Astro 358/Spring 2006

(48915)

Galaxies and the Universe

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Figures from Lecture 28: Tu May 2

Review: Major Mergers, Minor Mergers, Dynamical Friction

Major Mergers

Major merger of 2 disk galaxies = merger of 2 disk galaxies whose mass ratio ranges from 1/1 to 1/3

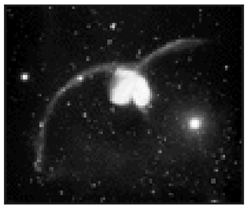
à this type of merger eventually destroys the stellar disk by inducing violent relaxation (VR) in the stars.

à VR causes the stars in the two spirals “lose memory” of their disk distributions and to redistribute into a 3-D configuration with an $R^{1/4}$ profile, as is seen in elliptical galaxies

à Thus, the end-result is often considered to be an elliptical galaxy

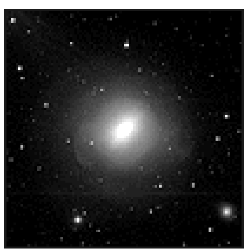
The Toomre Sequence

Credit: Vera Rubin (CIW/DTM)
NGC 5426/5427



Credit: Francois Schweizer (CIW/DTM)
NGC 4038/4039

Credit: Francois Schweizer (CIW/DTM)
NGC 7252



Credit: Francois Schweizer (CIW/DTM)
NGC 3610

Credit: Digitized Sky Survey (AURA, Inc.)

The Toomre sequence is a sequence of different galaxies that appear to be in the different stages of a major merger, ranging from the early to the late stages below:

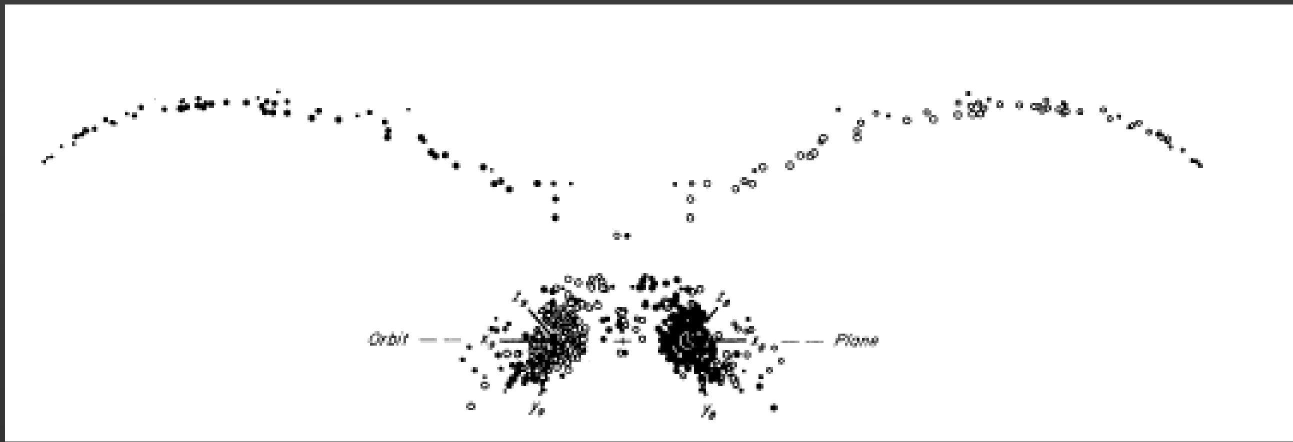
1) Gravitational forces fling out gas and stars into two extended tails. The similar length of the two tails 'reflects' the rotation of the two disk galaxies of similar masses.

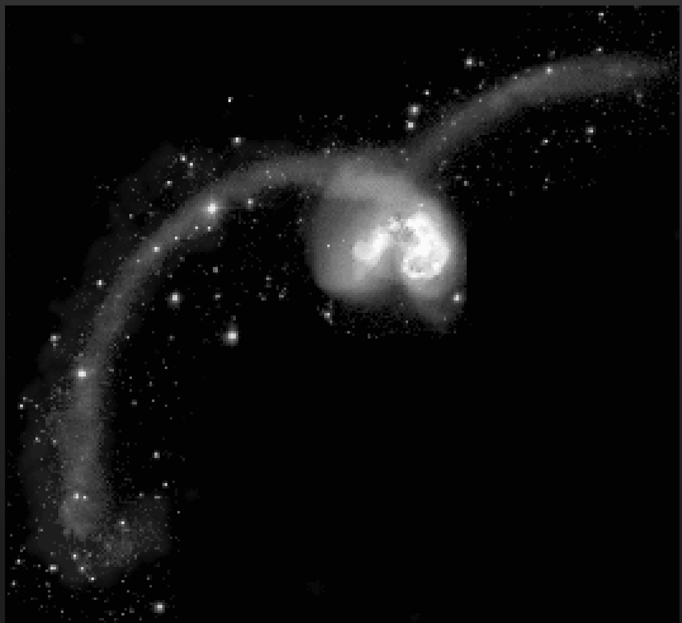
2) The stars in the tails fade away, while gas in the tails falls back into the galaxies to form stars.

3) The disks are destroyed via a process called violent relaxation. The stars in the two spirals "lose memory" of their disk distributions and redistribute into a 3-D de Vaucouleurs (R^1/4) configuration

4) End-product is an elliptical galaxy

Major Merger of 2 spirals

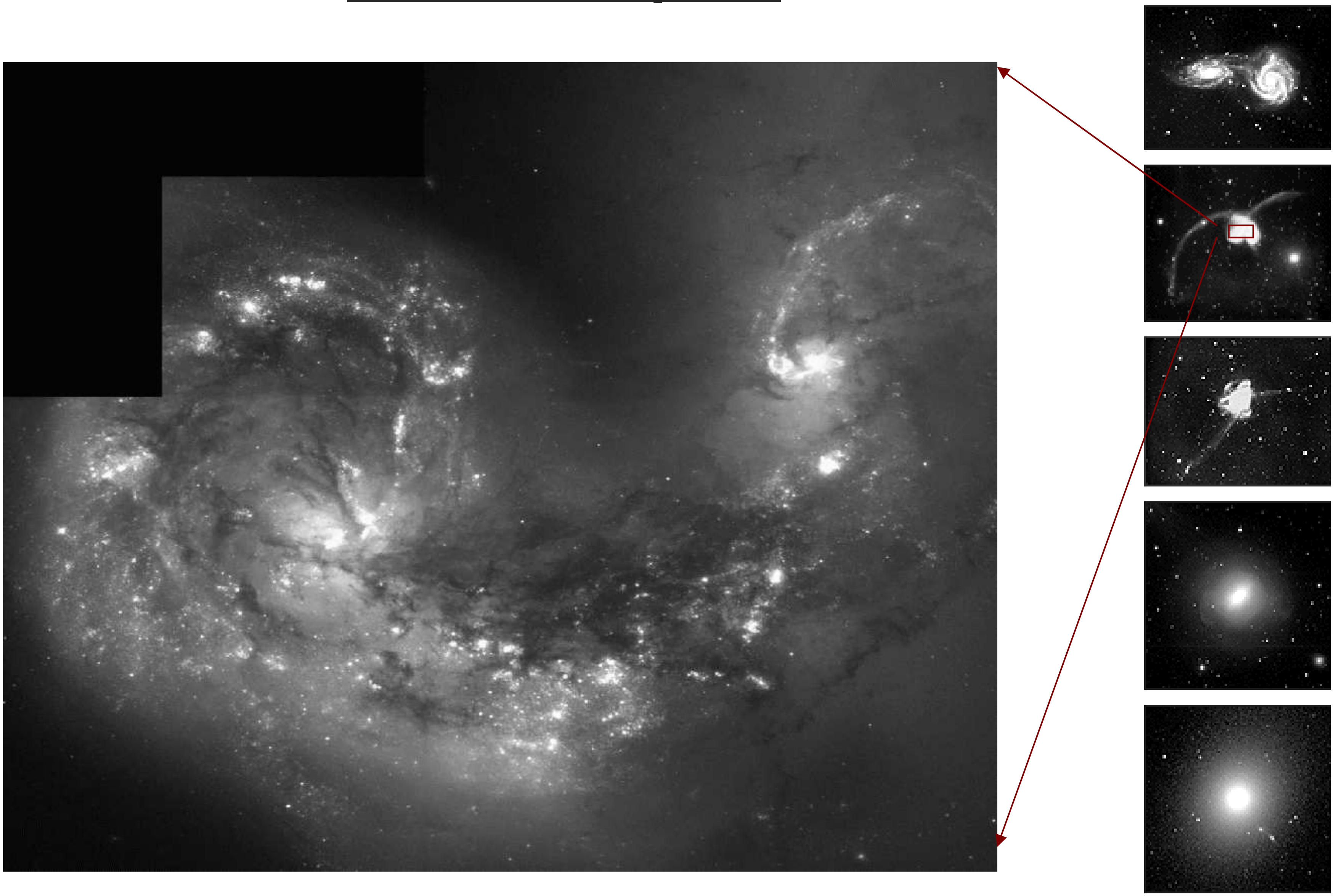




Computer simulation of ‘Galactic bridges and tail’ by Toomre & Toomre 1972

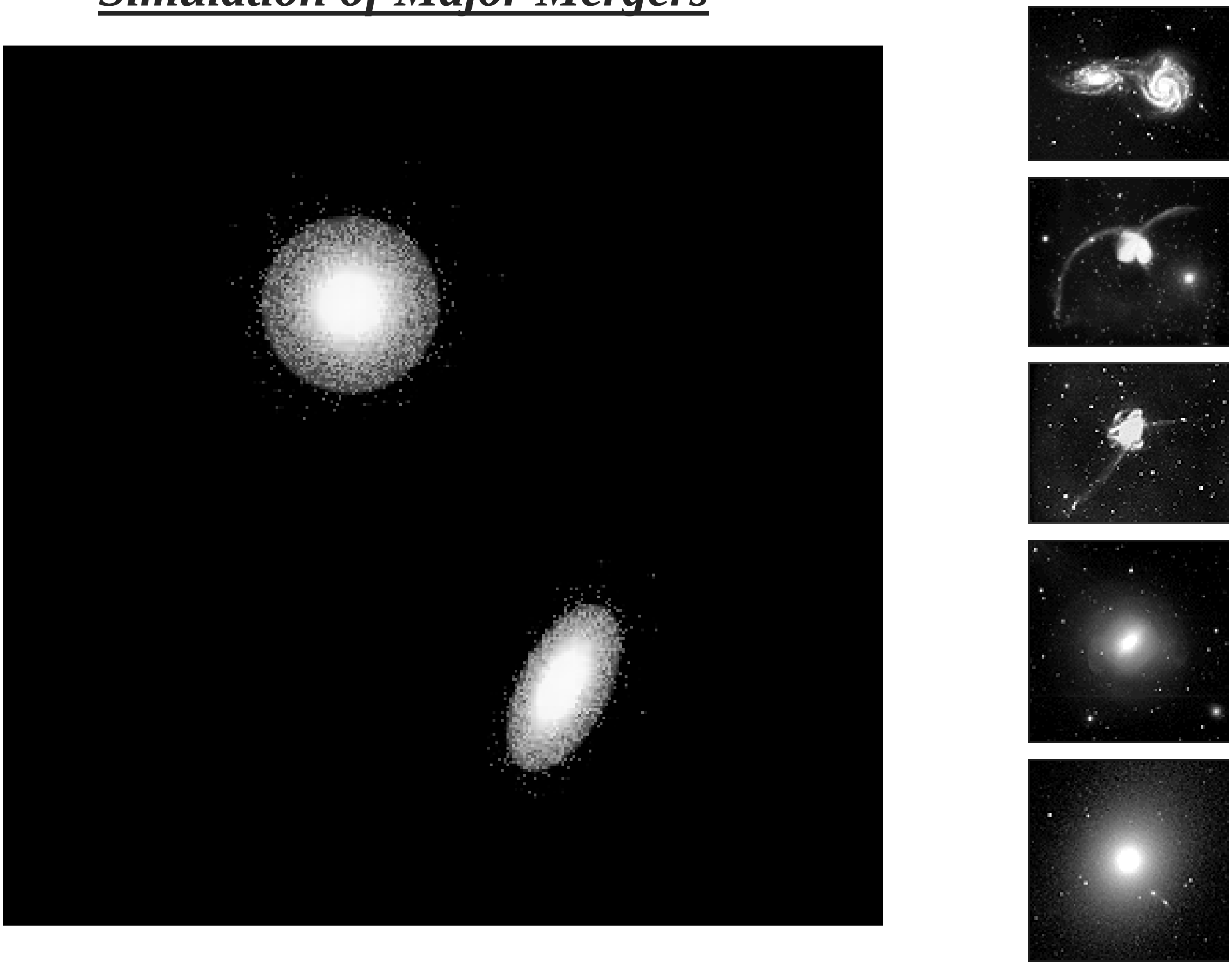
Observation of stars (green) and HI gas (blue) in NGC 4038/39 called The Antennae galaxy.
(J. Hibbard)

The Toomre Sequence



The Antennae system is part of the Toomre sequence on RHS
The HST image shows the central region only: it confirms the presence of 2 disks with gas stripped out

Simulation of Major Mergers



Merger of 2 spirals of similar mass destroys the disks and produces an elliptical galaxy!

Minor Mergers

Minor merger of 2 galaxies = merger of galaxies whose mass ratio is less or eq 1/4.

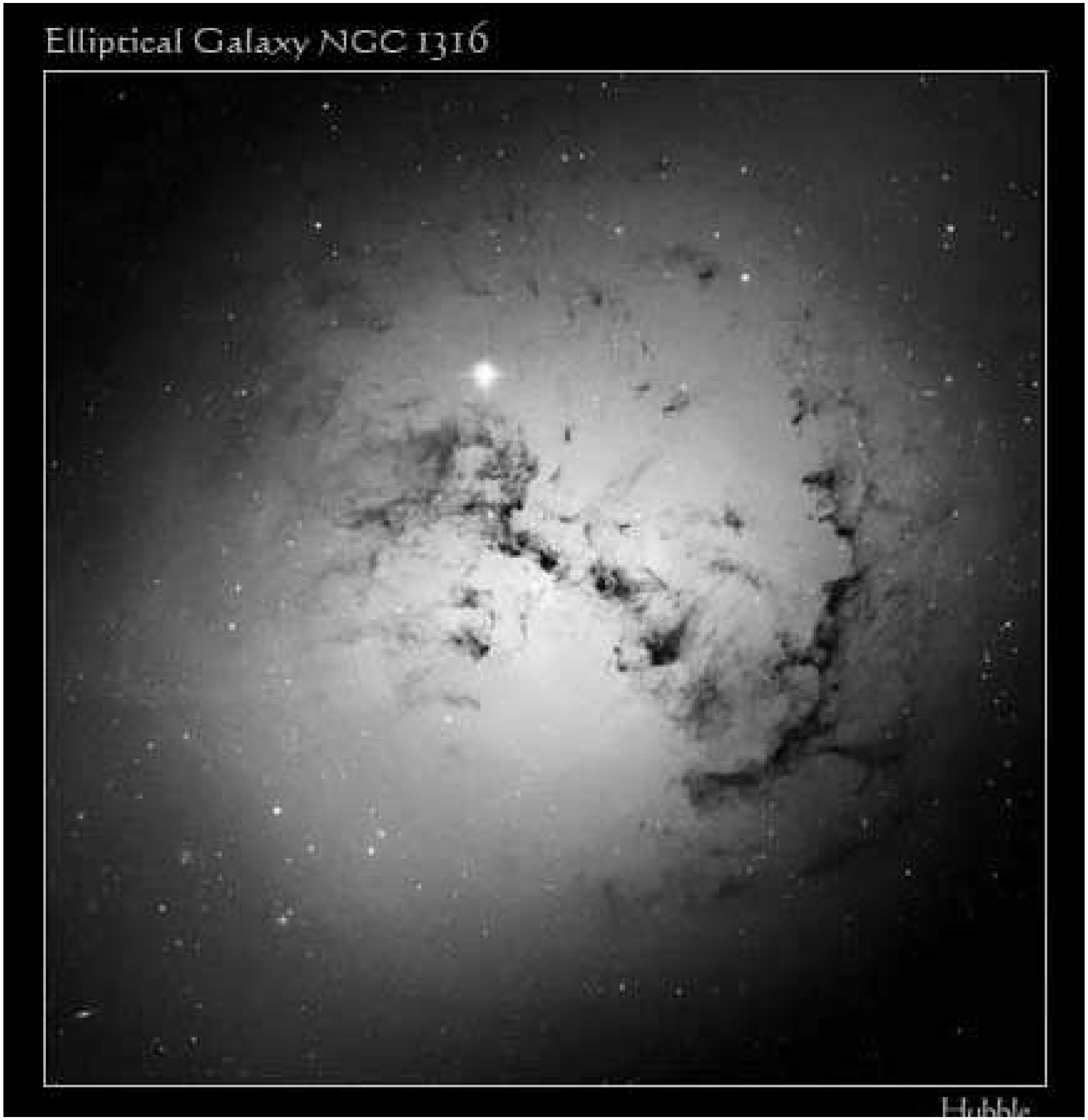
à if the larger galaxy is a disk galaxy, this type of merger <u>preserves the stellar disk</u> even though it can induce strong morphological distortions in the disk (arcs, ripples, shells, tails)

à this type of merger will often induce tidal tails of unequal lengths

Example : minor merger of an Sc with an dwarf galaxy

Example: minor merger of a dwarf or Sd galaxy with an elliptical

Minor mergers



The elliptical galaxy (NGC 1316) has recently cannibalized smaller spiral galaxies which are 1/10 to 1/100 its mass, and have lots of gas and dust

Dynamical Friction

As a satellite of mass M moves forward at speed V_c through a disk or halo, which is made of a sea of particles of smalller mass m (e.g.,stars), the satellite experiences a gravitational drag force called dynamical friction (DF).

DF converts orbital angular momentum of the satellite into spin angular momentum of the disk and halo of the main galaxy.

This causes the satellite to decelerate, lose angular momentum, and sink to the center of the system on a timescale

t_{df} proportional to $(R^2 V_c / M \ln\Lambda)$

$$t_{df} = (7 \times 10^7 \text{ years}) \ (10^8 \text{ Mo}/M) \ (V_c / 300 \text{ km s}^{-1}) \ (R/700 \text{ pc})^2$$

DF is efficient when M is larger, R is small and V_c is small.

Example : a clump of gas moving in a disk experiences DF from average stellar background

Example : a globular cluster at large radii in a galaxy sinks towards the center as a result of DF against the halo of stars

Example: a satellite galaxy is accreted during a minor merger by a larger galaxy. Satellite sinks towards center of larger galaxy due to DF between satellite and stars+DM halo

NGC 2782: what type of merger is this?

The visible light image shows
- a relatively undisturbed disk
- a 20,000 pc tail to the left

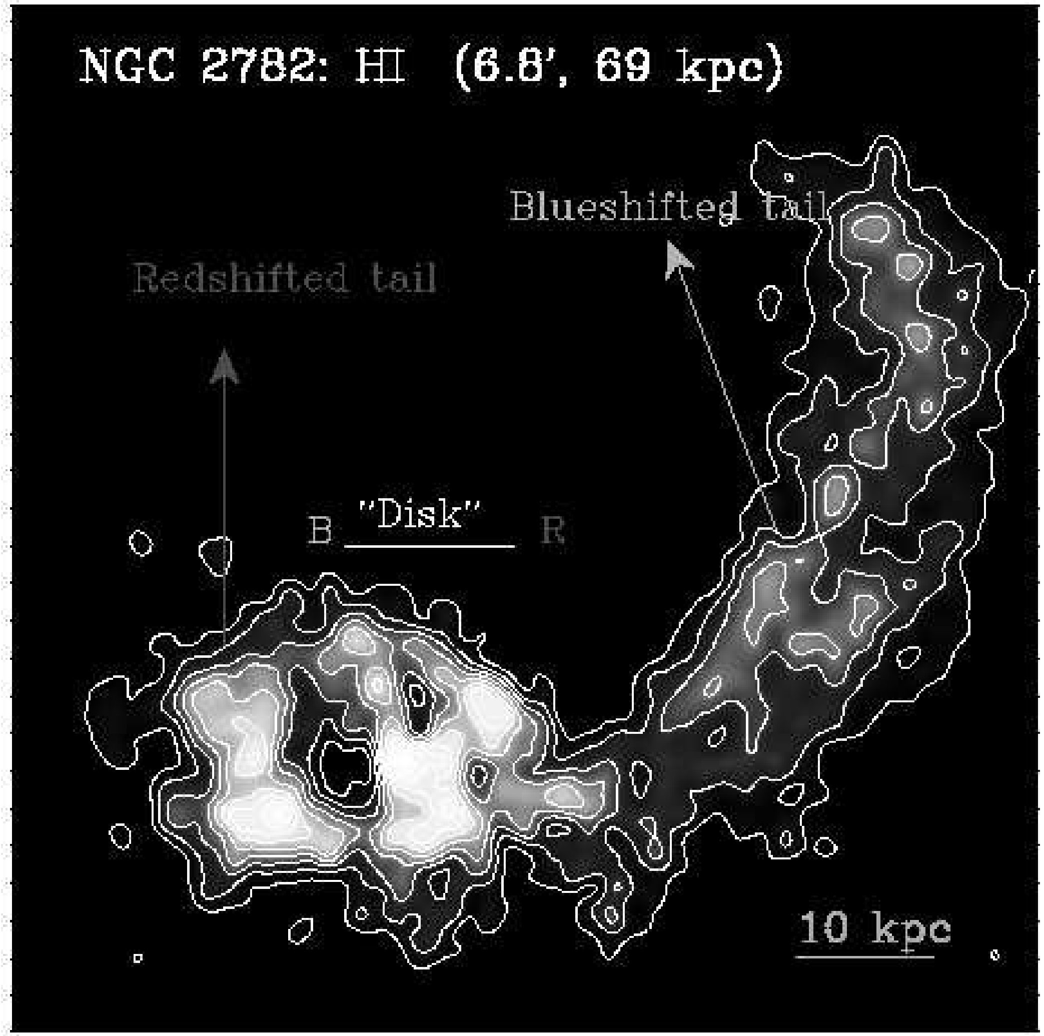


Image at 21 cm (atomic H) shows the disk and a HUGE 50,000 pc tail to the right

Is our own Galaxy Interacting?

- The Milky Way, is part of the Local Group, a set of ~40 galaxies that are bound by gravity. (Includes 3 massive spirals, 4E/dEs, 17 dwarfs dSph, 12 dIrr/Irr).

- 90% of the luminosity of the local group come from 3 massive spirals
  M31 (Andromeda SAb), Milky Way (SBbc), M33(SAcd)

- Closest neighbors of the Milky Way are Sagittarius (dwarf), LMC (Irr), and SMC (Irr)
  Sagittarius (dE): 0.08 x 10^6 lyr ; LMC (Irr) : 0.16 x 10^6 lyr SMC (Irr) , distance = 0.19 x 10^6 lyr

LMC; Irr; 30,000 ly across

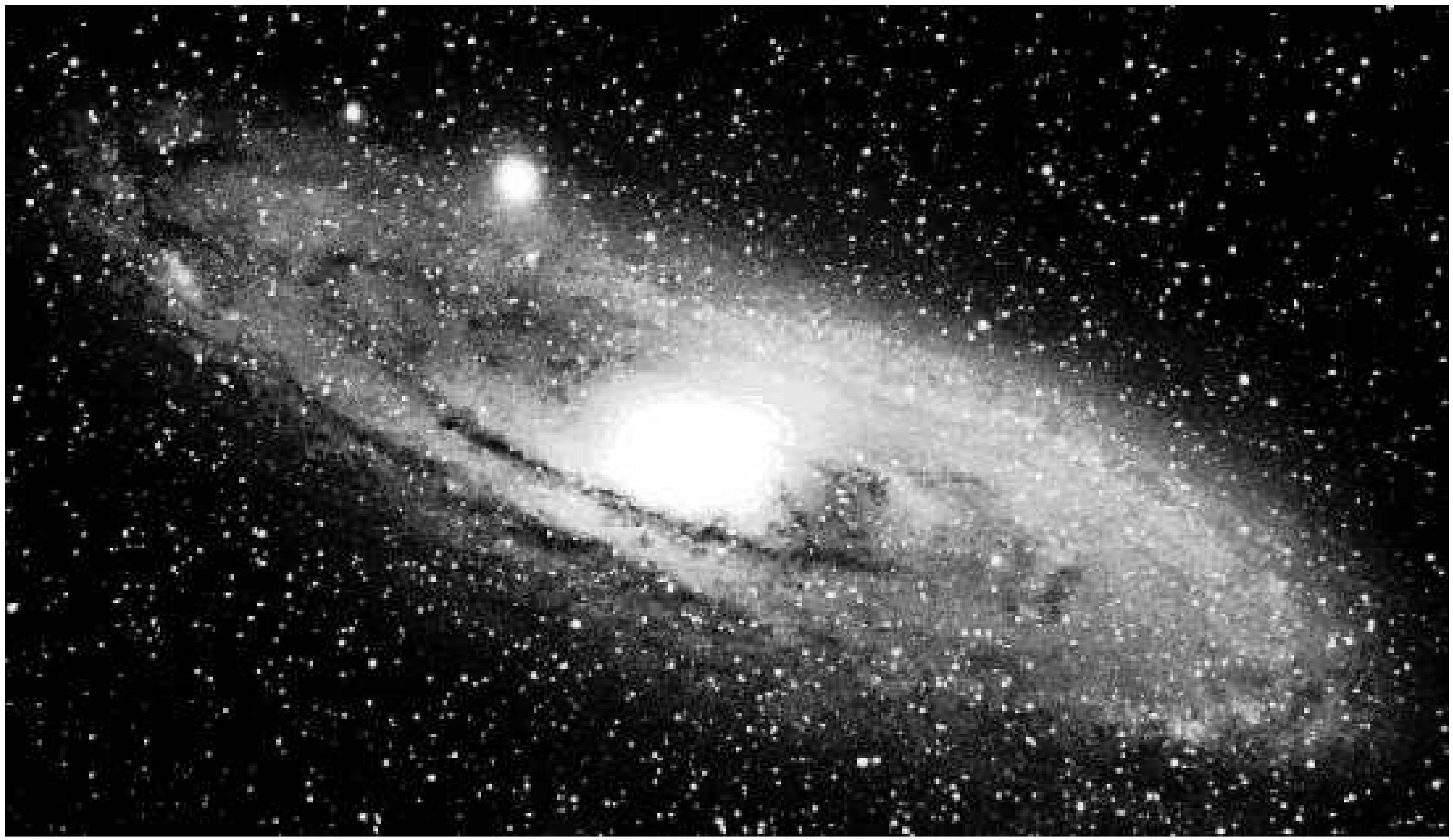
SMC; Irr ;18,000 ly across

The Milky Way (an SBbc galaxy) is currently undergoing several interactions

à It is presently 'digesting' the Sagittarius (dwarf elliptical) galaxy_.

à It is interacting with SMC (Irr) and LMC (Irr) producing the Magellanic bridge of atomic H

à It has a warp and this may be due to a past accretion of a satellite



à The Milky Way is moving at 83 km/s toward M31 (Spiral SAb) located 2.5 million ly away. Major merger in 10 Gyr

Data meet models
or
Problems with Hierarchical Λ CDM models of Galaxy Evolution

Comparison of data to hierarchical ΛCDM models

à good agreement on large scales (>few 100 kpc = scales of galaxy clusters)

à several problems/challenges on scales of galaxies

A) Substructure or missing satellite problem

B) The problem of present-day bulgeless galaxies

C) The Angular Momentum Catastrophe

A) Substructure or missing satellite problem

No of low mass galaxies (dwarf satellites) in local neighbourhood is 10 -100 times lower than the no of low mass DM halos at z=0 predicted by models.

Possible solutions to the substructure problem?

1) Models have too much power on small scales, and over-predicts no of low mass DM halos

2) Suppression of star formation: The models predicts the correct no of low mass DM halos, but somehow the baryonic gas disks inside the DM halos are not forming new stars. This suppression of star formation would make the low mass disks 'invisible'.
To make progress: need to model star formation in the model by inputting better physics of star formation

B) The problem of present-day bulgeless galaxies

Models predict that on average each DM halo had at least one major merger over the last 13.7 Gyr. If this is true then

à the stars in their baryonic disks of (gas and stars) would have been redistributed into an R^1/4 de Vacouleurs 3-D system = a bulge of a spiral or an elliptical galaxy

à most spirals should have a bulge by z=0

But the problem is : we see many ‘super-thin’ and bulgeless galaxies at z=1 to 0 !

Sab Sa   Sb Sbc Sc Scd   Sd

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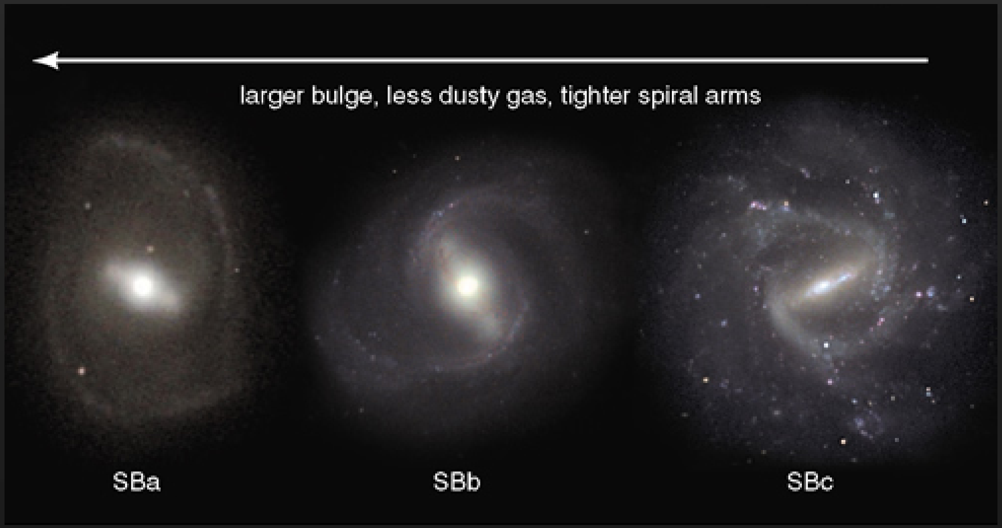
Nuclear cluster , no bulge



Possible solutions to the bulgeless galaxies problem

1) Major mergers of disks which are extremely gas rich (e.g.k, with 90 % of the mass as gas, 10% as stars) can avoid forming a bulge (Robertson et al 2004).

Reason: Violent relaxation affects stars and not gas.

But this solution only 'delays' the problem, without solving it

à such ultra gas-rich disks are only likely to exist at very early epochs ($z >> 5$)

à with time they would convert their gas into stars to become star-rich disks (by $z=2$)

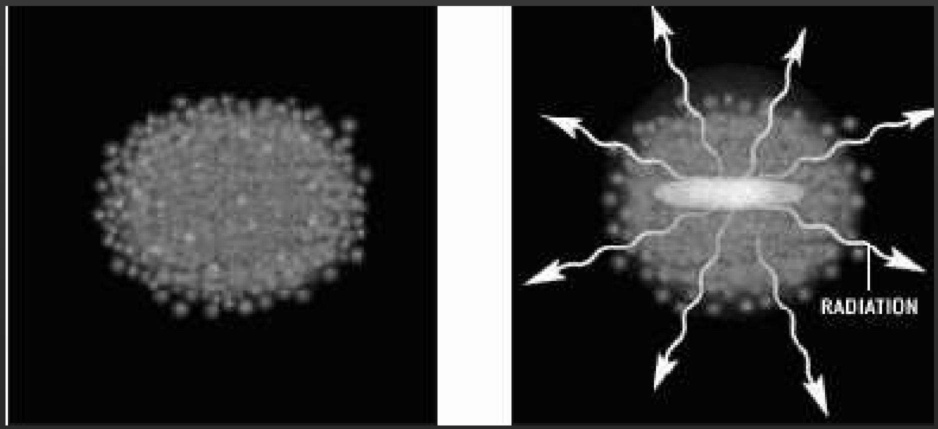
à such disks would eventually merger to produce bulges, unless major mergers become completely rare at $z<2$.

C) The Angular Momentum Catastrophe

Can be stated as “ Angular momentum of present-day z~0 disks is ~10 times too large compared to the model predictions”

Review how disks form

Initially (DM=red + gas=blue) are coupled and form a fluid that is uniform except for some dense ‘clumps’/proto-galactic clouds.



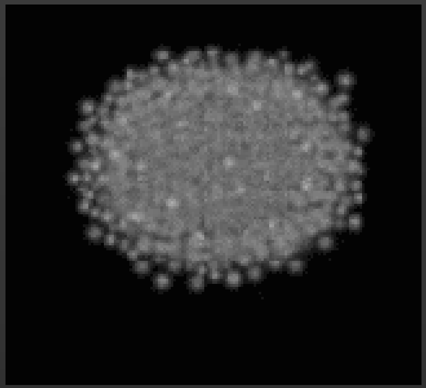
In these clouds, gas density is high enough that the gas cooling time is low. As gas cools, gas and DM decouple because

à DM is non-dissipative and stays in a 3-D halo

à Gas cools, radiates and collapses to form a flat thin gas disk inside DM halo

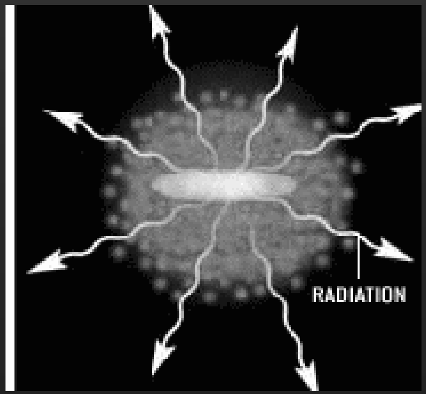
Possible solutions to the Angular Momentum Catastrophe problem

1) Maybe the gas loses too much angular momentum as it decouples from DM halo to form the disk. What could cause this excess loss of angular momentum L ?



a) Maybe the gas is too clumpy, causing dynamical friction to remove too much L

- Possible solution = feedback from star formation!
- How does it work? Supernovae blow the gas into a diffuse form reducing its clumpiness
- But …… sometimes the amount of star formation that is needed to make the gas diffuse enough is so LARGE that it destroys the entire disk and halo!



b) Maybe the galaxies are undergoing too many mergers, which remove too much L from the gas

Possible solution = get <u>empirical constraints</u> on the merger rate from galaxy surveys and compare to the models in order to check if models have too high merger rates.