Chapter 16: Galaxies

A. Classification.

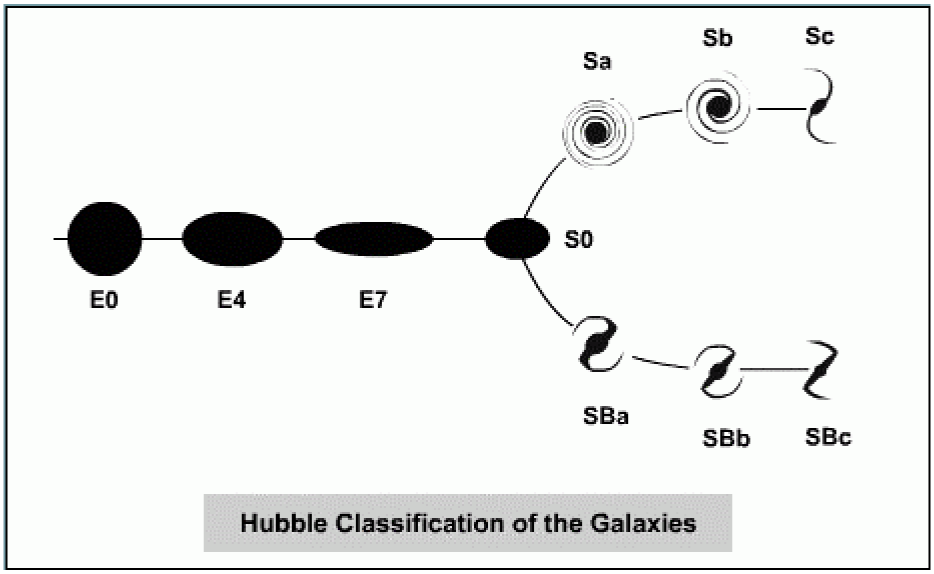


Figure 1: Hubble Tuning Fork Diagram

1. Spirals. Contain many young blue stars.

    a. Type Sa: large central bulges and tightly wound arms.

    b. Type Sb: smaller central bulges and more open arms.

    c. Type Sc: very small central bulges and loose spiral arms.

Figure 2: Sa Galaxy

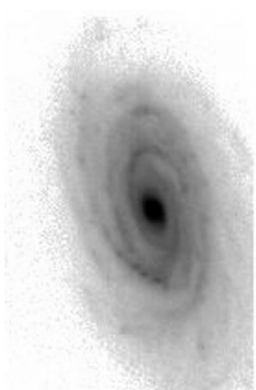


Figure 3: Sb Galaxy

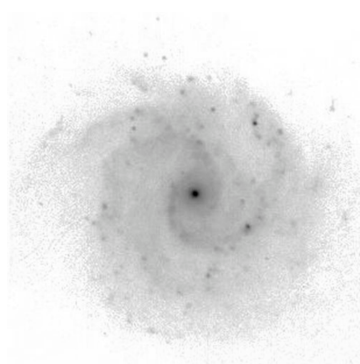


Figure 4: Sc Galaxy

2. Barred Spirals: differ from spirals by possessing a bar of stellar and interstellar matter passing through the center and extending into the disk. Contain many young blue stars.

a. Type SBa: large central bulge and tight arms.

b. Type SBb: smaller central bulge and more open arms.

c. Type SBc: very small central bulge and loose arms.

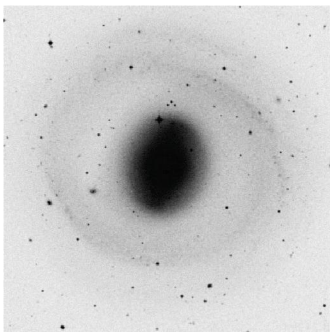


Figure 5: Sba Galaxy

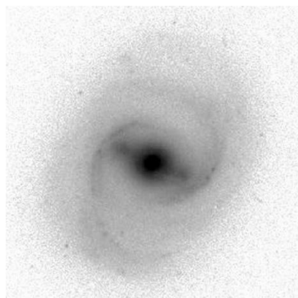


Figure 6: SBb Galaxy

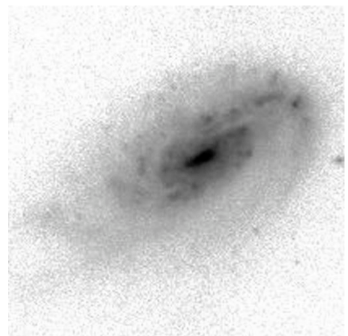


Figure 7: SBc Galaxy

3. Flocculent Spirals: Spiral arms formed by self-propagating star formation.

a. Poorly defined arms.

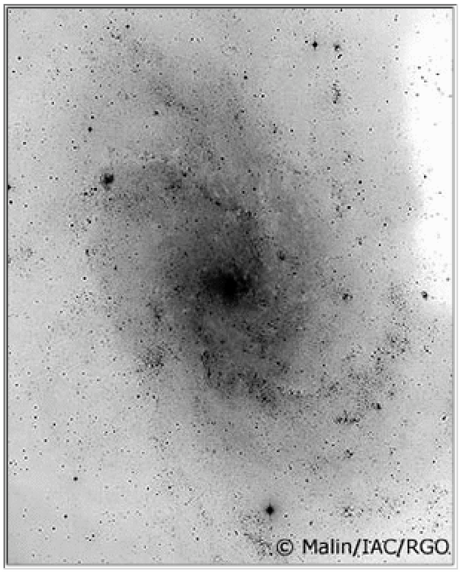
b. Star formation triggered by deaths of OB stars, which continually generate spiral arms. Fragments of arms are generated rather than complete arms.

4. Grand-Design Spirals: Spiral arms formed by spiral density waves.

a. Well defined arms.

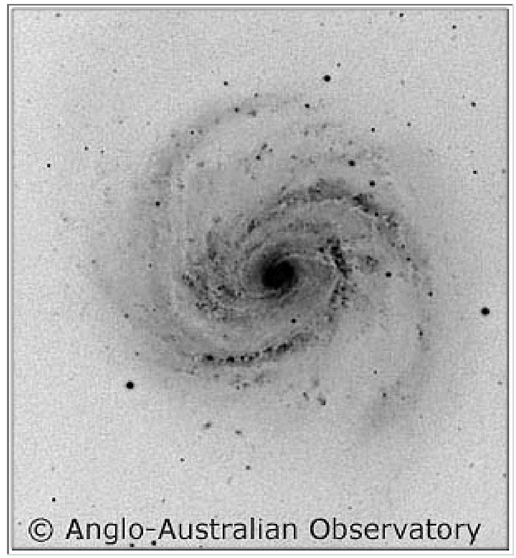
b. Compression waves that travels about half the speed of the disk rotation.

c. Spiral density waves should only last about a billion years. Recent interactions with other galaxies are thought to trigger spiral density waves.



M33 is representative of flocculent spirals. It's arms are patchy and not easy to trace.
Credit: David Malin/IAC/RGO

Figure 8: Flocculent Spiral



M100 has clearly defined spiral arms and a well organised spiral structure.
Credit: AAO/David Malin

Figure 9: Grand Design Spiral

5. Ellipticals: Consist of old stars (Pop II and old Pop I),no disk, gas or dust (lack 21-cm radiation).

    a. Giant Ellipticals. Can be as large as several Mpc in size and contain trillions of stars.

    b. Dwarf Ellipticals. As small as one kpc in size and contain as few as one million stars. Probably very common. Due to their low luminosity compared to other galaxies they are probably under counted.

    c. Ellipticals are also classified by the degree of flattening or ellipticity where E0 are spherical and E7 are the most highly flattened.

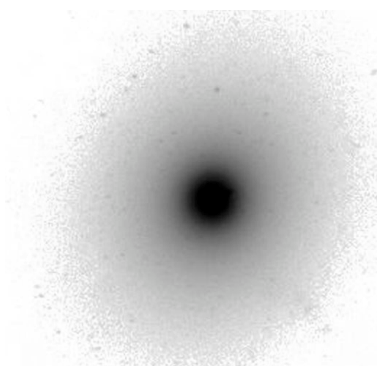


Figure 10: E0 Elliptical

Figure 11: E6 Elliptical

6. Irregulars: Contain Pop I and Pop II stars along with gas and dust.

a. Irr I: look like distorted spirals.

b. Irr II: very strange looking. Some may be the results of colliding galaxies.

c. Dwarf Irregulars: Most common type of irregular. Probably as numerous as dwarf ellipticals, and under counted due to their low luminosity.

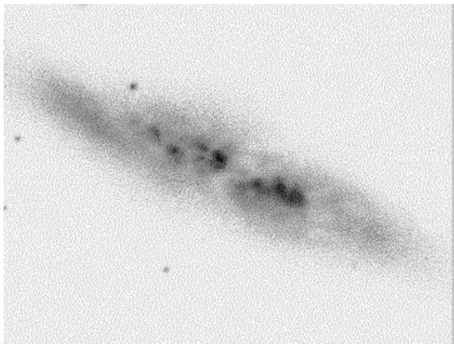


Figure 12: Irregular Galaxy

7. Lenticulars: Have a central bulge and disk like spirals but lack the spiral arms. Look like something between an elliptical and a spiral.

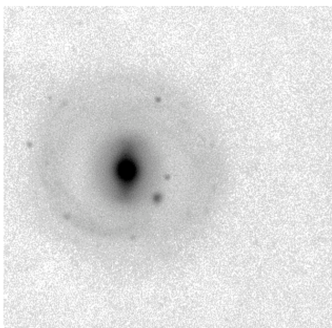


Figure 13: Lenticular Galaxy

B. Distributions of Galaxies.

1. Distance Indicators for nearby galaxies:

a. Cepheid variables. Cepheids in M100 have been observed by HST. These are good out to several megaparsecs.

b. RR Lyrae variables. These are good out to the Magellanic Clouds

2. Local Group: contains about 40 galaxies in a volume 1 Mpc across.

a. 3 spirals and the rest are dwarf ellipticals and irregulars.

b. The Local Group is a cluster of galaxies held together by their mutual gravity.

3. Beyond the Local Group: there are about 100 billion galaxies outside our Local Group arranged in clusters.

a. Standard Candles:

i. Cepheids.

ii. Supernovae.

iii. Bright H II regions.

iv. Globular clusters.

v. Brightest red and blue supergiants.

vi. Brightest galaxies within clusters.

vii. Tully-Fisher relation. Correlation between rotational velocity and the total luminosity of a spiral galaxy. Independent of other standard candles.

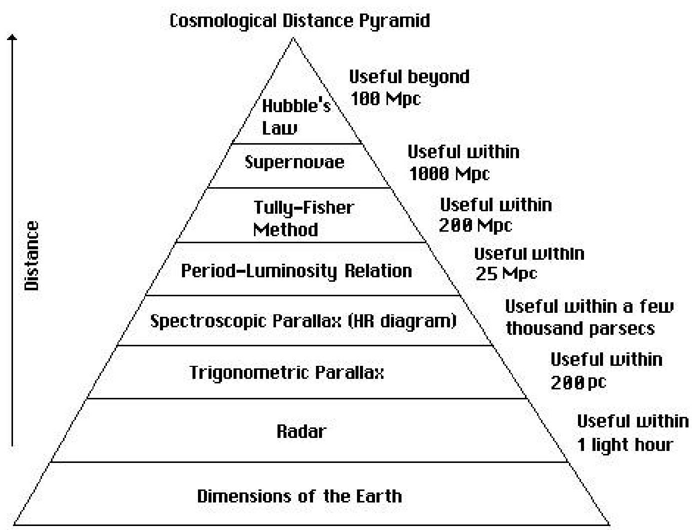


Figure 14: Distance Pyramid

C. Clusters of Galaxies.

1. Virgo Cluster: nearest cluster to the Local Group.

a. About 2500 galaxies in a volume 3 Mpc across.

b. 20 Mpc distant.

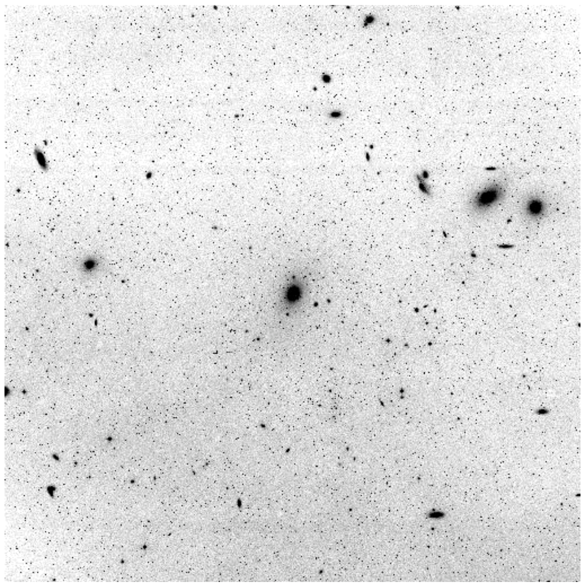


Figure 15: Centra Region of the Virgo Cluster

2. Coma Cluster.

a. Contains over 10,000 galaxies in a volume 3 Mpc across.

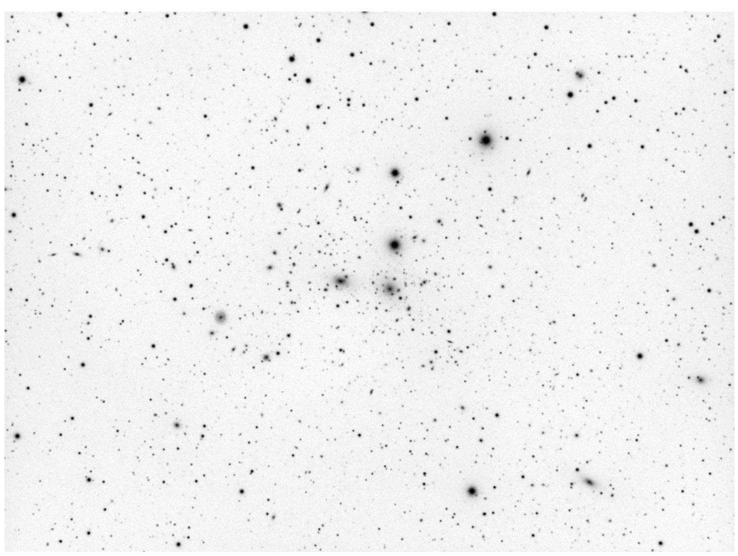


Figure 16: The Coma Cluster. Most of the faint objects in the center are galaxies.

3. Thousands of clusters are known.

D. Superclusters: clusters are arranged in larger groupings.

1. Local Supercluster: Local Group, Virgo Cluster, and several others.

a. Total mass = 10^{15} solar masses.

E. Galaxy Masses.

1. Individuals.

a. Rotation curves (application of Kepler's 3rd law).

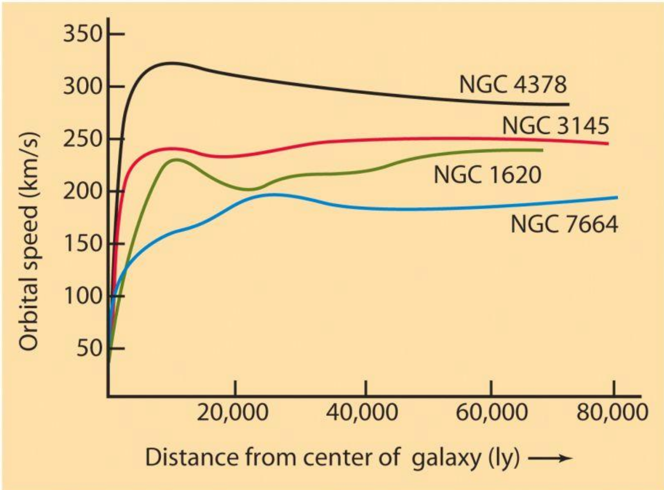


Figure 17: Rotation Curves of several galaxies.

b. Rotational velocity from Doppler broadening (basis of the Tully-Fisher distance technique). Estimates of a galaxy's size then lead to an estimate of its mass.

c. Binary galaxies (apply Kepler's 3rd law). Not very useful since the periods of motion are very difficult to determine. Periods are typically billions of years.

2. Clusters.

a. Virial method: technique that calculates how much mass must be present to prevent a cluster from flying apart based on the observed speeds of the galaxies within the cluster.

F. Dark Matter.

1. Radio observations of individual galaxies indicate the presence of halos containing 3 to 10 times more mass than can be seen.

2. Virial method gives masses 10 to 100 times greater than the visible matter.

3. Gravitational Lensing: Allows astronomers to measure the mass of a galaxy or cluster of galaxies. Visible matter can't account for the amount of gravitational lensing observed. At least 90% of the mass is dark matter.

4. Rotational curves are flat, which indicates the presence of dark matter.

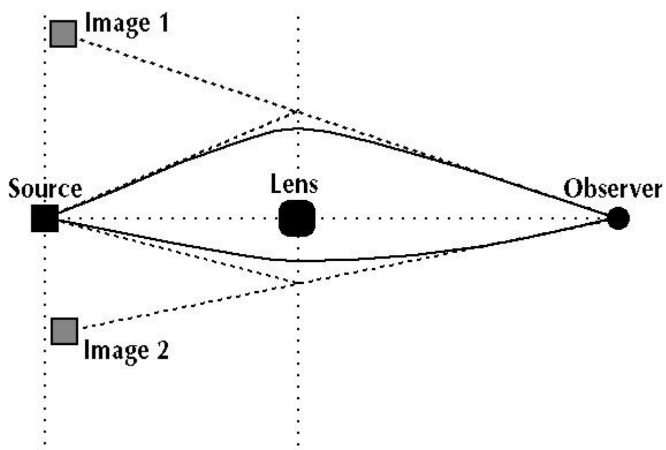


Figure 18: Geometry of a gravitational lens.

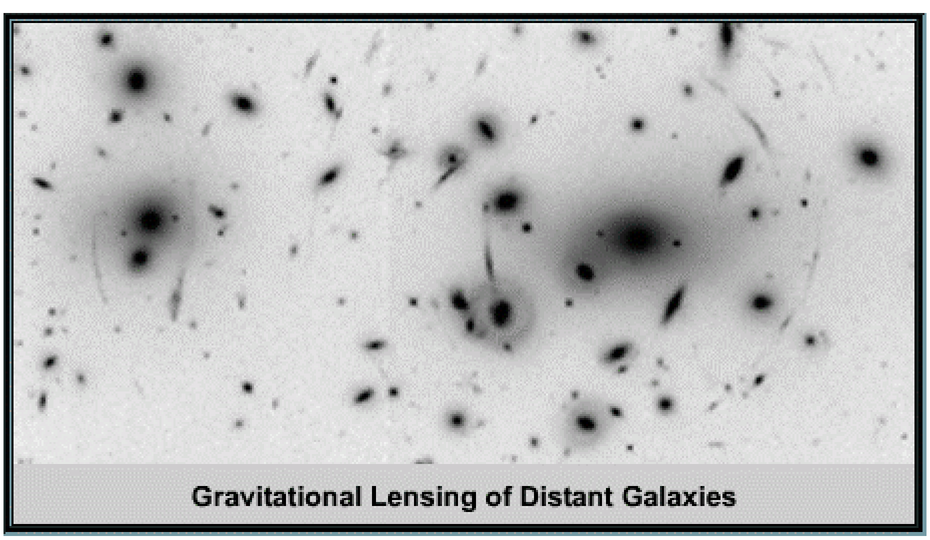


Figure 19: Image of actual gravitational lenses.

G. Intercluster Gas: x-ray observations have revealed presence of hot gas (1 million K) between galaxies.

Coma cluster images. Visible light on the left and X-ray image on the right.

1. Mass is equivalent to the visible mass.

2. No gas has been observed outside of clusters.

3. Gas is thought to be produced by the mergers of galaxies.

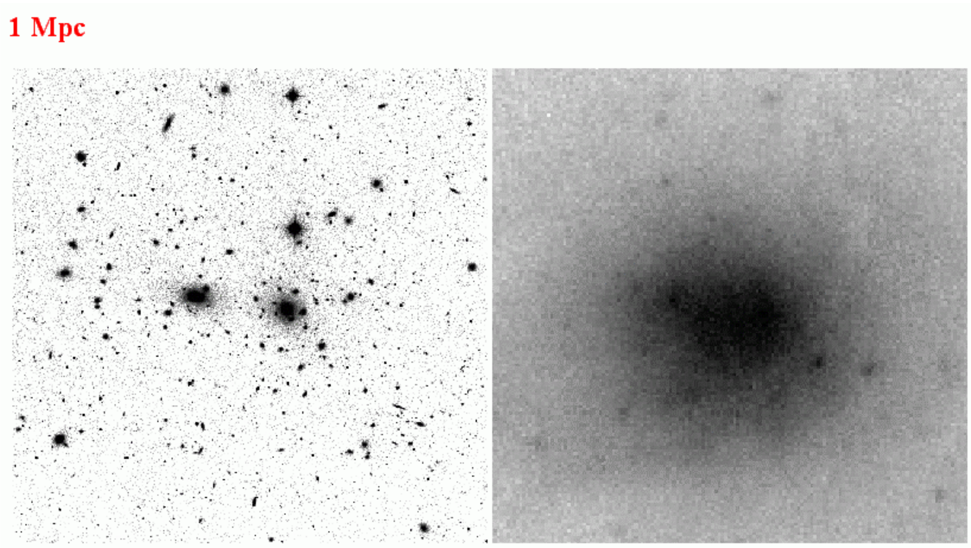


Figure 20: Visible and X-ray images of the Coma Cluster showing intercluster gas.

H. Hubble's Law: all unclustered galaxies and clusters are receding from one another with velocities that are proportional to their distances.

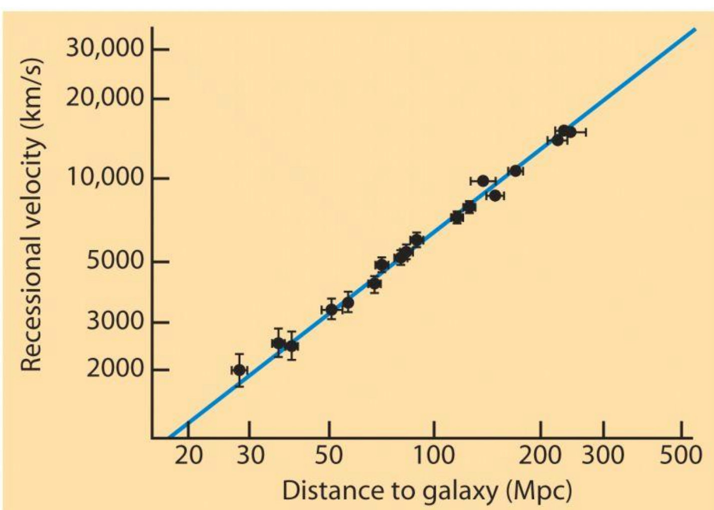


Figure 21: Hubble’s Law

1. Hubble's constant (Ho = 65 km/s/Mpc). Various methods have values ranging from 50 to 80 km/s/Mpc.

recessional velocity = Hubble's constant x distance

V = Ho x D

Hubble's constant tells us the age of the universe.

1/Ho = (1/65)Mpc/km/s*3.09x10 km/Mpc = 4.75x10 sec

= 15 billion yrs

Recently, accurate measurements of the Hubble constant using the Hubble Space Telescope have come up with Ho = 72 +/- 8 km/s/Mpc, which gives an age for the universe of 13.6 billion years. The oldest stars in the Milky Way Galaxy are probably 20 billion years old!

2. Useful for calculating distances to the most remote objects.

I. Large Scale Structure.

1. Galaxies are arranged in a network of filaments surrounding empty regions called voids.

2. Voids are like giant bubbles in space.

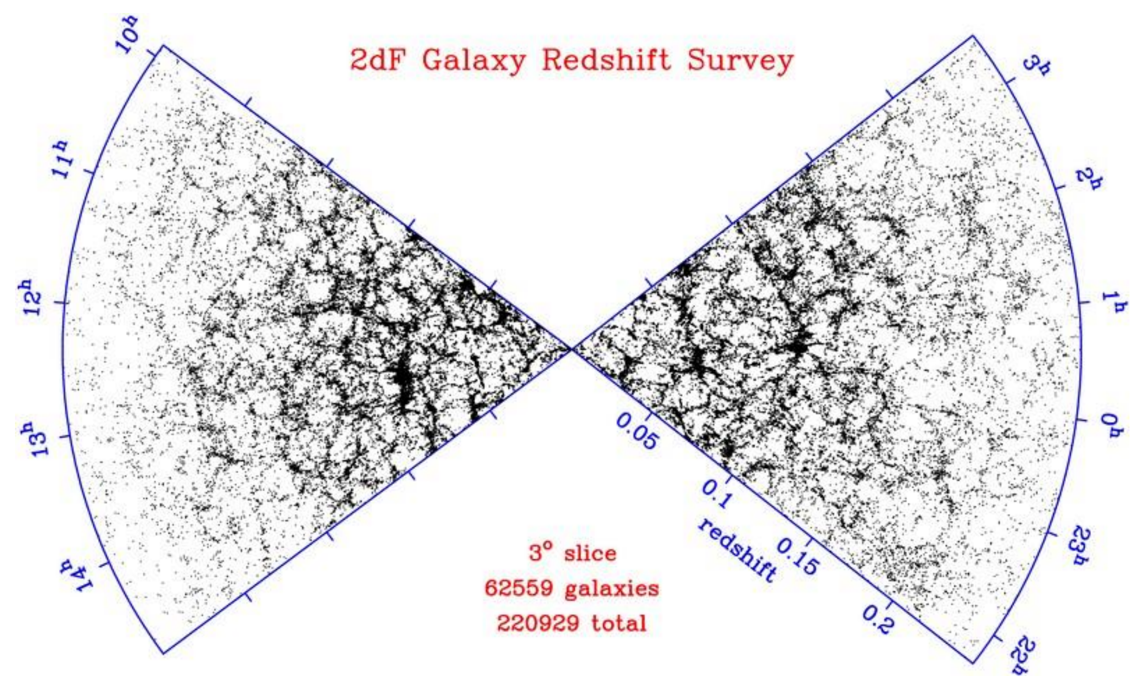


Figure 22: Galaxy distribution showing filaments and voids.

3. Greatest concentrations of galaxies are where several bubbles meet.

J. Galaxy Evolution and Formation.

1. Normal galaxies do not evolve from one type to another.

a. All normal galaxies contain old stars indicating that they are all the same age.

2. Galaxy formation:

a. Pregalactic gas blobs formed from density fluctuations in the early universe.

b. Small galaxies formed from the gas clouds.

c. Large galaxies formed later after small galaxies merged with others.

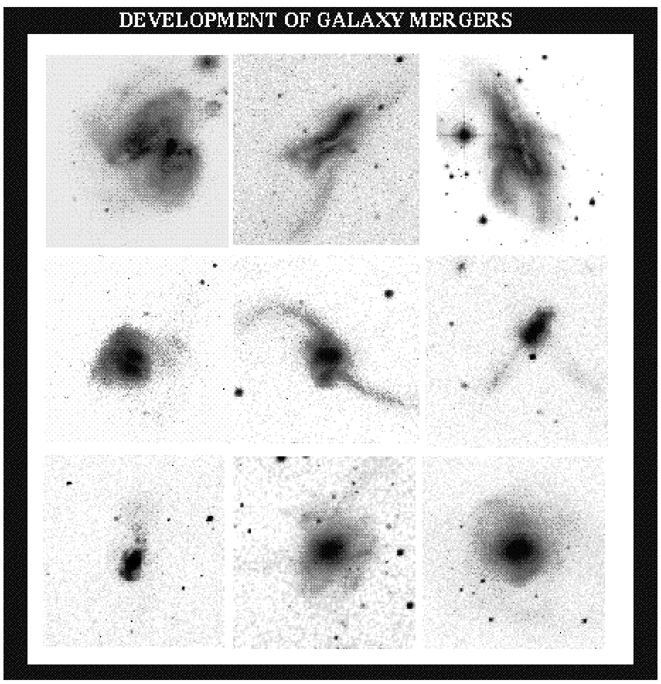


Figure 23: Several galaxy pairs showing mergers.

3. Ellipticals vs. Spirals.

a. Ellipticals formed from rapid star formation that consumed all gas and dust.

b. Spirals formed from slower star formation that is still ongoing.

c. Recent simulations indicate that collisions between galaxies of comparable size can destroy a spiral's disk and process most of the gas into stars resulting in an elliptical galaxy.

4. Observations.

a. Spirals are rare in regions of high galaxy density.

b. Large ellipticals are common at the centers of clusters.

5. Mergers and Interactions.

a. Interactions between galaxy halos will cause the galaxies to spiral and coalesce together into a larger galaxy.

i. Galactic cannibalism: when a small galaxy merges with a larger galaxy.

b. Starburst galaxies: rapid star formation resulting from an interaction with another galaxy.

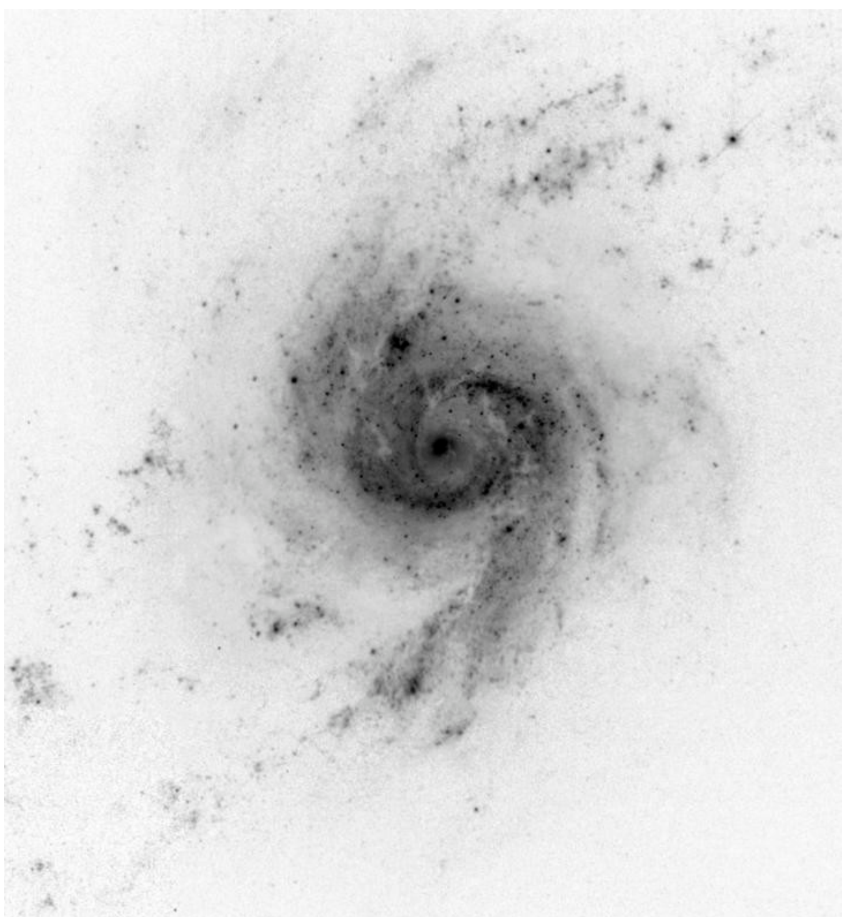


Figure 24:Starburst galaxy NGC 3310.