Observations of Galaxy Collisions and Prediction of Resulting galaxies

RAJESH KUMAR DUBEY

LOVELY PROFESSIONAL UNIVERSITY, INDIA

Outline

- **Galaxies and their general classification**
- **Galaxy Collisions**
- **Types of Collisions**
- **Resulting Galaxies**

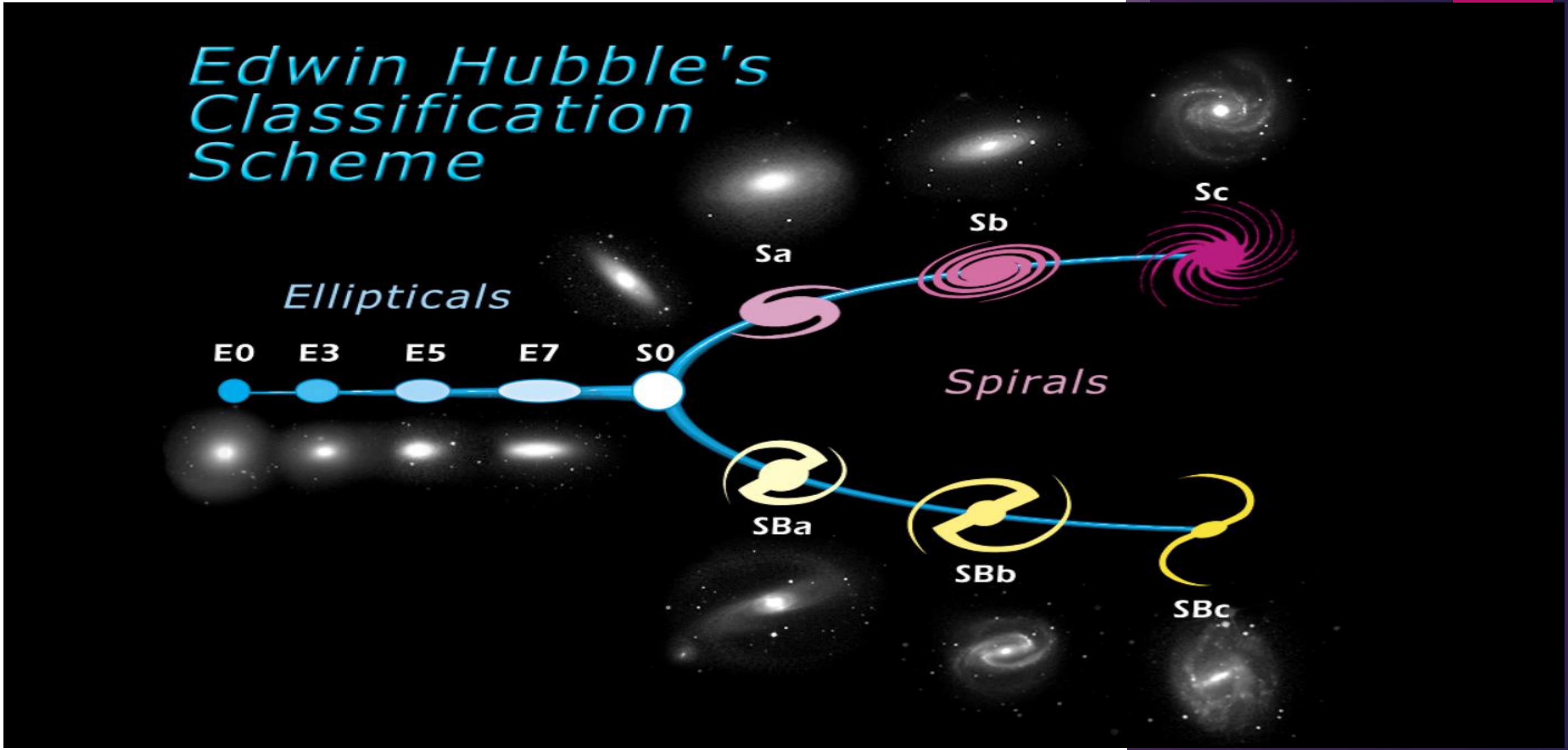
Edwin Hubble poses inside the 200-inch Palomar telescope a few years before his death in 1953.

NED/STEER/HUCHRA/RIESS; NASA/ESA

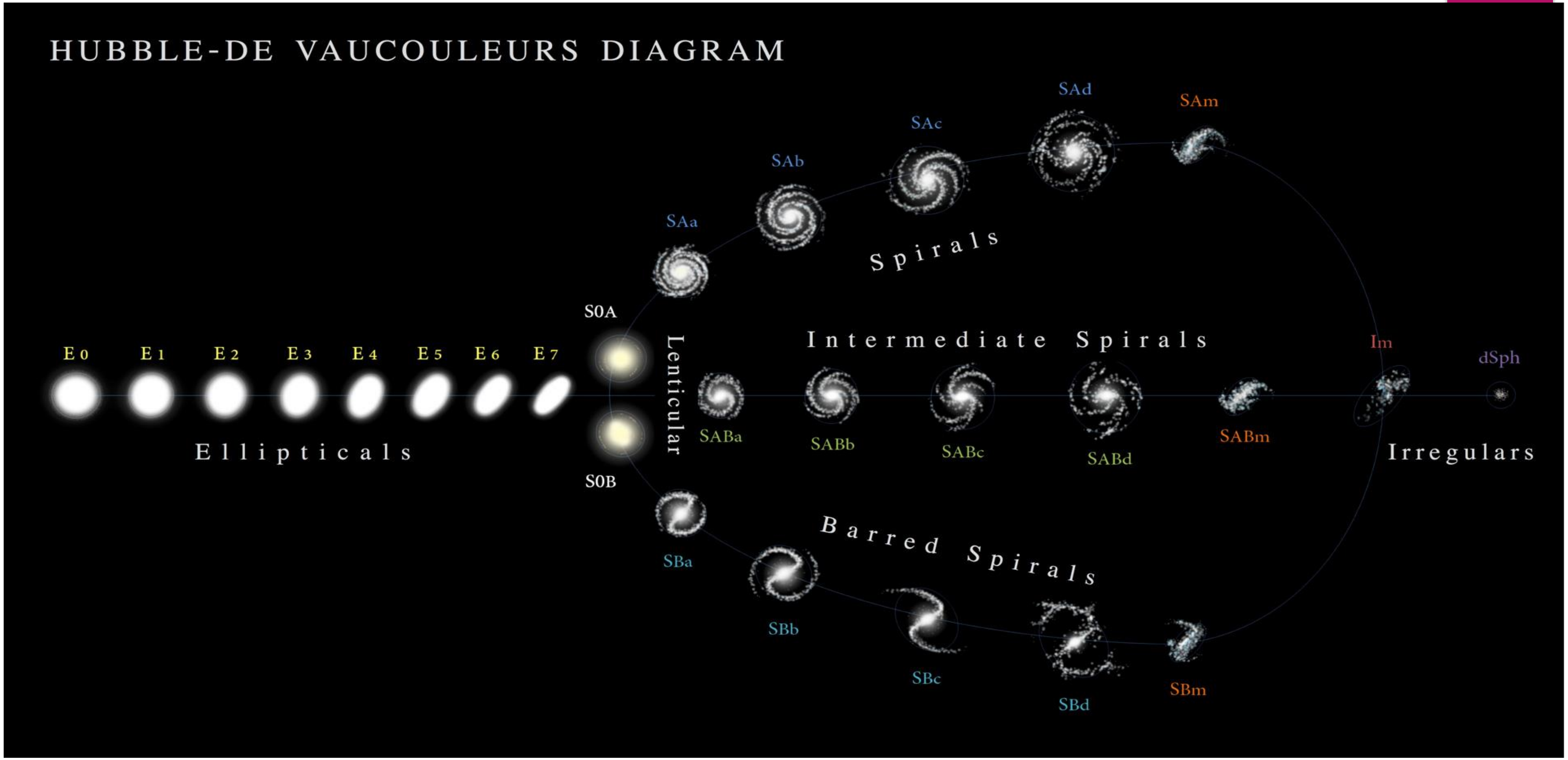
Edwin Hubble

(1889-1953)

- Measured distances to nearby galaxies using Cepheid variables
- Galaxies are islands of stars
- Developed a classification scheme for galaxies.
- Discovered the Expansion of the Universe
- Space telescope named after him!



Edwin Hubble's Classification Scheme
Ellipticals
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirals
SBa
SBb
SBc



HUBBLE-DE VAUCOULEURS DIAGRAM
SAd
SAm
SAc
SAb
SAa
Spirals
S0A
Intermediate Spirals
Im
dSph
E0
E1
E2
E3
E4
E5
E6
E7
Lenticular
SABa
SABb
SABc
SABd
SABm
Ellipticals
Irregulars
S0B
SBa
Barred Spirals
SBb
SBc
SBd
SBm

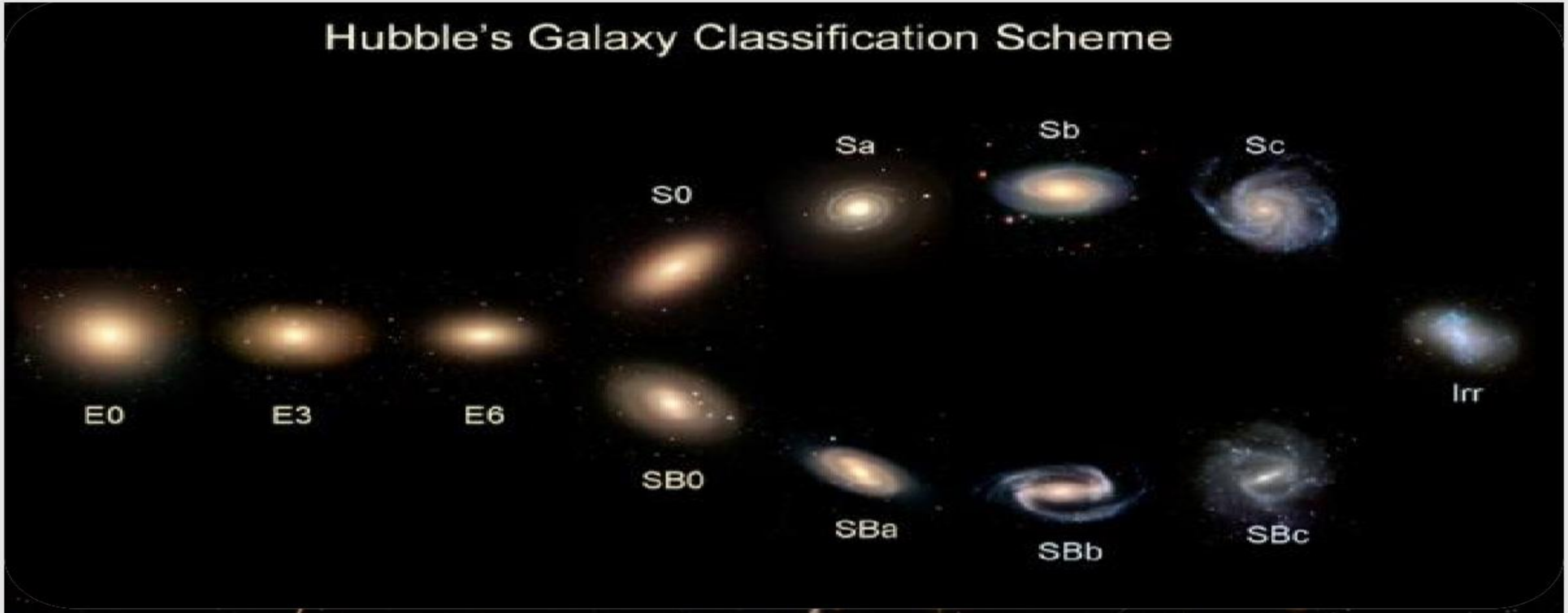
Galaxies can be grouped into four major categories: spirals, barred spirals, ellipticals, and irregulars

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.*

Lenticular galaxies are intermediate between spiral and elliptical galaxies

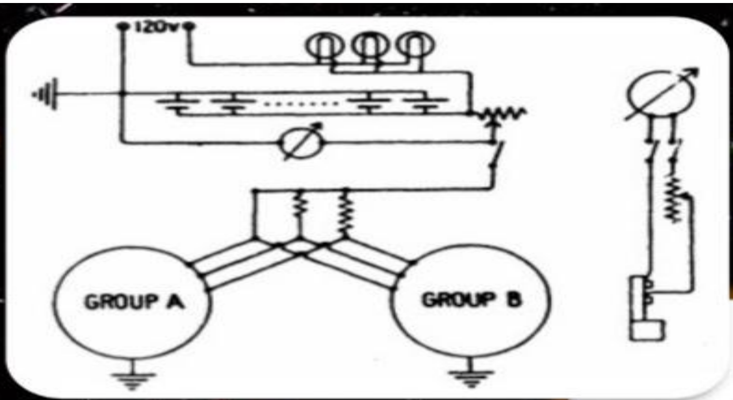


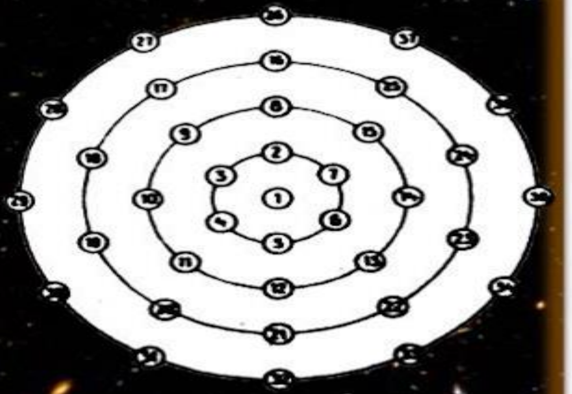
Irregulars do not seem to fit the Hubble tuning fork…
(Credit: http://hendrix2.uoregon.edu/)

First Models

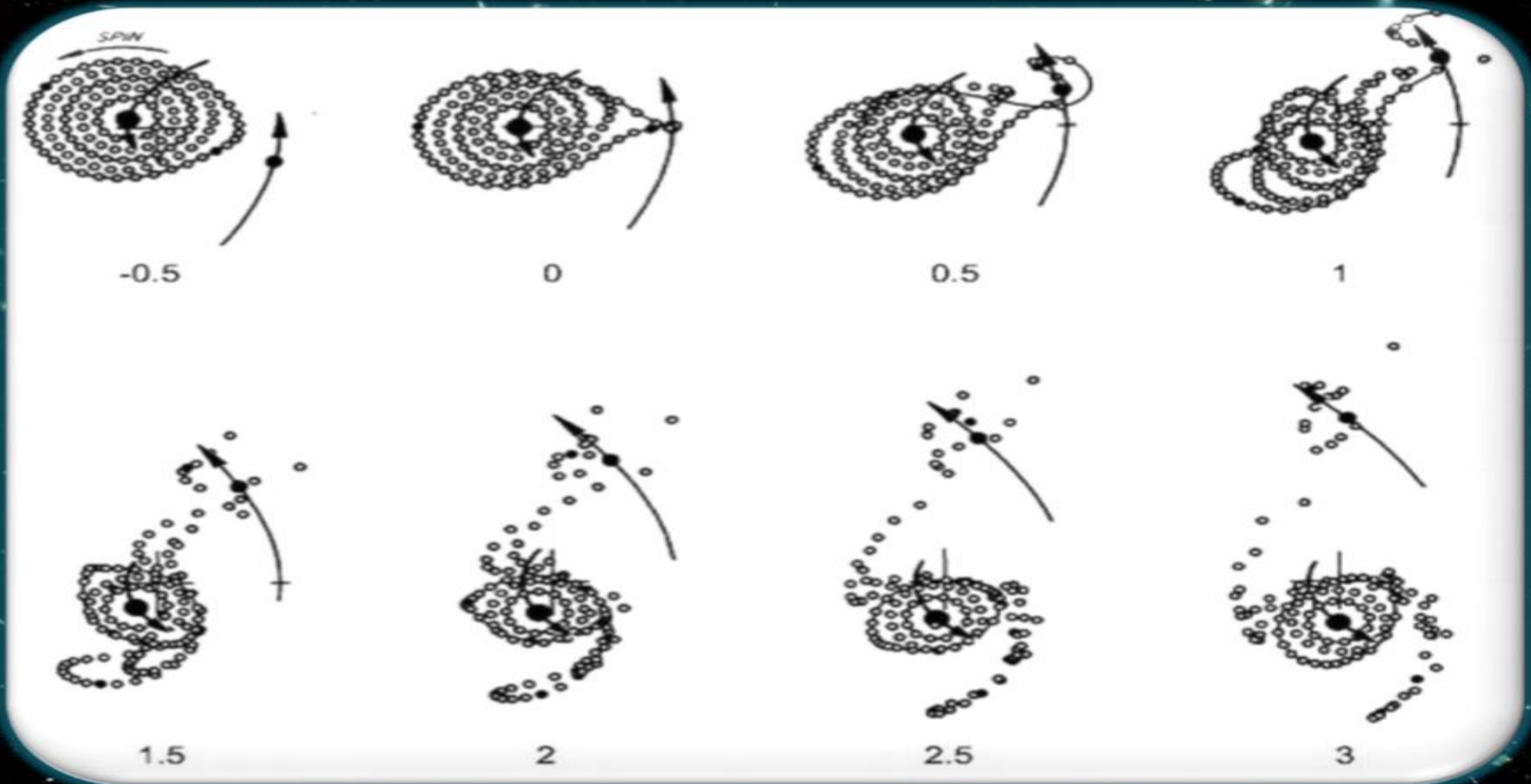
Swedish astronomer Erik Holmberg's (1941) paper - the first to present models of galaxy interactions, using an analogue computer made of photocells and 74 bulbs, where the $1/r^2$ intensity falloff represented gravitational forces.

Alar and Juri Toomre (1972) – early computer model of tidal interactions; *N*-body simulation of effects in well-known galaxies





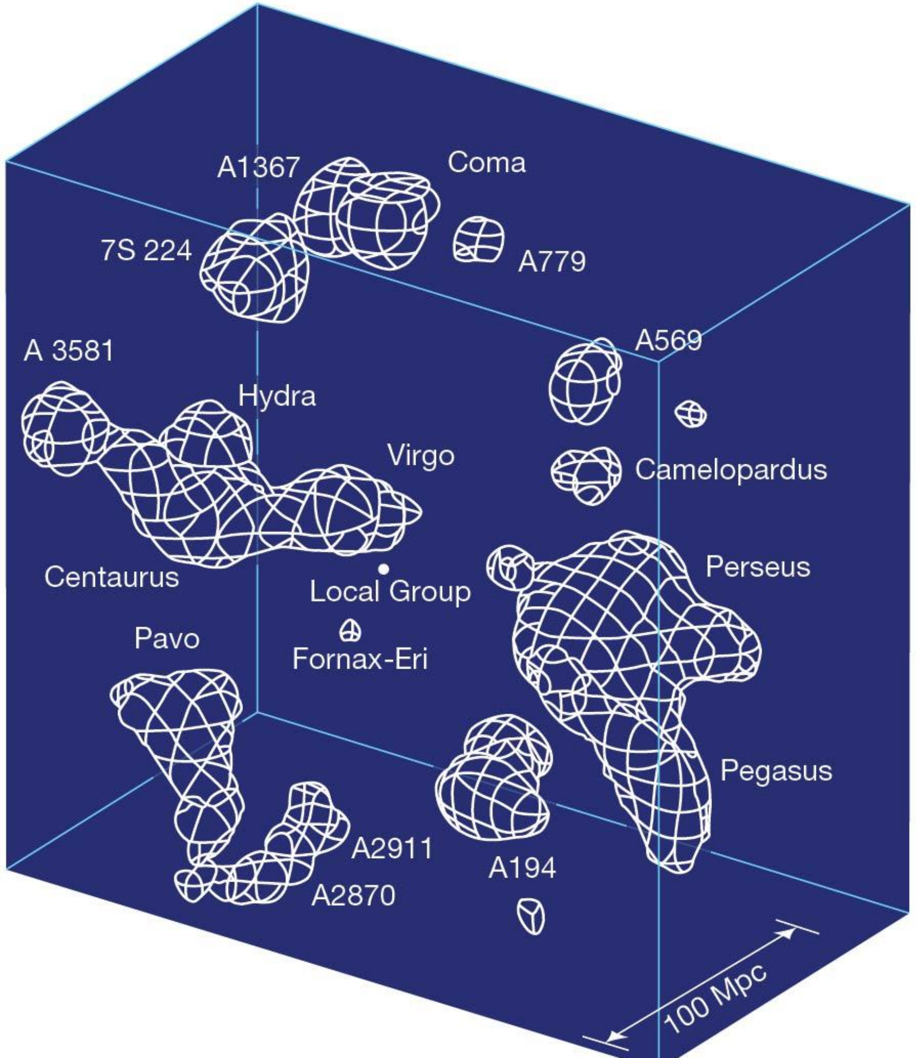
Holmberg's model of interacting galaxies.
Left: Coupling scheme and arrangement of bulbs. Right: Simulation of interaction (From: Holmberg (1941))



Toomre and Toomre 1972 - Tidal Formation of Spiral Arms in M51

The Universe on Very Large Scales

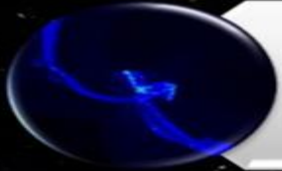
- Galaxy clusters join in larger groupings, called **superclusters**.
- 3D map of the superclusters nearest us; we are part of the Virgo Supercluster.
- Galaxies are held together by mutual gravity and orbit around a common center. Interactions between galaxies is quite common, especially between giant and satellite galaxies



Evidence for Interactions

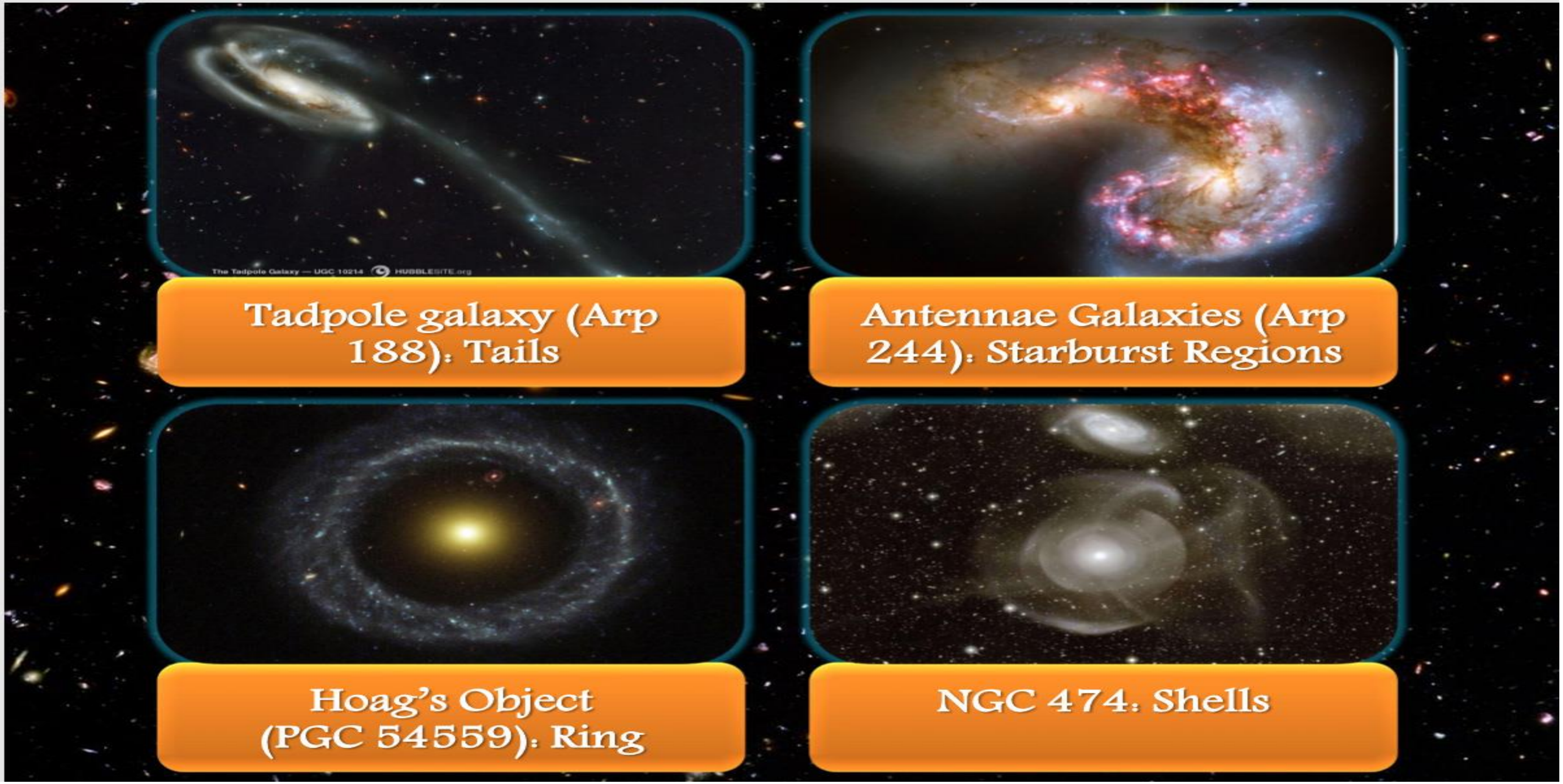
Galaxies are not isolated – they are born in gravitationally bound clusters and groups and often have close companions – inevitably, they have at least one strong interaction during their 'lifetime'.

Evidence for this are the observed formations – kinematically decoupled nuclei, gas, dust or rings decoupled from the main body; grand arms, super-star clusters; fine structure such as plumes, tails, shells, ripples, arcs, wings, bridges, X-shaped isophotes (such as the Antennae galaxies)



These features are successfully modeled in computer simulations – their formation strongly depends on the encounter geometry and on the resonances between the rotational and orbital motions

Numerical simulations of collisions between two spiral galaxies produce objects with surface brightness profiles resembling the $r^{1/4}$ (de Vaucouleurs) profile – the same smooth surface brightness profile as ellipticals


The Tadpole Galaxy — UGC 10214 HUBBLESITE.org
Tadpole galaxy (Arp 188): Tails
Antennae Galaxies (Arp 244): Starburst Regions
Hoag's Object (PGC 54559): Ring
NGC 474: Shells

The giant elliptical galaxy Centaurus A shows a split personality because it hides a gaseous spiral at its core.
When Centaurus A collided with a spiral galaxy 300 million years ago, it slurped up the spiral's gases, which formed a new spiral inside the larger galaxy.

Image released Oct. 22, 2012.
Credit: ESO

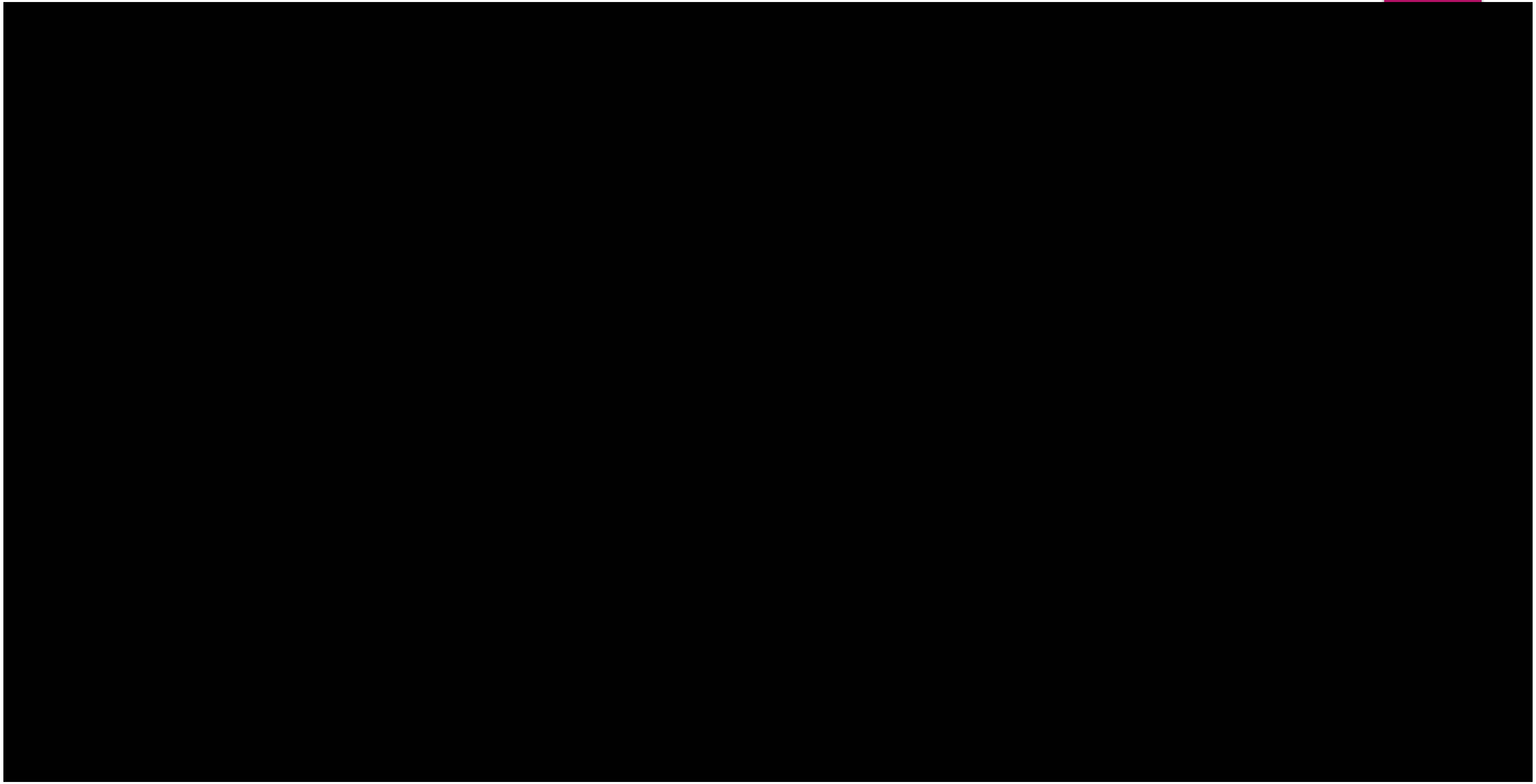
Galaxy Merger and Interactions

Studying the statistics of the present-day galaxy distribution is a powerful tool for constraining cosmological parameters.

Can compare real observations with the results of computer simulations – e.g. 2dF galaxy redshift survey.

Simulations follow the evolution of galaxies as structure grows

Simulations vs Observations



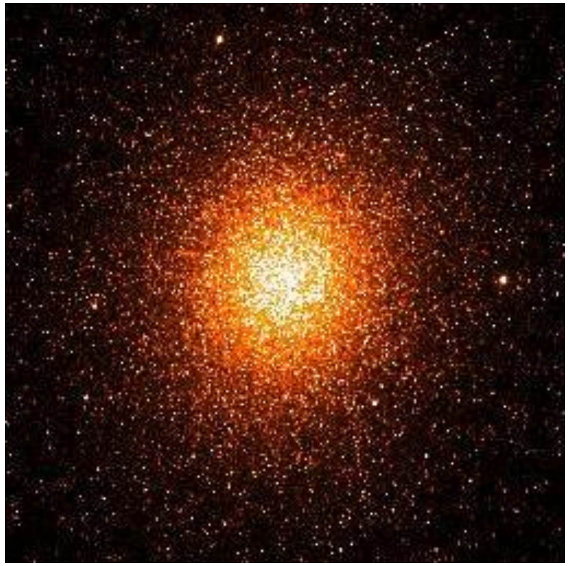
How Improbable are Stellar Collisions?

Most fascinating aspects

1. Most of the matter involved doesn't collide with anything.

2. Most of the mass in a typical galaxy consists of collisionless dark matter. Thus, dark matter from the companion galaxy passes through that of the target with no effects except for those due to their collective gravitational forces.

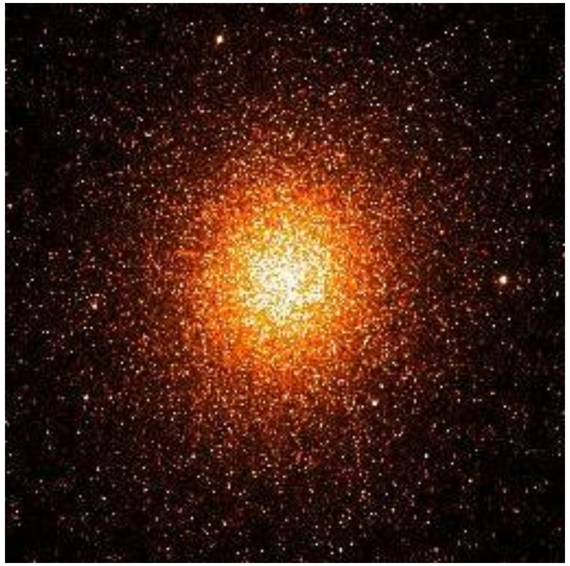
3. There is only a very small probability for direct star-star collisions.



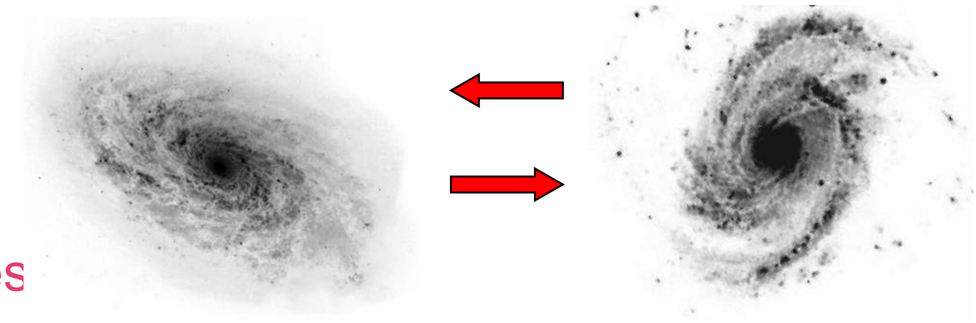
How Improbable are Stellar Collisions?

Most fascinating aspects

1. The cross section of a star like the Sun is about 10^{17} m^2,while the surface density of stars near the Sun is of order 10 per light year squared (10^{-32} m^{-2}).
2. This implies that the collision probability is of order 10^{-15} for a typical star.
3. The stellar density is much greater in the centers of galaxies, but the basic point is not changed.



What happens when galaxies merge

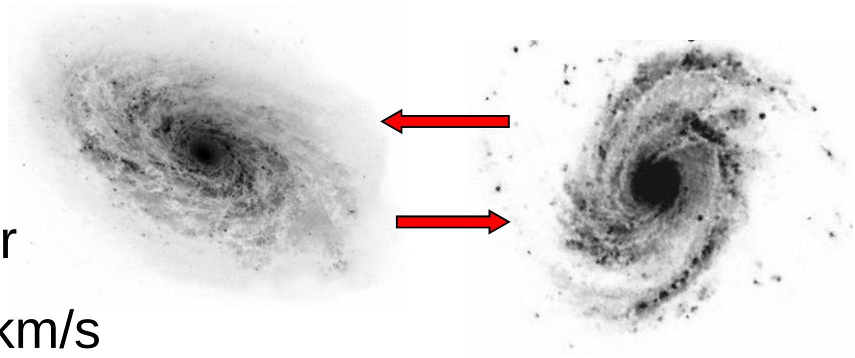


What happens when galaxies merge?

- Their stars don’t collide, but some of the galaxies K.E. is transferred to the random motion of the stars.

- Galaxies experience a ‘drag’ force, known as ***Dynamical Friction***

What happens when galaxies merge

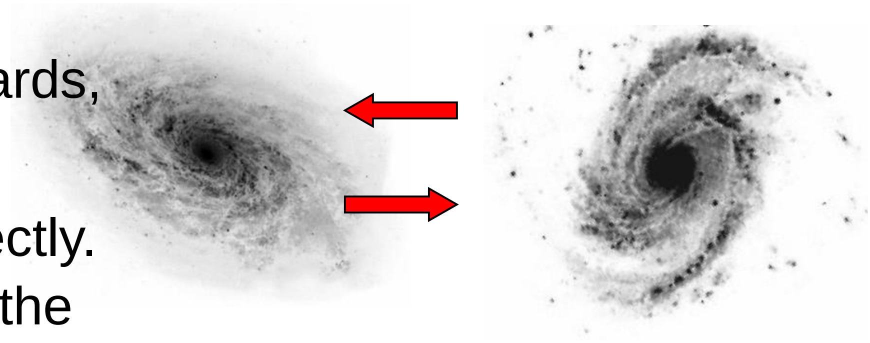


1. Galaxy collisions involve a tremendous amount of energy.

2. Two objects with masses of the order of 10^{12} solar masses or 2×10^{42} kg meet with typical relative velocities of about 300 km/s

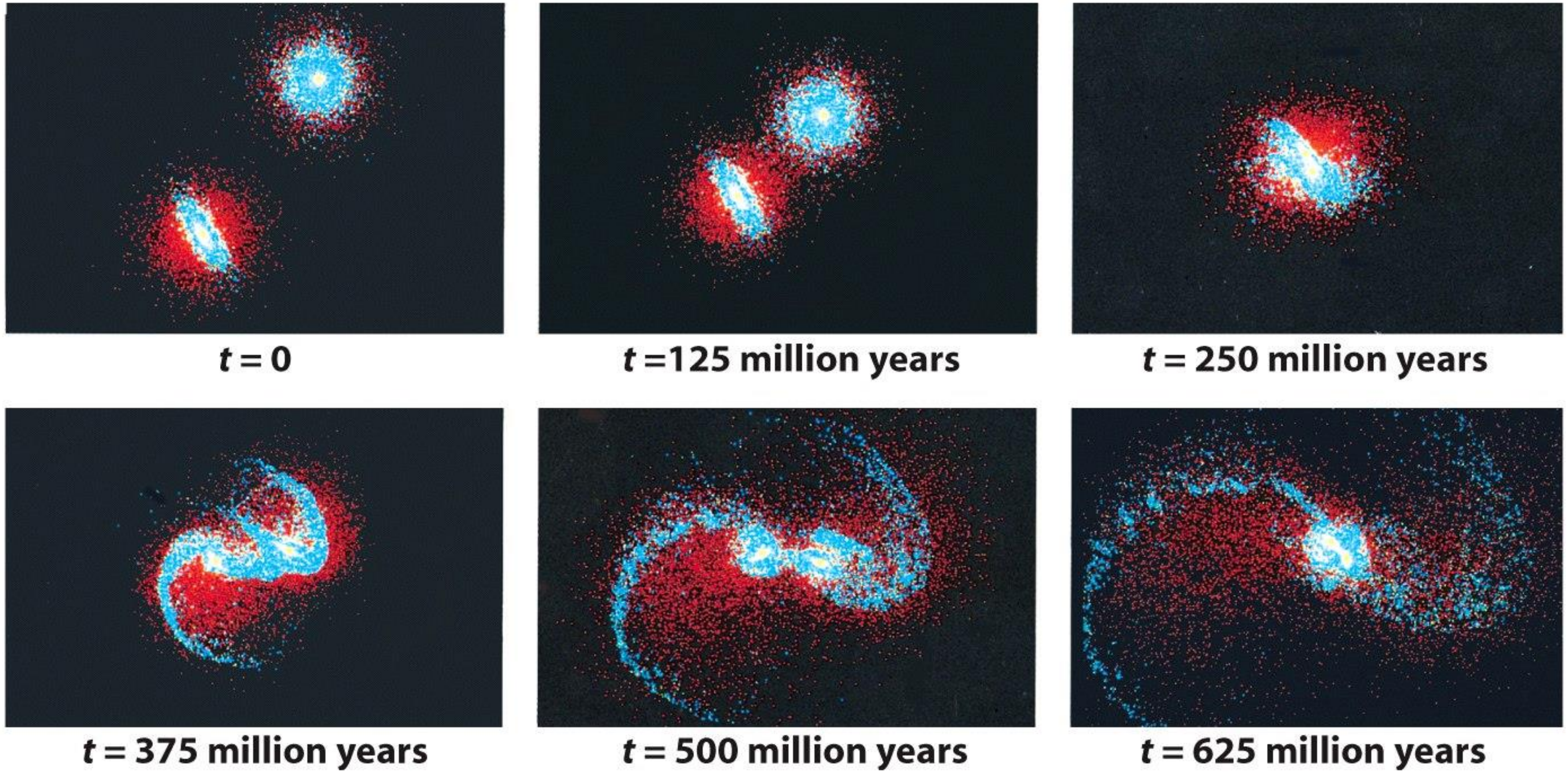
3. Collision energy is of order 10^{53} J. This is energy is equivalent to about 10^{8-9} supernovae, e.g., a number of supernovae that ultimately can be produced in the merger of the two galaxies

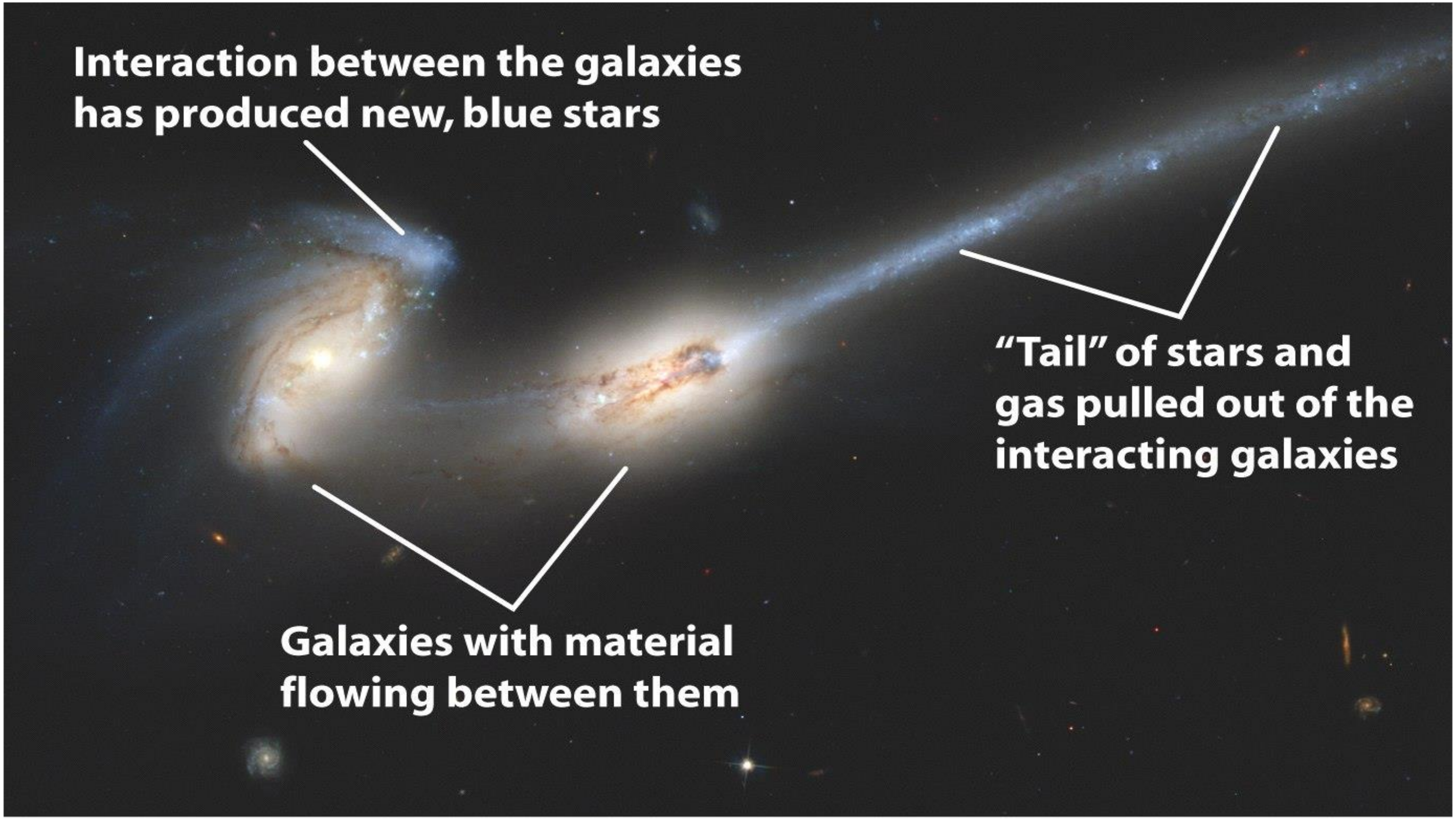
What happens when galaxies merge

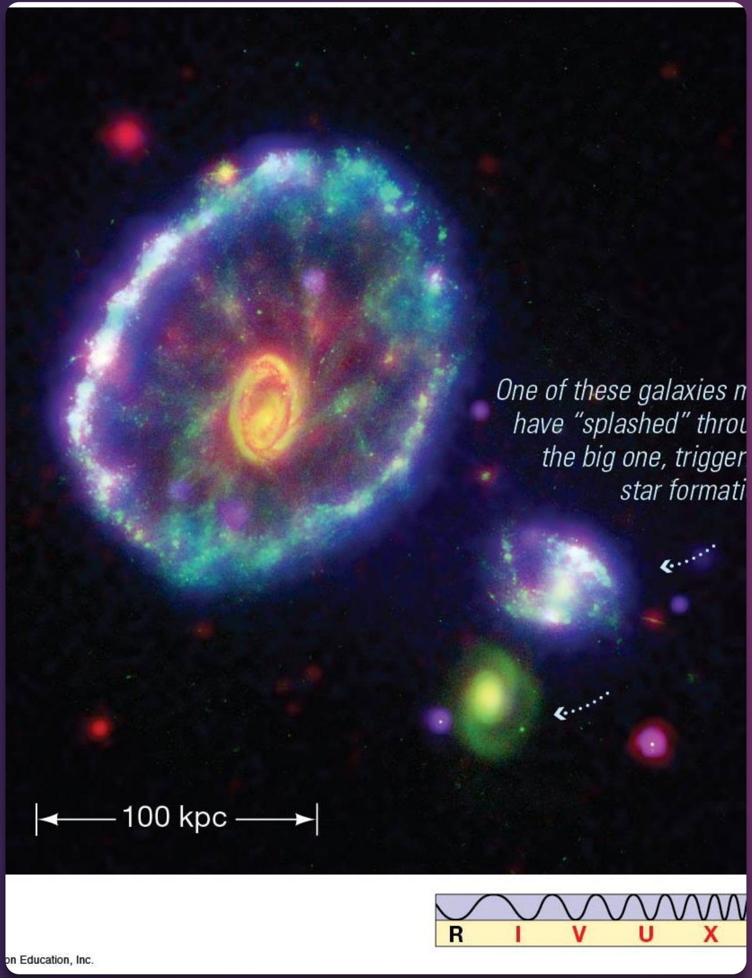


1. Galaxy collisions are extremely slow by terrestrial standards, with typical timescales of order 3 x 10^8 yrs., or 10^{16} sec.
2. There is little hope of observing any of the dynamics directly. Moreover, these systems are caught at random times in the interaction.
3. Main reasons why it is so difficult to interpret the observations, and arrange the systems in a physical classification scheme

The gravitational effects during a galactic collision can throw stars out of their galaxies into intergalactic space



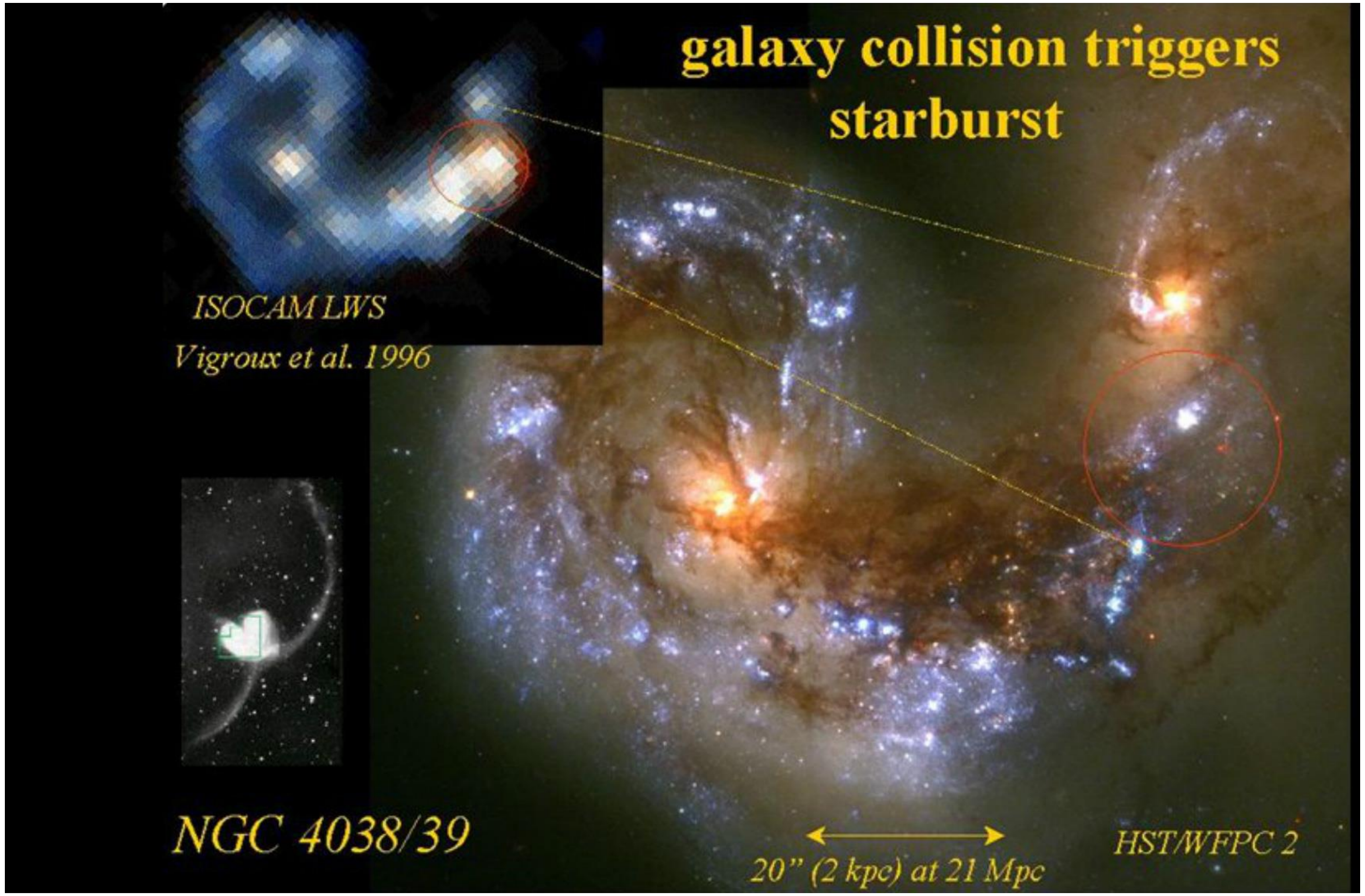

Interaction between the galaxies has produced new, blue stars
“Tail” of stars and gas pulled out of the interacting galaxies
Galaxies with material flowing between them



The separation between galaxies is usually not large compared to the size of the galaxies themselves, and
galactic collisions are frequent.

The “cartwheel” galaxy on the left appears to be the result of a head-on collision with another galaxy, perhaps one of those on the right.

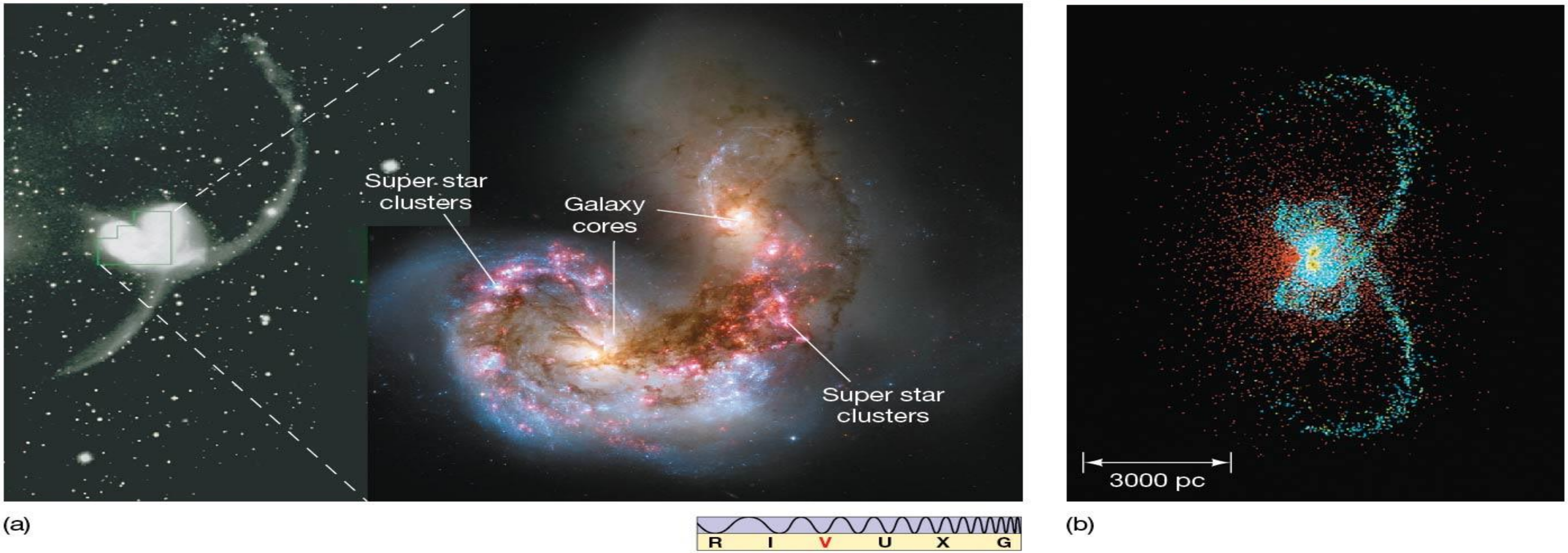
This galaxy collision has led to bursts of star formation in both galaxies; ultimately they will probably merge.



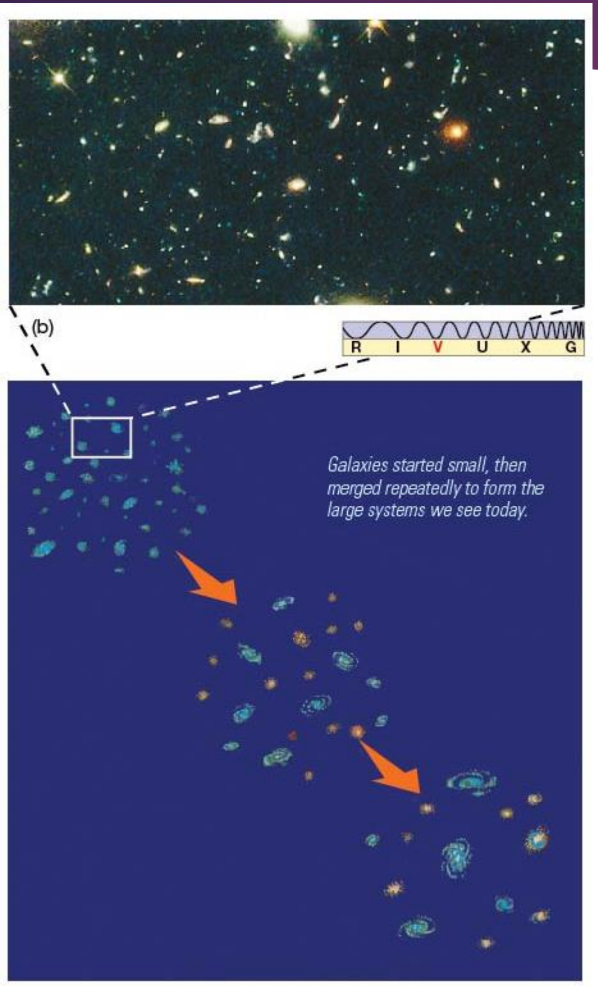
The Antennae galaxies collided fairly recently, sparking stellar formation. On the right is a computer simulation of this kind of collision.

Collisions seen in these real images at left can be studied in computer simulations like that at right.

Such simulations demonstrate the crucial role played by dark-matter halos during galaxy interactions.

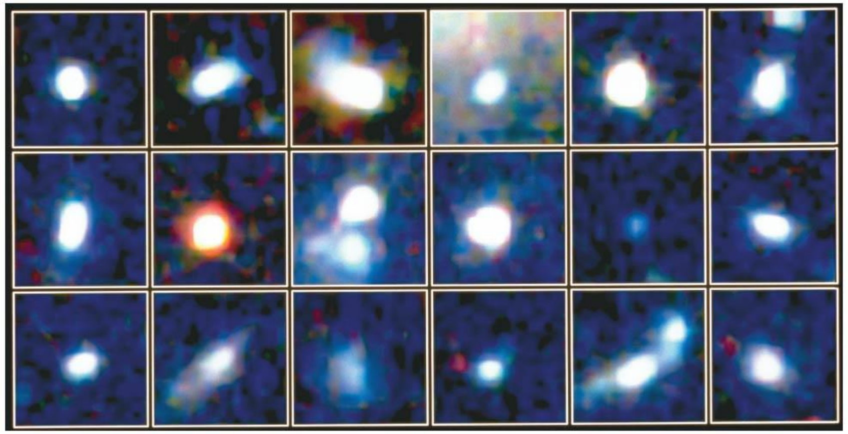


Galaxy Formation and Evolution



(a)

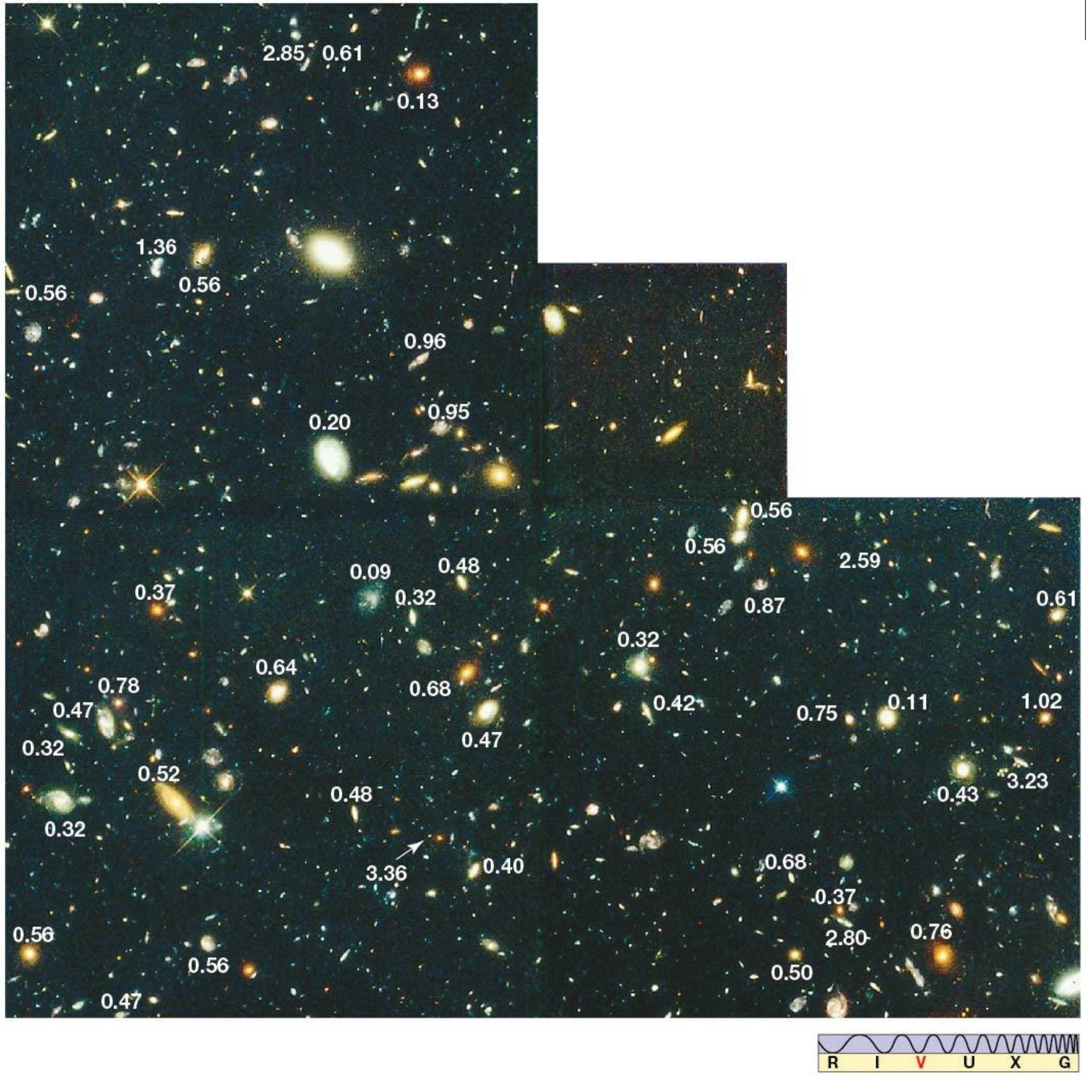
- Mergers of smaller galaxies and star clusters are believed to play a role in the formation of the galaxies we see today. Image (c), shows large star clusters found some 5000 Mpc away. They may be precursors to a galaxy.



(c)

Galaxy Formation and Evolution

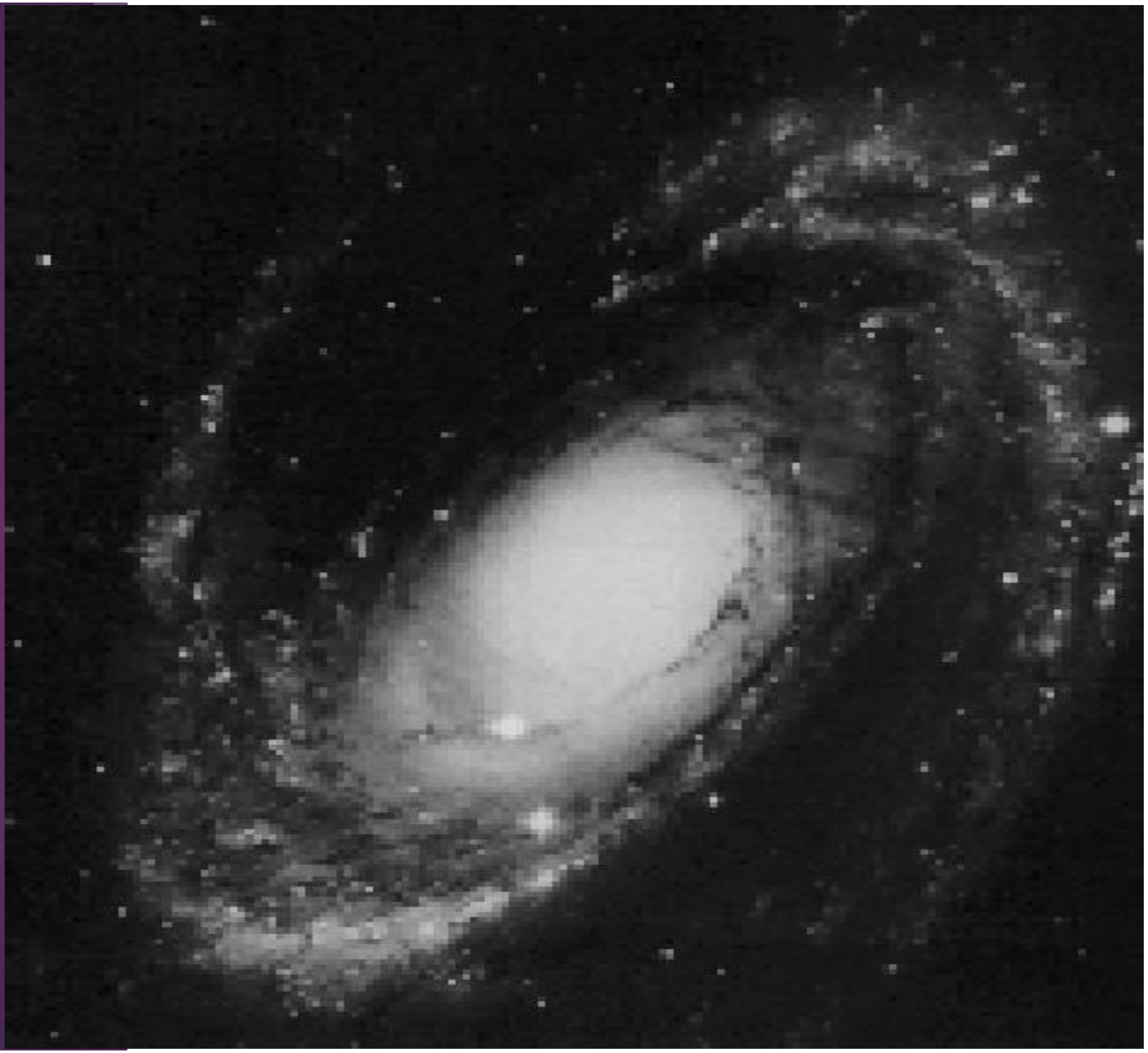
- This Hubble Deep Field view shows some extremely distant galaxies. The most distant appear irregular, supporting the theory of galaxy formation by merger.



High speed 'collision' of 2 disk galaxies

- Galaxies are not slowed down enough to become a bound pair
- Galaxies separate, but their disks are "dishevelled"; stars acquire random motions, causing disks to 'puff off'
- Can form spiral arms or bars

e.g. spiral arms of M81

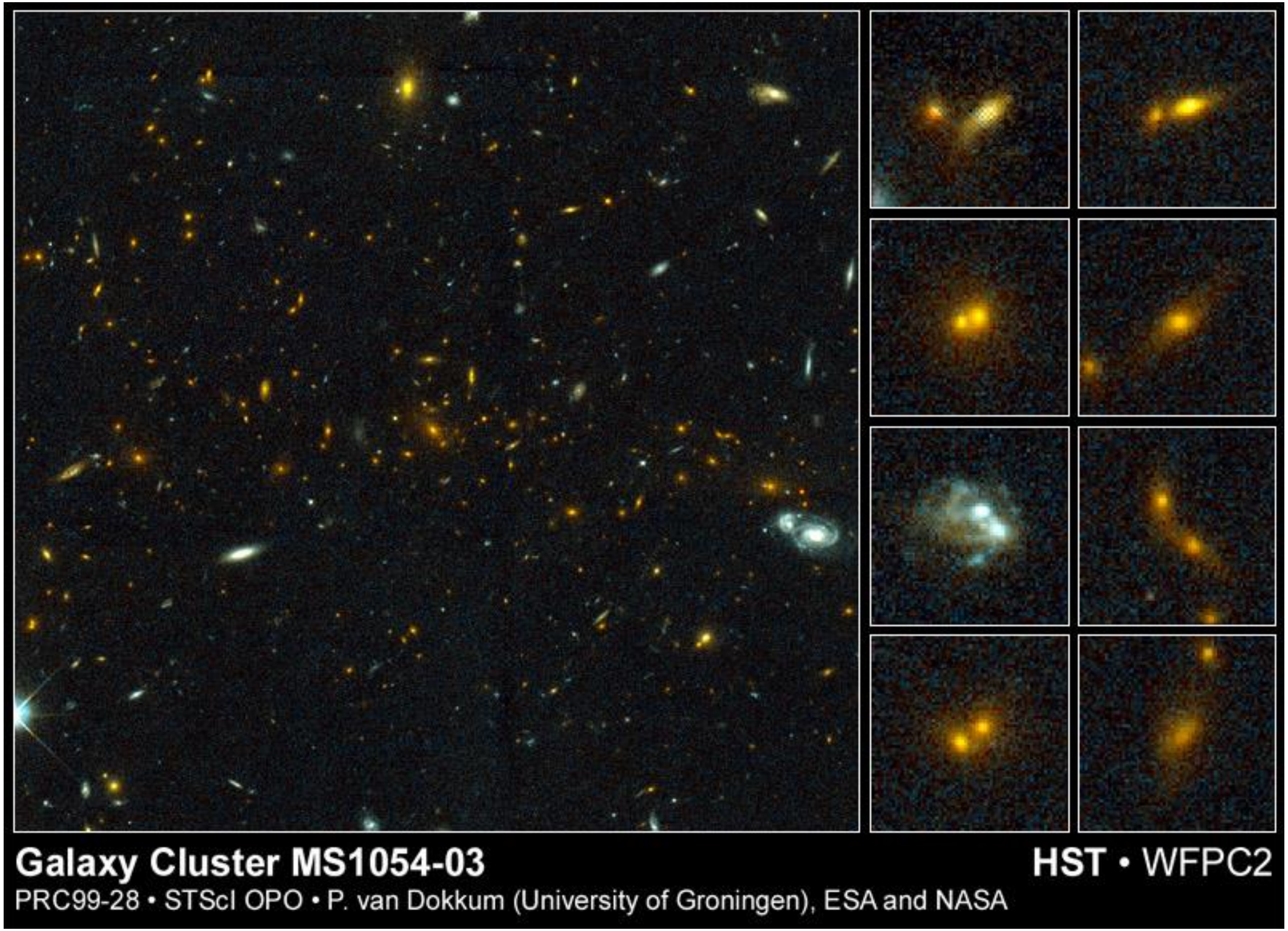


Bar of M91

High speed ‘collision’ or ‘fly-by’ of 2 disk galaxies

- Galaxies are not slowed down enough to become a bound pair.
- Galaxies separate, but their disks are ‘dishevelled’: stars acquire random motions, causing disks to ‘puff up’.
- Can form spiral arms or bars
- Multiple ‘close encounters’ may destroy disks all together;

  explains lack of disk galaxies in the cores of rich clusters

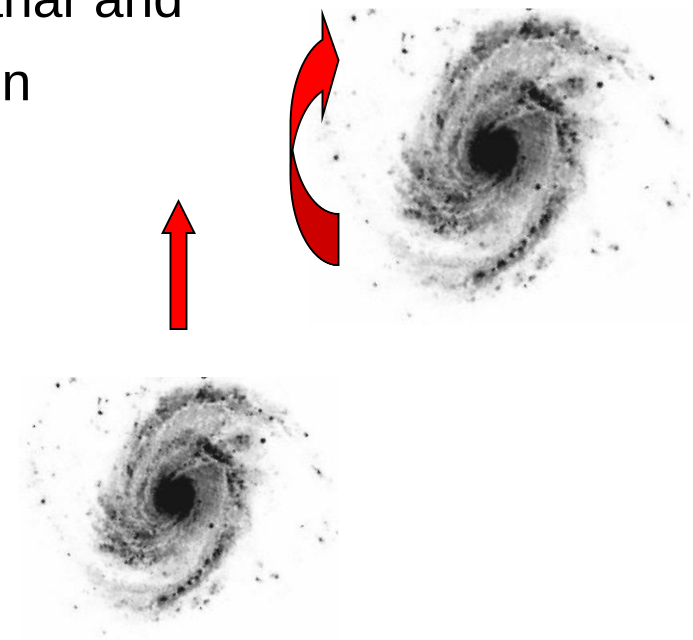

Galaxy Cluster MS1054-03
HST • WFPC2
PRC99-28 • STScI OPO • P. van Dokkum (University of Groningen), ESA and NASA

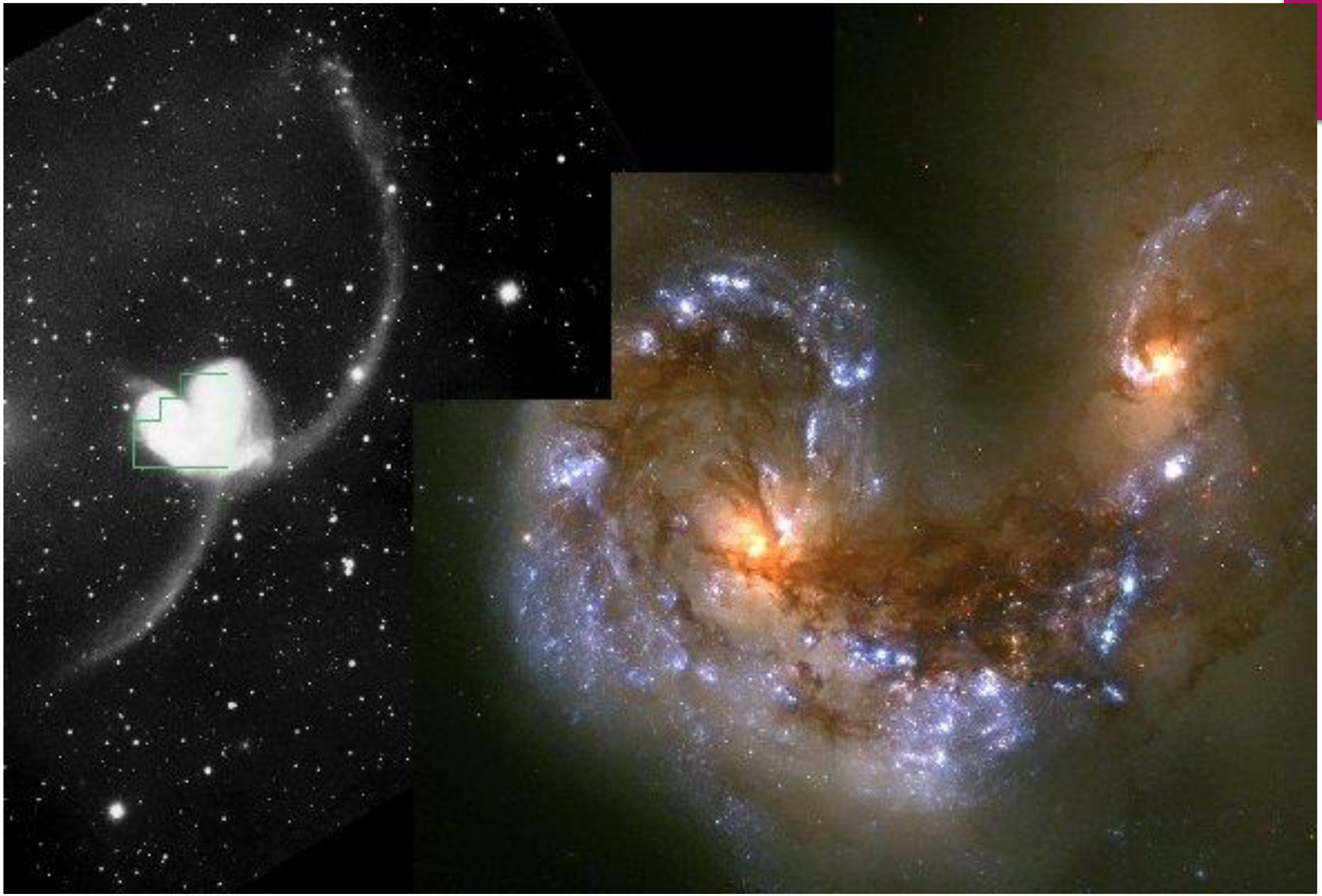
Slower ‘collision’ or ‘fly-by’

- Much greater disturbance – particularly if co-planar and direction of fly-by aligned with direction of motion

- Relative velocity of stars in galaxy A and B is significantly smaller; stars spend a long time in close proximity

- Interaction can draw out a long **tidal tail** which may persist for several Gyr



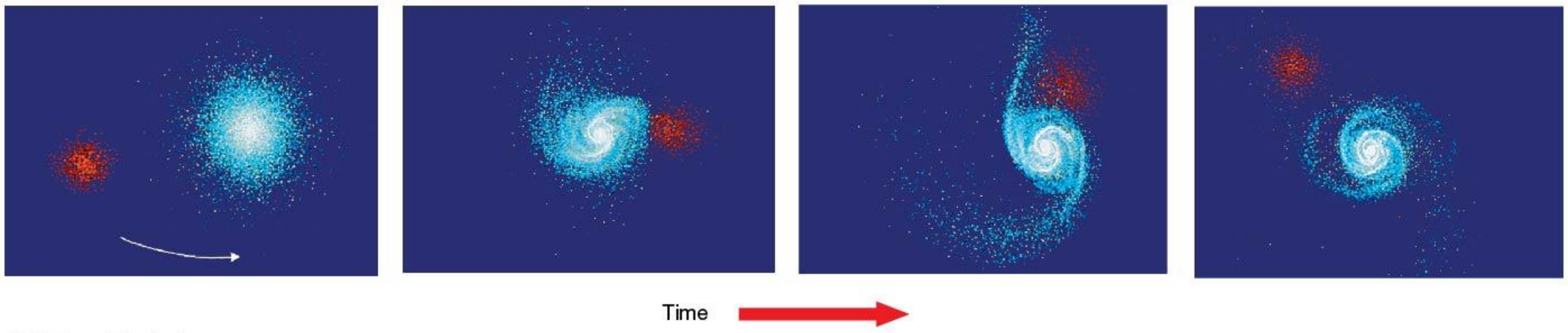


Slower ‘collision’ or ‘fly-through’

- Head-on collision can produce a **polar ring** galaxy

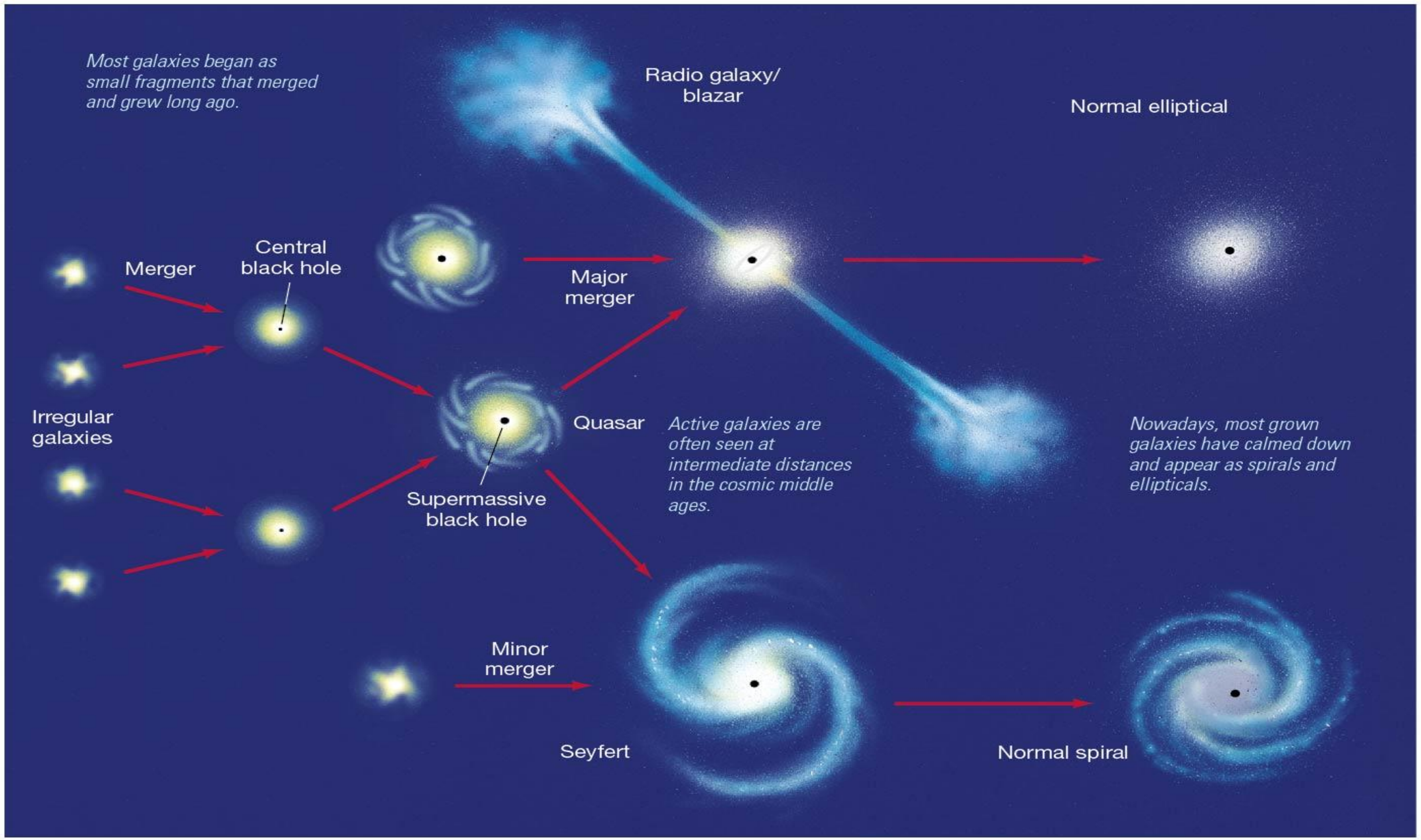
Smaller Galaxy to Spiral

- This shows how interaction with a smaller galaxy could turn a larger one into a spiral.



Possible Galaxies

- This figure shows how galaxies may have evolved, from early irregulars through active galaxies, to the normal ellipticals and spirals we see today.



When Galaxies Collide

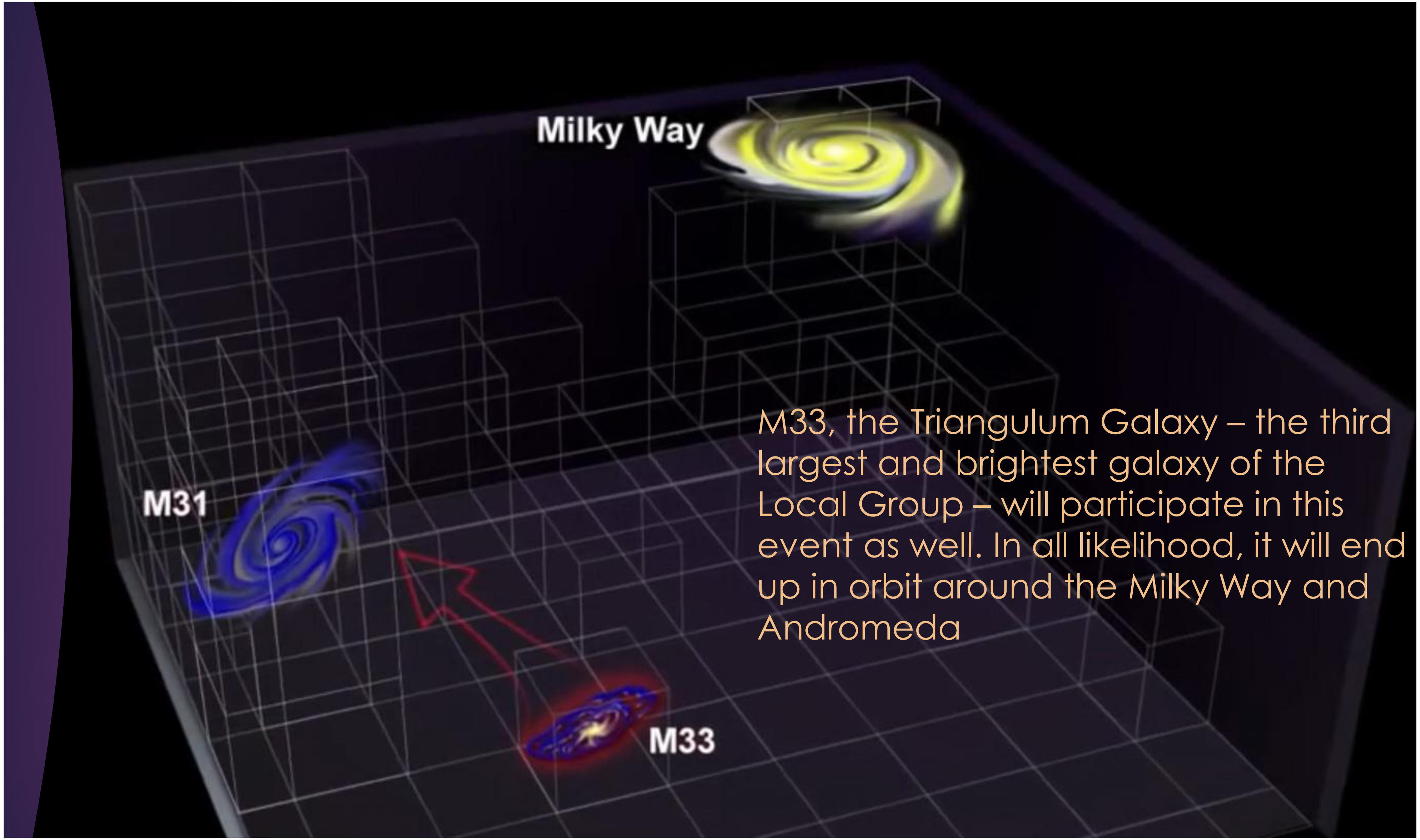
Individual stars almost never collide

Larger Galaxies are formed:

- Disk galaxies (S0) merge with surrounding globular clusters
- Disks collide to form both elliptical and spiral galaxies
- Colliding spirals may lose integrity and become elliptical

In about four billion years …

The Milky Way will collide with Andromeda!

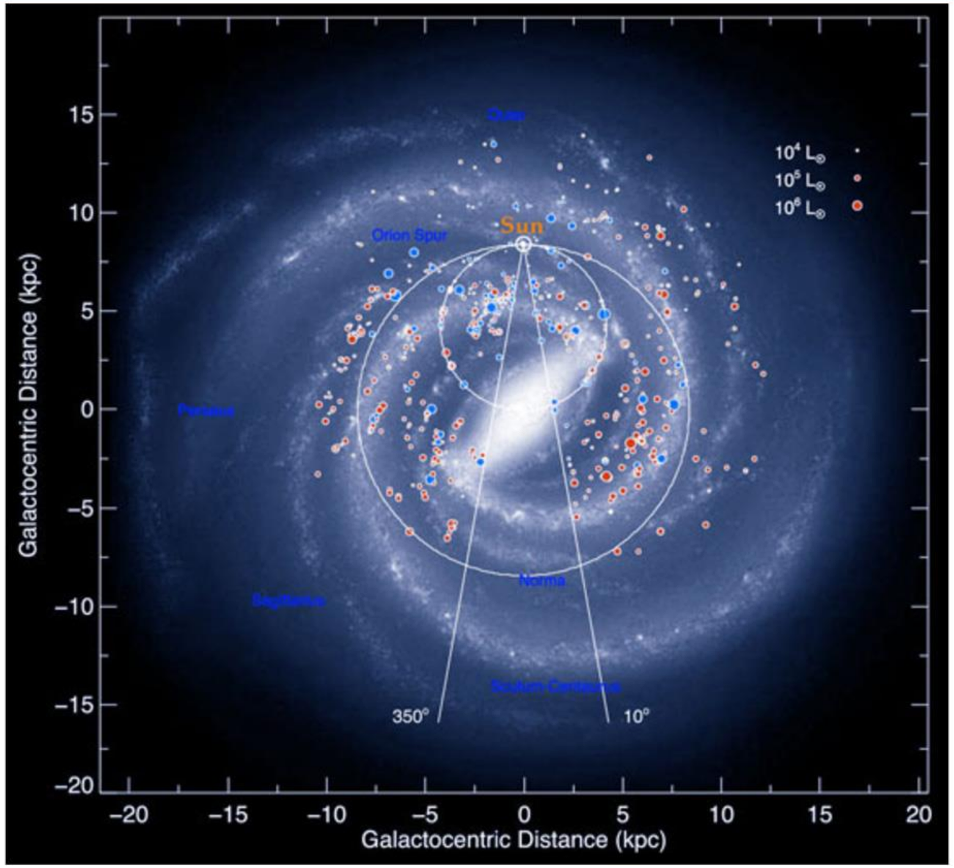


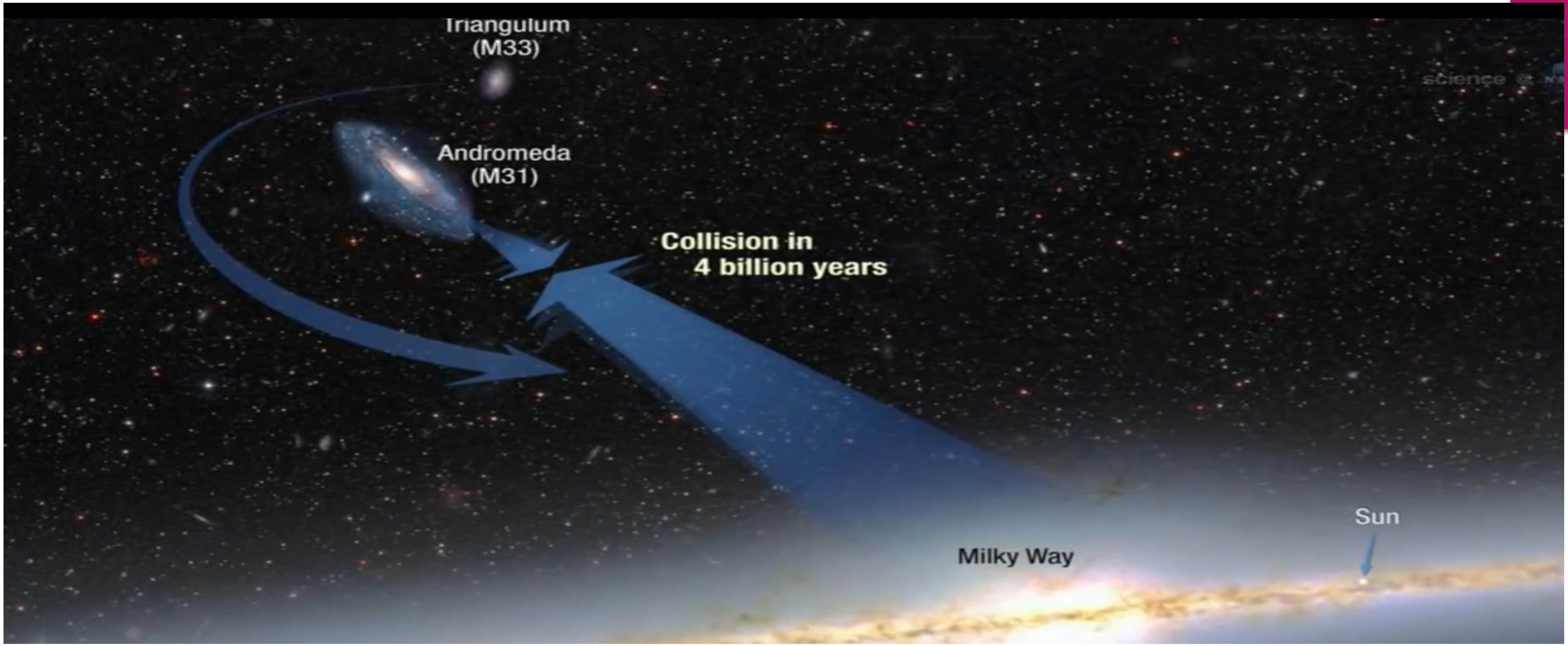
M33, the Triangulum Galaxy – the third largest and brightest galaxy of the Local Group – will participate in this event as well. In all likelihood, it will end up in orbit around the Milky Way and Andromeda

For our Milky Way

- In our wildly unfashionable arm of the Galaxy, stars are spread so far apart that they almost never collide.

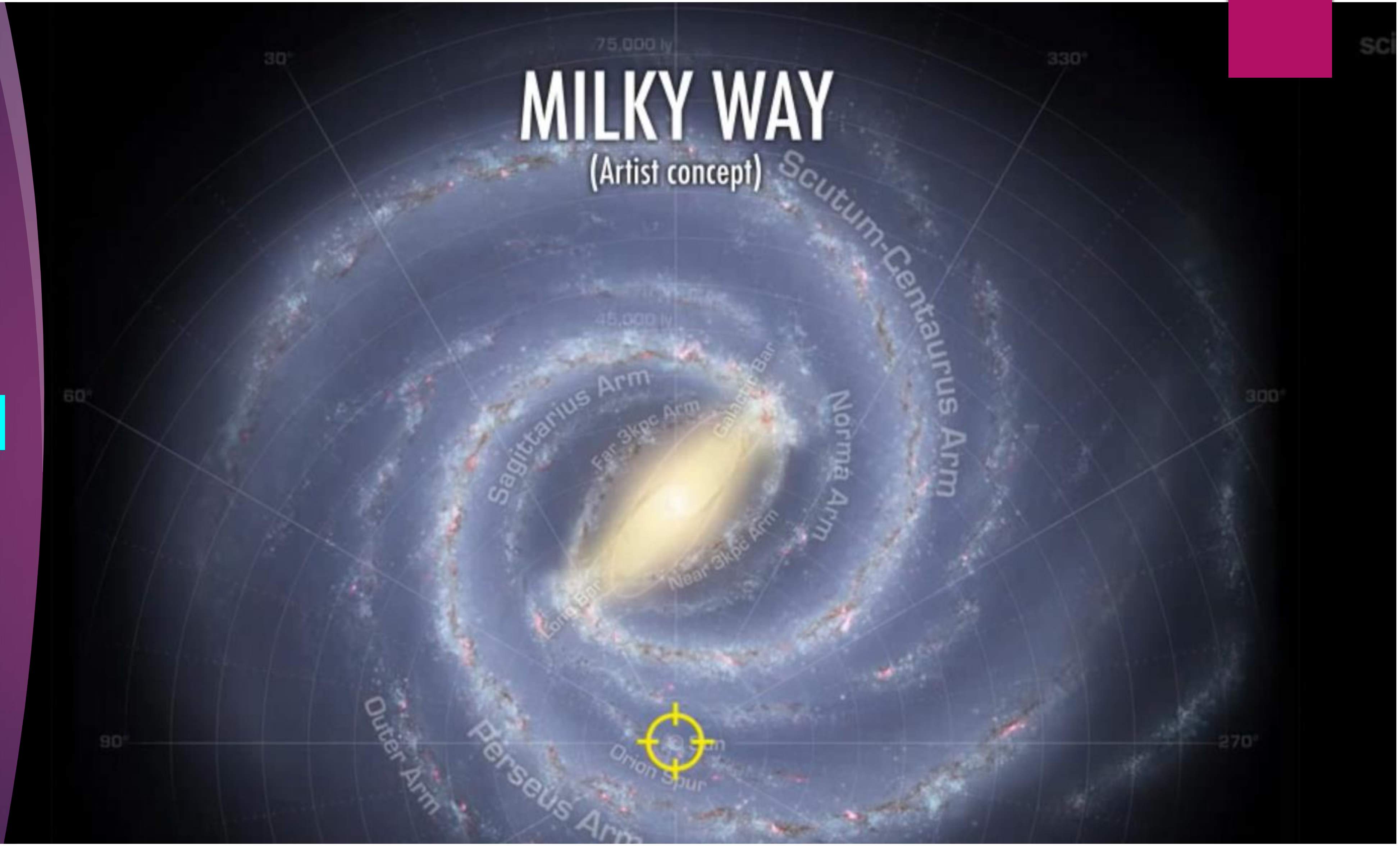
- The chances of our colliding with a Black Hole are even lower.





Andromeda is approaching our galaxy at a rate of about 110 km/second (68 mi/s)

The Collision Spot



Summary

- Merger of small galaxies to form a larger galaxy is probably an important part of galaxy formation.
- Collisions are also important.
- Merger of spiral galaxies probably results in an elliptical.

Happening every where in Universe

Don’t Panic

Thank you