1.4: Other Galaxies and Large-scale Structures in the Universe

Learning Objectives

- You will know the types of galaxies: spiral, elliptical, irregular
- You will know that galaxies can be grouped into galaxy groups and clusters and form web-like structures on the largest scales

WHAT DO YOU THINK 1.4.1: DIFFERENT TYPES OF GALAXIES

Three students are talking after class about the topic for next week: galaxies.

> **Germaine**: Our professor said that next week we'll talk about different types of galaxies. Aren't they all the same, like a cinnamon swirl?
> **Holly**: I've seen a bunch of pictures of galaxies and some look different, more like a big ball.
> **Ignacio**: I think there are different types. Those spiral ones—like Germaine's cinnamon swirl—are by themselves, but there are others that string together like spider webs.

Being able to measure distances was key to figuring out what galaxies are. Well into the early 20th century, there was still much debate about the nature of these objects. Some astronomers believed that all of the fuzzy patches in the sky were relatively nearby clouds of gas and dust, or in other words, nebulae. As technology improved and distance measurement techniques became more accurate, astronomers realized that some of the fuzzy-looking extended objects we see in the sky are indeed other galaxies: They are distant collections of hundreds of billions of stars, with attendant gas and dust. The reason they look fuzzy is that they are so far away that we cannot resolve the stars within them with our eyes or with binoculars. In fact, the astronomer Edwin Hubble (1889–1953, for whom the Hubble Space Telescope was named) was the first to prove that one of the fuzzy patches in the sky, Andromeda (M31), was actually a neighboring galaxy. Hubble announced his discovery in 1925; until this time, astronomers debated whether or not all of the objects in the sky were part of our own Galaxy.

Under dark skies, the Andromeda Galaxy can be seen even with the naked eye in the Northern Hemisphere. In the Southern Hemisphere, two other galaxies can be seen with the naked eye: the Large and Small Magellanic Clouds. In cosmic terms, these galaxies are relatively close to the Milky Way —Andromeda, for example, is "only" 2.5 million light-years away. Most galaxies are much farther away. Their distance makes them faint, and so we need telescopes to observe them.

Figure $1.4.1$: The Hubble Ultra Deep Field illustrates some of the variety of sizes and shapes of galaxies. A few foreground stars within our own Galaxy can also be seen in the image: look for bright objects with cross-shaped spikes (an artifact introduced by the structure of the telescope). Credit: NASA/STScI.

Figure $1.4.1$, the Hubble Ultra Deep Field, demonstrates the vast number of galaxies we can observe when we train a powerful telescope on the sky for a long period of time. To collect this image, astronomers pointed the Hubble Space Telescope at an apparently blank area of the sky and collected many snapshots totaling an exposure time of one million seconds. The long exposure time of this image allows it to reveal very distant, faint galaxies.

In the Hubble Ultra Deep Field, we see an example of the assortment of galaxies found in the Universe. They are classified into three main types: spiral, elliptical, and irregular (Figure $1.4.2$). Like our Galaxy, other spiral galaxies usually have on-going star formation. As a result, they still have younger, bluer stars. They are typically found in regions of the Universe that are less densely packed with galaxies. The Milky Way and nearby Andromeda Galaxy are relatively large, massive spirals galaxies.

Elliptical galaxies look like balls. Sometimes they are squashed or elongated, like footballs or even cigars. All of these shapes go under the name of spheroidal. They are usually found in denser regions of the Universe, and they have less gas, dust and star formation than spiral galaxies. Elliptical galaxies usually contain mostly older, redder stars than spirals do.

The majority of galaxies are irregular in shape, meaning they do not exhibit spiral or ellipsoidal character. In fact, they don't really show any discernable general trend in their shape, hence the name irregular. Both the Large and Small Magellanic Clouds are irregular galaxies.

Finally, a few rare galaxies are called active galaxies. They emit a tremendous amount of energy from their cores, and therefore appear very bright. This energy output is thought to be due to an in-falling stream of material onto the central black hole in the galaxy. Active galaxies can by any type of galaxy, though they are usually very large spiral or elliptical galaxies. We will study them in more detail in later chapters.

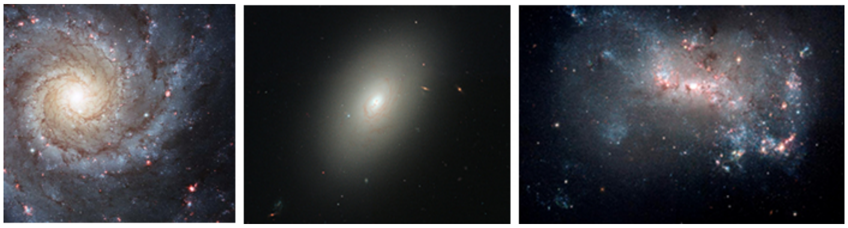

Figure $1.4.2$: (a) Spiral galaxy M74. (b) Elliptical galaxy NGC 4150. (c) Irregular galaxy NGC 4449. Credit: NASA/STScI.

1.4.1: GALAXY GROUPS AND CLUSTERS

Like stars, but on a much larger scale, the majority of galaxies are found in small "groups." Galaxies within a group are gravitationally bound to each other; in other words, they orbit each other due to their mutual gravitational pull. The Milky Way and

Andromeda galaxies are members of a group that we call the Local Group (Figure 1.4.3). The Local Group actually contains 40–50 galaxies, most of which are called "dwarfs" because they are very small compared to large galaxies like the Milky Way.

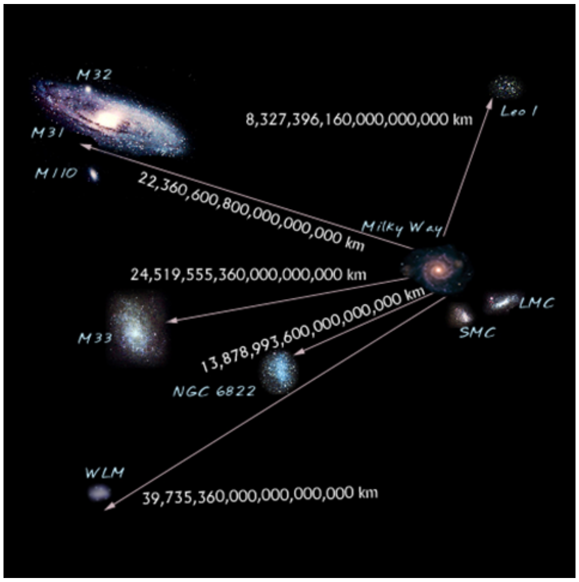

Figure 1.4.3: Diagram of the galaxies that make up the Local Group, with sizes approximately to scale (but distances between them are not to scale). Credit: NASA/HEASARC/Maggie Masetti.

Some galaxies are grouped into clusters (Figure 1.4.4). Clusters of galaxies contain hundreds to thousands of galaxies, and some clusters are themselves grouped together into larger "superclusters." Galaxy clusters also contain clouds of hot gas (30–100 million kelvin), and this gas comprises more mass than all of the galaxies in these cluster. The hot gas can be observed with X-ray telescopes. Like galaxy groups, clusters of galaxies are held together by gravity. Although the galaxies and gas in a cluster are quite massive, they do not have enough mass for gravity to keep the cluster bound together, so we know there must be a large amount of additional mass - dark matter - in a given galaxy cluster to keep the cluster from flying apart.

Figure 1.4.4: Hubble ACS image of galaxy cluster Cl0024+17. The majority of yellowish-looking galaxies in this image, and some of the blue galaxies, are members of the cluster. Other galaxies in the image are foreground and background galaxies. You can also see a few foreground stars from our own Galaxy in the image. Credit: NASA/HST/ACS.

1.4.2: LARGE-SCALE STRUCTURE

On the largest observable scales, we have seen a web of galaxies and galaxy clusters filling the Universe. The galaxies and clusters are found in thin, filamentary structures and sheets, something like a three-dimensional spider web, or maybe a better analogy is the pattern of bubbles in a bubble bath. In the space between the filaments and sheets (the regions inside the bubbles in the analogy) are regions devoid of galaxies (Figure 1.4.5).

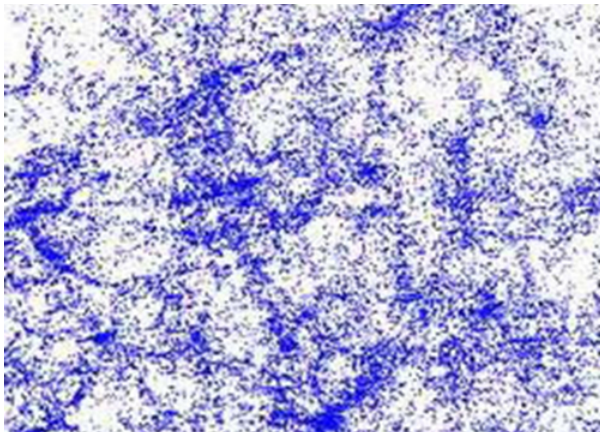

Figure 1.4.5: A small sample of the 2dF galaxy survey, approximately half a billion light-years across. Each blue dot represents a galaxy. The large-scale structure of space is web-like, with large filaments and superclusters of matter, and great empty spaces known as voids. Credit: Anglo-Australian Observatory

Table 1.6 Galactic Scales and Larger

Mass of a galaxy	10^8–10^{12} solar masses
Disk of the Milky Way Galaxy	100,000 ly
Halo of the Milky Way Galaxy	500,000 ly
Disk of the Andromeda Galaxy	220,000 ly
Distance to Andromeda Galaxy	2.5 million ly
Size of a galaxy cluster	3–30 million ly
Mass of a galaxy cluster	10^{14}–10^{15} solar masses
Typical size of voids in the cosmic web	30–500 million ly