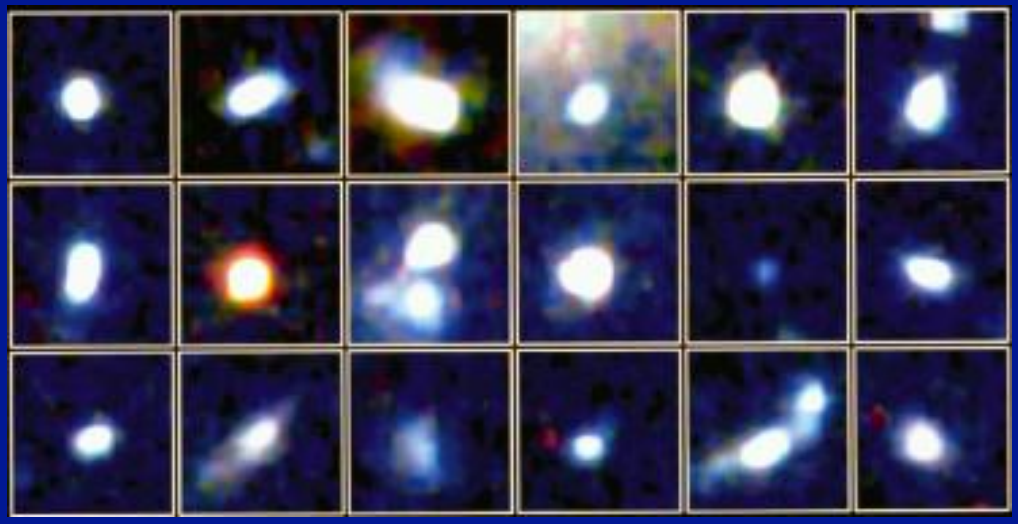


Another Ring Galaxy: AM 0644-741

How do Galaxies Form?

Old idea: they form from a single large collapsing cloud of gas, like a star but on a much larger scale.

New idea: observations indicate that "sub-galactic" fragments of size several hundred parsecs were the first things to form. Hundreds might merge to form a galaxy.



Deep Hubble image of a region 600 kpc across. Small fragments are each a few hundred pc across, contain several billion stars each. May merge to form one large galaxy. This is 10 billion years ago.

Clicker Question:

What do we call a galaxy with an unusually high star formation rate?

A: a ring galaxy

B: an elliptical galaxy

C: a starburst galaxy

D: a proto galaxy

Clicker Question:

How do galaxies form?

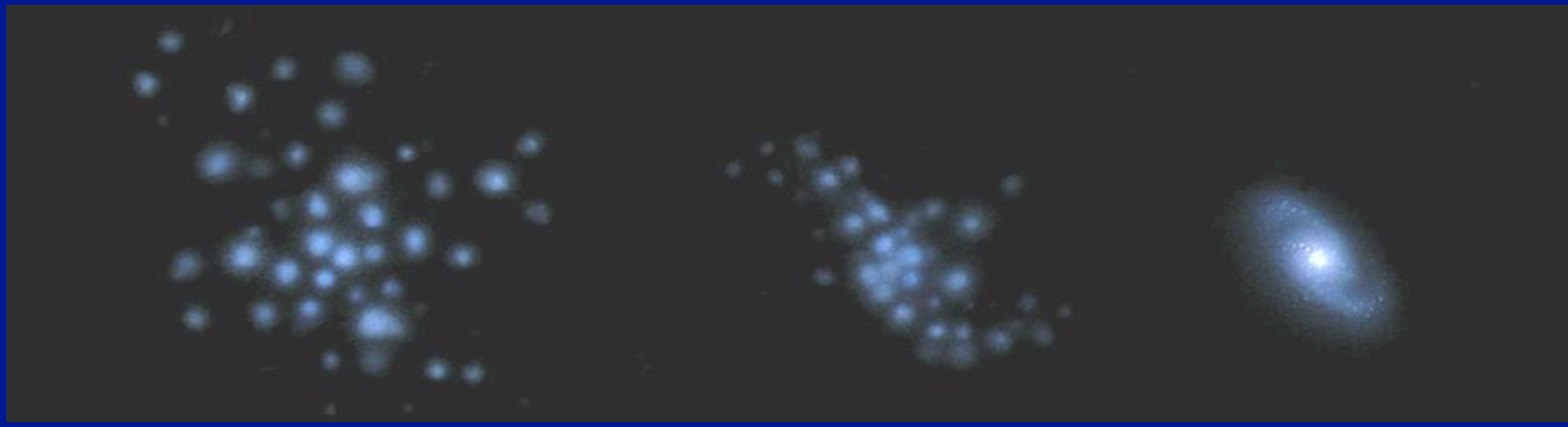
A: From the collapse of a single giant gas cloud.

B: From the gradual collection of individual stars

C: From combining many dwarf galaxies

D: By splitting a supercluster into smaller pieces.

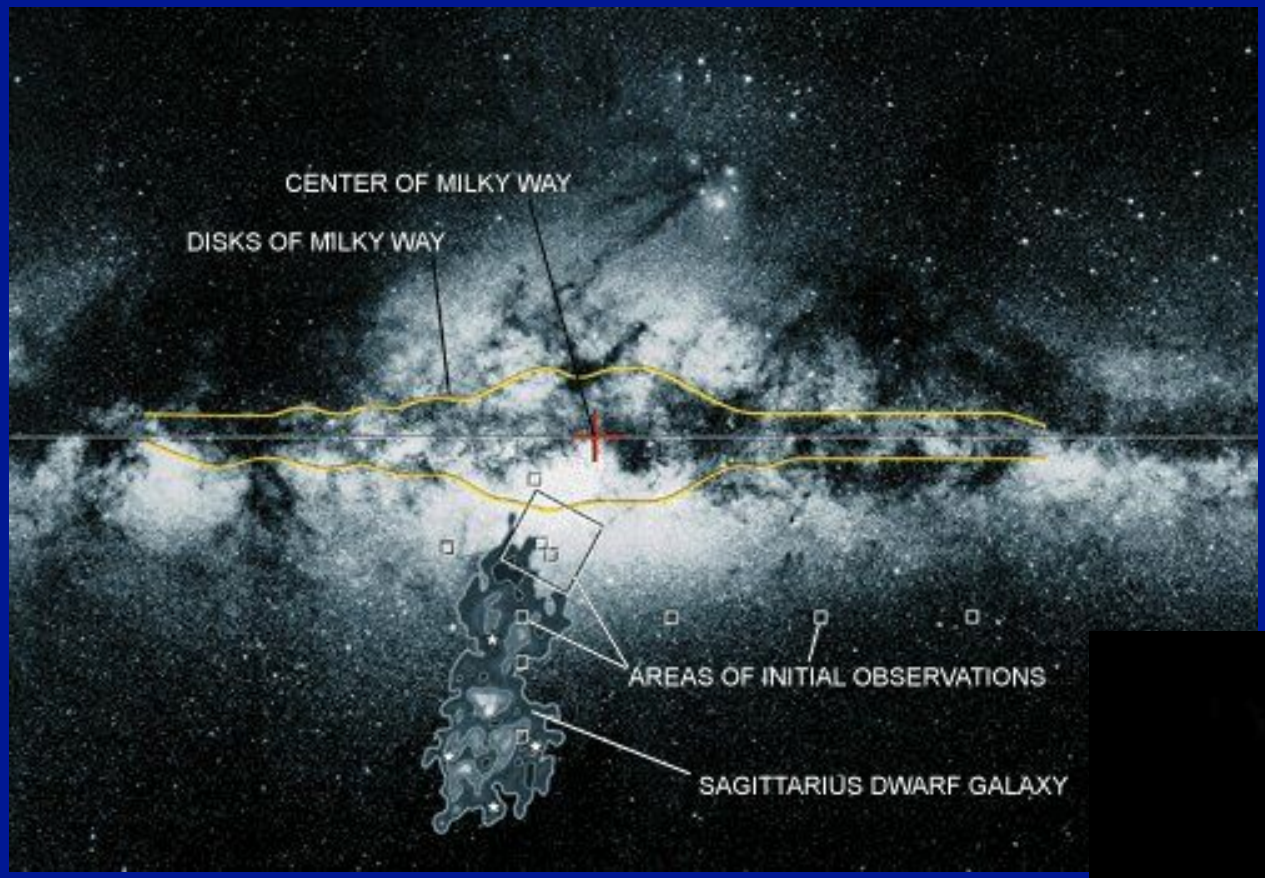
Schematic of galaxy formation

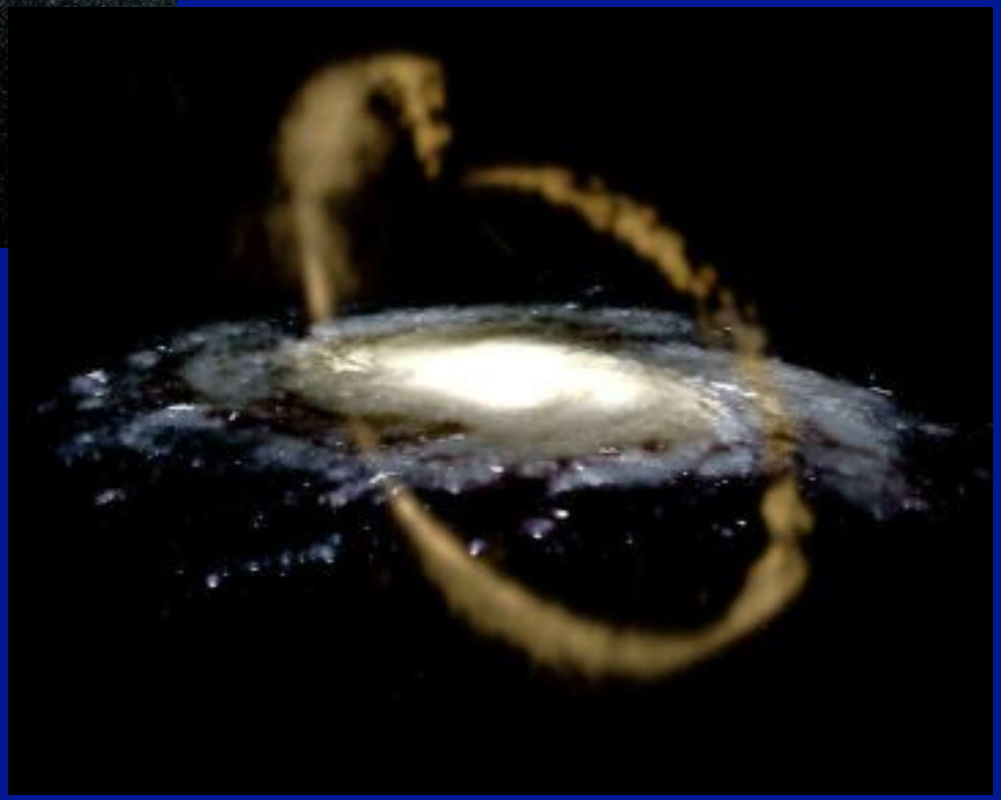


Subsequent mergers of large galaxies also important for galaxy evolution.

Galaxy formation a very difficult problem because we must look to great distances (back in time to the early universe) to see it happening.

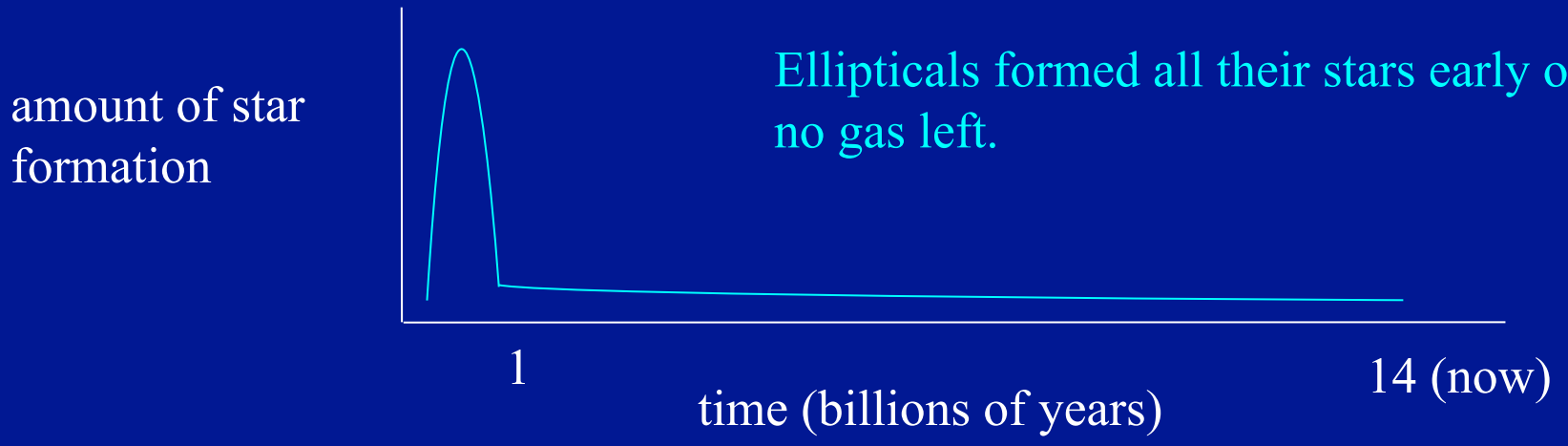
The Milky Way is still accreting dwarf galaxies

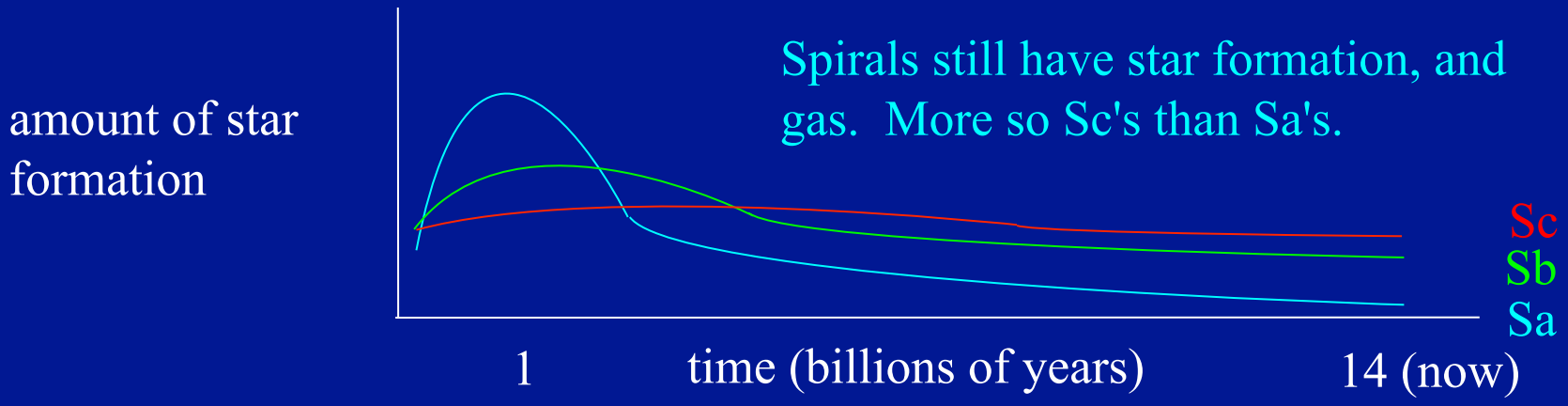




Artist's impression of tidally stripped stream of stars from Sag. dwarf. Predicted in simulations. Later found observationally.

"Star formation history" also related to Hubble type:





Irregulars have irregular star formation histories.