Chapter 1

The Place of Unlit Gases and Dust in the Universe

In a most general sense, this book is about the continuing cycle between dark and light in the universe, all that this entails, how it is interrelated, and the prospects for observing it. Perhaps connecting the ‘dots’ may influence you to look at things in space in a broader sense; if it is all to make sense, collectively, it is impossible to separate the topic from a larger cosmic perspective.

Before time began we assume there was nothing that we would describe as dark or light. It is thought that the ‘Big Bang,’ that term used to describe the beginning of everything, occurred about 13.7 billion years ago. Most elements did not exist, yet to be created by the nuclear processes of stars; of the state of matter at the time, the majority was hydrogen, along with much lesser quantities of helium-4; little else existed, probably consisting only of tiny amounts of lithium, beryllium and deuterium, with any other possible trace elements still mired in controversy. There was no observable light for hundreds of millions of years, and thus the early universe was dark. Stars were yet to come into being. Thus the light and dark in the universe is only the result of cosmic evolution, central to this writing.

The moment of creation – the ‘Big Bang’ – was certainly nothing like many a layman’s faulty notion of a huge explosion radiating and expanding outwards from a single point into a spherical universe all around us. Although superficially the Big Bang could be seen as such, creation was not the product of just one point expanding like the stretching of a rubber sheet. It was actually caused by *all points together* in the universe, (although perhaps seeming to be an apparent single point), expanding equally in all directions, with everything rushing apart at the same rate relative to the next. This is, of course, a totally different reality, if you can get your mind around it.

Thus, all galaxies are rushing away from each other at equal speeds, but the combined and compounded effect is that the more distant the galaxy, the faster it

A. Cooke, *Dark Nebulae, Dark Lanes, and Dust Belts*,
Patrick Moore’s Practical Astronomy Series, DOI 10.1007/978-1-4614-1186-4_1,

Fig. 1.1 'Deepest ever' view of the universe showing galaxies from near the beginning of time – one billion years after the 'Big Bang' (Image courtesy NASA/Robert Williams & the Hubble Deep Field Team)

appears to be receding relative to us (their distances measured by 'redshift,' or the shifting of absorption lines in the red part of the spectrum, which allows us to calculate distances in space). Therefore we can observe no center to the universe at all and have no idea what lies beyond what we are able to observe; we may only be aware of a tiny corner of the totality, for all anyone knows.

It turns out that the edge of the universe, at least as we might imagine it – that mythical place that might be thought to harbor secrets from the beginning of time – apparently does not exist, or perhaps cannot exist even in theory. Such a model would depend on a sphere or some such shaped universe of sorts, something about which we can only speculate. Therefore, when we see a galaxy formed near the time of the Big Bang, it is not likely to be nearer any hypothetical edge of the universe than anywhere else; indeed to an observer from that galaxy, we would appear to be the same as it does to us – an early galactic formation from near the beginning of time. But not close to any particular place! Thus, while we are beginning to snag new prizes among the most primitively formed galactic structures (see Fig. 1.1) and have been able to look upon some of the earliest structures from the beginning of the cosmos itself, we are not seeing anything necessarily closer to any 'edge' of the universe than anywhere else.

Fig. 1.2 Gravitational lensing in galaxy cluster Abell 1689, and implied dark matter in the region (Image courtesy NASA, ESA, STScl (2010))

Galaxies *as structures* are not subject to the forces of the expanding universe, other than increasingly moving apart; they are bound together as separate entities by the forces of their own gravity, or more accurately stated, the warping of the space-time fabric. This is the same force that holds the Solar System together in orbit around the region's greatest concentration of matter, the Sun, which insures that no lesser mass can warp the fabric sufficiently to escape the dish-like confines that its huge mass has imposed on its tiny corner of space-time. And plenty of matter, other than what we can see, appears to exist in these huge galactic concentrations – enormous quantities of invisible 'dark matter,' a less tangible component, yet to be properly defined, that gives each galaxy its otherwise unexplainable mass. In fact, dark matter comprises the majority of a galaxy's mass. But we can't see this matter, only experience its effect.

A dramatic demonstration of this warping of space-time (Fig. 1.2) was shown in the Hubble Space Telescope image reproduced here, including multiple distorted apparitions of the same object. Appearing not unlike the effects of a poorly shaped lens, akin perhaps to viewing a scene through the bottom of a bottle, the image is bent all around the field into a circular deformation; in this Hubble image, there appear to be several restatements of several distant galaxies. Because of the effects of such lensing, scientists were able to synthetically superimpose the bright patches seen here – their projections of dark matter itself, which is, of course, invisible. Although such dark matter is the ultimate of all dark things in the universe, it is nevertheless far beyond the scope of this book, and remains still an enigma in the upper echelons of scientific research. It is not visible by any means.

However there is other, more tangible dark matter – *unlit* matter – comprising a large portion of the galactic structures that we can see, if indeed in a somewhat indirect manner. Throughout many of the billions of galaxies in the universe, there exists much gas and dust in all shapes and forms, and which contribute greatly to their overall visible mass. What lies between most of the stars is the stuff of star creation – interstellar matter – the lifeblood of ongoing galactic evolution, and where we will place most of our attention in this book. Few observers of the sky remain unaware of the many apparent dark 'gaps' punctuating the stellar fabric, especially as we navigate our telescopes across the Milky Way inward toward the galactic center, across thousands of light years to the brightest regions of Sagittarius that surround the galactic core.

Perhaps the subject matter of an astronomy book – about what *cannot* be seen – seems unlikely, but in truth, most of the matter in the universe cannot be seen. But what about all that we *can* see? Considering our position deep within one of the spiral arms of a great and mighty galaxy, it might have occurred to us that the spectacle all around us appears surprisingly faint, especially since the galaxy consists of hundreds of billions of stars. One would imagine that it would be hard to stay *out* of brilliant light when, in fact, the opposite is true. All this merely illustrates the galaxy's true scale, as well as revealing that most of the galaxy's volume does not consist of stars, or even illuminated matter. The stars themselves occupy only a tiny fraction of the vast total expanses comprising each galaxy, and the distances between them are so great that even those closest to each other would appear as no more than points of light to a solar system inhabitant of any of one of them, something we experience from our own location in space, of course.

In reality, the term 'emptiness of space' does not ring quite true, since interstellar space is far less akin to a vacuum than the uninitiated might suspect. Even between galaxies some traces of matter still exist, albeit exceedingly rarified, though closer to an absolute vacuum than anything we can achieve on Earth. It is, however, essentially nothing, if not quite a scientific absolute. (Thus, what separates us from other galactic destinations is, more than anything, time itself, since it is inconceivable that 'nothing' could have dimensions as we normally know them; this is an easy realization of the concept of the space-time continuum.)

As we grow up, astronomically speaking, the realization of the huge distances separating each star, and the unimaginable size of the universe itself, is probably accompanied by an increasing and sobering reality of just how 'insignificant' our Milky Way home actually is, a mere one of hundreds of billions of galaxies. However, from our own vantage point, it seems as if we are looking out into eternity at endless stars, when, in fact, what we are seeing is mostly confined to the 'pitifully insignificant' 110,000 light years of our own neighborhood backyard.

The original idea to write this book did not come about from any grand vision to embrace the link between many types and varieties of dark object or dark feature in deep space. Rather it emerged from an originally smaller vision just to feature, describe and analyze those intriguing dark lanes apparent in so many star clusters, especially and most notably of the globular variety. Interestingly, these features may have separate origins and makeup to everything else we will look at! However, the original concept was to prove far too limiting, as similar-appearing attributes and features also exist within many other objects in space!

It is easy to overlook the fact that it often is the dark features within many types of deep space objects that define them, or at the very least make them distinctive. And certainly, as a subject overall, there seems to be extremely limited reference material available, specifically for the observer about this aspect of the universe – at least to be found in some manner collected all into one place as a topic unto itself. It certainly seems that it has been accorded less attention than it deserves. Most descriptions are sketchy at best, and usually go no further than superficial mention of these dark features' existence. Worse, often there is no mention made at all, let alone much meaningful discussion about some features we can clearly see in the eyepiece. And therein began the focus of this entire book; surely, obscuring matter anywhere in all of the cosmos begs at least part of our attention, its potential, perhaps even now, still underestimated. The fact is that other dark features in many different types of deep space objects are interconnected, with the lone exception, it would seem, of the mysterious dark lanes seen in many globular clusters.

Within our own galaxy, the Milky Way, we can readily detect vast regions of dark and tangled matter between all that glows – the matter that is not illuminated by the energy from nearby stars – which only becomes 'visible' when projected against brighter backgrounds. Aside from the larger and immediately obvious dark nebulae of the galaxy, we have probably observed smaller dark patches within the star fields as well. Additionally, we are all surely familiar with the intersecting dark lanes in smaller illuminated structures, such as those within the famous Lagoon Nebula, M8, and M20, the 'Trifid Nebula.' We may also be at least superficially aware that when observing these types of spectacle the very essence of how we see them is defined by apparent turns, folds, swirls and other features as a result of intertwined dark, or partly dark, dust and gas. And perhaps not every observer is aware that most illuminated nebulae are merely small illuminated parts of a far greater, effectively *singular* dark whole (although divided into linked components) extending over a wide swath across the galaxy; most of this larger (dark) nebula remains invisible – while blocking a great deal of the light from anything that lies behind it. We cannot observe it directly, but it is fitting recognition and reminder that much within our own system remains hidden, even from such close range.

As the light grasp of our telescopes increases, so does the degree of illumination of whatever we are viewing, depending on, of course, how far we stretch and dilute the brilliance of the image with ever-higher magnifications. By inference, so too is contrast affected as apertures increase, and hence, the larger the telescope, the various shades of darkness that may weave through illuminated subjects become an increasingly important part of the view. What we cannot ‘see’ directly, or see only faintly, is actually just as important as what we can see brightly illuminated, even though we may not ever have contemplated the sight in such terms. Maybe we have not contemplated it at all. This is not to say that such spaces, lanes and features are present, or even significant in everything, but when they are, three-dimensional effects (when we are really only seeing a two-dimensional image) and other visual characteristics are likely to become intrinsic to the view.

We are already well aware that within our galaxy there are copious amounts of obscuring matter in the light path. Apparent gaps seldom represent a true void in the stellar fabric. We also probably know that outside the great band of the Milky Way, dark voids may actually be just that – voids, as there is indeed much ‘space’ in outer space – although we are not primarily concerned with them in this writing. However, long exposures of these regions usually show far distant superimpositions of ever-increasing layers of remote galaxies bridging the seemingly limitless expanse and all at different stages of evolution going back through time – that which has elapsed since the Big Bang of 13.7 billion years ago.

Nevertheless, the fabric of the cosmos is not consistently spread out, and these galaxies exist in clumps – superclusters – rather than being evenly distributed, a still-existing reminder of the fluctuations and variations in the vibrations of what the iconic Fred Hoyle sardonically termed long ago as the ‘Big Bang’ itself. (Hoyle steadfastedly stuck to his steady state theory, rejecting any suggestion of a moment of creation, for him too close to a religious concept, to be sure.) However, we need to look at the full cosmic picture in order to be fully aware of the implications of all we are studying, as well as recognizing perhaps the additional potential we have as observers.

The Nature of Dark Things in Deep Space

If all that is unlit in the universe is to be our focus for a while, let’s briefly examine what constitutes non-illuminated cosmic matter, although we will return to each category in greater depth during subsequent chapters. We now know that all dark nebulae, lanes and belts surrounding many spiral galaxies (other than those recently observed from near the beginning of time) that we can see (or rather do *not* see), consists of gas and dust – the ‘interstellar medium’ – and is of that same fundamental material. While not everything we see may yet belong to a galaxy’s vast reserves, with only one possible exception, it is all made of the same fundamental stuff.

Galactic dark belts represent, of course, a greater whole, and pervade deep into the entire discs of these galaxies. We only see them as belts because we are looking into those galactic planes from the side; the individual diffuse nebulae we see in our own galaxy are merely parts of a similar whole. The degree that gas and dust is concentrated horizontally into those galactic ‘equatorial’ belts depends on the mass of the galaxy itself; the gas and dust of those of lower mass and slower rotation tends to be spread more evenly throughout the broad entire disc instead of being most concentrated into the equatorial regions. Thus, some edge-on spiral galaxies show no dust belts at all, while others display ever-greater degrees of the phenomena, since its presence, and the form in which we perceive it, are dependent upon galactic type, mass and rotation; the variety is considerable. Additionally, those galaxies showing the most striking dust belts usually have the fastest rates of stellar formation and evolution, and thus are fundamentally less stable than those showing a lesser presence of dust lanes.

While dark gases and dust exist in other galaxies just as they do in our own, we will need to approach observing them differently, because these galaxies all lie far away from our own system. It is a simple fact that we will not be able to see unlit material within other galaxies resembling in any way the variety of seemingly individual spectacles that comprise the Milky Way's dust belt. However, it is likely we will discover that dark belts or other dark details we can see in other distant systems are actually no less satisfying to view – albeit revealed as larger entities rather than the smaller sub-structures of our own galaxy. Instead, the many individual dark features of other galaxies are homogenized into a magnificent union of dark formations, which often are seen as entire encircling belts. In many ways, the view may be even more pleasing because it is an opportunity to study the greater form and nuances of entire galaxies from a perspective akin to how our own would appear to hypothetical observers elsewhere in the universe.

Of the makeup of interstellar matter, the heavier elements of the dust itself are largely made up of microscopic-sized carbon compounds, calcium and certain silicates and a myriad of additional trace elements, all formed as a by-product of the nuclear fusion processes that occur over the galaxy's individual stars' life cycles. Typically, the galactic gas component of the interstellar matter is rich in various forms of hydrogen, including the potentially luminous molecular HII, some helium and other gases, including carbon compounds such as carbon monoxide.

Illuminated diffuse nebulae are part of the same interstellar medium – but where star formation is taking place – and thus typically consist both of gas and dust. Of those visible to us, it is probably accurate to state that 99.9% of them reside within our own galaxy. This is not to say that they do not exist elsewhere – it is just that most of them are far too distant for our humble telescopes to show as more than blobs and brighter mottling, just somewhat brighter than their surroundings, no matter how big the aperture at our disposal! Thus, the Milky Way is home to all of the complexes of swirling gases that we can observe in any detail. But there are other types of illuminated nebulae in our neighborhood, too. Despite being made of the same components, planetary nebulae reflect the recycling processes at a different stage, but occasionally they also show dark lanes or details; however, as the by-products of individual stars they are quite small, so those that we can observe belong exclusively to our own local neighborhood.

In the Milky Way, our own Sun, being neither an especially young nor yet old Population I star (more later), but decidedly middle-aged, is located within the galactic thin disc. Because we are positioned within the arms, our own perspective is thus edge-on relative to the galactic center, which we can easily see as we look towards the Sagittarius region of the Milky Way. (However, there is no truth that the skewed *orientation* of our view of the galaxy relative to the Solar System gave rise to any recent hypothesis by astronomers at the University of Massachusetts that

Fig. 1.3 The Great Rift. This wide-angle view shows much of the dust belt encircling the Milky Way Galaxy (as imaged from Death Valley, CA). The galactic core lies to the right, in the most brightly illuminated Sagittarius region, seen here as if 'standing back' – more in the manner we perceive the dust belts of other galaxies to be (Image courtesy NASA/National Park Service)

our Sun actually may be a captive star from the recently discovered Sagittarius Dwarf Irregular Galaxy). This system is presently being absorbed into the Milky Way, and since its path through the Milky Way directly intersects our Solar System's position and orientation, it was rumored to be a plausible explanation for the angle we see the galaxy – diagonally instead of in the same plane. (Any theory of an external origin of the Sun, if proven, rather than being formed from the raw materials of the Milky Way itself, would cause some considerable rethinking of past assumptions!)

Various panoramic images of the Milky Way reveal the nature of our own galaxy and show a direct resemblance to that of many galaxies positioned edge-on to us (one of the most similar to our own galaxy perhaps being NGC891 in Andromeda). Only very short exposures are necessary from our privileged ringside position in the local galactic plane to see the fantastic complexity of tangled, twisted and filamentary conglomerations encircling it in such a remarkably spun web – almost resembling steam and smoke rising out of a newly extinguished inferno on a mountain slope.

A larger view of the Milky Way reveals a continuous great winding and patchy dark band, showing dusty tentacles that seemingly reach out in all directions, as well as brilliantly illuminated nebulous portions interspersed throughout it. These are indeed all parts of an encircling system of gas and dust that extends through the 'thin disc' (see later: The Realms of Stars) almost to the core and has become known as the Great Rift, because it appears to divide the galaxy into two parts (Fig. 1.3). Such formations must be the norm in millions, indeed billions, of galaxies throughout the universe. Even though we will never see other galaxies in the same kind of detail with which we can view our own, it is hard nevertheless to tire of these grand features that we can often discern in them. The sheer variety of stunningly dark dust belts is amazing, rendered all the more so by the perspective imposed on the objects by their great distances.

All of those galaxies available to most amateur observers will likely be within 100 light years of planet Earth. (Don't worry; there are plenty to see.) The fact that much of the Milky Way's surrounding belt, and seemingly most of those belts of other galaxies, remain dark means, of course, that no irradiation is taking place, or that the light being generated or reflected is being absorbed by them. Existing in all shapes and sizes, larger regions of dusty galactic matter in the Milky Way can block out entire star fields, star clusters or bright nebulae. Astronomers must depend on techniques other than the visually conventional to detect them. While, over the larger cosmic timetable these regions will evolve continually as a result of star formation, by blocking the light from behind them in the meantime, the great dark belts appear like dissecting bands, or the dark mottling effects we observe so often within the spiral arms of face-on galaxies.

Historically, the large quantities of obscuring dust between our line of sight and the core of the galaxy made studying the heart of the Milky Way difficult. Although we might be aware of vast regions within the band of the Milky Way where stars seem particularly plentiful, such as the Sagittarius Star Cloud, M24, we could easily conclude that we are peering right into the heart of the galaxy. Though this may be almost true, the reality is that there are no regions where we may actually do so, and where so-called 'windows' closest to the galactic core exist, we can expect them to be quite small where our line of sight in not blocked by dusty matter. Modern infrared imaging has also helped greatly in this respect, and the very core of the Milky Way has now been studied effectively. In addition to such techniques, there are a limited number of tiny gaps in the galactic dust that enabled astronomers in the past, as well as present, to glimpse areas very close to the core. The best known is 'Baade's Window', a 1° square within 4° of the galaxy core (2,000 coordinates: 18032s3002; approximately 15' wide); and through which there is hardly anything to interfere with our direct line of sight inwards. Through this 'window,' the celebrated twentieth-century German astronomer Walter Baade was able to study the structure of the galaxy via RR Lyrae class variable stars in the region (old, low mass, metal poor Population II stars, typically found among the stars of globular clusters, and helpful in measuring cosmic distances).

More recently, such windows have allowed astronomers to take advantage of gravitational lensing of light (the bending of light as predicted by Einstein in the General Theory of Relativity) passing through the region to study the structure of the galaxy, as well as its very core. Because of such research, contemporary astronomers have been able to make a strong case for the Milky Way being, in fact, a barred galaxy. Apparently, the bar points directly at us, making easy identification of this formation even more difficult. Two globular clusters that have helped in galactic studies, including Baade's, lie in the heart of this region and are worth noting: NGC 6522 and NGC 6528. In themselves relatively unexceptional, the clusters just happens to lie deep within a sea of the background of stars, and within this region we can easily begin to sense the decreasing degree of stellar separation at the galaxy's center, with countless stars evenly distributed across the entire field of view. NGC 6528 is situated right on the border of Baade's window itself. Increasing apertures or exposures soon make clear, however, that we will encounter great difficulties, in fact, and for us, impossibilities, in seeing right through it to external space beyond. But at least we know we are peering close to the very heart of the galaxy.

The Interstellar Medium in History

Historically, the understanding of non-illuminated matter in the galaxy has had a short timeline, and we should never underestimate the significance and contributions of the venerable pioneers of this research, which was often carried out under the most difficult, strained, and dangerous circumstances. The first published findings in the nineteenth-century on dark features in deep space objects were surprisingly late in coming. But a new day had already dawned with ever-larger telescopes beginning to appear on the horizon. Most of the great instruments of the time were of Newtonian design; optical technology of the day necessitated large focal ratios. This resulted in long, bulky and unwieldy tubes, with precariously high, rickety viewing platforms and cumbersome mountings. William Herschel's great telescopes were typical of this kind of design with their inherently perilous operation, and one of his telescopes in particular paved the way for all that was to follow. This was his grand 48-in. (122 cm) of 1789 (Fig. 1.4), better known as his

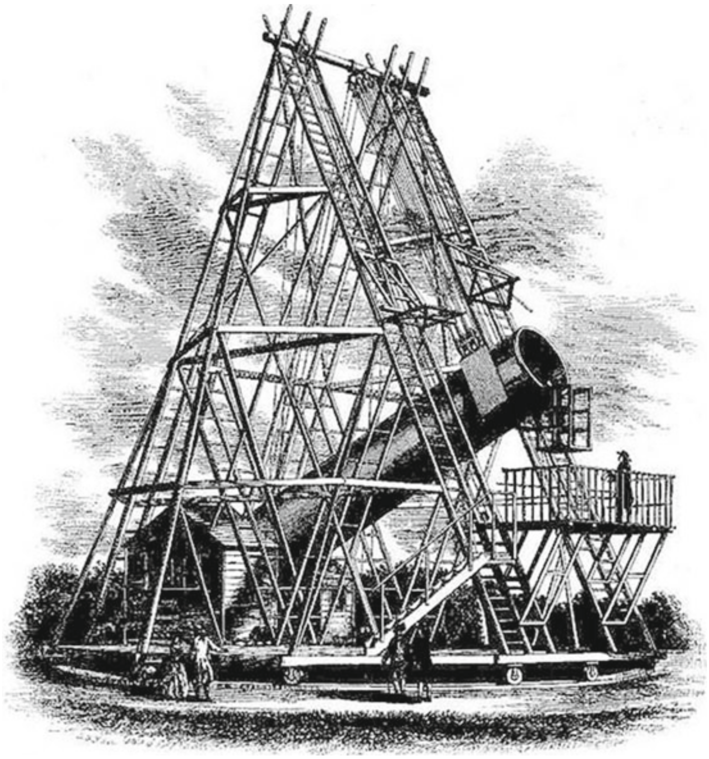

Fig. 1.4 Herschel's 40-ft telescope

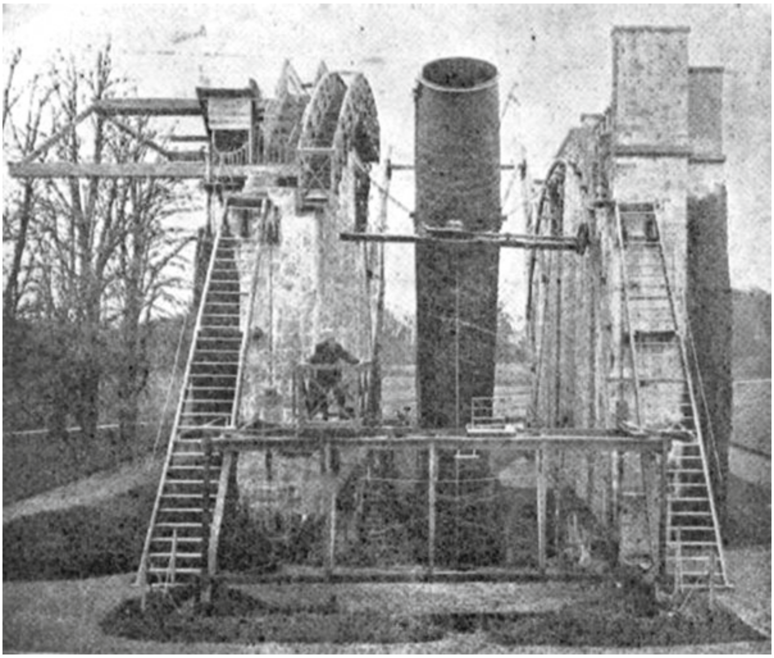

Fig. 1.5 The 72-in. 'Leviathan' of William Parsons, 3rd Earl of Rosse, 1845

40-ft (10-m) telescope, due to its length, and which was for half a century the world's largest.

No such nicety as enclosed domes existed then, and these pioneers typically were exposed to every whim of the frequently poor climatic conditions of the many European locations in which they were situated. However, it is significant that even with such a grand instrument at his disposal, the astute Herschel still was unable to begin to find a crack in the code of galactic evolution that we have come to know today, and neither did science in general. And despite the considerable size and power of his telescopes, the visually astute Herschel certainly made little if any direct reference to any dark features he may have observed, so we must assume that these features remained largely undetected, or considered insignificant. It would have to wait for others, and thus we find the first actual reference to such features only emerging as recently as the mid-nineteenth century.

Herschel's masterpiece was followed by Lord Rosse's mighty 72-in. 'Leviathan of Parsonstown,' which was to remain by far the largest telescope in the world until well into the twentieth century (Fig. 1.5). Because of some significant discoveries of dark features in deep space objects made by Rosse with this telescope, we should single him out as the true ancestor of all that we are concerned with in this book. One of the most famous revelations made with the 'Leviathan' were the dark

'Propeller Lanes' in the globular cluster M13 in Hercules, which Rosse described and sketched in detail (see Chap. 5). Along with this, he sighted and drew dark features in numerous other structures, most notably the dark patches within the Owl Nebula, M97, and the great dividing belt in galaxy M81, both in Ursa Major.

With his great telescope, Rosse and his team, Robinson and South, used their combined skilled eyes and tireless dedication to make many other contributions. Importantly, they were also responsible for the first revelation of spiral form within galaxies (specifically, that of the Whirlpool Galaxy, M51, followed by many others, including and notably M33, M58, M63 and M101); of course, spiral form happens to be a key indicator of the cycle that transforms non-illuminated matter into stars.

Rosse's other discoveries included identifying no less than 231 galaxies, dutifully recorded in many fine sketches, all made under conditions that would deter those of fainter heart. And all of this was done under physically stressful situations, utilizing optics of a quality far inferior to those of today, with clumsy telescope tracking, controls and primitive eyepiece designs to boot, as well as by other negative factors beyond their control. In Rosse's case, by the way, these included the particularly unfavorable location of his observatory at Birr Castle in Ireland, the relative poor reflectivity of the speculum metal primary mirror, the need for frequent re-polishing and figuring (let alone the casting of such large sizes of the mirrors he used), not to mention the severe limitations of movement of the 72-in. telescope's mounting, which would seem unworkable to any amateur today, let alone a professional. However, the record shows that certainly the telescope was far from the albatross some have painted it to be.

One has to ask just how many enthusiasts would even attempt to fabricate such a monster telescope, institute a serious research program, and bankroll it all by themselves? It took until 1917, with the advent of huge glass-mirrored telescopes and the legendary 100-in. Hooker Telescope on Mount Wilson, CA, that Rosse's grand 'Leviathan' ambition was finally superseded, and now with many of the unfavorable factors, thankfully, eliminated. With this particular telescope, and Edwin Hubble the user, what happened next was to change the state of knowledge forever. The good news is that the historic telescope, long left to deteriorate and wither on the vine, is restored and back in use today, but with a new glass mirror and significant mechanical refinements to its tracking system. All of this has been done without compromise to the integrity and appearance of the original. Fortunately, Rosse's grand vision and legacy are once again on display for all to appreciate and benefit from its use anew.

Astronomers in the United States are fortunate to have a direct link to the advancing mirror-making technologies that made the 100-in. telescope possible, in addition to a reminder of the challenges faced by the astronomers of this period, in one of few other active telescopic survivors of this period, the 36-in. Crossley Reflector. Built in England by A. A. Common in 1879, and one of the first large reflectors to utilize glass mirror-making technology, it was donated to the Lick Observatory in 1896. This particular telescope was the first to demonstrate the value of time exposures, and so figured significantly in developing what soon would be utilized for the recognition of dark nebulae and galactic structure, among other things.

The Crossley's overall configuration makes it a classic in line with standard nineteenth-century practices; featuring a standard Newtonian focal position at the top of its long tube, to this day there is more than a degree of the risks of old involved with its use. However, it remains a perennial favorite. Housed in one of the first domes (dating from that time), it maintains a busy schedule by any standards, although a limited one these days for ongoing research. Nevertheless, despite being radically transformed over the years into the telescope more familiar today, its identity remains typical of the time of its origin, and it is an instrument that requires considerable adroitness from the observer, as well as being a continual reminder of how far we have come.

Nineteenth-century astronomers surely would be shocked and stunned to know that the universe we know today is infinitely more frightening in proportion and complexity than anything they suspected; they would have been aghast to realize the true nature and scale of all they were observing. Those 'spiral nebulae' only described what they thought they saw, as to them the universe consisted of 'merely' the heavens encompassing the vault of the Milky Way. Already, the universe as they knew it seemed overwhelmingly daunting. While nineteenth-century man's perception of the cosmos would be found ultimately to be severely limited, the scale they did envisage is nevertheless overwhelming by any normal standards. However, normal standards do not apply in the cosmos. The shocking truth, soon to be known, was that it represented only a universe of relatively tiny proportions – a several hundred billionth of its actual totality.

The Realms of Stars

The positions of stars in each galactic 'island universe' are subservient to the governance of their host, according to its predetermined structural order, consisting of up to hundreds of billions of stars, and vast, visible and invisible gas and dust regions that serve as reservoirs of material for star-making. The galaxy's resources of gas and dust exist primarily in what is termed its 'thin disc' – that is, viewed from an edge-on perspective, the wide, but thin (spiral) extensions of young predominantly blue stars on each side of the central bulge. Widely distributed among this stellar population, regions of the formerly dark HII component (molecular hydrogen) of the gas in the 'thin disc' becomes fluorescent by the fusion processes of hot young stars, and as we view face-on galaxies this glowing gas may be visible as mottled patches within the dark dusty regions in the arms around those galaxies' discs: these are the cradles of stellar creation. The young stars that make up these spiral arms are extremely rich in heavy elements (metal rich), which is hardly surprising since this is the region packed with star-making gas and are termed Population I stars. When the fusion processes of neighboring stars heats the accompanying interstellar dust, usually intermingled in quantities throughout the gas clouds, often it may also emit additional radiation in infrared wavelengths, in addition to any fluorescence that may be occurring.

Population I stars are predominantly comprised of hydrogen and helium; all other elements exist in trace amounts and cannot be considered major components. The region of the galactic 'thin disc' is predominantly made up of young stars (Population I type). Beyond it, as the concentration of stars dissipates away from the core, above and below, the stellar population gradually blends into a somewhat broader thick disc of older redder stars (Population II stars), as well as constituting the galactic bulge at the center. Because this region formed and matured in earlier times it is all the less likely to be the home of spectacular nebulae. Most of the gas will already have been used up in nucleosynthesis (the fusion processes of stars). These Population II stars would have been formed before their own nuclear processes created the heavier elements common in Population I stars and their orbiting solar systems. Thus these stars, the oldest stellar survivors, are relatively deficient in heavy elements ('metal poor') and appear to have entirely different, even gentler lifecycles. They are also increasingly metal deficient the further they are located from the galactic center. We should be aware that a majority of familiar elements (excluding hydrogen and helium) are considered metals in astronomy; in earthbound chemical terms most of them would never be considered such. In astronomy, elements such as carbon, oxygen, and nitrogen are also designated as 'metals,' so we should take care not to confuse stellar metals with familiar earthbound varieties.

We have to admit, however, that we know surprisingly little about the histories, or origins of Population II stars, although there is much that may be deduced. But it does not stop there. In order for Population II stars to have come into being, it is theorized that a yet more esoteric, but unobserved, category of stars existed before them: Population III stars, which it is believed formed soon after the Big Bang, and disappeared from the scene relatively quickly, because Population II stars are among the oldest things in the universe. Population III stars would have had virtually no metal content because most, if not all, heavier elements could not have been created yet, but they do seem, at least in theory, to be necessary for the evolution of the cosmos. Certainly none are around for us to see, so their existence at one time can only be speculated.

As such, certain recent observations of early 'faint blue' galaxies from near the edge of the observable universe seem to indicate their existence at one time. Only time will tell, but it is safe to say that, for our purposes in practical astronomy, we can ignore them, although it does not hurt to understand their probable role. And their existence seems to be the only rational explanation for the creation of the increasingly metal-rich interstellar matter – the very ingredients that made Population II stars possible (and those of Population II type similarly created the matter necessary for Population I stars). While observable examples of Population II stars feature a very low metal content, it would appear that they are nevertheless substantially richer than would have been those of Population III. You may recall that very few elements, let alone heavy ones, existed at the time of the Big Bang.

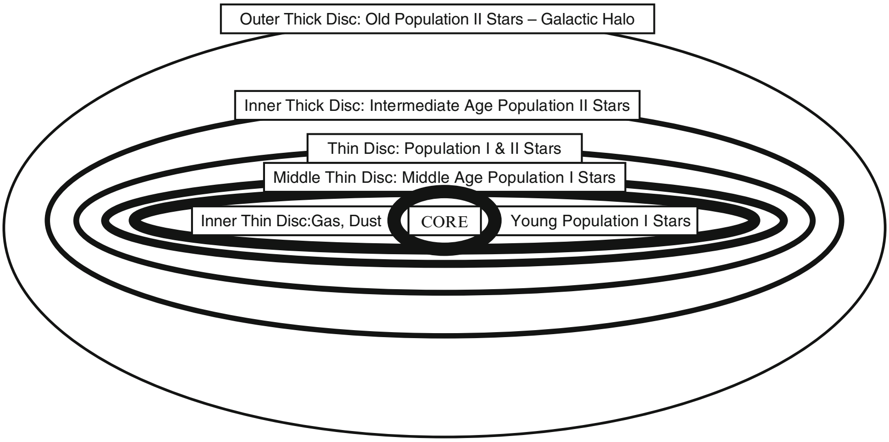

Fig. 1.6 Distribution of star populations in the Milky Way

It took nuclear processes, presumably those of stars, to create them. Thus, in theory each generation of star shows increasing degrees of metallicity, as the interstellar matter they were created from becomes increasingly metal rich. While Population I stars would seem to be the final destination of all possible stellar forms, and the Periodic Table of the Elements seems to deny the possibility for the creation of further elements, is it nevertheless impossible to say for sure that a successive star population, theoretically ‘off the radar’ in a way we cannot foresee, could evolve? There is as of yet, however, nothing in the universe to suggest such a possibility, so it must be considered pure conjecture.

In Fig. 1.6 we can see how the stellar populations follow the galactic form closely: the oldest, most metal poor stars being furthest from the plane of the galactic core at the extremes of the galactic halo, and the most metal rich (the youngest) occupying the innermost plane of the thin disc. As has been observed, the stars of new clusters gradually drift apart, which represents the beginning of the migration process away from the core relative to stellar metallicity.

Meanwhile, it is quite common for a certain amount of both gas and dust to exist in the regions around even old Population II stars, and in the thick disc as well as the central bulge, even though this old matter appears incapable of fostering stellar birth. It is reasonable to assume that its composition differs from the bulk of interstellar matter (and may be what is frequently observed in globular clusters – objects consisting of virtually all Population II stars). Within the galaxy there are multiple varieties of sub-categories of stars as well, as might be expected. However, we should spend a little effort to understand all that makes things visible in the universe (stars) in order to gain a better grasp of the subject at hand – what is not visible! We should look closely at the end of stars’ life cycles and how they recycle their elements to live once again – and how this relates to all things dark.

Stellar Life Cycles

Of the two major stellar categories, Population I and II stars, the scenarios described below apply generally to those of the Population I category; remarkably little definitive is still known of the life cycles of Population II stars beyond scientific deduction and subjective speculation. However, we may sum up with certainty, albeit somewhat generally and simply, what takes place at the end of the life cycles of Population I stars, which happen to be pivotal in the ongoing evolution of the galaxy. Those interested in looking further may wish to consult one of many available Hertzsprung-Russell color diagrams, which show well the relationships between temperatures and luminosities of stars during their life cycles.

A star begins its life predominantly composed of hydrogen, some helium and traces of essentially all of the other elements. Every astronomer knows it does not ‘burn’ its fuel, but rather through the fusion process of hydrogen creates heat and light, as well as an increasingly large core of helium (often termed ‘ash’), formed at the expense of its hydrogen. Ongoing fusion in the mature star core creates ever more intense conditions, and heavier elements are proportionally produced from that activity in the form of byproducts. Meanwhile, some stellar mass is lost through its conversion to radiant energy, in a manner directly proportional to its mass. The star’s mass dictates its speed of fusion and radiation output – the more massive the star, the faster fusion will take place and the hotter it will be.

Stars are held for most of their lives in a kind of thermal equilibrium, whereby the internal nuclear furnace maintains sufficient outward pressure to stop further collapse and implosion. During this phase, stars are termed as being in the ‘main sequence.’ But eventually all of this has to come to an end, and stars of different masses will meet different fates. Various stellar masses dictate different outcomes for stars; the key to the subject at hand, however, lies in the vast numbers of single average stars of less than about 9 solar masses, and that comprise more than 90% of the stellar population of most spiral galaxies. (Most of the stars that make up the galaxy average not more than 5 times the Sun’s mass.) We can outline the ways they meet their demise as follows.

Slow Decline

The key, as far as the future of the galaxy is concerned, is the life cycle of Population I stars, of at least half, but not more than 9 times the mass of the Sun, and are part of the main sequence. The limited mass of these stars ensures that they will experience a *relatively* gentle demise that enriches the galaxy with future star-making material. During this process, they will redistribute their elements in highly reusable forms, especially gas and dust that is likely to eventually contract to become new Population I stars and solar systems. Our own Sun, an average one at that (despite being somewhat inappropriately termed a “yellow dwarf” – a name used only to distinguish the majority of stars from those that have already become giants), is surprisingly late in life, and twice as much helium now makes up its mass as does hydrogen. But fear not; it probably has a few billion years to go…

The sequence of events in later age for stars, such as the Sun, will likely cause them to become bloated with age and to evolve as red giant stars possibly of hundreds of solar diameters. The majority will become typical red giant branch stars, still fusing hydrogen into helium (though no longer at the center of the cores), while the cores continue to accumulate helium ash. When core helium is nearing completion of its fusion processes, the star cools and enters a later sequence, the ‘horizontal branch phase,’ and contracts from giant status for a relatively short time. Soon hydrogen in the shell surrounding the core begins fusion (the ‘triple-alpha process’) and the star once again expands into supergiant status, termed an ‘asymptotic giant branch star,’ or might we say, the ‘last hurrah.’ Other stars (termed ‘carbon stars’) fuse carbon from helium instead by the same complex process and fall into this asymptotic category as well; needless to say, the list of variants goes on and on. However, they are all types and forms of red giant regardless, although their true coloration is closer to different shades of orange.

While such giant stars will probably envelop and ultimately consume anything comprising an orbiting solar system, they will have relatively cool surface temperatures (±5,000°C), because of the tenuous makeup of their huge orange glowing shells. However, their total luminosity (due to their great size) will increase dramatically, potentially by as much as thousands of times, as their dimensions continue to grow. Gravitational hold on the stellar body continues to weaken as the star becomes increasingly tenuous. At the same time dusty matter (the leftover portion is presumed to become the stuff of planet formation at another time) from the stars’ late fusion processes is shed outwards in the expansion, as the rapidly declining stars begin the process of joining the ranks of other planetary nebulae.

Planetary nebulae are a large part of the future of the universe, but especially, they are the ‘opening salvo’ to all that is the focus of this book. Small in comparison to the grander diffuse nebulae, these nebulae nevertheless may be as much as an entire light year across. Within a relatively short space of time in cosmic terms, this wide surrounding dusty stellar matter can grow large enough to be observed in backyard telescopes in finite shapes and forms, the original stellar discs never being possible to resolve (or any surrounding solar systems!) during the main life of the star itself. Typically, a tiny but extremely hot and intense central white dwarf star (all that remains of the star itself) may be also visible in the eyepiece; the light is the radiant energy being emitted by these stars’ cores that excites the HII within the nebulous shell into the luminescence we see. At these temperatures, the now predominant helium ash increasingly undergoes further nuclearsynthesis into carbon and oxygen. But it is only a matter of time before all nuclear reactions cease completely, and from there, the remaining stellar cores cool off slowly, to become white dwarf stars (true dwarf status this time!), consisting essentially of carbon and oxygen (with some variations, such as neon and magnesium, when higher temperatures are present). The more massive the star, the smaller will be the remaining dwarf star – unsurprisingly, perhaps, owing to greater internal gravity and compression; they are often less luminous, too, because of much decreased surface areas. Ultimately, the dusty and gaseous matter left over and spewed out from these dying stars becomes diffused into the more familiar forms of dark nebulous clouds we see intermingled throughout so many galactic arms.

White dwarf stars are thus extremely compressed structures of tiny proportions, incredibly hot, and radiate heat and light left over from all of the fusion of the past, but not nearly so much as neutron stars (see supernovae). Some white dwarfs can collapse into neutron stars with specific chemical compositions, although most are not appropriately dominant in these elements. However, their elemental makeup prohibits the generation of any further new energy other than that created by the forces of compression.

As their temperatures slowly drop, it is now only a matter of time before the dwarf stars fade into blackness, and finally from view (admittedly, a lot of time, since none are yet known). Even faster cooling of these incredibly hot and compressed stars is prevented by a significant ‘atmosphere’ of what remains, in addition to further reduced cooling efficiency via the limited area of their small size. Surfaces of these stars are dominated by differing blends and proportions of varying elements, which give rise to different spectral properties. These elements can be hydrogen or helium, sometimes (but rarely) carbon, and even unused matter from the dark clouds of their creation; in effect this insulating blanket also allows the white dwarf a far longer lifespan than would normally be considered possible. In a final wrinkle in the life cycles of Population I stars, additionally, it seems that collisions of some white dwarf stars are theoretically possible within elliptical galaxies and which would result in another amongst the various categories of supernova, that of sudden death.

Sudden Death

Stars more massive (generally, single stars – blue supergiants – of masses of at least 9 of our suns, and frequently as much as 50) are much more active than smaller stars, and suffer a far more violent demise. Ultimately unstable, they recycle their elements in the most spectacular fashion possible, termed a Type II Supernova, as they are pre-destined eventually to explode in cataclysmic fashion, showering vast regions of space with new and highly radioactive elements created in the process, as well as the other remnants of their makeup. These are the ultimate heavy metals, astronomically speaking (The Veil Nebula, designated NGC 6960, 6974, 6979, 6992, 6995 in Cygnus, and Crab Nebula M1 in Taurus are classic examples, close enough to home that we can witness the aftereffects of such explosions quite dramatically and within a short time span, cosmologically speaking).

The processes of such stellar core collapse and the subsequent explosion of such stars are complex, but near the end of the life of such a star, most of its heavy elements have been used up in the ongoing nuclear fusion processes. Soon, this 'progenitor star' is no longer capable of generating sufficient energy within its core to support its own mass, something that had always been the case throughout its mature life. Increasingly, as the core weakens, primary nuclear fusion takes place outside it, and as its outer layers expand and cool as a consequence, the core continues to contract while the rest of the star's shell slowly assumes red giant status. As a result of many changes and phases occurring in sequence, the pace of fusion of the remaining fuel within the core only becomes more intense. After fusible materials are used up, the core continues to contract under its own gravity, increasingly becoming non-fusible iron, while adding further to its mass by drawing in matter from layers adjacent to it.

Once the core has reached the critical mass of a maximum of 1.4 solar masses (a key measurement known as the 'Chandrasekhar Limit' – the maximum core mass that can be sustained against internal collapse by 'electron degeneracy pressure'), the now unstable heart of the star suddenly collapses, and at the point of the last degree of compression possible (according to the laws governing subatomic particles) the layers surrounding the compact core rebound with the terrifying speed of a cosmic bounce – a kind of miniature Big Bang on a 'merely' stellar scale. The result of this is the ultimate drama: a gargantuan explosion in the form of a supernova, with newly created highly radioactive elements from the superheated cataclysm being spewed far into space. Such huge releases of energy can cause night to become day through vast regions of the galaxy, and any possible life on relatively nearby star systems to be totally wiped out. Aside from the fast-expanding shattered shell of highly radioactive, usually highly visible glowing material, all that remains in the aftermath is a tiny supermassive neutron star. This last core remnant of the former massive star is an orb of almost unbelievable density and small dimensions (a few miles in diameter at most), and consisting solely of neutrons: subatomic particles, where the Chandrasekar limit no longer applies. In the normal sense of the term, these stars cannot collapse further because of the laws of physics pertaining to the space that neutrons can occupy. Most of these exceedingly dense units of matter range from between 1.35 and 2.1 solar masses.

Some neutron stars become fast-spinning pulsars, but the largest among them have the likelihood of another type of final collapse into an abyss of their own creation – a black hole. According to theoretical physics, all stars being more than five solar masses will indeed become black holes at the end of their life cycles, supernova or not. A recent Chandra telescope observation and analysis of the prominent X-ray source SN1979C, the remnant of a giant supernova in M100, a galaxy in the Local Group and lying at a distance of 50 million light years, seems to confirm that it is indeed a black hole – unsurprisingly of at least five solar masses. While we are observing an event soon after it occurred, it nevertheless occurred long before humans walked Earth, and so what we know of this black hole, importantly from a historical perspective, uniquely reveals such a phenomenon in its infancy; however, we can only speculate about how things have progressed in the intervening 50 million years.

Other Varieties of Sudden Death

There are other types of supernova explosions that also take place with regularity in double star populations of galaxies, though the outcome is still roughly the same in intensity. Type 1a Supernovae appear to be the result of the interactions of two stars in a binary system, at least one of which may be a white dwarf star. The gradual gravitational transfer of matter from the more massive star to the lesser dwarf will eventually result in its core exceeding the Chandrasekar limit. The result is the inevitable cataclysm in the form of a supernova, once internal collapse and final rebound begins. Those categorized as Types 1b and 1c refer to massive stars that have lost their outer envelopes of hydrogen (Type 1b) or hydrogen and helium (Type 1c) by the stripping actions of a larger companion star which, in turn, creates an unsustainable instability. Regardless, for life forms of any solar system within 100 light years of a supernova, the chances of survival would be questionable at best, so we should be thankful that locally, in the Milky Way, there few stars within that range that appear to constitute a threat. However, there are one or two….

Lesser Explosive Outcomes

Because of the similarity of the terms, it would be easy to confuse novae, yet another life cycle outcome, with supernovae. One way or another, for stars too small to become supernovae, becoming white dwarf stars is usually the final stage for all of them. However, other than the explosive hallmark that defines both types of explosive stellar event, the differences are great, as the star exploding as a nova usually lives to see another day. For those that exist in a binary system, where typically a red giant is its companion, as with Types 1a-c, the gradual gravitational siphoning of hydrogen from the giant star to a more massive dwarf will eventually result in a colossal explosion, a sequence and outcome that may commonly occur multiple times in the same system. However, such a huge explosion is still in no way comparable in scale to those of supernovae, as it does not destroy the stellar core!

But the fact remains that the life cycles of all of these larger stars have nothing to do with the formation of dark nebulae, or dark and dusty lanes, and with one possible exception to the rule (the shattered debris formed in the aftermath of supernova explosions) will not involve dark features of any kind!

Regardless, at the end of stars' lives, one way or the other, the majority of their mass will have been sent back into the galaxy, either in the form of matter or energy. For average-sized stars, most of the matter of their original being will join the great reservoir of galactic dark nebulae, most of this ultimately to be reborn in reincarnations as new stars (see Chap. 3.) Supernova explosions do not eliminate future benefit to the galaxy, though. Much of the stuff spewed far into space from those vast cataclysms will be reused within the structures of new solar systems. Iron, one of the major components of the final stages of their life cycle, is produced in

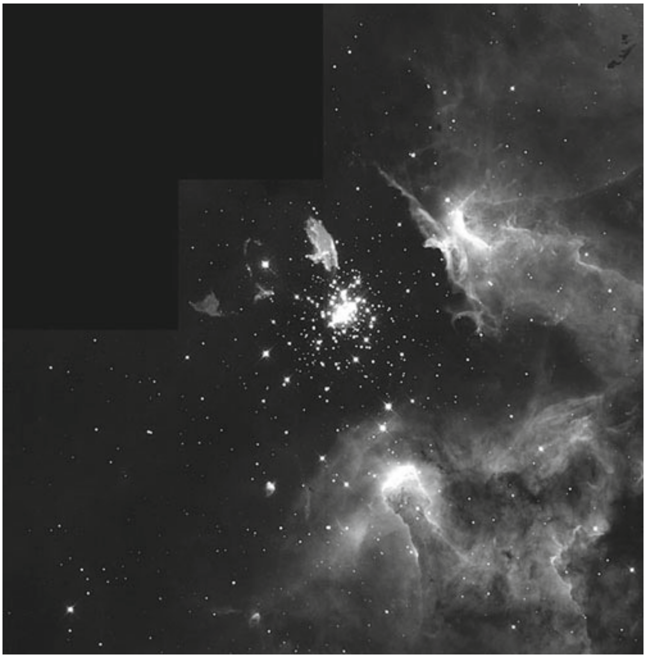

Fig. 1.7 NGC 3603 (Image courtesy NASA, ESA, & Hubble Heritage)

massive quantities in the fusion leading up to such events and is, of course, very common within our own Solar System. And there is a huge abundance of this element on planet Earth. In fact, all the elements heavier than oxygen require the mighty processes of supernovae for them to form, or those occurring immediately before. Many of these elements, often existing in only trace amounts in our midst, may be found throughout our own Earthbound environment, and so it seems that the flexible nature of our universe is never more evident than right in our own backyard.

In Fig. 1.7, some evidence of the life cycles of Population I stars may be seen firsthand. Columns of gas (more 'Pillars of Creation') may be seen here, apparently dark material collapsing into luminous (protostars), soon to become full-fledged stars. A cluster of young stars takes center stage in this image. The clarity of the surrounding space is striking, so the multiple stellar birth has not only used up most of the formerly unlit matter around it, but any remaining matter has been pushed away from the cluster by the winds of its own creation. We can easily see this effect on this image. Bok Globules may be seen to the upper right of the illuminated nebula (see Chap. 4). There is also a fine example of a nearby star at the end of its life cycle (named Sher 25): although casually, it resembles a planetary nebula, with the familiar ring formation, as well as a clear example of bipolar emissions on both sides at right angles to it (see Chap. 7), this particular star of some 60 solar masses is actually revealing its own precursor for a potentially huge supernova explosion.

In as much as none of the doomsday scenarios just described is anything we would wish to experience, they represent the varieties of ways that some of the existing stellar matter is returned to the galaxy, and often in the form of new stars. As long as there is the possibility for newfound nuclear reactions evolving out of any recycled raw material, the galaxy will remain a living, gigantic star factory. However, all star formation is destined eventually to come to a halt. Despite the constant process of matter being shed from stars that will never become supernovae, only a portion of these stars' total matter is recycled each time, the remainder being converted to energy. Insufficient star replacement will take place to sustain the universe in the long term. And for larger stars destined to explode as supernovae, those elements capable of enabling star formation ultimately will have been converted into heavier elements (remember, not all stars create star-generating matter by becoming planetary nebulae!).

Thus, all stellar formation will come to an end, all fusion will cease, and light and heat will gradually be extinguished. When that time comes, whatever is left over of the last stellar nuclei will slowly fade into the obscurity of brown dwarfdom, a slow decline into cold black dwarf corpses – to a place of ultimate darkness, stillness and cold, a graveyard that all matter eventually must occupy. The universe as we know it will fade into the ultimate abyss.

Although no star has yet been observed in a condition of being totally extinguished (becoming a black dwarf), it is only because the cooling time for any of them to reach that status still exceeds the age of the universe itself! Beyond this, we can only speculate, since no one knows for sure whether the cosmos contains enough mass to 'implode' via the theory of the 'Big Crunch' (it seems improbable), possibly to start the whole process over again, or just expand into infinity (the 'closed' and 'open' models of the universe). Unfortunately and regardless, observing such esoteric darkening stellar remnants is beyond the resources of the amateur observer.

Meanwhile, a truly remarkable website (courtesy of Cornell University Library) and resource to past and recent astronomical advances may be accessed at: http://eprintweb.org/S/authors/All.

Many items relevant to dark attributes in deep space objects may be found on this site. By opening the astrophysics tab and entering the last name of any astronomer (a two-step process), a seemingly countless file of full research papers on every facet of cosmology may be found and downloaded. Its value cannot be underestimated, although one has to spend considerable time to find specific files.