PART I

The Universe

CHAPTER 1

Our place in the Universe

The realm of the galaxies

All life as we know it exists within the bounds of the single planet that we call home. For centuries mankind has gazed towards the heavens and wondered whether there may be others like ourselves, living on distant worlds like our own. Only recently have technological advances allowed us to begin gathering information that may provide some clues. The vastness of space is difficult for the human mind to comprehend, as such enormous sizes and distances are beyond those we encounter in our daily lives. Yet understanding how Earth fits into the grand scale of the Universe provides us with an important new perspective on life.

4 The Universe

To us Earth is a vast planet, yet on the scale of the Universe we are a mere grain of sand. This chapter will provide an important sense of scale by explaining the size and contents of the Universe. Beginning at our own Solar System, we will take a look at the Sun and the relative sizes of the planets in orbit around it, using analogies with everyday objects and distances that we can understand more easily. We then move outwards to our nearest stars, in reality millions of miles away yet still close in terms of the Universe as a whole. Gravity holds together the group of stars closest to us, forming our Galaxy, the Milky Way. Contemplating increasingly larger distances, we will see that the Milky Way is only one galaxy in a cluster of galaxies, and that this cluster is only one of an infinite number of clusters in our Universe.

1.1 The Sun and planets

The Sun, its family of planets with their moons, and a large number of smaller bodies, form the *Solar System*. Earth, the third planet from the Sun, travels around the Sun at an average distance of 93 million miles (150 million kilometers).[1] This distance is defined as one astronomical unit or AU. Between Earth and the Sun lie the planets Mercury and Venus. Outside our orbit lie the planet Mars, the giant planets Jupiter, Saturn, Uranus, and Neptune, and the frozen world of Pluto (see Figure 1.1). Pluto, the outermost planet, travels in an elliptical orbit at distances from the Sun ranging between 3 and 4 billion miles (5 and 6 billion kilometers), some 30 to 40 AU.

Pluto now appears to be the largest of a large group of objects, called the Kuiper Belt, which lies in a zone surrounding the Sun. Far beyond the orbit of Pluto are the comets, small icy bodies that surround the Sun in a spherical halo called the Oort Cloud. Beyond that, space contains nothing but a few atoms of hydrogen per cubic centimeter until we reach the stars that are the Sun's neighbors. These

[1] In this book, we use the Imperial System units first, with the metric system units in parenthesis.

Previous page: Hubble Ultra Deep Field infrared view of galaxies billions of light-years away. NASA, ESA, and R. Thompson (University of Arizona)

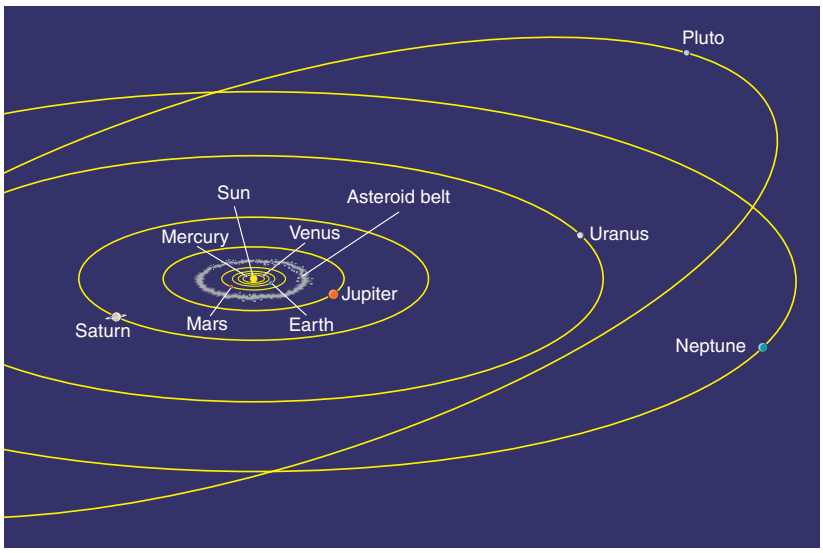

FIGURE 1.1 The Solar System.

nearest stars are approximately 30 trillion miles (50 trillion kilometers) away.

An analogy will help to clarify the meaning of such enormous distances. Let the Sun be the size of an orange; on that scale Earth is a grain of sand circling in orbit around the Sun at a distance of 30 feet (10 meters); Jupiter, 11 times larger than Earth, is a cherry pit revolving at a distance of 200 feet (65 meters) or one city block; Saturn is another cherry pit two blocks from the Sun; and Pluto is still another smaller grain of sand at a distance of ten city blocks from the Sun. The nearest stars are orange-sized objects more than a thousand miles (1500 kilometers) away.

An orange, a few grains of sand close by, and some cherry pits circling slowly around the orange at a distance of a city block; more than a thousand miles (1500 kilometers) away is another orange, perhaps with a few specks of planetary matter circling around it. That is the void of space.

1.2 The Sun's nearest neighbors

The Sun's closest neighbor is the star Alpha Centauri. Alpha Centauri is 24 trillion miles (38 trillion kilometers) from our Solar System, or slightly closer than the average distance

between stars in our neighborhood. It is actually a triple star – a family of three stars formed simultaneously out of a single cloud of gas and dust. Ever since their birth, the three stars have circled one another under the attraction of gravity.

The largest of the three stars in Alpha Centauri resembles the Sun and possesses a similar surface temperature and color. The middle-sized star of the triplet, somewhat smaller than the Sun and orange in color, circles around the largest star in a close waltz at a distance of 2 billion miles (3.2 billion kilometers). One turn around takes 80 years for this pair. The third member is a very small, faint, red star, a tenth as large as the Sun, which circles the two other members of the triplet at a distance of a trillion miles (1.6 trillion kilometers), completing one turn in a million years.

The Alpha Centauri group are the closest stars to us that are bright enough to be visible to the naked eye. However, the Sun may have still closer neighbors – very small, dimly luminous stars – too faint to have been detected thus far. There may also be burned-out stars that have exhausted their fuel in the space between the Sun and Alpha Centauri. Finally, there may be many bodies the size of planets, too small to glow by their own energy, in the space around us. All these possibilities await the future exploration of the regions outside the Solar System.

1.3 Our Galaxy

The Sun and its neighbors are only a few among approximately 400 billion stars that are bound together by gravity in an enormous cluster, called the *Galaxy*. Most, if not all, stars in the Universe are held within such clusters. These other clusters also are called galaxies.

The stars in the Galaxy revolve about its center as the planets revolve about the Sun. The Sun itself participates in this motion, completing one circuit around the Galaxy in about 225 million years. The Galaxy is flattened by its rotating motion into the shape of a disk, whose thickness is roughly one-twentieth of its diameter. The Sun is located within the disk about three-fifths of the way out from the center to the

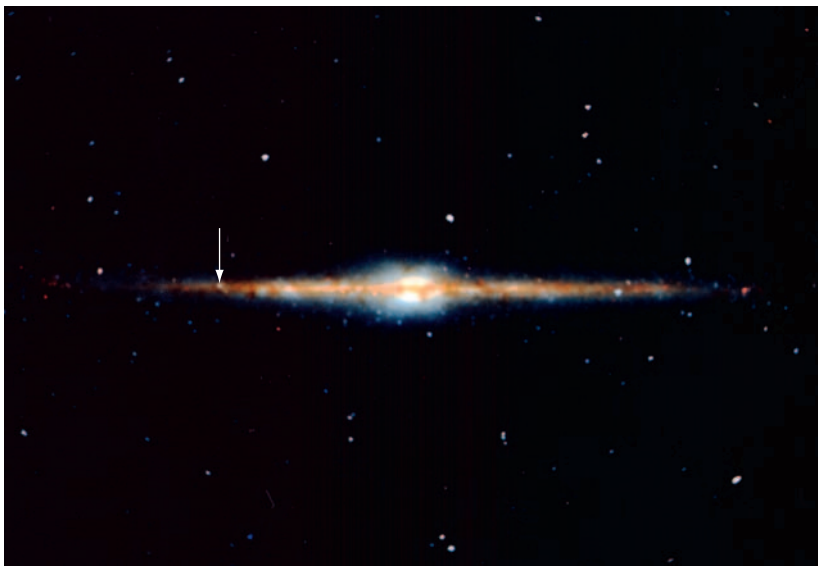

FIGURE 1.2 The Milky Way Galaxy viewed edge-on. This image of the Galaxy was obtained with the Cosmic Background Explorer (COBE) satellite in the infrared part of the spectrum. The thin disk of the Galaxy and the central bulge are visible because obscuring dust is transparent in that region of the spectrum. The arrow indicates the position of the Sun in our Galaxy.
NASA Goddard Space Flight Center

edge. A spherical clump of closely spaced stars, called the central bulge of the Galaxy, surrounds the galactic nucleus at the center of the disk (Figure 1.2).

The general appearance of the Galaxy is shown clearly in photographs of other galaxies that are similar to ours and that happen to be oriented in space so that we see them at different angles. If you could stand outside the Galaxy and view it edge-on, it would look very much like NGC 4013[2] (Figure 1.3), with a layer of dust and gas clearly visible in the plane of the Galaxy. Viewed face-on, the Galaxy would look like NGC 3310 (Figure 1.4), with spiral arms in which most of the bright stars of the Galaxy (including the Sun) are located.

Our relative position within the Galaxy is evident when we look up at the night sky and see a luminous band stretching across the sky – the Milky Way (Figure 1.5). This band is composed of so many stars that they are not visible as separate points of light but blend together. The irregular dark lanes running through the center of the Milky Way are caused by

[2] NGC: New General Catalogue, a catalog of extended objects – galaxies, star clusters, and nebulas – compiled by Cambridge University astronomers in 1890. Another such catalog is the Messier Catalogue (M), an earlier compilation published by Charles Messier, a French astronomer, in 1784.

FIGURE 1.3 Edge-on view of the spiral galaxy NGC 4013 that lies about 55 million light-years from Earth. The image, taken by the Hubble Space Telescope, shows huge clouds of dust and gas extending along the galaxy's disk.

NASA Jet Propulsion Laboratory (NASA-JPL)

the extensive clouds of fine dust, concentrated in the central plane of the Galaxy, which block out the light of many stars.

An inspection of the Milky Way with even a modest-size telescope reveals the immensity of the number of stars concentrated in the Galaxy. In Figure 1.6, tens of thousands of stars can be seen, although only a very small portion of the night sky is shown.

The vastness of the space between the stars is difficult to comprehend. The same analogy that we used to clarify the meaning of the size of the Solar System is helpful in attempting to comprehend the emptiness of the Galaxy. Suppose again that the Sun is reduced from its million-mile (1.6 million-kilometer) diameter to the size of an orange. The Galaxy, on this scale, is a cluster of 400 billion oranges, each orange separated from its neighbors by an average distance of more than 1000 miles (1600 kilometers). In the space between, there is nothing but a tenuous distribution of atoms and a few

FIGURE 1.4 The spiral galaxy NGC 3310, resembling our Galaxy viewed face on.
NASA and The Hubble Heritage Team (STScI/ AURA)

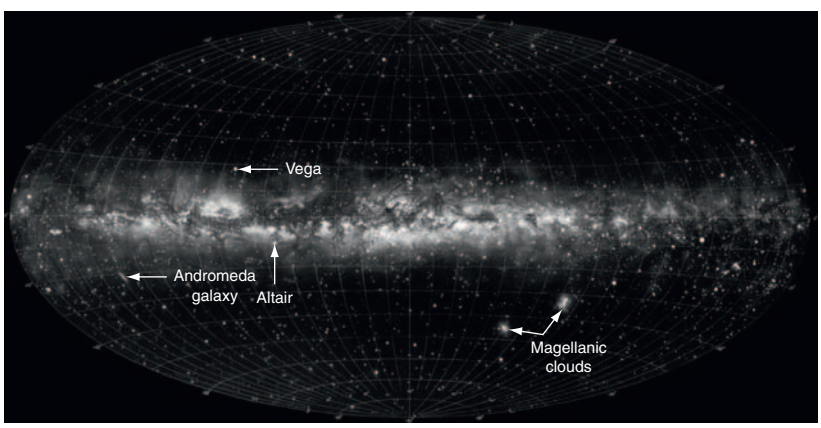

FIGURE 1.5 The Milky Way: An edge-on view of our Galaxy as seen from the inside. In this image, the whole of the sky is projected onto a two-dimensional map. The Magellanic Clouds, visible only in the Southern Hemisphere, are two dwarf galaxies anchored to our Galaxy by its gravitational force, each containing only a few billion stars.
Lund Observatory, Sweden

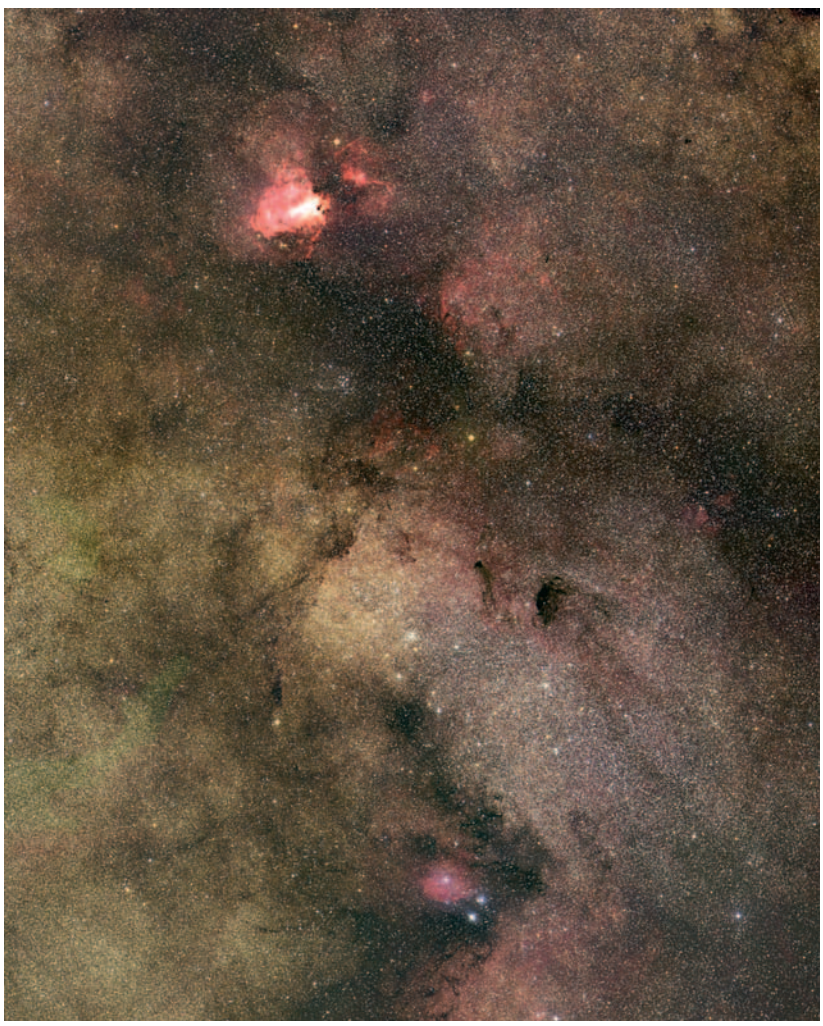

FIGURE 1.6 A small region of the night sky showing a background of tens of thousands of stars in our own Galaxy.
© Anglo-Australian Observatory/David Malin Images

molecules and dust grains. That is the emptiness of space in the Galaxy.

The stars within the Galaxy are separated from one another by an average distance of 30 trillion miles (50 trillion kilometers). To avoid the frequent repetition of such awkwardly large numbers, astronomical distances are usually expressed in units of the light-year, defined as the distance covered in one year by a ray of light traveling 186 000 miles (300 000 kilometers) per second. This distance turns out to be approximately 5.9 trillion miles (9.5 trillion kilometers); hence, in these units, the distance from the Sun to Alpha Centauri is 4.3 light-years, the average distance between the stars in the

Galaxy is 5 light-years, and the diameter of the Galaxy is about 100 000 light-years.

1.4 Neighboring galaxies

Although the stars within our Galaxy are very thinly scattered, they are, nonetheless, relatively close together in comparison to the space that separates our Galaxy from neighboring galaxies. The distance to the next nearest galaxy comparable in size to ours is more than 2 million light-years, or 20 times the diameter of our Galaxy. It is difficult to imagine the emptiness of intergalactic space. Once outside the Galaxy, we encounter a region empty of stars and nearly empty of gas and dust.

No vacuum ever achieved on Earth can match the vacuum of the space outside our Galaxy. But if we go far enough away from the Galaxy, we come to other galaxies, collections of billions of stars held together, like ours, by the force of gravity. These galaxies are island universes – isolated clusters containing vast numbers of stars – each separated from the others by the void of intergalactic space.

The closest large galaxy, similar to the Milky Way Galaxy in size, is the Andromeda Galaxy, which is about 2.2 million light-years away from us. This galaxy happens to resemble our own closely in size and shape; it is a disk-shaped spiral of stars, gas, and dust, containing a few hundred billion stars in all, the entire collection of matter slowly spinning around a central axis like a gigantic pinwheel (Figure 1.7).

Andromeda is the only major galaxy visible to the naked eye, and it is the most distant object that can be seen without the aid of a telescope. However, it is not conspicuous, despite the fact that its intrinsic brilliance is roughly 100 billion times that of the Sun. Because of its enormous distance, Andromeda is barely visible to the naked eye, under the best conditions, as a very faint patch of light. But if it is photographed with even a modest-sized telescope, the faint patch is seen to have a structure that resembles our Galaxy, with a brightly glowing center, a distinct impression of spiral arms, and dark lanes formed by obscuring clouds of dust.