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Cosmic Heritage

Evolution from the Big Bang to Conscious Life

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Contents

1. Setting the Scene

Our connections to the early universe are profound. The universe and its contents have evolved continuously all the way from the Big Bang to the present, and this has made us what we are today. We are part of the universe. This is our Cosmic Heritage.

The very matter we're made of comes from the earliest moments of the universe. The physical laws that govern our universe were there from the start. At one stage darkness turned into light, as stars and galaxies formed. When we now look out into the universe we look back into the past, so we can readily follow the history of the universe by observing galaxies – beads on the string of time.

The elements are constantly being brewed up in stars, and have accumulated over the aeons. The continuing process of star formation led to by-products such as planets, many of which may be suitable habitats for life. Organic molecules formed in the surrounding space. The scene became primed for life.

Our Earth is one of those planets, and life emerged a relatively short time after the Earth was formed. Over the history of the planet a great many species have taken their turn. More than 99% of them eventually became extinct, but they are always being replaced by newly-evolved species.

We have come to realize that all living things on Earth, including ourselves, are members of one single family. And that life itself is just based on 'information'. This information is the code of life, common to all life forms, from bacteria to us. It is written and saved in our genomes. The atoms and molecules of which we are made may come and go, but the information written in our genomes remains with us forever.

Brains have evolved as much as anything else in our bodies, and our brains happen to have become exceptional. As a result, at the moment we humans are dominant on this planet, and

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undoubtedly unique in being able to contemplate the distant universe.

We know that planets exist around other stars – perhaps billions – and some may also harbour living creatures. We have no idea how these may compare with us. Given the huge timescales available in our universe, they would almost certainly be millions or billions of years more advanced or less advanced than we are. In any case, we are probably not alone in the universe.

This can all be put into perspective by compressing the entire 14-billion year history of the universe into just 1 year. The Big Bang occurred with great fireworks at the very start of the new year. The first stars and galaxies had emerged by mid-January, although our own Sun and Earth didn't form until early September. Later that month the first primordial life appeared on Earth. But it was only in December that complex life appeared and the evolution of life on Earth really took off, and it wasn't until 30 December that the famous extinction of the dinosaurs took place. Recorded human history started just seconds before midnight on New Year's Eve, and modern technology in the last fraction of a second.

It is impressive that scientists have been able to piece this story together, from such diverse fields of research and with such rigour. But of course many mysteries remain, and we have no idea how much further the story will take us. We can imagine, but we don't know what the future may hold.

To set the scene for our cosmic story, this first chapter provides a very brief tour of the universe. The next few chapters then provide essential background leading up to the chapter on the Big Bang, and thereafter the book follows the evolution of the universe and life to the present and beyond.

What's Out There?

A glance up at the sky at night gives little indication of the drama of the universe. The Moon and planets follow their predictable courses, and the stars appear to sit fixed in their places. There is a deep sense of peace. Only the darkness of the night sky betrays the violence of the distant universe.

In Our Solar System

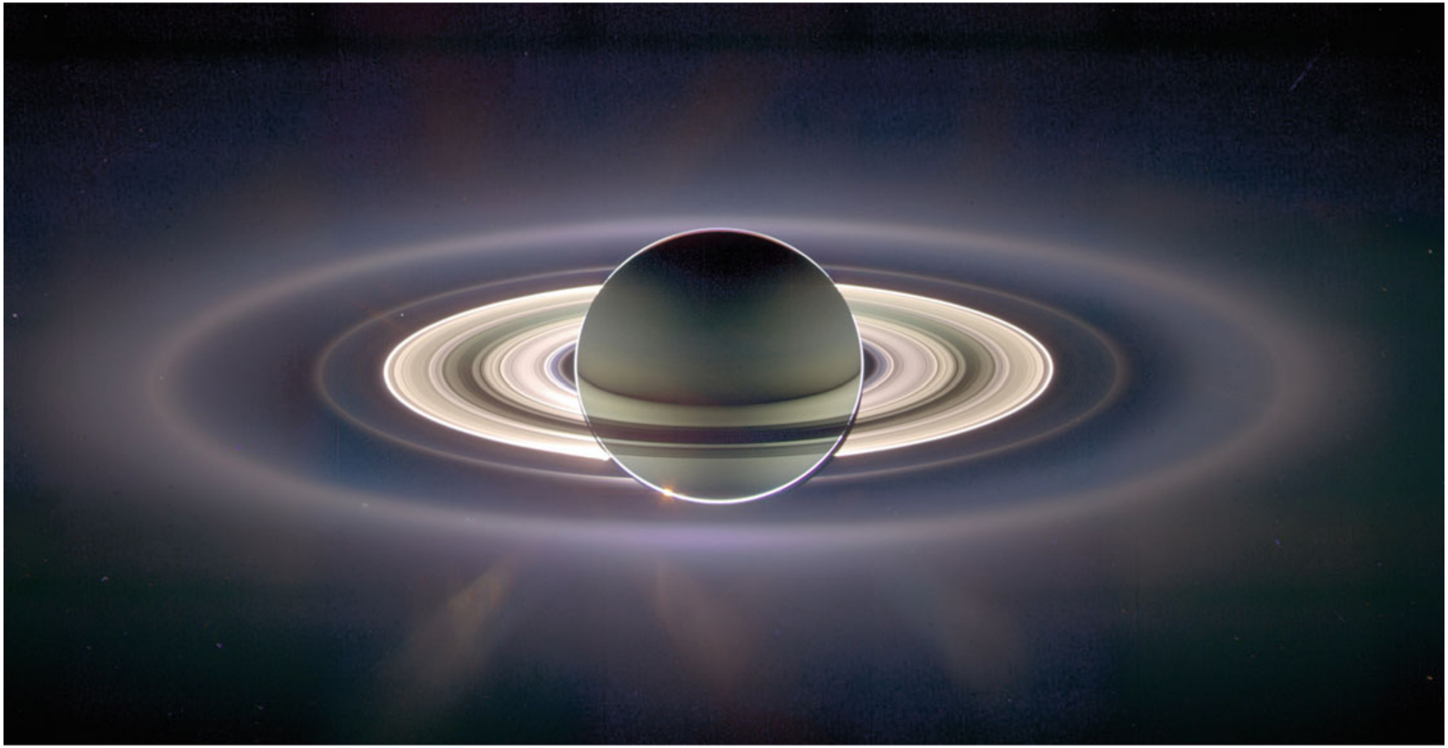
The solar system is our cosmic backyard. At its centre is the Sun, our local star, and a typical one at that. The Sun, like all normal stars, derives its energy from nuclear fusion; it 'burns' hydrogen into helium. The Sun dwarfs everything else in the solar system, all of which, including the planets, is just debris left over from the formation of the Sun 4.6 billion years ago. The eight planets, of which Earth is one, orbit the Sun in a nearly flat disk, and moons like ours also orbit most of the other planets. Interspersed with the planets are much smaller bodies, rocky asteroids, and icy comets are sometimes swept in from the outer regions of the solar system.

To give an idea of relative scales, let's start with something fairly small and close – our Moon. Its diameter, 3,500 km, is about a quarter that of Earth. Its distance from Earth, 384,000 km, corresponds to only 18 days of commercial flying (about ten round-trip flights from Europe to Australia). A one-way trip to the Moon on Apollo, including various orbits and manoeuvres, took a few days. These are scales we can easily grasp.

The other planets in the solar system range in diameter from about a third that of Earth (Mercury) to 11 times (Jupiter). The mass of Mercury is only 6% that of Earth, and the mass of Jupiter is over 300 times that of Earth. While the Earth takes a year to complete its orbit around the Sun, close-in Mercury whizzes around in a quarter of a year and far-out Neptune takes a leisurely 165 years. The planets are neatly placed in two categories: the small inner rocky planets (Mercury, Venus, Earth and Mars), and the large outer gaseous planets (Jupiter, Saturn, Uranus and Neptune). Six of the eight planets have moons orbiting around them; the three largest planets each have dozens of moons.

Dominating the solar system is the Sun. It accounts for 99.9% of the mass of the solar system. It is over 300,000 times more massive than the Earth, and about a hundred times bigger in diameter.

The distances involved start to become impressive when you consider the whole solar system. Even Earth, one of the inner planets, is some 150 million kilometres from the Sun. This is so far that it takes *light* over eight minutes to travel from the Sun to the



The Sun is eclipsed by Saturn in this spectacular image taken by the Cassini spacecraft in 2006. Our Earth is the tiny dot which may be just visible between the upper left portions of the outer rings of Saturn. At that time Cassini was about 2 million kilometres from Saturn, and the Earth was 1.5 billion kilometres in the background. Makes you appreciate the immensity of the solar system, let alone the universe. Image courtesy of NASA/JPL/Space Science Institute. The Cassini mission is an international collaboration between NASA, ESA and several other partners. Credit: CICLOPS, JPL, ESA, NASA

Earth[1]; seven minutes ago the Sun may have switched off and we wouldn't know it yet (although we shouldn't worry too much about this, as the Sun is expected to last for another several billion years).

The far outer reaches of the solar system are occupied by the Oort Cloud, a spherical zone of billions of icy comets, which extends out to a light-year (about nine trillion kilometres) from the Sun. The total extent of the solar system may be considered to be that over which the Sun's gravitational pull exceeds that of nearby stars, the closest of which is four light-years away. At the remote boundaries of our solar system our Sun would appear no brighter than several other stars visible in the sky, and its gravitational field would have almost faded into the galactic background. A size of trillions of kilometres may seem big, but it's tiny on the scale of the universe.

How do we know so much about distant objects? In the solar system we have had the advantage of spacecraft missions over the last half century. We have sent probes to all the planets and several moons, and landed spacecraft on Mars and our Moon, including several manned missions to the Moon. One spacecraft, NASA's Pioneer 10, has gone well beyond the most distant planets and will eventually leave the solar system entirely. These have all brought us close-up views, copious amounts of detailed information, and even return samples. But the fly-by probes have still relied on passive observations from a distance, as do (obviously) studies of the Sun. And for objects beyond our solar system, passive observation is all we have. How can we know so much from 'mere observation'?

The two main modes of observation are imaging and spectroscopy. Imaging is pretty obvious; we want the sharpest and most sensitive images we can get. In spectroscopy we spread out the spectrum of light into its component colours (wavelengths), from red to blue, using a spectrograph. We're all familiar with the

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[1] Light takes time to travel. Its speed is 300,000 km/s. The speed of light is constant, and nothing travels faster than light; the speed of light *in vacuo* is the 'ultimate speed limit'. Therefore, astronomical distances are often expressed in 'light-years', the distance that light can travel in one year. That distance is about 9 trillion kilometres, which, written out, is 9,000,000,000,000 km, or simply 9×10^{12} km. (The latter 'scientific' notation will sometimes be used in this book for convenience. The superscript 12 gives the number of zeroes following the 9. A small number can be expressed in a similar way: 0.004 is 4×10^{-3}.)

appearance of a spectrum. The same process gives us the colours of a rainbow, and we can reproduce it easily at home with sunlight shining through a prism. The spectrum of an astronomical object gives us a huge amount of information. Usually we can see sharp, narrow bright (emission) or dark (absorption) features at specific wavelengths in the spectrum. These are due to atoms and molecules in the distant object, and are referred to as emission and absorption lines. There can be anywhere from a few to thousands of these lines in a given spectrum. Their relative strengths tell us the chemical composition of the object. The lines can also be shifted along the spectrum by the motion of the object. If the object is moving towards us, the lines are shifted towards the blue, and if the object is moving away from us, the lines are shifted towards the red. These are called blueshifts and redshifts, and the phenomenon is commonly referred to as the 'Doppler effect'. We experience the acoustic Doppler effect when we hear the siren of a speeding ambulance: it is high-pitched when approaching us, and low-pitched when going away.

The light we normally see (with our own eyes) is referred to in astronomy as 'visible' or 'optical' light. It is actually a narrow part of the whole electromagnetic spectrum, which ranges from short wavelengths (gamma-rays, X-rays, ultraviolet rays) to long wavelengths (infrared, millimetre and radio), with the visible part in the middle. The atmosphere of the Earth is opaque to much of the electromagnetic spectrum, and only the visible and radio wavelengths can easily get through. Therefore, we can only use optical and radio telescopes on the ground; the rest has to be done using satellites or spacecraft above the atmosphere. Almost all our observations are made using the electromagnetic spectrum.

Such observations have made possible sophisticated and detailed knowledge about objects far beyond our solar system, in our galaxy, and even in the very distant universe, as we shall see.

In Our Galaxy

Our solar system resides in a comfortable neighbourhood of an ordinary disk-like spiral galaxy. The nearest stars, the ones we can easily see at night, are four light-years or more away from us, and the full extent of our galaxy is over 80,000 light-years (almost a million trillion kilometres). We are located in the flat disk of this galaxy, which can therefore be seen edge-on – it is the Milky Way band extending across the sky, most prominently visible in the southern hemisphere. The diffuse 'milky' appearance is due to the approximately 100 billion stars crowded into the plane of our galaxy, most of which are similar to our Sun.

Our galaxy contains a wonderful 'zoo' of astronomical phenomena (as do all galaxies, but in our own galaxy we can see them close-up). Almost all of the visible contents of our galaxy are related in one way or another to stars, so a good way to make an inventory of the contents of our galaxy is to follow the life cycles of stars.

All stars form in essentially the same way. They originate in dense clouds of gas and dust. Our galaxy, like all galaxies, contains an interstellar medium. That is, the space between the stars is not completely empty, but rather contains a dilute distribution of atoms, molecules and dust particles spread throughout our galaxy. The average density, about one atom per cubic centimetre, is very low by comparison with the best vacuums we can produce here on Earth, but it is enough to ultimately produce the hundreds of billions of stars in our galaxy. The present interstellar medium is comprised of about 70% hydrogen, 28% helium, and 2% heavier elements by mass.

The interstellar medium is not perfectly uniform. Its density varies, and it is these variations that make the formation of stars possible. All matter attracts other matter through the force of gravity, and any over-dense region will grow and become denser as it sweeps up matter from adjacent regions of the interstellar medium. Over the course of time such concentrations become dense enough that complex molecules and dust grains can form and grow into what we call molecular clouds. These are the nurseries of stars. We can see them with the naked eye by looking at the Milky Way at night; the molecular clouds are opaque and block out the light from background stars, so they appear as black splotches along the Milky Way.

These molecular clouds continue to become denser and denser with time, through gravitational attraction, and when the density becomes great enough, a star is born. This process will be described in some detail in Chap. 8, but here we just point out some of the pyrotechnics produced in the process. While the infalling matter becomes more and more concentrated into a rapidly spinning accretion disk (also known as a protostellar disk or protoplanetary disk), emerging out of the opposite poles of the opaque accretion disk we eventually see bright, narrow, linear 'jets' of emission, which can illuminate matter lying in their paths. These are called protostellar jets, striking features which are hallmarks of young star formation.

When a fully-developed massive young star has been formed, its heat pressure starts to blow most of the parent molecular cloud away, and its bright light is reflected through gaps opening up in the cloud, in what are referred to as reflection nebulae. Much more impressive, though, is when the star has cleared a large volume and its intense radiation ionizes the inner regions of the fragmenting cloud (removing negatively charged electrons from atoms to form ions), which causes these regions to glow, rather like neon lights but on an enormous scale. These are emission nebulae; they produce some of the most spectacular and famous images seen in astronomy, such as the Orion Nebula. Emission nebulae are found wherever massive new stars are being formed; they are so prominent that they serve as beacons to help us find new regions of star formation.

After the star has cleared its surroundings, including the gas and dust of the protostellar disk, some debris still remains, too massive and compact to be blown away. This debris includes planets, their moons and asteroids. These become permanent residents, orbiting around the newly born star. Further out is a vast cloud of icy comets, the last remnants of the original molecular cloud.

Until 1995 the only planets we knew were those in our own solar system, and anything else was speculation. Now we have discovered over 500 planets orbiting other stars, and soon that number will rise into the thousands. It seems that most stars are accompanied by planets; if so, there may be billions of planets in our galaxy, many of which may support life. The fundamental discovery of the first 'extrasolar' planets in the 1990s will be described in detail in Chap. 17.

Once a star has blown away its parent cloud, it lives much of its life in splendid isolation in space, along with its planetary entourage, a sphere of hot gas like the Sun. Its brightness is due to ongoing nuclear fusion processes. We see stars all around us, but as we are located within the disk of a spiral galaxy, which we therefore see edge-on, most of the stars we see are concentrated along the Milky Way, the plane of our galaxy. There are many types of stars, the differences being largely based on mass. They include brown dwarfs ('failed stars' that didn't have enough mass for nuclear burning), normal stars like our Sun that live for billions of years, and massive stars that burn themselves out in just a few million years.

In later life stars go through various convulsions, which cause some of their outer regions to be ejected. We see these as illuminated and ionized shells surrounding the stars. The most famous and spectacular are the planetary nebulae, so called because in early telescopes they appeared to be circular disks of light, similar to the early images of other planets in our solar system. Nowadays we know exactly what they are and what they're made of. The Hubble Space Telescope website contains awe-inspiring images of hundreds of planetary nebulae.

By far the most impressive of the stellar end of life convulsions are the gigantic explosions called supernovae. One supernova explosion can be as bright as an entire galaxy of 100 billion stars. They typically occur in an average galaxy once every century or so. In our own galaxy, in spite of the obscuring dust in the edge-on plane that we observe, four supernovae have been observed and recorded over the past millennium, so we know their locations and ages. Luckily, none of them was too close. Supernovae reach their peak luminosities quickly, and are still as bright as billions of stars for a week or so. The vast shell of ejected material is called a supernova remnant. It can shine brightly at some wavelengths for a hundred thousand years or so, until it just merges with the general interstellar medium.

Stars produce and distribute the 'heavy elements' such as carbon, which are vital for life as we know it. The convulsions that stars undergo late in their lives, including supernova explosions, are an essential part of this process.

What remnant is left at the end of a star's lifetime? Again, it depends on the initial mass of the star. In the case of a low-mass or typical star like our Sun, the remnant becomes a white dwarf star, so called because it is hot and small. From that point on it just gradually becomes cooler and less luminous.

The core of a star whose original mass was more than eight solar masses collapses to become a neutron star, comprised largely of closely-packed subatomic particles called neutrons. A neutron star is incredibly dense – about as dense as an atomic nucleus. It is typically just 10 km in radius, yet more massive than the Sun. A teaspoon of its material would have a mass of more than a trillion kilograms. As it formed from a star that was spinning, albeit slowly, it ends up spinning rapidly (like a figure skater pulling in her arms), with periods ranging from seconds to a thousandth of a second, and almost exactly at a constant rate. It can be as good a timer as an atomic clock.

If neutron stars do indeed rotate with typical periods of the order of a second, and if they were to produce narrow beams of emission, pulses could be observed each time the beam pointed towards the Earth, just as a rotating lighthouse beam is seen as a series of flashes. This is just what is observed, and the objects are called pulsars.

Black holes are even more famous. The core of a star whose original mass was over 25 solar masses will keep collapsing without end, ultimately becoming a black hole. This is absolutely unavoidable. Unlike white dwarfs and neutron stars, which are blocked from collapsing beyond certain points by the fundamental laws of physics, nothing can stop the collapse of a sufficiently massive star. It collapses 'all the way', and becomes a black hole.

Nothing can escape from a black hole, not even light. A black hole is caused by the extreme deformation of space by a very compact mass; it is the ultimate space-time warp. The boundary around a black hole at which the speed needed to escape the gravitational attraction of the black hole equals the speed of light is called the event horizon. There is no way we can know anything about what happens inside the event horizon.

Although they are themselves invisible, black holes can still be detected through their effects and interactions with other matter. Black holes can cause the bending of light from distant objects behind them, and close interactions can result in matter spiralling into a black hole, generating great heat and light. Black holes would seem to mark a definitive end to the life cycle of stars. But do they?

Just because a star is dead doesn't mean it can't be resurrected. Many stars are found in binary systems, containing two stars orbiting around each other. When one member of a close binary pair dies (for example as a white dwarf) the other can bring it back to life. When the companion reaches the 'convulsive' stage in its life, its loosely held outer gas can be transferred onto the white dwarf, providing it with a new energy source. As the matter accumulates on and around the white dwarf it gets hotter, ultimately reaching the point at which nuclear fusion can begin. This causes a thermonuclear flash on the surface of the white dwarf, and the binary system attains the luminosity of a hundred thousand stars for a period of a few weeks. This is called a nova. The accreted material is ejected, and the accumulation process starts all over again.

Binaries involving neutron stars are similar in principle, but the gravitational fields and energies are much greater. The gas accreting around the neutron star is so hot that it emits copiously in energetic X-rays. For this reason these are called X-ray binaries. The thermonuclear bursts in these cases are short (a few seconds), but they radiate a hundred thousand times the luminosity of the Sun. They recur over periods of hours to a few days. Some X-ray binaries may contain black holes rather than neutron stars; the most convincing case is an object called Cygnus X-1, which contains a star 18 times more massive than the Sun orbiting an unseen companion which, from X-ray spectroscopy, is almost certainly much more massive than a neutron star.

There is one important phenomenon in our galaxy which has nothing to do with the standard stellar life cycle: the galactic centre. One might easily suspect that something special must be happening at the very centre of our galaxy, but what? The galactic centre is totally obscured from our view by intervening interstellar dust, as both we and it are located in the relatively dense plane of the galaxy, and the distance between us and the galactic centre is large: 27,000 light-years, or 260 million billion kilometres. However, complete obscuration only occurs at optical wavelengths; in other regions of the electromagnetic spectrum (such as the radio, millimetre, infrared and X-ray bands), the view is essentially unobscured. Through meticulous observations we now know that there is a supermassive black hole at the very centre of our galaxy, with a mass 4 million times that of our Sun.

So there you have it – the galactic zoo, which includes molecular clouds, protostars, protostellar disks and jets, reflection nebulae, emission nebulae, planets, the variety of stars, planetary nebulae, novae, supernovae, brown dwarfs, white dwarfs, neutron stars, pulsars, X-ray binaries and black holes. And the galactic centre with its supermassive black hole.

Beyond Our Galaxy

A hundred years ago it was thought that our galaxy was the entire universe. Now we know that the universe is enormously bigger. Beyond our galaxy lie vastly more galaxies – many billions of them, each containing anywhere from tens of millions to trillions of stars like our Sun. Our galaxy is just average. Typical galaxies are tens to hundreds of thousands of light-years in size. They are separated from each other by millions of light-years, and the density of matter in the space between them is of the order of one atom per cubic metre. The galaxies are 'dots' in a universe that is billions of light-years in size.

The same objects and phenomena that we described in our galaxy are commonplace in the billions of other normal galaxies of various types spread throughout the universe. There are minor differences – ours is a spiral galaxy, elliptical galaxies have less of an interstellar medium, and irregular galaxies generally have more – but these details don't change the big picture.

By using our most powerful telescopes and the technique of spectroscopy, it has been possible to determine that distant galaxies are made of exactly the same elements and atoms as we find in our own galaxy, and that the same laws of physics apply in the distant universe as here on Earth.

We can observe supernovae exploding in both nearby and distant galaxies. Even brighter events are sometimes observed, probably caused by imploding massive stars or mergers of binary neutron stars. These are called gamma-ray bursts; some of these are the brightest explosions ever observed in the universe (one was visible with the naked eye even though it was 8 billion light-years away), and some are amongst the most distant known objects.

Most galaxies in the local universe are quiescent grand-design ellipticals or spirals, but some galaxies exhibit a wondrous range of exotic behaviours. Pairs of galaxies may be seen doing a sort of 'cosmic dance', rotating closely about each other with arms 'joined'. Others are colliding, essentially passing through each other again and again until they finally merge into one (much larger) galaxy. In some, the supermassive black hole at the centres are being 'fed' by gas and stars in unstable orbits, and spectacular outflows can result. These can cause huge jets and 'bubbles' penetrating the intergalactic medium on opposite sides of the galaxy, and extending far beyond the dimensions of the galaxy itself. These often emit copiously at radio wavelengths, in which case they are called 'radio galaxies'. Even more dramatic are the 'quasars', which we see when the rotation axes of the galaxies are pointed almost straight at us. The light from jets of matter emitted from the nuclear region around the central supermassive black hole is enhanced by an effect of relativity, and all we can normally see of the galaxy is just this brilliant point of light, which appears far brighter than the rest of the galaxy combined. Because of their enormous brightness, quasars can be seen out to vast distances and early times – the light we see from the earliest quasars has been travelling to us for over 13 billion years. It is thought that most if not all galaxies contain black holes at their centres, formed billions of years ago when the galaxies themselves were being formed. In most galaxies today (like ours), the black holes are quiescent because of lack of fuel – they are 'starved monsters'.

Galaxies are not distributed uniformly. They tend to be clustered in groups, and distributed in gigantic filaments and sheets throughout the universe. These are the largest structures known, extending over hundreds of millions of light-years (several billion trillion kilometres). They grew, over the history of the universe, from small primordial fluctuations in the distribution of matter in the very early universe. Their evolution can be traced and their structures replicated extremely well by large computer simulations.

The huge masses of galaxies and clusters of galaxies can actually distort the images we see of more distant galaxies. This results from the fact that gravity can bend light, an effect predicted by Einstein in 1915. The effect is called 'gravitational lensing'. If a massive galaxy is very close to our line of sight to a much more distant galaxy, we can sometimes see two or more images of the distant galaxy; in cases of almost perfect alignment the distant galaxy is smeared out into a ring surrounding the image of the intervening galaxy. When the intervening object is a dense cluster of galaxies, we can see many arcs centred on the cluster. It is a spectacular effect.

Observations by the Hubble Space Telescope (HST), in particular the famous 'Hubble Deep Field', have revealed astonishing views of the distant universe. The Hubble Deep Field is a small region of dark sky, chosen because there happened to be no bright stars or galaxies in that particular direction. It is truly an uncluttered view of the distant universe. It was dubbed a 'blank field'. In 1995 the HST continuously stared at that blank piece of sky for 10 complete days, so the sensitivity reached was phenomenal.

Astronomers were absolutely staggered by the resulting image. It was unlike anything they had ever seen before. The Hubble Deep Field image is dominated by thousands of small, faint, ill-formed galaxies of irregular shape, as far away as the most distant quasars. We are looking out to the distant universe as it was less than a billion years after the Big Bang. At the limit of the most sensitive HST surveys today, we can see a hundred billion galaxies over the whole sky, and there are more. These observations changed our view of the universe forever.

The Frenzied Sky

Everything in the universe is moving. This includes the 'fixed stars' we see with the naked eye, and even the most distant galaxies. They just appear to us to be stationary because, even if their true motions are large, their distances from us are so huge that nothing seems to change (on our timescale). With large telescopes and precision satellites we can now readily measure the motions of stars in our own galaxy.

Everything changes in brightness too, on one timescale or another. Pulsars pulse. Stars have hiccups and sometimes eject huge shells of matter. Distant quasars fluctuate in brightness, sometimes in violent bursts. Novae recur. Supernovae happen only once, but when they do it's impressive, as they can be as bright as an entire galaxy. And these explosions occur across the universe. As there is a supernova event roughly once per century in a typical galaxy (probably more in the early universe of rapid star and galaxy formation), this means that hundreds of thousands or millions of supernovae are going off in our observable universe every day. Look above you and think of the whole sky peppered with millions of outbursts happening all the time. The peaceful night sky mentioned at the beginning of this chapter is actually a frenzy of activity, but most of it is far too faint to be seen with the naked eye.

The Darkness Beyond

The rich zoo of cosmic inhabitants described above does not extend forever. Imagine the following thought experiment, in which we 'peel away' the layers of the universe, one by one, from the nearest to the furthest from us. We start with the familiar sky as seen with the naked eye. The closest objects we see are our neighbours in the solar system – the Sun, the Moon, and the brightest planets. Now imagine that these are 'switched off' – they are no longer visible to us. The sky we see now is dominated by the nearest stars and the familiar patterns of the constellations. Switch these off. The sky will now be dominated by more distant stars in our galaxy, spread over the sky but concentrated towards the diffuse band of the Milky Way, itself comprised of billions of stars. Switch all these off and we turn off our entire galaxy. The sky is now dominated by the nearest galaxies – the Magellanic Clouds, the Andromeda Nebula, and several others. Switch these off. The sky now appears almost uniformly sprinkled with billions of distant galaxies. Finally, we switch all of these off, right out to the distance of the first galaxies and stars. The sky is now totally black. We have reached back to what is sometimes called the 'edge of the universe'. It is actually the near side of the 'cosmic dark ages'. At the far side is the Big Bang and all the activity of the very early universe. These will be discussed in the following chapters.

The diverse objects and phenomena that we see in the universe, and the huge scales of distance and time, may seem astonishing to us. Certainly the cosmos is magnificent and awe-inspiring. But to astronomers the objects in the universe are as real as the distant mountains we see here on Earth. The Apollo Moon landings brought this home to all of us. In some ways astronomical discovery is not so different from the days of geographical exploration hundreds of years ago, when distant shores were not known. We are discovering what is really out there. The distances are impressive, but no more so than, say, the incredibly small scales that we explore in subatomic physics, or the astonishing degree of the complexity of life all around us here on Earth. And we have become accustomed to timescales approaching those in astronomy through the science of geology. We also shouldn't forget that we humans now number almost 7 billion. (That means that the hundred billion stars in our galaxy amount to only about 14 stars per person.) We are ourselves part of the universe of large numbers. Still, the universe is a pretty big place.

Now that we are familiar with many of the inhabitants of the universe, we can move on to consider the large scale properties of the universe as a whole. We enter the field of cosmology.