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Jamal N. Islam
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Introduction

What will eventually happen to the universe? The question must have occurred in one form or another to speculative minds since time immemorial. The question may take the form of asking what is the ultimate fate of the Earth and of mankind. It is only in the last two or three decades that enough progress has been achieved in astronomy and cosmology (the study of the universe as a whole) for one to be able to give at least plausible answers to this kind of question. In this book I shall try to provide an answer on the basis of the present state of knowledge.

To appreciate the possibilities for the long-term future of the universe it is necessary to understand something of the present structure of the universe and how the universe came to be in its present state. This will be explained in some detail in Chapter 3. In this introduction, I shall briefly outline the contents of this book to provide a 'bird's eye view' to the reader. All the terms and processes mentioned in this summary will be explained in more detail in the succeeding chapters.

The basic constituents of the universe, when considering its large-scale structure, can be taken to be galaxies (Fig. 1.1), which are 'islands' of stars with the 'sea' of emptiness in between, a typical galaxy being a congregation of about a hundred billion (10^{11}) stars (e.g. the Sun) which are bound together by their mutual gravitational attraction. The galaxy that we inhabit (together with the Sun and the system of planets of the Sun, called the solar system) is referred to as the Milky Way or simply the Galaxy. The universe can be defined as the totality of all galaxies which are observable and others which

Fig. 1.1. A rich cluster of galaxies in the constellation Fornax, showing a variety of structural types. The cluster is held together by the mutual gravitational attractions of its member galaxies. In 10^{27} years, a large cluster such as this may be reduced to a single black hole smaller than the smallest galaxy shown.

are causally related to the observable ones. There are strong indications that, on the average, galaxies are spread uniformly throughout the universe at any given time.

It is found observationally that all galaxies are receding from each other so that the universe is not static but is in a dynamic state. This recession of the galaxies from each other is referred to as the expansion of the universe. From the rate at which galaxies are moving away from each other it can be deduced that all galaxies must have been very closely packed about 10–20 billion years ago. It is generally believed that at that time there was a universal explosion in which matter was thrown asunder violently. Later the matter condensed into clumps, to become the galaxies of the present time. The recession of the galaxies is a remnant of the initial explosion, the so-called ‘big bang’.

One of the most important questions in cosmology – to which the answer is not definitely known – is whether the expansion of the universe will continue forever, or whether the expansion will halt at some time in the future and contraction set in. The model of the universe which expands forever is usually referred to as the ‘open’ universe, while that which stops expanding and begins to contract is called the ‘closed’ universe. Thus one of the most pressing questions in cosmology is whether we live in an open or a closed universe. The ultimate fate of the universe depends on the answer to this question. There are some indications that the universe is open, but this is by no means settled.

What will happen to the universe eventually if it is open? Since the basic constituents of the universe are galaxies, we can examine this question by asking what will happen in the long run to a typical galaxy in an open universe. Consider, then, a typical galaxy. It consists mainly of stars. All stars evolve with time and eventually die, that is, they reach a final stage after which very little further evolution takes place, at least in time scales of tens of billions of years. There are three such final stages for a star, namely those of white dwarf, neutron star and black hole. These final states will be explained in detail in Chapters 6 and 7. For the present it will be sufficient to note that these are states in which matter is in a highly condensed form, the most condensed being a black hole. Given sufficient time, all stars in the galaxy will die, that is, reach their final states of white dwarf, neutron star or black hole. We refer to

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stars in these three states as dead stars. Sufficient time in this case is between a hundred and a thousand billion years or perhaps longer. Thus, in about a thousand billion years the galaxy will consist of dead stars and cold interstellar matter in the form of planets, asteroids and smaller pieces of matter, still bound together in their mutual gravitational attraction. Different galaxies will of course continue to recede from each other, so that the average distance between galaxies will be much longer than at present.

The next significant changes in the galaxy will take place over a much longer time scale, in which a substantial number of the dead stars will be ejected from the galaxy altogether by coming into close collisions with other stars. In a billion billion (10^{18}) or a billion billion billion (10^{27}) years or so, 99% of the dead stars may be ejected from the galaxy in this manner. The remaining 1% of the dead stars will form a very dense core which will eventually coalesce into a single black hole whose mass will be about a billion solar masses. We can call this the 'galactic black hole'. The process described in this paragraph will be referred to as the stage of dynamical evolution of the galaxy.

I have defined the three final states of dead stars as states in which very little further change takes place in time scales of tens of billions of years. When time scales very much longer than billions of years are considered, these final stages do change. In fact a black hole of the mass of the Sun does radiate in very minute amounts and thus continues to lose its mass. A black hole of solar mass will disappear altogether by this radiation process in about 10^{65} years, which is very much longer than the time a galaxy takes to reduce to a single black hole. This radiation of a black hole is not significant while the dynamical evolution of the galaxy proceeds. However, once the galactic black hole has been formed, one can ask whether this will last forever or whether it will suffer further changes. In fact the galactic black hole will evaporate completely in about 10^{90} years. A supergalactic black hole, that is, one formed out of the collapse of a large cluster of galaxies, will evaporate completely in about 10^{100} years. Thus in 10^{100} years or so all black holes will disappear and all galaxies in the universe will have been completely dissolved. The universe will then consist of stray neutron stars and white dwarfs and other smaller pieces of matter that were ejected from galaxies during their dynamical evolution. These dead stars and pieces of matter will be wandering singly in the ever-growing and vast emptiness.

There will be some slow and subtle changes in the remaining pieces of matter over time scales which are long compared with 10^{100} years. What will be the ultimate form of the remaining pieces of matter? Here we come to the crucial question of the long-term stability of matter, the answer to which is not known. Some possibilities will be discussed in Chapters 10 and 14. One possibility is that white dwarfs and neutron stars will collapse spontaneously into black holes and subsequently evaporate, as suggested by the laws of quantum mechanics. The time scale for this is $10^{10^{76}}$ years! (If I write the word 'billion' a billion times, the resulting number will be minute in comparison with $10^{10^{76}}$.)

What about the long-term survival of civilization and of life in an open universe? It is almost impossible to predict what forms living organisms will take in the long run assuming they can survive. However, the survival of civilization and of life depends on the availability of a source of energy, and one can discuss the latter. It will be seen in Chapter 11 that, at least in principle, there will be adequate sources of energy available for 10^{100} years or so. Beyond this time civilization will have to face the problem of surviving indefinitely on a fixed finite amount of energy. This is an unresolved question but some of the possibilities will be considered in Chapter 11.

The picture presented above is likely to prevail if the universe is open. What if the universe is closed? Suppose the universe turns out to be closed in such a manner that when it reaches its maximum expansion, the average intergalactic distance is about twice that of the present time. Then this maximum will be reached in about 40 or 50 billion years. After reaching this maximum it will be almost as if a movie film of the universe were taken until the time of maximum expansion and then run backwards. After about 90–110 billion years, the universe will become very dense and hot and soon afterwards there will be the so-called 'big crunch', in which all matter will be engulfed in a fiery implosion. There is very little chance of survival of any form of life in this case. What happens after the big crunch, or whether there is an 'after', is not known.

I should emphasize that the picture presented in this book is on the basis of the present state of knowledge. Even this proviso must be further qualified. The basis of this book is a model of the universe known as the standard model, which will be explained in detail in Chapter 3. I think it is fair to say that a substantial majority of cosmologists believe that the standard model is correct in its essentials. However, there is a small minority of cosmologists which adheres to the concept of one or other of some non-standard models. We shall not be concerned with the non-standard models in this book, with the exception of one, the steady state theory, which will be discussed briefly in Chapter 13. The reader will also notice that the black hole features prominently in this book. A black hole has not yet been discovered, although there are powerful theoretical and some indirect observational reasons for believing in the existence of black holes. There may be respectable scientists who do not believe in black holes, but it would appear that a majority of experts in gravitational theory subscribes to the view that black holes must exist. In this book we shall assume that black holes do exist.

The picture presented above of the open universe changes somewhat if we consider the possibility, which has recently been put forward by some physicists, that the proton, which is a constituent of all matter, is unstable with a long life-time. That is, it is conjectured by some physicists, for reasons which will be explained in detail in Chapter 14, that all protons will eventually disintegrate. This possibility has important bearing on the far future of the universe and we shall discuss this in Chapter 14.

Why should one bother about the ultimate fate of the universe? One answer to this question is similar to the answer to the question about climbing Mount Everest: because the problem exists. It is in the nature of the human mind to seek

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incessantly new frontiers of knowledge to explore. The ultimate fate of the universe and of civilization is an interesting problem, not least because, as we shall see in the course of this book, it raises fundamental questions in physics, astronomy, biology and other branches of knowledge, the answers to which, if they can be found, may lead to important advances in these fields.

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Our Galaxy

In astronomy one uses distances and periods of time large compared to terrestrial ones. The word 'astronomical' has in the English language come to mean some very large quantity. When discussing the universe as a whole one uses even larger distances and periods of time than those used in ordinary astronomy. The convenient unit for measuring distances in astronomy is not the kilometer or the mile, but the light year, which is the distance traversed in a year by light moving at the speed of about 300 000 kilometers a second (km/s); a light year is approximately 9×10^{12} km or 9 million million km. To have some idea about the light year, let us consider some familiar distances and convert these to 'light travel time'. The circumference of the Earth is about 40 000 km, so in one second light can travel round the Earth more than seven times. The distance to the Moon is 371 000 km, so it takes light between 1 and 1.5 seconds to travel from the Earth to the Moon. The mean distance of the Earth from the Sun is approximately 150 million km. This distance is covered by light in 8–8.5 minutes. The mean distance from the Sun to Pluto, the furthest planet in the solar system, is approximately 5900 million km, which distance is covered by light in about 5.5 hours. A light year is thus almost 1600 times the distance from the Sun to Pluto.

When measuring distances in the solar system, the light year is too long so astronomers also use as a unit the mean distance of the Earth from the Sun. This unit is referred to as the astronomical unit. The distance from the Sun to Pluto is about 39.5 astronomical units. One light year consists of about 60 000 astronomical units.

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Astronomers often use another unit instead of the light year, namely the 'parsec' which is approximately 3.26 light years. This unit comes about as follows. As the Earth revolves around the Sun, some of the nearest stars trace out ellipses in the sky against the background of very distant stars whose directions do not change. The maximum angular radius of such an ellipse, when expressed in seconds of arc, is known as the trigonometric parallax or simply the parallax of the star. It can be shown that the reciprocal of this parallax measured in seconds gives the distance of the star in parsecs. Thus a star at a distance of 1 parsec has a parallax of 1 second of arc, and a star at a distance of 2 parsecs has a parallax of 0.5 seconds of arc, and so on. This is one method by which the distances to the nearest stars are calculated. Thus Alpha Centauri, which is the nearest star, has a parallax of 0.75 seconds of arc, so its distance in parsecs is the reciprocal of this number, that is, about 1.33 parsecs. This is equivalent to about 4.34 light years. A million parsecs is referred to as a megaparsec.

On a clear, moonless night one can see thousands of stars and also the bright, cloudy patch of light stretching across the sky, noticed since ancient times and known as the Milky Way. The stars that one sees through the naked eye and even those that one sees through an ordinary telescope, belong, together with the Sun and the solar system, to the system of stars which constitutes our galaxy. This galaxy is known variously as the Milky Way, Milky Way Galaxy, our galaxy, or simply the Galaxy. In fact the word 'galaxy' is derived from the Greek *galaxias kyklos*, meaning the milky way. I shall usually refer to it as the Galaxy. The Galaxy is in the shape of a flat disc, with the Sun and the solar system about two-thirds of the way from the centre to the circumference of the disc. When one looks in the plane of the Galaxy one sees many more stars than when one looks away from this plane. The many stars in the plane of the Galaxy appear in the sky as the Milky Way. The disc that the Galaxy comprises is about 80 000 light years in diameter and about 6000 light years thick. There is also a spherical halo of stars around the disc about 100 000 light years in diameter. The density of stars in the spherical halo is much less than the density in the disc. It seems to have been the English instrument-maker Thomas Wright who first suggested in 1750, in a book entitled *Original theory or new hypothesis of the universe*, that the Milky Way consists of stars that lie in a flat slab, a 'grindstone' extending to large distances in the plane of the slab.

With an ordinary telescope one can see many faint and cloudy patches in the sky in addition to the stars and the Milky Way. As early as 1781, the French astronomer and comet hunter Charles Messier (1730–1817) published a catalogue of 103 such objects to help other comet hunters to avoid mistaking these objects as early stages of a comet. Even today astronomers refer to the objects which appeared in Messier's catalogue by the prefix M followed by a number denoting the position of the object in the original catalogue. Thus, for example, the Crab Nebula, which is the remnant of an exploding star (more about this later) is called M1, since it was the first object in Messier's list.

Messier's list of objects, which were called 'nebulae', was added to by the German-born English astronomer William Herschel (1738–1822) and by his son John Herschel (1792–1871). William Herschel, who was originally a musician, discovered the planet Uranus in 1781 and was responsible for important advances in astronomy of the period. William Herschel made a list of about 2000 new nebulae. John Herschel continued his father's programme and in 1864 published *The General Catalogue of Nebulae* which was a list of 5079 faint objects. John Louis Dreyer (1852–1926), the Danish astronomer, improved on John Herschel's list by publishing in 1888 (with supplements in 1895 and 1908) the *New General Catalogue of Nebulae and Clusters of Stars*. This list, which was still a standard work in the late 1950s, contains nearly 15 000 nebulae and star clusters. This was a remarkable achievement considering that the observations were carried out visually with the aid of a telescope, but without the use of photographic equipment.

Many of the objects in Messier's catalogue are in fact objects within our Galaxy. His catalogue contained many 'star