Life in the Universe

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The Abundance of Extraterrestrial Civilizations

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To Kathy Faber-Langendoen,

Ed Cheng,

Katie Dusenbery,

James Attarian,

and

Carol Penning

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Preface

This is a book about life in the universe, intended for use in introductory college courses on this subject. This topic has generated considerable interest among the general public, especially fans of science-fiction movies and books. Indeed, with the increasing skills of special-effects teams and makeup artists, some of the movies have become quite believable in their appearance – if not in their portrayal of physics – to the degree that many moviegoers accept the existence of extraterrestrial beings as *truth* and their presence here on Earth as *fact*.

Many students entering typical 'Life in the Universe' classes are sure that at least *some* of the tales of encounters with UFOs must be real, that Earth is frequently visited by beings from another world, that Earthlings are occasionally abducted for testing aboard extraterrestrial spaceships, and that spacecraft are currently streaking among the stars to bring more alien scientists eager to study our biology and our culture.

Other students are less easily convinced: they will believe in aliens only when their existence is 'proven' conclusively. They may assert that suitable conditions for life cannot *possibly* exist beyond our own planet, that despite the billions of stars in our galaxy, we are unique.

Which of these viewpoints is closer to the truth? Do aliens exist? Are they aware of *us*? Do they have the means and the desire to travel here to study us? Is the Earth a very special place? Is our existence here so improbable that we are essentially alone as we stare out at the universe and wonder? Or is the actual scenario somewhere in between?

These are some of the questions to be discussed in this book. Unfortunately, the correct answers for most of them are unknown at this time, and it will be left to the reader to form his or her own opinions on these issues. It is the hope of the author that such opinions will be based on scientific facts and sound logic rather than wild speculation that disregards our current understanding of nature; it is the goal of this book to present a broad spectrum of observational evidence and scientific principles that can be used to formulate coherent opinions on the various aspects of this subject.

The reader will be led down a variety of paths; some of these will arrive at a single conclusion, but most will present the reader with options. Some of these options may be more entertaining, some more palatable, while still others may be more logical. Ultimately, the reader's views are his or her own. This is not to say that all opinions are equally valid, for this cannot be. (Note that we *can* say that two opposing opinions cannot *both* be correct without knowing for sure which one is closer to the truth.) The reader will often have to choose between exciting, popular ideas with little scientific basis and more mundane, commonplace explanations that do not require any mystical beliefs. Throughout the book, the reader will make numerous choices, which should culminate in a consistent expression of belief – one that the reader may find surprising.

In order to properly explore the subject of extraterrestrial life, the reader will need some familiarity with basic astronomy, chemistry, biology, and physics. However, because this book is intended for use in general education classes, no previous experience in any of these sciences is presumed. Topics from these areas will be introduced as they are needed, and developed only to the degree required for comprehension of the problem at hand. This book is not intended to serve as a complete introductory text for any one science; rather, it assembles and presents the fundamental knowledge needed to explore a particular problem that spans several branches of science.

Ideally, this book will discuss – or at least mention – *all* of the major factors in the debate over extraterrestrial life. Realistically, this goal may be difficult to achieve, simply because it is not immediately obvious (or generally agreed) which factors are *most* important to the existence of extraterrestrial civilizations. A crucial factor might have been overlooked; or future observations could turn up new evidence leading to a completely different solution from any of those described in these pages. (If aliens land on the White House lawn next week, this book will need to be revised.) Such is the nature of science.

In any event, it is hoped that this book will be a reasonable guide to those wishing to participate in the discussion on extraterrestrial life. At the very least, it should give the reader a new perspective on alien invasion movies.

Chapter 1
Our Place in the Universe

In which the problem is stated, the scale of the universe is presented, the boundaries of the search are set, the origin of the universe is discussed, and the cast of celestial characters is introduced.

Defining the Question

As indicated by the title, the general subject of this book is "Life in the Universe". However, for reasons that will soon be made clear, this text will attempt to focus on a somewhat more specific topic – "The Abundance of Extraterrestrial Civilizations". By what steps do we get from "Life in the Universe" to "The Abundance of Extraterrestrial Civilizations"?

We could begin by asking simple questions, such as "Is there life in the universe?", to which the answer would be an obvious 'yes': *we* are life and we exist in the universe. Of course we are more interested in whether there is life *other* than ourselves in the universe, life that does *not* come from Earth but rather is **extraterrestrial** (from beyond Earth). With this modified question – "Is there *extraterrestrial* life in the universe?" – the answer becomes less obvious, and yet is still likely to be positive. There are many forms of life on Earth alone, ranging from very simple one-celled creatures to complex beasts such as ourselves, and it would seem likely that in the vastness of the universe there should be some other place where simple life forms have evolved.

As interesting as it would be to know that some type of pond scum exists on a distant world, such news would be unlikely to fascinate the general public for very long. In fact, the means by which we might determine the existence of extraterrestrial pond scum is by no means clear, as neither we, nor the pond scum (we suspect) have mastered interstellar space travel as yet. Far more intriguing would be the discovery of an extraterrestrial species with a degree of intelligence similar to (or perhaps superior to) our own. Our question then becomes "Is there extraterrestrial *intelligent* life in the universe?"

There may be such life out there, but it will be very difficult to discover *them* unless they have become sufficiently technically adept to send and receive interstellar radio messages or travel among the stars to visit us. Such feats will require not only intelligence but also bodies with appendages that permit the beings to carry out engineering projects, environments that supply the necessary raw materials for these activities, and governments that are capable of organizing individuals to fund and execute such ventures. In short, we are looking for a *civilization* at least as intelligent and technical as we are, one that is capable of interstellar radio communication and possibly some limited space travel, bringing us to "Are there extraterrestrial *civilizations* in the universe?"

Now the question is getting very interesting, but it still is wide open. The universe is very large, and either a single extraterrestrial civilization or many would be sufficient to provide an affirmative answer. What we really want to know is not just whether *any* are out there but how many there might be. Knowing the *abundance* of extraterrestrial civilizations would permit us to estimate how close to us the nearest one might be and whether we might hope to make contact with them. Our question has now become "How *abundant* are extraterrestrial civilizations in the universe?" But what is the universe?

A Sense of Scale

As mentioned above, the universe is a very big place. In order to establish just how big it is, let us consider a few terms that are used to define astronomical scales.

The first of these is **solar system**. 'Solar' refers to the Sun, and the solar system is our Sun and the collection of objects that orbit about it – primarily planets (and the moons that orbit them), asteroids, and comets. The Sun is a star, and we are relatively close to it; the stars are suns and are extremely far away. Each star has the potential to have a planetary system of its own, and we have begun to discover such systems around nearby stars.

The second term is **galaxy**. A galaxy contains an enormous number of stars and their planetary systems, huge clouds of interstellar gas and dust, and the remains of stars that have died, all of which are bound together by gravity. Galaxies vary in size and shape; our galaxy – the **Milky Way** Galaxy – includes a few hundred billion stars, making it considerably larger than the solar system. Figure 1.1 shows a sketch of the nearby Andromeda Galaxy, which is similar to the Milky Way. If we could view the Milky Way from the Andromeda Galaxy, our Sun would be essentially invisible, lost in the glare of the much more luminous stars that produce the bulk of the galaxy's visible radiation.

The last term is **universe**, which very simply includes *everything* there is. Looking out from the Milky Way, we see other galaxies, some relatively nearby (such as the Andromeda Galaxy) and many more remote galaxies, extending as far as the telescope can see. For example, the Hubble Ultra Deep Field image was obtained by pointing the Hubble Space Telescope at a tiny portion of the sky apparently devoid of galaxies and exposing for nearly three months; the resulting image revealed a host of previously unknown galaxies, verifying that the currently observed collection of galaxies is merely the tip of the iceberg. The universe is so large that we observe only a very tiny portion of it. We do not know its full extent, but extrapolation from the more closely studied regions indicates that the universe appears to contain *billions* of galaxies.

Figure 1.1: M31 – the Andromeda Galaxy.

Clearly, these three terms are not synonymous, but represent a hierarchy of size. We will be careful in this book to apply *universe*, *galaxy*, and *solar system* in their proper places and to *not* use them interchangeably. The reader is advised to adopt a similar approach.

Sizes and distances in astronomy are generally too large to comprehend easily. To put them in a simpler perspective, let us measure the time it would take light to travel each distance, in the same way that we often refer to the length of an automobile excursion in terms of the time required for the trip. Because light travels at a constant speed (300,000 km/s) through the vacuum of space, we can easily express distances in terms of light travel times. For example, the circumference of the Earth is about 40,000 km; light requires (40,000 km) ÷ (300,000 km/s) or about 1/7 second to travel this distance. (Of course, light would not travel in a circle around the Earth, as it prefers to go in straight lines instead.)

In a similar fashion we can find that light takes about 1.3 seconds to travel the 384,000 kilometers between the Earth and the Moon, an interval that produced delays of about 2.5 seconds in the conversations between the Apollo astronauts on the moon and the NASA mission control personnel on the Earth. This effect can also be observed on those television newscasts that utilize communications satellites to relay their signals from distant corners of the globe; the roundtrip travel time using a geosynchronous satellite in a 42,000-kilometer-radius orbit produces a conversational delay of about one half second between each question and answer. Although noticeable, these delays are not usually long enough to cause any serious problems.

The Sun is about 400 times as far away from Earth as the Moon is, and consequently, sunlight requires about 500 seconds (8.3 minutes) to reach Earth. This means that the Sun actually rises about 8 minutes before we observe sunrise, but again, this generally does not cause any great difficulties in our lives.

The distance between Earth and Mars varies as the two planets orbit the Sun, with light travel times between the two planets ranging from about 4 to 20 minutes. This delay places significant restrictions on the control of spacecraft and landers sent to explore Mars; they cannot be operated in real time from the Earth because the round-trip delay of 8 to 40 minutes is just too long. (Note: Control of spacecraft is usually accomplished through radio signals, which also travel at the speed of light.) Spacecraft must be programmed in advance to obtain particular images, and mobile landers must be able to fend for themselves because the Earth-bound backseat driver is too far removed from the action.

The outer planets are even farther away: Jupiter is about 43 light-minutes from the Sun while the dwarf planet Pluto is about 5.5 light-*hours* away. In the distant future, if we should ever establish a base on Pluto, the radio communications will be extremely tedious, with 11-hour-long gaps between questions and answers. At these distances, normal conversations will be quite impossible (and technically correct science fiction movies will become extremely slow-paced).

Beyond the planets, the solar system is represented by a host of small bodies, including comets and other icy worlds, extending to perhaps 1.5 *light-years* from the Sun – a great distance indeed. In these outer reaches of the solar system, the Sun's gravitational control receives an increasing challenge from neighboring stars: **Alpha Centauri**, the *closest* star system to our Sun is 4.3 light-years away, while Sirius, the brightest star in our night sky is about 8.7 light-years distant. The light from these stars requires several years to travel to Earth, meaning that we observe them now as they were several years ago. Our information about stars is never current, but this is not really a problem for astronomers, who are used to looking backwards in time with every observation.

The several thousand stars visible to the naked eye are spread over a wide range of distances extending up to a few thousand light-years from the Sun; for example, it is 520 light-years to Betelgeuse in the constellation Orion, and 1600 light-years to Deneb in Cygnus. In general the other stars in the Milky Way are quite far from the Sun and also from each other, at least in our corner of the Galaxy. Most of the few hundred billion stars that form the Milky Way are spread throughout a flattened pinwheel shape about 80,000 light-years across. Our solar system is not at the center of this pinwheel, but lies about 25,000 light-years from it. These distances are all so great that light cannot traverse them in less than a human lifetime. As the speed of light marks an upper limit on the rate at which material bodies can travel, this would seem to pose some major difficulties for interstellar spacecraft and their crews attempting to explore the Galaxy. This problem will be further examined in Chapter 8.

Outside the Milky Way there are plenty of other galaxies, but only a few of them are relatively nearby. The Large Magellanic Cloud, one of several satellites of the Milky Way, is about 160,000 light-years from us, and the Andromeda Galaxy, the nearest large galaxy (comparable in size to the Milky Way), is about 3 *million* light-years distant. Other galaxies beyond that include the Pinwheel Galaxy (M101) at 27 million light-years, the Sombrero Galaxy (M104) at 37 million light-years, and M87 at 42 million light-years. Of course, many extremely remote galaxies have been found, at distances up to 10 billion light-years or more – close to the estimated age of the universe. At these distances the time delay becomes more important because stars and galaxies change significantly on time scales of a few billion years. What we see now at these great distances is the way the galaxies were very long ago, soon after their formation in some cases. This backwards look in time provides astronomers with a way to probe the distant past, to determine how the universe has changed over time.

Light travel times that range from a fraction of a second to several billion years give some indication of the scale of the universe we inhabit. Another approach is to model the universe using familiar objects; unfortunately, we lack a set of familiar objects that cover the necessary range of sizes and distances. Instead, we can use the same objects to construct a series of 'leapfrog models' that will take us from the Earth to the distant galaxies.

Consider a golf ball, which has a diameter of about 1.7 inches. If the Earth were the size of a golf ball, the Moon would be a small marble about 4 feet away, and the Sun would be a sphere 15 feet across, located about a third of a mile away.

Now if the *Sun* were the size of a golf ball in Omaha, Earth would be a small sand grain 5 yards away. The orbit of Pluto would define a sphere about 400 yards across, and the realm of the solar system's comets would extend to Minneapolis, Davenport, and Wichita. Alpha Centauri would be another golf ball, located in Salt Lake City.

If *Pluto's orbit* were the size of a golf ball in Omaha, Alpha Centauri would be only a fifth of a mile away, the center of the Galaxy would be in Denver, and the disk of the Milky Way Galaxy would extend from the Mississippi River to the Pacific Ocean. On this scale, the Andromeda Galaxy would lie about a quarter of the way to the Moon.

But if the *Milky Way Galaxy* were the size of a golf ball, the Andromeda Galaxy would be another golf ball only about 31 inches away. The Pinwheel Galaxy would be 8 yards away, and M87 would lie about 12 yards distant. The most remote galaxies that we now observe would be about 2 miles away, but the universe extends far beyond that: those galaxies whose light travel times are greater than the age of the universe are beyond our observational grasp.

Our current capabilities do not allow us to travel at – or anywhere near – the speed of light, and thus the extent of our personal exploration of the universe is severely limited. Humans have managed to visit the Moon in person – a distance of about one light-second – with a travel time of a few days. We have also explored parts of our solar system by sending space probes to planets a few light-hours away, with travel times of a few years. At these speeds, expeditions to the nearby stars – a few light-years away – would require travel times of 10,000 to 100,000 years, which seem prohibitive to beings with life spans of about 100 years. Journeys between galaxies a few million light-years apart would appear to be out of the question (at least for us). Unfortunately, our observational reach far exceeds our transportational grasp.

Limiting the Search

Because the universe is far too large for us to observe in its entirety, we can hardly hope to determine just how many extraterrestrial civilizations there may be in it, let alone meet them all. At the other extreme, with our growing knowledge of the other worlds in our solar system, it becomes increasingly apparent that none of them provide homes for other intelligent beings. We are almost certainly the *only* civilization within the solar system, as any others this close by should have made their presence known to us or been discovered by our space probes by now. (Humans have established planet Earth as a source of radio emissions that is unique within the solar system and easily detected from the distance of the other planets. A similar civilization within the solar system would not have been overlooked.)

Because the universe is too big for us to examine thoroughly while the solar system is too small to hide any extraterrestrial civilizations, it seems logical to study an object of intermediate size – the Milky Way Galaxy in which we live. With billions of stars in the Milky Way, there is tremendous potential for extraterrestrial civilizations, some of which might be close enough to us that we could actually make contact with them. Whether extraterrestrial civilizations are *common* or *rare* among the stars of the Milky Way is the main subject of this book.

If our Milky Way can be considered to be a representative sample of all the galaxies, then we might be able to make a statement about life elsewhere in the universe. Unfortunately, we do not know the number of civilizations in the Milky Way, nor do we know whether this number is typical, abnormally high, or abnormally low compared to the other galaxies in the universe. For that, we will need to learn something about the various types of galaxies and how they originate. We will start by examining the beginning of the universe.

THE TALE OF COSMOLOGY

When we look out into space at the galaxies around us, we find that they are all in motion. The motion of each individual galaxy can be resolved into two components: one along our line of sight (the radial velocity) and one perpendicular to our line of sight (the tangential velocity). These two components are measured by completely different methods.

Measurement of the tangential component involves observing the rate of change of a galaxy's position on the plane of the sky. But because the galaxies are so far away, this motion is extremely slow and not easily perceived. The radial component is much more readily determined because motion along the line of sight produces a change in the observed frequency of the light we receive. This **Doppler shift** is relatively easy to obtain for objects that are sufficiently bright, and astronomers have used this tool to measure radial velocities of stars and galaxies for many decades.

Radial velocities of stars within the Milky Way show that they approach and recede from the Sun in roughly equal numbers, an appropriate result for a random distribution of velocities. (This velocity distribution is not completely random however, as the stars have some ordered motion about the center of the Galaxy.) One might expect to find a similar arrangement of the velocities of galaxies, but this is not the case; all except our very closest neighbors are moving *away* from the Milky Way. Furthermore, there is a link between a galaxy's radial velocity and its distance from us: the more distant galaxies are moving away more rapidly, with the radial velocity being proportional to distance. This result is known as the **Hubble law**, after its discoverer, Edwin Hubble.

While we can explain the observed *stellar* radial velocity distribution in terms of the orbital motions of stars within the Galaxy, the motions of the galaxies are a bit more puzzling. The rushing away of essentially all of the galaxies might seem to be in defiance of the law of gravity, and their rushing away from *us* seems to imply that *we* are somehow special. Neither of these conclusions is particularly attractive to those who work in the field of **cosmology** – the study of the nature, origin, and evolution of the universe.

Cosmologists prefer a universe that obeys the **cosmological principle**, which says that the large-scale view of the universe should be the same from any galaxy inside it. The distribution of the galaxies we observe from the Milky Way should not be dramatically different from that observed by intelligent beings in the Pinwheel Galaxy or in any of the galaxies in the Hubble Deep Field image; in short, there should be no special vantage point in the universe. But, as noted above, the Hubble law would seem to imply that we *are* in a special galaxy, as the other galaxies are rushing away from us. This apparent contradiction disappears if astronomers in the Pinwheel Galaxy (or any other galaxy) would also find the rest of the galaxies rushing away from *them* in accordance with the Hubble law.

But how could that be? How can observers in *any* galaxy see the other galaxies rushing away from them? The general explanation for this observation is that the universe is *expanding*, causing the distances between the galaxies to increase with time. The galaxies themselves do not expand, nor do the stars, planets, and living beings inside them; only the space that fills the universe is getting bigger. As a very simple example, consider a set of buttons sewn on a strip of elastic; when the elastic is stretched, the strip gets longer, and the buttons get farther apart, but they do not get any larger. The expanding universe accounts nicely for our observation of the Hubble law, and it is consistent with the cosmological principle.

But why is the universe expanding? The currently prevailing explanation is called the **Big Bang Theory**. It says that once upon a time, all the matter in the universe was packed very tightly together in a hot, dense knot called the **primeval fireball**. This fireball then began to expand and cool towards its present state; the start of this expansion is what we call the **Big Bang**.

While we cannot directly observe the actual Big Bang event, we can use our understanding of physics to try to determine the physical conditions and the forms of matter that would have been present in the early moments of the universe, which would have been quite different from our present conditions. The primeval fireball was very hot and quite dense, and the matter was not organized as it is today, into galaxies, stars, planets, and people. Instead, the matter in the universe was all in the form of tiny elementary particles: protons, neutrons, and electrons. These particles combine to make the atoms – to be discussed in Chapter 3 – that comprise our current material world. One type of atom is relatively easy to form: because the nucleus (center) of a hydrogen atom is a single proton, the universe formed hydrogen atoms quite naturally, once it had cooled sufficiently.

Radiation was also present in the early universe in the form of high-energy photons, which interacted continuously with the elementary particles. At first, these interactions prevented the formation of atomic nuclei larger than hydrogen as any protons and neutrons that attempted to combine were immediately blasted apart by the radiation. However, as the universe expanded and cooled, the radiation field became less energetic, permitting the formation of some of the smaller nuclei such as helium, by the process of **nuclear fusion**.

Fusion involves the buildup of larger nuclei from smaller ones and/or elementary particles; it requires protons to bond together in the atomic nucleus even though their positive electrostatic charges normally cause them to repel each other. If they can be brought sufficiently close together, protons can be bound by the **strong nuclear force**, which is more powerful than the electromagnetic force at short range. In the early universe, extremely high temperatures provided protons with enough energy to overcome their electrostatic repulsion and give fusion a chance to proceed.

Given enough time, nuclear fusion might have converted much of the universe's initial hydrogen supply into heavier elements; but the rapidity of the expansion following the Big Bang prevented such an occurrence. The cooling that accompanied the expansion of the universe soon deprived the protons of the energy they needed to overcome the electrostatic repulsive force, halting fusion after only about 30 minutes of activity. Even so, about 25% of the mass of the universe was converted into helium during this interval, with most of the remainder left as hydrogen. Hardly any nuclei heavier than helium were produced, due to a lack of stable nuclei at the next stage of fusion. Formation of the heavier elements necessary for life would have to await the arrival of the stars.

By about a million years after the Big Bang, the expansion and cooling of the universe had weakened the radiation field to the extent that nuclei and electrons could combine to form neutral atoms, a step that also made the universe transparent to visible light. (We cannot see backwards in time beyond this point because the earlier universe was opaque.) Another consequence of the continually weakening radiation field was the emerging dominance of matter over radiation. As the universe expanded, it became progressively easier for matter to begin to form large-scale structures. About a billion years after the Big Bang, the universe began to produce some of the familiar types of objects we observe today: huge clouds of atoms began to form into galaxies, and within them, smaller clouds of atoms condensed into clusters of forming stars. But formation of planets such as Earth could not occur until a sufficient abundance of heavier nuclei had been created.

As noted above, all but the very nearest galaxies are observed to be rushing away from us. But will this continue? What is the future of the universe? The basic Big Bang cosmology offers two different models. In the **closed universe**, the galaxies' outward rush will be slowed by their mutual gravitation until the expansion is finally halted, following which a contraction period will begin and continue until everything in the universe smashes together in an event termed the 'Big Crunch'. In the **open universe**, the galaxies' outward rush will be slowed by their mutual gravitation, but the braking will be insufficient to halt the outward motion, and the universe will expand forever.

One way to attempt to determine which of these models is closer to the truth is to measure the average density of matter in the universe: higher density should produce stronger gravitational forces and lead to a closed universe, while lower density and the resulting weaker gravity should produce an open universe. Over the years, measurements based on the number of galaxies visible in a given volume of space have indicated a relatively low density and, thus, an open universe.

The Big Bang cosmology involves a fairly well defined beginning to the universe, and thus should yield a determinable age. The age of the universe – the time since the Big Bang – can be estimated from the observed expansion rates and measured distances of galaxies. For example, knowing that your car is traveling at 60 miles per hour away from your home, which is now 180 miles behind you, would allow you to conclude that you have been traveling for three hours. In a like manner, we can measure the distance and radial velocity of a given galaxy and use them to calculate the time required to achieve the separation between that galaxy and our Milky Way. Naturally, there are complications: your car needed some time to reach its cruising speed and may have had to slow down for a town along the way; similarly, the rate of expansion of the galaxies has not been constant, due to gravitational braking and other factors. Even so, this procedure should give us a reasonable value for the approximate age of the universe; values have typically ranged from 10 billion years for closed universe models to 15 billion years for open models.

Of course, the situation is not really that straightforward. The Big Bang model has occasionally had to be modified in order to account for new evidence. First came the inflationary universe, which included a brief period of extremely rapid expansion very soon after the Big Bang, followed by a gradually decelerating expansion. A more recent development is the discovery that the universal expansion is actually *accelerating*, rather than decelerating as previously thought, due to a mysterious entity called **dark energy**. The nature of this repulsive force that appears to be driving the galaxies apart is not yet understood.

Our discussion of cosmology brought us to the point at which stars began to form in the first galaxies, perhaps a billion years or so after the Big Bang. Much more needed to happen before life could form on Earth, or anywhere else, but those stories will be related in future chapters. For now, let us note the principal relations between the Big Bang cosmology and our search for extraterrestrial civilizations.

First, our most current estimates place the age of the universe at 13.7 billion years. While this seems to us to be a very long time, it is certainly not an *infinitely* long time. The processes involved in producing galaxies, stars, planets, life, and intelligent beings will each have some minimum time requirements.

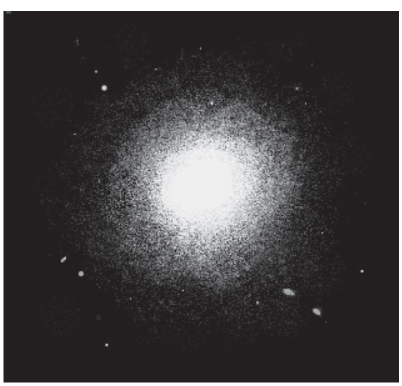
If any of these processes are extremely long – on the order of billions of years – then the finite age of the universe may limit the abundance of civilizations.

Second, the raw materials of life must be present before life can form. In Chapter 3 we shall investigate the types of atoms that make up our life; the *origin* of these atoms is then important to the development of our life and possibly other life in the universe. When and where do these atoms form? It was noted above that only the two simplest atoms – hydrogen and helium – are formed in significant quantities by the Big Bang. Other types of atoms, including the majority of those needed for terrestrial life, are formed later on inside the stars. The formation of life had to await the production – and subsequent release – of these atoms, and this may also place limits on the abundance of civilizations.

Dance of the Galaxies

Galaxies are huge collections of matter scattered throughout the universe. We detect them primarily by the *light* they emit, most of which is produced by the enormous numbers – typically billions – of stars residing in each galaxy. In addition to the stars, there are clouds of gas and dust (from which stars form) and presumably planets, moons, asteroids, comets, etc. comprising planetary systems that accompany at least some of the stars. With all galaxies being initially composed of the same elements – those produced by the Big Bang – the potential for life in other galaxies would seem to be at least as great as it is here in the Milky Way. But is it? Are all galaxies created equal?

As we look around the universe at the galaxies within reach of our telescopes, we find that they are not all alike. Astronomers classify galaxies into different groups according to their shapes. **Elliptical galaxies** have elliptical profiles, and presumably the three-dimensional shape called an ellipsoid: from any direction, its profile would be an ellipse. Some of these galaxies – such as the giant elliptical galaxy M87, shown in Figure 1.2a – have circular profiles and perhaps spherical shapes. Other galaxies exhibit spiral patterns of stars, spread throughout a relatively flat disk shape, with a concentration of stars in a nuclear bulge at the center. These **spiral galaxies** vary considerably in appearance due to the size of the nuclear bulge, the tightness of the wrapping of the spiral arms, and the direction from which they are viewed.



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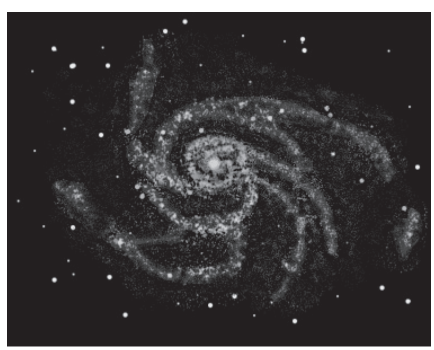

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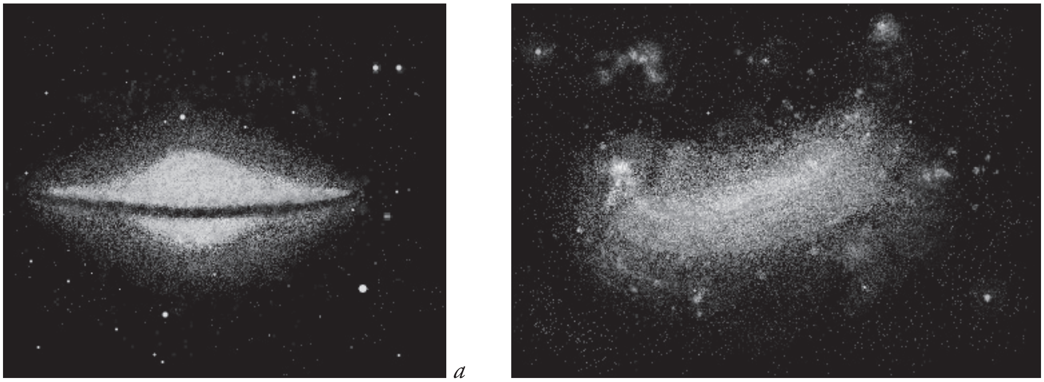
Figure 1.2: (a) The giant elliptical galaxy M87; (b) The face-on spiral galaxy M101 – the Pinwheel Galaxy.

Spiral galaxies seen *face-on* may appear as giant pinwheels in the sky, such as M101 – shown in Figure 1.2b; those seen *edge-on* – as the Sombrero Galaxy M104 in Figure 1.3a – hide their spiral structures and masquerade as faint, flattened light bulbs. A third class of galaxies has no special structure or common feature to unite them; these **irregular galaxies** tend to be relatively small and not very luminous, making them difficult to spot at large distances. The Large Magellanic Cloud shown in Figure 1.3b is one example.



a *b*

Figure 1.3: (a) The edge-on spiral galaxy M104 – the Sombrero Galaxy; (b) the Large Magellanic Cloud – a nearby irregular galaxy.

What makes a particular galaxy elliptical, spiral, or irregular? This is not yet fully understood by astronomers, but it may involve several factors, such as the mass of the galaxy, the rate at which it rotates, and its proximity to and interactions with other galaxies. Galaxies seem to be organized into clusters, with individual galaxies bound to a cluster by their mutual gravity. This keeps them relatively close together as they orbit in the cluster as bees around a hive – really big, extremely slowly moving bees, that is. Because of the immense sizes of the galaxies, they occasionally bumble into each other. These interactions may result in mergers of the two participants or mere distortion of their structures.

In either case, the lives of beings in these galaxies may be affected by such events – for better or for worse. Galactic collisions may destroy existing civilizations; alternatively, they may destroy existing dominant-but-not-very-intelligent life forms and thus help to clear the way for evolution of a more intelligent species. We do not know *all* the astronomical events that may have been necessary for our own existence here on Earth, nor do we know what specific astronomical catastrophes may lie in our future, waiting to destroy us. But we should not presume that the universe is generally friendly to and supportive of civilizations such as ours.

We do know that our Milky Way Galaxy is a member of a small cluster of galaxies known (here on Earth) as the **Local Group**. This cluster contains two large spiral galaxies – the Milky Way and the Andromeda Galaxy – and 20 to 30 smaller galaxies of various types. The two large spirals serve as centers of activity with several small galaxies orbiting closely about each. The two best-known satellites of the Milky Way are the Large Magellanic Cloud and the Small Magellanic Cloud; both are irregular galaxies visible as naked-eye objects in the far southern skies. Astronomers have evidence that the Magellanic Clouds interact with our Galaxy, both having passed through the outer part of the Milky Way's disk about 200 million years ago; effects of this passage on civilizations that may have lain in their path have not yet been documented.

Galactic Real Estate

As we view it from the Earth, the Milky Way appears as a faint band of light across the night sky. Using telescopes, astronomers have discovered that this light comes from an enormous number of faraway, faint stars, and that the band appearance is due to the flattened shape throughout which the stars are distributed.

The Milky Way is apparently a large spiral galaxy. Most of its stars – estimated at 100 billion to 400 billion in number – reside in the **disk**, an approximately planar region with a diameter of about 80,000 light-years and a thickness of a few thousand light-years. (Figure 1.4 shows an edge view of the disk, along with the other parts of the Galaxy.) At the center of the disk is found the **nuclear bulge**, a spherical region densely populated with stars; in the very center of the Galaxy (the Galactic **core**), a massive **black hole** apparently lurks, devouring whatever stars, gas, and dust dare to approach it. Surrounding the nuclear bulge and the disk is a larger, but less populated spherical volume of stars called the **halo**. If we could view the Milky Way from above the plane of the disk, we would see the **spiral arms** emanating from the nuclear bulge. Our Sun is one of the disk stars, located near a spiral arm about two thirds of the way out from the center to the edge of the disk, a distance of about 25,000 light-years. We live in the suburbs of the Milky Way, far away from the violent stellar neighborhoods found in the more congested regions of the Galactic core.

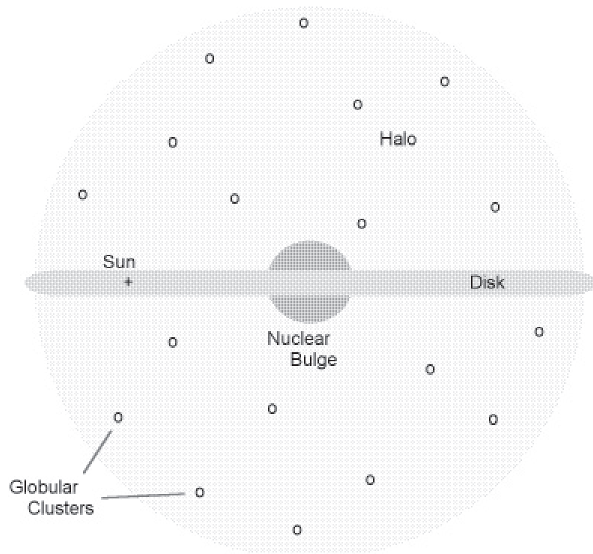


Figure 1.4: Diagram of the Milky Way Galaxy – viewed edge-on.

The stars in the Milky Way are bound together by the Galaxy's gravity, much as the planets in the solar system are bound to the Sun by its gravitational force. And just as the planets orbit the Sun, so too do the stars orbit about the Galaxy's center of mass. Stars in the disk (such as the Sun) follow reasonably circular orbits *within* the disk while stars in the halo plunge right *through* the disk on their more elliptical orbits about the center. (In doing so, they do not collide with the disk stars, due to the extremely large interstellar distances and the relatively small targets the stars present.) The motions of the stars are quite leisurely, at least on a human time scale; the Sun requires about 240 million years to complete one turn about the Galaxy. Stars at different distances from the center will have longer or shorter periods, causing the Galaxy to rotate differentially, rather than as a solid disk. Thus, over very long time-scales, the stars shift with respect to each other, perhaps causing real difficulties for extraterrestrial civilizations attempting to produce accurate navigational maps of the Milky Way.

The Galaxy contains much more than just stars. Some of the stars are organized into *clusters*; astronomers believe that stars *form* in clusters, some of which then drift apart over time while others remain intact. The star clusters that hold together the longest are those with the most stars and hence, the strongest gravity. These **globular clusters** contain around 100,000 stars or so and are distinguished by their roughly spherical appearance and the denser concentration of stars toward their centers. They are distributed throughout the halo and have orbits similar to those of the halo stars. Smaller clusters, with about 100 to 1000 stars, are called **open clusters** or **galactic clusters**; these are found spread along the plane of the Milky Way. In general, they are younger, more recently formed clusters that have not yet had time to disperse. Figure 1.5 shows images of typical star clusters as they appear in a small telescope.

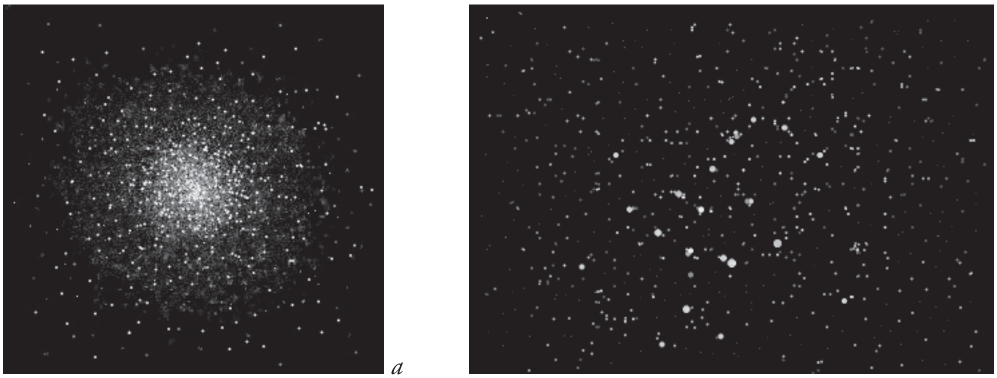


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Figure 1.5: (a) A globular star cluster; (b) an open star cluster.

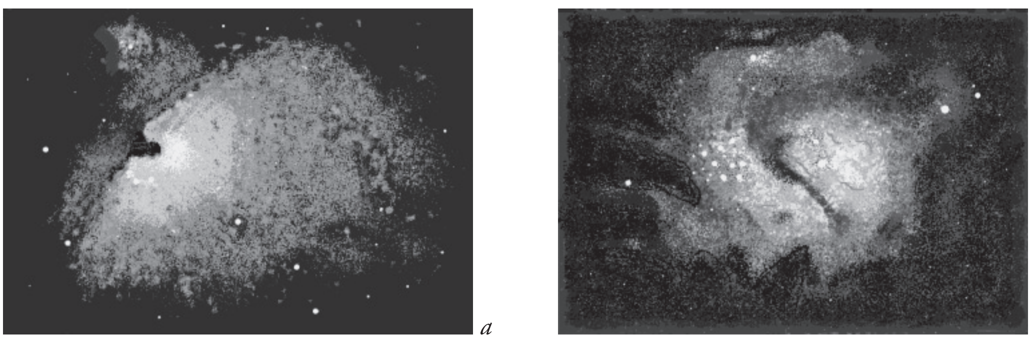

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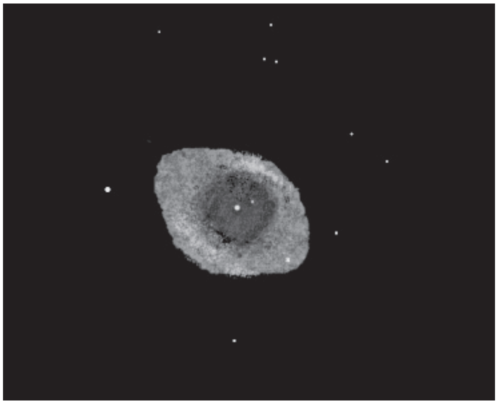
Figure 1.6: (a) M42 – the Orion Nebula;
(b) M8 – the Lagoon Nebula. Both are interstellar gas clouds – regions of star formation.

Between the stars are huge clouds of gas and dust, called **nebulae**. Within some of these nebulae new stars are forming; gravity pulls the individual particles of a cloud together, concentrating them in the center to produce a new star. Figure 1.6 shows examples of two such regions of star formation in the Milky Way.

Within other nebulae, stars are dying. When some stars end their lives, they expel their outer layers back into space, providing the interstellar clouds with more materials to be recycled into new stars. Figure 1.7 shows representatives of the two principal mechanisms for accomplishing this important task – the planetary nebula and the supernova remnant.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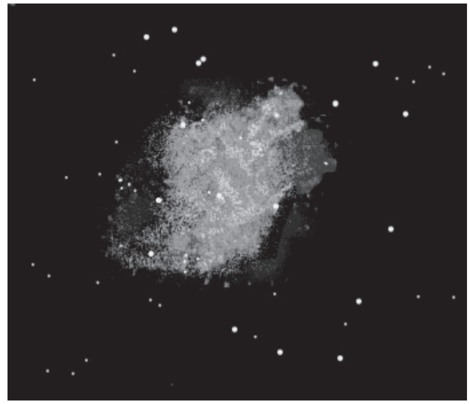
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Figure 1.7: (a) M57 – the Ring Nebula (a planetary nebula); (b) M1 – the Crab Nebula (a supernova remnant).

Stars are not all identical; they exist in a wide range of sizes, temperatures, luminosities, and evolutionary stages, as will be discussed in Chapter 6. Some stars still inhabit the clusters in which they were formed, and many stars are actually **binary stars** – systems in which two stars orbit each other, held together by their mutual gravitational forces.

Around at least some – and perhaps most – of the stars are **planets**, generally smaller, cooler bodies, such as the Earth, Mars, and Jupiter. Planets seem to come in a variety of sizes, with a range of different surfaces, as will be seen in Chapter 5. Planets form together with stars, out of the same gas and dust clouds.

Around some planets will be found **moons**, also known as **natural satellites**. These too come in a variety of sizes with many different surfaces, in addition to having different parent planets with which to contend.

Also orbiting about stars will probably be **asteroids** and **comets**; these are leftover materials from the star formation process. Asteroids and comets are both fairly small and quite numerous in our solar system, and we might expect them to be similarly abundant in most other planetary systems – but there are no guarantees. Characteristics of these bodies will be presented in Chapter 5.

Which of these locations in the Galaxy might be good places for extraterrestrial civilizations to live? Our civilization has evolved on a planet, and we normally tend to think of extraterrestrials doing the same, although this may not be the case. If we assume that most species of intelligent extraterrestrial beings will be similar to us in having a *molecular* basis for their structure, we can probably disregard a few classes of objects for very simple reasons: sites that are too hot for most molecules to exist (the surfaces of stars) will clearly be unsuitable; sites where the density of matter is so low that interactions between molecules would be extremely rare (interstellar clouds) will also be less likely to support life. The best environments for life such as ours will probably be those that have suitable temperatures and densities for molecules to exist and interact, on time scales significantly shorter than the lifetimes of the environments. In the next few chapters we will explore the parameters that govern molecules, environments, and their lifetimes.

Main Ideas

- Although the subject of extraterrestrial life is certainly interesting, the focus of this book is on extraterrestrial civilizations with which we might be able to communicate.
- The universe is so immense that humans cannot possibly explore much of it; there may well be extraterrestrial civilizations in it, but we will most likely never find out about them if they exist in galaxies outside ours.
- Our solar system is relatively small, and we have explored enough of it to be quite certain that there are no extraterrestrial civilizations within it.
- Our Galaxy contains a few hundred billion stars, scattered across a visible disk about 80,000 light-years across; it may or may not contain extraterrestrial civilizations close enough to us that we might discover them.
- The Galaxy includes a wide variety of astronomical objects, but only a few of them, such as planets and moons, are likely to serve as sites for intelligent life.
- The universe appears to have begun about 13.7 billion years ago at the time of the Big Bang; thus there has been a limited amount of time available for the development of extraterrestrial civilizations.

Keywords

Alpha Centauri
Big Bang
black hole
cosmological principle
disk
extraterrestrial
globular clusters
irregular galaxies
moon
nuclear bulge
open universe
solar system
star
Andromeda Galaxy
Big Bang Theory
closed universe
cosmology
Doppler shift
galactic clusters
halo
Local Group
natural satellite
nuclear fusion
planet
spiral arms
strong nuclear force
asteroid
binary star
comet
dark energy
elliptical galaxies
galaxy
Hubble law
Milky Way
nebula
open clusters
primeval fireball
spiral galaxies
universe