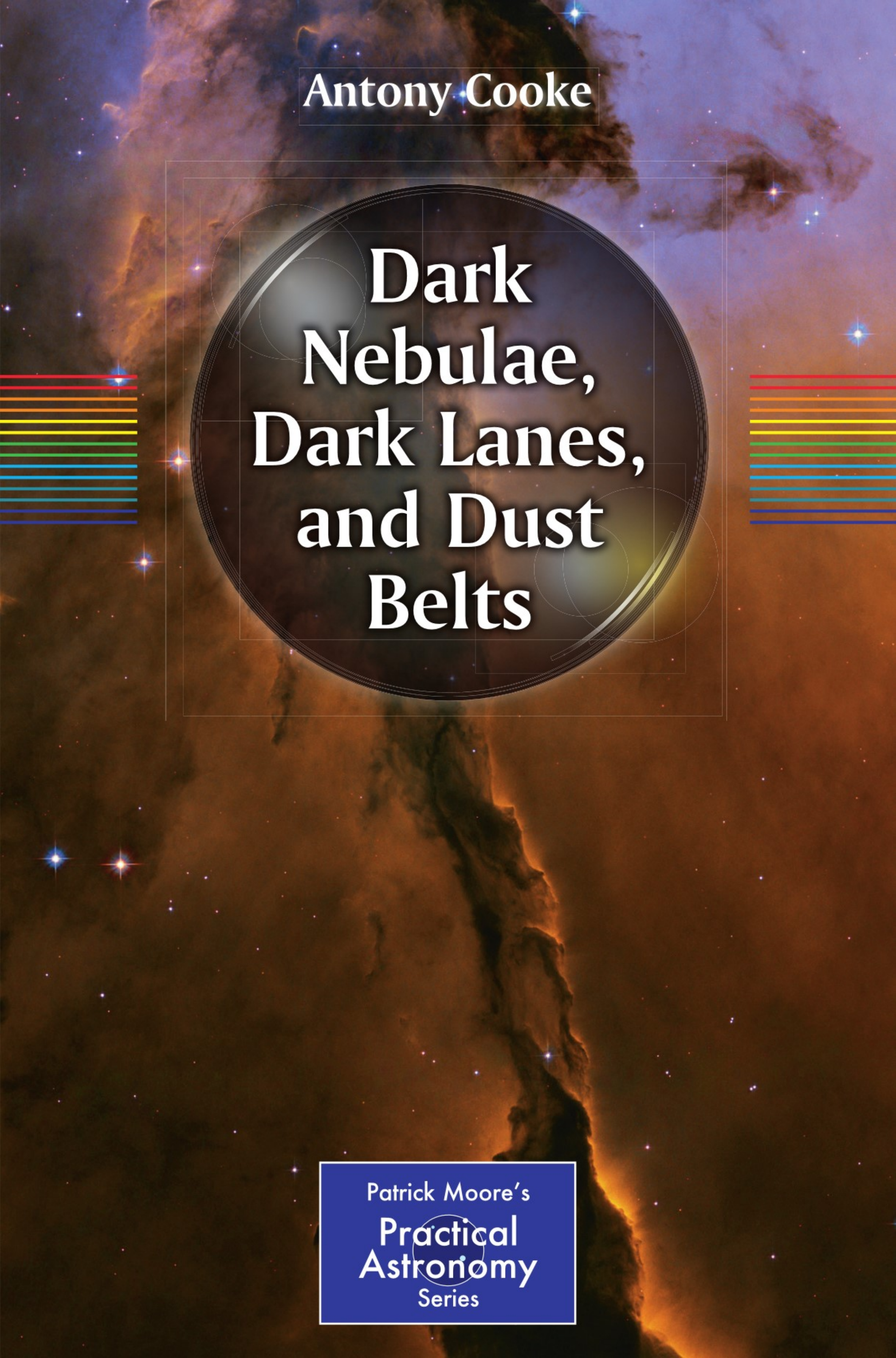
Antony Cooke

Dark Nebulae, Dark Lanes, and Dust Belts



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Dedicated to Tim Sprinkle, my fellow aficionado of the dark skies. His loyal friendship and enthusiasm for astronomy are only equaled by a willingness to help me haul my bulky equipment out to the wilderness, and most often in conditions that would make those fainter of heart stay at home.

About the Author

Antony Cooke's passion for both astronomy and music was clear from an early age, although it was music that ultimately claimed his career. As solo cellist he has played and recorded worldwide. He was also a professor of music at Northwestern University in Chicago. Presently, he is a prominent Hollywood studio musician, as well as a composer for prime time television. However, it has often been said that science and music go hand in hand. With applied and theoretical astronomy never being far behind, he has pursued it as a serious avocation.

As an observer always looking for ways to improve his experience at the eyepiece, Cooke has constructed many telescopes over the years. Increasing apertures were always the hallmark of his often-quirky designs. Finding that the 18-in. aperture of his present telescope was still insufficient to deliver the kind of performance he had in mind, he experimented with newer technologies to bring these elusive goals ever closer. Successful viewing of dark objects requires great contrast. In this respect, some of the newer equipment has proven to be invaluable, enabling dramatic viewing of many dark objects and features in real time and without the need of CCD imaging.

As an author of astronomy books, Cooke also has written *Visual Astronomy in the Suburbs* (Springer 2003), *Visual Astronomy under Dark Skies* (Springer 2005), and *Make Time for the Stars* (Springer 2009). With *Dark Nebulae, Dark Lanes and Dust Belts*, his astronomical writings continue.

Contents

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

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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

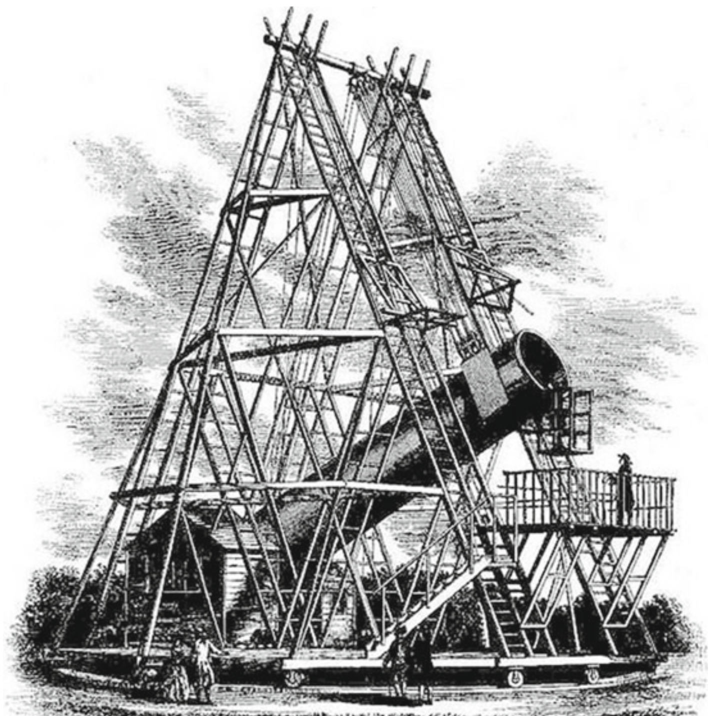

Fig. 1.4 Herschel's 40-ft telescope

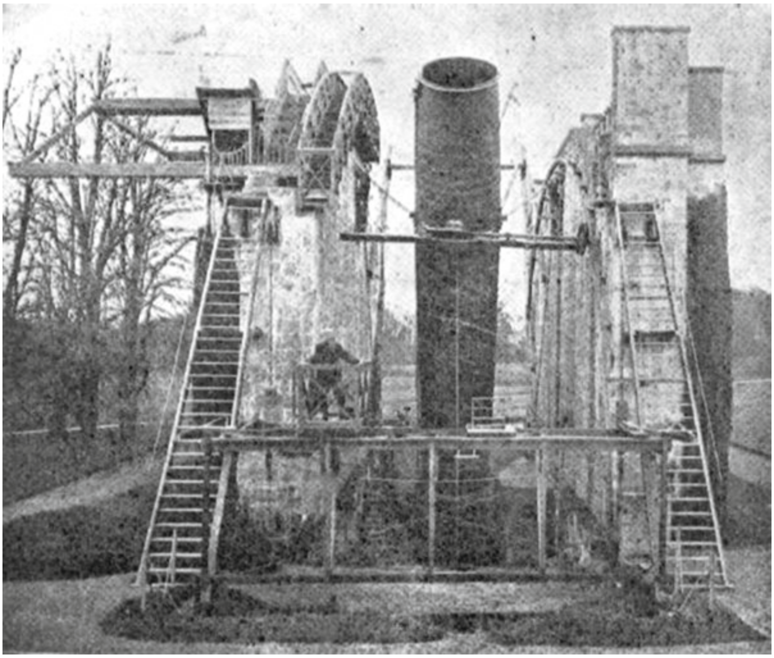

Fig. 1.5 The 72-in. 'Leviathan' of William Parsons, 3rd Earl of Rosse, 1845

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.

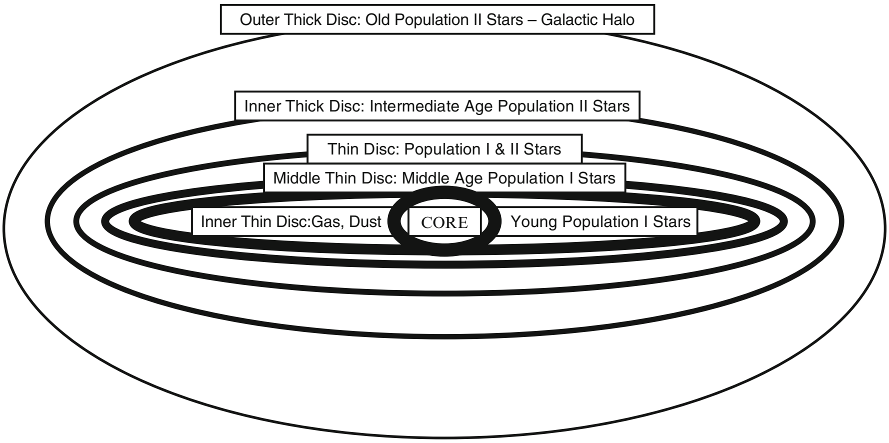

Fig. 1.6 Distribution of star populations in the Milky Way

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

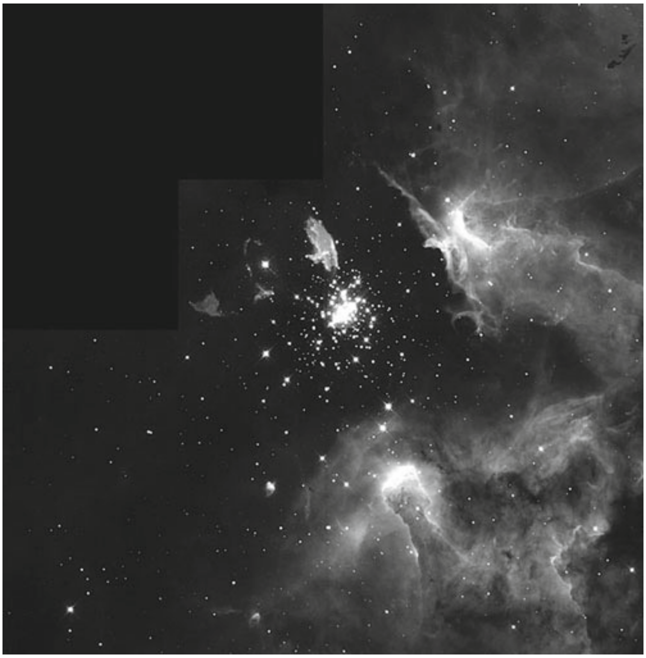

Fig. 1.7 NGC 3603 (Image courtesy NASA, ESA, & Hubble Heritage)

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.

Chapter 2

Defining Our Viewing Parameters and Methods

Since this is first and foremost a book for the observer, let us clarify the use of any term referring to 'dark' things in space, and discard all those that we cannot physically see for ourselves. First we need to deal with the ultimate of dark subjects: dark matter and dark energy, likely the bulk of the mass and energy in the universe. However, while accounting for as much as 95% of the total, and being completely invisible, the combined effect of the two is accountable to researchers attempting to analyze the expansion and total mass of the universe. To date, there are some plausible theories concerning these mysterious components of the universe, and these are the only explanations we have for the apparent giant deficiency of mass and energy in the cosmos. Separately or together, they are successfully implied, even proven, and indirectly observable in measured galactic rotation, orbital velocities and temperatures of galaxy clusters, as well as in the readily seen imaged gravitational lensing of galaxies and other objects located far beyond (see Chap. 1, Fig. 1.3) – even within the Milky Way itself.

Dark matter itself is reckoned to be the dominant component of galaxies, appearing to constitute *most* of all galaxies' mass or control over their development; apparently dark matter entirely fills each galactic halo (the vast, roughly spherical matter all around, 'above' and 'below,' all galactic discs, including those regions with a very tenuous stellar population). Regardless, in the sense of all we are considering here, is not dark matter itself, or its effect upon the order of the universe, observable within any deep space object; the prospect of seeing it is still not within the parameters of the average observer or any other. Therefore, it is important that the reader not confuse the subject at hand in this particular writing with this most baffling, and perhaps most significant part of the universe, yet to be understood or properly defined.

By the same measure of what is meant by the term 'dark,' let us also exclude from this discussion all of those other extremely subtle cosmic discoveries that

A. Cooke, *Dark Nebulae, Dark Lanes, and Dust Belts*,
Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4614-1186-4_2,

often utilize the same or similar terminology but are applied to a different class of celestial phenomena entirely. These are also not normally observable, at least in the generally accepted sense of the term. In recent years, advanced space age technologies have uncovered dark lanes even around individual stars (likely comprising matter for forming solar systems), or even leftover dark and dusty matter around planets (such as in the case of Neptune, where a dark mantle many times the planet's diameter orbits around it). The term 'dark lane' has even been used to describe certain near-undetectable features in the white icy Martian polar caps.

The list can go on, but suffice it to say that these types of phenomenon cannot be included for the purposes intended here, especially since it is unlikely any of them would be even remotely possible to observe with the means normally available to most observers. And it is hardly necessary to comment that we will not be expecting to see that most feared of dark phenomena – black holes – yet to be observed or imaged by any means. However, as in other cases of esoteric questioning, it has been possible for major research institutions to observe and measure the effects of them. (The effect of a massive black hole at the heart of the Milky Way has been studied from observations – made in not normally visible wavelengths – of stars circling around its extreme inner core.)

What we will look at, however, includes many examples – some notable – from among those that typify the traditionally accepted definitions of the terminology (dark lanes, dust lanes, dust belts, dark nebulae), and which include the dusty mantles encircling and permeating many galaxies, the mysterious dark tentacles and lanes crisscrossing many globular star clusters, occasional dark bands and mottled regions within some planetary nebulae, dark voids within our own star system that snuff out clouds of background stars or luminosity (i. e., Barnard's Dark Nebulae), those unlit and partially lit portions within otherwise bright diffuse nebulae (especially star-forming regions of infant open star clusters). Supernova remnants commonly contain dark details that contribute much to their visual splendor, even if their makeup is not truly dark. More than a few mature open star clusters (those that have mostly emerged from their cradle cocoons of creation) also command a little attention, not because of themselves but because of remnants of dark lanes or unlit regions that seem to be revealed in their midst. Overall, it seems there is considerable potential. However, the very nature of these phenomena requires a more subtle approach than with most others.

As astronomical observers, often it seems there are few extremes to which we will not go in order to gather every possible photon of light from the remote reaches of space. The obsession to extract the maximum from whatever may be there is only normal, after all, since the universe, as we know it, is only defined to our senses by what we can see. It's our natural common compulsion. However, it seems that whatever we are able to see is never enough, brilliant enough, or sufficiently telling in detail to lay the monster to rest. Indeed, the reality is that we are always grasping at shreds of detail, and those shreds of detail that we are able to see always lie tantalizingly close to the visual limit – which explains the popularity today of imaging over actual live observing in the amateur community.

Regardless of our approach, though, as observers of one type or another, the countless faint glowing specks and diffuse patches that populate the vault above continue to beckon us all – almost hypnotically. Thus, the never-ending, age-old ‘disease’ (sometimes termed and well-known in astronomical circles as ‘aperture fever’), which affects (infects?) the majority of observers, is always a constant reminder that the cosmos will only begrudgingly yield its secrets to mere mortals. However, those very difficulties we encounter as observers should also be a constant reminder of the need to remain open to any and all means available that may enhance the performance of whatever equipment we already have, whether our viewing is live or via imaging. Strangely, different approaches, and especially new technologies, have become competitive issues to many in the amateur astronomical community – even sore spots – as what is considered an acceptable method to one is an anathema to others. (As primarily a live observer, this author, too, has been guilty on occasion of not being too eager to praise the more indirect methods of observing, such as CCD imaging. Guilt indeed.) Even the word ‘cheating’ has been used when describing certain means other than those ordained by others! However, shouldn’t the objective only be to *see* more? We should all keep this in kind before dismissing anything out of hand.

In the ongoing quest for more light and better vision of one kind or another, it is all too easy to overlook the fact that dark objects in space are only visible as a consequence of being observed as a kind of cosmic silhouette against glowing backgrounds; they may even appear to shape many illuminated subjects. As any avid observer knows, dark structures in the cosmos consist of more types than just the familiar dark nebulae of the Milky Way, although many have much in common. Whether viewing ‘local’ spectacles, such as star clusters, illuminated and planetary nebulae, or examining details in far-flung distant galaxies, one would be hard pressed not to notice the many dark and dusty lanes, belts, streaks, spots, and voids that characterize or punctuate so many of them. Perhaps many of us have spent only a little more than superficial time exploring these phenomena, let alone really contemplating or even fully comprehending their significance.

What Types of Dark Feature Can We Expect to See?

Some straightforward, easily observed examples (Fig. 2.1a–h) typify the various categories of dark features that form much of the basis of this book, and that we can expect to be able to observe. While being among the most prominent, and readily observed examples, they clarify the essence of what is being discussed, even though the majority are not likely to be quite so accessible at the eyepiece. Most of those shown in Fig. 2.1 may be seen even with fairly small apertures (though with larger ones, naturally they will appear more striking and detailed).

(a) Within the ‘Lagoon Nebula,’ M8, the bright open cluster of newly forming stars irradiate and effectively illuminate the surrounding molecular hydrogen (HII) gas, which serves as a backdrop for the many dark lanes transecting it.
(b) The famous ‘Propeller Lanes’ – the first such dark features to be noted in a globular cluster – show readily at the 2 o’clock position towards the right upper side of the Great Hercules Cluster, M13.

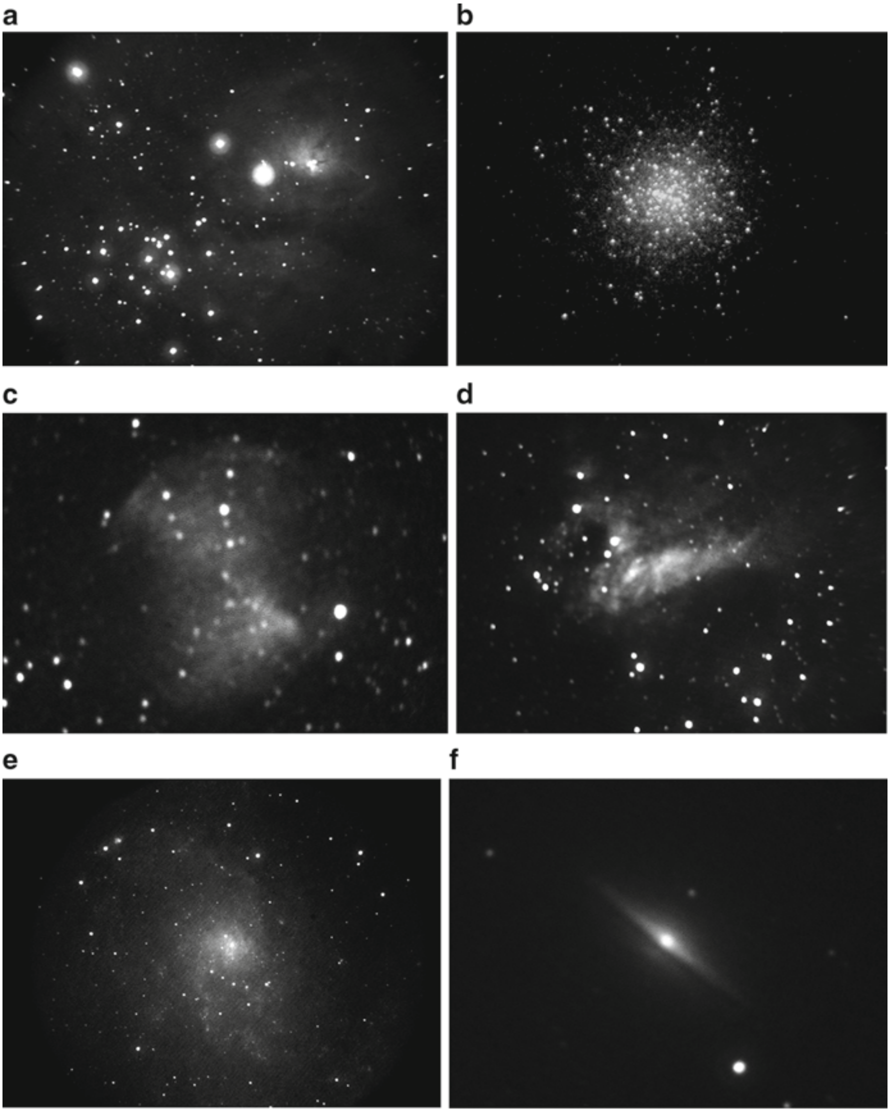

Fig. 2.1 (**a**–**f**) Deep space objects showing dark features (**a**) M8, the Lagoon Nebula; (**b**) M13, the Great Hercules Cluster; (**c**) M27, the Dumbbell Nebula; (**d**) M17, the Omega Nebula; (**e**) M33, the Pinwheel Galaxy; (**f**) M104, the Sombrero Galaxy; (**g**) M82, the Starburst Galaxy; (**h**) M1, the Crab Nebula (Images by Antony Cooke: standard digital camera, 18-in. Newtonian Reflector, Generation 4 image intensifier; exposures from 1 to 10 s)

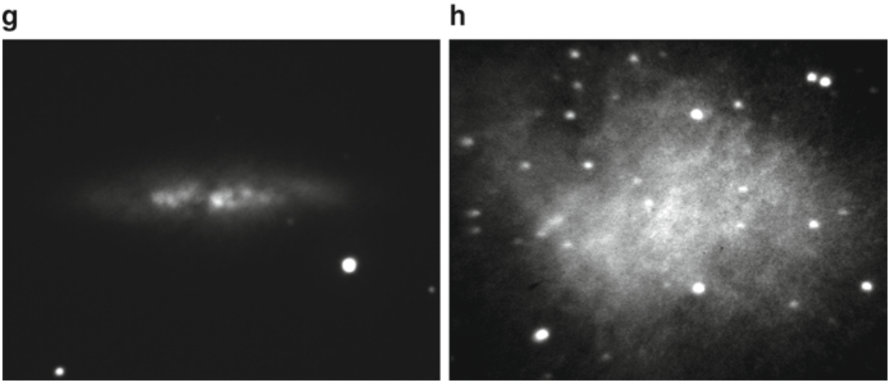

Fig. 2.1 (continued)

(c) Within the planetary 'Dumbbell Nebula,' M27, can be seen many dark details including intriguing concentric striations, presumably produced by variations in stellar wind vibration and difficult to detect by most means of observing (see "Viewing Skills, Accessories and Other Considerations" later in this chapter).
(d) The 'Omega Nebula,' M17, illuminated by young stars and defined by dark nuances. Even the surrounding space is made noticeably darker on one side than the other by the presence of dust.
(e) The 'Pinwheel Galaxy,' M33, is notable for its many mottled HII regions in its spiral arms (the largest being similar to our own 'Great Nebula in Orion,' M42), as well as dark details (interstellar matter) throughout the whole structure.
(f) The prominent dust belt surrounding the 'Sombrero Galaxy,' M104, is the defining feature that characterizes its appearance, in addition to the slightly oblique but otherwise edge-on, presentation relative to us.
(g) The striking bipolar character of this Starburst Galaxy are on full display to see, appearing as dark features intersecting the core at near right angles to it; the galaxy is bright and substantial in the field of view, and the detail is plentiful and complex.
(h) Remarkable irregularities are visible in the overall structure of this star wreckage (the remains of the supernova of 1066); while dark features in such objects are not common observing fare for observers, occasionally a few such details may be present and justify the effort at the eyepiece, as can be seen in this rare example.

While the dark regions and details shown in these examples are immediately obvious, hopefully they will serve to suggest a little of the enormous viewing potential awaiting the observer. More interesting, ultimately, are the many subtle and specific nuances and shapes comprising each dark feature, as we delve a little further and deeper into each one. Indeed, it seems there are no two such structures or features quite alike.

Preparing the Eye for Observing

Dark lanes or features may be elusive in nature, since they are not illuminated, after all, but contrasted against what are usually pretty faint illuminated larger regions. As an approach to preparing for a viewing session, perhaps the best first step might be to seek out fine images from a large observatory, the Hubble Telescope, or possibly exceptional amateur examples, *if* appropriate ones can be found. By the word appropriate, the inference is that the images are not awash in light, eliminating any subtle dark detail in order to show what is illuminated. It is all too true that whereas imagery of the Hubble Telescope and other advanced instruments are serving us much better these days, you will likely often be disappointed to find how wildly overexposed the central regions of many subjects are in order to show the full extent and glory of the spectacle. The upshot is a magnificent sight, obtained, though, *usually at the expense of those very dark features that we might have hoped to see with our telescopes!*

Those very bright regions are what make dark features visible, of course, but usable exposures on these images cannot be taken for granted. However, the listings of objects at the end of each chapter of this book reference the features under discussion, a little pertinent information for each object, as well as listing suitable images that are available online wherever useful. There is nothing better than examining in advance a good representation of what one is looking for, or hoping to see. Sometimes previously missed faint dark features 'jump out,' or at least take on new significance in the live view when we are better prepared. Naturally, some of these referenced images are more helpful than others; many may be simply too low in resolution to help in defining subtleties of the type we might hope to see at the eyepiece.

Thus, because of the intended purposes of much observatory imagery, keep in mind that live viewing often produces surprisingly different visual impressions of everything we see. This is particularly noticeable with images of globular clusters, which may be unrecognizable in their real time counterparts. Although the details shown in such grand imagery are not likely to be visible at the eyepiece, those that we *might* have seen are all too often erased by the brilliant stellar illumination all around as it intrudes into everything in the frame. Many such examples of globular clusters show finely resolved stellar populations right to the cores, while appearing completely devoid of any evidence of the dark lanes that have become the source of much discussion and controversy. Frequently, this is due to the length of exposure that allows some of the light of stars *behind* the dark obscuring material to penetrate and register, or perhaps it is the finesse of the image (as in many Hubble Space Telescope examples) that actually detracts from the eye's sensitivity to noticing subtle irregularities. Rest assured, the lanes, at least as we know them visually, have not disappeared! It is a sad fact that a healthy supply of appropriate images of globular clusters, and often many other deep space objects – that we might have hoped to use as a guide – simply don't exist in most readily accessible reference sources. Whenever you are fortunate enough to find them, you might try to affect a kind of reversed mental polarity (in approach if not actuality), where you consciously allow any dark features to define what you see, and not the other way around. This can be applied in live viewing, too, of course.

The challenge of finding appropriate resources doesn't stop with images but also, surprisingly, extends to written reference materials. For the most part, you will soon become aware that within commonly available sources, to find anything beyond the most general or superficial remarks, even the most basic descriptions about dark regions and features is also something you cannot take for granted, because usually all of the attention is focused instead on what is illuminated, or on other more esoteric aspects. It remains an unexpected challenge to find insightful, detailed information or descriptions about any of these dark phenomena. And certainly, it is rare to find in detailed discussions about specific deep space objects more than the mere acknowledgment of to any features' existence – if anything at all. Perhaps odder still in many respectable sources is the frequent omission, or even the slightest reference, to *celebrated* dark features, now generally well-known and regularly sighted, such as, for example, the famous 'Propeller Lanes' in the great globular cluster, M13, in Hercules (Fig. 2.1b).

The observer should always remember to bear in mind, though, that just because part of any subject may appear dark, it does not necessarily follow that dusty matter is present; it may be that there is simply nothing there! In other instances, dark details may be merely less luminous portions of a whole. Regardless, once our interest in looking for such features has been prompted, it is likely that we will always look at everything just a little differently, just to make sure we don't miss anything. And viewing is still likely to be interesting when we are not seeing true dark features, because what is merely *less* illuminated still may appear to be sculpting what we see.

Actually, while many amateur observers have pretty much ignored what is unlit in the universe, they are in good company. Apparently, most of the great observers of the past have given the subject surprisingly short shrift, too, as specific and detailed descriptions of cosmic dark features seems always to have been in short supply. Among those 'big league' astronomers, certainly one notable exception was the legendary E. E. Barnard, who was so fascinated by one type of dark phenomenon – the dark nebulae of the Milky Way – that he cataloged and carefully plotted them, 370 in all. There are, indeed, in Barnard's catalog detailed descriptions of these phenomena, although perhaps not all of them are necessarily helpful to the amateur observer. However, at least it would be good to find the same level of readily available descriptions for everything else that is dark in space, too. Thus, this book is a small attempt to begin to redress the overall imbalance for the observer, especially one who has access to a moderate-to-sizeable telescope and some decent viewing situations – that is, dark, transparent air.

For obvious reasons, within this writing we cannot look into more than a fraction of all that there is to see. But with the degree of attention accorded those selected for analysis in this book, there should be enough to ponder that it might cause the observer to re-examine alternative viewing approaches and some interesting new potential targets.

Viewing Skills

- First of all, for seeing any dark features or detail, there is nothing to beat dark sites and dark adaptation. The cosmos is never awash in visible light for the amateur observer, and contrast remains the key. Thus we need to maximize whatever ability we have to register the very light against the dark features that show. Always allow a little while for dark adaptation before any serious observing begins – just 20 min away from light sources should accomplish much of the benefit we need. However, with enhanced electronic viewing devices (see later) of all types, their viewing screens are so brilliant relative to anything we are used to in astronomy that much adaptation won't even be possible, let alone necessary! We will, however, still need dark skies.
- Remember that only the central portion of the retina provides detail in vision (the macula), and the outer portions are the most light-sensitive. That old skill known to all seasoned astronomers as averted, or indirect, vision, will reveal dark regions and details better than anything else, plus it costs nothing! While there are differences among many in the astronomical community on how much boost it can actually provide, there can be little doubt that successfully utilized, it can result in near dramatic gains in whatever the eye is able to detect.
- The word 'detect' is the key here, and while our peripheral view of the world shows nothing like the amount of detail we see in the central field, our first consideration is becoming aware of otherwise elusive sights. Once spotted, 'seeing' them more readily with ones' central part of vision becomes almost a routine. Typically, most people who have never spent any time with a telescope in the dark are unaware of this benefit. Others may suffer from the terrible medical deterioration of the central vision known as 'macula degeneration,' and will be all too aware of this critical aspect of eyesight.
- You might experiment with what part of the eye's field of vision is most effective; many observers feel that the inner part of the field is more sensitive than the outer, although this writer does not recommend one over the other. However, all of our natural reflexes try to bring our attention towards the central macula as we observe. Thus, the skill of this part of astronomical 'seeing' involves learning to steer one's visual reflexes away from the brain's natural visual 'programming' to center the image for detail. Instead we have to apply them to a technique that defies all of our instincts: scanning the image around the periphery – something that requires practice and patience to fully master. It is made all the more difficult by the eye's tendency to 'flicker' around the field in protest. However, once mastered, new details suddenly appear more readily.

- Additionally, from time to time you might throw the image in and out of focus; the newly focused image seems to refresh the eye, and details seem more readily revealed. The eye also seems to benefit from starting to focus again from scratch, and perhaps we will find that the point of sharpest focus seems to vary by tiny amounts. We can only assume that the eye may impose certain focal adjustments of its own that may put additional strain on it; relieving this strain could therefore only benefit.
- You might try periodically tapping the telescope tube – thus taking advantage of the sensitivities of one's vision to motion in order to snare subtleties in the field of view that may initially escape attention. It may even help in initially locating an object, after which the object seems to take on increasing prominence. While we know that cats' vision is dominant toward motion, humans also share a degree of the same sensitivities.
- There is also the matter of determining ideal illumination in the eyepiece view via the magnifications we select. If there is too much brilliance, often by utilizing too low a power, any subtle dark features could become washed out, something certainly true of many time exposures. Although the eye does not store light in the same manner as do time exposures, it is not able to prevent the encroachment of light on surrounding areas. The way we see brighter stars as somehow larger than dimmer ones illustrates this well. Thus such underutilization of magnification only contributes further to any existing lack of awareness we might have of the dark features themselves.
- In a seeming contradiction, it is also true that many deep space subjects only reveal their true dark details to the maximum extent when subjected to magnifications that one would normally consider ridiculous for faint subjects, but such powers may be effective through the unique attributes of the particular object under scrutiny. After all, decreased illumination in the eyepiece would also seem to mean less contrast – at least theoretically that would seem to be the case, but in practice that is not how it plays out. The eye has certain inexplicable attributes with regard to its specific sensitivities, although highly subtle indeed. Only trial and error will determine which power selections to use. Therefore, always take the time to try several magnifications *for each object in view;* there will always be one with which dark features stand out better than the others. Any skilled observer has experienced these seemingly inexplicable quirks of optics and vision, and probably is at a loss to explain them.

Utilizing these simple techniques adds to our 'seeing' skills – the ability of the eye and the brain to extract and transmit any and all scraps of visual information, ultimately assembling what we 'see' by assembling them into a composite, an amazing testimony to the special human abilities to put such a jigsaw puzzle together. While the process sometimes may be slow, the effect of it is that whatever is eventually perceived to be present in the image becomes obvious, but only after the fact! The upshot of all of this is so striking that one can hardly imagine how these subtleties and details were not easily seen at first glance.

As with all things in practical astronomy, in addition to these viewing skills and others acquired over extended time at the eyepiece, good viewing conditions, a minimally light-diffracting telescope, and some additional specialized types of equipment can all help further with the rather delicate subjects we are looking at. And dark features are always delicate subjects to be sure. Plus, while no special additional equipment, beyond the normal hardware amateur observers use, is actually a *necessity,* in order to participate most effectively there can be no doubt that certain filters and electronic devices (most are highly infrared sensitive) do show dark regions better – and also reveal some that would otherwise be invisible. Also by ramping up the illumination of what we see, they provide increased contrast and even ease of viewing. Indeed, if the opportunity allows, it is interesting to observe these objects through a succession of natural, filtered, and intensified viewing, (and still through as wide a range of magnifications as the subject will allow). In each of these methods of viewing, quite a noticeable variety may be seen, when just as strikingly different aspects become more or less prominent.

Equipment, Accessories, Viewing Skills, and Other Considerations

Telescopes

Astronomy has always been tied closely to the development of optics and telescope design. It has only been possible to ascertain proper scientific conclusions with the advent of more sophisticated means of probing the cosmos, and thus, we cannot blame earlier observers for incorrect conclusions they may have drawn; they were only able to deduce what they did from the quality of information reaching their eyes and minds. Indeed, we can only marvel at just how much they were able to accurately determine. We benefit today not only from better optics than many earlier observers had at their disposal, but also from a better understanding of the many subtle nuances of the subjects we are seeing. Although all of them may look dark, certainly they all do not fit the same blanket description!

Because one cannot overemphasize the critical need for contrast in observing anything dark, that is, the degree of illumination versus a similar degree of darkness, success is thus tied to aperture at the most superficial level. It is also tied to optical quality and design. In this regard, modern instruments hold a tremendous advantage over those available to earlier astronomers. Thus, while all telescopes today probably will deliver greater contrast than anything available not so long ago, obtaining the maximum potential contrast is only as good as the telescope design will allow. Considering what is available, many optical and mounting designs are, quite frankly, less than ideally suited to delivering this important attribute. It is dependent on various factors, including introducing too much scattering and diffraction of light, instability of the assembly itself, even awkwardness imposed on live observing, all of which degrade either the image or what may be gained from the efforts taken, to a greater or lesser degree.

There is no shortage of comments regarding the relative merits of different types of telescope, but a few additional words emphasizing an all important ingredient – contrast – for revealing best all that is contained within this book would not be out of order. Telescopes with large secondary mirrors, for example, such as the very popular lens/mirror catadioptric designs, are among the least suited to this form of astronomy (to say nothing of other forms of it), because of their huge, light scattering secondary mirrors, as well as the light absorption caused by the additional corrector plate optical component. Although they may be capable of giving us fine images through later computer processing, for live viewing, regretfully, they are much less than ideal. And poorly mounted instruments that vibrate, wobble, do not allow fine adjustments, are awkward to manipulate, or that otherwise react unfavorably to every tap and gentle wind gust will likely prove just as damaging to the eye's ability to resolve fine detail, especially the ever-subtle and elusive character of dark objects and features.

Perhaps surprisingly, more than a few dark objects and features will provide dramatic views at the eyepiece. However, aside from a crucial need for the darkest skies and most transparent air possible, having a few extra tricks up our sleeves will be found to be helpful. A good, larger pair of binoculars will prove invaluable, or an extremely low power, wide aperture scope. Once commonly termed a 'richest field' telescope (RFT), this might prove even better for all but the smaller nebulae. Many of these nebulae are extended objects that will not only benefit from wide fields of view but also the increased contrast that low powers bring about.

Refractors, with no secondary mirrors to cause diffraction, may appear to be an ideal choice for our purposes, but still need to be approached carefully, as they present other detrimental issues all of their own. For sufficiently large apertures, most achromatic telescopes of this variety will prove too costly to buy and come with a host of other drawbacks, not the least of which is chromatic aberration, especially among the larger sizes, along with drastically increasing weight and unwieldy lengths with every inch of aperture gained. Chromatic aberration, appearing as bright color fringes around focused objects, and not completely solved by the development of achromatic lenses, would tend to eliminate these telescopes as an ideal choice for seeing subtle dark details near the periphery of any object, along with rapidly increasing problems of this type seen in the larger examples. And this is even if apertures approaching the much more typical amateur Newtonian (8 in. and larger) were practical from a cost standpoint. As a final comment, it is fair to say that the color-fringed images seen in any of these larger achromatic refractors would shock habitual users of almost any other type of modern telescope.

Apochromatic refractors were designed to overcome all such chromatic aberration problems, and certainly they do; they offer almost faultless performance in this regard, along with reasonably compact focal lengths. However, while likely to be the best of all, optically, of all the refractor family (indeed, of any other?), sadly their extremely high price relative to aperture makes them a questionable choice for most amateur budgets, at least if live viewing is your main priority. For imaging, they can hardly be faulted, despite the fact that resolution is still commensurate with aperture. Regardless, some remarkable amateur imagery has been produced by surprisingly small apochromatic refractors – although not more so than with fine Newtonian reflectors of little more aperture – but the apochromatic refractor's very compactness compared to other refractors (typically featuring focal ratios far lower than normal achromatic varieties), and simplicity of use may make such a telescope the choice of the astro-imager on the go, if not the live observer of subtle deep space objects. Perhaps the more significant downside, though, is obtaining them in larger sizes – unless money is no object, and portability not a requirement – because they rapidly become disproportionately heavy and costly with increasing size. Prepare to be stunned by the prices of these larger sizes. Those that the average observer is likely to have will not usually exceed 7 in. (17.5 cm), and in fact, in the commercial marketplace significantly larger sizes than 7–8 in. are actually unknown to this writer. Even then, this still does not deal with the type of telescope that offers the most ease of use from a visual standpoint. And sadly, it is not the apochromatic type. For live viewing, as opposed to imaging, considering that virtually all varieties except the Newtonian require that the observer to peer in from underneath (or use a diagonal, which further reduces image brightness), this seemingly innocuous characteristic is more significant than it may seem at first blush. And we should fully realize that larger apertures of good quality always produce more detailed images than comparable smaller ones; thus, for my money, this brings us back to the Newtonian. Other types of reflector still do not have equal advantages and come with other drawbacks of their own.

The Newtonian reflector design (actually known formally as dioptric) ought to be taken more seriously by those all too quick to ignore its lineage, performance, and sheer value. It is still the best overall telescope for the money and comes with some significant advantages over any other design. Isaac Newton, the scientific colossus, not only produced the exquisite design itself (a more pure form there never has been), but he solved the problems of optical mirror making to the degree that reflecting telescopes finally became practical.

Because we are looking for contrast above all, Newtonians with longer rather than shorter focal lengths feature smaller secondary mirrors, and, in addition to their optical simplicity and purity of design, scatter the least light and will thus prove the best contrast performers among the reflector breed. For maximum results, however, many may suffer from too large a secondary mirror in configurations of short focal ratios; try to select one with a diameter less than 20% of the primary. Even less, say 15%, is better yet. However, since all Newtonians are virtually certain to utilize secondary mirrors with appreciably less than the huge catadioptric secondary average of 35%, a good one will provide infinitely superior viewing (especially of subtle subjects in deep space) than any of these telescopes would offer at the best of times.

It is worth pointing out that the telescope used for all of the author's imaging in this volume is of the Newtonian design, but its F4 configuration and 22% secondary mirror makes it less suited than would be those of longer focal lengths and smaller secondaries. However, in practice, the quality of the telescope and its substantial 18-in. aperture (to say nothing of its outstanding mechanical design) certainly compensates to a large degree, and most observers would be hard pressed to tell too much difference between this instrument's performance and one with a secondary mirror significantly smaller. The payoff is, of course, that such telescopes, with their short focal lengths, have made what would have been truly sizable and unwieldy instruments of yesteryear quite practical today, something we must always consider when transporting our equipment to places where the sky is truly dark and transparent. Long focal ratios and small secondaries in this configuration are capable of delivering results not significantly inferior to the best refractor designs, contrary to popular misconception. It is fairly safe to say that the very best refractor would still not perform much better than a fine Newtonian of perhaps no more than a third larger. However, such telescopes are likely to be more difficult to transport to favorable sites, if not impossible.

Remember, above all, for seeing dark detail, we need light grasp, along with good optical quality and design if we are to have the best resolution and contrast possible. This means optics that are clean and scratch free. In addition, the telescope preferably should have ease of use, portability (in order to get to dark sites), and, presumably for most people, the affordability that still allows all the other requirements! These qualities are the name of the game. None of the things featured in so many commercial products today (all those fancy electronic 'features'), which cost so much and deliver so little in terms of viewing itself, are likely to provide a real return for the money. With the exception of good digital setting circles (which become quite critical when tracking down dark shadows of the night), there are few such features that offer value in line with the high cost at which many of them come.

Regarding suitable apertures, for live viewing of all dark subjects and features, sadly it is not realistic to expect *exceptional* views of anything other than the most prominent dark objects (and thus, relegating the potential to those relatively nearby), with apertures much less than 8 in. (for a reflector). While lesser sizes are far from useless for the purpose, only more substantial apertures than these will have any realistic prospect of resolving the more subtle features and details, especially the least obviously dark ones at that. By way of differing eyesight capabilities as well as viewing skills, some observers might disagree and lower or raise that number somewhat. However, hardly anyone would disagree that the true realm of witnessing deep space at the eyepiece, and accordingly being able to see potential dark features, lies with apertures significantly *larger* than the minimums any of us might recommend.

Thus, it is fair to say that the best potential *for viewing at the eyepiece* is most likely to be delivered for most observers using telescopes of 12–20 in., and in good conditions. Otherwise, a more indirect approach with smaller apertures, utilizing time exposure or compound imaging of one type or another, may be the only avenue for the serious observer in order to best pursue what is described here. While indirect forms of observing may suit many, it will not suit all, although it does enable telescopes of apertures much smaller than those discussed here to offer surprisingly impressive results. And while image intensifiers (more below) enable moderate apertures to perform with the light grasp of much larger ones, resolution is still dependent on aperture itself; however, contrast will be enhanced. These devices really come into their own when coupled to the more imposing apertures available to amateurs, such as the the range just mentioned. As with everything else in astronomy, ever-increasing apertures of high quality (and hence ever-increasing light grasp) will deliver ever-increasing results.

Specialized Filters

Despite the fact that many of today's advanced polarizing filters were originally designed to soak up the sky glow of cities, they often do noble service in dark conditions, too, by blocking competing wavelengths within or even around the objects we are trying to study. Once this potential was realized, many different types of specialized wave-blocking filters would soon emerge, produced in numerous varieties.

Common in the marketplace today, no manufacturer offers a more sophisticated or prolific range than those offered by Lumicon (now owned by Parks Optical). With the use of these specialized filters best suited to different objects, some objects appear distinctly more luminous than with unaided viewing – perhaps surprisingly even under the best and darkest of conditions. Subjects seem to stand out from the backdrop much more noticeably, and many dark regions often take on new prominence. Although there are so many different filters, it is fair to say that only narrowband varieties are truly useful. However, keeping an open mind and trying whatever may be on hand still remains the best approach. By this, you can take it that some of the broadband varieties intended for general purpose are of limited value to our special needs, but you should probably try them anyway. One never knows what experimentation may bring with any particular object.

Some of the more sophisticated catalogs of such products are worth perusing. Lumicon's specialized filters for general deep space use include Ultra High Contrast (UHC) filters for enhancing illuminated nebulae, Oxygen III (doubly ionized oxygen) filters for certain illuminated and planetary nebulae as well as supernova remnants, their special and much celebrated 'Horsehead' filter, also potentially useful for a host of other faint nebulae, but made famous for showing that single item exclusively.

It is always worth checking the catalogs of the major telescope manufacturers as well, such as Meade and Celestron; they offer extremely comprehensive ranges of filters at reasonable prices, even if not necessarily quite as sophisticated a product line as that produced by Lumicon. Another company, Orion, while essentially supplying products to a broader segment of the astronomical public, also produces perhaps the best narrowband filter overall, under the name 'Ultrablock.' In the opinion of this writer, this filter works perhaps more effectively on a wider range of subjects than does any other, while also being surprisingly affordable ($100). Certainly no aspiring observer of dark and delicate detail should rule out any of these accessories casually, as they will pay for themselves many times over with impressive results that they are likely to produce at first glance through the eyepiece. Always bear in mind, however, that despite the increased contrast, the view will be dimmer, and they are not usually effective when used in conjunction with electronic enhancing devices (see below).

Electronically Enhanced Viewing

This is not the first book in which this writer has extolled the virtues of some very advanced electronic technology available today. Criticisms of this preference are hard to understand in light of the advantages that they bring and in spite of their relatively high cost; but there is nothing to beat a closed mind. There are several options, although those referred to here are either CCD video devices or image intensifiers. Aside from dramatically boosting the brilliance of what we see, part of their effectiveness is that they are so responsive to infrared and other wavelengths normally invisible (or only slightly so), making parts of hitherto dark regions show as illuminated to some degree, thus rendering them visible where they were not before. On a more immediately obvious note, they also boost the bright backdrop of emission nebulae, and many truly dark details may become more readily visible through the greater contrast resulting from their use. For the observer, this is one of their greatest strengths (especially concerning image intensifiers); it certainly more than compensates for their less than strong responses to light wavelengths in the blue part of the spectrum. However, dark skies are essential for most of the benefits of contrast; otherwise the effects of sky glow are also increased, which will void much of these subtle gains. As with every other type of viewing, the key to the best results still remains the quality of the air and the degree of darkness itself.

Regardless, the value of enhancing devices is frequently misunderstood; some people simply will never try anything beyond what they consider to be a valid observational approach. Many were jaded by the use of such devices long ago, while the technology was still in its infancy. It is likely that these same people have not tried a modern image intensifier eyepiece. But should astronomy be relegated to a sport where there are prizes for purists and ideologues, even when others may be actually seeing more? In the great scheme of things, it seems to this writer that anything that can help extract more insights ought to be fair game. But more specifically, let us examine individually how each of the two primary electronic aids may help us:

Image Intensifiers

The most advanced image intensifiers today, in particular Generation III, but even more so those of Generation IV, often dramatically reveal dark lanes in many deep space objects. (We can safely discount earlier generations in this quest, as they introduce too much image noise and too little enhancement of what we are trying to see.) While the wavelengths of light emitted from HII regions suits the response of these devices well, there is another benefit. The extreme heat (±10,000°K) of those same regions causes infrared radiation to be emitted, too, and because image intensifiers are also responsive to these wavelengths, otherwise unseen radiation becomes visible. Thus, these regions are further enhanced, and colder, dark and dusty regions are even better contrasted against them. However, image intensifiers are less favorably suited towards blue wavelengths, making reflection nebulae harder to see!

Furthermore, since image intensifiers have a less useful range of magnifications than we may be accustomed to, only larger apertures coupled with these devices allow higher powers to be used effectively. This is an important consideration, quite outside further increases in the brilliance of the image. An advantage with late generation (IV) devices is superior resolution than any other type of electronic viewing device. However, because some dark subjects only reveal the most interesting fine detail when examined more closely, we may not always be able to take advantage of the resolution in every case, another downside with smaller apertures.

Despite the brilliance of their output, the selected characteristic green phosphor screens of image intensifier tubes are nevertheless geared towards *some* degree of dark adaptation, although the images they produce are brilliant by astronomy-in-the-field standards. While this may seem less so in the dark of night, you may safely use a dim flashlight (or a bright one when used indirectly) to look at charts without compromising whatever degree of dark adaptation is needed and remains. Incidentally, while the intensifier the green color may be initially distracting, in the darkest conditions the eye, and eventually the brain, registers the image more simply as black and white.

CCD Video Cameras

Less direct than image intensifiers, but still possible to use as live viewing devices of sorts, frame-integrating CCD video cameras also provide good potential for enhancing and detecting dark detail. Relatively inexpensive, they have a strong response in the red and infrared part of the spectrum, even if not quite as much as the best image intensifiers. However they remain highly viable options for the observer looking to extract more from his or her telescope time and especially budget. By and large, because many of the previous comments about image intensifiers apply to CCD video cameras as well, we need not elaborate too much; suffice it to say, the primary differences with CCD video lie with the observing experience itself. While the chips they utilize are amazingly sensitive to low light levels, and offer some of the same advantages as image intensifier eyepieces, they lack true real time capabilities (but only by a few seconds!) and do not have quite the crispness, resolution, and refinement of view. The result of compounding many individual frames to build the image simulates the live experience fairly effectively, although viewing is confined to a monitor, and the personal connection unique to live viewing is somewhat diminished, if not lost altogether. But don't be put off by the frequent elitism decrying any types of electronic device – or the use of *anything* outside the most accepted norms of observing (the norms established according to others' ideas). These new-fangled tools do the job.

Observing with Electronic Enhancing Devices

The following comments apply to both image intensifiers and to a large degree to CCD video cameras as well; the responses of both are similar, if not quite identical, through much of the spectrum:

- *Globular Clusters*. The light from globular star clusters is skewed toward the red and orange frequencies, due to their makeup of old Population II stars. Thus, this very type and its characteristic coloration means that with electronic enhancement, we can expect significantly more dazzling views of these objects than the views of many others. While image intensifiers, especially, make some objects take on a subtly different appearance – due to the differences in the spectral response of these devices versus the human eye – globular clusters are a perfect fit. Significantly differences to the overall visual impression of the structure and form of such clusters, as might be the case in objects where a wide range of light wavelengths are present, do not apply. This is despite the minor downside that the subtle dimensional effects we experience in the conventional view – where such clusters appear to loom out towards us in a ball of lighted points – are lost, which is an illusion anyway, of course. Electronically, these objects tend to look altogether more two-dimensional, although in no way does it negatively impact the prominence of dark lanes within these clusters. These are actually greatly enhanced.
- *Dark Nebulae*. With these subjects, there is always unseen potential for surprises. Being parts of the interstellar matter we know as the great dark belt of the Milky Way, it has often been reported that image intensifiers reveal nebulous patches, as well as other unexplained sights, where none are cataloged on any standard chart! However, what we are likely seeing are regions within the interstellar matter made newly visible by the intensifiers' response to infrared wavelengths: maybe star birth activity is taking place deep within a dusty cloud, or a faded deep space object is still emitting some heat. Although any number of other possible explanations could also apply, these tools' special value to the astronomer is only further emphasized. Naturally, where star fields are particularly bright, any dark nebulae present will be greatly enhanced; the densest among them (i.e., molecular clouds such as B86) standing out like a long time exposure. Larger regions of dark nebulae may be very effectively viewed with low magnifications (in conjunction with an RFT – see earlier), or no magnification at all (see Chap. 3).
- *Galaxies*. With image intensifiers, these objects provide some of our greatest viewing pleasures and surprises, as well as some of our greatest disappointments. It seems there is no way to precisely predict the way any galaxy will

appear; some that one might expect to show little detail (such as face-on spirals with predominantly young blue stars in the galactic arms) can provide remarkable views. Surprisingly, in such instances, spiral form is often significantly enhanced where gas and dust is being irradiated to a significant degree and well placed, although the overall glow that fills out the galactic halo in conventional views is usually absent. Instead, cleanly separated spiral arms may be seen, sometimes strewn with mottled patchiness (i.e., M51), and dark regions between them often show well. However, just the opposite may result when irradiated interstellar matter is buried deep within the galactic structure.

Where galaxies are seen edge-on (i.e., NGC 891, NGC 4565), dark interstellar matter present in the arms is seen in concentration instead – through the galactic plane towards the core as dust belts. Here, these devices will seldom disappoint, throwing typically dark regions into stark relief against a typically brilliant hub, and usually with pronounced detail all along the belt. While greatly enhanced in brilliance, featureless galaxies such as ellipticals, being composed chiefly of old red stars, still do not appear more visually interesting than in the conventional view. Their forms will only appear more prominent because of their dominant Population II star makeup; however, dusty matter is still absent! We may have some pleasant surprises, however, with certain lenticular galaxies, as with some irregular, peculiar, and starburst galaxies (i.e., M82, NGC 253, NGC 5128), which usually have hugely varied and striking dark regions and features, and may produce some of the most exceptional views of all.

- *Diffuse Nebulae*. Because these regions are often where star formation is taking place, we are likely to find electronic image enhancement particularly helpful in exposing unsuspected detail, while throwing many hot and irradiated regions into more striking prominence. Because these nebulae frequently contain reflection components as well, we can expect to see these aspects much reduced, sometimes rendered even invisible. However, dark details are likely to take on new prominence (i.e., the 'dark lagoon' in M8), while the dark 'folds' and other shapes take on new significance (i.e., M42, M16). Some nebulae will resemble long images of exposure photography.
- *Planetary Nebulae*. These subjects, made visible by irradiated molecular hydrogen and hot ash, will seldom disappoint. Often, some examples suddenly reveal remarkable amounts of detail, such as the 'Cat's Eye Nebula,' NGC 6543, where the twisted helical-appearing form for which it has become famous jumps out in the view at first glance. We would be unlikely to see such revelations in conventional viewing without giant apertures. Other planetaries will show the ionized rings, regions where irradiation is taking place most strongly as the winds from the central stars push the glowing HII and ash ever further outwards and, characteristically of many planetaries, with startling clarity. Any dark detail and features present that are usually lost in the conventional view may be significantly enhanced. The variations of such detail are potentially limitless, and we may regard these objects as some of our best opportunities for image intensification.

Astronomy Software

Many observers have increasingly utilized advanced computer applications, the best of which provide extensive catalogs and information. This type of software is the new horizon for many, and brings a level of professional observatory sophistication to amateur observing that would have been unheard of not so very long ago. Among the very best is the *SkyX Professional Edition* for Windows or Mac, available from Software Bisque, which will provide detailed 'specs' for every conceivable object, as well as create and print custom sky charts, including dark nebulae from several catalogs. This software can even direct and drive your telescope with unrivaled accuracy and offers almost limitless additional capabilities. Certainly such means represent a new world of true accessories today, especially for those looking for a more refined approach to their observing or imaging sessions.

Imaging Method for Illustrating This Book

With the author not being an astro-imager in the accepted sense of the term, in some circles his alternative to commonly ordained imaging methods might be met with similar rejection to the hi-tech accessories just discussed! However, the goal was to provide a decent guide to what might be expected *in the live view at the eyepiece under dark skies* – with moderate to large apertures, utilizing a wide selection and composite of live viewing approaches (eyepiece alone, with special filters, CCD video viewing, image intensifier eyepiece, etc.) – a good overall average, one could say, if such a thing is possible. Without overlooking the fact that things always look better in the live view than on the printed page, a little comparison to results in the field will soon give the reader a good basis for expectation.

Because, from the author's perspective, it was also necessary to accomplish this in a fast, simple, straightforward manner, the images contained in these pages were obtained in the same ready and straightforward manner as those deep space images that were featured (and described as his best method to date) in *Make Time for the Stars* (Springer 2009), only with the slight refinements experience brings. It should also be emphasized that, while indeed the results do noble service in these pages as a good visual reference, they still lack that certain indefinable 'something' of the live view, as ultimately does all imagery. Thus, in addition to the allowances one must make according to equipment utilized, etc., one must adjust one's expectations accordingly and reasonably. It is always better in person. In certain cases, because the specific range of responses of the image intensifier utilized is so different to that of the eye, the images may not be *exactly* as one would see with conventional viewing. In other instances, certain attributes stand out better, and sometimes not as well. However, this is only a general caveat; the images are not radically different from what might be seen live, and as such, remain well in line with such views.

Simply stated, all images (unless otherwise credited) were obtained by the author in the following manner:

- Short exposures were made at the eyepiece, via image intensifier (Generation 4) and either a standard digital camera with manual settings, or CCD video camera, with the focus carefully adjusted and as wide a setting as possible for the aperture.
- The camera was secured with a universal adapter that clamps directly onto the image intensifier eyepiece; considerable care was taken to ensure accurate alignment of these components.
- A Barlow lens was frequently included at times for extracting maximum resolution of detail, sometimes necessitating significantly longer exposures than utilized in the past, usually a couple of seconds or so, though never more than 15 s for the very faintest of subjects. Consequently, such lengthy exposures, of course, also necessitated more accurate polar alignment of the telescope, something that may be less stringently adhered to with 2–4 s exposures. Regardless, in concept at least, these images are as close to snapshots as possible.
- Every effort was made to maximize the use of pixels in the frame, including using the zoom lens of the camera to fill it to the maximum. In many instances it will be necessary to do this in order to eliminate coma at the edges of the field, the downside of the Newtonian reflector configuration.
- From the CCD video stream, single frames were extracted in what amounted essentially to 1/30 of a second snapshots! This reveals the great light sensitivities of these devices and the advanced chips they use. The camera was attached to the telescope tube, but for extremely wide angles was not coupled to the telescope optics; instead, a non-magnifying 1.5-in. primary lens with adapter was used.
- Generally, ISO settings never exceeded 400, in order to reduce image graininess.

The images are all are monochromatic – not in color – by default. Thus the illustrations used in this volume are comfortably presented in monochrome. (Image intensifiers are not designed to do otherwise, since they are set for maximum response at specific frequencies.) Because the intensifier output is green, the camera was set for maximum vividness in that part of the spectrum, which helps to compensate a little for differences on the printed page. Regardless, in deep space, this is also how the eye tends to perceive most color; when starved of its usual light levels, color is sacrificed for sensitivity, and the vivid hues we usually see in today's grand deep space imagery is not how we would ever see these objects were they close on hand, even situated nearby! While those spectacular colors do, in fact, exist, the low levels of light we would experience from almost any vantage point in space would still render them virtually colorless to our eyes. Of course, individual stars do show color, albeit in a somewhat more restrained fashion than we might believe we are seeing. In the appearance of the vault above, color is at a premium. Regardless, it is the absence of blatant color in extended objects that is the point here; we are primarily concerned with dark, colorless features anyway.

In spite of the care that one must take to secure optimal results, there can surely be nothing easier, or so frequently unexpectedly revealing, as this particular method of imaging. And seeing results immediately in the field on the screen of the camera does have its rewards after all; just ask any user of CCD video cameras. Only a little further experimentation is necessary for best results with each piece of equipment (telescope, camera, object, etc.), but suffice it to say, just as with film, keep the camera ISO setting low to moderate; otherwise, it will most likely lead to unsatisfactory, grainy images, which no amount of post processing can seem to eradicate. You might also keep the camera image size set only to medium (or even less) to avoid really large, unwieldy frames. One is hardly likely to need an image as wide as a room, or one that reveals no more detail than a smaller one; maximum resolution possible will likely already have been obtained much before this. We will not be able to attain the fine resolution of a long time exposure anyway. For those observers primarily bent towards live viewing, but interested in recording some of what they see by this method, post observation image adjustment at the computer is mercifully minimal.

Summing Up

Despite the author's bias towards visual astronomy, this is not to say that *nothing* here will apply to other less direct means of observing, such as long exposure imaging of any kind; indeed, virtually all of what is contained here is relevant to any form of practical astronomy. Perhaps this is even more significant than it seems, should it cause practitioners of any type to expand or refine their approach and stress dark features in their images. However, unless dark features or any particular object are accessible to the *visual* astronomer, they were not likely to feature in the author's imagery. Some of the more esoteric examples of dark or dust regions, such as Bok globules (possibly visual evidence of the condensing stages of stellar birth), remain primarily imaging subjects, and even then the unfortunate fact remains that quite sophisticated means are still required to capture them. However, if inspired to take up the chase of such difficult dark subjects, the most avid astro-imagers today are not likely to be deterred!

Because we cannot undertake a review of everything that there is to see, or even a fraction of it, the purpose of selecting certain subjects to review in detail is to merely introduce apparently often-neglected possibilities, if not also to encourage an added meaning to deep space observing. We will sample a good cross section of subjects and explore the potential in detail. If the result is a greater awareness of at least the type and range of features present and worth looking for, then the desired objective will have been achieved. (In the examples chosen for in-depth discussion, where observatory images add otherwise hard to describe insight, they will be included). After initially indicating the most immediately obvious dark region(s), the primary goal will be to spotlight as many dark features as possible within the entirety of the subject, either by simple description or graphic illustration. Some details will be subjective; others will only be explained away because illuminated matter is not actually present and a void truly exists. In describing them, it will not be enough to state merely that there is ‘a dark lane’ or a ‘dark region’!

Finally, we should always bear in mind that observing dark subjects and features, while fully tracing their extent and implications, requires a degree of patience along with all the refinements of well-practiced astronomical ‘vision.’ Perhaps properly anticipating the full visual potential is the most important preparation of all, as long as we do not end up with a mindset that ‘imposes’ details that aren’t there. We would not willingly wish to become modern-day ‘Martian canal’ observers, after all.

Chapter 3

Dark Nebulae

Perhaps the most celebrated and revealing dark nebula of them all, B33, the Horsehead Nebula in Orion (Fig. 3.1, above), evokes the essence of these clouds – dark, dusty, swirling gaseous expanses, looking almost like thick smoke from a newly ignited brush fire. These dark clouds might seem to be the destroyer of all things in the universe, but instead, in a complete contradiction to their appearance, it turns out they are the driver of galactic evolution.

Dark nebulae, central to this writing as the most immediately obvious of all cosmic dark places, would naturally be the most significant part of any study of celestial dark objects. To the uninitiated, these regions might seem quite uninteresting – merely starless regions. It is all too easy to overlook the fact that the dark interstellar matter that comprises them is part and parcel of the majority of all dark subjects we will observe. You will already realize that galactic dust belts, lanes in open star clusters (those seen in globular varieties are presumably of a different, though possibly related form), some of the most interesting features in illuminated nebulae, even occasional dark detail in planetary nebulae, are just other manifestations, conglomerates of the same thing. Certainly the place of dark nebulae in the ongoing evolution of the universe cannot be underestimated, and so, we will attempt to get to the crux of all they mean to us as observers.

Conceptually, at least, dark nebulae are relatively straightforward to understand, since there is little controversy about them, their role, or what their makeup constitutes, and they are found throughout in a large proportion of most types of galaxies. (The one notable and consistent exception to this is elliptical galaxies, old structures that used up the matter of their dark nebulae eons ago; see Chap. 5.) The largest local examples in the Milky Way may even be detected without a telescope, such as the huge Pipe Nebula in Ophiucus (see later this chapter), the totality of their expanse obscuring some of the brightest regions near the central core of our

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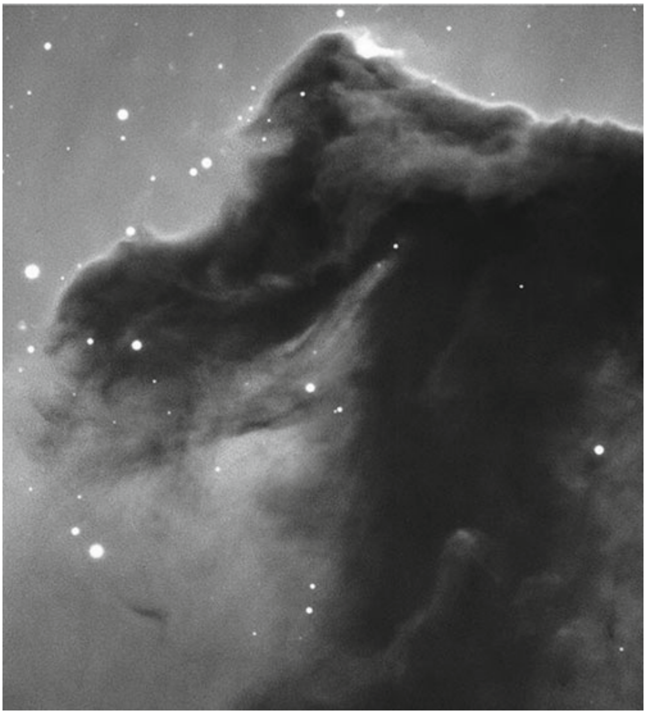

Fig. 3.1 The Horsehead Nebula, B33 (Courtesy ESO)

own galaxy. However, such individual spectacles correspond to only small parts of the great dark bands (dust belts) that surround many galaxies.

By these same determinations, the Pipe Nebula is no exception, as it is merely part of the vast dark belt surrounding our own Milky Way. Other dark structures within our own galaxy are frequently far more esoteric, much smaller and finer than the main components of the dust belt, their relative diminutive size being the reason, of course, why their counterparts are not observable outside our own system.

While we only see these nebulae because they are silhouetted against brightly illuminated nebulae, in this respect, we will find that dark and illuminated nebulae are often completely interconnected. Although the Horsehead Nebula appears to be a complete entity unto itself (it is actually just a tiny feature within the greater Barnard's Loop), it is silhouetted against a bright nebulous region, to which it presumably belongs. Regardless, Barnard thought it sufficiently independent as a feature that he awarded it a separate designation.

In their purest and simplest form, dark nebulae appearing in isolation (external to illuminated nebulae) remain among the most delicate and difficult objects for amateurs to observe, more often appearing to be merely sparsely populated star fields. In most instances, they strike less dramatic poses than do most other celestial sights, but some do reveal a clear presence nonetheless, with straightforward outlines. In the cases of dense, or large and expansive examples, these outlines may be more readily traced to their full extent – as long as conditions favorable to seeing them permit.

It is fortunate that the bulk of them lie in the bright galactic plane (refer again to Chap. 1), because it is only this placement, of course, that makes it possible to see any of them at all. If galactic structures were any different, we would probably have had to accept that dark nebulae were beyond the scope of normal observations, which would be a pity indeed, since these nebulae hold the keys to the future of the galaxy. Fortunately, we can relish the opportunities we have to look at these places, often being able to see various stages of creation taking place within them.

So, despite not being the easiest deep space objects to see, the rewards of doing so are considerable. Luckily, many dark nebulae are prominent enough to be immediately obvious when set against sufficiently bright backgrounds, likely to be star fields, or illuminated portions of the very (once dark) nebulae of which they may be a part. In some cases, isolated dark galactic nebulae are so dense that they appear like holes cut into the space fabric. It is not surprising that this had been the deduction of most, if not all, observers of earlier times – in a historical context surprisingly recent.

We should remind ourselves just how young the science of modern cosmology – as pioneered by Hubble – actually is. The dark nebulae of the Milky Way have long been familiar to astronomers, even though they were not sure what they were actually observing until well into the twentieth century. It took modern telescopes to show they were not actual voids in space; certainly most dark nebulae *look* like voids upon casual inspection, or even with detailed examination in a good telescope. Thus with the equipment and the state of the art in astronomy of the time, one can easily understand the misidentification.

Even the legendary E.E. Barnard (of the late nineteenth and early twentieth century, one of the keenest observers ever, and who will forever be associated with dark nebulae), was among those at first perplexed by what he saw in these apparent voids. Although he believed early on that some of them represented something other than gaps and spaces in the stellar fabric, he did originally think many were true voids. It took more sophisticated photographic methods and ever-grander telescopes to settle the argument once and for all. Ultimately, Barnard became the leader in a field that went on to add many other disciples, having been the only observer at one time sufficiently intrigued by what he saw to produce a catalog of the dark nebulae. This catalog is still famous and in use to this day. Barnard had finally concluded correctly the consistent gaseous and dusty makeup of dark nebulae.

Barnard's celebrated list encompasses virtually all the major observable examples, as well as more than a few that are challenging for live viewing, being mainly photographic objects, even for large instruments. However, and significantly for our purposes, in the northern hemisphere and much of the southern, all of those visible in amateur scopes will be found in his catalog. So although not all of his dark nebulae make for ready live viewing, Barnard's catalog remains the main list, first and foremost, for anyone interested in the subject. Those dark nebulae in his catalog still carry the designations 'B' before the number he assigned to each one of them, and as such are as easily identifiable as Messier, or NGC catalog numbers. We should bear in mind that the number of dark nebulae interconnected and weaving among illuminated examples is quite significant; some, but not all, of these dark components also fall into Barnard's catalog. (Perhaps the astute observer will be aware that some of Barnard's prominent dark nebulae are not listed in the reference listing at the end of this chapter. The reason is that these appear as part of larger illuminated nebulae; see Chap. 4.)

However, Barnard's catalog represents only a fraction of all those structures discovered and cataloged since, and categorized – one way or the other – as dark nebulae. Noted South American astronomers Eduardo Bica and Carlos Dutra (at the University of São Paulo, Brazil) compiled a far larger listing from multiple sources with a total in excess of 5,000, although needless to say, the vast majority of these objects will not be accessible even to the advanced observer.

Even for such an early catalog as Barnard's, the extent of it is remarkable. Many of his nebulae are extremely small, or insufficiently dark to be readily visible, and one may safely assume that these were strictly photographic nebulae for Barnard as well. Also they may be too inconspicuous to be seen in all but the lengthiest of time exposures, and with larger telescopes than most observers will ever dream of owning.

The reason for the disparity of sizes is not always coincidental but is also due to different stages of evolution of these clouds (more later). With Barnard's nebulae all belonging to the Milky Way, however, many remain possible to see readily with only moderate means, with maybe only a third of them remaining completely beyond the capability of live viewing in most instruments; these should be considered subjects for imaging. However, we should not expect to find most of these nebulae as straightforward as other deep space objects; many will stretch the viewing skills of the most seasoned observer. And naturally, because these nebulae exist within the galactic thin disc itself, most lie in that plane among the richer star fields and are not simply scattered throughout the sky (the galactic halo); this bright background makes seeing them possible.

The Transformation of the Interstellar Medium into Stars

Whereas the cloud-like interstellar matter – dust and gas – found in galaxies (with at least some spiral structure) is plentiful in loose formations throughout most of the galaxies' thin discs, it exists most especially within the spiral arms. Despite the tenuous nature of dark nebulae, they are so vast that there are, in fact, stupendous quantities of this matter in most galaxies – so much so that it would dwarf the mass of our 'little' Sun by countless millions, maybe billions, of times. Thus this matter is an abundant resource for continued and long-term star creation. However, some speculation remains whether any interstellar matter, or any other at all matter exists between the arms. Although it seems that some amount of it may be capable of passing through the arms and into the space between them, we do not see star formation taking place there. We must therefore assume it is too rarified, as well as lacking catalytic action from shock waves (see below) from the various life cycle and other processes of surrounding stars. However, there are examples of galaxies where the regions between the spiral arms do appear to be unusually dark, although further evidence would be needed to confirm the suspicion.

These dark clouds are extremely cold places to be sure, with inner temperatures so low that no normal prospect for any physical changes seems remotely possible. This means that some special processes will have to take place, particularly the star formation we associate with them, for any transformations to occur. Considering that the mean temperature of the greater cosmos is close to absolute zero (which theoretically does not exist because background cosmic microwave radiation ensures that it will remain at a 'toasty' −270.27°C), the average temperatures deep within most dark nebulae would not be significantly higher. We can project that typically they have temperatures ranging from a mere −258°C to −266°C. In each dark cloud, such low temperatures occur because the dust component blocks out external radiation from any nearby stars that could provide warmth, with any that might escape being of the distant far-infrared spectrum, with wavelengths of not more than between 40 and 400 μ. However, this still corresponds to extremely low temperatures, which are virtually undetectable except by advanced measuring systems.

Although exact distances and dimensions of individual dark nebulae are hard to determine, we can usually tell which clouds are relatively close, simply because, by default, the more distant ones will have stars appearing increasingly in the foreground. However, it has been possible at least to determine that some dark nebulae are truly vast, sometimes covering expanses in excess of 100 light years across. These expanses are held in a form of suspension against sudden collapse by their own magnetic fields, in a delicately stable (but usually only temporary) balance against the mighty forces of the very gravitational forces that holds them together.

These internal gravitational forces are not unlike the electrostatic attractions of small materials to form larger ones, somewhat akin to that of the spontaneous gathering of 'dust bunnies' in your home – or astronomically speaking, the formation of planetoids from leftover dust and rubble. Individual nebulae within the greater whole usually exist as ill-defined shapes, sometimes formed into vast separated twisting and narrow shapes, such as winding strands and lanes, with extremities often drawn out into tentacle-like fingers of light-blocking matter. Although it is difficult to postulate why the frequently characteristic serpentine-like shapes of these nebulae form (indeed, there seems to be not much in the way of discussion of this), it would seem that it may be due to the same structural gravitational pulling of the galaxy – itself, typically drawn into an elongated structure in its own right with the stars being aligned along a relatively flat plane (the galactic thin disc); perhaps the effects of winds formed during star creation are also contributing factors. Gravitational forces alone do not seem to explain, however, the tendency of fine filaments of dusty matter rising (or falling) perpendicular to the axis of certain galaxies, something very much true of the dust belt surrounding the Milky Way. Observations of such perpendicular formations in galaxies, and notably within NGC 891 (via the Hubble Telescope), have prompted new research for an explanation (see Chap. 6).

However, gas and dust are only approximate terms for what the dark clouds actually are, since they are certainly nothing like those we are used to seeing in our Earthbound environment – the dust component not being comparable to something gritty to be swept up off the floor! In the deepest and darkest portions of the clouds, hydrogen exists in large quantities, but also helium and many other complex gaseous compounds of nitrogen, oxygen and carbon (as CO, or carbon monoxide) can be found in measurable amounts, as well as ammonia, and even water constituting part of their complex makeup, and trace compounds of numerous ‘metallic’ elements.

Most of the dust component, so-called ‘ash’ by-products left over from certain classes of dying stars (as they become planetary nebulae and shed material) consists of ultra-fine particles of silica and carbon compounds, along with some sodium, magnesium and iron. The internal temperatures are so low that frozen molecules of some of the gases quickly coat the dust particles of the cloud. However, it is only the dusty component, not the gas, that blocks visible light, especially that which falls within the blue portion of the spectrum; thus it functions as a light filter of sorts. Therefore, it is not surprising that many color images of these structures show stars at the fringes of the nebulae appearing red in coloration, since light of this wavelength is less prone to absorption. However, the sheer volume of large dark nebulae, or the density of highly compressed smaller ones, prevents any visible wavelengths of light at all behind them from penetrating, and they appear like black voids in an otherwise illuminated space fabric. These nebulae, which formed after having attracted sufficient quantities of similar material to form into substantial structures, have a future in common that many of them may have shared in the past, as the nebula-generating properties of vast numbers of old stars is an ongoing process in the galaxy.

While the clouds may have existed in a kind of equilibrium for a long period of time, ultimately, however, dark clouds with sufficient mass may begin a slow collapse, signaling the beginning of a chain of events and a new cycle of stellar creation. This collapse is triggered by several possible causes, all of which produce variations in the internal pressures of the cloud:

- Shock waves from cataclysmic events, especially supernovae, novae, or even nearby stars as they become supergiants.
- Variations in gravitational forces that occur all the time as stars and dark nebulae intermingle.
- Interstellar winds, sufficient to cause potentially pressure changes for collapse to begin.
- Increases in radiant energy from passing stars, which may also be the catalyst.

Thus, any or all of these influences can cause sufficient changes to the internal gravity of these dark clouds, often enough to overcome their internal magnetic fields and allow that very internal gravity to take hold. The by-product of all of this is the formation of unevenly dense clumps of the dusty and gaseous matter. As the density of this increases, chemical changes begin to take place internally, as these clumps are now on the way to becoming what is termed ‘molecular clouds’: smaller, much more dense clumps of gas and matter that take on the predominantly molecular composition of ionized hydrogen, better known by its chemical term HII (the key molecular hydrogen component that may be made iridescent by hot young stars in their midst).

Of varying intensities of blackness, sizes and shapes, the dusty makeup of these molecular clouds often results in dramatic ‘star-extinguishing’ effects, as they readily absorb the light of more distant stars or luminosity when they are condensing into compressed forms. The volume of the ‘second stage’ compressed interstellar medium is very small relative to the total, but perhaps as much as half the mass of the total reservoir is accounted for by it, showing the degree of compression that is taking place. Despite the fact that the same elements and compounds as before still exist together, astronomers are able to determine which clouds are, in fact, true molecular clouds; these appear quite distinct with spectroscopic analysis.

As we move away from the galactic core, by the time we reach our own Solar System, this molecular matter is barely in evidence. Most of it exists closer to the core, and in an even shallower plane than the already near flat galactic thin disc (see Chap. 1, Fig. 1.5). Molecular clouds are not all of small dimensions; indeed, they can also appear in huge sizes. The degree of final compression will be so great that they may have much further to go, as many small clouds were once vast, even though some are of significantly greater total mass than others. They are already the result of considerable compression. Because heat is increasingly radiated outwards from and by the increasingly dense dusty component of the cloud, some of the energy is thus removed from the total mass while it evolves into ever-higher densities. Acting much like the action of refrigerator coils, this further cooling of the cloud allows, in turn, further contraction of the entire region.

Scientists term the increasingly dense clumps of matter ‘evaporating gaseous globules,’ or EGG’s, a key condition essential for the interstellar matter to be capable of fostering stellar life. Radiant energy now escaping falls into the mid-infrared spectrum, essentially at around 5–40 μ, so we can see that the previously sub-frigid temperatures have fully ‘thawed’ (in Earthbound perspectives it would be considered hot); the dust in the clouds now is beginning to glow with infrared radiation.

Finally, however, internal equilibrium can no longer be maintained (when further external influences take place), and an implosion of matter takes place as the dense central portion of the individual clumps collapses rapidly inwards, forming a relatively small hot core. This then becomes heated by further contraction under its own gravity until the resulting compression creates sufficient internal heat to form a ‘protostar.’ With the exception of those that lack sufficient mass (these become pale brown dwarfs, since they are too cool to develop into adult main sequence stars), the point of no return has been reached: it is now too late to prevent further collapse and the subsequent inevitable creation of a stellar nuclear powerhouse.

Fig. 3.2 B68 (Image courtesy VLT ANTU & FORS1/ESO)

Infant protostars may reach temperatures at their cores of as much as a million K. For dark nebulae, in an analogy to "where there is smoke there is fire," wherever there are microwave emissions there is surely star formation happening at some stage within them. We might have hoped that B86, the 'Ink Spot' (see 'Observing' section), or B68, (Fig. 3.2), both appearing like deep wells into an abyss and prime candidates among molecular clouds for early stellar births, would reveal protostars deep within. Although they are both undergoing early collapse on the way to producing protostars, or even protostar clusters, given the obvious density of both of these examples, recent infrared imagery has unmasked stars lying far behind them. Thus, since they are not yet sufficiently dense, we can see that it is still too soon in the contraction process for any such core to have formed and become superheated into illuminated beacons of early stellar creation. The time scale of such beginnings is truly cosmic indeed.

Over as much as hundreds of thousands of years (another drop in the bucket in cosmic terms), young protostars draw in more of their surrounding dark molecular clouds, becoming ever denser and hotter and finally evolving into adult stars. This is the end product of the all-determining factor of the universe – the action of gravity, perhaps better considered the bending of space/time by the mass of the matter within it. Thus, former molecular clouds become intense, powerful energy generating, fully fledged hydrogen-to-helium machines, just like our own Sun, with effectively contained nuclear 'explosions' held in check by their own powerful internal gravity and producing huge quantities of heat by fission. However, now they produce less actual light than that generated by the earlier protostars!

It is believed that, with most of the immediate surrounding gases having been taken up in the creation of new stars, the comparatively cool dust component and small amounts of unused gases surrounding them will become compressed and drawn into relatively close orbit, ultimately to become the substance and rubble necessary to solar system creation. Apparently, as this dust bonds into rocky lumps, more recognizable forms such as asteroids, or even larger solid planets are the end result; by the same token, leftover gases will condense to become gas giant planets, such as Jupiter or Saturn. (Jupiter is considered to be a bit too small to have become an independent brown dwarf star.)

Ongoing research seems to point to a considerable resemblance between interstellar dust and matter we can still find within our own Solar System. However, the larger apparent size of Solar System dust particles, relative to that believed to make up dark nebulae, serves to keep the controversy alive, though perhaps they merely point to the effects of ongoing normal gravitational attraction. Regardless, the theory lends considerable weight to the link between all of the constituent parts of the dusty components of galaxies and where it goes. This seems to be the only rational explanation, although clearly much more research yet is needed to settle it.

Exactly how each star will mature and age, as well as revealing its own specific curve of energy emissions, will depend critically upon its individual mass. Meanwhile, as the development of the new star keeps continuing, further compression occurs, but so, too, is an additional need for a more efficient way to dissipate the resulting heat, if the further evolution of the new star is not to be stopped outright. In a curiously beneficial coincidence, this is accomplished via the generation of increasingly hot infrared radiation away from the now superheated dust component within the larger nebula cloud. The dust has now become visible in the near infrared spectrum, at around 0.7–5 μ, and temperatures of up to 5,000 K are now rising relatively rapidly. As the young star continues to draw in more of the surrounding gases to build upon its expanding foundation, from our perspective the entire process is nevertheless so slow it may appear to be in equilibrium.

At this stage of star formation, the mean temperatures of the irradiated regions may become as hot as the surfaces of some mature stars themselves, with typical temperatures reaching as much as 15,000 K and more. Later stages of star formation result in the now hot molecular hydrogen HII component of the surrounding nebula, which begin to fluoresce by the action of ion excitation. The once dark nebula is now becoming transformed into an emission nebula. In the Milky Way, there are numerous examples of the above processes occurring in large numbers within most of the greater dark nebulae; larger and denser dark clouds are required in order for actual clusters of stars to form (such as those open clusters of young stars we see immersed within all the grander illuminated nebulae), as well as for the formation of more massive stars themselves. This may result in the formation of new open star clusters and large brilliant nebulae, jewels of the heavens.

Some prime examples are the Great Nebula in Orion M42; the ‘Lagoon Nebula,’ M8; the ‘Christmas Tree Cluster,’ NGC2264; or the ‘Keyhole Nebula,’ NGC3372 (see Chap. 4). Cluster-bearing illuminated nebulae represent extremely fertile fields of energized matter to be sure.

If we wish to see these nebulae, however, as long as large amounts of the dust part of the cloud remain, it may make ready observations problematic; we can only speculate on the number of unseen new starry regions of the Milky Way that we may not yet know, despite ongoing infrared and other microwave research. Thus, while many nebulae we may consider completely dark are already harboring stellar formation, infrared radiation emanating from deep within them sometimes is able to reveal whether star-forming activity is in fact taking place. Even though we cannot see them in the normal sense of the term, formerly undetected subjects within as well as behind these nebulae have been imaged by infrared and other non-visible wavelength emissions. (Some far-distant galaxies have even been discovered in modern times by this technique of peering through dark clouds of the Milky Way. This technique has also allowed astronomers a glimpse at the very core of our Milky Way Galaxy itself – a region obscured by some of the thickest dust clouds – the old ‘Zone of Avoidance’ of earlier astronomers). It should now be readily apparent that this very light-obscuring region of the Milky Way, the much-maligned bad apple of the old nineteenth century, turns out to have a most significant role to astronomers and in the galaxy after all; its extreme density reveals a pivotal one if ever there was, and we know now that considerable star creation is going on behind ‘closed doors.’ Without this scale of ongoing stellar evolution within the galaxies, they would have little future as structures we recognize.

In extremely bright nebulae, well-known features called ‘Bok globules’ (after the noted twentieth-century astronomer Bart Bok, who discovered and documented them) are sometimes to be seen, set starkly against the illuminated backdrop (Fig. 3.3). These small clumps of very dark condensed matter (actually small molecular clouds) may be merely the extremely dense core remnants of far grander dark nebulae, with much less dense outer parts, now used up in star creation. This certainly seems the most likely explanation among several possibilities, including the possibility that they are collapsed clouds of dark nebulae just about to become protostars. More likely, it seems that the ‘globules’ have not had the opportunity to become such stars in their own right because heat of the surrounding brilliant stellar furnace has prevented them from experiencing further internal collapse. So, as they apparently hang in the ultimate stellar conundrum, a true cosmic ‘Catch 22,’ they await their demise, ultimately facing final annihilation by the intense heat all around them.

The role that dark nebulae play, and the processes of transformation that they undergo, is thus key to understanding what takes place on a grander cosmic scale. Little, it seems, in space exists in isolation and is unaffected by anything else. With this cycle of stellar evolution we can see how the most significant part of all that has made the universe what it is has kept it a work in progress, in a state of constant change. Since even a constant climate is also unknown on Planet Earth,

Fig. 3.3 Hubble space telescope image of Bok globules in NGC 281 (Courtesy NASA, ESA & the Hubble Heritage Team [STScl/AURA])

and apparently also unknown on the other planets of the Solar System, astronomers have long understood the transitory nature of all things; most people see Earthbound changes only within their own life spans and likely do not know or contemplate possible developments on a cosmic scale. Ongoing variations of Earth's orbit (axial tilt and the Milankovitch theory), the possibly significant role of possible variations in the output of our own star, the Sun, even possible starburst effects (admittedly slight) from absorption of dwarf galaxies into the Milky Way may impart to the Sun could have an influence. And of course there are the influences of the far mightier, perhaps some unknown, processes of the greater universe itself.

Online Reference Materials

Much information on these nebulae as well as useful images may be found online; some of it dates from long ago, but the recorded observations are no less valid today. For observers it should come as no surprise that much of Barnard's research is still useful. Some examples of what is available is given below:

1. An invaluable on-line reference for many of Barnard's actual photographic plates and observations, along with detailed descriptions and identifications, may be accessed at http://www.library.gatech.edu/barnard. These photographic plates, while poor by modern standards of imaging, were what led the field of research on these objects.
2. The complete Barnard's Catalog in numerical sequence may be accessed at http://dvaa.org/AData/Barnard.html, with excellent descriptive data collected by Al Lamperti. This is perhaps the best resource for the practical observer.
3. A further definitive resource may be found within the historic record of the American Astronomical Society, via SAO/NASA Astrophysics Data System (ADS). This site has provided Barnard's own published notes on his findings in 1919, covering those dark nebulae he had identified up to that time – "On the dark markings of the sky, with a catalogue of 182 such objects" may be downloaded at: http://adsabs.harvard.edu/full/1919ApJ....49....1B.
4. However, even more significant and valuable for the observer must surely be the remarkable paper dating from 1930, "Visual Observations of Dark Nebulae" by W. S. Franks and available to download from the same invaluable SAO/NASA archives at: http://adsabs.harvard.edu/full/1930MNRAS..90..326F. This document covers most of Barnard's catalog with detailed descriptions for each object. Collectively, one might only wish that such papers were readily available for the many other categories of dark astronomical subjects!
5. Another, more general but highly informative website, http://astroshed.com/milkymap.html, features an interactive black-and-white photographic chart with all of the greater dark regions of the Milky Way clearly showing, along with labeling of the constellation borders. Featuring numbered references to many prominent objects directly superimposed on the chart in a panoramic image, one may click on a number, and the identity of the nebula is displayed at the bottom of the page. Though limited in scope (only the most prominent nebulae can be shown), the site nevertheless provides a valuable general reference, and it may help put the entire dark belt of the Milky Way into better perspective for those new to this kind of sky chase.

Observing Dark Nebulae

Dark nebulae of the Milky Way bring their own set of observing problems, distinctly different from those we encounter with most deep space subjects, simply because most do not stand out sufficiently starkly against the background glow with the same distinctness of illuminated subjects. Their diffuse nature tends to make them blend into the surroundings, and their outlines are often hard to spot, let alone discern. Coupled with this, the large sizes of many make them often too large to fit within the fields of view of even moderately low powers.

It might seem that these shadows of the sky would do better with astro-imaging than direct viewing; indeed, many of them do. Nevertheless, we should not be deterred, since a sizable percentage may be observed at the eyepiece successfully, as Barnard showed us and documented accordingly. Although we may not consider ourselves to be budding Barnards, because of the landmark work he did we do have the benefits of knowing where to look and what to look for, plus the advantages of modern equipment and accessories. We also understand better the nature of what we are looking at.

The use of image intensifiers or CCD video cameras will be found to be very effective for these subjects. When wide field views are needed, one outstanding application consists of attaching a low or non-magnifying primary component to the device and simply pointing it skywards (Collins Electro Optics can supply one to fit their own image intensifier eyepiece). The highly contrasted views of dark nebulae (and many other things) – all over the place – will be enough to convince anyone of the unique value of image intensification, as long as you can be persuaded to try one in the first place! Such assemblies of image intensifier, primary lens and camera are easy to attach to the sides of most decent-sized telescope tubes. For smaller dark nebulae, especially molecular clouds with very dark characteristics, image intensifier devices may also be well utilized in the main telescope focuser itself, and work as well as any conventional eyepiece. But remember, such weighty assemblies will considerably alter the balance of any mounted telescope.

The Great Rift and the Cygnus Rift

We will start by spending some time with the greater collective dust belt of the Milky Way, better known as the Great Rift. This celebrated region of the Milky Way received its name due to the vast clouds of folding and twisted dark interstellar matter that appears to split the galaxy in two parts, containing most, if not indeed all, of the cataloged individual dark nebulae. Although only representing the segment of matter as seen from our perspective in the galaxy (that part that blocks the light between the core and the Sagittarius Arm in which our Sun is located), it provides a good impression of our galaxy as it would appear from this side of it, were we located far away in space.

Seeming to originate in Cygnus, the Cygnus Rift region contains some of the most interesting sights in Northern Hemisphere skies, as well as one of the brightest regions of stars, known as the Cygnus Star Field. Best viewed with very low magnification, or none at all, the Cygnus Rift is a broad and contrasting star-studded dark belt, clearly visible without any optical aid at all in clear dark skies. The entire

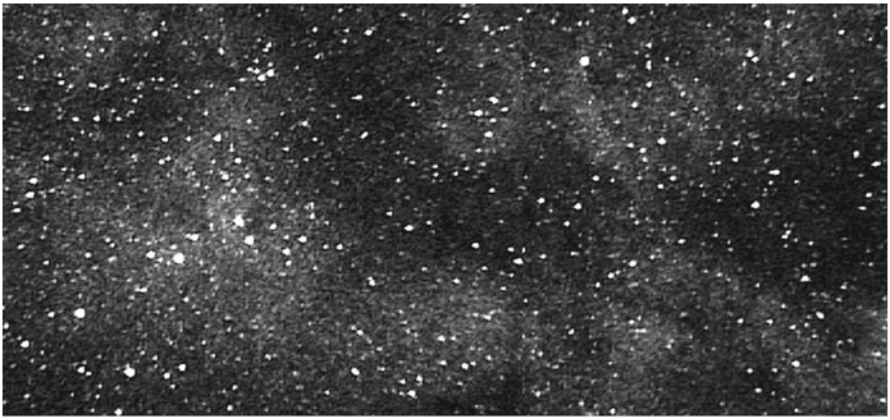

Fig. 3.4 The heart of the Cygnus Rift: the region within the 'cross' of Cygnus (AC: composite of two video frames)

belt of the Great Rift contains enough matter to generate millions, and probably billions, of stars the size of the Sun, as it works its way through the center of the galaxy via the core region (where it is revealed most dramatically), and extends as far south as the constellation Centaurus. Unfortunately some of this southern extension remains below the horizon for many Northern Hemisphere observers. The image in Fig. 3.4 was taken with an image intensifier and a non-magnifying primary attachment; resolution within such short, single video frame exposures (1/30 s) is limited, but the panorama is quite effective, and well representative of live views through the assembly.

Large Dark Nebulous Regions Along the Great Rift

Because the most conspicuous dark nebulae obviously lie close to the brightest portion of the galactic plane – in the densest part of the galaxy and closest to the galactic core, the majority of most readily observable examples of the Great Rift lie in Southern Hemisphere constellations, notably Sagittarius, Scutum, Scorpius and Ophiucus. With their vast reserves of dark nebulous matter, we would naturally expect these regions of dense interstellar matter to be the most productive in star creation. Certainly there seems to be no shortage in this region of dense star fields and new open clusters at many stages of evolution. Other regions also may have similar attributes, but none so intensely striking as these. Smaller dark nebulae within these regions of sprawling dust and gas reveal ongoing condensation into ever-denser matter, and as such may already be harboring new stars that may not be directly observable.

In Scutum alone we see much interstellar matter, appearing loosely and winding throughout the star fields, as well as the presence of rapidly condensing molecular clouds. Two such clouds are B95 and B312, which lie close to the galactic plane, of which particularly celebrated is B312, a striking arrow-shaped nebula, quite dark, dense and pointing north. In Fig. 3.5, another wide-angle video frame, we can not only see these nebulae but appreciate their relative small scale in comparison to the greater nebula fields. We can also readily locate and observe many other dark

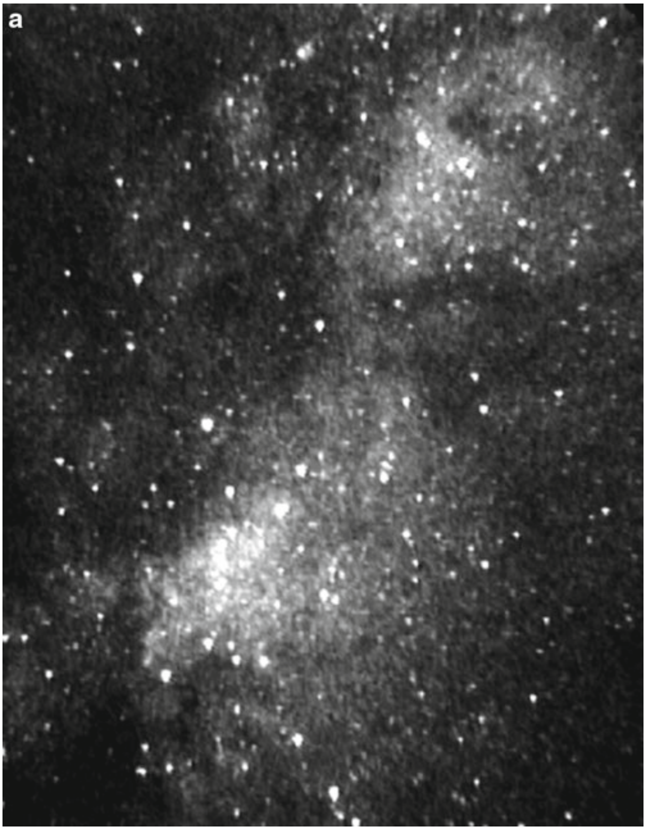

Fig. 3.5 (**a**) B95, B312 and other dark nebulae in Scutum (AC). (**b**) (1) B95: a small region of deep blackness and rapid contraction; this cloud is thought to be largely comprised of condensing interstellar medium, prevalent in molecular HII. (2) B 312: a highly celebrated dark nebula: a molecular cloud appearing like an arrowhead against the starry backdrop. This nebula can withstand moderate magnification, is dark and is clearly defined, again a region of rapid contraction being transformed into matter capable of star formation in the relatively near future. (3) B314: striking dark rift adjoining other dark nebulosity, very typical of many similar strands of dark dusty matter throughout the Milky Way's dust belt. (4) B97: A larger, dark, but Ill-defined region deep in the clouds of interstellar matter. (5) B103: a dark swath cutting across the stellar fabric

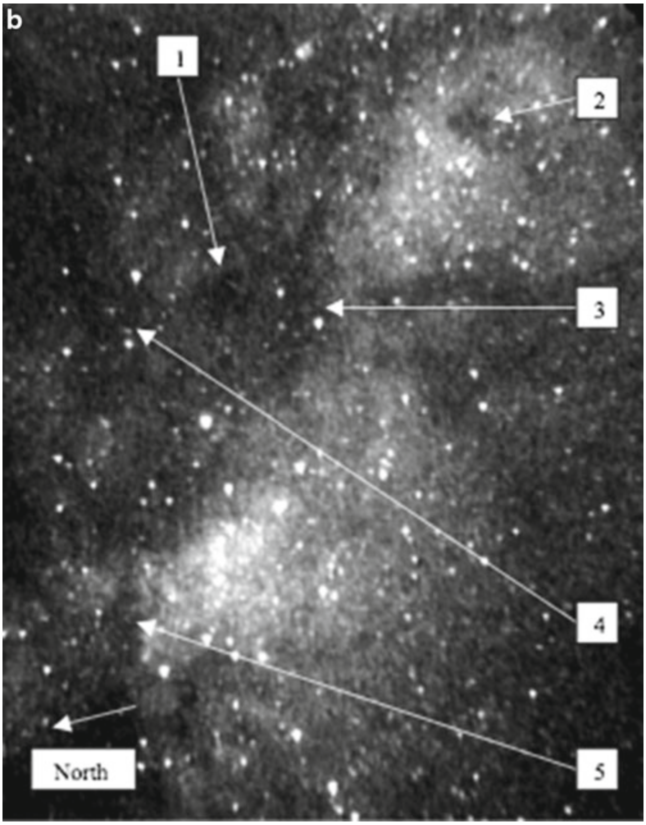

Fig. 3.5 (continued)

nebulous regions, including B103, B97 and B314. As is typically the case, precisely where one nebula starts and another begins is quite vague, since many are interconnected.

You will notice many 'rifts' of dusty matter extending at near right angles to the main rift in this image. This is quite normal to the Milky Way and a common occurrence within the galaxy.

The 'Pipe Nebula' and Other Dark Nebulae in Ophiucus

No less impressive than the previous region of the Great Rift is that part of it located within Ophiucus. Once again, because of its proximity to the galactic core, this region is literally jammed with dark nebulae in every direction. A large complete entity, and probably its most famous member, is the ‘Pipe Nebula’; its additions (often called the ‘Horse and Rider’) actually comprise several dark components (notably B65, 66, 67 and 256, often cited as sub-nebulae). But only two main nebulae make up the famous pipe itself – B59, the stem and the bowl, and B78, which is an area of extreme density, long and narrow, typical of many dark nebulae. The image (Fig. 3.6) below illustrates well the tangle of dark matter that weaves through this part of the galaxy; to the right is the part of the Great Rift (see below). By now the somewhat vague outlines of these nebulae should be becoming increasingly obvious.

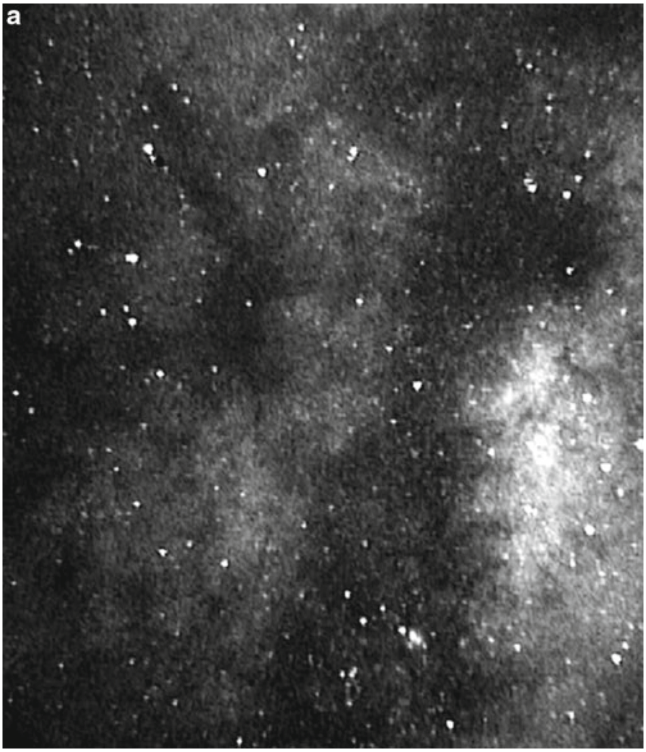

Fig. 3.6 (**a**) The ‘Pipe Nebula’ and environs in Ophiucus (AC). (**b**) (1) B59: the long, straight stem of the ‘Pipe Nebula.’ (2) B78: the bowl of the ‘Pipe Nebula,’ a very dense focus of the entire region, and one of the darkest larger dark regions in the Milky Way. Surely a region of rapid contraction and ultimately has great potential for new star formation in the foreseeable future. (3) A prominent part of the ‘Great Rift’ that divides the galaxy (see later). (4) B77, B269: parts of the rider of the larger ‘Horse and Rider.’ (5) B268, B270: the horse’s head of the ‘Horse and Rider.’ (6) B79, B276: smaller separate dark nebulae. (7) Location of the ‘Snake Nebula’ B79 (see below), too small a feature to show on this frame

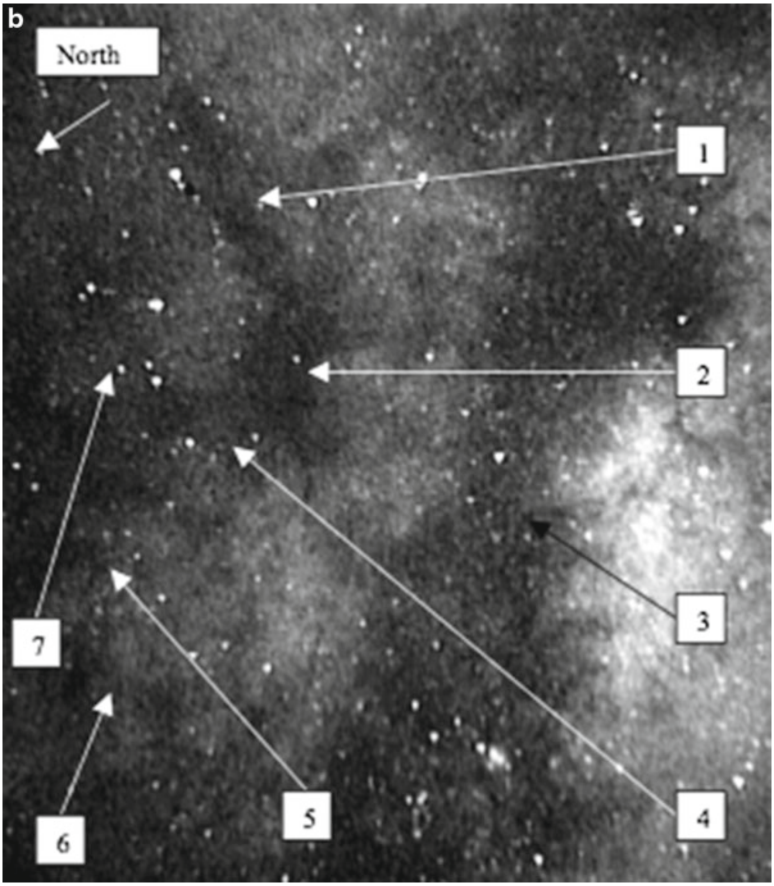

Fig. 3.6 (continued)

B72, the 'Snake Nebula'

B72, the 'Snake Nebula,' referenced above, is an example of a condensing molecular cloud. Reasonably sized – covering an area of almost 40′ – this rather startling dense nebula may be found winding its way through a corner of Ophiucus in the star-packed region we have just examined in macro scale. Appearing as a narrow dark channel with curious near right-angle turns, the thickest and most prominent section appears in the lower right of Fig. 3.7. The remainder, which would represent the head and tail, may be harder live visual targets, but the nebula is one of the more celebrated sights among dark nebulae, especially to see for oneself at the eyepiece.

Fig. 3.7 B72, the Snake Nebula (AC)

Low to moderate powers will prove best, but as always with dark nebulae, only use the minimum power necessary; higher powers than needed will only dilute the contrast. When in the vicinity, it may be worthwhile trying to spot four other small, more typically shaped molecular clouds – B68, 69, 70 and 74 – close by, lying in an arc formation, unfortunately out of the frame but located beneath the lower extremity of the image here. Of those, B68 is the most significant and most easily sighted in live viewing (see Fig. 3.2).

B86, the 'Ink Spot'

Within the larger dark nebulous regions we can expect to find many examples of smaller, denser dark nebulae, their blackness depending on the degree of compression that has taken place. Accessible in the Northern Hemisphere, the 'Ink Spot,' B86 in Sagittarius (Fig. 3.8), is one of the finest examples we will find of a small rapidly condensing dark cloud. Because of the nature of these objects, other molecular clouds may prove challenging, since their visibility depends upon (a) their density, and thus the degree of darkness, and (b) the amount of back illumination.

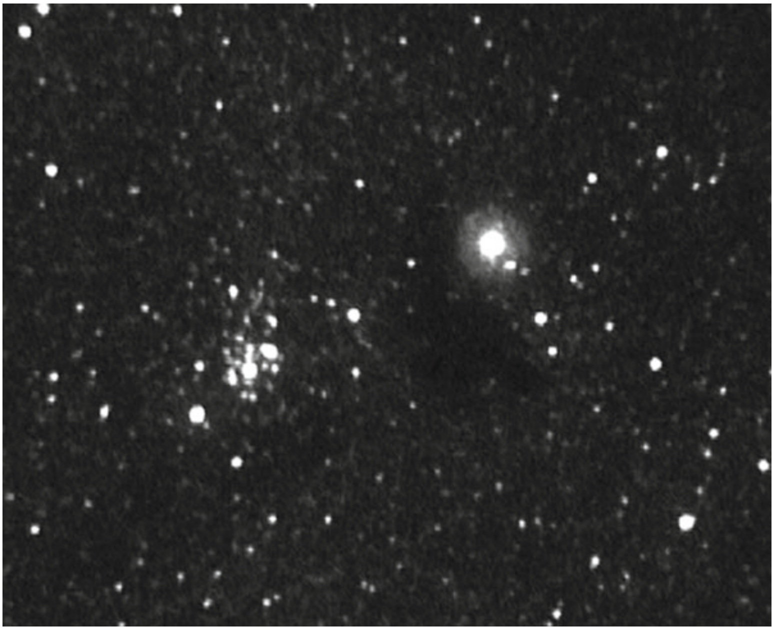

Fig. 3.8 The 'Ink Spot,' B86 (AC)

Obviously, even the densest cloud will not be visible if nothing bright lies behind it. B86, appearing unsurprisingly near an open cluster (NGC 6520), seems to emerge from the trail of dusty matter left over and adjacent to it. The cluster shows that this region has had a very active history with molecular cloud material, now used up in star creation. Appearing as an endless anvil-shaped hole plunging into the abyss (as does the equally famous 'Coal Sack' of the Southern Hemisphere), it is quite easy to see in clear transparent skies and shows well with medium low powers. The view here is quite typical of those through moderate apertures in good conditions. We could argue that the trail of dark nebulous matter lying directly under the image of the cluster represents something akin to dark lanes in open clusters, if not exactly fitting the description. This, again, is a video frame, remarkable in itself and taken through the main focuser of the telescope.

The dark nebulae of the Milky Way remain frequently ignored by too many observers; however, as shown here, they may represent some of our best and most significant viewing potential. The realization, with these sights, that we can observe creation taking place, rather than dismissing them as unimpressively vague objects, may be sufficient to spur the observer on.

Suggested List of Viewable Dark Nebulae

The list of dark nebulae below represents a good cross section of many of the best examples to observe. While not in any way intended to be complete, it is comprehensive and varied, including limited but appropriate observing information for each item. Unfortunately, some of these nebulae might seem less interesting visually, a conclusion one could reach as reflected by the shortage of imagery for a proportion of them. To this end, we owe a special debt to Martin Germano, dedicated observer and astro-imager, who (using equipment much in line with many users of this book) has steadfastly and skillfully photographed dark nebulae for many years and has shared so much of his work online; without his superlative efforts, we would have no good reference images online for many more of these objects. It will be found that some of these nebulae are quite startling to behold and well worth the effort to locate and observe, although one needs dark transparent conditions as the primary consideration.

Each object is listed with, where applicable or available, its *catalog number* first (NGC or other), its *magnitude* next, followed by object *type*, a short *description* of interesting features in parenthesis, angular *size*, *coordinates*, and the *constellation* in which it can be found. Below each object is a link where the most suitable reference image may be found online, if available, together with brief comments regarding the image(s).

Object	Angular size	Coordinates	Constellation	Comments
B5	22′×9′	03480n3254	Perseus	Typical long dark nebula; 1° north following O Perseus; somewhat vaguely defined
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart3.jpg				*Only located image (Barnard plate)*
*				
B7	600′	04330n2606	Taurus	Blotchy, thick dusty 'paw print' E-W, & connected to B209, B211, B213, B216, B217
http://www.starrywonders.com/b7labels.html				*Nebulae labeled on image*
*				
B26-28	20′	04552n3035	Auriga	Jagged dark patches make up the whole
http://tvdavisastropics.com/astroimages-1_000069.htm				*Magnificent image; perfect guide*
*				
B33 *'Horsehead Nebula'*	6′×4′	05409n0228	Orion	Very dense dusty part of larger dark molecular cloud, set against bright nebulosity; very difficult visually; try special *Lumicon* 'Horsehead Nebula' filter
http://www.saratogaskies.com/b33-sho-full.jpg				*One of the more detailed images*
http://www.celestronimages.com/details.php?image_id=4901				*Good reference image to show relative brightness in live view*
*				
B34	20′	05435n3239	Auriga	Round 'hole' with lanes on west side; near open cluster M37
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart7.jpg				*Image on Barnard plate*
*				
LDN 1622	6′×5′	05546n0200	Orion	A jagged, many-pronged dark formation with a tiny reflection nebula to SW
http://apod.nasa.gov/apod/image/0705/ldn1622_carboni.jpg				*Perfect image and guide*
*				
B35	20′×10′	05455n0903	Orion	Conspicuous long void in field of stars
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart6.jpg				*Image on Barnard plate*
*				

B37	180′	06328n1038	Monoceros	West side near to bright nebulae NGC 2245 & 2247
N/A				*No satisfactory image found*
*				
NGC 4755	10′	12530s6030	Crux	Open cluster. Adjacent to 'COAL SACK' dark nebula; closely placed bright stars
'Jewel Box' & 'Coal Sack'	420′×240′	12520s6318		Most prominent dark nebula of Southern skies; adjacent to NGC 4755 cluster – see 'Jewel Box' cluster
http://www.teara.govt.nz/files/p7489snp.jpg http://seds.org/messier/Pics/Ngc/cen_crux_car.jpg				*Images do not do the starkness of the object true justice; regrettably, this is among the better examples*
*				
'Dark Doodad Nebula' (not cataloged)	3°	One end starts at: 12260s7240	Musca	Large, exceptionally dark streak, well defined, adjacent to globular cluster NGC 4372
http://www.capella-observatory.com/ImageHTMLs/StarFields/NGC4372.htm				*Dark nebula clear; high resolution image*
*				
B40	15′	16147s1859	Scorpius	With B41, immersed in bright nebula 50′ north following Nu Scorpio; probably denser part of the greater dark nebula of the region
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart12.jpg				*Image on Barnard plate*
*				
B42 'Great Nebula of Mu Ophiuchi'	200′	16226s2326	Ophiucus	Vast, not completely dark region; unspectacular visually and quite diffuse
http://www.astroimager.net/Page-180-CCD-208.html				*Diffuse nature well shown*
*				

(continued)

(continued)

Object	Angular size	Coordinates	Constellation	Comments
B50	15′	17029s3424	Scorpius	Strikingly irregular dark void, appearing like a deep well; fragmented prongs to west side
http://astroshed.com/milkymap.html				*May be located on numbered Milky Way image*
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart17.jpg				*Good image on Barnard plate*
*				
B53	30′ × 10′	17061s3335	Scorpius	Near B50; arc shaped long nebula
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart17.jpg				*Image on Barnard plate; pronounced dark void*
*				
B55	15′ × 12′	17066s3200	Scorpius	Irregular shape; tiny B56 adjacent
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart17.jpg				*Less pronounced nebula on Barnard plate of region*
*				
B256	50′ × 10′	17122s2851	Ophiucus	Jagged, vague lane 1.5° south of stem of Pipe Nebula
http://apod.nasa.gov/apod/image/0905/pipeneb_beletsky.jpg				*May be located R middle bottom of image*
*				
B 61	10′ × 4′	17152s2021	Ophiucus	Striking, small long dark cloud
http://martingermano.com/Film/Images/B61.jpg				*Good B/W image by Martin Germano*
*				
B63	100′ × 20′	17165s2129	Ophiucus	Large, fairly dark cloud; binocular object, part of 'Horse and Rider': front foot region
http://www.pbase.com/jhapeman/image/85346125				*Rearwards curved front right foot of 'horse'*
*				
B64	10′ × 15′	17172s1832	Ophiucus	30′ preceding globular cluster M9. Curved, very dark nebula; thin 'waist'
http://martingermano.com/B64.htm				*V. Good B/W image by Martin Germano*
*				

B59	300′	17210s2700	Ophiucus	2° south of Theta Ophiuci; Stem of Pipe Nebula; very large, essentially binocular object
B78 *'The Pipe Nebula'*	200′	17330s2600		2.5° south following Theta Ophiuci; Bowl of Pipe Nebula; similarly of large proportions; low power essential; the great void noted by E. E. Barnard in 1906
http://apod.nasa.gov/apod/image/0905/pipeneb_beletsky.jpg				*Outstanding detailed image of the entire nebula (B72 may be seen in context at upper middle of image)*
http://www.pbase.com/jhapeman/image/85346125				*Highly revealing view of greater region, showing the 'Horse and Rider,' with 'Pipe Nebula' being rear quarters of the horse*
*				
B259	30′	17220s1919	Ophiucus	50′ south following globular cluster M9; in region of B64
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart18.jpg				*Image on Barnard plate*
*				
B68	4′	17226s2344	Ophiucus	Dark blotch, 'Bok' globule-like contracting molecular cloud; not unlike B86, near B72
http://ep.yimg.com/ca/I/skyimage_2090_106691541				*Close up of nebula; high degree of darkness and dustiness is clear*
http://www.astropix.com/HTML/D_SUM_S/B72.HTM				*Fine image, shows B68 in context with B72*
*				
B72 *'The Snake Nebula'*	30′	17235s2338	Ophiucus	Famous winding S-shape, more difficult visually than B143. Use lowest power
http://www.feraphotography.com/Ceravolo/Snake.html				*Well detailed image. See also B68*
*				

(continued)

(continued)

Object	Angular size	Coordinates	Constellation	Comments
B276	30′	17374s1937 17380s1950	Ophiucus	Part of larger nebula (including Pipe Nebula, Hind's Nebula, B270 and B63: often termed 'The Horse and Rider'), with extending points; narrow streak of B79 (a little separated from it)
http://astrophotography.aa6g.org/Astrophotos/b276.html				*Very detailed, well contrasted image of this portion of the whole. To see the 'Horse and Rider' refer to 'Pipe Nebula' image*
*				
B283	80′ × 60′	17513s3353	Scorpius	Conspicuous long channel through star field, with narrow mid-section
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart24.jpg				*Vague dark region at center of Barnard plate*
*				
B287	25′ × 15′	17544s3512	Scorpio	Faint reflection nebula at edge
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart28.jpg				*Image on Barnard plate: a difficult object at best*
*				
B84	16′	17575s1740	Sagittarius	Multi-pronged nebula in rich star field, 1.5° north of cluster M23. B83 is small dark nebula at upper right
http://martingermano.com/Film/Images/B83a_B84.jpg				*Outstanding B/W image*
*				
B86 *'The Ink Spot'*	4.5′ × 3′	18030s2753	Sagittarius	An amazing 'snuffing out' of stars – appears as a hole in the fabric; near edge of cluster NGC 6520; easy to observe, very dark small nebula
http://panther-observatory.com/gallery/deepsky/doc/B86_TEC_c120.htm				*Detailed view of nebula and cluster NGC* 6520
*				
B88		18038s2423	Sagittarius	Dark regions in Lagoon Nebula
http://www.nightskyinfo.com/archive/lagoon_nebula/lagoon_nebula.jpg				*See Chap.* 5: *M8*
*				

B87	12′	18043s3230	Sagittarius	Parrot's Head; 4.5° south of cluster NGC 6520; many stars superimposed
http://tas.astroshots.net/Pingley%20Site/Barnard-87-large.jpg				*The best of few images; to see 'Parrot's' requires some imagination*
*				
B303	6′ × 1′	18092s2400	Sagittarius	Dark crescent in bright nebula IC 4685
http://www.dl-digital.com/images/Astronomy/Nebulae/M-8-AreaFinalCombine-redo2-3.jpg				*Nice detailed view of whole region, and fine winding dark lane in middle of bright nebula NGC 6559*
http://www.noao.edu/outreach/aop/observers/n6559connor.jpg				*Close up of B303 dark nebula*
*				
B92	15′ × 8′	18155s1814	Sagittarius	Prominent 'hole,' near edge of small sagittarius star cloud and smaller B93, complex woven structure
http://seds.org/Messier/Pics/Jpg/m24b92mg.jpg				*Effective B/W image*
*				
B93	12′ × 2′	18169s1804	Sagittarius	Ragged streak 30 min following B92
http://seds.org/messier/Pics/Jpg/m24b93mg.jpg				*Immediately adjacent larger B92 in field*
*				
B95	30′	18256s0640	Scutum	Indefinite cloud 2.6° north following bright nebula M16
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart28.jpg				*Moderately difficult region (on Barnard plate)*
*				
B312	100′	18309s1508	Scutum	Remarkable triangular leading edge (a dark arrow 2.5° following M17 nebula with sharp north boundary) of otherwise vaguely defined nebula
http://www.celestialimage.com/page272.html				*Ideal B/W image in brilliant star field context*
*				

(continued)

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Object	Angular size	Coordinates	Constellation	Comments
B100	15′	18326s0912	Scutum	Well defined, with smaller B101 forms an arc
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart35.jpg				*Nice image on Barnard plate; small nebula but pronounced*
*				
B314	35′×25′	18370s41	Scutum	Large nebulous region
p://dso-browser.com/dso/info/B/314?lat_deg=&lat_min=&lat_sec=2&lat_hem=&month=5&day=11&year=2010&timezone=&lon_deg=&lon_min=&lon_sec=&lon_hem=&min_alt=0&hour=0				*Dim image, but shows extent of nebula well*
*				
B103	40′×20′	18392s0637	Scutum	Vague outlines; on north preceding side of Scutum star cloud; almost v-shaped
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart36.jpg				*Image on Barnard plate; notched shape on one side*
*				
B104	15′ ×1′	18309s1508	Scutum	20′ north of Beta Scutum; unmistakable sharp cut in star fabric: figure 7-shaped
http://mstecker.com/pages/astscutumstarcloud.htm				*May be seen at top (slightly right) of image*
*				
B108	3′	18496s0619	Scutum	Double streak; 0.5° preceding cluster M11; less stark dark nebula
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart39.jpg				*Extremely small, extremely difficult object (on Barnard plate)*
*				
B112	12′	18512s0640	Scutum	Small, vague region; lies south of M11
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart36.jpg				*Barnard image; extremely challenging*
*				

B133	10′×3′	19061s0650	Aquila	Very typical long shape; in Scutum star cloud 2° south of Lamba Aquila
http://martingermano.com/Film/Images/B133.jpg				*Another fine B/W image from this fine observer (Martin Germano)*
*				
B142	50′ ×80′	19407n1057	Aquila	Narrow winding lanes 3° north preceding Altair
http://aida.astroinfo.ch/displayimage.php?pid=4492&fullsize=1				*Seen here with B143; B142 is separated to right*
*				
B143		19414n1101	Aquila	Celebrated irregular ‘C’ shape in middle of star field
http://www.perseus.gr/Astro-DSO-Nebulae-Dark-B143b.htm				*Easy to identify!*
*				
B145	35′×6′	20028n3740	Cygnus	Curved streak in bright star field
http://www.astrographica.com/index.php?q=gallery&g2_itemId=6780				*Huge but exceptionally detailed image*
*				
B343	13′×5′	20135n4016	Cygnus	Typical long dark nebula 1.7° preceding Gamma Cygnus
http://martingermano.com/B343.htm				*Another very revealing B/W image from Martin Germano*
*				
B346	10′	20267n4345	Cygnus	Patchy area 2.8° preceding and 1.5° south of Deneb, sometimes termed ‘The Northern Coal Sack’
http://www.hawastsoc.org/deepsky/images/cyg/b346.jpg				*Excellent B/W image of nebula*
*				
B347	4′×1′	20284n3955	Cygnus	Narrow triangle 1.2° following and 20′ south of Gamma Cygnus
http://martingermano.com/B347.htm				*Martin Germano again. VG B/W image*
*				

(continued)

(continued)

Object	Angular size	Coordinates	Constellation	Comments
B150	60′ × 3′	20506n6018	Cepheus	Curved filament 1.6° south of Eta Cepheus
http://www.astrosky.it/index.php?id=217				*Spectacular image showing full extent and detail of the nebula*
*				
B352	20′ × 10′	20571n4522	Cygnus	Lies north of North America Nebula; the ‘Gulf’
http://www.saratogaskies.com/image.pl?i=18				*Identified on image*
*				
B164	12′ × 6′	21465n5104	Cygnus	Arc-shaped dark nebula
http://www.library.gatech.edu/Barnard_Project_W/platechart/platechart48.jpg				*Difficult region (at left of Barnard frame)*
*				
B168 & IC 5146 ‘*Cocoon Nebula*’	100′ 12′ × 10′	21532n4712 15340n4716	Cygnus	Narrow elongated E-W lane ‘Cocoon Nebula’ (emission) with young star cluster at SE end; ‘Horsehead’ filter may be needed to see nebula effectively
http://www.ricksastro.com/DSOs/cocoon-h16.jpg				*Nice image with ‘Cocoon Nebula’ at one end*
*				
B169-171	80′	21589n5845	Cepheus	Narrow curved lanes 3° north following IC 1396; not the darkest examples; B174 is the largest of those neighboring dark nebulae numbered 169–174. See below
http://www.madpc.co.uk/~peterv/astroplover/ST10Pics/LesGranges2008/Medium/B169-71.jpg				*Excellent reference image*
*				
B173-174	22′	22073n5905	Cepheus	S-shaped nebula 3° north following IC 1396; very dark; stars in foreground of B174
http://www.flickr.com/photos/iyacalgary/3948874970/				*Near center of image; IC*1396 *large bright region right of center*

Chapter 4

Dark and Dusty Regions in Bright Diffuse Nebulae

For observers, diffuse nebulae offer some of the most glorious sights available throughout the entire visible universe. Essentially vast, brilliantly illuminated fields of gas and dust, they are the indirect result of what may have seemed an unlikely transformation of the once dark interstellar medium (Fig. 4.1).

By default, virtually all of those that are observable belong to our local galaxy, since others are far too distant to be readily available to observers. One notable exception, of course, is the 'Tarantula Nebula,' NGC 2070, within the Large Magellanic Cloud, which in essence belongs to our local system; next in line, NGC 604 lies within another spiral galaxy, M33 in Triangulum, the nearest galaxy after M31 in Andromeda. Although this is a truly huge nebula to be sure, it is nevertheless too distant to be viewed, or even imaged in any meaningful way with typical equipment.

The definition of 'diffuse nebulae,' of course, covers a wide range of spectacles, but typically what first comes to mind are those vast expanses of illuminated, twisted and woven shapes that stud the celestial fabric in fantastic and brilliant forms. However, aside from uneven distributions of matter and whatever stars are within them, it is mostly the existence of dark and dusty material (in varying degrees) that renders their appearance so astounding, many looking more like folded curtains, capes, and other features, or figments of the imagination, than their true reality. It is all too easy to overlook the fact that more than one variety of nebula frequently makes up the whole – at least as far as the most spectacular are concerned, and it is also fair to add that they are only further enhanced by the presence of deeply embedded hot young star clusters, something common to all the most spectacular examples.

We have already reviewed how the molecular hydrogen component (HII) of once-dark clouds of gas (nebulae) in space becomes visible when illuminated by the radiant energy of nearby hot young stars (which turns them into emission

A. Cooke, *Dark Nebulae, Dark Lanes, and Dust Belts*,
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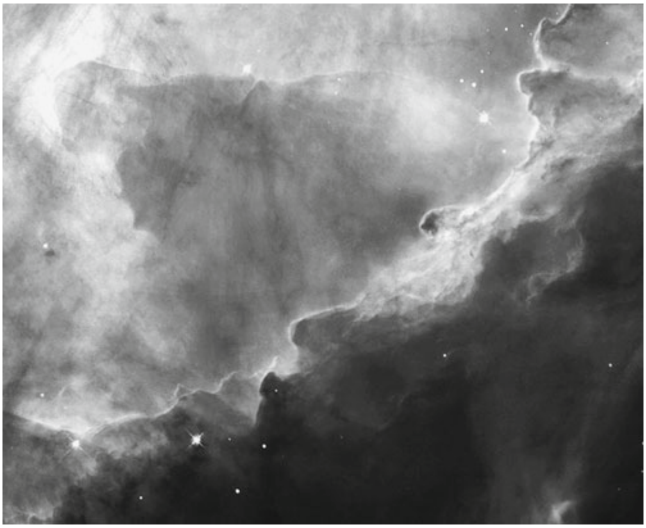

Fig. 4.1 Dark nebulous clouds within the brightly illuminated 'Omega Nebula,' M17 (image courtesy NASA and ESA)

nebulae). When favorable quantities of star-forming matter are present these stars are frequently grouped with others into new open clusters. You may also be familiar with the process by which some regions of localized dust and gas are made visible merely as a result of reflected starlight. This light, in the blue part of the spectrum, is a predominant wavelength of the new stars, and thus it is hardly surprising that much of this light is available. Because the blue region of the visible spectrum is most readily diffused and scattered, it is the characteristic of this wavelength that makes reflection nebulae visible. Completing the picture, and actually tending to define it, remnants of *unlit* gases and dust create the all-important visual illusion of depth and complexity. Although such nebulae are indeed deep and complex from a physical standpoint, the apparent twisted forms they seem to take is more illusory than reality – after all, we have no means to see dimensionally across such vast distances of space. However, among illuminated diffuse nebulae these defining ingredients, and the precise ways that they are intermixed, are the keys to forming our best observational subjects.

Thus, as part of every magnificent illuminated nebula, we will usually see emission, reflection and dark nebulae components. Different viewing techniques and accessories will often emphasize one type, sometimes at the expense of at least part of others. For our purposes in this writing, however, it is specifically those regions of dark unlit or partially illuminated matter within these nebulae that will command most of our attention – the factors that contribute so much to give the nebulae the form and spectacle we perceive. It is this unique blend that makes up most of what is so magical in such awe-inspiring sights as the ‘Great Nebula in Orion,’ M42, the ‘Eagle Nebula,’ M16, or the ‘Omega Nebula,’ M17 – revealed to us not only by the dazzling energy of many new stars within them but probably even more by what is not illuminated by that energy.

Although there are also plenty of nebulae exclusively of one type, this usually results in less interesting visuals. A few of those, however, rank among the grandest, at least from an observer’s perspective, the result of fewer temperature extremes, with stellar winds sculpting the scene. Logically, such nebulae tend to be smaller in size, too. Molecular clouds are far from consistent in texture and distribution, and this, of course, has much to do with the way each nebula appears. Because the exact proportions and placement of the primary ingredients of the nebulae have much to do with the range of light wavelengths reaching us, their appearance differs greatly from example to example.

It is easy to overlook these important factors within illuminated nebulae that further sculpt the spectacle before our eyes. In addition to the effects of visible light, radiation and heat created by new stars, are types of interstellar turbulence – winds that can cause ‘bubbles,’ or compressed ‘walls’ of gas, and numerous visible signs of cosmic ‘shock’ that ultimately influence many of the twisting folds we observe: true celestial artworks in progress. The dark cocoon of gas surrounding the cluster NGC 2244 deep within the ‘Rosette Nebula’ complex in Monoceros shows us the very forces of interstellar winds, as the gases surrounding the cluster are being pushed outwards to form what we see as the center of the ‘rosette’ itself. Note also the very fine dark and spidery lanes in the inner illuminated ‘ring,’ as well as the extremely mottled nature of the entire nebula itself. However, do not expect to see all of these fine details at the eyepiece (Fig. 4.2).

We can also detect other processes within some illuminated nebulae, too. Many of the fine streaks detected in them are actually the luminous expulsions of matter from very young stars still buried within the still dark structure; these are known as ‘Herbig-Haro objects,’ after the astronomers who finally unlocked the code to how they were formed. These fast-moving streams of matter, from jets of gas emitted from the poles of stars of more than two solar masses, become luminous by the resulting pressure of their collisions with the surrounding dusty matter. They are also one of the factors that help to clear the region of remaining gas and dust, something regularly seen around many new stars. Once again, it is the HII component in these formations that makes them visible, although it will be infrequently that we actually sight such a delicate object in the eyepiece; they are almost exclusively photographic in nature.

And we must not overlook the consequences of sudden and dramatic events, such as supernovae, that may trigger visible waves of gas compression and may lead to star-making activity. With yet another form of radiant energy, just the heating processes of stars within some of them may also cause portions of the interstellar dust itself to emit infrared light, compared to the ion-excited luminescence of HII gases. Although not occurring within normally visible wavelengths, (as you may recall from Chap. 2, image intensifiers can render it so), especially those frequencies closer to radiant light. We should thus readily appreciate how orbital

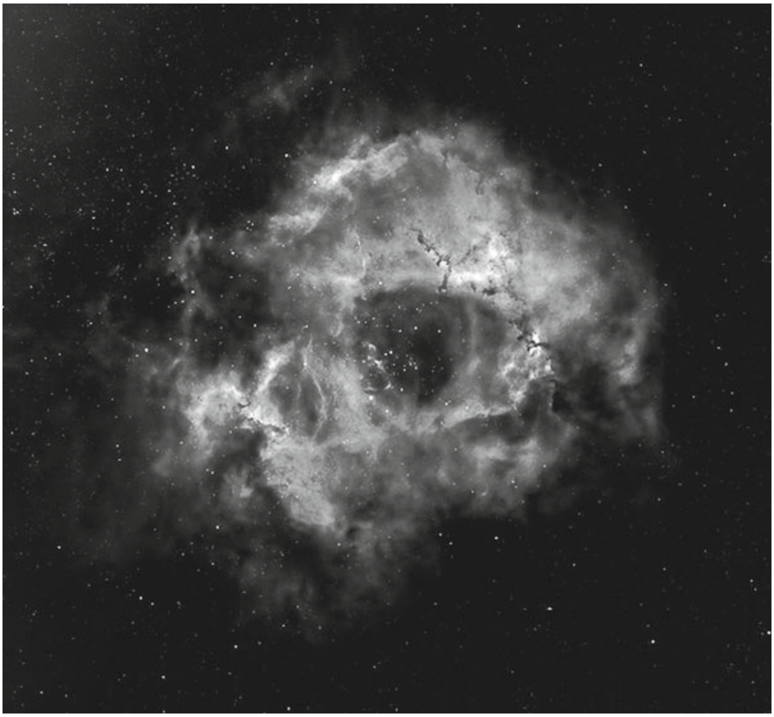

Fig. 4.2 The Rosette Nebula (image based on data obtained as part of the INT Photometric H-Alpha survey of the Northern Galactic Plane, prepared by Nick Wright, University College London, on behalf of the IPHAS collaboration)

telescopes designed to view wavelengths far outside those normally visible may capture significantly different appearing images of familiar objects, often to the extent that they are unrecognizable.

Pure reflection nebulae are gentle by nature and not the hothouses of new star formation that emission nebulae are, nor are they made visible by any reactive activity of their own making. Quite cold in temperature, they are likely to be more subtle in luminescence than those of emission types. In contrast, the high temperatures of emission nebulae also make them very strong in the red and infrared part of the spectrum.

For those enthusiasts of color imaging, other fundamental elements may also be present in the mix of the great nebulae, adding further colors, or at least traces of them, as can be seen in most color CCD time exposures of them. For example, when the radiation of nearby stars creates double ionized oxygen, the gas gives off a characteristic green hue, resulting in prominent spectral properties responsible for those infamous 'forbidden lines' of antiquity – the dark spectral lines that could not be explained by scientists of the time, and explained away by the hypothetical element 'nebulium' (see Chap. 7). With the grandest spectacles tending to consist of both emission as well as reflection components, again it is the variations of dark cloud formations interspersed throughout them that have the most significant influence on our Earthbound interpretations as the astounding forms so familiar to us.

Certain other visible illuminated nebulae may be the tattered remnants of isolated, relatively local supernovae. Regretfully, only a few are within range for the amateur observer. As forms of emission nebulae illuminated by radiant energy, because the remaining neutron star is solely responsible for lighting what we see, generally they are more diffuse, delicate and much fainter than the type of illuminated nebula of the previous categories. They are often characterized by striations and wisps, as might be expected of the surviving remnants of an explosion (i.e., the 'Veil Nebula' in Cygnus, NGC 6960, 6979 and 6992/6995) and unlikely to show true dark regions, other than intermingling fingers of the blackness of space behind, or variations in density. The most notable exception to much of this is the 'Crab Nebula' M1 in Taurus, which being relatively recently created has not yet had time to separate into well-isolated and faint strands and shreds. Thus within this fairly luminous (at Magnitude 9) and reasonably sized object (at approximately $420'' \times 300''$), it is possible to see a broader nebula with innumerable and typical striated wisp-like forms that have started to emerge in the aftermath (a recent event in cosmic time, dating from 1054). Darkened regions among the tangle of exploded matter are unlikely true dark entities; presumably most of them are gaps and variations in density of the exploded matter, and merely the background of space itself. However, certainly, parts of the nebula are more brilliantly illuminated than others (see observing section).

Additionally, no one could dispute the existence of dusty gases enveloping certain open clusters, such as the bright, puffy nebulosity in the nearby and conspicuous Pleiades Cluster, M45. This has been classified as a reflection nebula, which indeed it is, although of a less typical origin. We know now that this dusty interstellar cloud (that happens to be passing by, on a cosmic timetable) is unrelated to that cluster's creation, and it is illuminated solely by reflected light from the cluster's stellar components. There must be many such examples throughout the galaxy, though none so easy to observe as in this particular nearby spectacle.

We should understand that all such nebulae have relatively short life spans, cosmically speaking, since the low gravitational attractions of typical loose groups/open clusters of stars (underlying all larger illuminated nebulae) ultimately will cause the stars to slowly drift apart, continuing to do so as their metallicity gradually lessens and the stars age and migrate ever further from the galactic thin disc. Quite aside from the gradual depletion of the interstellar medium in star birth, as the stars become independent of each other the illuminating source is removed, and the grand spectacles put on by the nebulae that once enveloped them will gradually fade away. Others will form by the same processes that gave us all of those we know.

Observing Dark Features Within Illuminated Nebulae

For ways to observe these sights, our options are quite varied. In some of the best-known examples, the nebulae are so large and bright that fairly low powers will show extensive detail. We will often see all the more complex structural forms, and with a well-illuminated image in the field of view, these subtleties are not hard to come by. For increased resolution of fine detail, the brilliance of many of these sites will allow considerable magnifications on small portions within the entire nebulae.

Unfortunately, the brilliance of all illuminated nebulae cannot be taken for granted; the majority of them are of a low total surface brightness, which does not help when using higher powers to see detail. This is especially problematic with smaller and distant nebulae, which may require the use of higher powers, although emission nebulae, with the typically accompanying red and infrared portions of their spectrums, respond very favorably to electronic enhancing devices. However, one must remember with the use of electronic aids that any reflection components when present will tend to fade, sometimes to be lost entirely in the view, since the blue light of these nebulae is not well suited to the sensitivities of electronic devices in general. When both emission and reflection components are equally present, the view will be significantly altered.

The many available light pollution/nebula filters may also drastically enhance the live images of mixed component nebulae, regardless of viewing location, although most of these filters also reduce the visibility of reflected light. Additionally, certain filters (such as Lumicon's 'Horsehead Nebula' filter) may enhance elusive dark regions of illuminated nebulae, something we are seeking to accomplish. However, many people will be reluctant to purchase expensive filters that produce dramatic results on only a few subjects. Regardless, such filters may provide invaluable service, since they enhance the appearance of radiant portions of these objects, usually without filtering out all of the reflected light in the blue spectrum. Although they may dim the overall view somewhat (the appearance of objects may be an acquired taste) on perhaps at least a majority of subjects, the observer will usually see more detail when utilizing them than not. With pure reflection nebulae that are delicate or dim, these filters may prove to be less helpful. However, it is always fair to say that many illuminated nebulae will show wonderfully well with no viewing aids whatsoever (other than good eyepieces), revealing themselves in many ways, and perhaps more readily than any other type of deep space object. It remains up to individuals themselves, for their own purposes and expectations, to determine which subjects respond best to any specific viewing approach.

Most illuminated nebulae do not equal the visual splendor of the famous examples we see in textbooks; in real life these evocative deep space objects tend to be delicately displayed with subtle details and outlines. Regardless, the types of features that define them are consistent. Even in many less brilliantly lit nebulae, striking characteristics may be present; they may be just a little more difficult to observe. We will look at a few of the brighter examples, as they will serve us better to demonstrate the characteristics common to many. They may make it easier to locate such features within other less prominent examples; while long time exposures will clearly reveal these features in most examples, live viewing requires considerably heightened awareness of what we should look for. Perhaps the most celebrated example, the Great Nebula in Orion, M42, is the best starting point, its brilliantly revealed and varied features, along with huge size, making for easy recognition in the live view through almost *any* decent telescope.

The Great Nebula in Orion (M42) and Greater Region of Barnard's Loop

As a spectacle, the Great Nebula in Orion, M42, is probably rivaled only by the Great Nebula NGC 3372 in Carina (regretfully, visible only in Southern Hemisphere skies). M42 is one of the most celebrated deep space objects of all. However, it is merely one small corner of the vast Orion Molecular Cloud, which encompasses many other less prominent illuminated nebulae, including 'De Mairan's Nebula,' M43 (the comma-shaped nebula adjoining M42; see below); the 'Horsehead Nebula,' B33; the 'Running Man,' NGC 1977; the 'Flame Nebula,' NGC 2024; and 'Barnard's Loop,' Sh2-276 (named after the same Barnard), a huge luminous arc that partly encircles all of these.

Specifically, sprint just a few degrees further to the north of M43 and the 'Running Man' Nebula NGC 1977 can be found, also part of the larger nebulous region. Being predominantly a reflection nebula, it is fairly faint, but the unusual linear dark nebulae crossing it are worth the trouble of trying to observe. They do indeed resemble its namesake and are true dark lanes. However, be prepared to spend some time at the eyepiece for these characteristics to be seen convincingly.

Not far away and still connected to the greater whole is the most famous dark nebula in the region – if not the most famous of *all* dark nebulae – B33, the 'Horsehead Nebula.' This nebula instantly brings to mind any number of well-known images. It is intermingled within a region of considerable illuminated brilliance. Unfortunately, this most famous of dark nebula is also among the hardest to see, often requiring a certain specialized filter, made exclusively by Lumicon just for this one sight! Worse yet is to attempt to view this nebula with an image intensifier, since it is situated precariously close to Sigma Orionis, a double star sufficiently bright that snagging it in the field would probably cause irreversible damage to the image plate. Otherwise it would likely be an exceptional object to view and image in this manner; almost needless to say, be advised, should you own one, turn your intensifier on it at your peril. And lastly, one must not forget the 'Flame Nebula,' NGC 2024, also part of the region's continuing dark nebulous curtain. Perhaps next in line among significant nebulae of the area, sadly, for image intensification, it, too, is situated precariously close to that same bright double star.

M42

M42, containing every major feature of nebulae all at once (emission, reflection, dark nebula components, a star nursery and brilliant star cluster in the making, and all manner of 'folds' as evidence of stellar winds), must rank high in any survey, with so much on view that is easily seen and identified. At a distance of less than 1,400 light years it is quite near, cosmically speaking, which makes the total dimension of M42's illuminated structure of around 25 light years appear very large. In the eyepiece its huge apparent dimensions (approximately $85' \times 60'$) make it seem to spill out of any field of view, almost regardless of magnification. Its brilliance of magnitude 4 is second to none, literally shining light on the face of the observer. Although Barnard did not label any of the dark components of this nebula in his catalog, they are such significant parts of it that they define much of what we see and the impression it makes.

Just as striking in this dazzling spectacle are the many curtain-like features, creases, dark lanes and walls of compressed gas that punctuate the nebula. Although many of these details consist of dark or only partially lit regions, they are not all of identical consistency or luminescence. It is partly this quality that, to many observers, imparts the impression of velvet drapes. In looking east and west, these lanes seem to be drawn out of the central blaze of stellar brilliance to take on a striated appearance, their outstretched all-embracing arms giving rise to their nickname of the 'Bat Wings.' Towards the point of origin of these 'wings,' dusty material seems most concentrated and forms into the well-known dark yet mottled incursion into the Huygenian Region, a feature better known as the 'Fish Mouth.'

Fortunately for us, the nebula is brilliant enough to allow for a variety of viewing methods, including various light pollution filters that may yield valuable insights, revealing more of the extent and fine details of the 'wings' without reducing effective image brightness, even rendering these features more easily seen. On both sides of the greater nebula are strikingly curled and circular dark forms, appearing to finally wrap around the spectacle. Many observers delight in seeing traces of color in the nebula, including reds from ionized hydrogen, green from doubly ionized oxygen, shades of blue and even violet emanating via reflection from stars deep within the nebula, and even colorful reddish hues from ionized sulfur. But remember, all color in deep space exists in trace amounts only.

In the image below (Fig. 4.3), seemingly countless young hot stars stud the entire huge central region, which typically causes overexposure, and despite that exposure being a true snapshot it reveals just how bright this subject actually is! This is one of the brightest sights in the entire sky.

That dazzling blaze, the center of attention of the whole and known as the 'Huygenian Region,' is a stellar nursery of legend; it contains the famous quartet of hot stars at its heart known as the 'Trapezium,' a prominent group and a true multiple-star system. By increasing the magnification (or reducing image exposure substantially), the true identity of the star-forming Huygenian Region is suddenly easily seen, including countless fine dark details and subtle features of interest.

Fig. 4.3 The Great Nebula in Orion, M42, with M43 (*left*) (AC)

It is hardly necessary to point out the large number of them revealed even in the simple image, Fig. 4.4. While observing the region at the telescope, you might look for the small, dark, cocoon-like cavity that the 'Trapezium' itself occupies (indicated by three unnumbered arrows). This exists mostly as the result of stellar winds (caused by the increasing temperatures of the young stars) pushing matter away from them, and presumably partly because much of the surrounding gases have been used up during the production of these stars. This has left clouds of dust (dark mottling) and unused gas, shown here glowing due to the ongoing HII ionization processes. Infrared light emission from the dust may also be responsible for some of the glow in image intensifier images.

The image (Fig. 4.4) shows most of the details as they would appear in the eyepiece when utilizing a higher power. This quickly executed image is truly remarkable, especially for all that it shows of the fine inner details formerly the domain of only large professional facilities. Puffy cloud formations are striking, almost reminiscent of Earthbound atmospheric varieties, as are numerous subtle dark details, and the chance to see ever-increasing numbers of tiny faint young stars forming at the beginning of their lifecycle – widespread throughout the region. Live viewing will often reveal many of these stars under good conditions, where you may see as many as 20–30 just in this central area, and with only moderate optical aid.

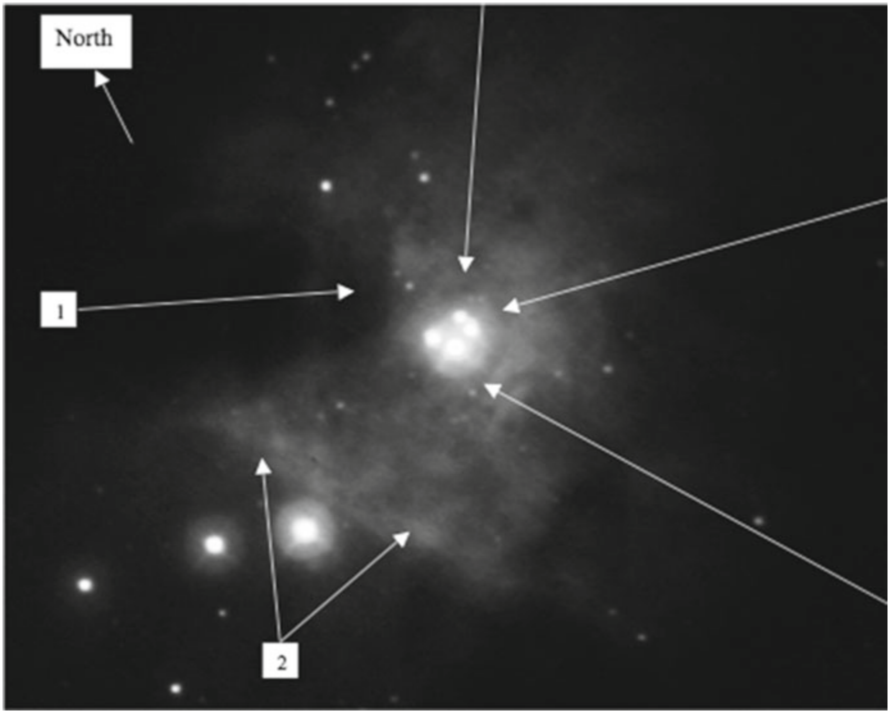

Fig. 4.4 The 'Huygenian Region' and 'Trapezium' in M42 (AC). (1) The 'Fish Mouth,' perhaps the single most celebrated dark nebulous component in M42. (2) The bright mottled bar of illuminated gas outlining the southwestern end of the Huygenian region

Star hunters have cataloged hundreds of them throughout the region. Be sure also to take note of the straight mottled bright bar of illuminated gas that outlines the western border (near the bottom of this image); although less prominent on this image intensifier version, observatory images show this as a multi-colored feature many times as bright as its surroundings. This is a prime example of double- and triple-ionized gases in the process of being pushed away from the searing cauldron by a wall of stellar winds.

M43: De Mairan's Nebula (Part of the Greater Whole of the Orion Nebula)

Connected to the northern side of M42 lies M43, a striking 'comma'-shaped nebula, but really just an extension of its much larger companion, with the illuminating star NU Orionis at its heart. Be sure to look closer to see what gives the nebula that distinctive shape; there is a stark dark nebula running down its northern side, much

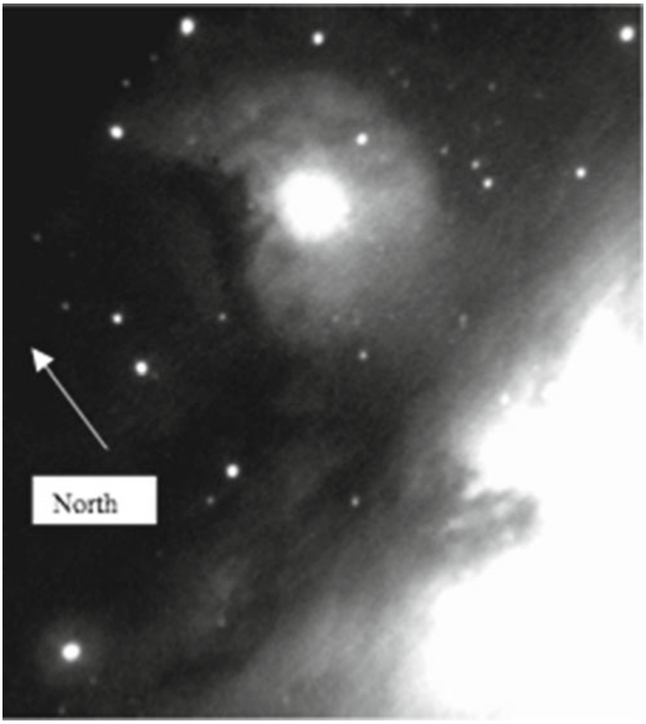

Fig. 4.5 M43 (AC)

darker than the better known adjacent 'Fish Mouth' in M42, then working its way westward as it cuts an entire corner from the nebulous region.

Had NU Orionis, the HII exciting star at the heart of M43 and an unexceptional star among the sea of high energy, young stars, been hotter, M43 would have appeared considerably more brilliant. The resulting higher radiation would possibly have lit up other unseen gas, while causing more of the dusty dark clouds to glow increasingly with infrared light. As it is, the dark nebula component appears very dark indeed in the eyepiece, seemingly darker than the surrounding space. Careful observations reveal that it continues to extend west and southward, almost completely blocking any light that may be emanating from behind. Also note the less conspicuous dark streaky 'branches' within the comma-shaped nebula itself and traces of illuminated gas on the opposite side of the main dark lane. Because the entire Orion Nebula region is so loaded with interstellar dust, some of the light of the faint young stars is often intermittently blocked to a degree that many appear to disappear or seem to be variable as the clouds waft by! NU Orionis is perhaps the most prominent example in the entire group, but it is still subject to apparent variability by movements of the swirling dust and gases that surround it (Fig. 4.5).

The 'Omega Nebula,' M17

The 'Omega Nebula' M17 in Sagittarius is another magnificent sight among illuminated nebulae near the hub of the galaxy and also aptly demonstrates several aspects of the sculpting effects of dark nebulous matter throughout what we see. Although the very bright (6th magnitude) nebula is made visible by a vibrant young open star cluster deep within it – perhaps near the height of star creation – the yellow coloration of this predominantly emission nebula is as striking as the many dark and shaded details that fully define its appearance. Accordingly, the nebula takes a rich form, corresponding to dark zones and other subtle darkening and shading; more likely, most of what we perceive as apparent folds and three-dimensional curvature of the glowing nebula is not at all as it seems.

Visually, while not huge, M17's apparent dimensions are sufficient to easily render it large enough for detailed observations. To this writer, it always seemed in the live view that the blackness of space was greater on one side of the nebula than the other, something readily born out in the image here (Fig. 4.6). The apparent

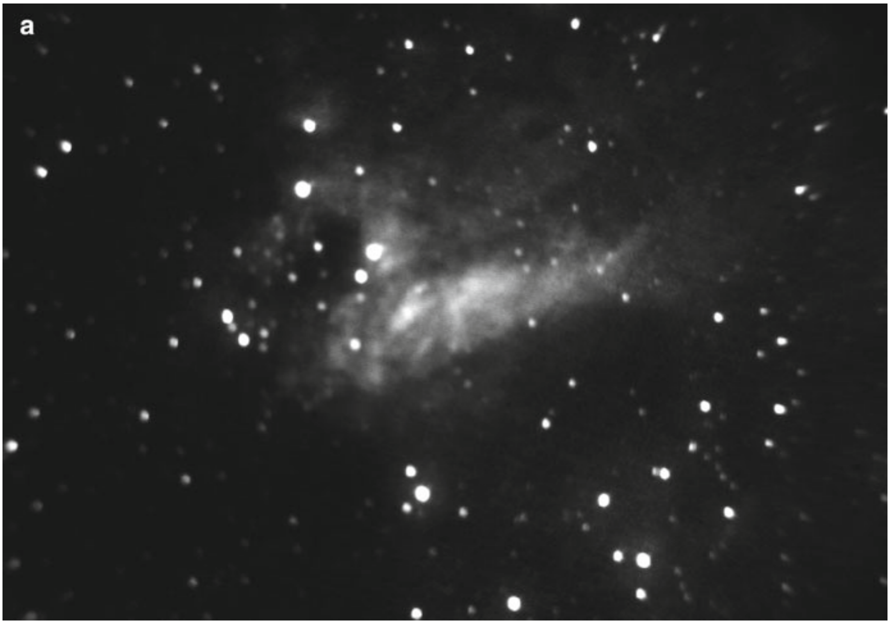

Fig. 4.6 The 'Omega Nebula,' M17 (**a**) AC and (**b**): (1) this divide from top to bottom reveals an apparent visual border in the interstellar clouds between that which is illuminated and that which is non-illuminated. Regardless, the sudden darkening on this side of the nebula is somewhat startling. (2) An apparent dark parting in the illuminated gas, but would seem actually due to variations in the makeup of the dusty intrusion relative to its surroundings. (3) A striking dark nebulous 'V' formation within the brightest part of the illuminated region.

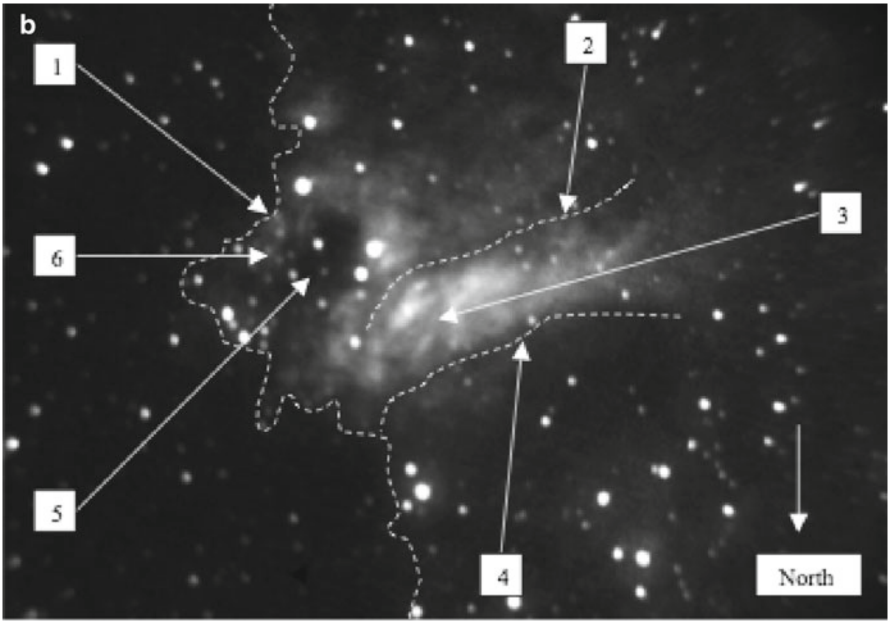

Fig. 4.6 (continued) This is one of the features that impart a winged, swan-like appearance to the nebula. (4) A sudden change in illumination, not unlike (**2**), and apparently again due to another dusty intrusion; north of here, it appears to continue expansively as a generally less illuminated part of the nebula. Compare this side of it to the other to the south. We can assume that various stellar winds are responsible for these variations in density. (5) Perhaps the most interesting feature in the entire nebula, appearing as a hollowed out circular region, and again apparently the result of stellar winds from the heart of the cluster blowing the dusty matter outwards. This is similar to the hollowed-out zone we see in the ‘Rosette Nebula,’ and from our perspective forms the ‘swan’s’ neck and head. (6) This region, just southeast of the dark hollow, seems to be the nursery of most of the youngest stars, just beginning to emerge from their incubation as protostars

border at the edge of the illuminated nebulous matter is striking; it is not, however, a true void in the fabric, merely corresponding to a part of the greater cloud of interstellar matter yet to be illuminated. We know that this is the correct analysis of what we are seeing, because this region lies so close to the galactic core that it certainly is not a transparent, relatively starless part of the Milky Way! Rather, the stars that we do see are superimposed in our line of sight in front of the obscuring dust.

As one may notice about some other brightly lit nebulae, surprisingly, those dark regions within this nebula do not appear in Barnard’s catalog. Regardless, their role and significance is not diminished.

The ‘Eagle Nebula,’ M16

Much harder to see, let alone to easily image, but one of the most evocative sights in the entire sky, is the ‘Eagle Nebula,’ IC 4703. Lying within the area of the open cluster M16 in the constellation Serpens, it is a nearby celestial neighbor to the Omega Nebula, M17. One should not miss the opportunity to observe both while in the region.

Despite the relative small size of the Eagle itself, (only 7 arcmin), there can be few observers who do not relish the possibility of seeing the great formation looming out of the clouds; however, it is not an easy mark. The nebula is not bright (far less than the 6th magnitude value of the illuminating star cluster), and despite the fact that Barnard himself was the first person to photograph the prominent dark columns, fully revealing them for the first time, strangely they do not appear in his catalog. Although not nearly as difficult a target as the ‘Horsehead Nebula’ in Orion, it nevertheless requires very transparent skies and a considerable degree of patience, illustrating again how vague most features within illuminated nebulae usually are. One needs to adjust one’s expectations accordingly; observers of antiquity missed the nebula entirely. One should be prepared for something far less grand in the field of view than the dramatic Hubble imagery perhaps has led us to expect.

Looking at this spectacle, a hot young cluster (approximately only 5 million years old) illuminates the surrounding HII gases, while the stars shine like large jewels and the eagle-like dark segmented cloud emerges from out of the midst, as if in flight and apparently heading right toward us. Despite its considerable distance of 7,000 light years, even such fine detail as the bird’s talons seem to be resolved, as well as a ruffled plume of dust in its wake. However, it is these very features within the much darker region than that surrounding it that are believed to consist of rapidly condensing interstellar medium on the verge of spawning new stars. At the uppermost tips of these dark columns, rocket-like offshoots appear to be actual forming protostars, otherwise known as EGG’s (see Hubble Telescope image in Fig. 4.7). This region has, of course, become better known as the ‘Pillars of Creation’ after detailed imagery by the Hubble Space Telescope revealed its true detailed nature for the first time.

While seeing it at such close range hardly gives the visual impression that has made this nebula famous, the ‘pillar’ at the right of the image is usually seen to represent the talons, and the middle ‘pillar’ the head and body. The pillar on the right is much fainter in the live view than it appears here and is not seen as part of the great flying bird. The illusions of the Eagle only become realized at the eyepiece, and more clearly in smaller, less detailed images that show the entire nebula in its surroundings. In what amounts to a real-time image (Fig. 4.8) made by the author, although not standing up to a larger scale, the picture does provide a fairly representative impression of the way the nebula and its adjacent star cluster can be expected to appear (in moderate apertures under really dark skies), once the eye has made its adjustments. The two main ‘pillars’ comprising the ‘eagle’ in the Hubble image are clear enough toward the top middle of the image. The illuminated tip of

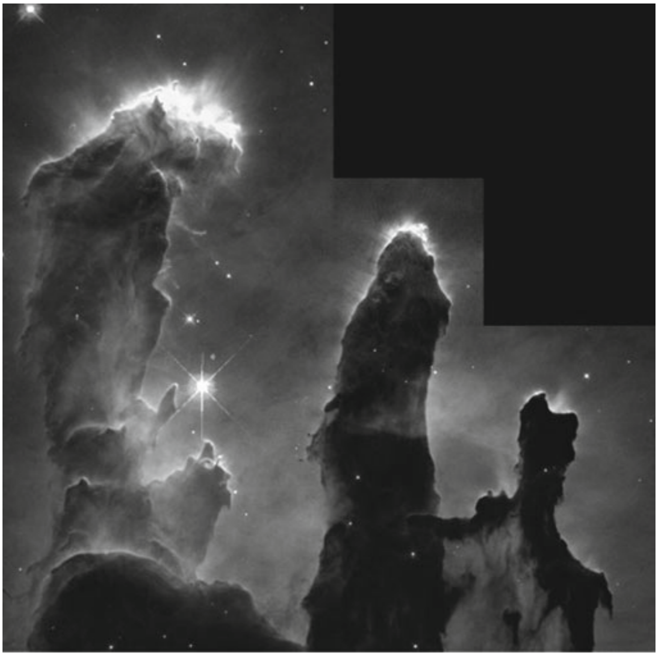

Fig. 4.7 Portion of the 'Eagle Nebula,' M 16 (image courtesy NASA and the NSSDC)

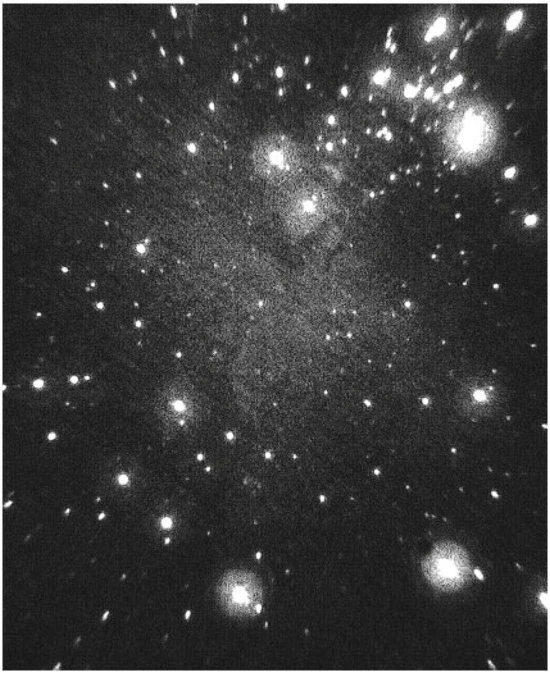

Fig. 4.8 The 'Eagle Nebula,' M16 (AC)

the leftmost 'tower' in Fig. 4.7 is also evident, forming a triangle with the two closest bright stars. More significant, though, is that suddenly now the 'eagle' can be seen in context as it takes flight. The image is quite magical, especially considering the very short length of its exposure.

More detailed imagery certainly exists that shows increasing finesse within this sight, but one should not expect the live view to compare with them. Make no mistake, this is a delicate subject, in no way competing with M42 or M17 in immediate visual splendor or magnitude, nebulae so grand that they register immediately with the greatest of ease and speed, and in most of their full glory at that. Therefore, patience and viewing skills will be necessary in order to experience the wonder of this spectacle, although the cluster is an easy and appealing object all by itself. The brilliance of the cluster makes its precise location easy to find.

The typically violent processes of unstable nearby giant stars frequently serve as the catalyst in triggering the very creative forces that bring into existence yet more stars; however, it can also destroy them before they can mature, like a animal eating its young. However, this is the way of dark nebulae and the star clusters that inhabit many of them, as illuminated nebulae are transient structures that experience relatively fast evolutions. Because of these rapid changes it is fortunate at this point of time that we can experience such a grand spectacle as the 'Eagle.' Likely at this distance, it has already become unrecognizable, and indeed there is now some evidence that a nearby supernova may have shocked this particular structure into oblivion long ago – before we even knew of its existence.

The Trifid Nebula, M20

The 'Trifid Nebula,' M20, is one of the most prominent and beautiful illuminated nebulae in the sky. The main nebula is of the emission variety, surrounded by a lesser reflection component, with its greatest concentration on the northern side. Spanning approximately 28′ in the field of view, it ranks among the largest appearing of such nebulae, and visually of the 9th magnitude. This famous nebula also has some very striking and clear-cut dark lanes intersecting at the center (finally, here, we see a separate listing for these in Barnard's catalog! – B85), visually appearing more like those we may expect to see in other types of structures. While similar dark linear lanes may be found in other nebulae, such as the 'Running Man,' NGC 1977, and the 'Lagoon Nebula,' M8, perhaps none are so immediately obvious and strikingly arranged as those we see here, quite prominent at first glance and traceable beyond the primary glow of the nebula.

Significantly, in the image intensifier picture here, the reflection component of the nebula does not register very strongly. Regardless, it is fainter than the emission component seen so readily, but not difficult to see in conventional viewing. However, the dark lanes under discussion lie within the emission component of the nebula, so the image here fulfills our purpose. Regardless, the conventional view is not so different as to make the nebula unrecognizable. Look at the lane as it travels to the right of the image; it can clearly be seen extending well beyond the most

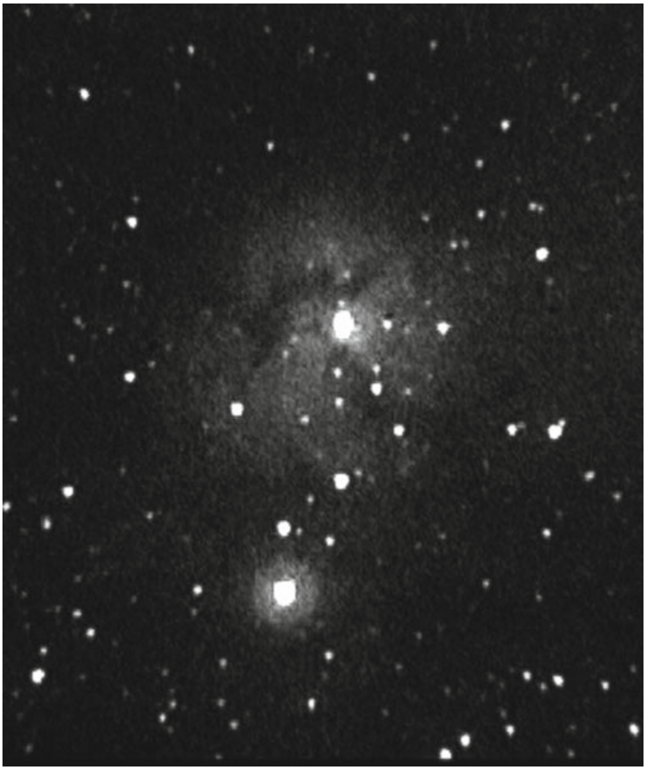

Fig. 4.9 The 'Trifid Nebula,' M20 (AC)

brilliantly lit region and into the surrounding less illuminated reflection nebula component. The brightest 'star' at the heart of the emission nebula is in fact a multiple star (HD 196692); it is a test for eyes and equipment to determine how many stars form the system. With the author's telescope and image intensifier, it may be broken into no less than six components. In fact, there are seven in total. However, we should not overlook the numerous other young stars within this cluster.

This nebula is also unusual in that traces of color may easily be seen at the eyepiece, more so than in practically any other nebula. It may be enhanced with a good narrowband filter, whereby the emission component appears strikingly of a pinkish hue, and the bluish tinge of the reflection part is quite pronounced. Meanwhile, the star near the bottom of the image (numbered HD 164514, a 7th magnitude supergiant) lies at the heart of the main reflection part of the nebula and is responsible for most of that component's illumination, which appears of a distinctly bluish tint in conventional viewing (Fig. 4.9).

The Hubble Space Telescope has also provided photographic evidence of EGG's within M20 (evaporative gaseous globules), those clumps of matter in the final

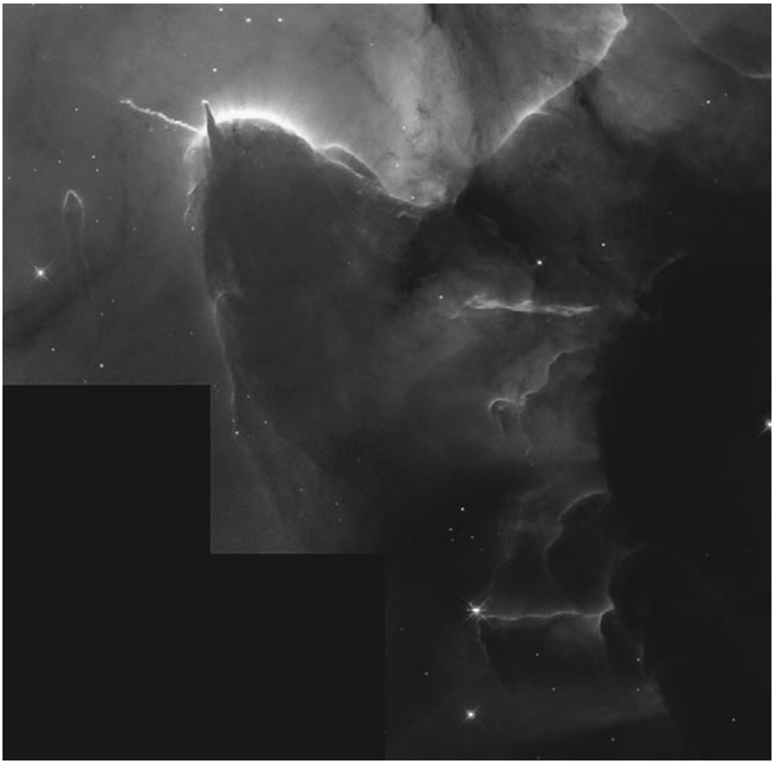

Fig. 4.10 Embryonic stars within the 'Trifid Nebula' (image courtesy NASA and the NSSDC)

stages of compression ultimately to become stars, appearing quite similar to those imaged within the 'Eagle Nebula.' In Fig. 4.10 we can see these features. At its estimated distance, any number of possible changes will have likely taken place compared to what we see at this moment in time, as in the case of M16. It appears that this very star-bearing region is being destroyed by the heat and radiation from the powerful multiple star, and possibly does not even exist at this time, some 7,500 years after the light left the object.

Supernova Remnants: M1, The Crab Nebula in Taurus

Without assigning them a separate chapter, it is difficult to determine if these structures are closer in type to illuminated nebulae or planetary nebulae, since they have indirect links to both. Not part of the normal ongoing regenerative processes of stellar elements, supernovae nevertheless are responsible for providing trace amounts of rare and exotic elements, many of which exist in the common environment. We do not usually think of iron as a rare or exotic element, but without supernovae, this critical and widespread material would not exist at all. As it is, iron forms most of Earth's core and is widespread in the environment as one of its most common elements. As the final element to be produced in the fusion processes of stars destined collapse into neutrons (or seen as pulsar stars as a result of the beam of radiation being aligned with our line of observation) they shower their outer mantles into space as supernova explosions, to become part of the dusty component of greater interstellar matter of the host galaxy. Because the Crab Nebula, M1, has a pulsar at its heart, we know that the explosive force that created it was a Type II Supernova, Type I being incapable of producing pulsars.

We only see the remaining torn and shattered remains relatively locally, since they are not large enough to be observed across vast distances. This prominent example is only 420″ × 290″ (corresponding to an actual dimension of 14 light years at its widest point), sufficient to view effectively at this range but insufficient were it placed at a much greater distance. Therefore our prospects are limited to a handful of supernova remnants at most. Additionally, their luminescence comes about solely via the radiant energy of a remaining neutron star at their heart, which may excite various superheated ionized elements, including leftover helium and hydrogen, and also others produced in the late stages of the star's life, but predominantly carbon, oxygen and iron. Specific elemental makeup and proportions will be determined by total stellar mass, so spectral analysis enables astronomers to calculate that of the original star. The 'Crab Nebula's' original star has been thus estimated to have been of the order of less than 12 solar masses. However, a significant mystery surrounds this nebula in that insufficient mass remains, perhaps less than a quarter, of what is presumed to have been that of the original star. To date, the mystery remains unsolved, all theories yet to be borne out by research (Fig. 4.11).

However, we do enjoy a fairly close up view of the nebula, at around 1,400 light years. Being relatively young, its evolution can be observed, as it is still far from late stages of that which we see in the much older 'Veil Nebula' in Cygnus, altogether fainter and more subtle, while arguably many times more beautiful! But we must understand that dark detail within these structures are more likely gaps or irregularities in the illuminated fabric than true dark features, although they still make for some interesting and relevant viewing. In the case of M1, we can delight in the many fine tendrils, fine shaded (even dark) details, and perhaps even glimpse the effects of its progenitor pulsar star. Although a difficult target to be sure, at the eyepiece the author has observed not only the star itself but also traces of the shockwaves of matter being pushed away in arcs around it. While obviously not revealed to the degree as in the exquisite close-up images by the Hubble Space Telescope (Fig. 4.12), it seems a marvel to be able to witness a little of this scene firsthand (Fig. 4.13). It should be pointed out as a caution that this feat was only made possible through the use of decent aperture (18 in./46 cm) and an image intensifier eyepiece. Should anyone still doubt the value of such electronic devices, perhaps this is the place to end the argument. Dark details, such as we are likely to see, are also plentiful in Fig. 4.13.

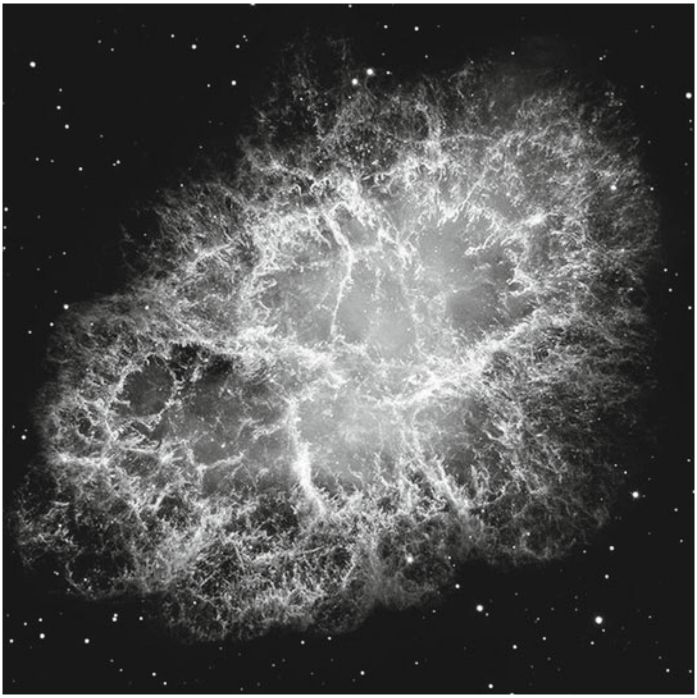

Fig. 4.11 The 'Crab Nebula,' M1 (HST image courtesy NASA and ESA)

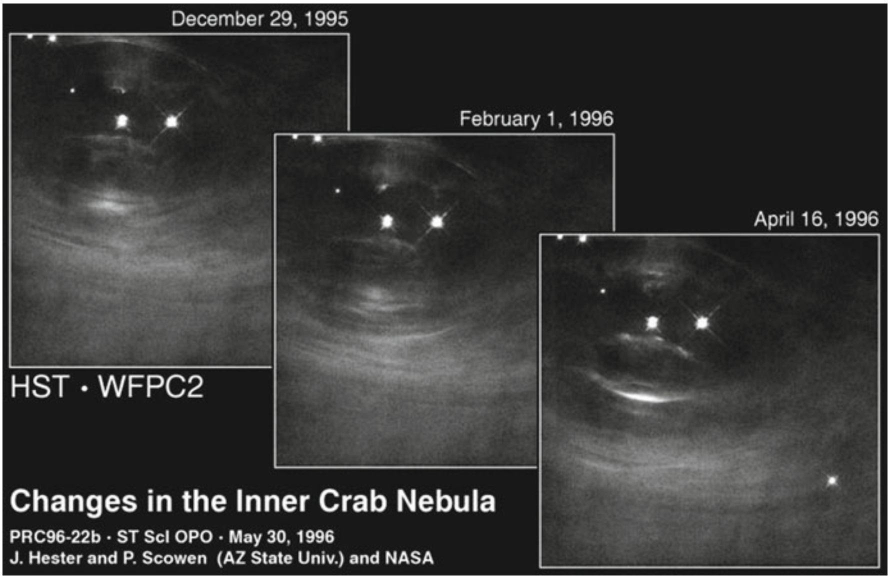

Fig. 4.12 The pulsar in the 'Crab Nebula' (images courtesy NASA and ESA)

Summing Up

Thus, perhaps the sequence of events has become more meaningful: the slow transformation of cold, unlit matter into stars; then the long decline into becoming planetary nebula, supernovae or novae; the gathering and clumping of leftover matter from these processes to form dark nebulae; and finally, the rebirth into new stars and solar systems, much like the proverbial phoenix rising from the ashes. This continuing circle of events underscores the idea that much of what we may have

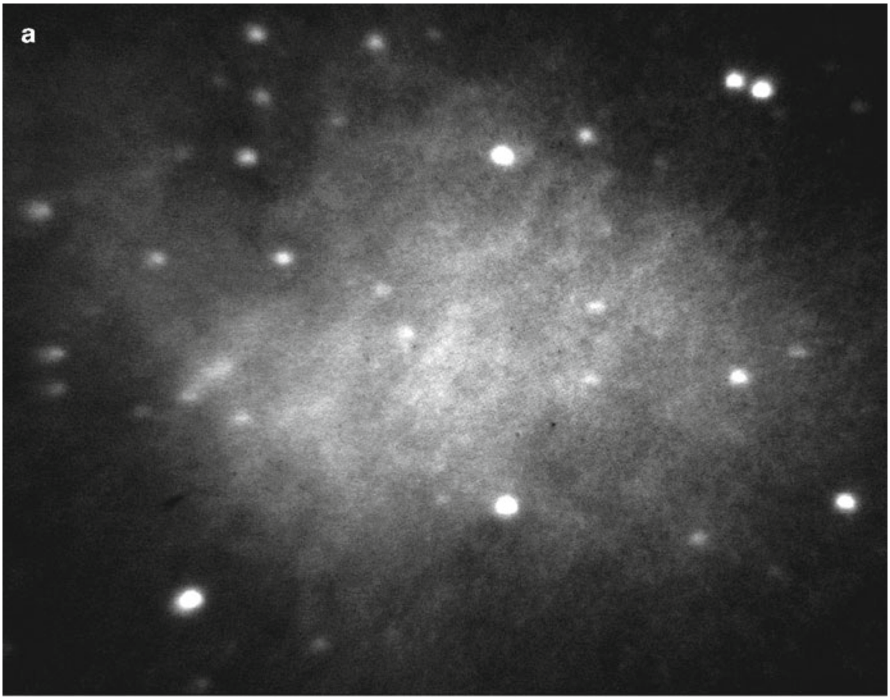

Fig. 4.13 The 'Crab Nebula' (**a**) AC and (**b**): (1) The pulsar star; do not confuse this with the brighter accompanying star adjacent to it. It seems remarkable by any standards that we are able to see this tiny object – not more than 20 miles (28–30 km) in diameter – across a distance spanning 1,400 light years. (2) Close to the pulsar is its accompanying star, a true double star to it and a continuing source of matter to the pulsar. This star is extending the pulsar's period of radiant activity, with estimated temperatures likely measurable in millions of degrees. (3) The dark region showing so prominently on the Hubble image which, upon examination, appears due to actual voids in the luminous cloud, as well as being of a lesser luminosity, which is probably due to the nebula being more tenuous in this region. As with most supernova remnants, these are probably not true dark details of the type we see in other objects. (4) Amazingly, these are the traces of the shockwave seen in the Hubble Space Telescope images. (5) Another darker region, similar to (4) but less striking. This region is not prominent on the Hubble image (where it shows as a slight indentation but also shows on many other images)

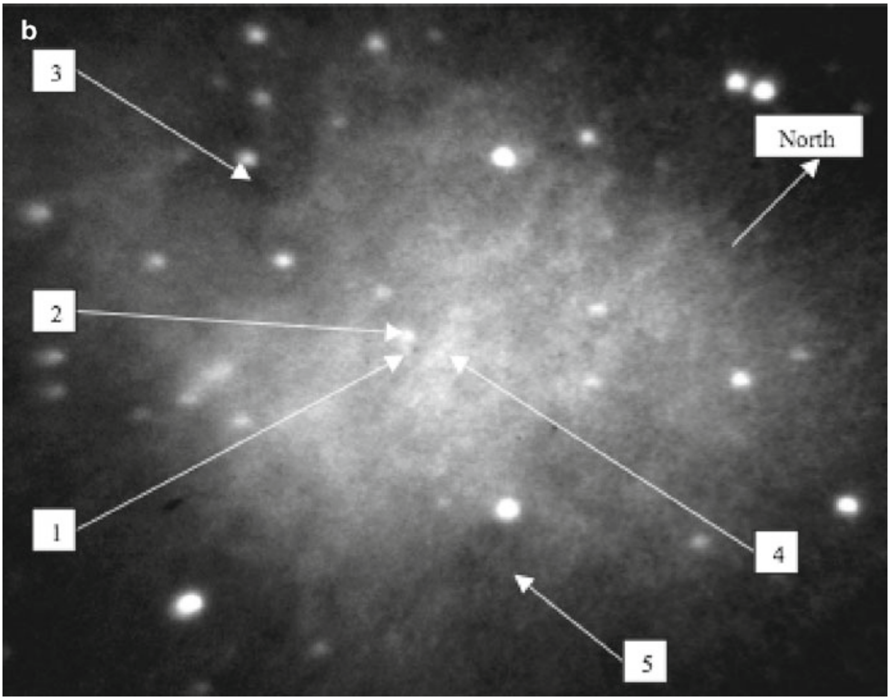

Fig. 4.13 (continued)

considered separate entities are, in fact, much the same thing. The only difference is our perspective – that is, what stage of cosmic evolution is an object experiencing at this present moment of time.

Suggested List of Illuminated Nebulae Containing Dark Features

Because illuminated nebulae are frequently faint and subjective to a degree, precise magnitudes and dimensions are always debatable; they may be perceived differently according to many variables. Many are also far from easy subjects in which to see dark features; this will depend on available equipment and circumstances. In light of this, many of the author's own estimates and those of others have not always agreed; thus, this catalog has been revised to be more in accordance with the prevailing estimates of a wide range of many contemporary observers. As a result, the various designations are more in line with those found in *The Night Sky Observer's Guide* (Kepple and Sanner; Willmann-Bell, Inc.) than *Burnham's Celestial Guide* (Robert Burnham; Dover), and appear more as averaged estimates rather than exact determinations. However, the updated approach should not be taken to imply any less reverence for Burnham and especially the unique insights that he provided; Burnham's very comprehensive system was built on solid perceptions, scientific evidence and logic.

Each object is listed with, where applicable or available, its **catalog number** first (NGC or other), then its object **type**, **magnitude** and a short **description** of interesting features: angular **size**, **coordinates**, and the **constellation** in which it can be found. Below each listed globular cluster is a link(s) where the most suitable reference image – at least, from a perspective of revealing dark details – may be found online, if available, together with comments regarding the image(s).

Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 281 'Pac Man'	Emission nebula	7.5	35′×27′	00528n5636	Cassiopeia	Dark features punctuate the nebula
http://en.wikipedia.org/wiki/File:NGC281HunterWilson.jpg				*Good amateur image; more useful in preparation than many more detailed images*		
*						
NGC 1952 'Crab Nebula'	Supernova remnant	8.4	420″×290″	00534n3197	Taurus	Much complex and subtle detail
http://antwrp.gsfc.nasa.gov/apod/ap091025.html				*Sensational Hubble Telescope image*		
*						
NGC 1976 (M42) 'Great Nebula in Orion'	Emission/ reflection nebula	5	60′×85′	05354s0527	Orion	Exceptional; finest in N. hemisphere; new star formation; dark lanes, mottling
http://www.telescopes.cc/m42large.htm				*Beautiful image that shows Huygenian region well resolved and not overexposed*		
*						
NGC 1973/5/7 'Running Man'	Reflection/ emission nebula (bright segments)		4′×5′	05351s0444	Orion	Combined dark lanes of three bright nebulae make up running figure; adjacent to M42
http://www.adm-astronomy.com/index.php?option=com_content&view=article&id=99&Itemid=163&lang=de				*Satisfying image showing dark lanes well*		
*						
NGC 1982 (M43)	Emission/ reflection nebula		18′×15′	05356n0516	Orion	Comma-shaped nebula; adjoins M42 across a dark lane
http://en.wikipedia.org/wiki/File:M43_HST.jpg				*Very revealing Hubble image*		
*						

NGC 2024 'Flame Nebula'	Emission nebula		30′×30′	05407s0227	Orion	Connected to 'Horsehead Nebula' region, with wide dividing dark lane and branches
http://www.astrocruise.com/milky_way/flame.htm				*Dark detail well resolved*		
*						
IC 434/B33 'Horsehead Nebula'	Emission nebula/ dark nebula		6′×4′	05410s0228	Orion	Includes famous 'Horsehead Nebula,' B33; very difficult visually; try special *Lumicon* 'Horsehead Nebula' filter
http://www.saratogaskies.com/b33-sho-full.jpg http://www.celestronimages.com/details.php?image_id=4901				*One of the more detailed images* *Good reference image to show relative brightness in live view*		
*						
NGC 2068 (M78)	Emission/part reflection nebula		8′×6′	05467n0003	Orion	Bright, mottled, with two embedded stars; dark lanes and dark cloud separating small nebula NGC 2067
http://ep.yimg.com/ca/I/spaceimages_2083_26266437				*Shows lanes and degrees of darkness*		
*						
NGC 2070 'Tarantula Nebula'	Bright emission nebula	8	40′×20′	05380s6906	Dorado	Extraordinary object within 'Large Magellanic Cloud'; dark lanes and swirls throughout; rivals even M42
http://www.cosmotography.com/images/lrg_ngc2070.html				*Very revealing image; features easily identifiable*		
*						
NGC 2237/2239/2244 – 'Rosette' complex	Emission nebula and open cluster	5.5 (cluster)	80′×60′	06323n0503	Monoceros	Impressive; center of the cluster sits in the dark heart of the rosette itself; much dark detail and intersecting lanes; use low power; nebula is faint
http://enchantedskies.net/Rosette2008Big.htm				*Highly enhanced color, but revealing image*		
*						

(continued)

(continued)

Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 2261 Hubble's 'Variable Nebula'	Emission?/ reflection?	10	3′×1′	06392n0844	Monoceros	Fan-like shape; variable outline and internal dark details believed to be shadows cast by swirling dust clouds. At one light year across, it would seem to preclude such rapid changes, the conventional explanation
http://apod.nasa.gov/apod/image/9910/hubblevarneb_hst_big.jpg http://www.noao.edu/outreach/aop/observers/n2261westphal.jpg				*Two good examples of differences in appearance of the nebula*		
*						
NGC 2264 'Christmas Tree Cluster' and 'Cone Nebula'	Open cluster and emission nebula, with dark nebula	3.9	35×15′	06411n0953	Monoceros	Immersed in large and spread out nebulous region; includes small dark 'Cone Nebula' at tip of 'Christmas Tree Cluster', 'Fox-Fur Nebula', and other faint dark rifts though the greater region
http://www.aao.gov.au/images/captions/aat013.html http://www.jacanaent.com/Astronomy/Images/Nebulae/NEB51FoxFurNebula.jpg				*The 'Christmas Tree Cluster' and 'Cone Nebula': a remarkable image* *Remarkable image of 'Fox-Fur Nebula'*		
*						
NGC 2337	Emission, reflection and dark nebula	11	18′	07043n1118	Canis Major	Dark lane crossing its midsection; head of faint 'Seagull Nebula' IC 2177
http://apod.nasa.gov/apod/image/0903/Seagull_BarrettDavis.jpg					*Image shows entire 'Seagull Nebula' and NGC 2327*	
*						

NGC 2467	Emission nebula	8	12′	07525s2624	Puppis	Prominent small nebula, with dark lane running through center; visible portion much smaller than whole
http://jthommes.com/Astro/images/SH2-311_C8MFR15_PS2GBSH.jpg						*Shows full extent of the nebula*
*						
Vela Supernova Remnant	Supernova Remnant			08352s4511	Vela	A web of streaks
http://fuse.pha.jhu.edu/~wpb/hstvela/VELA_SNRBert.jpg				*Typical fine image; not the easiest visual object*		
*						
NGC 3372 'The Great Nebula in Carina' *Includes dark 'Keyhole Nebula'*	Emission nebula Dark nebula	_	80′×85′	1045s5952	Carina	Magnificent sight, bright loops and swirls, with numerous dark lanes crossing, much in the manner of the 'Trifid Nebula.' Contains famous variable star Eta Carinae
http://apod.nasa.gov/apod/image/0405/carina_tan_big.jpg http://apod.nasa.gov/apod/image/9801/keyhole_noao.jpg				*Tiny dark 'Keyhole Nebula' at center* *Detail of the 'Keyhole Nebula'*		
*						
NGC 3576	Emission nebula	_	2′	11115s6122	Carina	Beautiful loops and dark dusty intrusions
http://apod.nasa.gov/apod/image/0803/NGC3576_NB_2000crawford.jpg				*Extraordinary image, with all features clear*		
*						
NGC 6559	Emission nebula		5′	18068s2408	Sagittarius	Contains 10 m. Star; connected to the Lagoon Nebula region; dusty regions; B303 trailing above bright emission nebula arc
http://www.noao.edu/outreach/aop/observers/n6559connor.jpg				*Bright arc caused by stellar radiation (new stars at bottom of image)*		
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
Rho Ophiucus Complex	Reflection, emission and dark nebulae			16270s2530	Ophiucus	Rho Ophiuchi triple star at heart of reflection component
http://www.astronet.ru/db/xware/msg/1214830/RhomosaicM_mmg_f.jpg.html				*Amazing image of entire region; all dark details shown to great effect*		
*						
NGC 6188 and 6193	Emission and dark	6	15′	16412s4846	Ara	Just below tail of Scorpius; startling abrupt transition from illuminated to dark; within wide region studded with dark nebulae
http://web.olp.net/vgallagher-olp/NGC6188-20080606.htm				*Shows abrupt transition clearly; colors poor*		
*						
NGC 6334 'Cat's Paw Nebula'	Emission nebula		30′×22′	17204s3551	Scorpius	Complex, patchy, with many dark lanes crossing it
http://apod.nasa.gov/apod/image/0803/catspaw_noao_big.jpg				*Magnificent image, although one should not expect to see the nebula with anything approaching this kind of brilliance or vividness*		
*						
NGC 6514 (M20) 'Trifid Nebula'	Emission/reflection nebula		28′	18023s2302	Sagittarius	Exceptional nebula, one of the finest in the sky; three bright, dark lanes; illuminating star is a multiple
B85	Dark nebula			18026s2302		Dark lanes in Trifid Nebula
http://www.cosmotography.com/images/lrg_m20.html				*Good overall view*		
http://hubblesite.org/gallery/album/entire/pr2004017c/large_web/				*Close up of heart of nebula and multiple star (image intensification reveals all components with larger amateur apertures); note detail of dark nebula*		
*						

NGC 6523 (M8) 'Lagoon Nebula'	Emission nebula	5	80′×40′	18038s2423	Sagittarius	Exceptional; with cluster NGC 6530; many dark lanes and condensing globules; 'Hourglass' shows prominently with image intensification
http://www.nightskyinfo.com/archive/lagoon_nebula/lagoon_nebula.jpg					*Fine image, with dark lanes well shown*	
*						
NGC 6559	Emission nebula		8′×5′	18068s2408	Sagittarius	Contains 10 m. star; connected to the Lagoon Nebula region
http://www.dl-digital.com/images/Astronomy/Nebulae/M-8-AreaFinalCombine-redo2-3.jpg				*Nice detailed view of whole region, and fine winding dark lane in middle of bright nebula NGC 6559*		
http://www.noao.edu/outreach/aop/observers/n6559connor.jpg				*Closeup of B303 dark nebula within NGC 6559*		
*						
NGC 6618 (M17) 'Omega Nebula'	Emission nebula	6	45′×35′	18208s1611	Sagittarius	Exceptional detail; embedded stars
http://www.universetoday.com/wp-content/uploads/2009/05/m17.gif			*B/W relatively unspectacular image, but prepares the eye better than most; note degrees of darkness surrounding nebula*			
*						
NGC 6611 Open Cluster (M16) with IC 4703 'The Eagle Nebula'	Emission and dark nebula (illuminated by NGC 6611)		30′×26′	18186s1358	Serpens	Remarkable but faint nebula, full of detail reminiscent of flying eagle (dark portions); needs larger apertures and preferably enhancing devices in order to see properly
http://www.noao.edu/image_gallery/images/d6/04086x.jpg				*Perhaps the most dramatic image ever taken of the region, with all significant dark features clearly on display*		
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6726-9	Reflection and emission nebulae		9′×7′	18603s3637	Sagittarius	Very dusty dark region; adjacent to globular NGC 6723
http://apod.nasa.gov/apod/image/0906/Korona_oreshko1800.jpg				*Gorgeous and very revealing image; blue portions are reflection; otherwise emission and dark region*		
*						
NGC 6888 *'Crescent Nebula'*	Emission nebula		18′×12′	20120n3821	Cygnus	Faintly visible; caused by strong stellar winds from Wolf-Rayet star; subtle dark filamentary regions
http://www.noao.edu/image_gallery/images/d6/04494y.jpg				*A much more dramatic and informative view than is remotely possible live*		
*						
NGC 6960, 6979, 6992/6995 'The Veil Nebula'	Emission nebula Supernova remnant		70′×6′ 60′×8′	20457n3043 20564n3143	Cygnus	Large, lengthy filamentary structures, delicate, but full of dark lanes and wisps of varying intensities
http://www.koenvangorp.be/photos/2007_09_15-veil_1500.jpg				*General view of entire region*		
http://hubblesite.org/newscenter/archive/releases/2007/30/image/c/format/large_web/				*Hubble closeup detail of segment*		
http://en.wikipedia.org/wiki/File:WestVeilHunterWilson.jpg				*Fine view of NGC 6960 portion*		
http://www.stargazing.net/David/QSI/NGC6992QSI532.html				*Nicely detailed b/w view of eastern portion*		
*						

IC 5067 'Pelican Nebula'	Emission nebula and dark nebula		80′	20469n4411	Cygnus	Possible to see in same manner as nearby NGC 7000, though fainter; dusty regions punctuate the glowing gas to sculpt the pelican
http://www.nightsky.at/Photo/Neb/Northamerican_Pelican_APO.html				*Image shows its relationship with NGC* 7000		
*						
NGC 7000 'The North American Nebula'	Emission nebula	–	120′ × 100′	20588n4420	Cygnus	More of a binocular object; broad, diffuse and not bright; dark 'gulf' B 352
http://www.saratogaskies.com/ngc7000-50pct-1024x1536.jpg					*Very clear and revealing image*	
*						
NGC 7023	Reflection nebula		18′	21005n6810	Cepheus	One of the brightest reflection nebulae, with dark lanes and mottling galore
http://www.phys.ncku.edu.tw/~astrolab/mirrors/apod_e/image/0112/ngc7023_lula_big.jpg					*Full of intricate dark lanes and details*	
*						
IC 5146 'Cocoon Nebula'	Emission nebula		12′ × 10′	1534n4716	Cygnus	Low brightness; difficult; at SE extremity of B 168. A Lumicon 'Horsehead' filter may aid viewing greatly
http://www.ricksastro.com/DSOs/cocoon-h16.jpg					*Nice image of dark nebula B168 with 'Cocoon Nebula' at one end*	
http://apod.nasa.gov/apod/image/0903/IC5146_fleming50.jpg					*Closeup of Cocoon Nebula*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 7380	Emission nebula and open cluster	7.5	25′×30′	22476n5804	Cepheus	Striking dark lanes cut into the nebula from N and S
http://en.wikipedia.org/wiki/File:SH2-142HunterWilson.jpg				*Remarkable amateur image, showing nebulous component very well*		
*						
NGC 7635 'The Bubble Nebula'	Emission nebula	12	15′×9′	23205n6112	Cassiopeia	Adjacent open cluster M52; the 'bubble,' caused by stellar winds from large young star, is sustained by gases outside -a larger, much fainter emission region
http://apod.nasa.gov/apod/image/0901/BubbleNeb_wood.jpg					*Fine view of the nebula*	
http://www.newforestobservatory.com/wordpress/wp-content/gallery/otherimages/Bubble_NFO.jpg					*View of the nebula and nearby cluster M52*	

Chapter 5

Dark Lanes in Star Clusters

For generations, many observers have commented upon apparent dark lanes in star clusters, most notably the presence of clearly defined dark streaks and divides in globular clusters. While some parallels to them may be found in the meandering lanes occasionally seen in open clusters, especially around their periphery, the dark features observed in globular clusters more frequently are characterized by relatively linear, narrow formations, lanes that follow the circumference, and other more angular intrusions (Fig. 5.1).

Might these be attributable to gravitational forces of one kind or another? This is just one question among many, but it seems dark lanes in both open and globular varieties of star cluster have always posed more questions than answers. Whether or not the existence of these features can finally be verified to lie within the clusters, to those who are certain they have observed them, the highly structured character that is their hallmark seems different from anything else we see in deep space – apparently unique attributes of these objects. It is hard to imagine that they are external to the clusters, and certainly they do not appear to be merely quirks of some explainable observational, even photographic, mirage. Frustratingly, few detailed references about them seem to be available, other than the occasional mention in certain texts about the existence of some of the more prominent lanes. However, what is available in the mainstream press usually is little more than brief remarks that a dark lane(s) is present, with very little specific information about it (or them) for the observer. Detailed descriptions remain all too hard to find, when it would seem natural to expect. It is odd, even when referenced, that such features as have been reliably reported, *even imaged* within so many of these clusters, remain so casually or sketchily dealt with; mere acknowledgement of their presence does little to enlighten us, especially in conjunction with the lack of explanation for what they might be.

A. Cooke, *Dark Nebulae, Dark Lanes, and Dust Belts*,
Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4614-1186-4_5,

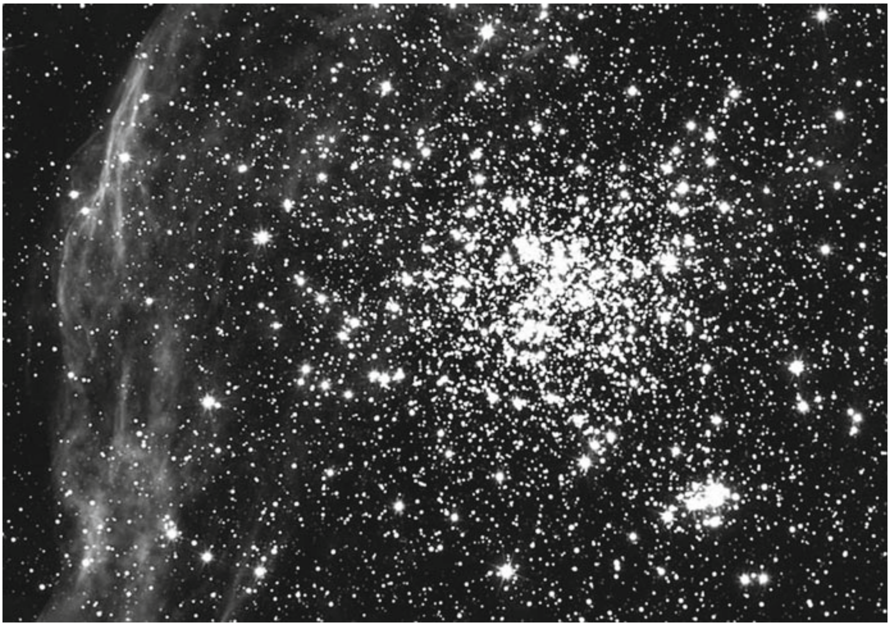

Fig. 5.1 NGC 1850: A globular-like cluster in the Large Magellanic Cloud, with nebulous remnants, presumably of past supernova explosions. Could similar wispy, sinewy dust and gas such as this possibly explain the dark lanes reported in many of the Milky Way's true globulars? (image courtesy NASA, ESA)

Regardless, the striking and frequent appearance of certain finely 'cut' dark lanes in globular star clusters have become well established in many astronomical circles, even if not yet universally embraced. However, even here, all too little commentary remains the norm, even concerning the best-known and recognized examples – despite the fact that such features seem to have little, if indeed nothing, in common with any of the other dark features we are able to observe throughout the entire universe. The apparent presence of these lanes within the ancient Population II stars, would seem to contradict the presumption that the clusters are devoid of what would be considered interstellar matter. Thus, many astronomers have questioned whether the lanes really exist at all, and hypothesize that they may be only illusions caused by random stellar alignments, or even shreds of non-illuminated dust between our line of sight and the clusters themselves. However, the unique, often spindly, appearance, at least in some of the better-known examples, makes this presumption always questionable to anyone who has seen them. Regardless of what the lanes constitute, in the absence of science defining their being, the prospect of what such features represents remains a significant, perplexing, but fascinating unknown.

Regretfully, viewing star clusters within other galaxies is not a prospect for most observers, although the glowing gases from new open star clusters within the spiral arms are frequently visible; indeed, these regions are the very essence of large segments of galactic evolution. Those few globular clusters that are visible in other nearby galaxies are only *just* visible, however. With only one or two exceptions, (such as G1 in the Great Galaxy in Andromeda, M31, where we're lucky to resolve a star or two), none is possible to see as anything resembling a star cluster; it would seem that none of them provide any opportunity to be observed as they look in reality. This is simply because all other globulars – huge as they are – are too remote to show themselves from our standpoint as being anything other than tiny points of light, let alone reveal anything so esoteric as dark lanes at such great distances. Interestingly, our neighboring galaxy, M31, long thought to be similar in size and makeup to the Milky Way, may host three times as many globular clusters as our own galaxy.

Locally, whereas globular clusters are far fewer in number than open clusters (which are relatively new formations and comprised of far fewer stars), there are nevertheless sufficient examples showing the mysterious dark lanes to keep us busy, even after discounting those less stunningly revealed in the eyepiece. For the observer they offer considerable variety, since it seems that all of them differ, albeit subtly, but usually quite obviously in appearance. For the show they put on, globulars remain a perennial favorite of star parties, seldom disappointing any novice or even greatly experienced observer. Despite the obvious resemblances of the most basic forms of dark lane from cluster to cluster, there are no two globular clusters or intersecting lanes even *slightly* similar.

Regardless, all of our opportunities to see dark lanes in globular star clusters lie entirely within the realm of the Milky Way, but the list is sufficiently long to provide enough interest and variety to make the chase worthwhile. In our galaxy, officially, the list numbers some 152 such examples, but considering the faintness and distance of some of them, there could well be many more hidden behind interstellar dust. At least 175 quite possibly exist, with the potential for even more. To observers, not all of these will be of interest, or even readily observable, but up to 75 of them may offer good prospects, depending on one's level of interest and persistence. Thus, this volume and the observing list in this chapter will not attempt to deal with any outside the observer's normal realm.

The descriptive term of globular cluster is slightly misleading: not all of these objects take an exact spherical 'globular' form, many appearing more as flattened, slightly elliptical shapes, as well as sometimes showing unevenly distributed or lopsided structures, even right at the core. Explanations for this apparently have nothing to do with gravitational influences of their parent galaxy, as might be reasonably assumed. Rather, the reasons appear to lie entirely within each cluster, as a result of axial rotation, and the other internal gravitational influences of the stellar population, as well as stresses brought about by other factors from individual stars within them.

The list of open clusters, however, is far more extensive, even if visible dark lanes within them are more limited. Because many young stars must still be hidden by galactic dust, it is hard even to estimate just how many open star clusters exist in our own galaxy, but it is calculated to be in the tens of thousands.

The existence of possible lanes in open star clusters may have a logical and rational explanation. One could reasonably speculate that they represent the leftover dusty debris of stellar creation. However, because of the wide separations of the stars in these clusters, it is still debatable that all of the ‘lanes’ that have been reported, or even imaged, are real features at all. Visually, they certainly appear to be somewhat different in nature than those we see in globular clusters: fainter, less defined, less contrast, usually more meandering and wider, as well as lying to one side of the clusters. And certainly there can be no doubt that the opportunity to see such features is limited by the greater separations of the stars themselves; open clusters do indeed describe the form aptly. But there can be no doubt that something ‘lane-like’ may be glimpsed in certain open clusters, especially in the periphery surrounding them; these ‘lanes’ show on many photographs. And often they do appear to be somewhat darker than the surrounding regions of stars and any remaining illuminated matter. Although the stark linear features we often see in globular clusters do seem dissimilar to anything we note in open clusters, for the most part, it would not seem unreasonable to speculate that they, too, could have had partly similar origins, even if the stars comprising them have a different history.

Other than the most prominent dark lanes that are easily captured in an image, astro-imagers will perhaps have more difficulty in seeing features than live observers, because the very length of exposure necessary for producing grand imagery tends to obliterate any trace of dark detail. The surrounding stellar brilliance simply washes out such subtleties in the frame. Although an overexposed image can sometimes reveal unmistakable evidence that your eyes were not deceiving you, most of the time the fine subtleties that define dark features in globulars are lost in the glare and atmospheric disturbances; as always, experimentation is in order. Perhaps some less spectacularly bright images would probably not be too steep a price to pay for snaring some actual indisputable lanes. We must not forget that, even at the closest distances, these dark features are subtle at the best of times. The eye has a special capability of snagging fleeting moments of detail that enter and exit the view so quickly that no time exposure can isolate and register them. Additionally, skilled observing results in the mental compounding of such transitory moments, so that details that were initially unseen eventually stand out more clearly. It is therefore unlikely that you will find many images – made by any method – that truly reveal the special properties of dark regions and filaments that are so uniquely varied from cluster to cluster, but most especially as exposures grow longer.

On some recent impressively detailed Hubble Space Telescope imagery, and of clusters of both forms, the very lanes and dark features that we perceive in the eyepiece seem to vanish altogether, or at best are only occasionally detectable. Regardless, those traces that remain seldom appear imposingly in these images at all, and there is usually nothing to suggest any of the unmistakable fine dark lines that we believe we see. We can only ponder whether (a) this is because most of the features do not really exist at all; (b) are just differences in stellar distribution; (c) are washed out by light from behind the lanes; (d) the large separations of brilliant stars in the imagery has diluted fine linearity; or (e) if any number of other possibilities or combination of factors are taking place that we still are unable to determine.

Although vexing questions continue to be asked, anyone who has seen the lanes for themselves will not need convincing that what we are experiencing is different from all the possibilities raised above. And it should be stressed that there seems to be nothing about these lines that in any way is comparable to the famous (or infamous) sightings of Martian 'canals' so long ago. In most instances we can assume that there is something to the existence of the lanes, because at least some of them may be successfully recorded by camera, even showing clear details on some old photographs.

Regardless, at least for the purpose of glimpsing such subtle entities, perhaps live viewing is best of all, especially when undertaken with a wide range of magnifications to enhance them; maybe it still holds a unique value, even in this day and age. However, we should keep mind that while some of the features described in the upcoming section are hardly controversial at all – at least, in as far as the appearance of them is concerned – many are partially subjective, or perhaps even completely so. And we should not overlook that some also will be dependent on particular viewing techniques, accessories and the objectivity of the observer himself or herself. Finally, it has to be said that some dark features noted in both types of clusters are not particularly 'lane-like,' although they certainly appear dark; regardless, those that we see in globulars are certainly not at all in line with any expectation we may have for their far more dense and close distributions of stars.

Understanding the Role of Globular Clusters in Galaxies

Scattered throughout the haloes of galaxies in the cosmos, globular clusters seem to be the constant companions of all of them. It seems these clusters are common in all galaxies of masses large enough to support them. The ages of these clusters are probably similar to that of the universe itself, which brings all manner of issues about their origins and their host galaxies into question. They rightly deserve their own category, all the more so since many are rich in dark details. Some galaxies seem to have an inordinate share of globular clusters, with ellipticals frequently hosting up to a thousand or more. Some galactic colossi, such as the giant elliptical M87, may have as many as 500 times or more the number of globular clusters in the Milky Way.

The majority of stars comprising globular clusters are notable for their low metal content (that is, elements heavier than helium). As very old Population II stars, they have long been thought to be some of the oldest objects in the universe (dating in range between at least 9 and 12+ billion years – versus the typical age of open clusters, which tend to be as little as a 1,000 times younger). They may owe their present chemical composition now partly to the depleting effects of advanced age, although they were formed in times where the elements found in Population I stars were in short supply or even non-existent. However, it seems that the metallic makeup they do have represents byproducts of the fusion processes of even earlier Population III stars.

It has also been postulated that the cataclysmic effects of early star and galaxy formation caused such massive interstellar turbulence that the heavy elements were simply blown right out of these clusters, which had formed by some undetermined process. The exiting metal-rich gas would then have likely been absorbed by a nearby galaxy, ultimately allowing the creation of newer, slightly more metal-rich globular clusters in a similar, if not quite so violent, manner early in the life of the universe. Lured by the forces of gravitational attraction, this could explain why those clusters are more metal-rich than others, relatively speaking, and are located, unsurprisingly, closer to galactic cores. However, it does not explain why isolated Population II stars are no different from those we find in globular clusters!

This very makeup, history and possible age of these objects at one time created a potential contradiction and conundrum whereby the universe itself appeared to be measurably younger than the age of these clusters. Although this scenario does not seem plausible by any stretch of the imagination, the explanation probably lies in inaccuracies of the measurements of the cosmic time scale. Recent studies call such ages into question, and while no one disputes that globulars are truly ancient, on an even larger time scale it is also possible that these structures are no more than middle-aged after all, with the life cycles of their Population II stars still little understood. More research is clearly needed, but should the latter scenario turn out to be the case, it would shake long-held beliefs about them to the core (no pun intended).

In most galaxies, the region surrounding the core is most densely populated with globular clusters, the distribution of which gradually thins out throughout the halo with ever-increasing distance from it. The globular cluster population is also likely to echo the oblate forms of its host galaxy with similar oblate distribution. (Looking towards the core of our own galaxy, the Sagittarius region is closest to it and hence is the region of strongest gravitational attraction, and so it is to be expected that a large proportion of globular clusters would be concentrated in that area, and indeed they are.) Globular clusters may also be readily found wherever much cosmic instability is taking place, the newer ones having formed in starburst or merging galaxies, and always apparently the result of high pressures within the surrounding vicinity. These remain among the few clues we have to their origin. In such accelerated periods of star formation and evolution, all Population I stars would have rapidly exhausted their supplies of star-making material, and this could explain their decline and ultimate absence from within these clusters. However, and perhaps frustratingly, there appears to be no correlation at all between relative age, metallicity and the appearance of dark lanes and features in globular clusters.

Unlike open clusters, globular clusters seem to have lives almost independent of the gravitational forces of the greater galaxy and have withstood the mighty tugging without becoming fractured or quickly obliterated. Also, while both types feature many double-star systems, open clusters are consistently comprised of metal-rich young Population I stars, something completely contrary to the relatively bloated, metal-poor old yellow and red Population II stars we find in globular clusters. In contrast again, the stars of globulars have a uniquely different life cycle (still somewhat of a mystery) than that of the Population I stars that constitute the bulk of galaxies (other than elliptical and, to a slightly lesser degree, lenticular galaxies), where the ongoing lifecycles and processes of death and rebirth are well known. Thus, regardless of the timeline of when globular clusters came into being, their fundamentals are quite strikingly different from those of the rest of the galaxy. And, in common to all regions of Population II stars, there appears to be no ongoing star creation in globular clusters, the absence of the stuff of star creation apparently being used up long ago. Thus we must still acknowledge that little finite is known about how these stars – or even the clusters themselves – came into being in the first place. We can, however, be at least reasonably sure that their stars were forbearers of those belonging to the Population I category by supplying the key heavier elements required.

At first glance, globular clusters often resemble dwarf elliptical galaxies, but lacking the apparent presence of dark matter, would seem to be of a different origin – or are we just missing a part of the equation? In fact, there is much evidence to suggest that many of them may be the inner core remnants of satellite dwarf spheroidal galaxies. After all, these small galactic systems typically are seen close to large galaxies, slowly in the process of being absorbed and stripped of their stars. Considering the present huge size of the giant Omega Centauri NGC 5539 (yet to be reduced to more normal proportions by the tidal forces of the Milky Way), and the striking fact that it contains *both* Population I and II stars, it has long been suggested that this particular scenario might explain its origin. Thus, Omega Centauri, along with one or two others of a casually similar makeup, could probably represent one of the galaxy's newest galactic acquisitions, although no one can do more than theorize and speculate.

Other globulars, regardless of their origin, have clearly been donated from nearby small galaxies during the process that led to those lesser galaxies being tugged into the Milky Way. It is possible, of course, that globulars were formed independently of any of the galactic structures that dominate the cosmos. However, because of these remaining uncertainties, as of yet, we can only guess about their origins. And if they are indeed remnants of galactic cores, could their dark and dusty matter have been sucked out somehow by their new host galaxy?

In spiral galaxies these clusters usually lie outside the arms themselves (above and below them), in orbits largely independent of the host galaxy's rotation. Early in the twentieth century, pioneering research on orbital motions of Milky Way globulars was a major focus of Harlow Shapley's astronomical pursuits, and his research was largely responsible for whatever insights we have about the role they play in the galaxy. Along with the conclusions drawn by a number of other astronomers, V. V. Kravtsov of the Sternberg Astronomical Institute in Russia documented in 2001 that globular clusters are divided into two categories: old and young (relatively speaking, of course). Specifically, the more youthful globulars local to the Milky way have different characteristics of motion (even opposite!) around the galaxy and seem more tied to dwarf spheroid galaxies orbiting it rather than being originally part of the main galaxy, lending additional weight to the argument that the origins of such dwarf galaxies and globular clusters have more in common than previously may have been suspected.

Orbital motions around the galactic center by these clusters (typical, oddly enough, of an elliptical nature) shows that their orbits often take them far outside the normally accepted confines of the Milky Way. One or two notoriously controversial globulars, especially NGC 2419 the 'Intergalactic Wanderer,' were thought to exist independently of the Milky Way, but just recently have been demonstrated in fact, to belong, to it after all. The orbit of this cluster is so wide that it was long considered to roam independently in space and it was difficult to account for its placement. But such an orbit now seems more akin to long period comets of our Solar System – on an entirely different scale, of course! Orbiting in an extremely distant elliptical orbit (300,000 light years), it is *twice* as far away as the Magellanic Clouds, and its orbit is almost three times the width of its host galaxy. It is a remarkably luminous cluster, and even at its great distance still shines at magnitude 10.4.

Despite its apparent dimensions being only 6′, careful examination will also reveal some traces of dark streaks and lanes in an otherwise fairly uniform-appearing cluster without stellar resolution. As always, whether these dark features are real or merely the effects of irregular alignments and stellar distribution is still unknown. However, because of the compressed scale of what we are seeing, as well as the fineness of the details, the likelihood of these lanes existing externally – superimposed on our line of sight – seems less likely, because they compare in relative terms with closer examples. Structurally loose, not unlike the very favorably placed M4, its stars are also quite sparsely populated in comparison to many globulars.

Could this, though, be all there is to explain what we perceive as at least some of the mysterious lanes? Again, we have no answers. Interestingly, close-up imagery also shows some similar bars and loops to those of M4 (see later).

Not unlike the 'Intergalactic Wanderer,' M54 is particularly interesting, another among more remote Milky Way globular clusters. Twice the apparent size of NGC 2419 and much denser, it is nevertheless too distant (at 87,000 light years) to easily resolve into stars and dark lanes. Image intensified viewing with higher magnifications does indeed begin to break the stars of this cluster apart, although detecting or resolving any dark lanes in this particular subject will be far beyond practicality for most observers. And because not all globular clusters show such features, they may not even be present. However, the cluster serves to illustrate another point that may further build the case that some globular clusters in the Milky Way have an external origin. Recent research indicates that M54, though now a captive of the Milky Way, may in fact, have belonged to the Sagittarius Dwarf Elliptical Galaxy (not the more familiar Sagittarius Dwarf Irregular Galaxy), or even possibly be all that is remaining of its core! However, you may recall that the lack of significant dark matter within globulars would seem to fly in the face of this theory, unless, of course, one stage in their evolution is yet unaccounted for; thus, much needs to be explained, and their origins will remain for now a mystery, but hopefully to be solved in due time.

As a relative newcomer to the scientific community (only being discovered in 1977), the little Sagittarius Dwarf Elliptical Galaxy is believed to be the remaining part of a larger, but still small elliptical galaxy, in the process of being slowly absorbed by the huge Milky Way system. Even in space, the big fish devour the smaller ones. And it seems that there are at least three other Milky Way globulars that probably once belonged to this galaxy as well. Another, Palomar 4 in Ursa Major, the ‘Serpens Dwarf,’ is almost as distant as NGC 2419, and next to that example the most remote of the Milky Way’s globular clusters. At magnitude 14.2, and hard to see in comparison, its mottled appearance reveals that considerable galactic dust is blocking most of its light. But this type of dark obscuration seems very different to what may be responsible for the lanes we see within the clusters themselves. Nevertheless it is something of a prize to find in the field of view.

Star Interactions and Stellar Makeup of Globular Clusters

In these structures we see a gradual but significant concentration of stars towards their centers, where the stars may be as little as a small fraction of a light year apart – up to 1,000 stars per cubic parsec (one parsec equaling 3.26 cubic light years). This is a concentration around 10,000 times greater than our own solar neighborhood; try to imagine so many close stars in the sky at once! Additionally, stars as ‘insignificantly small’ as our own Sun would be rarities in globulars, as the majority of their stellar populations are at least twice as massive and have the potential to become huge red giants – if they haven’t done so already. The compact size and stellar concentrations within these structures are remarkable, since it is estimated that few globulars exceed 100 light years in diameter.

With stellar populations of as many as a million stars, it is hard to imagine any planet would experience anything resembling night! Nevertheless, the interacting gravitational forces would be so great, as well as constantly varying, that these factors would seem to eliminate any chance of stable solar systems existing around any of the stars themselves. Thus, the prospect of intelligent beings within these systems looking skyward into such a stellar jewel box would be remote indeed!

The interactive play of gravitational forces within the clusters may also explain why some atypical star types appear sometimes within their boundaries (especially of the variable type). However, the array of motions, near misses and gravitational pulls also causes the frequent appearance of some decidedly unusual and unstable stellar forms (blue stragglers, millisecond pulsars and low-mass X-ray binaries), far more than we see in star populations outside globular clusters. The interactions of all of the stars in the cluster would certainly produce many wildly eccentric and irregular orbital paths, which would be infinite in their variety. It would seem likely that powerful forces of stellar interaction would often cause fundamental changes to normal star fusion cycles, not to mention causing irregular distributions, or even to capture external stars by the cluster’s own gravitational pull. It is notable that the occasional planetary nebula has been observed within four Milky Way globular clusters, especially since this seems to suggest a contradiction with a non-recycling stellar population.

However, by and large, orbital motions of the stars of globulars are what would be expected. All the stellar members revolve around a dense ‘nucleus’ of the most concentrated stars, from the edge of the cluster orbiting ever faster closer toward the center, and, as such, are completely different to the motions of stars comprising spiral structures of galactic systems, which are governed by different physical laws (see Chapter 6). Significantly, though, for us as observers such gravitational interactions finally appear to explain the frequent chains and loops that we can see in the less dense regions of many of these clusters, and which have fascinated observers for so long. Because many observers had long questioned whether such features were real, it is pleasing that at least this controversy has provisionally been put to rest. Could such forces also have produced gaps in otherwise uniform distributions of stars and thus have pulled them into chains and loops – producing the mysterious dark lanes?

As globular clusters age, a period of internal collapse gradually takes place, briefly slowed and halted when the interactions of the clusters' numerous multiple stars produce forces that prevent anything further. Eventually, however, the gravitational effects of so many stars randomly interacting upon each other also produces sufficient acceleration in certain members of the cluster to fling them out of the cluster itself, as the older clusters enter the next phase.

With the shedding of some of the total cluster mass, internal collapse resumes. This is something we may be witnessing in the apparent shedding of some of the stellar members in those clusters – those spidery 'arms,' whose trails of stars seem to be more than merely coincidental in their formation and appearance. Apparently the host galaxy itself (the Milky Way) plays a role in attracting some stars away from the cluster and is continually involved in the slow stripping away of the clusters' members, as each globular approaches the galactic core during the closest approach of its elliptical orbit. In these cases, such spidery 'arms' as we see around such clusters represent trails being drawn towards the Milky Way's core (adding to the significant quantities of Population II stars already existing there).

It has been projected that far into the future, all the stars of all globulars will have been absorbed into the greater whole. Meanwhile, as the stars of each globular cluster are gradually drawn together to form an even more massive and dense core, the opposite of stellar shedding can also occur as a result of new gravitational interactions. Speculation is still rife as to whether black holes have formed at the cores of many of these structures. Long considered to be theoretically a logical outcome of cluster evolution, at this stage, however, this is still as uncertain as is also exactly what represents the next phase of their existence. We can only ponder such things. However, all the controversies about these structures continue to make it impossible to be absolutely definitive about any aspect about them.

Examining the Mysterious Dark Lanes

For the purpose of this writing, the most interesting aspect of star clusters of both types remains the common occurrence of what look like dark lanes intersecting them, quite different in appearance to Barnard's nebulae. Today this is still something of a mystery, even a scientific enigma. There has been a good case made for some leftover remnants of the interstellar medium remaining in the vicinity of many open clusters. Some traces of dark dusty matter do indeed seem to be evident around certain examples, indicating that not all dusty and gaseous matter has been necessarily used up or blown away during star and solar system creation. However, it is fairly difficult to observe such dark nebulous forms at the eyepiece, especially since the total luminosity of open clusters tends to be only moderate and the stellar members sparse. Thus it is difficult to tell if we are seeing actual lanes or just gaps in the fabric. However, such lanes do indeed seem all too apparent on some images, showing a basis in reality at least to the perception.

Regardless, recent investigations have failed to eliminate the unique-looking dark lanes to many observers so frequently evident in globular clusters. Thus they remain one of the more interesting and challenging controversies that surround them, although there are significant authoritative sources that do not seem to acknowledge them at all. One cannot help but notice the conspicuous lack of discussion in these places about any such feature. However, while it seems reasonable that leftover matter might be present in the vicinity of many recently formed open clusters, the existence of such star-forming matter at this late stage in globular clusters seems to be an unlikely scenario. But, are we perhaps seeing merely unusable dusty leftover matter, akin perhaps to that found around some open clusters, but presumably of a different composition, while reflecting some part of Population II star life cycles instead? In order to block out the light of portions of such dense populations of brilliant stars, it would seem that whatever constitutes their makeup would have to be quite dense. Because we know so little about how Population II stars came into being in the first place, it does not seem unreasonable to articulate such thoughts.

Since Lord Rosse first noted and sketched the appearance of lanes in 1845 (the "dark rifts") within the globular Great Cluster M13 in Hercules (Fig. 5.2a) with his giant 72-in. telescope (the 'Leviathan of Parsonstown'), they have been a source of controversy among some in the astronomical community. Commentary from that period reveals inquisitiveness and bafflement about the lanes from the very beginning, and they remain the best known of such phenomena. A column by Edwin S. Holden of the Lick Observatory, published in *The New York Times*, from 1892, discussed the lanes ('channels') at great length, but ultimately was unable to come up with any cohesive explanation. (It is interesting how all things in space were compared, comfortably, with Solar System subjects at that time!) Long after Lord Rosse discovered and described those 'rifts,' better known now as the 'Propeller Lanes,' they 'disappeared'(!) for decades and were considered likely to have been transient or perhaps only temporary features. Interestingly, the ever-perceptive Robert Burnham, in his *Celestial Handbook,* makes clear reference to the lanes, at a time (during the mid twentieth century) when few observers seemed to notice them. Often described as being "at one time visible," however, it seems that observers simply forgot what to look for or where to look, or maybe they expected more immediately obvious lanes: a prime example of lack of visual preparation.

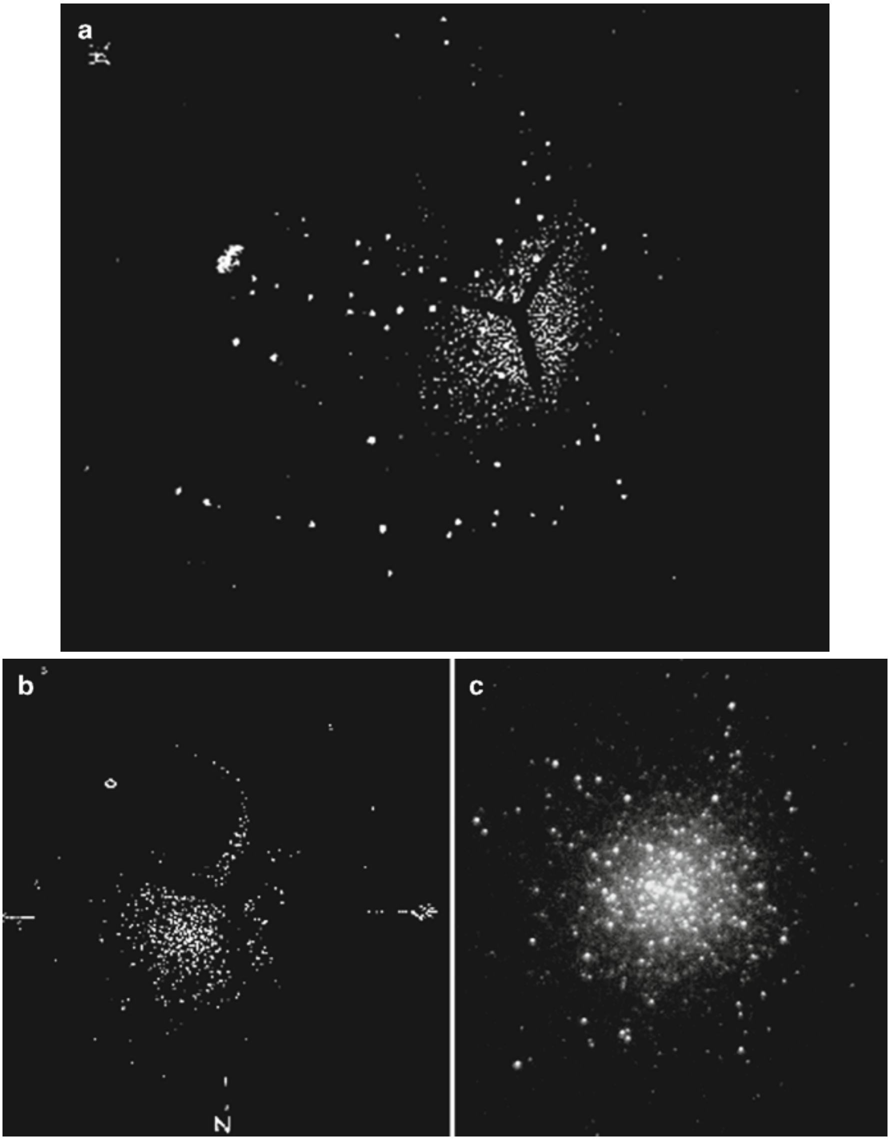

Fig. 5.2 (**a**) M13, The Great Cluster in Hercules: Drawing by Lord Rosse (1845; 72″ reflector) (Reproduced by kind permission of the American Astronomical Society (AAS)). (**b**) Sketch by H.C. Markham 1886, 12″ Refractor (Reproduced by kind permission of the American Astronomical Society (AAS)). (**c**) Image by Antony Cooke 2009; 18-in. reflector

However, certain photographs from before and after Burnham's time reveal them quite clearly, and so thus, it would seem that most observers were looking in the wrong place! But perhaps the lanes' appearance really did change.

In Rosse's original sketch, the lanes appear at a decidedly central location within the cluster, which may account for these features being 'lost in action' for so long. Only a half century later, in the 1888 book *Nature* (edited by Norman Lockyer), the three dark lanes in the cluster are mentioned. However, and conspicuously at that, reference is made that the lanes appeared *at a distance from the center*, so some off-centering may have always been the case, despite their appearance in Rosse's sketch.

In the *Astronomical Journal* of 1886 (Volume 7, issue 164, pages 156–157), Prof. Mark Harrington provided Rosse's sketch of M13, along with his description and a sketch by H. C Markham (Fig. 5.2b). Compare Rosse's image, Fig. 5.2a, with b from 1886, where their position is located significantly to one side of the cluster. An astute observer, Rosse was not likely to have been careless in his original placement of the lanes, so what are we to make of this? Although the drawing is similar to Rosse's, there does indeed appear to be a marked change evident in the position of the lanes themselves. This was followed by a startling summation that while at that time it had not been determined what the 'rifts' constituted, *their position in the cluster had indeed changed during the half century that intervened between his observations and those of Rosse*. Half a century indeed could have provided sufficient time for possible shifting of the lanes' position.

So regardless of how much off-centeredness was actually meant by the comment in Lockyer's book, it does indeed seem possible that the lanes' positions – at one time during the century-and-a-half separating Rosse's sketch and present day views – could have actually rotated around the cluster relative to our present viewing point. Or, if the lanes are instead dark interstellar matter lying externally to the cluster, could it be that the alignment of the cluster and lanes relative to our viewpoint has simply drifted? A typical present day view of M13 (Fig. 5.2c) may be seen and compared. Although such views do not appear to differ significantly to those of 1886, we may never know if they moved between that time and that of Lord Rosse! Regardless, mid-twentieth-century photographs do not indicate anything noticeably different in the lanes' position than present day views, so the mystery remains. Speculation by this writer and others concerning any possibility (and measurability) for relative motion of the lanes in M13 could valuably be expanded with research toward finding answers to these questions in *all* such objects.

Visually, we should differentiate between two distinct types of dark lane in star clusters. First, and perhaps less startling, are those lanes that appear often as fairly wide swaths, cutting through and typically located around the clusters' outer structure. These can appear in both open and globular varieties. So although quite apparent in many globulars, they are not exclusive to them; similar *looking* dark lanes may be seen in other deep space structures, too, especially bright nebulae. In open clusters, they are likely to be quite randomly placed and shaped, although more frequently appear more to one side of the cluster, even externally to it. However, when seen within globular clusters, these lanes typically take more arc-like forms, sometimes lengthy, frequently coinciding with these clusters' rounded outlines; in other instances, they can be seen as finger-like or V-shaped protrusions, jutting into the structure at random places.

However, and significantly, the second type of dark lane in question is exclusive to globular clusters and seems to differ substantially from any dark feature crossing any other deep space object. These lanes typically take the form of fine, sometimes straight dark lines, of a character, while not necessarily comparable with the famous lanes seen in M13, do show some similarities at times.

Striking once sighted, their presence is very common in a surprisingly large proportion of these clusters and may be placed adjacent to the core itself. Could it be (once again), that the gravitational influences of the clusters' multitudes of close stars has shaped as yet unidentified dark material into such formations? Or could it be the direct result of the influence of those very visible star chains we see so often within them to produce gaps in the otherwise consistent fabric? Continued careful examination of this latter variety of lane, along with some available research studies, makes it difficult to conclude that they are external to these clusters, since usually there does sometimes indeed appear to be a link to the form they take and the alignments of adjacent stars within the cluster. Sometimes, since the lanes seem to follow lines or chains of stars, even outlining them, this does not seem unreasonable (see M79, later, for an example of this phenomenon). Certainly, their uniquely fine, often straight characteristics would seem to be at odds with what we observe elsewhere. Unfortunately, all too little comment is readily available in documentation from the astronomical community, and as such, it is rare to find any meaningful discussion about this phenomenon at all. We can therefore only speculate on their origins, although there have been a handful of astronomers who have been so struck by the lanes that they have studied them, despite failing to reach definitive conclusions.

Although nothing concrete can be ascertained from any study to settle the matter once and for all, the comments of these researchers seem to go further than remaining 'on the fence.' In 1959, in the *Astronomical Journal* of the American Astronomical Society, Dr. Helen Sawyer Hogg (who worked with Harlow Shapley, especially regarding the study of globular clusters) wrote a very telling article (Volume 64, Number 10) on globular clusters. Towards the end of the article her words must surely have rung true for anyone who has spent long hours trying to make sense of the dark lanes and other such features seen in these objects. Significantly, Dr. Hogg also pointed to the limited attention paid them, even at this level of research, but especially pointed out that the striking appearance of such lanes in many globular clusters, along with a less conspicuous appearance in others, was not dependent on latitude. Thus, this took into account those regions of increased interstellar matter in the galaxy between Earth and the clusters. One would naturally expect to encounter increased dusty matter closest to the plane of the galaxy and in the direction of greatest dark nebula concentration. One can readily see that this factor seems to have no apparent effect on the presence or non-presence of dark lanes, or the degree of how strikingly they appear in any particular cluster.

While referencing that the lanes themselves had never been conclusively demonstrated either to be real or a result of alignments of star chains and other random gaps, in quoting her expertise with photographic evidence, Dr. Hogg was firmly of the opinion that the features were indeed true nebulous matter, while acknowledging that the generally accepted scientific position is that any such dark interstellar matter cannot exist within a globular cluster. However, some of Dr. Hogg's other key points revealed a logical analysis and thought process. She remarked:

- That comparisons with other similarly placed deep space objects revealed no such features, especially within objects situated at high latitudes in the galaxy.
- On the small dimensions of the dark lanes, and the value of high contrast filters in observing them effectively (both characteristics borne out by this observer).
- On the need to measure any possible light absorption of stars bordering the lanes themselves.
- That, and most significantly, if such features were seen in other deep space structures, no one would question that they were part of them!

However, research to date has still been unable to determine whether the lanes are located within the clusters themselves, or between the observer and them, which remains the critical and most perplexing issue. It is quite important to the discussion that while globular clusters have been used to study and measure the effects of dimming caused by dusty interstellar matter, regrettably, not of such dimming of the stars within the clusters themselves. Such dusty matter is broad in scope, producing generally increased reddening of the stellar components according to distance and has been useful in plotting the locations of greatest dust concentrations. Thus, globular clusters have helped to ensure that the interstellar medium of our own galaxy is well accounted for. However, at no time does there seem to be any correlation between it and further analysis of dust absorption around the fine lanes we see in the clusters themselves.

On the other side of the coin, in his report from the 1970s, Harry H. Ricker III published the findings of his study on interstellar dust filaments, which included careful reference to those that appear to belong to globular clusters. In his opinion, Ricker concluded that long exposure images revealed these streak-like structures extend far beyond the clusters themselves, and thus belong instead to the interstellar fabric. But the controversy has never gone away, as there seems to be an absence of further comment on Ricker's thoughts from anyone in the astronomical community. And if these streaks are common to all interstellar space, as Ricker supposes, the bright background created by globular clusters makes a direct comparison to it problematic, if not impossible. Certainly it is still possible that at least some of the apparent lanes we see in open clusters, if not all, could be attributed merely to random separations of the stellar components.

Surprisingly, in a stunning contradiction to Ricker's position, in its entry on globular clusters in the online *Encyclopedia Britannica* the exact opposite conclusion is reached! In attempting to explain the phenomena, the article makes comment on the difficulty of explaining the presence of dark lanes in globular clusters.

However, the summation of its remarks about these features is that such nebulosity could *not* be the result of superimposed matter in the line of sight between the observer and the cluster itself! Unfortunately, this traditionally unimpeachable source fails to cite any scientific study or evidence to support this uncompromising conclusion, so apparently we must continue to ask if shockingly bad science is still practiced in high places.

As has always been the case, it thus remains challenging to find the kind of information and ongoing research that might help put the question to rest. However, the visual phenomenon remains, whatever the explanation, providing more than enough reason to keep looking. As shown in the Hubble Space Telescope image in Fig. 5.1, gaseous shreds are seen in the vicinity of cluster NGC1850 (lying within the Large Magellanic Cloud). Despite the fact that we are looking upon a very different class of 'globular-like' cluster, that is not only in its infancy and comprised of Population I stars at that, is it nevertheless totally unreasonable to suppose that perhaps this image may hold a key to unlocking the secrets of the dark lanes in the Milky Way's own globulars? The gaseous and dusty matter does appear in linear strands and shreds. Could something similar have created the apparent lanes in those globulars billions of years ago, when their own Population II stars, too, were in their infancy? If so, we can only conclude that such remaining matter is apparently being gravitationally held in some kind of suspended equilibrium that prevents its dissolution. Farfetched? Maybe.

Regardless, these mysterious features remain among the most fascinating observable aspects of each cluster in which they appear. Strangely, seldom are they considered by most observers to demand careful examination as entities in themselves, presumably since the lanes are easily missed when looking for brighter things. Thus they continue to be often overlooked entirely, not even worthy of comment when glaringly present in the field of view! However, once one has let go the initial awe of the magnificent glowing orbs themselves, including the unique attributes of each one's stellar components (i.e., form, size and distribution), for those observers whose interest has been stimulated by the sight of lanes within these structures, they may represent the most interesting aspects of all.

Observing Dark Lanes in Star Clusters

Dark lanes in star clusters have other special visual qualities that do not necessarily typify those we see in dark lanes or belts within other celestial sights, often jumping out only with increasing time at the eyepiece – at which time they appear so obvious it is hard to imagine they were not readily seen in the first place. Although narrowband filters have special value, again there can be no doubt that image intensifiers (and to a lesser degree, CCD video cameras) take contrast to the next level in star clusters, a quality that may prove invaluable. The reason for this is simple enough – stars are only perceived as points of light; there is nothing diffuse or questionable about how they will appear – either they are visible or not.

Regardless of a star's dominant color it emits a broad spectrum of light. Stars that can be seen without intensification will always be more brilliant with intensification. Although old red/orange Population II stars dominate globular clusters, 'red/orange' stars will be brighter than 'blue' stars, but blue stars will still be brighter than in the natural view. Thus, because image intensifiers exaggerate the illumination of all stellar points (and hence, the overall luminosity of the cluster), dark lanes tend to stand out against these points. This is even more pronounced in globular clusters, of course, because of their predominant red/orange star makeup. Naturally an appropriate amount of magnification needs to be selected in order to split these clusters into points, especially with the smaller clusters. However, it is not necessarily a requirement to resolve stars to the maximum extent in order to bring out any lanes between them. As long as sufficient power is utilized to reduce glare and resolve *fine* lanes, this is the primary consideration, since delicate dark features tend to be the norm within many globular clusters. However, because image intensifiers offer a more limited range of useful magnifications than that of simple optical eyepieces, utilizing the most appropriate power to make out lanes may not be possible in every case.

Furthermore, it is probably fair to assume that most observers will not have access to an image intensifier, so nothing here is meant to imply that observing dark features in globular clusters *without* such equipment cannot be realistically undertaken – far from it! While intensifiers do offer tremendous advantages for sure, making dark detail starkly obvious, in many instances they may not necessarily reveal any more information than may be attained with care and time at the eyepiece. There are, of course, times that they will, so their special value cannot be overestimated. However, regardless of preferences or means, one should always try using whatever is on hand, not excluding various narrowband filters, and in conjunction with conventional eyepieces, image intensifiers or CCD video cameras, because the outcome is always uncertain, with the potential for revelation always possible. For instance, although narrowband filters may reduce overall brilliance at the expense of seeing dark lanes, in many instances, thus, their use will be a 'wash.' However, the opposite is almost as likely to occur in other examples. We should, however, be aware that filters of any kind are less likely to be beneficial with electronic enhancing devices; they usually only dull the view without significant advantage. But one never knows for sure. So perhaps the most important aid of all when viewing of these objects is an open mind; allow sufficient time for the eye to fully settle and extract detail.

You will also find that sometimes there are multiple ways that one may 'see' a cluster. According to the moment, the less prominent lanes may appear to regroup themselves into differently connected wholes, but this may be subjective rather than actual. Less questionable dark lanes gradually make their presence known fairly definitely, becoming unmistakable. Many other dark features are subtle to be sure, which may be why some of the visual conclusions in the following pages may not concur with yours. Similarly, imaging methods differ from one observer to the next, and with consequently differing results. No matter. Look for yourself, and always stay open to the prospect of possible sighting of dark lanes in any star cluster.

Open Clusters

Despite whatever we may be able to see, open clusters remain at the periphery of this topic; although dark lanes may be seen in numerous examples, with only a few exceptions there is little comparison to be made with the prominent lanes we frequently see in globular clusters. Regardless, it would be a disservice to oneself not to spend a little time with some of the more prominent members of this category; the results will prove interesting at very least, and perhaps suggest the prospect of seeing features previously never considered.

The 'Wild Duck Cluster' M11

M11 is perhaps the most strikingly dense of all nearby open clusters, to the extent of sometimes being compared visually to a globular cluster. Impressive in any view, though not more than 13′ in size, it was so-called because of its resemblance to a flock of ducks in flight, with a characteristic 'V' of ducks in the fore. The sight of what appear to be increasingly wide dark lanes mostly ahead of the 'leading' edge of the cluster has been a cause of speculation for a long time; they may be readily seen at the eyepiece. Careful examination of the region on this side of this cluster does indeed tend to suggest that we are observing more than just spaces between the stars. However, it is hard to be certain. The appearance of lanes in this cluster is all the more interesting due to their placement to one side, their striated zigzagging form, and the depth of darkness on that side of the cluster being unquestionably more than on the other. The 'leading' line of imaginary birds is sharply cut from the pack by one such lane, perhaps the most prominent of many emerging from the center of the cluster and present on one side only.* Looking objectively at Fig. 5.3 will make it hard to conclude that no true lanes exist. The 'lanes' only seem increasingly prominent as the image scale is reduced (lean back), especially if one partially closes ones' eyes when examining it.

(*Any doubt that perhaps this particular cluster has been incorrectly identified as an open cluster can be laid to rest by examining readily available color imagery; the unmistakable identity of the cluster's blue Population I stars is easy to see.)

M52 in Cassiopeia

Another example, M52, in itself is a rather ordinary looking, quite sparse open cluster, of apparent 13′ dimensions (Fig. 5.4a). However, more interesting are the curious dark lanes – again to one side of the cluster, although essentially external to it, and somewhat looking rather like a cosmic hand blocking the light of the stars (as indicated in Fig. 5.4b). Instead of the more 'logical' placement of the lanes as we see in M11, in this cluster the lanes are at right angles to its overall apparent orientation. Again, try slightly closing your eyes to best see the apparent dark lanes. Are they real or simple coincidence of random dust and stellar alignments?

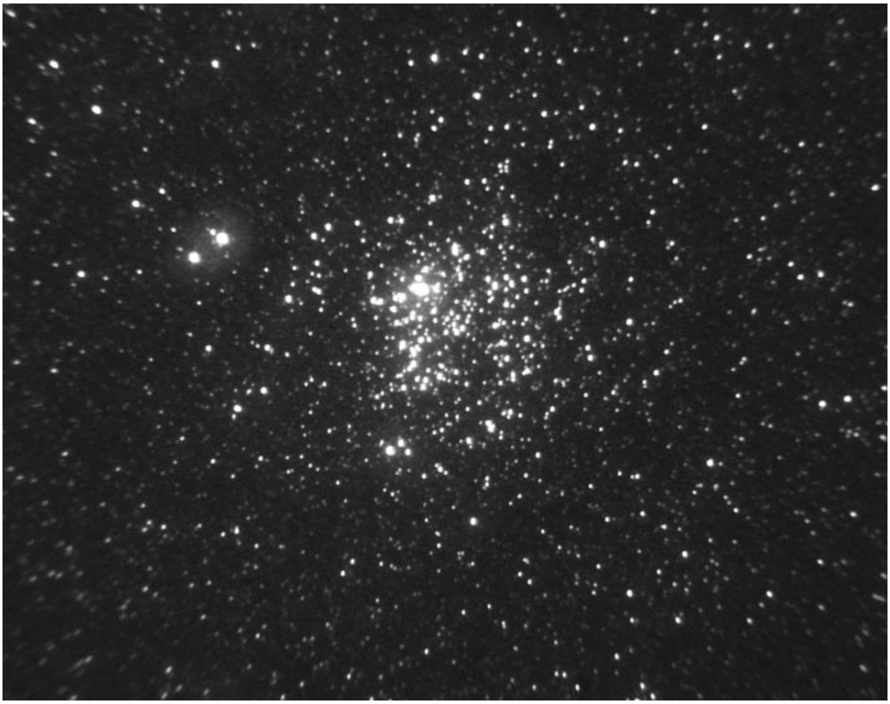

Fig. 5.3 M11, The 'Wild Duck Cluster' (AC)

No logical explanation for the existence of these lanes seems more fitting than one where leftover dusty matter from the star-forming dark nebula has been blown out of the heart of the cluster back into the surrounding space. Regardless, the presence of dark lanes within open clusters is always more questionable than with globular clusters – which, in itself, is yet far from proven. Thus we always have to remain objective and be open to any possible explanation for what we believe we see, and this is no more the case than with open star clusters; we must also resist any tendency to 'see' what is not there, or to conclude that it is definitely one thing or another. Still, the argument for the existence of such lanes remains compelling.

Globular Clusters

Although the search for evasive dark lanes in open clusters can prove enormously satisfying, it is such features within globular clusters that remain the ultimate prize. No longer the vague ghosts we see in open clusters, dark lanes in globular varieties usually are more obvious; certainly they are projected against far brighter backdrops.

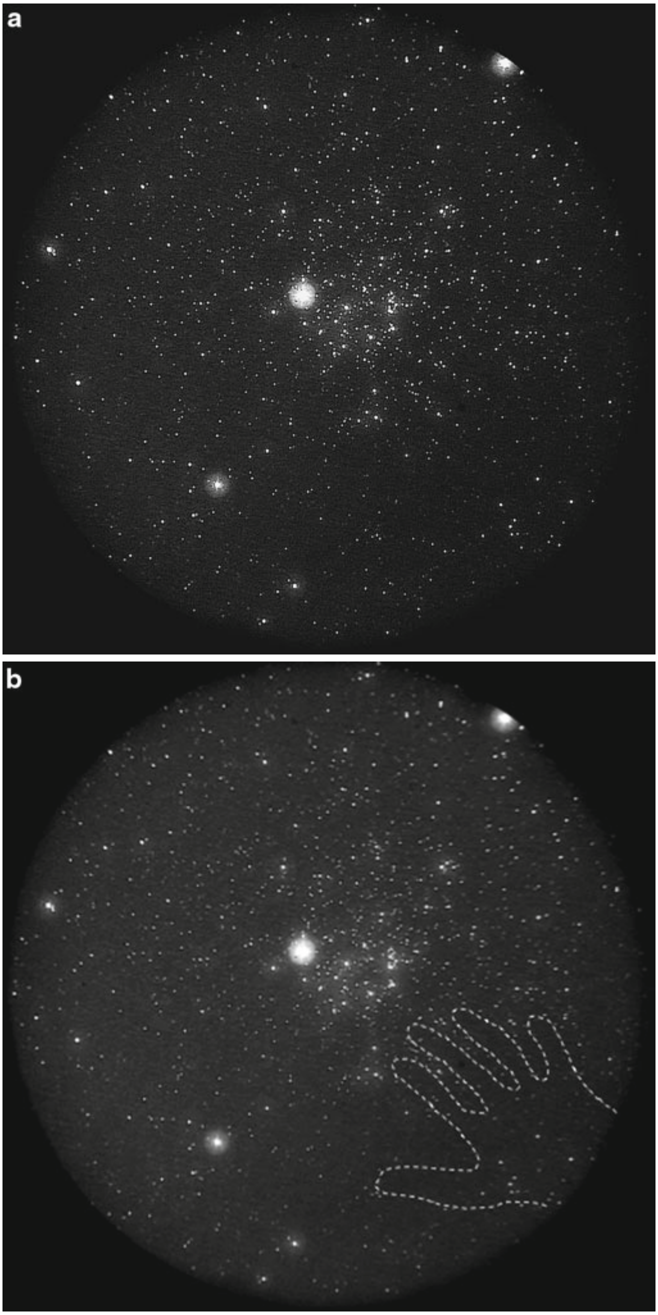

Fig. 5.4 (**a**) M52 (AC). (**b**) indicating 'hand-like' lanes

Messier 22

One of the grandest spectacles in the entire sky, M22 in Sagittarius will never disappoint even the most jaded viewer, and it will put on a decent show even from light-polluted locations. Many observers consider this globular the finest in the northern skies, even more than the celebrated and more distant M13 in Hercules, despite the actual size of the latter globular being far greater. It is hard to disagree. M22 is much closer, however, which gives us a cosmic ringside seat, so to speak. That the cluster appears so huge is only because of its proximity to us of 10,000 light years, which makes it among the closest of all. In fact, at 'only' 70 light years in diameter, it is small in comparison to the dimensions of many others, but it is stunning to view, at better than 6th magnitude, of an apparent huge 32′ size, and with an easily resolved stellar population.

A glimpse at the image Fig. 5.5a of this awesome sight provides a ready assessment of all the possibilities that globular clusters offer us as observers, in this case

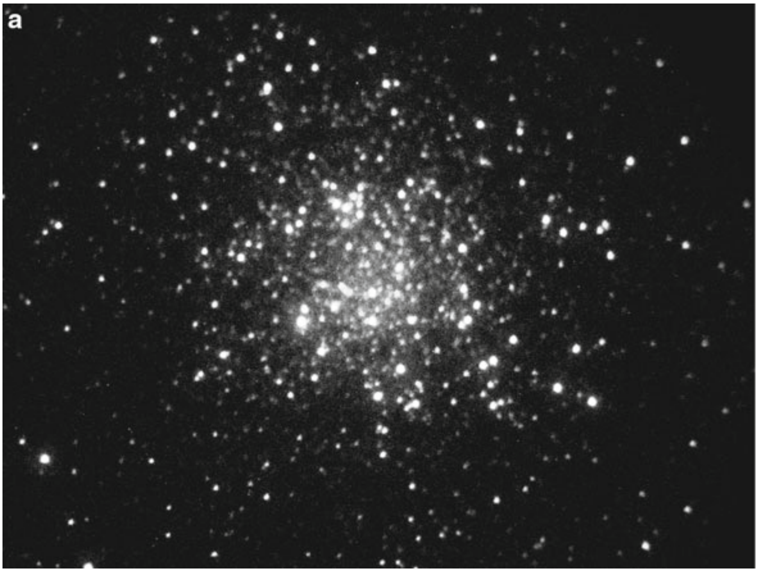

Fig. 5.5 (**a**) M22 (AC). (**b**) **M22** (1) A very striking and dark serpentine-like lane twists right across the periphery of the cluster. Careful examination even of long exposures will reveal traces of this long dark lane. (2) An extremely prominent heart-shaped 'marker' for reference and orientation in this cluster is this bright arrow-like grouping of stars, giving easy orientation. They stand out immediately, even in long exposures. (3) Look carefully: here are perfect examples of fine, linear dark lanes of the type so characteristic of globular clusters (*bold unbroken lines*); these stand out more clearly with time at the eyepiece. (4) It is easy to trace this wide, less deeply obscured V-shaped region as it weaves its way deeply into the cluster. (5) Another dark serpentine lane cuts a path across on the opposite periphery, not quite as pronounced as in (1) but well visible nonetheless. More striking is the way it seems to cut off and destroy the cluster's symmetry on this side, giving it an almost flat contour.

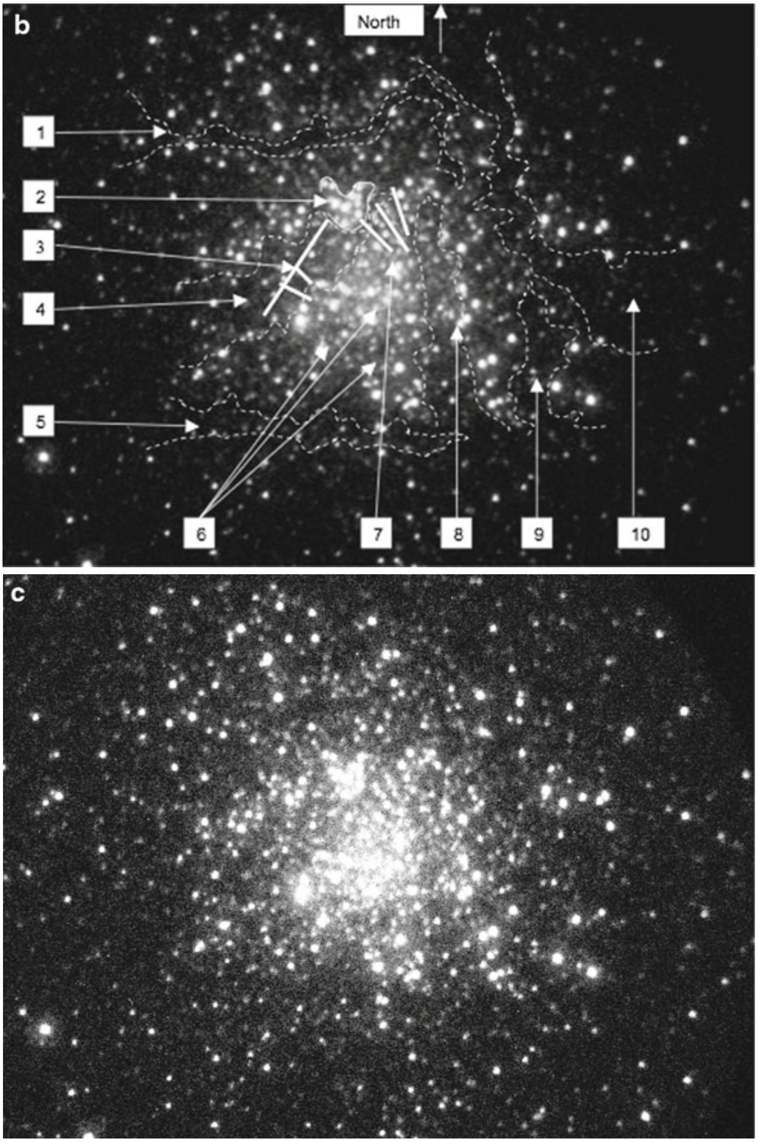

Fig. 5.5 (continued) (6) Here are three darkly mottled regions; less pronounced examples of a similar nature may be spotted across other parts of the cluster. (7) Three parallel dark 'fingers' (*bold unbroken lines*): again, prime examples of the fine straight dark lanes we see in globular clusters, individually more typical of those that we will see in other clusters, as they cut into the brighter region of the cluster. (8) Another less pronounced wide lane, similar in some ways to (4), separates the brighter central portion from the perimeter. A unique aspect, perhaps, is the way it seems to separate further into mottled blobs. (9) A fainter example of a typical wide lane in this cluster also exists in this more distantly placed position; probably of a similar nature to (4) and (8), nevertheless it is placed across a less brilliantly lit outer part of the cluster. (10) Yet another dark lane snakes around the cluster, appearing to be part of (1), a feature that is so pronounced in the image. (**c**) M22, overexposed image

especially that of its relatively easily seen dark features. Look further, and you will continue to find more dark detail than you ever thought possible, as outlined and discussed here (see Fig. 5.5b).

M22 appears perhaps more studded with dark detail than other globular clusters, probably because not all of them are, in fact, true dark features. Large stars seem to spill out towards us, with many mottled and dark lanes blotted all across its face. The cluster is remarkably loose in its structure, lending some validity to the counter theory that dark lanes in clusters are merely uneven groupings of its stars. There is no way to tell if such random separations are typical of all globulars, even when more densely populated, and in any event, increasing densities of stars would entail increasing gravitational interaction between them. However, that might explain the lanes!

The image here, Fig. 5.5c, also makes clear just how much information is usually eliminated from the majority of images we see. We have become accustomed to the overexposure generally utilized on these subjects in order to reveal the full extent of the clusters' outstretched reach. However, M22 is rare among its brethren in that considerable overexposure is needed to entirely eliminate all the dark features!

Regardless, aside from the grand appearance in the eyepiece of this cluster looming out of the darkness towards us, an interesting anomaly exists within it, in that it is among the few known to contain a planetary nebula among its stars. (You may recall that such forms are rarities in the stellar populations of these ancient structures, so perhaps they have been pulled in by the globular's gravity from another external source.) Hubble telescope images have also revealed the possible existence within M22 of large planetary-sized bodies, the influence of which has been measured in the cluster. Thus we have evidence that solar systems are indeed possible in such crowded environments, though it would seem logical that planetary objects orbiting any star in a globular cluster would have highly unstable paths. Could such orbiting masses possibly have produced some of the lanes and irregularities we see in so many of these structures?

Because Fig. 5.5a is more typical of live views at the eyepiece than most images, we could also be led to assume that the considerable apparent unevenness of stellar illumination is the natural result of a wide range of star sizes and brightness. This is probably not the case, however. Rather, might it be the result of dusty clouds and trails of matter located somewhere in the line of sight between Earth and the cluster, even within the cluster? This appearance is even more the hallmark of M22 than most globular clusters. Although the detection of certain dark regions in these objects is partly subjective, there can be no doubt that many such features are perceived in reality, regardless of what is responsible for what we see.

Aside from the unevenly illuminated appearance in M22, a little careful inspection will begin to show increasing numbers of the telltale and convincing signs of actual fine, spindly and dusty lanes crossing the face of the cluster. Although the number and variety of these features is exceptional within this particular cluster, they are quite characteristic of those we see in other globulars, albeit being generally fewer in number. Use the guide in Fig. 5.5b and accompanying notes to trace these features in Fig. 5.5a, just as with other examples later in the chapter, comparing them back and forth.

Another aspect shown in M22, as with many other globulars, is the streaming of stars, presumably being drawn away from the cluster by the forces discussed earlier. Before galaxies, as island universes in their own right, were recognized and understood as such, these trails (as evidence of spiral form) were the subject of much discussion. Having discovered spiral form in the 'Whirlpool Galaxy,' Rosse considered it to be present in many other deep space objects as well; he believed he had observed it. As we know now, that is certainly not the case, although the cluster's rotation is evident: notice how linear star trails seem to radiate mostly clockwise. By contrasting what may be traced when examining many other images of this spectacular object, it may be quite problematic to recognize what we see here in this particular image, and rare to find any amount of discussion of anything detailed here.

In order that the details listed would show well in the image it was necessary, as we have discussed previously, to keep the exposures sufficiently short so as not to fog the image with light and thus obliterate delicate detail. Although standard exposures of globular clusters usually reveal further outward layers of stars, most surely would agree that the images utilized here are sufficiently resolved to compare fairly realistically with good views at the eyepiece. Since obviously what is best with any given telescope and conditions is a 'moving target,' suffice it to say the objective here was to demonstrate what should be discernable where moderate apertures, maximum observing potential and visual skills are all in play. And we must also be aware of the difficulties of directing one's attention to features within the cluster, some of which are none too obvious even to experienced observers. These features are represented as well as possible on the page, although in practice will probably be more subtle.

As is the case with many others, various magnifications and exposures show additional special traits in M22, some of which are more likely to be revealed at the expense of others. However, one cannot dismiss the value that different apertures and sky transparencies produce. Soon it will become apparent that the variations of illumination are so great that only careful examination with multiple powers will reveal all that there is to see. Figure 5.5c shows the effect of increased brightness, or indeed exposure on the same image. Look carefully at the upper left corner of this particular image, for example, where a fairly prominent narrow dark lane and multiple branches begin to show themselves. In fact, further inspection of the image shows that the cluster is studded with other such lanes in all directions!

It seems contradictory that such a dense group of gravitationally locked stars could possibly take such a near-random placement, so any conclusion that considerable interstellar dust is blocking some of the light from these stars would not be unreasonable. One could go much further with the overexposure than shown here, but it would result in total obliteration of all dark detail, the common conundrum.

Messier 4

Perhaps the best example of globular cluster to reveal loops and chains of stars, this relatively sparsely populated example also shows striking dark lanes as well.

Like M22, M4 (Fig. 5.6) appears so large (at 36′) only because it is nearby, when it is, in fact, quite modestly proportioned in comparison to other globular clusters. However, it is perfectly positioned to give us a revealing look into the order of stellar positioning within globulars in general; such features seem to indicate the effects of gravitational influences of one kind or another. Most striking is the pronounced central 'bar' of stars, a feature that has been commented upon for generations (and seen in other globulars, too, such as M79), although this cluster has so many interesting visual attributes that it is hard to decide which is most significant. However, some of the most striking features are outlined in the guide image and

Fig. 5.6 (**a**) M4 (AC). (**b**) (1) This is the pronounced central 'bar,' so much discussed by many commentators. Its brilliance and dominant form seem unique to any cluster. (2) This is perhaps the most prominent loop of stars in the entire structure; it is immediately apparent upon first glance. (3) A fairly long, arc-like chain of stars at the periphery of the cluster, and one of many. (4) Another chain of stars, but curved in the opposite direction to that of the cluster. (5) A shorter chain of stars, similar to (4) in its opposing curvature. (6) One of the longest chains outlining the cluster. (7) One of several long winding fine dark lanes that divide the periphery of the cluster; this one is very prominent. (8) A less prominent but similarly long and winding dark lane, curving further from the core around half of the circumference. (9) Another winding dark lane on the opposite side of the globular. (10 and 11) Suggestions of additional dark lanes, more distant yet from the core

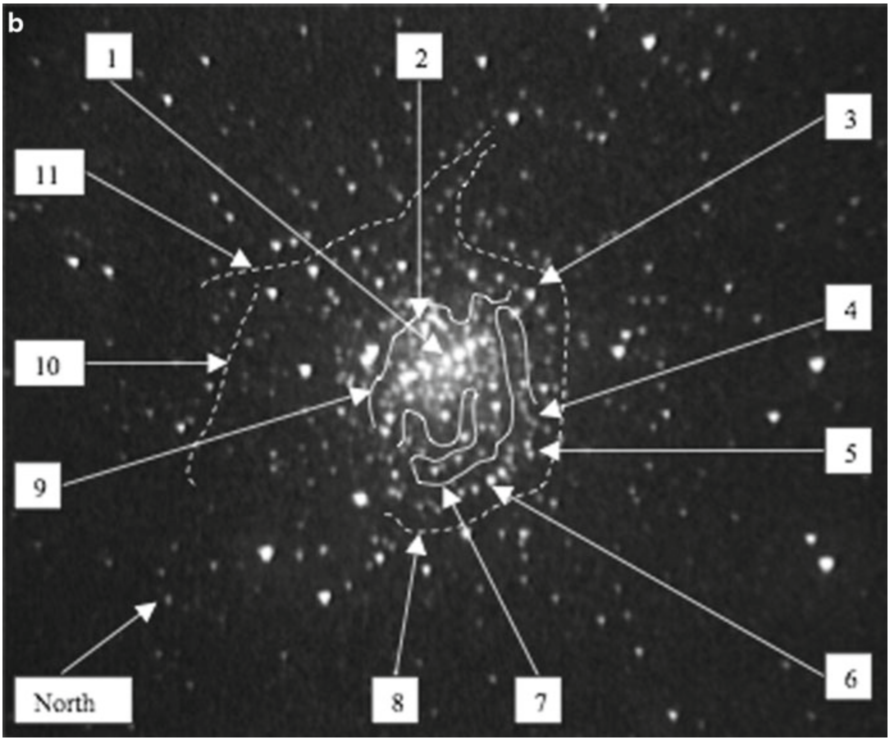

Fig. 5.6 (continued)

numbered references that follow. The apparent dark lanes are shown, in order of prominence, as solid single and dotted lines. You may also notice the many outward trailing lines of stars surrounding the greater cluster and seemingly pointing in the direction of apparent rotation; additionally, the cluster seems to be surrounded by multiple linear chains of stars.

Messier 15

Another fine example of globular cluster to examine is M15 in Pegasus (Fig. 5.7). At over 33,000 light years away, and with an apparent size of 18′, it is one of the most compact globular clusters in the Milky Way, its dense core revealing the evidence of intense stellar interaction and apparent collapse. The core is so brilliant that it suddenly outshines all that surrounds it without a gradual increasing brilliance towards it, the typical case in the majority of these objects. This certainly indicates core collapse, and not the usual migration inwards of the densest stars. Indeed, after ongoing research involving the Hubble telescope, it appears that M15

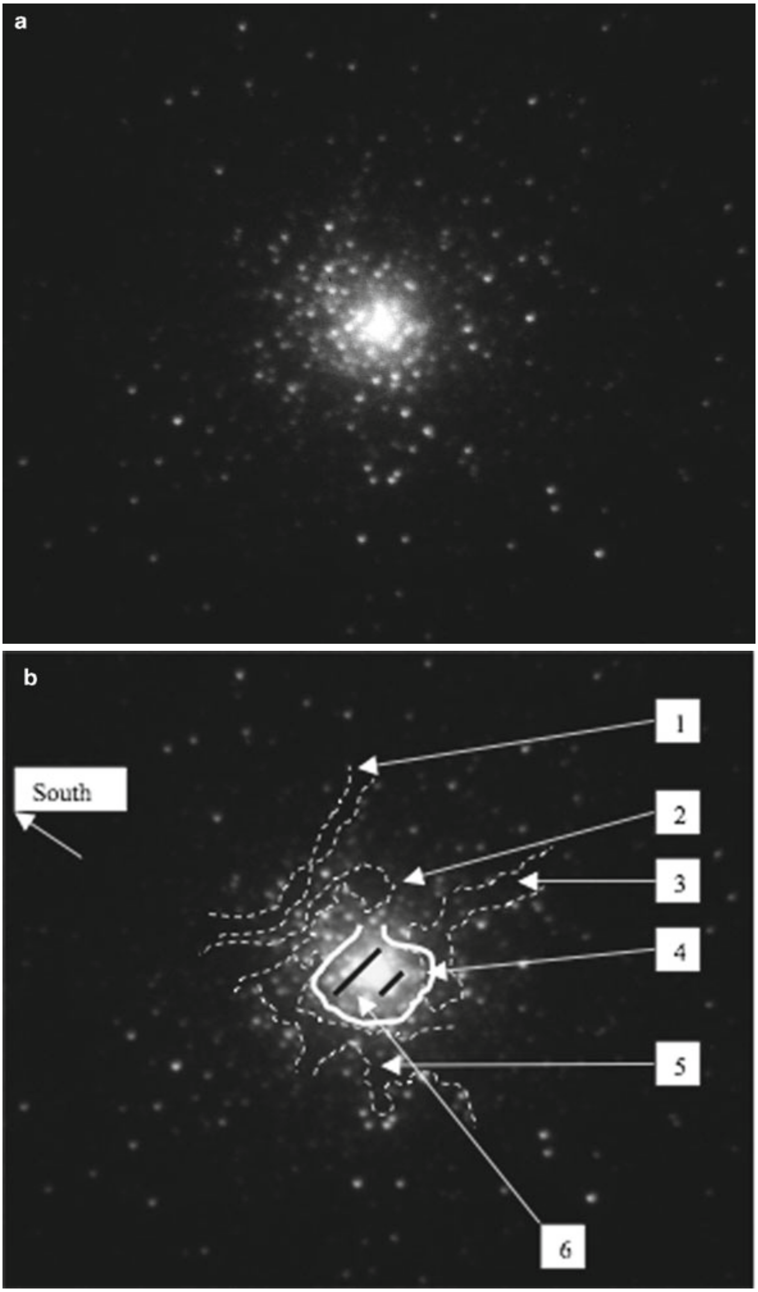

Fig. 5.7 (**a**) M15 (AC). (**b**) (1, 2, 3) These are serpentine-like lanes that wind across the outer perimeter of the cluster; (1) becomes extremely narrow, before opening out once again. (4) By comparison, a generally darker semi-circular lane, which seems to circumnavigate the entire brilliantly lit central region; well contrasted against the very bright collapsing core. (5) Another serpentine lane, similar to those in (1), (2), (3). (6) Here are two dark lanes (indicated by *black lines*) further inside the more diffuse 'lanes' of (4) and appearing to dissect the brilliant compact core into a less than circular form by 'slicing off' part of each side

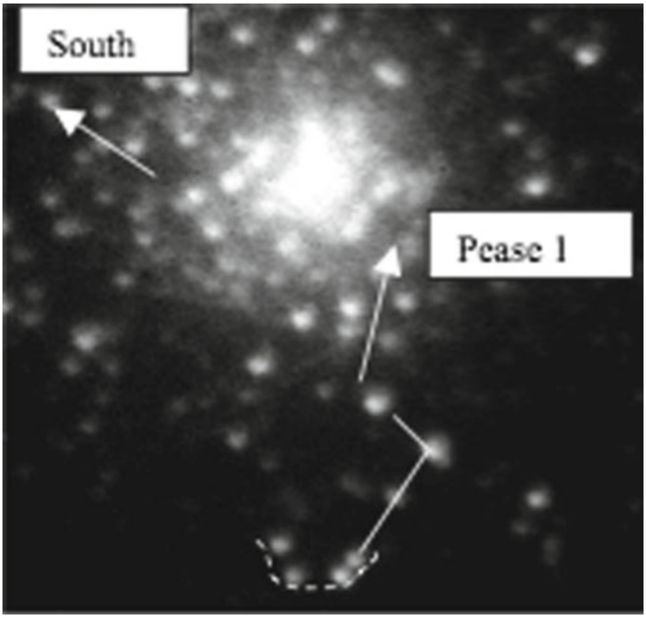

Fig. 5.8 Location of the planetary nebula Pease 1 (enlarged – same orientation), with markers and pointer for identification (AC)

harbors a massive black hole at its center, which is hardly a surprising finding. However, conclusive determinations still remain at the center of controversy.

Like M22, M15 is also notable in that it is one of only four Milky Way globular clusters in which a planetary nebula has been detected among its stars; it is visible in this image. Refer to the guide (Fig. 5.8), where it is revealed at the leading edge of a small clump of stars. At magnitude 14.9 (remember, this is the magnitude of the entire nebula, not the central star!), it is a faint object to be sure. As such, you will not be able to discern Pease 1 in the manner that other planetary nebulae are normally seen because it is far too distant; this includes the central star, of course, which remains well below the threshold of visibility. This is because most observable planetary nebulae lie within 1,500 light years, and Pease 1 lies at a distance 22 times as great. But you might take pleasure in catching a glimpse of the location of a truly rare sight while visiting the star cluster.

Some of the long winding lanes in M15 are highly reminiscent of those in M22, although at the highly concentrated core its overall appearance is totally different. Stragglers of stars being drawn away around the circumference of the cluster are also clear in the image; although not so pronounced a feature as in many other examples, they do not take a clear directional course. Needless to say, different eyes in different circumstances may see things differently and may also be able to discern more dark regions and lanes than detailed here. However, not all can be easily shown and indicated; and sometimes it is just hard to be sure of the exact details of all we are seeing.

Messier 79

This globular, M79 in Lepus (Fig. 5.9), is a very beautiful example, if relatively distant in. It is another case in point for its dark lanes and details; interestingly, it is perhaps part of the remnants of the newly discovered Canis Major Dwarf Galaxy. The possible designation of extra-galactic origins is still the subject of considerable controversy among the astronomical community, as are most things concerning globular clusters, and even the Canis Major Dwarf. However, the possibility of the exotic origin of this cluster is promising and would do much to explain its rather

Fig. 5.9 (**a**) M79 (AC). (**b**) (1) The prominent V-shaped dividing lane(s). A central bar of stars (a little reminiscent of that within M4) cuts through not quite the middle of the core itself. (2) This is a difficult lane to see, short and fine, and it may be hard to detect in live views at the eyepiece. (3) Another narrow lane, similar and virtually parallel to (2), on the outskirts of the cluster. Again, this will be difficult to see on all but the best nights and with larger apertures. (4) A lane close to and adjoining (2) and (3); quite fine, but a little longer and darker, as well as being a little easier to see and find. (5) Another peripheral lane, although of moderate width and prominence, with some curving around the cluster. (6) A curved lane, fairly prominent and relatively close to the core. (7) A wide dark region, sweeping away from the cluster. (8) Similar to (7), but its sweeping characteristic is in the opposite direction. (9) Indicated by adjoining, finer lines is a similarly 'V'-shaped lane from the core to the south, and easily seen on the image. (10) A curious arc of stars, presumably a coincidental alignment, but is it possibly indicative of tidal pull?

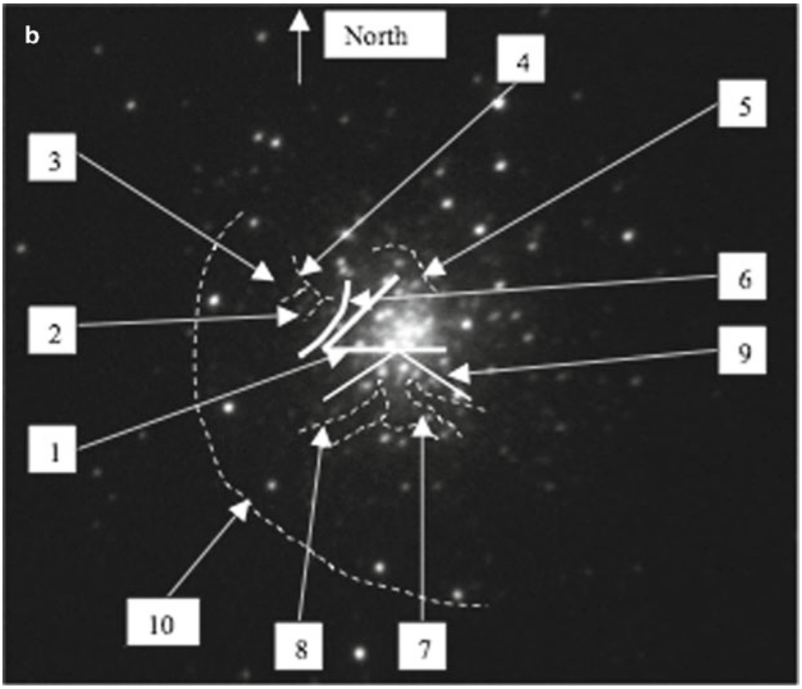

Fig. 5.9 (continued)

unlikely position so far outside that of the majority of globular clusters, especially any as large as this.

Characterized by a prominent V-shaped straight-sided dark streak across two parts of the core (a remarkable dark lane that divides its core into two uneven parts, and frequently ignored in many commentaries), superficially it appears otherwise as a well-homogenized subject with some stellar stragglers seemingly dispersed around it in anti-clockwise formation, again familiar to observers of these structures. Further examination of this subject will also reveal no less than two other, but less prominent, fine dark lanes running 45° to the central lane, plus a lopsidedly shaped core, looking more like a parallelogram. Additionally, still more fine lanes may be found, albeit even less pronounced, plus other wider regions of darkness. Smaller in the field of view than many of the better-known clusters (an apparent 9′), it is nevertheless of substantial dimensions, being more than 110 light years in diameter. Certainly, the most prominent dark lane alone, and the globular's overall brilliance justify the time spent at the eyepiece.

Overall, aside from that semi-circle of stars surrounding it, one cannot help but notice a kind of linear dominance within this cluster. These chains of stars appear to outline the dark lanes, something we often see in globulars, as discussed earlier.

Messier 2

A colossal cluster, populated by over 150,000 stars and at least 175 light years in diameter, beautiful M2 in Aquarius ranks as one of the largest of all of the Milky Way's globular clusters. Because of its distance of over 37,000 light years, it appears fairly compact (at 16′) in the eyepiece but is strikingly beautiful and luminous because of its grand stature. Exquisite, silvery and refined, the observer may conclude that the cluster consists of many small stars, when, in fact, it is the distance and density that creates this illusion, something that quickly explains the almost magically fine appearance of its stellar population. John Herschel famously thought its appearance was remarkable and likened it to "a heap of fine sand!"

Careful examination reveals that the cluster's stellar distribution is far from even, having multiple regions of uneven illumination, along with corresponding dark lanes. However, the most significant dark lane curves around one side of the cluster and may be seen quite easily in Fig. 5.10 to the left in the image. Interestingly, once

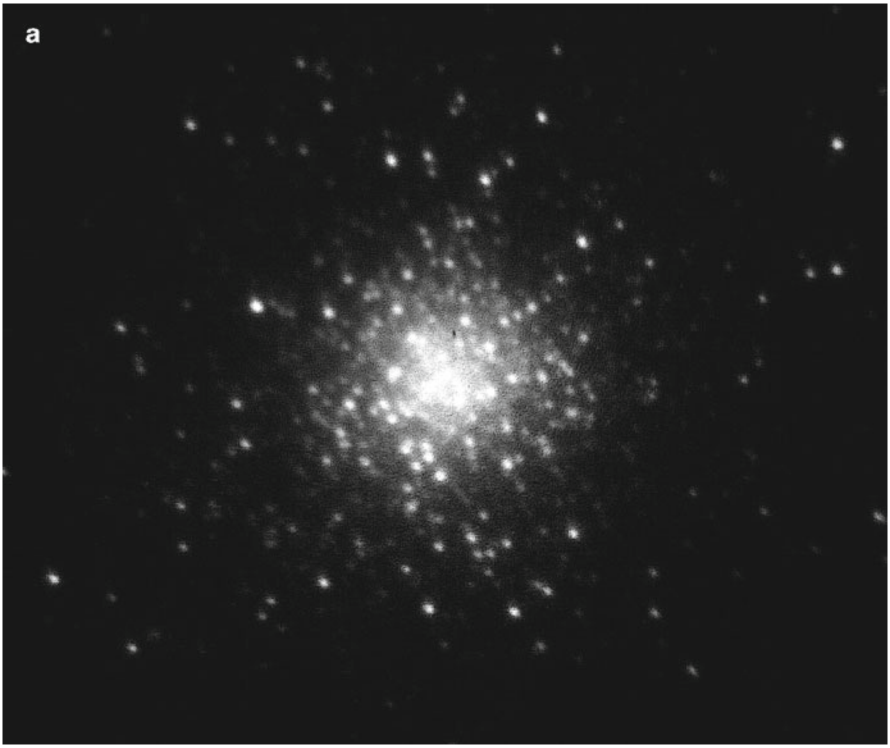

Fig. 5.10 (**a**) M2 (AC). (**b**) (1) This is the reported dark lane of so many observers, which definitely can be seen to occupy just one side of the cluster. Appearing more like a dark shadow than a sharply outlined lane, nonetheless, with averted vision it is striking indeed.

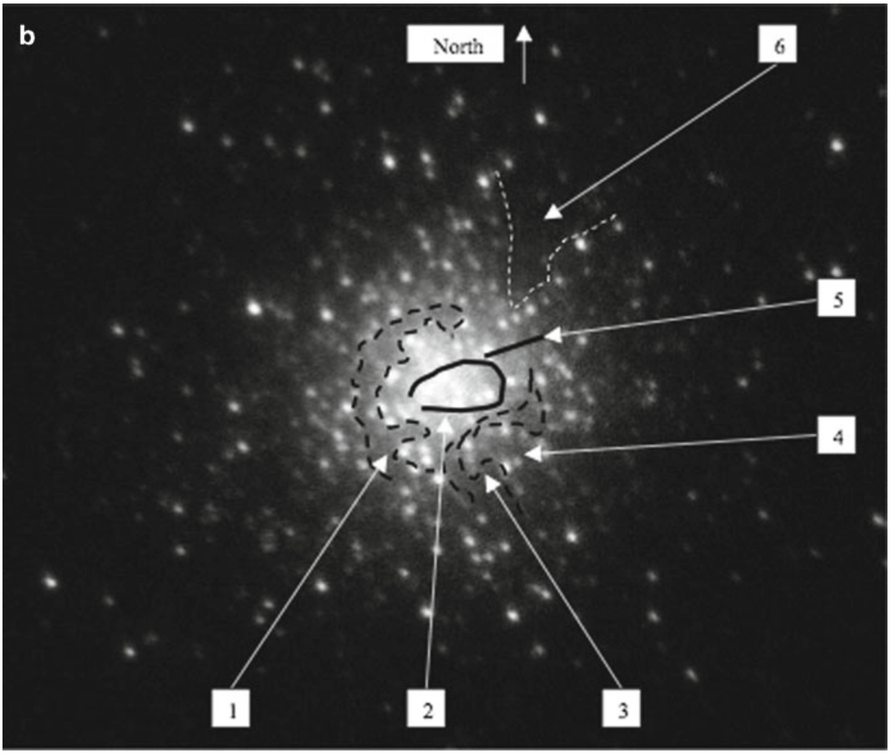

Fig. 5.10 (continued) (2) Within the better-known dark lane region there exists a further dark region, encircling most of the cluster, and easily obliterated in longer exposures. (3) It can be seen that another lane, similar to (1), although not nearly so prominent, also exists, completing a ring around the better part of the periphery. (4) Another dark region, not unlike the famous lane but less well-placed, so that it may not be noticed or elicit comment. (5) The fine straight dark lane referred to in the text, a typical feature of globular clusters. (6) Striking dark V-shaped dark notch cuts into periphery of the cluster

the position of this lane is known, it is not too difficult to trace it on highly exposed images of the cluster, where vestiges of its dark form often remain. There is also one fine, straight lane pointing outwards at the 2:30 position; it is this very type of lane that seems unique to globular clusters. Additionally, many straight chains of stars radiating outwards give an almost three-dimensional effect of an exploding ball of lights.

Additionally, keen eyes might be able to detect many more dark indentations, and even more lanes around the circumference of the cluster; they certainly appear to be the result of some amount of obscuring matter, rather than haphazard arrangements of the stars. Their overall appearance frequently parallels the streams of stars radiating straight outwards in all directions.

Other Globular Clusters Showing Dark Lanes

If we approach viewing all globular clusters in the manner just outlined it will be discovered that there are very few that do not offer something worth a second look. If the number of potential examples that reveal telltale dark streaks and lines seems almost endless, it is, in fact, because there are very few globular clusters entirely devoid of them. Obviously, some lanes are more prominent than others, and such features as may be present might not be immediately obvious; naturally, different clusters will be more forthcoming than others, and viewing methods and conditions that offer the greatest contrast will be the most productive. The type and form we might expect these dark features to take should by now be clear, together with how they actually might be anticipated to appear in the eyepiece.

Most of those we have previously detailed are relatively prominent in the sky, among the most likely to have elicited a few comments (albeit limited) in publications that they reveal dark lanes; certainly these grander examples will tend to be the most generous in this regard; the list can easily be expanded to include many other well-known globular clusters and includes especially M3 in Canes Venatici, M5 in Serpens, M13 in Hercules – clusters no less compelling. However, one should not presume that lesser-known examples, typically not such brilliant spectacles, will be significantly less forthcoming.

M10

A glance at M10 in Ophiucus (Fig. 5.11), for instance, immediately reveals interesting details, all too typical of any globular cluster that is bright enough to provide some contrast. The complexity of what we see here is remarkable, from the lopsided appearance of multiple dark lanes, many of them of that fine serpentine character seemingly unique to globulars, to the ring-like semi-circular lane surrounding part of the core. The nature of these details separates this globular from most. Without providing the level of analysis we have utilized for prior examples, we will allow the image and guide to speak for themselves, but what we might expect to see should be increasingly clear by now. In M10, the remarkable number of dark lanes (represented by both black as well as white lines) is shown, with those on the periphery and less obviously tangible in dotted lines. Different observers will naturally report different results, but it would be hard to deny that this cluster represents a special treasure trove of fine dark details and lanes, and at an apparent 20′ size, it is large enough to deliver them.

While M10 is merely another example of the sizable resource awaiting us, this cluster is a fine one, to be sure. All in all, for those who may choose to study these objects closely, from the most striking and varied features in globular clusters to the faintness and rarity of dark lanes in open clusters, these deep space objects may provide sufficient reason to justify an observing program to the exclusion of practically every other.

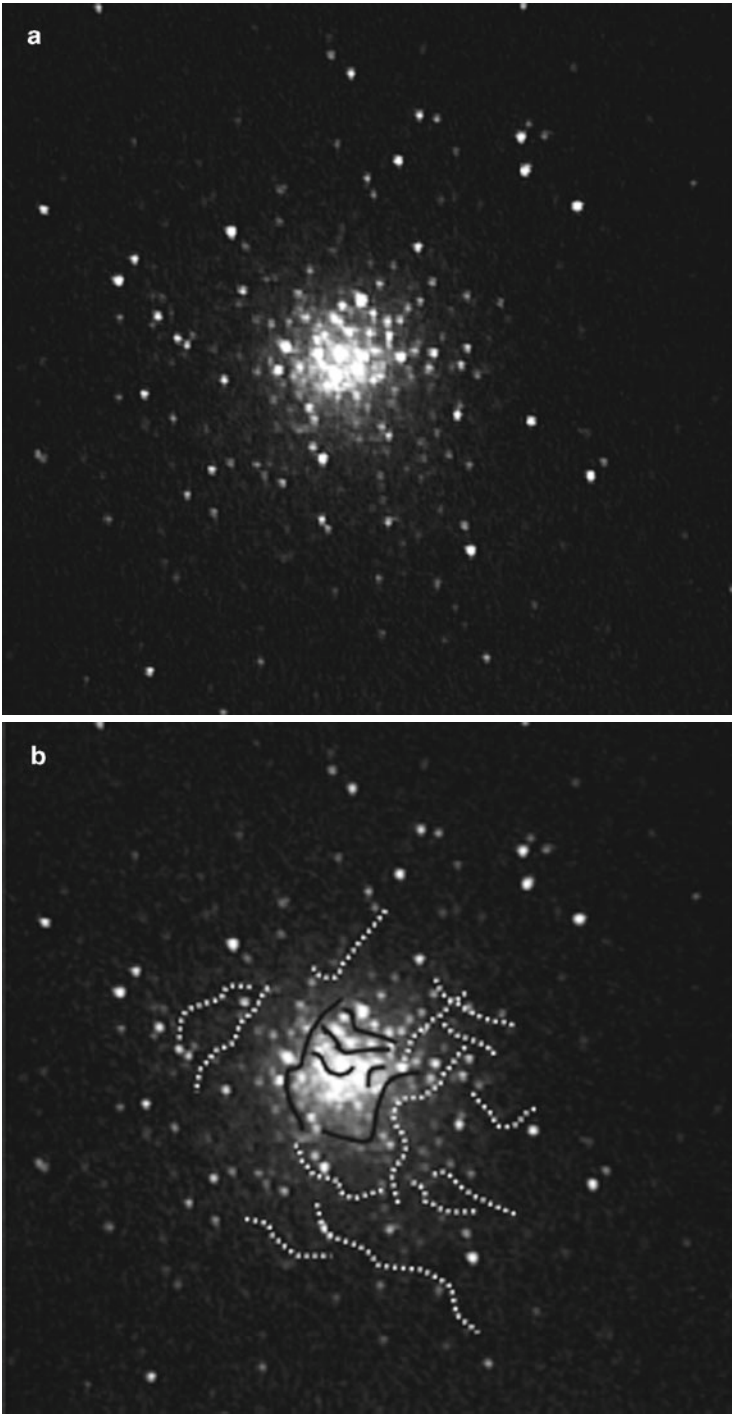

Fig. 5.11 (**a**) M10 in Ophiucus (AC). (**b**)

List of Star Clusters of the Milky Way Featuring Potentially Viewable Dark Lanes

This list of star clusters represents a good cross section of many of the best examples to observe, most featuring dark features of some kind. Although not in any way intended to be complete, the list is comprehensive and varied, and it includes some appropriate observing information for each item.

Precise magnitudes and dimensions are greatly subjective, and may be perceived differently according to many variables. As in previous chapters' listings, this catalog has been revised to be more in accordance with the prevailing estimates of a wide range of many contemporary observers. As a result, the various designations are more in line with those found in *The Night Sky Observer's Guide* (Kepple and Sanner; Willmann-Bell, Inc.) than Burnham's *Celestial Guide* (Robert Burnham; Dover) and appear more as averaged estimates rather than exact determinations. However, the updated approach should not be taken to imply any less reverence for Burnham and especially the unique insights that he provided; Burnham's very comprehensive system was built on solid perceptions, scientific evidence and logic.

Each object is listed with, its *catalog number* first (NGC or other), next *magnitude*, angular *size*, *coordinates*, the *constellation* in which it can be found, and a short *description* of interesting features. Below each listed globular cluster is a link(s) where the most suitable reference image – at least, from a perspective of revealing dark details – may be found online, if available, together with comments regarding the image(s). Globular clusters are among the most poorly represented deep space objects from the perspective of noting dark features. These features are subtle and do not reveal themselves easily; overexposure wipes them out, and even some of the finest highly resolved imagery tends to relegate them to obscurity. Although it would seem that the best detector of all is the human eye, infrared sensitive devices frequently render them more visible.

It should come as no surprise that a large proportion of globular clusters are high in the NGC catalog – located close to the heart of the Milky Way.

Object	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 104 '47 Tucanae'	4.5	25′	00240s7200	Tucana	Second only to 'OMEGA CENTAURI'; features many lanes and star chains, but large dark features are few; extremely dense core
www.atscope.com.au/newsky/ngc104_stl.jpg				*Best available image; some hints of lanes and chains visible in outer regions, although image overexposed overall in center*	
*					
NGC 288	9	13′	00528s2635	Sculptor	Relatively sparse, with dense core
www.sdss.org/iotw/ngc288.jpeg				*Useful image; not overexposed, and thus considerable dark detail is visible, as well as star chains*	
*					
NGC 362	6	13′	01031s7050	Tucana	Some suggestions of lanes around circumference
www.astrosurf.com/antilhue/ngc362.htm				*Good image, though center is overexposed; a striking short dark lane is visible on outer edge facing towards cluster core, plus other dark irregularities in the extremities*	
*					
NGC 884 and 869 Perseus Double Cluster	4.5	60′	02200n5708	Perseus	Definite traces of lanes in periphery of both clusters
http://apod.nasa.gov/apod/image/0912/DoubleClusterSpiked_fleming.jpg				*Remarkable image, revealing what appear to be dark lanes around and between both clusters*	
*					
M45 'The Pleiades' Open Cluster and Reflection Nebula	2	100′	03472n2470	Taurus	Much nebulosity around stars, but no emission component; many lanes and streaks throughout
http://apod.nasa.gov/apod/image/0711/pleiades_fs_big.jpg				*Wonderful clarity; some of the dark lanes and features will be visible in best circumstances*	
*					

NGC 1904 (M79)	8.5	9′	05245s2433	Lepus	Core strongly divided by obvious stark dark lane
http://www.tvdavisastropics.com/astroimages-1_0000aa.htm				*The only usable out of many otherwise disappointing images; while not being ideal, the image shows some of the attributes*	
*					
NGC 1912 (M38) Open Cluster	8	20′	05284n3552	Auriga	Dark nebulosity has been associated with this cluster
http://thebigfoto.com/wp-content/uploads/2009/02/messier-38.jpg				*Image does seem to reveal dark nebulosity permeating this cluster*	
*					
NGC 2099 (M37)	7	21′	05522n3233	Auriga	May contain some wider lanes
http://3.bp.blogspot.com/_N-36xJMPdm4/R7VA5ihNieI/AAAAAAAAAQ8/Ah6bD2HFj8c/s320/M37%2Bfrom%2Bdss.gif				*B/W image does seem to confirm lanes*	
*					
NGC 2168 and M35 Open Clusters	9 6	25′ 8′	06091n2421	Gemini	Two completely different open clusters in same field, sometimes confused as the same cluster; M35 being the youngest, NGC 2168 quite compact, populous and mature – once thought to be a globular. Hint of lanes seem evident
http://thebigfoto.com/wp-content/uploads/2009/02/messier-35.jpg				*Image seems to show some dark nebulosity and lanes in and around both clusters*	
*					
NGC 2419 'The Intergalactic Wanderer'	10.5	4′	07381n3853	Lynx	Most distant Milky Way globular – long thought separate to the galaxy – but it does, in fact, belong to it; interesting to see; image intensifiers and larger apertures may resolve stars and even dark details
http://apod.nasa.gov/apod/image/0901/ngc2419a7_hammar_c800.jpg				*Interesting image; reveals some inner dark lanes and irregularities*	
*					

(continued)

(continued)

Object	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 2447 (M93) Open Cluster	7	19′	07446s2352	Puppis	Compact bright cluster
http://www.universetoday.com/wp-content/uploads/2009/12/m93.gif				*Some nebulosity is clearly shown on image*	
*					
NGC 2808	8	7′	09123s6451	Carina	Grand cluster; has curious wedge-shaped dark region extending from near center
http://www.dartmouth.edu/~chaboyer/images/ngc2808.jpg				*Dark region clearly shown despite overexposure*	
*					
NGC 3201	6.7	18′	10176s4625	Vela	Striking lanes
http://seds.org/~spider/spider/MWGC/Pics/n3201_aat119.jpg http://www.astrosurf.com/antilhue/ngc3201.htm				*The Australian Anglo Telescope image, while not the most beautiful image, is more revealing than others and by far the best in dark detail (additional example listed below)*	
*					
NGC 4372	8	16′	12260s7240	Musca	Mostly 12 m. stars, many dark lanes and patches
http://www.astrosurf.com/antilhue/ngc4372.htm				*Patchiness shows well*	
*					
NGC 4590 (M68)	8	11′	12395s2645	Hydra	Contains dark lanes and patches
http://en.wikipedia.org/wiki/File:Messier_68_Hubble_WikiSky.jpg				*Image shows unevenness well*	
*					
NGC 4833	7.5	13.5′	12258s7240	Musca	Loops, chains and dark lanes in evidence
http://www.astrosurf.com/antilhue/ngc4833.htm				*Wide dark lanes to one side show well*	
*					

NGC 5024 (M53)	8	11′	13129n1810	Coma Berenices	1° distant from fainter NGC 5053; irregular outline; dark lanes intersect core region
http://en.wikipedia.org/wiki/File:Messier_53_Hubble_WikiSky.jpg				*With no ideal images, this at least reveals some hints of dark details*	
*					
NGC 5139 ‘Omega Centauri’	3.8	35′	13268s4729	Centaurus	Astounding; king of globulars; contains Pop I and II stars; well blended whole with few, if any, dark features, leading to questions about its origin
http://apod.nasa.gov/apod/image/0204/ngc5139_tan_big.jpg				*Very effective image; true to life, showing no dark lanes or regions*	
http://oc-aisig.org/gallery/main.php?g2_itemId=3748&g2_imageViewsIndex=1				*Beautiful small aperture image*	
*					
NGC 5272 (M3)	6	15′	13422n2823	Canes Venatici	Beautiful, well resolved to center; crooked lane to one side and other dark features
http://www.rppass.com/m3-004a.htm				*B/W image that shows some potential dark features*	
http://apod.nasa.gov/apod/ap070609.html				*Beautiful, if homogenized image*	
*					
NGC 5904 (M5)	6.5	16′	15186n0205	Serpens	Superb sight with prominent dark branch-like lanes
http://www.erschools.org/Teachers/brew/Astrophotography/Planets%20and%20Clusters/M5-4-16-2006.htm				*Considering the significance of this cluster, we are surprisingly poorly served by much mediocre imagery; this image shows some of the potential for dark lanes and regions*	
*					
NGC 5986	7.5	9′	15461s3747	Lupus	*Little known cluster, but significant for its dark lanes*
http://www.stsci.edu/~bond/ngc5986/ngc5986.html				*Lanes and unevenness show on this image*	
*					

(continued)

(continued)

Object	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6093 (M80)	8	10′	16170s2259	Scorpius	Small, bright; appears to radiate spikes of mostly 14 and15 m. star; some dark obscuration to one side
http://heritage.stsci.edu/1999/26/big.html				*Hints of dark features can be seen*	
*					
NGC 6121 (M4)	6	36′	16236s2632	Scorpius	Large, appearing open, and relatively sparse; known for striking loops and chains of brighter stars; bright ‘equatorial’ bar of central stars. Partly obscured by Milky Way dust
http://seds.org/Messier/Pics/More/m4noao.jpg				*Overall appearance is clear, though with fewer dark zones than eyepiece views*	
http://en.wikipedia.org/wiki/File:Messier_4_Hubble_WikiSky.jpg				*Core region with well-known bar and loop(s); these may be well seen in amateur scopes*	
*					
NGC 6171 (M107)	8	9′	16325s1303	Ophiucus	Irregularities and dark features cutting into its core
http://seds.org/Messier/Jpg/m107.jpg				*Partially shows the dark features; B/W*	
*					
NGC 6205 (M13)	5.5	15′	16417n3628	Hercules	Exceptional; grandest in N. Hemisphere; look for celebrated ‘propeller’ lanes to one side
http://www.perseus.gr/Astro-DSO-NGC-6205b.htm				*Lanes show discreetly at lower left*	
*					
NGC 6218 (M12)	8	13′	16472s0157	Ophiucus	Fairly sparse; dark features punctuate arms and outer regions
http://en.wikipedia.org/wiki/File:M12HunterWilson.jpg				*Image has great potential – many dark irregularities; even lanes may be glimpsed; star chains well shown*	
*					

NGC 6235	11.5	4′	16534s2211	Ophiucus	Relatively unknown globular; no significant dark features to view
http://archive.stsci.edu/cgi-bin/dss_search?r=16:53.4&d=−22:11&e=J2000&h=15&w=15&f=GIF&c=none					*B/W image*
*					
NGC 6254 (M10)	14	7.5′	16571s0406	Ophiucus	Near to globular NGC 6218 (M12); some dark lanes around edges and near core
http://www.allthesky.com/clusters/m10.html				*Dark regions detectable on image*	
*					
NGC 6266 (M62)	6.5	13′	17012s3007	Ophiucus	Irregular oval shape; dark lanes and patches
http://content.rogergroom.com/cms/000463.jpg				*Best of limited good images; overexposed at core, but outer dark features and lanes shown; B/W*	
*					
NGC 6273 (M19)	6.5	12′	17026s2616	Ophiucus	Oblate; near center of Milky Way; faint star population; dark lanes
http://upload.wikimedia.org/wikipedia/commons/3/38/M19HunterWilson.jpg				*Good image with dark regions clear*	
*					
NGC 6333 (M9)	8.5	8′	17192s1831	Ophiucus	Compact detailed cluster, with many dark details. B64 in field
http://archive.stsci.edu/cgi-bin/dss_search?r=17:19.2&d=−18:31&e=J2000&h=15&w=15&f=GIF&c=none				*Very nice B/W image with dark regions and lanes clearly shown*	
*					
NGC 6341 (M92)	7	10′	17171n4308	Hercules	Uneven distribution, smaller than nearby M13, but impressive; few dark details
http://aida.astroinfo.ch/displayimage.php?pid=4202&fullsize=1				*Good image of homogenous cluster*	
*					

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Object	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6352	9	8′	17250s4820	Ara	Anomaly: metal rich globular cluster; many fine stellar points
http://commons.wikimedia.org/wiki/File:NGC_6352.jpg				*Fine Hubble image of few available images; some lanes seem present, although in Hubble images they tend to disappear*	
*					
NGC 6362	8	9′	17320s6702	Ara	Even appearance, with lanes barely apparent; V-shaped star chain pointing to core
http://oc-aisig.org/gallery/main.php?g2_itemId=3751&g2_imageViewsIndex=1				*Good image among few*	
*					
NGC 6397	6	25′	17400s5340	Ara	One of the nearest globulars; majority stars 10 m; many uneven regions, lanes; core has collapsed
http://www.astrosurf.com/antilhue/NGC6397-NRGBhi.jpg				*Some lanes and dark features may be glimpsed*	
*					
NGC 6402 (M14)	9	11′	17376s0315	Ophiucus	Requires larger scopes; has dark lanes crossing part of core region
http://www.universetoday.com/guide-to-space/messier-objects/messier-14/				*Dark lanes visible on image (B/W)*	
*					
NGC 6475 (M7) Open Cluster	3.5	75′	17539s3449	Scorpius	Imaging does show a degree of darkness surrounding this cluster; do any lanes cross it?
http://thebigfoto.com/wp-content/uploads/2009/02/messier-7.jpg				*Clearly seems to show dusty matter in vicinity*	
*					
NGC 6522	10.5	2′	18036s3002	Sagittarius	A small cluster telescopically, in the heart of 'Baade's Window'
http://www.caelumobservatory.com/mlsc/n6522.jpg				*NGC 6522 is at left; a small dark lane is just discernable*	
*					

NGC 6528	11	1′	18048s3003	Sagittarius	A tiny cluster in the field of view
http://www.caelumobservatory.com/mlsc/n6522.jpg				*NGC 6528 is at lower right; some dark regions may be seen at outer edge of main cluster core*	
*					
NGC 6541	7	12′	18080s4340	Corona Australis	Bright, compact globular
http://www.ipac.caltech.edu/2mass/gallery/ngc6541atlas.jpg				*The best of many poor, overexposed images; some dark outer regions may be glimpsed*	
*					
NGC 6626 (M28)	8	10′	18245s2452	Sagittarius	Bright and dense; rich core; intersected by prominent dark lane
http://en.wikipedia.org/wiki/File:Messier28.jpg				*Not the best image, but lane well shown*	
*					
NGC 6637 (M69)	7.5	4′	18314s3221	Sagittarius	Unimposing in smaller telescopes; resolution of 14 and 15 m. stars needs larger apertures; near 9 m star
http://astroa.physics.metu.edu.tr/Astronom/SC/M69.HTM				*Some lanes show*	
*					
NGC 6656 (M22)	6	32′	18364s2354	Sagittarius	Exceptional; large, open, bright and resolved with many bright stars studding it
http://archive.stsci.edu/cgi-bin/dss_search?r=18:36.4&d=−23:54&e=J2000&h=28.8&w=28.8&f=GIF&c=none				*Possibly the most useful observatory image (B/W)*	
*					
NGC 6681 (M70)	9	7′	18422s3218	Sagittarius	Uneven stellar distribution
http://www.sidleach.com/m70.htm				*Interesting image – it seems to show lanes*	
*					

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Object	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6694 (M26) Open Cluster	8.5	14′	18452s0924	Scutum	A cluster that may have dark lanes
http://seds.org/Messier/Jpg/m26.jpg					*Image does seem to show a dark lane running through middle of cluster*
*					
NGC 6705 (M11) Open Cluster	7	13′	18511s0616	Scutum	Celebrated open cluster – rivaling many globulars; Lanes remain controversial
http://rst.gsfc.nasa.gov/Sect20/Messier11.jpg					*Does this image show any lanes, or is the appearance of them random placement?*
*					
NGC 6712	9	6′	18531s0842	Scutum	Relatively unknown, but worthwhile observing potential
http://jthommes.com/Astro/NGC6712.htm					*Amateur image reveals wide dark lane*
*					
NGC 6715 (M54)	9	8′	18551s3029	Sagittarius	Compact and bright; remarkable, apparently as magnificent as Omega Centauri, although situated outside our own galaxy. Belonging to the Sagittarius Dwarf Galaxy – not to be confused with NGC 6822 – it requires larger apertures to resolve any of its stars
http://www.mistisoftware.com/astronomy/images/m54_050708_2000.jpg					*Possibly the most revealing image, although do not expect to see lanes, here or live!*
*					
NGC 6752	6	20′	19119s5959	Pavo	Outstanding; loops, chains, lanes; many radiating streams of stars
http://oc-aisig.org/gallery/main.php?g2_itemId=2870					*Beautiful image, though not for revealing dark detail; few, if any, other good images*
*					

NGC 6779 (M56)	8	5′	19166n3011	Lyra	Consisting of mostly 11–14 m. stars; unusual location for a globular; challenging for smaller 'scopes to resolve
http://www.skyfactory.org/deepskycatalogue/NGC6779.html				*B/W image; telescopic views likely to be disappointing for dark lanes*	
*					
NGC 6809 (M55)	7	19′	19400s3058	Sagittarius	Large and loose; stars mostly fainter than 11 m; has curious wide partial loop-shaped dark notch to one side; well resolved in moderate apertures
http://en.wikipedia.org/wiki/File:M55HunterWilson.jpg				*Dark detail well shown on amateur image*	
*					
NGC 6838 (M71)	9	6′	19538n1847	Sagitta	Rich and compact; lacks a dense core; stars approx. 12 m.; has several dark lanes
http://www.perseus.gr/Astro-DSO-NGC-6838b.htm				*Lanes shown on image*	
*					
NGC 6864 (M75)	9.5	6′	20060s2155	Sagittarius	Fairly bright, compact and dense; traces of lanes; most stars 17 m
http://messier.obspm.fr/Pics/More/m75noao.jpg				*The most useful of many unhelpful images*	
*					
NGC 6981 (M72)	10.5	4′	20535s1232	Aquarius	Brightest stars no more than 15 m
http://www.kopernik.org/images/archive/m72.htm				*Image shows many lanes and dark regions*	
*					
NGC 7078 (M15)	6.5	18′	21300n1210	Pegasus	Exceptional, resolved lanes; irregular features; see text
http://ftp.seds.org/Messier/Jpg/m15.jpg				*Far from an ideal image, this B/W picture does show something of the dark lanes and irregularities*	
http://apod.nasa.gov/apod/image/0008/m15_hstheritage_big1.jpg				*Beautiful Hubble image confuses rather than clarifies, but many of the irregularities are at once apparent*	
*					

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Object	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 7089 (M2)	7	16′	21335s0049	Aquarius	Outstanding, compact, with fine stars resolved; look for dark features, especially the notable lane that crosses the northeast edge of the cluster
http://lvaas.org/mediagallery/media.php?f=1&s=20090927070033536&i=0&p=0					*As fine an image as exists, although little suggestion of the various dark features is evident*
*					
NGC 7099 (M30)	8	6′	21402s2311	Capricorn	Elliptical; lopsided stellar distribution; dark irregularities; star chains
http://www.racine.ra.it/planet/testi/Foto/m30.htm					*Poorly represented cluster; all imagery overexposed or ill-defined. Sadly, this is the best available, revealing a few dark irregularities*
http://en.wikipedia.org/wiki/File:Messier_30_Hubble_WikiSky.jpg					*Beautiful Hubble image, but probably not helpful in revealing any dark features*
*					
NGC7380 Open Cluster with emission nebulosity	7.5	25′ × 30′	22470n5806	Cepheus	Young cluster with much emission nebulosity; large shock waves evident (See Chapter 5)
http://www.ruppel.darkhorizons.org/IMAGES/ngc7380LHaRGB.jpg					*Effective image of cluster, with nebula in context*
*					
NGC 7654 (M52) Open Cluster	6	13′	23242n6135	Cassiopeia	The cluster does have the appearance of being surrounded by some dark lanes; adjacent to 'Bubble Nebula' NGC 7654
http://www.ipac.caltech.edu/2mass/gallery/m52atlas.jpg					*Shows dark lanes (?) on outskirts*
http://www.newforestobservatory.com/wordpress/wp-content/gallery/otherimages/Bubble_NFO.jpg					*With 'Bubble Nebula' in field*

Chapter 6

Dust Belts and Dark Features in Galaxies

For this chapter we will exit the confines of our own galaxy and venture out to the vast expanses of the greater universe. The very same types of dark features that we may observe locally are no strangers to distant locations, of course, except from so far away we will usually see them quite differently – mostly as large blends of what we previously saw as multiple dark objects. Now they will be melded into single, or at least far fewer, separate entities. The variety is considerable. Although certain other galaxies approximate the views of the vast twisted dark belt surrounding the Milky Way, (easily visible in grand photographic projections), it is hard to find another example with identical visual attributes throughout the countless galactic forms in the readily visible universe. The interconnected dark features we see are typically galaxy-wide dust belts, or, from above, large dusty regions (just parts of those same belts scattered within the arms of the nearer galaxies). Seen from the side they appear as great dark swaths of jagged matter dividing the illuminated whole into two parts. Were we able instead to isolate the many smaller dark nebulae from across intergalactic space they would look much like what we see within our own galaxy. However, what we are seeing, of course, is the greater form and extent of the galactic interstellar medium, something just as significant as anything else that makes up a galaxy. As such, it is appropriate to think of galaxies as star factories, and the dark interstellar matter the raw material.

Because of the huge scale of these galactic belts, the striking and bold contrasts they often show against the host galaxy, and the endless variety they present from example to example, you may even conclude that these are the ultimate dark features of all to observe. Indeed, these belts have the potential to provide some of the highest levels of satisfaction in observational astronomy, be it live or imaged. Ultimately, some avid deep space observers may be hard pressed to find that the relatively smaller 'local' sights within the Milky Way hold quite the same level of intrigue and interest.

A. Cooke, *Dark Nebulae, Dark Lanes, and Dust Belts*,
Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4614-1186-4_6,

Part of the fascination is in knowing that galaxies represent complete island universes in their own right, no less so than our own galactic home. The visibility of interstellar matter within them reinforces that we are witnessing vibrant and ongoing systems external to our own; who could be blamed for imagining the possibility of other civilizations within these systems? From the perspective of any of these remote destinations, a completely different view of the rest of the universe would exist. Instead of the somewhat personal vision we have of our place in the cosmos, the Milky Way would be just another galaxy, categorized in the same impersonal format we use for all other galaxies. Perhaps a catalog entry from a remote galaxy for our own little corner of the universe might read of it: "a huge barred spiral, featuring a striking but irregular dust belt with vertical extensions dividing its entire length…". We, as living beings within, would certainly be no part of that equation.

Always with the tantalizing prospect of discerning detail in remote corners of the universe, observational astronomy is all the more meaningful when the promise is fulfilled with something approaching the imagery displayed in books. This is not something that happens too often. We do have the prospect of seeing truly remarkable views of these structures in real time, although we will need to temper our expectations according to realistic potential, and for that to take place, we will need truly dark skies and transparent air. Even then, the brightest galaxy is still not exactly easy to see, which makes any realization in the eyepiece of spiral form itself a thrill that can hardly be exaggerated, as well as the sobering reality of the inconceivably large distances that separate us from what we see. This is especially the case since reasonable apertures of modern amateur telescopes perform this task even better than did the giant instruments of the nineteenth century.

Of those galaxies that present readily observable detail to the observer from Planet Earth (that is, within a radius of around 100 million light years), there are barely two even remotely alike in the eyepiece. It has to be said that while merely seeing spiral arms may be many an observer's greatest joy, there are innumerable other details that separate each example from the others. The best of them reveal pronounced dusty features, with all manner of subtleties, dark and light, the combinations of which have much to do with the unique appearance of each. With the theme and focus of this writing, we will thus cast our attention to all those dark details we can see, to include surrounding dust belts (which exist in a wide variety, frequently with surprising detail), other concentric dust lanes, regions of apparent darkness within or between spiral arms, the striking medley of dusty features in peculiar or colliding galaxies, or any number of other unusual dark defining detail.

We must return to the historic record; once again, it shows Lord Rosse at the forefront, as it seems he was the first observer to document dark features in galaxies. Because such revelations are scarce to find among published findings made during those times, Rosse's recorded observations of the dark central region of M82 make clear that his perception skills, as well as the power of his telescope, were on the cutting edge of his age. During the present day, however, with modern means and knowledge, we don't have to look far to find dark galactic detail.

The exception is, of course, elliptical galaxies, which remain largely featureless to our eyes; however, there are seemingly countless galaxies of the other varieties within reach that will yield something and make for productive viewing directly through the eyepiece.

Classification of Galaxies

To best appreciate which galaxies are most likely to show dark features, it will be instructive to review the standard classifications of galaxy types, which may be categorized according to their state of formation or structure; such characteristics play an important role as well in knowing what to look for in each type of galaxy. The straightforward system of classification that Edwin Hubble developed in 1936 is still in use today, although others have added to and refined it as they sought to go further. For our purposes, however, the basic Hubble system remains sufficient, largely without these additions. Below is a general synopsis of this system and the galaxies to which it applies, without undue later added on sub-categories:

- *Spiral galaxies:* 'S' denotes spiral structure; SA denotes unbarred form, that of the standard spiral; Early spirals, ('a' type), such as SAa galaxies, are indications that the galaxy will be dominated by a bright core and less pronounced spiral arms. A galaxy ('c' type) shown as SAc (a late type spiral) will tend to have more prominent arms and a less pronounced core, while other variants (ab, b, bc, c) all reflect different degrees of spiral evolution. Interestingly, 'early' and 'late' terminologies may possibly be misleading, and depend on which perspective of time we are referencing; 'early' type galaxies contain more old stars than do 'late' types. Thus 'late' means formed lately, and early from early in time. Occupying a shallow plane around the core, spiral arms contain numerous young stars and are home to their formation, and thus wavelengths of light being emitted from them tends to be predominantly in the blue portion of the spectrum – the characteristic wavelengths of young stars. Thus we can see the degree to which early spirals have exhausted their star-building materials, as the wavelengths grow increasingly yellow/red. As to their formation into spiral form, there is no correlation in galactic stellar motions to the 'Catherine Wheel' firework model, where the stars would gradually 'wind up' close to the core. Rather, they result from density waves that trigger arm formation and encourage star formation.
- *Barred spirals:* Barred galaxies follow a similar logic of classification. Although in many ways similar to non-barred varieties, they are plentiful, but fully barred galaxies do not quite exist in equal numbers. The SB designation is for barred galaxies, while SAB indicates a galaxy has certain qualities of both barred and non-barred. In fact, it turns out that more spiral galaxies show some degree of barred form than those that do not, even if only mildly; it takes only a little perturbation of stellar movement within the galaxy to cause the formation

of such structure. They are presumed to be transitional phenomena and are more likely to form in slower rotating galaxies. Higher speeds of rotation is the key to preventing bar formation by giving the stars and gas rotating around the core sufficient momentum to prevent them from falling inwards into a bar – a natural outcome of the galaxy's stars moving in lockstep relative to each other and the effects of any slight unevenness of mass densities within the galactic disc. Because only gas molecules can effectively exist in close proximity (stars always remain separated) the central mass of interstellar matter at the core is able to keep building during this period. We can sometimes observe this matter along the length of the bar.[1] Ultimately, however, the very mass of a strong barred formation works against it, as the increased mass around the core changes the gravitational balance and eventually eliminates the bar! Interestingly, it seems that gravitational irregularities caused by the bar itself can act as a catalyst for the collapse of the galaxies' greater dark nebulae, which, of course, results in new star formation.

Other than simple SB or SAB galaxies, we might see such designations as SBc or SBb, or even SAab. Such carefully blended designations of mixed-form barred and non-barred galaxies are not uncommon, presumably the result of bars in the process of creation or dissolution. In cases of both characteristics being present, and additionally being 'early' or 'late' examples, we may see even more complex designations, such as SABbc. Although this may seem complicated, really it is very straightforward; the descriptive letters follow a simple and logical sequence and serve to provide graduated and subtle differences from galaxy to galaxy.

- *Elliptical galaxies:* Among other galactic forms are ellipticals – classified as type E. These appear as essentially featureless shapes, from spherical through increasingly elongated, and are characterized EO to E7, the latter being the most elongated. Ellipticals appear to be the oldest galaxies, and as such, their predominantly Population II stellar makeup is heavy element poor (in astronomical terms, metal poor). Because most star-forming gas has been used up and is not being regenerated by these stars, the result is a mass of stars, homogenized into structures devoid of interesting visuals. Thus, their stellar makeup differs considerably from that of spirals, and they lack dark features because of their lack of star-forming matter; we can safely forget these galaxies in the context of this writing. Because the stars that make up these galaxies are quite deficient in heavy elements, the overall masses of elliptical galaxies are surprisingly low, although the largest examples may be comprised of more than a trillion stars. Even the largest examples are likely to have lower total masses than the average spiral, but they tend to dominate the central regions of the galactic clusters to which they belong.

[1]Such dark features along galactic bars were extensively studied, as well as being discussed in detail, by E. Athanassoula in his paper, "The existence and shapes of dust lanes in galactic bars" (Observatoire de Marseille), should the reader be interested in detailed analysis of these features, which is beyond the scope of this book (see reference section).

- *Lenticular galaxies:* SO types, sometimes take on a structure and shape in some ways similar to spiral galaxies, both barred and un-barred, and when seen edge-on may even have dust belts around their circumferences. These belts tend to gravitate towards their cores, however, and therefore do not take on the appearance of completely intersecting the entire length of the edge-on view. Although they have been termed 'armless spiral galaxies,' this designation is not altogether accurate. However, typically any spiral form within them is hard to detect, though it may be present to a small degree. Overall such structures are much less defined than traditional spirals, and more like ellipticals in many respects. Where they do show some spiral structure, they are known as SAO non-barred lenticulars and SBO barred lenticulars. Star makeup is predominantly of older Population II types, and the typical absence of significant amounts of usable gas and dust (interstellar medium) precludes much ongoing stellar creation. As such they appear to be one step away from becoming elliptical galaxies.
- *Irregular and peculiar galaxies:* Additionally, there are irregular galaxies (I), consisting of smaller, relatively unstructured forms; many dwarf galaxies are irregular, their forms appearing nebulous and vague (i.e., the Magellanic Clouds), although sometimes vague traces of spiral structure may be evident. We usually associate these galaxies with larger galaxies (in some ways analogous to small fish acting as companions to larger fish!).

  Peculiar galaxies (Pec) usually form as a result of gravitational interactions or actual collisions with other galaxies, so they would appear to be transitional. With dark detail galore resulting from interstellar matter being thrust into chaos, peculiar galaxies are likely to provide much fertile observing ground, especially with new stellar activity. Modern research has demonstrated that many actually are 'starburst' systems (see below), which typically, coincidentally, are also the result of galaxies colliding. The upshot of these collisions is the occurrence of powerful internal gravitational forces that lure and compress the interstellar gas towards the core of the larger and surviving galaxy; this increased pressure, in turn, generates enormous increases in stellar evolution and production. Supernovae must be a common event.

  Two prime examples of colliding galaxies are M82 in Ursa Major (see Fig. 2.1g), and NGC 5128 (Figs. 6.1 and 6.2), otherwise known as Centaurus A. Until recently, these were simply labeled peculiar galaxies, without an explanation for their bizarre form being understood. They are both stunning sights to behold. In the case of Centaurus A, this galaxy is a strong radio source that turned out most likely to be a large elliptical galaxy devouring a smaller spiral. Located near globular cluster Omega Centauri NGC 5139 in the southern sky and one of the brightest galaxies in the sky, Centaurus A is a most interesting and remarkable sight, but regretfully the galaxy is not readily accessible for many Northern Hemisphere observers. In comparison to the splendor of the ESO image (Fig. 6.1), Fig. 6.2 shows the galaxy's more likely appearance in the eyepiece, diminished maybe, but amazing nevertheless, especially when one is aware of the many dark subtleties on display.

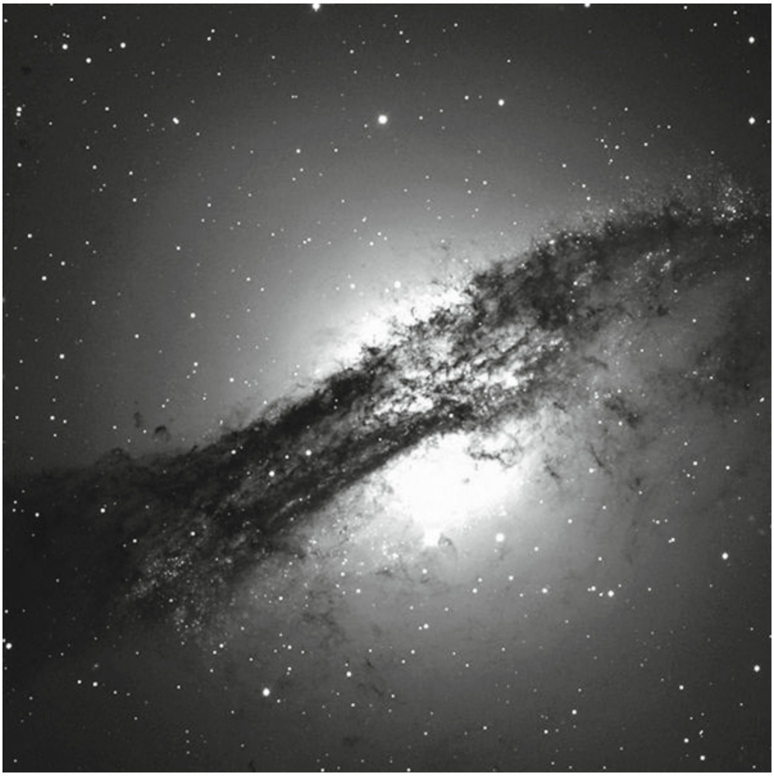

Fig. 6.1 Centaurus A, NGC 5128, a large elliptical galaxy colliding with a spiral, has resulted in a highly active starburst region within a wide dusty mantle (image courtesy ESO)

Thus it would seem that most peculiar galaxies probably share similar roots, and really do not represent a true separate galactic designation at all. However, the term still hints well at what we might expect to see and certainly is an apt designation for such transitional forms. Many of these galaxies, including both M82 and Centaurus A, emit a powerful ‘nuclear jet’ from both sides of the core at right angles to the galactic plane. To date, no one fully understands these jets, but they are plainly visible on many observatory plates in wavelengths not normally visible.

Other strange-appearing galaxies may be the result of ‘ram pressure stripping,’ having been deformed and transformed into unrecognizable shapes, something that also occurs in certain regions between members of a galactic cluster, known as the ‘intra-cluster medium.’ In galaxies, these significant regions of inter-galactic space create super-heated X-ray sourcing gases that cause violent winds within any nearby galaxy unfortunate enough to pass by, ultimately drawing star-forming dark materials right from it. The galactic victim may assume any number of distortions,

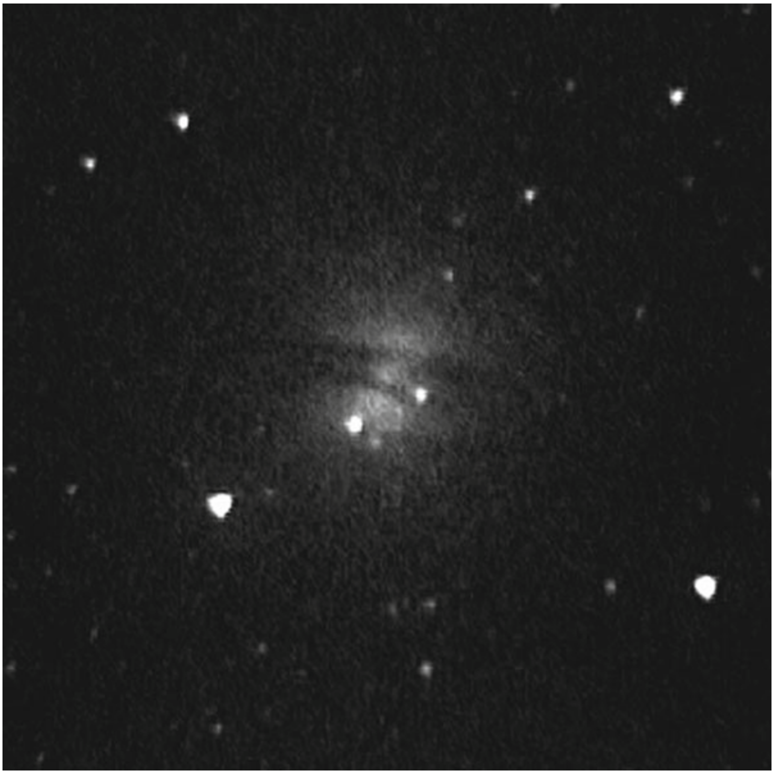

Fig. 6.2 Centaurus A, NGC 5128 (AC)

but likely it will result in strange dish-like shapes in the direction of the winds, along with the galaxy's dark nebulous material being blown right out of it in that same orientation, twisted and broken into fragments.

Because peculiar galaxies, especially, have many varieties of striking dark features, as well as frequently appearing explosive regions of star forming activity, they frequently offer remarkable viewing potential, especially with image intensifiers and CCD video cameras (to a lesser degree). Many otherwise unseen regions of glowing dust may be readily detected with their use, while dark regions are thrown into stark relief against more brightly illuminated backgrounds.

- *Starburst and Seyfert Galaxies:* Although not listed as different Hubble designated types, these are indicative of some variants in the normal galactic order that occur. We have already seen that many peculiar galaxies are the result of ongoing galactic collisions, usually causing them to rank also as starburst types, which feature accelerated rates of star formation. The subsequent merging of these separate entities into one is the presumed outcome. Because huge reservoirs of increasingly high-pressure gas may be suddenly available in the central region of such a galaxy, an unstable environment exists at least temporarily. The result is an onset of rapid star birth with extremely massive stars being created in far larger ratios than normally would be the case. Hence, the natural outcome of this would be frequent supernovae, which seem to be quite common in these galaxies. However, this condition is usually considered transient before the newly emerging larger galactic structure settles down again in its new form. Although there are numerous variations as to what constitutes such galaxies, the characteristics of accelerated stellar output are consistent, and explosive consequences the norm.

The other galactic variant worth mentioning here, Seyfert galaxies, appear to be the result of extremely dense gas concentrations surrounding and spewing from their highly active and radiant cores. They feature extremely bright nuclei, along with probable massive black holes at their heart, along with the bright emission characteristics of the gases of star fusion, but in highly ionized forms, including molecular hydrogen, oxygen and helium. The regions surrounding the typical massive central black holes are extremely active in ultraviolet and X-ray wavelengths, and radiate infrared spectral characteristic of higher temperatures than normally seen in other galaxies. While conforming in most other respects to conventional galaxies, Seyfert galaxies have been given the additional identifying characterization of Sy.

- Further letters added to the designation, outside Hubble's normal terminology and from which we might benefit, mean other characteristics are apparent. For example, SA(s) means the galaxy is 'S' shaped; (r) indicates the galaxy has a prominent ring close to the core. (See Seyfert galaxy NGC 1097 later.) Another example of later further refinements of Hubble's designations would be the lower-case letter 'd,' which refers to very late spirals with indistinct arms, often split into multiple components; however, we will not utilize this designation here. Because we are more concerned with specific dark features rather than the determining of any of a given galaxy's specific detailed structure – and as revealed by one form of viewing or another – it is probably sufficient to be guided by the larger characteristics alone, although occasionally the designation 'd' might seem warranted. For more complex designation refinements and additions, refer to such sources as *The Night Sky Observer's Guide* (Kepple & Sanner; Willmann-Bell, Inc.). There you will find a near-limitless array of all possible designations, along with detailed explanations, although at times this can be quite confusing. Generally speaking, these designations will do little to help us in our search for dark features. Just the classifications utilized in this text ought to be sufficient to guide us to those galaxies that are most likely to reveal significant detail. Regardless of what we might expect to see from any given designation, though, the chance for the unexpected always remains!

The term 'Hubble Tuning Fork' (Fig. 6.3) was coined to describe the often-sketched type of diagram that best sums up Hubble's galaxy designations, as just described. If we take the diagram at face value, all types of galaxies appear to be headed towards one final destination, that of becoming the elliptical type. Although the predominant Population II stars of these galaxies presumably have a

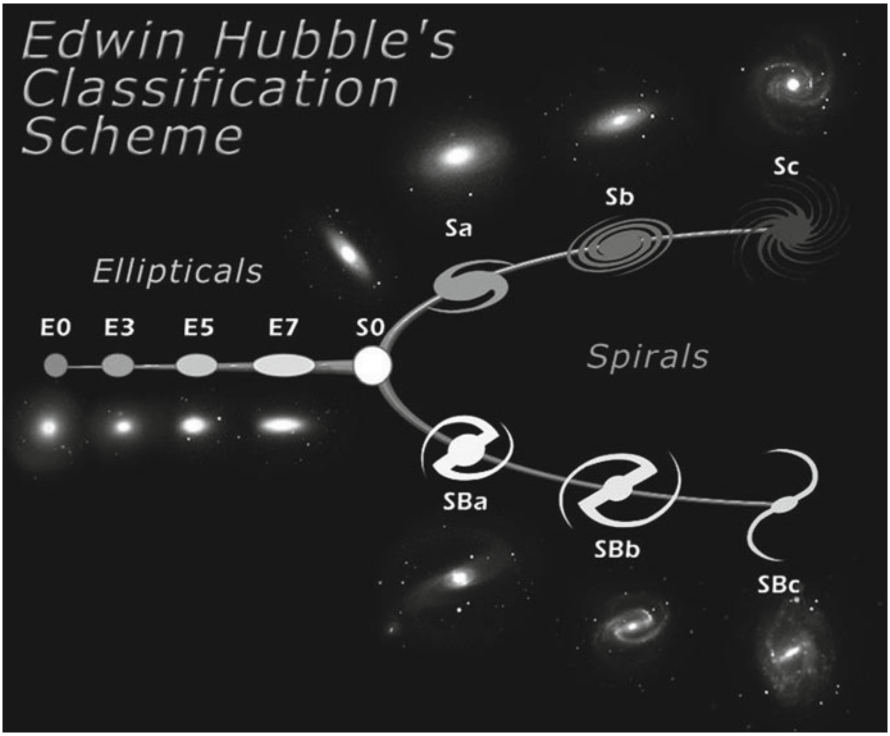

Fig. 6.3 The Hubble Tuning Fork (diagram courtesy NASA and ESA)

developmental cycle far different from the Population I stars of spirals, one can easily see how confusing early- and late-type spirals could cause them to appear on the diagram in the opposite order of their creation. Thus the analogy is not the simple sequence of events that it appears to be. Thus, the terminology might seem to imply that the predominant stellar makeup of ellipticals – those of Population II type – could somehow have evolved in reverse, where Population I stars making up early spirals morph into Population II stars! However, it can be seen that the order of spiral evolution on the diagram does, in fact, reflect an accurate scenario.

At least for now it certainly seems that ellipticals represent the ongoing fusion of many galactic collisions, and at this stage it is fair to say that the questions of these galaxies' creation and evolution remain yet to be fully understood. The theory that elliptical galaxies represent the last destination for all galaxies should not necessarily be the only conclusion to draw. However, it seems likely. It should come as no surprise that recent revelations show some star formation still taking place in parts of these galaxies (but of Population I types only); the collisions with star-bearing galaxies would be expected to snare ongoing generations of Population I stars and its interstellar matter. However, the long-term continuation of these types of stars seems limited, since the increased star-making matter and starburst activity that usually results from galactic collisions would accelerate both the formation and rapid demise of the new generations of Population I stars.

Regardless of the order of creation, the Tuning Fork does sum up the structures of galaxies extremely effectively and makes clear the similarities as well as the differences at a glance. Thus the simple presentation shown by Hubble's characterizations serves our purposes well.

Astronomers measure the total mass of any given galaxy by examining spectral lines, specifically with wavelengths in the hydrogen HII portion; the most massive galaxies, relative to Population I stellar content, to the least massive may be determined by formula. Unsurprisingly, those galaxies exhibiting significant star creation rank among the most massive since they contain so much unused or reusable material. Specifically, late-type spirals are comprised of most of those massive stars, their gas reserves sometimes exceeding the total mass of the component stars; earlier-type spirals are less so; lenticular types may have surprising amounts of gas, but typically much less than early spirals, their predominantly Population II star makeup not being very massive. Ellipticals are the least massive, relatively, of all types, their frequently huge dimensions belying their old metal poor stars.

Predominant gases present in star-bearing galaxies, aside from molecular hydrogen (better known as HII), are carbon monoxide, nitrogen and other carbon/oxygen or hydrogen/carbon compounds – even water vapor, helium, as well as many traces of exotic gaseous compounds. However, it is because of the HII regions, which fluoresce through ionization during stellar creation, that we can see so much of the processes involved.

Observing Dark Features in Galaxies

Our viewing prospects and potential are highly dependent on the internal makeup of galaxies, which is reflected relative to their designations. Visually, because SAa types have such bright cores and little, if any, prominent spiral structure, they often look virtually the same as ellipticals in the eyepiece. There will thus be almost no chance of seeing any type of detail, especially detail of the kind that is dark or dusty. SAb or c types offer better viewing opportunities, and they may be surprisingly forthcoming in face-on views with dark features in the live view (i.e., SAc type, M33 the 'Pinwheel Galaxy'), due to extensive and very active HII regions in the arms and the contrast that results within them. Galaxies often appear interesting only because of the dark features imposed on these structures that seem to define them and account for much of the way we see them.

Regardless of the viewing method you use, it is impossible to predict with certainty how any given galaxy will appear in the eyepiece. Ultimately, trial and error is still the last best guide, since all subjects react to telescopic scrutiny differently. However, if you are looking for the best candidates, at least you might start with those most *likely* to produce interesting dark features and visuals.

Obviously, the angle that any particular spiral galaxy is presented to us is of great significance, too, since the edge-on view provides the most compressed viewpoint, especially of its dusty matter. Barred galaxies, SB types, offer no less potential than unbarred SA types, and the same guidelines of categorization again may be followed. In some ways, their barred form makes them even more interesting to view. However, from an edge-on perspective, the concentrations of dusty matter make direct observations of galactic cores impossible, although the resulting dark 'equatorial' mantles can provide highly contrasted views against the light from the galaxies' stars. The dark belts we see in the best galactic candidates often cross their entire spans; variations in width, darkness, as well as other interesting features may be detected along the dust belts' lengths, including clumps of luminosity appearing as mottling and glowing formations. These clumps of luminosity are the very stellar birthplaces of stars within the galactic arms, where seemingly cold inert gas transforms before our eyes. If this activity were happening deep within the disc of the galaxy it is likely the resulting light would be obscured by concentrations of dust – and the effect of would only be compounded from the side orientation. Thus, it may be reasonably deduced that when we can see it in edge-on examples, such activity is occurring towards the outer regions of the arms.

Although we are therefore likely seeing more of the periphery of the dust belts than what lies deep within them, edge-on galaxies may present far more varied appearances than one may have suspected. We should also be aware that maximum concentrations of dusty matter tend to congregate not only in the flattest plane of the galactic thin disc but also nearest the core. These usually thin out progressively towards the perimeter, which explains why the dark belts of edge-on galaxies usually seem to trail off into undefined space.

While many galaxies are not precisely aligned with respect to our viewpoint, they are close enough to have similar attributes. In cases of many *almost* edge-on galaxies there may be further potential for other dark features to be seen within their overall structures, such as concentric rings and arms. We should also consider those dark regions between the arms of face-on and near face-on spiral galaxies, because most do seem to reveal darker spaces and lanes, often looking darker than the surrounding space. While it is generally believed that interstellar matter is confined to the arms, it has been reasonably suspected to exist in some degree between them, though clearly it is insufficient to foster new stars.

Despite interstellar material being spread throughout the galactic thin disk, the matter that comprises galactic dust belts appears relatively tenuous when we look above the spiral. Thus, throughout the full range of perspectives, from face-on to edge-on, galaxies may exhibit dark features in different ways, whether full-width circumferential belts (i.e., NGC 4565), dark regions and lanes within or between the arms (i.e., M64, the 'Black Eye Galaxy,' actually the result of a galactic collision; see observing section later), or dark spaces, even mottled dark blotches throughout the entire structure (i.e., NGC 253; see observing section later). And of course, the ultimate dark feature, a black hole – although invisible – is usually presumed to be at the center of most galactic cores. Present studies of stellar motions orbiting the center of the Milky Way seem to strongly confirm such a presence, although unsurprisingly, the black hole itself is not observable, even from this relative close range.

Elliptical galaxies, typically featureless, tend to be least interesting visually. However, in many ways their stellar makeup and distribution resemble the galactic bulges of spiral galaxies, giving rise to additional speculation about their past. Multiple collisions and fusions could also explain why the largest galaxies in any supercluster tend to be ellipticals, often of huge dimensions. Their bland appearance is thus to be expected, but their role in the cosmos is still unclear. (From the Milky Way Galaxy, as part of the Virgo Supercluster, we look out into space from our own place in space to two nearby giant ellipticals in Virgo, M84 and M87; these are central to the local galaxy supercluster, of which we are a part).

Somewhere between the two extremes of galaxy types – spiral and elliptical – are lenticular galaxies. Despite the occasional presence of well-contrasted dust lanes and traces of arms, the general lack of new star formation within them renders most of these formations fairly smooth and uniform in appearance overall. We should not expect to see any dust lanes spreading far and wide as with late-type spirals, but rather, concentrated close in to the core region. Nevertheless, unlike ellipticals, lenticular galaxies occasionally provide exceptional viewing potential. The beautiful and precisely edge-on NGC 5866 in Draco comes to mind, with its exquisitely defined narrow dust belt, one of the most striking in the sky (see observing section later).

When using electronic enhancing equipment, some simple guidelines may be useful – for example, the strongly enhanced appearance of edge-on galaxies with dust belts. The key to all of this is infrared light and HII fluorescence, both frequencies that suit these devices well. In this respect, one's expectations with enhancing devices may not match that of the conventional. In many face-on examples with predominantly bluer light emerging from hot young stars, one would normally expect the radiation emitted from within such regions to reduce the visibility of the arms. This, however, does not take into account where quantities of fluorescent gas are present, and such expectations are only sometimes in line with actual results.

Views of two grand galaxies reinforce the unpredictability of each subject's expected appearance with this approach. In truly dark locations, the 'Whirlpool Galaxy,' M51, an SAbc type, and the 'Pinwheel Galaxy,' M33, an SAcd galaxy – both face-on examples – are just two such sights that astound many observers each and every time. Although the designation SAcd seems ideal, SAbc would be less so. It might seem somewhat mysterious why M51 is the more impressive of the two visually. Here then, even with the various factors outlined above, perhaps it becomes clearer why it is impossible to always be accurate in anticipating results. We can be sure that when we are wrong, favorable light transmissions (due to thick fluorescent gas and visible from a perspective above the arms) are not blocked by thick accompanying dust; meanwhile, those mottled regions of active star formation may be sufficiently plentiful throughout the arms to outline spiral form or other features. Thus for the best viewing method to see dark detail or spiral form in face-on galaxies, as with everything else, ultimately you may just need to experiment.

With enhancing equipment, concentrations of red and infrared light in hot, dusty and gaseous regions (stellar nurseries) are more likely to be visible, and hence edge-on galaxies tend to be most obliging in this regard; in fact, they may be less striking in the conventional view due to that very dust! Dust grain size also plays a significant role, as the larger particles are capable of generating more infrared light than smaller particles.

However, wavelengths of visible light emitted by the creation of new stars may also become extinguished by thick concentrations of cold, dense and yet inactive regions of the very dust that enables future stars' creation; consequently, highly active regions in a galaxy may not be radiant with such frequencies from our viewpoint. The situation is further compounded by the diffusion of light resulting from its scattering by the dust grains themselves, especially where it is most dense.

For this reason alone, many galaxies with a strong red and infrared footprint not only may be among the least openly radiant in normal visible wavelengths but infrared and even ultraviolet wavelengths may be extinguished as well. However, this is a factor of degree from one galaxy to another. It is thus possible to see why, visually at least, all of these variants can cause the exact opposite effect we might have expected when viewing or imaging any given example, despite the method of observing chosen. Suffice it to say, one can hardly overemphasize the need for maximum contrast, regardless of how one goes about it.

Any means of increasing contrast will only make dark features more prominent, but some aids will do more harm than good, since galaxies are mostly quite faint and may be dulled overall as a consequence. UHC filters may well dim the view too much; we should remember how faint the majority of galaxies actually are. Thus we will usually lose more than we gain. One should never underrate the value of simple direct viewing with conventional eyepieces. In many instances, they will provide remarkable views, and always with the greatest extent of the galactic halo evident, along with certain intrinsic elements that are hard to describe. Image intensifiers, and to a slightly lesser degree, CCD video cameras, both of which are particularly sensitive to infrared light, may be ideal to turn loose on edge-on galaxies, with the typically strong infrared emissions of these subjects. This is not to say that they will be ineffective with others, but good results are more likely to be assured with galaxies placed edge-on and near edge-on relative to us.

However, because most galaxies are not exactly edge-on in regard to us, it is here that things get increasingly interesting. With increasingly face-on orientations, dark belts will shrink from view. It is quite normal to be disappointed by what follows, but there is always the prospect that multiple dark features within the arms may jump out, with widespread regions of distinct brighter mottling that reveals stellar birthplaces galore.

It is hard to be definitive about what to expect, since it depends on the galaxy under study and the density of interstellar matter under irradiation. Some of the grandest sights might have seemed to be the least likely to oblige, especially with enhanced viewing. This writer has been just as often astounded at what could be seen in the most unlikely subjects when using these devices (i.e., face-on galaxies) – usually considered the least likely to succeed. However, most often those that are the most surprising are Sac or SABc types, which you may recall have well developed spiral arms and frequently much star-forming activity. So perhaps such surprises are not so remarkable after all. However, in suburban situations, results are much more likely to be in line with one's initial negative expectations; these galaxies are unlikely ever to provide satisfactory viewing of such details. Thus, one should bear in mind that different viewing methods produce subtly different results. Nevertheless, most approaches do not make these subjects unrecognizable.

Edge-on and Near Edge-on Galaxies

In light of the often-dramatic appearance of edge-on spiral galaxies in the eyepiece, regardless of viewing method, let us begin with this category. Examples that are nearly edge-on with regard to us often show similar attributes, and indeed, because of the potential to glimpse inside the spiral, sometimes reveal previously unsuspected detail. The differences in what we may see from example to example are quite remarkable, and there is no way to predict exactly the appearance of any edge-on galaxy. Although the characteristics of these orientations are the dividing dust belts, these features may be more readily revealed than spiral form in face-on galaxies.

NGC 891

One of the most striking fully edge-on galaxies in the sky is NGC 891 in Andromeda which, along with larger appearing and brighter NGC 4565 in Coma Berenices, rank as the finest examples in the sky. NGC 891 is sometimes easily missed at first glance in the field of view, but may actually be the more visually interesting galaxy of the two. Only NGC 891 is precisely edge-on, but both galaxies are distinguished by their full-length, easily discernable dust belts, which divide them equatorially along their entire widths into two nearly equal components. (NGC 891 appears remarkably akin to hi-hat cymbals in a drum kit!).

NGC 891 was discovered by William Herschel and is categorized as an SA(s) b-type spiral. However, it seems there are telltale traces of what is often termed a 'peanut' shape in the central core region, normally a clue to the identity of barred spiral classes of galaxy.

Check the image below; although slight, the effect is there, so hopefully one might be forgiven for speculating that this could actually be a barred spiral of some kind. Some astronomers have compared NGC 891 to the Milky Way as a kindred galaxy, and indeed, confirmation of barred structure would make that comparison even closer, since modern astronomy has revealed that the Milky Way is likely also to be barred. At a distance of just under 30 million light years and as a member of the local supercluster of galaxies, NGC 891 does have a relationship to the Milky

Way, by default, both of which also belong to the same greater supercluster (the Local Group). NGC 891's distance can hardly be considered near, but it nevertheless ranks as one of the closer galaxies and looms remarkably large in the field of view, being an apparent 13′ in width. Often placed high in the sky for Northern Hemisphere observers, in good conditions it is among the most accessible galaxies to view.

Regardless of its outstanding attributes, NGC 891 does require a certain degree of viewing expertise and patience at the eyepiece. Some observers report missing seeing the galaxy entirely, although this is more likely an outcome of trying to view it in less than dark skies. However, because of its substantial size in the field of view, it appears perhaps dimmer than its stated magnitude suggests it should be, although at 10.6 it should not be expected to be among the brighter galaxies in the sky.

Once sighted and centered in the field of view, and with time to allow the eye to settle, it is possible to discern much fine detail in this exquisite sight. Most immediately apparent, even in fairly modest apertures, is the long dust belt, which completely dissects the galaxy into equal parts. However, it is fair to say that the *entire* length of this feature will only be seen with moderate to larger apertures, and only after beginning to take in the entire surroundings; indirect viewing helps, especially in initially sighting and centering the galaxy in the field of view.

The dust belt is widest and most prominently displayed near the galactic core, as would be expected, where it also parallels some of the region's more brightly illuminated knots. With yet more time at the eyepiece, more bright knots may be seen along the length of the belt, while the galaxy seems to be almost magically suspended in some strangely three-dimensional illusion, seemingly independent of its surroundings. Stereo viewing with binocular viewers only enhances this effect. In Fig. 6.4, the image of the entire galaxy, especially on the southern side of the dust belt, various traces of the bright mottling adjacent to it that are so prominent on well-known imagery may be detected; these bright patchy regions show in places as fine strands of light parallel to the dust belt. Such attributes exist to a lesser degree on the northern side, as can be better seen in Fig. 6.5b.

Detailed Hubble Telescope and other imagery have also revealed that the encircling dust belt features multiple spidery vertical extensions protruding into the body of the galaxy all along its length, although the underlying reasons for such ejections of dust at right angles to the belt itself are yet not determined. Because of its proximity, it is difficult to know how commonly such extensions may occur in more remote galaxies, where such fine detail is harder to resolve. Interestingly, even casual inspection of images of the dusty mantle surrounding the Milky Way shows that similar features are present in our own galaxy as well, adding more support to the hypothesis that the two galaxies may be near twins. Substantial traces of these very details, readily visible at the author's 18-in. telescope, in conjunction with an image intensifier eyepiece, look much as they do here.

A couple of the spidery dark vertical dust belt extensions in NGC 891 can actually be detected in the author's simple image, made improbably – as always – in seconds. They are easier to see when part of the image is enlarged, as in Fig. 6.5b. Although Fig. 6.5a and b show different parts of the galaxy (actually, the Hubble

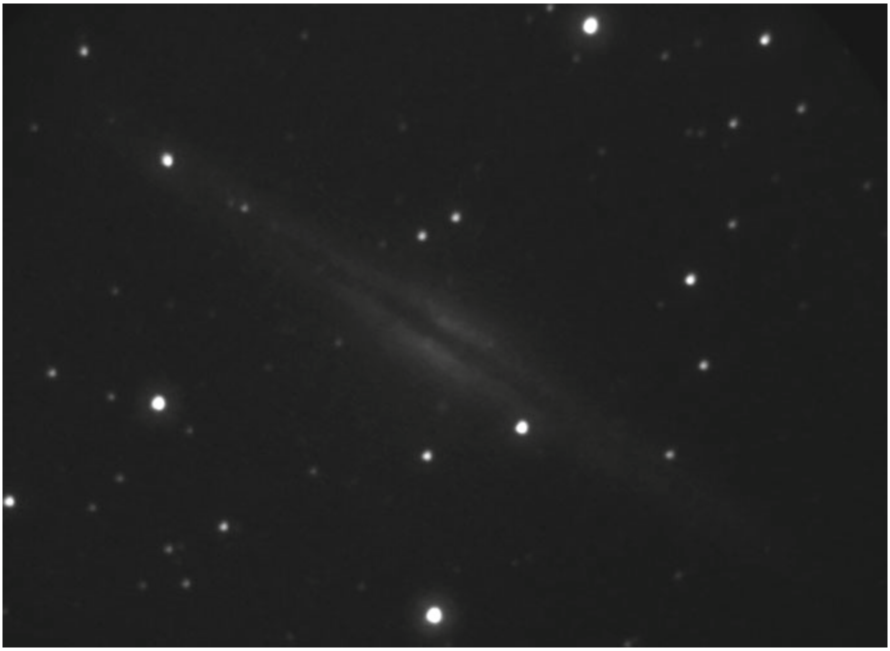

Fig. 6.4 NGC 891 (AC)

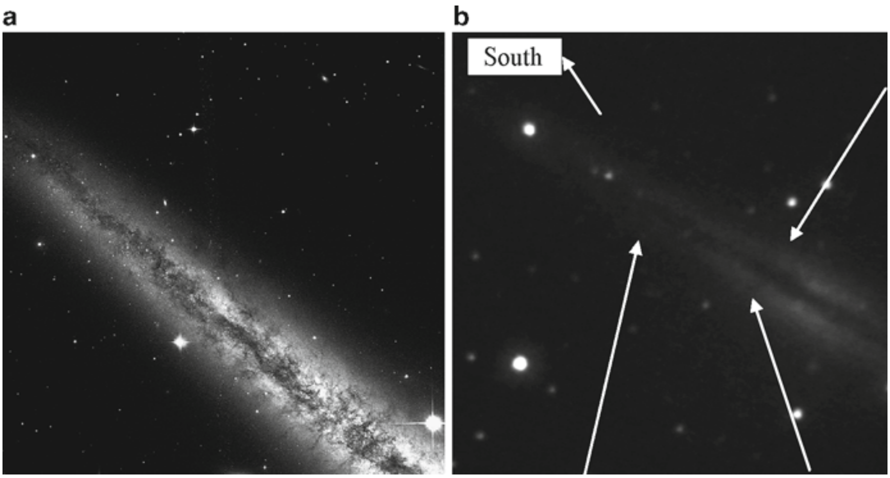

Fig. 6.5 (**a** and **b**) Courtesy NASA/STScl (AC)

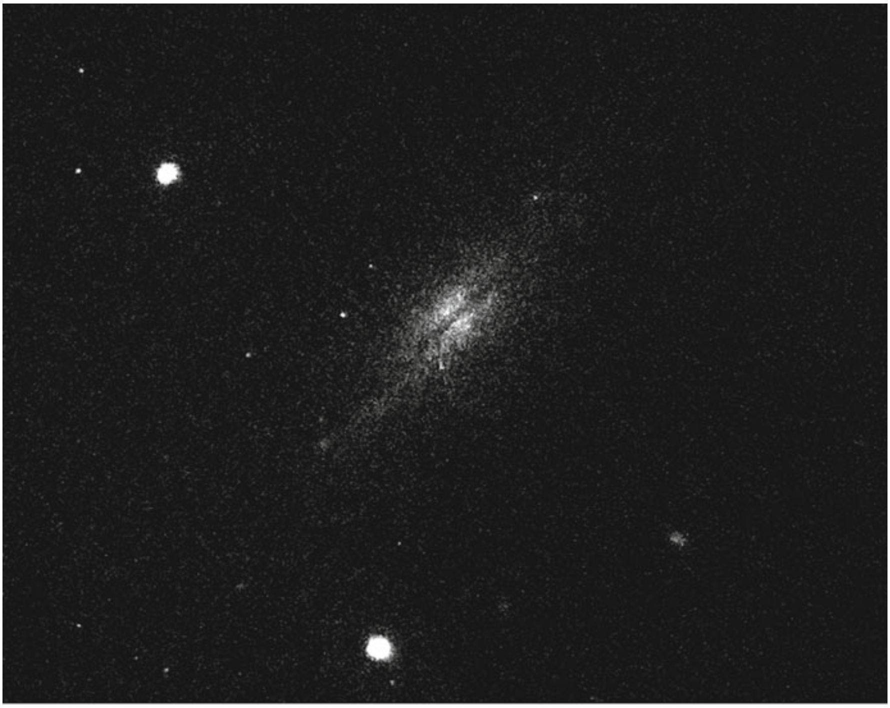

Fig. 6.6 NGC 5866 (AC)

Telescope image (b) is of the north side of the galaxy), the purpose is to illustrate the form that these extensions take, their appearance almost at right angles to the plane of the galaxy.

Those extensions just visible (indicated with arrows) in Fig. 6.5b are typical of all of those seen in this subject, along with a hint of the tangled nature of the belt itself. The Hubble image shows it interspersed with many unequal dark knots as well the bright knots well resolved along its length.

Given sufficient aperture and resolving power, CCD video cameras should also easily show the extensions, although viewing them with a conventional eyepiece may present a greater challenge. In general we can expect to find that galactic dust belts show a wide range of variation in character from galaxy to galaxy. But perhaps the greatest visual appeal of NGC 891 is that it is so eerily evocative of the depth and vastness of space.

NGC 5866

A small but stunning lenticular galaxy (at 4.4′ wide), and precisely edge-on, NGC 5866 in Draco is a fine sight in the field of view (Fig. 6.6). It is perhaps most well

Fig. 6.7 NGC 5866: Region nearest the core, showing the vertical dust belt extensions (image courtesy NASA, ESA and the Hubble Heritage Team (STScI/AURA))

known for its fine equatorial dust belt, something that is sometimes seen in such galaxies. Although its exact classification still remains slightly controversial, the appearance of the dust belt in the innermost part of the structure would seem to confirm that it is not a regular spiral. Interestingly, Hubble imagery also reveals vertical extensions to the dust belt, not dissimilar to those seen in NGC 891 (see Fig. 6.7).

M104: 'The Sombrero Galaxy'

Among near edge-on galaxies, we cannot forgo a closer look at M104, the 'Sombrero Galaxy' in Corvus, another prime observational example, and at 29 million light years surprisingly bright in the field of view, something that compensates to a large degree for its relative compactness (at approximately 8.5′ in width). As one of the greatest gems in the sky, it also has an impressive circumferential dust

Fig. 6.8 The Sombrero Galaxy (AC)

lane equal in visual impact to both of these prior examples. As an SA(s)a galaxy, it appears more as a gigantic dish with very little structure evident, but we could swear we can trace the very dark and wide, apparently unbroken dust belt all around the disc – an illusion, of course. In the image here we really can just make out some of its outline, as it wraps around the galaxy. Although unlikely to reveal any inner details to the live observer, it is nevertheless a visual feast second to none, its most striking attribute perhaps being the three-dimensional illusion of its circular shape in the field of view, almost looming out towards us from the dark background, like a huge chandelier, or maybe even…a sombrero hat! (Fig. 6.8).

The Sombrero is highly unusual in that little spiral structure is detectable, or perhaps even present. The fact that it is a late type spiral would not normally place it amongst the best viewing candidates, but it appears there is no trace of spiral arms to break up the extraordinarily prominent and unbroken dust belt all around its circumference. Presumably it is a form of ring galaxy, one where a lesser galaxy collided with the core of the larger, eliminating its spiral arms in the process. Such ringed forms are not unknown, and occasional unmistakable examples of such galaxies can be found in the local group. See Hoag's Object in Serpens (Fig. 6.9), a diminutive, extreme, though very clarifying example; perhaps it is not

Fig. 6.9 Hoag's Object (image courtesy NASA, Hubble Heritage Team, STScl/AURA)

too far out of line with the true form of the 'Sombrero.' In fact, recent infrared imagery from the Spitzer space telescope shows a remarkable resemblance to the very surrounding ring we see in Hoag's Object (Fig. 6.10). So, M104 may indeed be truly armless.

NGC 2683

A contrasting sight awaits us with another near edge-on galaxy, NGC2683 in Lynx, showing other variations of dark detail. It is an imposing and brilliant sight in telescopes of moderate and larger apertures, at around 9′ wide, fills a reasonable portion of the field of view. This SAb type is less than 30 million light years distant and is characterized by many fine complex, mottled, dark dusty lanes surrounding the centrally illuminated portion, although there is no clearly defined equatorial dust belt. However, at only 10.6 magnitude, in order to see any refinement of detail it does present the observer some challenge.

Fig 6.10 NGC 104 in infrared light (image courtesy HST/NASA/ESA)

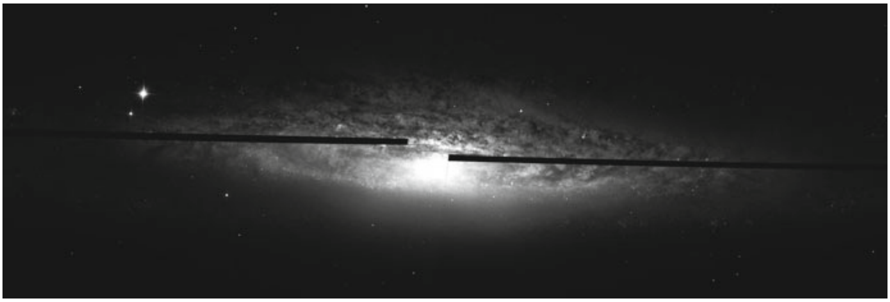

Fig. 6.11 NGC 2683 (Courtesy NASA/ESA. Hubble mosaic image)

At first glance, the mottled nature of the dust lanes gives the galaxy a slightly knotty appearance, due to the complexity and number of dark features wrapped all around the core. It is best to start by examining the outstanding Hubble Telescope mosaic image below (Fig. 6.11), where the galaxy's striking dark attributes are abundantly clear.

Remarkably, many of the visual attributes we can see so readily on the Hubble image are similarly visible or strongly suggested on the 'snapshot' on the following page (Fig. 6.12), a very typical view through the eyepiece of moderate-size scopes. Compare the two.

NGC 7331

Smaller (10′ wide) and less dramatic perhaps than those with extensive and obvious mottling, but exquisitely beautiful in the field of view, is NGC 7331 in Pegasus. It provides a view in line with expectations, as a partly edge-on SA(s)b galaxy lying at a distance of approximately 40 million light years, and shows a strikingly dark and dense dust belt to one side, along with clear though delicate evidence of spiral structure. The field of view to the western side is packed with more distant galaxies, three of which are revealed on this image intensifier snapshot, but unlikely to be glimpsed through the eyepiece as more than the faint traces indicated on the guide image.

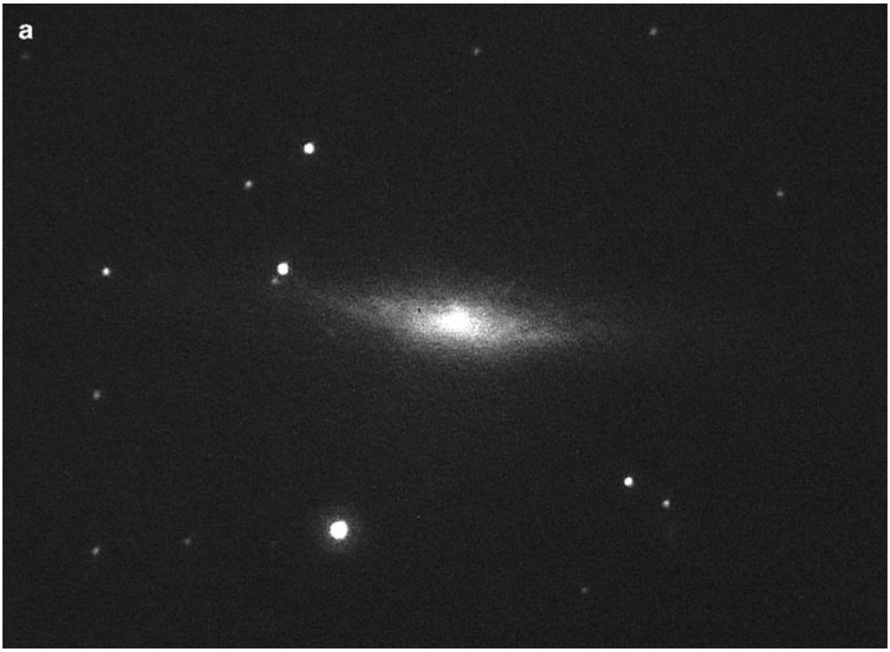

Fig. 6.12 NGC 2683 (**a**) (AC). (**b**) The following details in (b) are worth noting: (1) dusty and bright knotty regions surrounding the core are readily visible. (2) The ‘arc-like’ core region, with dark indentations on each side that is visible in many photographs, may be seen at the eyepiece once the observer is aware of its existence. (3) A ‘ghost’ of a distant galaxy (not numbered) shares the view, and may be glimpsed with image enhancing devices. (4) One of the more prominent dusty lanes that seems to take more a ringed form around the core. (5) The bright knot between lanes, visible on many observatory images. (6) This 14th magnitude star is positioned near the edge of the galactic halo. For easy orientation, another 13th Magnitude star and an adjacent fainter one on the fringe of the galaxy’s most illuminated portion serve as good reference points

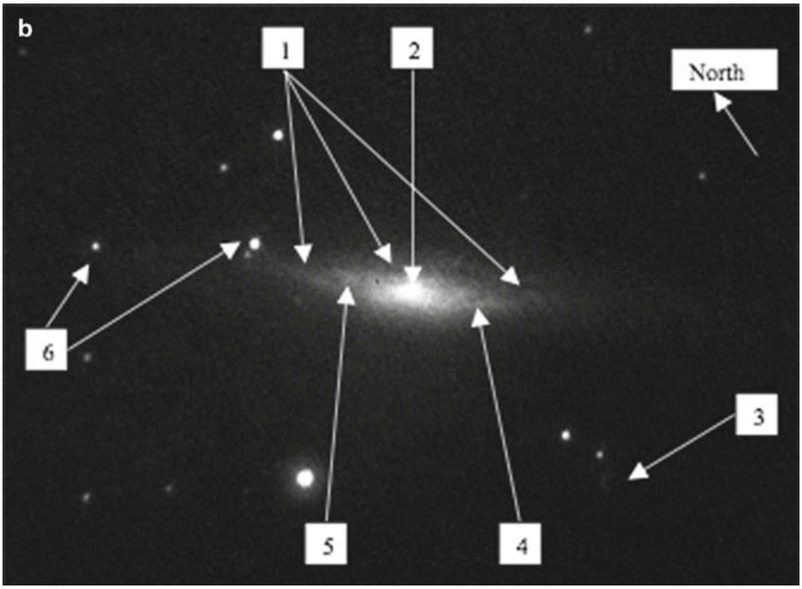

Fig. 6.12 (continued)

Face-on and Near Face-on Spirals Plus Starburst and Seyfert Galaxies

We will find that often a curious 'crossover' takes place between categories, where those galaxies likely to show most dark detail have their roots in more than one precise descriptive designation. It is hardly surprising that many of our best subjects turn out to have starburst or peculiar attributes, even if we do not necessarily list them in the category of their more prominent characteristics. This is never more evident than in examples that are at least partially edge-on, where such features are more likely to be apparent, but still with some of the attributes of fully edge-on examples (Fig. 6.13).

NGC 613

An interesting galaxy for a number of reasons is this multi-armed, almost face-on barred SABbc spiral, which would seem a good match to our expectations of visible detail. Led by its designation 'bc,' we would expect this type of galaxy to have prominent and wide spiral arms; certainly this is the case here, and the clear indications of star formation may be seen all along its length in the ESO image below (see

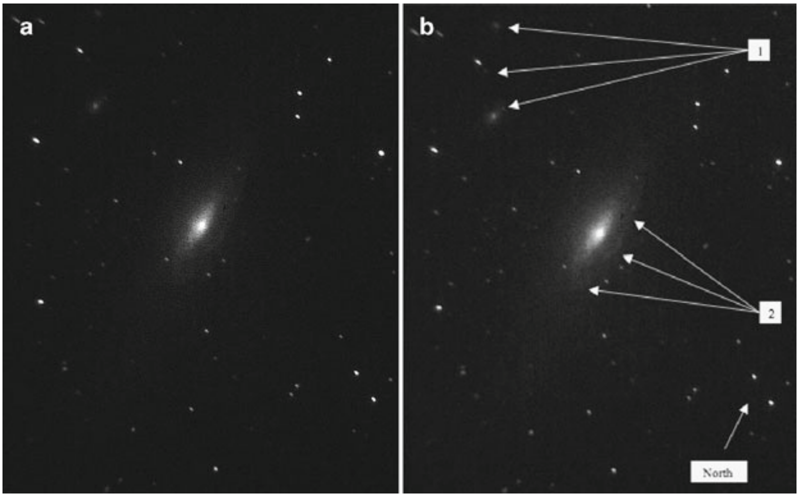

Fig. 6.13 NGC 7331 (**a**) (AC). (**b**) Indicated on the reference image are: (1) the faint smudges of distant galaxies appearing in the same field (the middle arrow refers to a faint smudge below the brighter star, not to the star!); further to the southwest are several more, too far to the left of this image to be snared in the field. (2) Prominent traces of fine, slightly mottled spiral arms encircles the prominent dust lane(s), which extends inward almost to the core. Other traces of spiral detail around the core are evident upon close examination, although we should not reasonably expect SA types to have thicker arms that those we see here

Fig. 6.14). The slightly side-on perspective exaggerates the galaxy's barred form. This image makes an easy comparison with what we are seeing at the eyepiece (a typical real time view at Fig. 6.15), and on this one can make out faint traces of nearly everything that is so clearly shown on the ESO image. Featuring dusty regions woven throughout its complex five-armed structure, it appears that dark interstellar matter bridges what would otherwise appear to be true gaps between the closely placed thick arms. Although fairly faint (10th magnitude) and small (5′ wide) in the field of view, the sight is exquisite to be sure, the galaxy's one prominently hooked arm jumping out at first glance, along with the barred form and dark detail between the arms, even along the bar itself (with a dusty trace along its central outline) if you are fortunate enough to have sufficient aperture and dark conditions at your disposal.

M64: 'The Black Eye Galaxy'

Originally presumed to be a conventional SAab spiral with a large, broad dust belt, it turns out that the 'Black Eye Galaxy' in Coma Berenices is a much more interesting galaxy than anyone had previously thought. Now generally believed to be the

Fig. 6.14 NGC 613 (image Courtesy ESO)

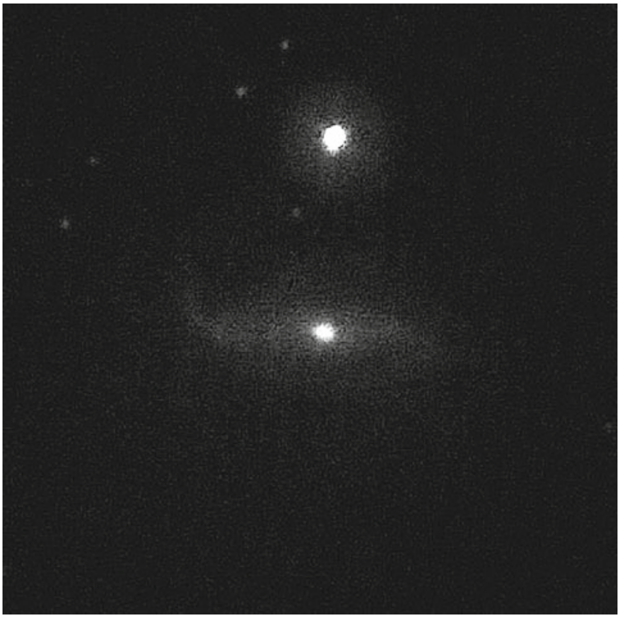

Fig. 6.15 NGC 613 (AC)

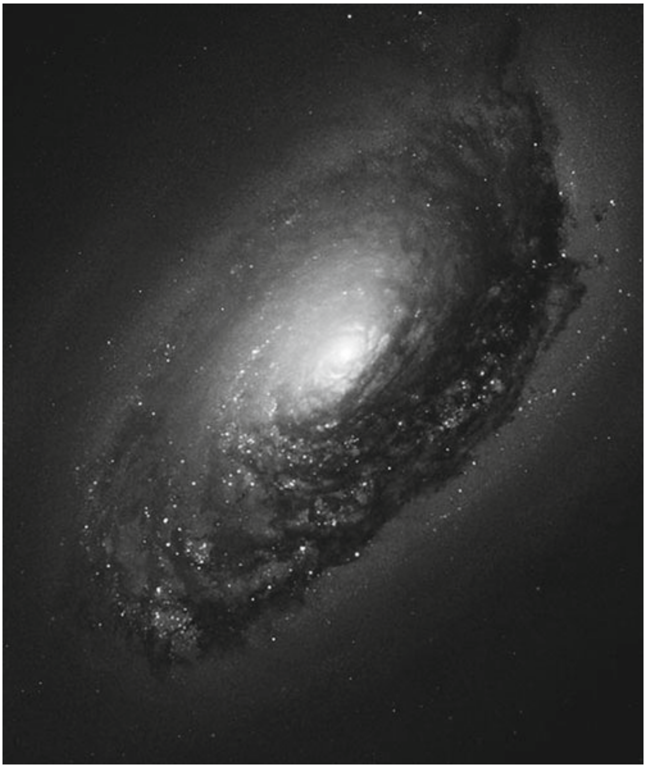

Fig. 6.16 M64, The 'Black Eye Galaxy' (image courtesy NASA and ESA)

result of a galactic collision and merger, it is much closer to peculiar or starburst status than previously thought, with vast regions of the belt experiencing starburst activity. Because this collision involved two galaxies of opposing orientations, the famous thick 'black eye' portion of the dust belt exposes much of what has been captured from the incoming galaxy, while the less visually interesting inner portion (the other galaxy) is rotating in the opposite direction! It is apparent that this has only increased the typical starburst effect within the zone closest to the opposing rotations.

The real time (image intensifier) images Figs. 6.17 and 6.18 are interesting on several counts. Fig 6.17 is more typical of the way the galaxy will appear in the eyepiece (certainly not representative of the full glory of the galaxy as shown in the NASA/ESA image in Fig. 6.16), and Fig. 6.18, made on another occasion, is less so, although many of the most significant traits are perhaps better shown than in most typical conventional real time telescopic views, despite its overly grainy appearance. Do not expect to see a large galaxy in the eyepiece, as M64 is less than

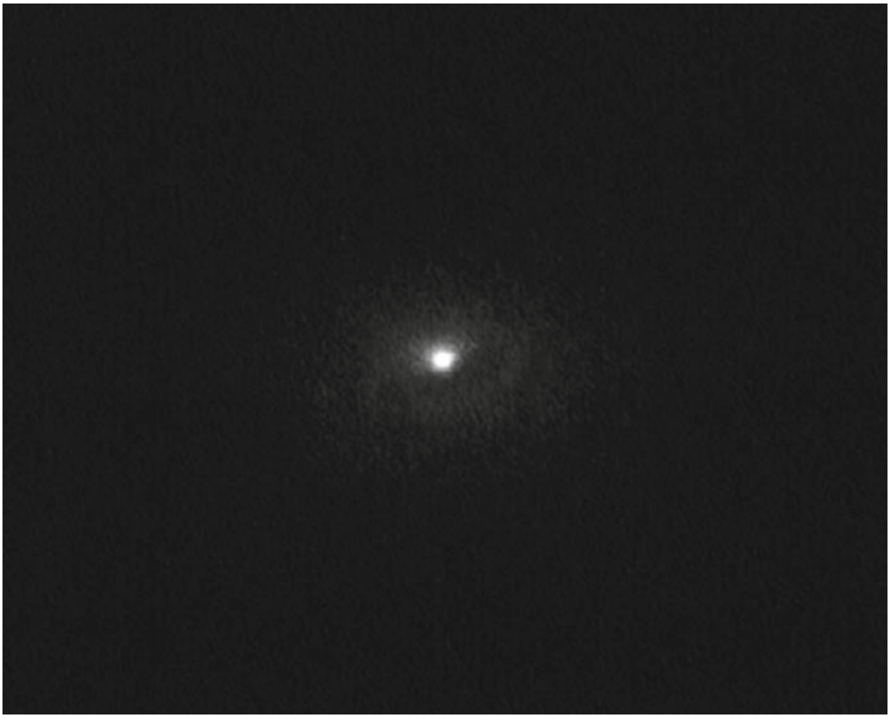

Fig. 6.17 M 64 (AC)

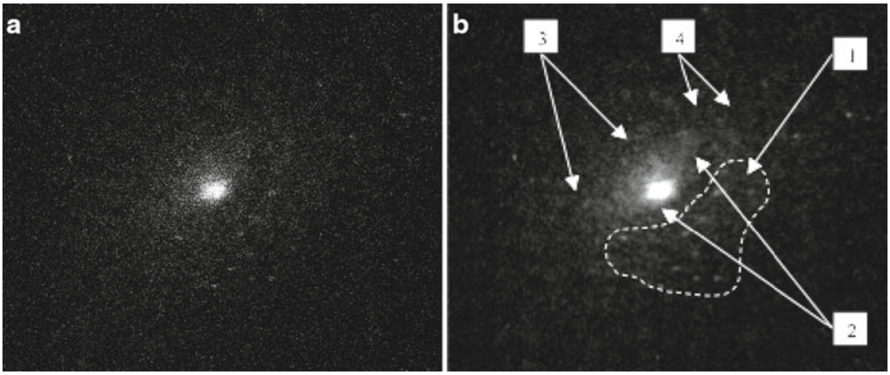

Fig. 6.18 M64 (**a**) (AC). (**b**) Notable features of the image in (b) are: (1) extensive starburst activity within the great dusty region, showing as bright spots. (2) The 'black eye' itself, amid the mottling. (3) Traces of the great dusty belt seen from the opposite side of the galaxy. (4) Faint evidence of the dusty arm peeling away from the 'black eye'

8′ wide; however, its brightness and well-contrasted extremely dark 'black eye' make it an easy target, obvious upon first glance.

In addition, many other traces of detail, clearly evident in the NASA/ESA image, may be seen in Fig. 6.18 with careful examination.

NGC 253

Another perennial favorite, among the finest galactic sights known to us, NGC253 in Sculptor is one of the most generous in showing tremendous amounts of dark detail readily (including many dark features). As an example of neither edge-on nor face-on, it is virtually without a peer. Categorized as a starburst barred spiral galaxy, type SAB(s)c, the galaxy is undergoing an immensely active period of star formation predominantly in the central core. Although past collision with another galaxy is not certain, this must surely remain probable based on its more recent past, despite the lack of obvious remnants of the other.

As it appears now, NGC 253 has arrived at a critical state, which will eventually play out to cause the galaxy to take on an entirely different appearance. (When our own Milky Way Galaxy eventually collides and merges with nearby Andromeda, M31, it will see a time of similar activity where star life cycles will play out at dizzying rates with dramatic and often highly explosive demises. Admittedly, this is many millions of years in the future.)

At around 12 million light years distant, NGC 253 is one of the closest galaxies, approximately three to four times as far as M31 but considerably more revealing in the eyepiece. Almost any view through any telescope will provide a dramatic sight of this huge, astoundingly detailed galaxy, and larger apertures will make fine spiral and dark detail become really obvious, along with all manner of twists and kinked lanes. And dramatic the view is. Visually, the galaxy is simply colossal, usually spilling out far beyond the confines of the field of view even at low powers (30′ wide). It is also remarkably bright, at 8th magnitude, and one does not need to strain to make out the many legions of detail. Two main spiral arms immediately can be traced all around the galactic core, and many dust lanes and knotty regions jump out at first glance, perhaps in greater abundance than with any other galaxy we can find in the sky.

Trying to make sense of the image and the angle it is presented to us also eventually leads the eye to a host of additional features. These include the central bar and the encircling form of luminous matter around the core, comprising part of the two primary arms before they sweep outwards. When viewed with just a little more magnification, the central region reveals increasing amounts of detail. We readily see much dark, dusty and knotty detail on either side of the core, and particularly within the main galactic halo. Towards the core there is a marked resemblance to fluffy Earthlike clouds, and these zigzagging kinks seem to be unique among our (local group) galactic viewing experiences.

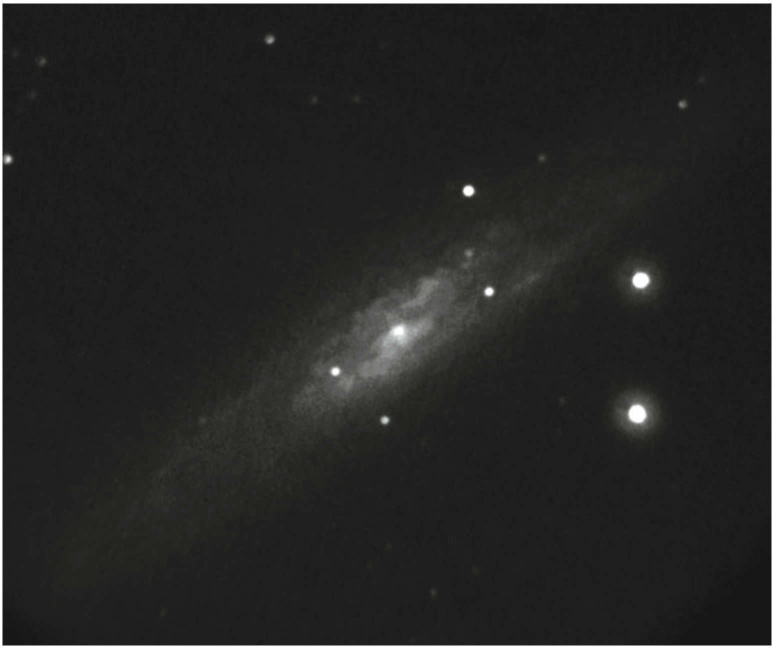

Fig. 6.19 NGC 253 (AC)

NGC 1097

The grand barred spiral NGC 1097 in Fornax is another interesting study. Categorized perhaps confusingly as an SBbSy1 type galaxy, it is a good example not only of a barred galaxy with the potential for visible detail but is also a Seyfert galaxy, which means that it has a dazzlingly bright core region with strongly ionized gases and a supermassive central black hole. At a distance of approximately 45 million light years, it is only moderately placed among the observer's best galactic spectacles, and in the eyepiece its 10.2 magnitude seems to be less; the apparent size is not an especially favorable 9′ either, although the central core is obvious at first sight. Nevertheless, it is satisfying to observe from many locations, surprisingly even in light-polluted surroundings, and there is much to see with a little patience. There is so much more to this galaxy than merely the "bright disc" usually described by amateur observers, but it does take decent apertures and outstandingly dark conditions to pry some of its more subtle secrets from it. Some of these are the dark spaces and details we are looking for, which become quite easily identifiable with just a little effort (Fig. 6.20).

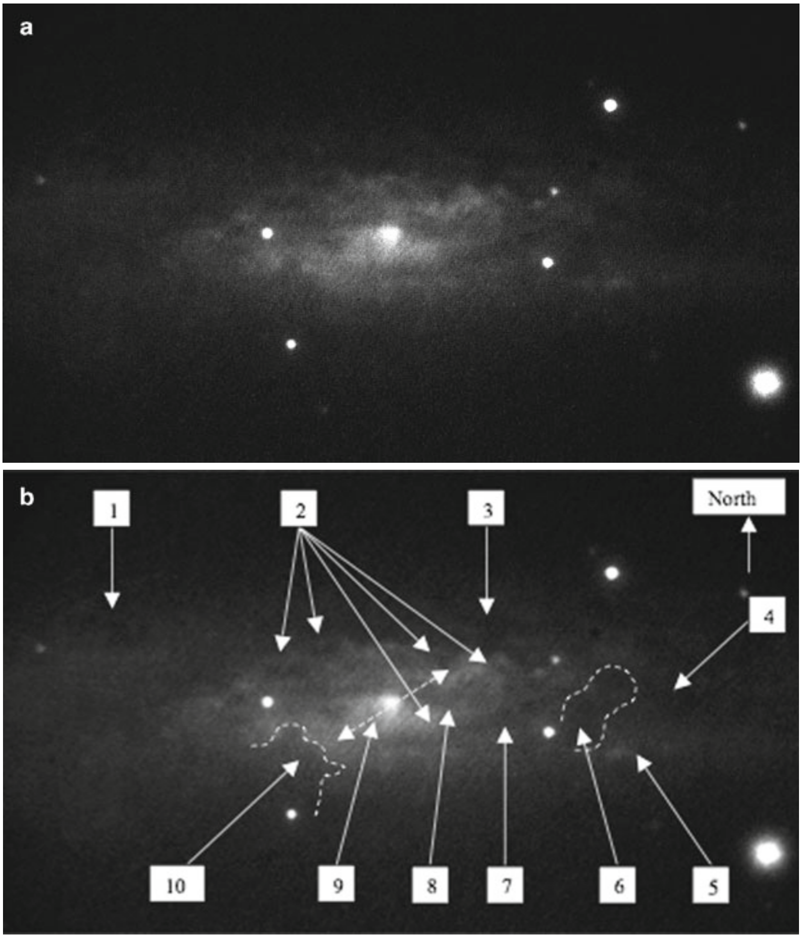

Fig. 6.20 NGC 253 central portion (**a**) (AC). (**b**) (1) The outlying dusty region is well shown, intermingled with the northern arm. (2) Multiple dusty spots and mottling are readily visible, all part of the encircling shroud of the arms adjacent to the bar, and before they sweep out from the galaxy. (3) Dark, many-pronged recesses and notches are well resolved. (4) A dark outlying region within one of the spiral arms is well seen. (5) The southern arm; extensive mottling is evident throughout the region. (6) One of the two spiral arms is easy to spot, although it is quite narrow. (7) This is the much-celebrated dark lane, now only one of many notable dark features. (8) A dark region around the core that seems to show that dust is placed throughout the thin disc of the galaxy. (9) Look very carefully: here are traces of the central bar itself. It is not obvious; one just has to know that it is there. However, with just a little patience, its presence – angled, among patchy mottling that makes it easy to miss – will reveal itself unmistakably. This is especially so at lower powers (see again Fig. 6.19), where the suggestion of greater linear luminosity shows itself in the direction marked. Try 'squinting' at the image here, and you will more than likely be able to detect it readily. (10) This is another well-defined dark region, part of the southern spiral arm, and much larger than most, it appears to be dark detail at the end of the central bar as the arm begins to separate away from it

Fig. 6.21 NGC 1097 (image: Courtesy ESO)

Let us first examine what may be seen of this galaxy at the eyepiece of moderate to large amateur telescopes. Figures 6.21 and 6.22a–c should lead you to some of its more significant and observable attributes. Under truly dark skies, the two arms of the spiral form can just be detected (although one needs to look very carefully), along with the barred shape of the galaxy. Looking further, beyond the brilliantly illuminated central core, traces of dark lanes and regions between the arms seem evident. Although these are not as dark as the surrounding void of space, this demonstrates well the dilemma of whether interstellar matter can exist in these regions, as well as how much of the matter of a galaxy remains barely illuminated. There are also subtle areas of brightness other than within the twin arms themselves, hot dusty regions that show relatively well under image intensification, or even CCD video cameras. All in all, when one is aware of what is actually there to see, and despite the challenges that come with this subject, this galaxy will gradually yield some of its secrets.

Figure 6.21, courtesy European Southern Observatory (ESO), makes clear all we are discussing, albeit in much brighter, more defined and exquisite form than we will ever be able to see. Interaction with the small elliptical companion galaxy, NGC1097A, causes the spiral arm that intercepts it to become distorted, although this will probably be impossible to observe directly. The brilliant central region (which contains a gargantuan black hole at its core), appearing as a bright 'bulls-eye,' may actually be glimpsed this way at the eyepiece (see Fig. 6.22c), even under poor conditions. This author has even seen this particular feature easily from heavily light-polluted suburbs.

a

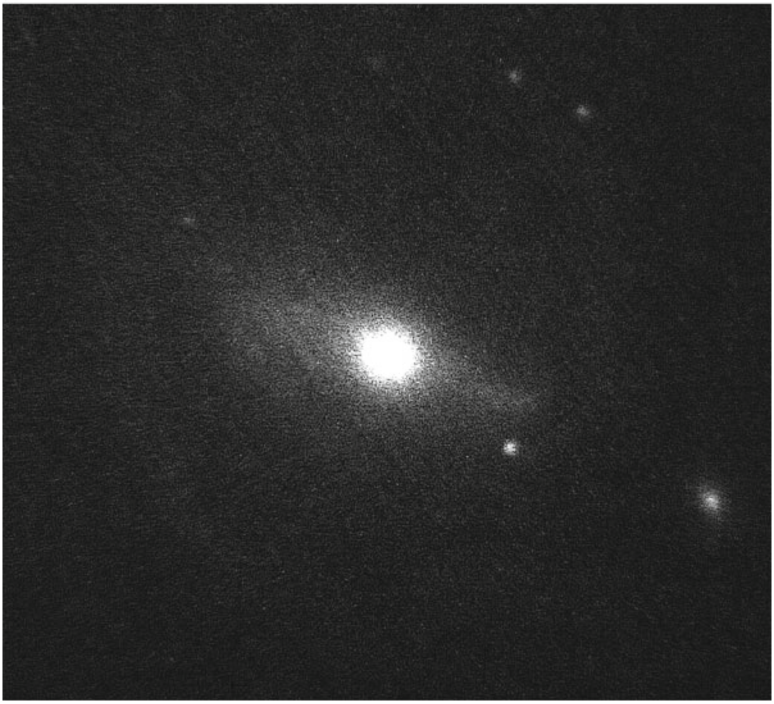

Fig. 6.22 NGC1079 (**a**) (AC). (**b**) (1) The curved upturned end of the bar can be seen in this image. It should be possible for some observers to view this at the eyepiece. (2) The small dark region between the bar and one of the arms stands out against a brighter background and is one of darkest regions in this galaxy. (3) The void between the dwarf galaxy NGC1097A and the two arms just shows here. (4) The dwarf elliptical galaxy companion NGC1097A. (5) The distorted brighter region being pulled from one of the spiral arms may just be seen with some care and patience. (6) Here is another portion of the dark region between one of the arms and the central bar (see [2]), in this case appearing like a notch in the structure. (7) The large dark near-void between the main hub and one of the arms is not too difficult to detect; while tenuous compared to the arms, we can see on the ESO image that it is not entirely dark, with some stars creating a luminous veil throughout the galactic disc. (8) The bulls-eye effect of the core is easy to see under most circumstances with keen eyes. It is actually a manifestation of an extremely dense region of stars surrounding a supermassive black hole – one of the largest on view so close to home. (9) In this close-up of the central core region, note the bright knot of light on the western side that is also quite prominent in the ESO image. (**c**) AC: Detail of core, shorter exposure (compare to ESO image))

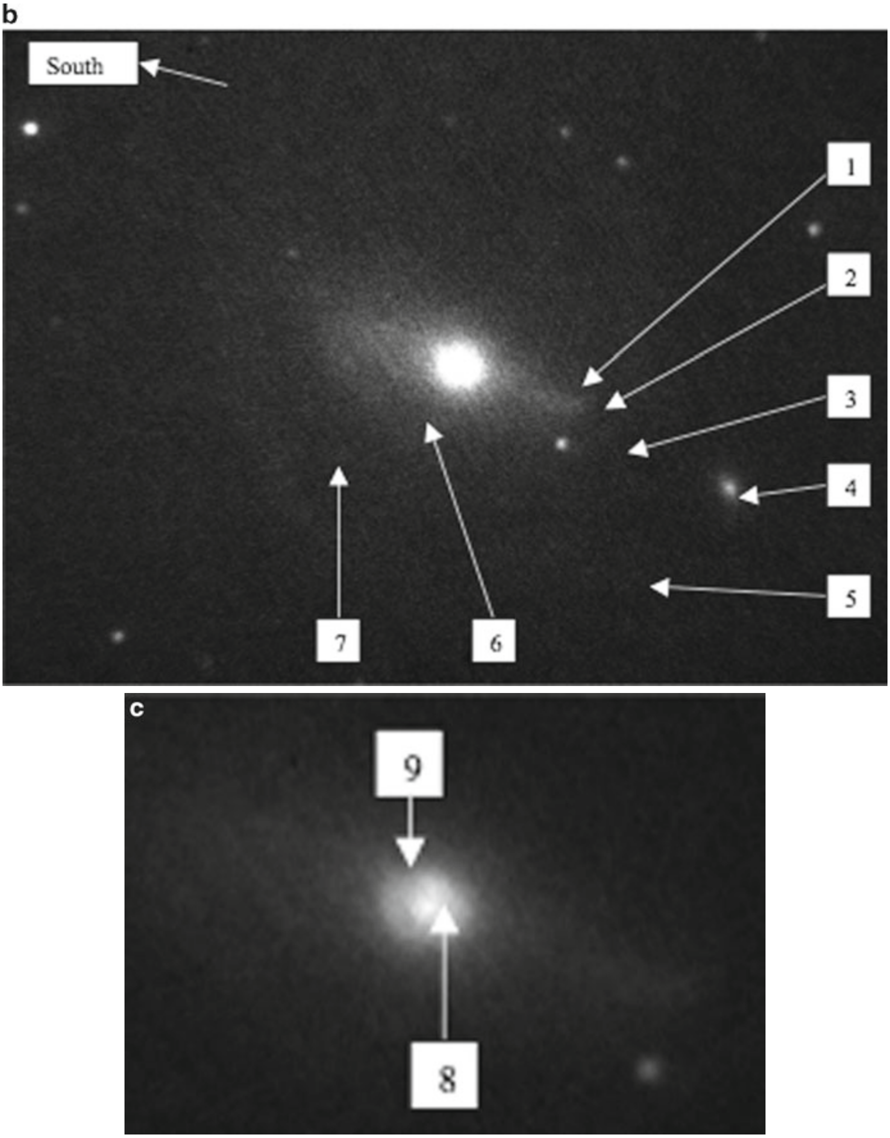

Fig. 6.22 (continued)

NGC 1068 (M77)

NGC 1068, also known as M77, is an enormous SA(rs)bSy Seyfert galaxy around 170,000 light years across and approximately 60 million light years distant. It is moderately well placed for observations, although not large in the field of view (8′). However, the core region is bright and finely detailed.

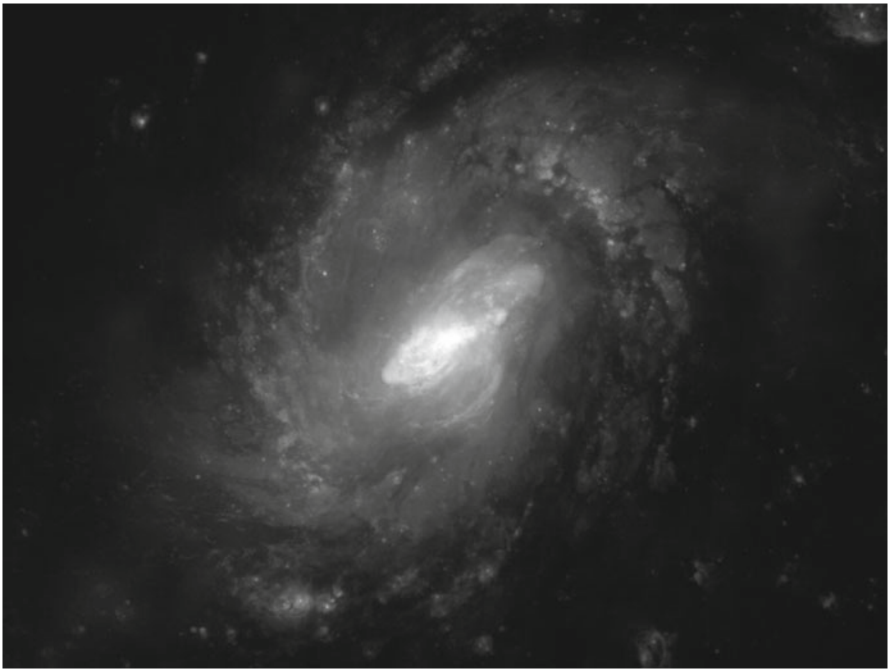

Fig. 6.23 NGC 1068 (M77) (image: X-ray NASA/CXC/MIT/C. (Canizares, D. Evans et al.), Optical (NASA/STScl), Radio (NSF/NRAO/VLA))

NGC 1068 rewards the observer readily at the eyepiece with a brilliant form showing some mottled spiral structure and a prominent dark notch, the product of large amounts of star-making gases and dust spewing rapidly from the core, so characteristic of Seyfert galaxies. It is estimated that at its heart, and the source of its intense X-ray, infrared, and ultraviolet activity, is a supermassive black hole of approximately ten million solar masses.

A second dark intrusion becomes soon apparent, just outside the first, representing an even larger quantity of dusty matter. As with NGC 1097, we see a 'bulls eye' effect at the core of this galaxy, for all the same reasons. With care, in the live view, we can see much of what is apparent on time exposures: a prominent central region, indicative of its Seyfert status, barred structure, some mottled spiral detail throughout the halo and especially near the central region, the dark and dusty matter apparently between the arms, as well as the fainter but very present galactic halo in striking contrast to the highly active central region. The remarkable composite NASA image (Fig. 6.23) and the numbered features in the real time image (Fig. 6.24b) will hopefully make the descriptions of the dominant features clear.

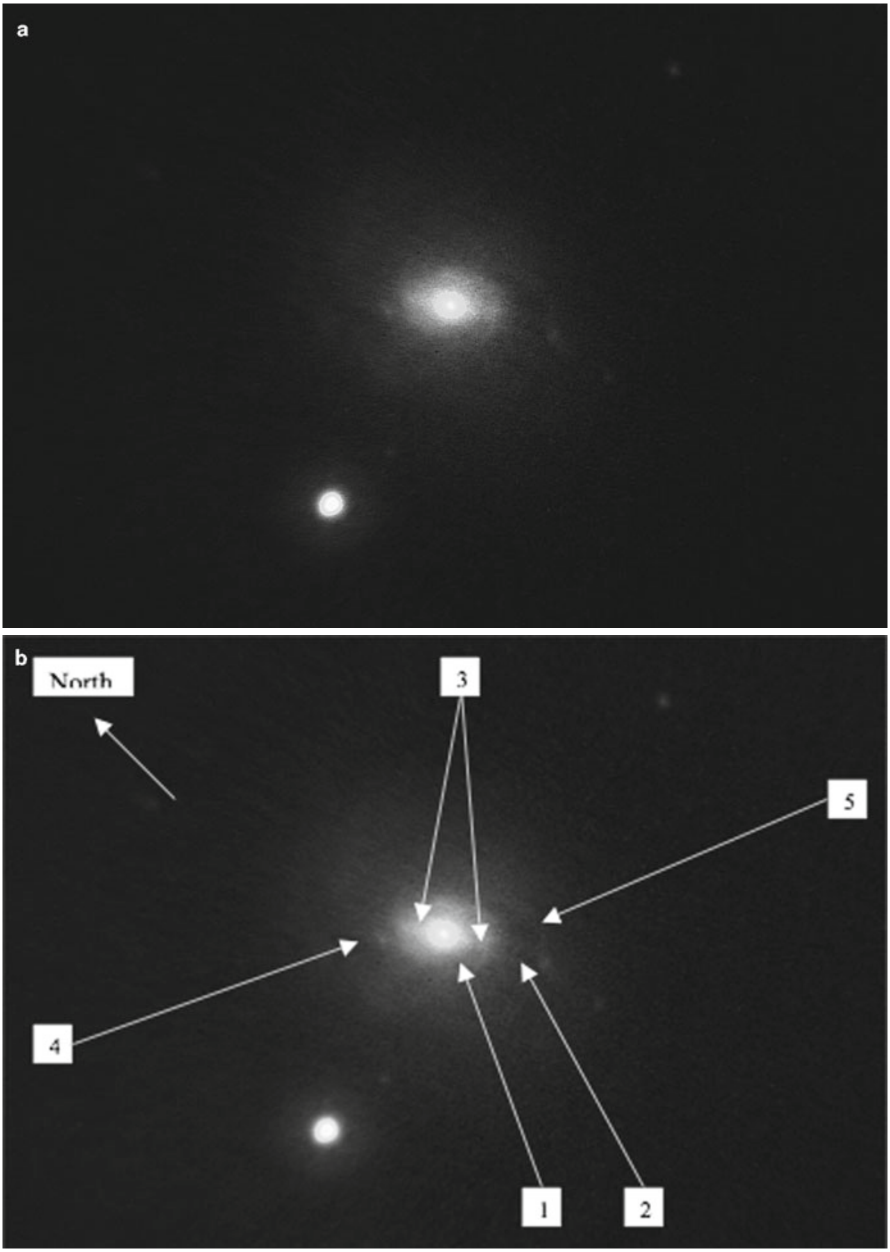

Fig. 6.24 NGC 1068 (M77) (**a**) (AC). (**b**) (1) The referenced prominent dusty notch, immediately visible in the eyepiece view. (2) The second visible dusty notch, much larger than the [**1**] but less prominent in the eyepiece. (3) The barred structure is clearly visible. (4) One of the mottled parts of one spiral arm, which shows prominently on observatory images. (5) The most easily seen spiral arm, with a bright knot at its extreme part

For most deep space observers, galaxies probably hold the most potential; certainly they represent the ultimate quest for telescope users, lying in the far reaches of space, always meriting whatever time we are able to spend with them.

Suggested List of Readily Observable Galaxies with Dark Lanes/Belts or Other Interesting Dark Features

This list represents a cross section of worthwhile galaxies to observe, all featuring dark features of some kind. Not in any way intended as complete, it is nevertheless a comprehensive listing of some of the most prominent and observable examples, with appropriate observing information for each item. It is presumed the reader will pursue further galaxies to observe, armed with the awareness of features this selection has provided.

Precise magnitudes and dimensions are greatly subjective and may be perceived differently according to many variables. Additionally, ongoing research has resulted in many galaxies being re-designated. The author is also aware of inconsistencies between many of his own estimates and those of others, and thus, this catalog has been revised to be more in accordance with the prevailing estimates of a wide range of many contemporary observers. As a result, the various designations – always overall averages rather than exact numbers – are more in line with those found in *The Night Sky Observer's Guide* (Kepple & Sanner; Willmann-Bell, Inc.) than *Burnham's Celestial Guide* (Robert Burnham; Dover). However, this should not be taken to imply any less reverence for Burnham and especially the unique insights that he provided; Burnham's very comprehensive system was built on solid perceptions, scientific evidence and logic.

Each object is listed with, where applicable or available, its **catalog number** first (NGC or other), object **type**, **magnitude,** angular **size**, **coordinates**, the **constellation** in which it can be found, and a short **description** of interesting features. Towards the end of the listing, the formerly infamous 'Zone of Avoidance' is unmistakably clear to see; the gap in listed galaxies is noticeable between NGC 5907 and 7331.

Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 224 (M31)	SAb	3.5	180′ x 70′	00427n4116	Andromeda	The nearest major galaxy; extremely large and bright but dark lanes and detail not immediately obvious
apod.nasa.gov/apod/ap021021.html					*Considering how elusive the lanes are in this nearby galaxy, this is perhaps the most revealing image. Although many images of this grand and nearby galaxy are available, surprisingly few reveal much of the delicate detail throughout its structure with any degree of clarity*	
*						
NGC 134	SAbc	10.5	8.5′ × 2′	00304s3315	Sculptor	Impressive; near edge-on with prominent dust lane; NGC 131 (small galaxy SB) nearby to the west
http://www.eso.org/gallery/v/ESOPIA/Galaxies/phot-49-07.tif.html					*Visually, this galaxy appears quite similar to M31 but with considerably more obvious dark detail. This is a stunning image, with exceptional resolution of detail, including the complex dusty regions and lanes, without ruinous overexposure*	
*						
NGC 253	SABc near edge-on	8.0	30′ × 6′	00476s2517	Sculptor	Spectacular large starburst galaxy; thick with many dark features and details; spiral form easily visible
apod.nasa.gov/apod/ap060421.html					*Although not the crispest image, there is a lot of dark detail visible in this image, especially of that vertical to the galaxy plane*	
http://www.ipac.caltech.edu/2mass/gallery/ngc253atlas.jpg					*This image, taken in infrared, shows well the barred structure of the galaxy*	

(continued)

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
*						
NGC 598 (M33) 'Pinwheel' Galaxy'	SAcd face-on	6.5	65′ × 40′	01339n3039	Triangulum	Large; hint of spiral structure even from poor locations; dark features throughout; bright nebula NGC 604 visible in spiral arm
http://seds.org/MESSIER/Jpg/m33.jpg					*A fine image, showing dark lanes clearly*	
http://en.wikipedia.org/wiki/File:M33HunterWilson09.jpg					*The dustiest regions among other dark lanes show best in this image*	
*						
NGC 613	SABbc	10	5′ × 2.5′	01343s2925	Sculptor	Large. Core; small spiral arms
http://apod.nasa.gov/apod/ap040213.html					*Probably the most beautiful image*	
http://nedwww.ipac.caltech.edu/level5/Lynds/NGC613.html					*A study of dark lanes in negative B/W*	
http://commons.wikimedia.org/wiki/File:NGC613-hst-R814G606B450.jpg					*Hubble image of core detail, especially of dusty regions and lanes*	
*						
NGC 628 (M74)	SAc face-on	10	10′ × 10′	01367n1547	Pisces	Spiral arms, bright knots and dark details visible.
http://www.spacetelescope.org/images/screen/heic0719a.jpg					*Highly revealing Hubble image*	
http://seds.org/messier/JpgSm/m74.jpg					*Perhaps more immediate value to the amateur observer, with clear delineation of primary observable dark lanes*	
*						
NGC 891	SAb edge-on	10	13′ × 3′	02226n4221	Andromeda	Full-width equatorial dust belt; wonderful object; fainter version of NGC 4565
http://www.yale.edu/ycaa/ngc891_wiyn_big.gif					*The best overall image, with the attributes discussed in this chapter well shown*	
*						
NGC 1055	Sb Edge-on	10.5	7′ × 3′	02411s0026	Cetus	Prominent dark belt
http://www.nasaimages.org/luna/servlet/detail/NVA2~4~4~6201~106727:NGC-1055-and-M77					*The best resolved image; enlarge to show thick dust belt*	

*						
NGC 1068 (M77)	SAB	9	8′ × 7′	02427s0001	Cetus	Bright, with some dark lanes; faint spiral structure
http://commons.wikimedia.org/wiki/File:NGC1068-hst-R658GB814.jpg					*Perhaps the most telling image out of many. Most overexpose the central region, the only part amateurs are likely to see*	
*						
NGC 1097	SBbc	9	9′ × 5.5′	02463s3016	Fornax	Some dark detail in bar and spiral structure; striking ringed core
http://www.eso.org/gallery/v/ESOPIA/Galaxies/phot-35d-04-fullres.jpg.html http://apod.nasa.gov/apod/ap090727.html					*Image used in chapter* *Astounding false color infrared image, showing subtle structure discussed in chapter with unique clarity*	
*						
NGC 1232	SABc face-on	10.5	7′ × 6′	03098s2035	Eridanus	Mottling, some dark detail and spiral structure. Small spiral companion NGC 1232A nearby, appearing almost as does NGC 5195 with M51
http://www.eso.org/public/images/eso9845d/					*Perhaps the most useful image, with dark lanes and details better shown than in others*	
*						
NGC 1365	SBb face-on	9.75	8′ × 5.5′	03336s3608	Fornax	Striking barred spiral with ringed core; faint dust lanes along bar. New research indicates it may be a close twin to the Milky Way
http://apod.nasa.gov/apod/image/9906/ngc1365_vlt_big.jpg http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/34/image/d					*Detailed image with dark lanes well shown* *Closeup of core region, with extensive dusty regions well shown*	

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
*						
NGC 1566	SABbc face-on Seyfert galaxy	10.25	8′ × 6′	0420s5450	Dorado	Striking spiral with many lanes between arms and branches
http://www.aao.gov.au/images/captions/aat054.html					*Good image with dark lanes clear*	
http://sscws1.ipac.caltech.edu/Imagegallery/image.php?image_name=sig05-013					*Infrared image showing dusty regions between arms to good effect*	
*						
NGC 1792	Sc	10.75	5′ × 2′	05052s3759	Columba	Starburst spiral; enhanced viewing may reveal many fine dust lanes heated to infrared wavelengths
http://www.eso.org/gallery/v/ESOPIA/Galaxies/phot-33b-03-fullres.jpg.html					*A relatively difficult object, though full of fine dust lanes. Good imagery hard to find without overexposure*	
*						
Large Magellanic Cloud: undesignated dwarf galaxy	Irr. Possibly barred galaxy remnant	1	6°	05200s6900	Dorado	Contains many objects: see Burnham. Probably remnant of small barred galaxy in tidal interaction with the Milky Way. Bar still visible
http://ails.arc.nasa.gov/Images/Astrobiology/AC87-0459.html					*Possibly best of generally unrevealing imagery. Dark detail is present but hard to resolve at the eyepiece*	
*						
NGC 2403	SABcd face-on	9	25′ × 11′	07369n6536	Camelopardalis	Spiral structure; dark lanes around core
http://server1.wikisky.org/?img_source=IMG_904716:all&ra=7.618333&de=65.7&zoom=9&show_box=1&box_ra=7.618333&box_de=65.7&box_width=50&box_height=50					*Probably the best of generally unrevealing imagery*	
*						

NGC 2683	SAb	10	9′ × 2.5′	08527n3325	Lynx	Almost edge-on; dust lanes between arms close to core
http://upload.wikimedia.org/wikipedia/commons/8/8f/NGC_2683_Hubble_mosaic.jpg					*Very detailed image with many dark lanes clearly shown for plotting view at the telescope*	
*						
NGC 2903	SABbc near face-on	9.5	12′ × 6′	09322n2130	Leo	Elongated; mottled, dark lanes and details
http://apod.nasa.gov/apod/image/0707/ngc2903_gabany_lg.jpg					*Live viewing will only show the central, main part of the galaxy, but this clear image will help the observer make sense of the dark lanes and details that can be seen*	
*						
NGC 2964	SABbc	11.5	3′ × 2′	09429n3151	Leo	Some mottling and dark details
http://nedwww.ipac.caltech.edu/img6/1994CAG2..B…0000S/NGC2964b:I:IIIaJ+GG385:s1994.jpg					*Perhaps the most revealing image (negative B/W), showing dusty lanes between arms better than majority*	
*						
NGC 3031 (M81)	SAab	7	24′ × 13′	09556n6904	Ursa Major	One of the most beautiful spirals in the sky; fine faint spiral structure very difficult in real time; darkest lane to west
http://physics.uwyo.edu/~eschlawin/low_res_galaxies/ngc3031.jpg					*B/W Spitzer telescope image that shows structure better than most*	
*						
NGC 3034 (M82)	IO Irr. (prob. Distorted Spiral)	8	12′ × 6′	09558n6941	Ursa Major	Amazing sight; early starburst galaxy; many dark lanes of matter shooting from core 90° to axis
http://www.daviddarling.info/encyclopedia/M/M82.html					*Extremely useful Hubble image; completes the eyepiece view*	
*						

(continued)

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 3184	SABbc face-on	10.5	8′ × 7′	10183n4125	Ursa Major	Subtle arms, knots and dark regions
http://www.noao.edu/outreach/aop/observers/n3184westphal.jpg					*Potentially valuable image for observers because of difficulty in discerning dark detail*	
*						
NGC 3190	SAa	11	4′ × 1.5′	10181n2150	Leo	Edge-on, prominent tiny dust lane
http://www.eso.org/gallery/v/ESOPIA/Galaxies/phot-17-06-w1.jpg.html					*Clearest image showing twisted structure/dust lanes well*	
*						
NGC 3351 (M95)	SBb	10	12′ × 6′	10440n1142	Leo	Bright core; dark zones on each side
http://www.astr.ua.edu/gifimages/m95r.gif http://www.aao.gov.au/images/captions/aat097.html					*The B/W image (1st.) is a fairly close representation of how we will see the galaxy at the eyepiece, although the 2nd. image explains better what it is that we are seeing*	
*						
NGC 3521	SA	10	6′ × 4′	11058n000	Leo	Bright nucleus; dark lane(s) on W side
http://www.saratogaskies.com/image.pl?i=7					*Not the grandest image, but for our purposes, the most revealing*	
*						
NGC 3556 (M108)	SBc	10.75	8′ × 2	11115n5540	Ursa Major	Irr. dust lanes; mottled; bright bar; near ‘Owl’ Nebula
http://observing.skyhound.com/archives/apr/M_108.html					*Most helpful of many less than ideal images; B/W*	
*						
NGC 3623 (M65)	SABa near edge-on	10	9′ × 2′	11189n1305	Leo	Mottled; dark belt on W side; other dark detail
https://seds.org/messier/Jpg/m65.jpg					*The familiar dust belt reaching out, and its concentric form is well shown on this image*	
*						

NGC 3627 (M66)	SABb	9	8′ × 3′	11202n1259	Leo	Magnificent. Uneven appearance, dark regions, especially W; spiral detail
http://seds.org/messier/JpgSm/m66.jpg					*A most useful image; while not the most pleasing it shows a refined resolution of the typical form we are likely to make out at the eyepiece*	
*						
NGC 3628	Sb Pec. Edge-on	10	12′ × 4′	11203n1336	Leo	With M65 and 66. Fine sight; prominent dust belt
http://apod.nasa.gov/apod/image/0504/ngc3628_croman_full.jpg						*Very useful image in revealing better what we see at the eyepiece*
*						
NGC 4013	Sb Edge-on	12	4′ × 1′	11585n4357	Ursa major	Tiny; dust lane resolvable in moderate apertures
*						
NGC 4038–39 *'The Ringtail Galaxy'*	SB Pec. IB Pec.	11 combined	5′ × 4′ 5′ × 2.5′	12019s1852	Corvus	Two colliding galaxies with multiple dark details, patches and bright knots; faint 'antennae' trail from each
http://www.universetoday.com/wp-content/uploads/2005-0530ngc4038-full.jpg					*Good guide image, although live views will not reveal nearly this kind of detail*	
*						
NGC 4157	SABb edge-on	11.5	7′ × 1′	12111n5029	Ursa Major	Full-length dust belt with subtle details
http://www.astrophotos.net/pages/GALAXIES/NGC%204157.htm					*The best of limited imagery*	
*						
NGC 4192 (M98)	SABab edge-on	11	8.′ × 2′	12138n1454	Coma Berenices	Irr. appearance due to orientation, but really a two-armed barred spiral with dark regions
http://martingermano.com/M98.htm					*Perhaps the best available image (B/W); dark features well shown*	

(continued)

(continued)

Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
*						
NGC 4216	SABb edge-on	11	7′ × 1′	12159n1309	Virgo	Thin with two other edge-on galaxies in field; fine dust belt to E; near center of Virgo Galaxy Cluster
http://astrophoton.com/NGC4216.htm					*Very refined image with dust lanes well shown*	
*						
NGC 4217	Sb edge-on	12	4′ × 1′	12158n4706	Canes Venatici	Small in field, with faint dust belt; nearby M106. High magnification needed
http://www.caelumobservatory.com/obs/n4217.html					*Dust belt well shown*	
*						
NGC 4244	Sb edge-on	10.75	13′ × 1′	12175n3749	Canes Venatici	Mottled streak; fine central dust belt; hard to detect visually
http://www.noao.edu/outreach/aop/observers/n4244oneills.jpg					*Perhaps the most revealing image*	
*						
NGC 4254 (M99)	Sac face-on	10	4.5′ × 4′	12188n1425	Coma Berenices	Short prominent arms; dark region between core and S arm
http://seds.org/Messier/Jpg/m99.jpg					*Perhaps the best guide image (B/W); while not the most detailed, the dark features (notchlike) show clearly*	
*						
NGC 4258 (M106)	SABbc	9	19.5′ × 8′	12190n4718	Canes Venatici	Striking spiral; short thick angled arms; dusty regions around core. A very satisfying galaxy to observ.
http://www.deepfield.at/gallery/messier_106_23.html					*Good image, showing structure and dark lanes*	
*						

NGC 4303 (M61)	SABc face-on	10	6′ × 5.5′	12219n0428	Virgo	Bright, mottled, straight arms; dusty regions; bar visible
http://www.noao.edu/image_gallery/html/im0781.html					*An image that reveals conspicuously the crooked arm on the west side that so characterizes the galaxy, as well as clearly delineated dark regions on each side of the core between the arms*	
*						
NGC 4321 (M100)	SABbc face-on	10.5	5.2′ × 5′	12229n1547	Coma Berenices	Mottled, giving appearance of detached arms; less clearly defined dark regions
http://www.eso.org/gallery/v/ESOPIA/Galaxies/phot-08a-06.tif.html					*Best captures dark lanes*	
*						
NGC 4236	SABb	10	21′ × 8′	12167n6928	Draco	Very mottled; patchy; some dark regions between arms
http://www.lostvalleyobservatory.com/imagelib/sitebuilder/misc/show_image.html?linkedwidth=actual&linkpath=http://www.lostvalleyobservatory.com/sitebuildercontent/sitebuilderpictures/ngc4236.llrgb.veryfinal6.July.9.2008.kbq.jpg&target=tlx_new					*Impressive image; seeing dark detail will be a challenge*	
*						
NGC 4402	Sb edge-on	12	3′ × 1′	12261n1307	Virgo	Fine equatorial dust belt; a prime example of a galaxy becoming distorted into unrecognizable form by ‘ram pressure stripping’
http://www.spacetelescope.org/images/screen/heic0911c.jpg					*Quote ESA website: "Some telltale signs of ram pressure stripping such as the curved, or convex, appearance of the disc of gas and dust, a result of the forces exerted by the heated gas. Light being emitted by the disc backlights the swirling dust that is being swept out by the gas"*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 4449	Irr.	10.5	4.2′ × 3′	12282n4406	Canes Venatici	Starburst small satellite galaxy. Fine sight; uneven, mottled, with dark feature near core. Compares to LMC (but smaller); appears to have remains of bar and spiral arms
http://apod.nasa.gov/apod/image/0707/ngc4449_hst.jpg					*Outstanding Hubble image*	
*						
NGC 4490 'Cocoon Galaxy' with NGC 4485	SBcd pec. Irr. or E	10 12.5	5′ × 2′ 1.3′ × 0.7′	12306n4138	Canes Venatici	NGC 4485 interacting galaxy. Dark lane on N side; pulled by smaller adjoining NGC 4485 into a pear shape; mottled detail. So called 'Cocoon' because both distorted galaxies are immersed in star- forming HII gas
http://www.lostvalleyobservatory.com/page24halrgbngc4490/					*Dark detail prominent*	
*						
NGC 4501 (M88)	SAb	10.5	5.7′ × 2.5′	12320n1425	Coma Berenices	Dark and bright knots
http://www.skyfactory.org/deepskycatalogue/NGC4501.html					*B/W image showing dark detail best*	
*						
NGC 4526	SAB O edge-on	10.5	7′ × 2.5′	12340n0742	Virgo	Between two 7 m. stars; dust belt faintly visible
http://imgsrc.hubblesite.org/hu/db/images/hs-1999-19-i-web.jpg					*Dust belt well shown*	
NGC 4559	SABc	10.5	10′ × 4′	12360n2758	Coma Berenices	Dark details including lane S of core
http://www.astrophotos.net/pages/GALAXIES/NGC%204559.htm					*The image best capable of showing dark lanes, although not the most detailed*	
*						

NGC 4565	SAb edge-on	10	14′ × 2′	12363n2559	Coma Berenices	Most famous edge-on galaxy, exceptional, prominent dust lane with mottling and other detail
http://www.delphes.net/messier/xtra/ngc/n4565.html					*Perhaps the image most revealing how the galaxy looks in the live view, but with greater contrast*	
*						
NGC 4569 (M90)	SABab	10	10′ × 3.5′	12368n1310	Virgo	Mottled detail and dark notches
http://www.zsolt-frei.net/Gcat_htm/Catalog/Jpeg/n4569_pg.jpg					*B/W Palomar image, but easily the most revealing of dark features*	
*						
NGC 4594 (M104) 'Sombrero Galaxy'	Sa/Sb near edge-on	8	8.5′ × 3.5′	12400 s1137	Virgo/Corvus	Astonishing; dark and prominent 'equatorial' belt gives illusion of being visible all around galaxy
http://www.spacetelescope.org/images/screen/opo0328a.jpg					*Nothing beats this Hubble image in any respect*	
*						
NGC 4631	SBc edge-on	9.75	14′ × 3′	12421n3232	Canes Venatici	Knots and mottling; dark details
http://skycenter.arizona.edu/gallery/n4631ms.jpg					*Dusty regions well shown without overexposure*	
*						
NGC 4656/4657	Irr. edge-on colliding galaxies	11	13′ × 2′	12440n3210	Canes Venatici	Near NGC 4631 bar/curved ends
http://www.obsessiontelescopes.com/gallery/18_large/18_Johannes_ngc4656.jpg					*B/W image shows details well*	
*						
NGC 4725	SABb	10.5	9′ × 7′	12504n2530	Coma Berenices	Curious 'sparkly' circular-appearing arms; some dark spaces
http://www.noao.edu/outreach/aop/observers/n4725blocks.jpg					*Cleanest and best image for dark detail between arms*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 4826 (M64) 'Black Eye Galaxy'	SAab	8.5	7.5′ × 3.5′	12567n2141	Coma Berenices	Structure visible; large. 'Black eye' is a broad dust lane on N side, resulting from galaxies merging; traces of spiral detail
http://hubblesite.org/gallery/album/galaxy/pr2004004a/					*Classic Hubble image – dust belt well resolved*	
*						
NGC 5128 Centaurus 'A'	SO pec.	7.5	31′ × 23′	13255s4301	Centaurus	Amazing sight. Round; mottled detail; prominent dark features; dark central band easily visible; result of galactic collision
http://www.capella-observatory.com/ImageHTMLs/Galaxies/NGC5128.htm					*With many images available, some more spectacular, this image is perhaps most useful observationally*	
*						
NGC 5055 (M63) 'The Sunflower Galaxy'	Sbc	8.5	10′ × 6′	13158n4202	Canes Venatici	Striking dark lane(s) to S side, with speckling along spiral arms
http://apod.nasa.gov/apod/image/0804/M63LRGB_hallas.jpg					*Stunning image, with features clearly shown*	
*						
NGC 5194 (M51) 'Whirlpool Galaxy'	SAbc pec. face-on	9	8′ × 6.5′	13299n4712	Canes Venatici	Spectacular; visually bridging to NGC 5195–9.6 m. Galaxy Pec. Spiral structure very apparent, much mottled detail; dark patches and lanes throughout
http://www.spacetelescope.org/images/screen/heic0506a.jpg http://seds.org/messier/JpgSm/m51.jpg					*It is not hard to find a good image of M51. However, for the purposes of plotting dark lanes well, the B/W image (2nd. listed here) is more useful*	
*						

NGC 5236 (M83)	SABc face-on	8	15′ × 13′	13370s2952	Hydra	Strong emission spectrum in nucleus; striking bar; dark lanes between unequal arms
http://www.maa.clell.de/Messier/Jpg/m83.jpg					*The best image for plotting dark lanes and dusty regions*	
*						
NGC 5457 (M101)	SABc face-on	9	22′ × 22′	14032n5421	Ursa major	Spiral structure detectable with low powers; dark details inc. lge. Feature S of core; mottled; knotty.
http://nedwww.ipac.caltech.edu/level5/Shapley_Ames/Figures/NGC5457.jpeg					*B/W image. Dark lanes show in reverse; fragmented nature of spiral arms clear, with dusty regions well shown*	
*						
NGC 5746	SAb edge-on	11	6.5′ × 0.8′	14444n0141	Virgo	Dust belt, bright condensations; not unlike NGC 4565
http://www.noao.edu/outreach/aop/observers/n5746bushey.jpg					*Shows prominent dust belt well, with mottling*	
*						
NGC 5866 (M102?)	SAO edge-on	11	4.4′ × 3′	15065n5546	Draco	Elongated with prominent very thin dust belt; exceptional and refined sight
http://zuserver2.star.ucl.ac.uk/~idh/apod/image/0606/ngc5866_hst_big.jpg					*Very useful Hubble image: shows true nature of dust belt clearly, full galactic halo, along with vertical extensions (as also seen in NGC 891)*	
*						
NGC 5907 'Splinter Galaxy'	Galaxy Sac edge-on	11	11′ × 1.5′	15159n5619	Draco	Needle shape, slightly twisted, with some mottling and dust obscuration possible with larger apertures; narrow dust belt
http://apod.nasa.gov/apod/image/0806/ngc5907_gabany_rcl.jpg					*Shows dust lane well, and recently discovered halo remnants of galactic encounter*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6744	SABbc face-on	10	18′ × 12′	19095s6351	Pavo	Magnificent spiral; lanes between arms; mottling, satellite galaxy visible
http://www.spiegelteam.de/ngc6744.htm					Reveals lanes effectively	
*						
NGC 7331	SAb	10.5	10′ × 4′	22371n3425	Pegasus	Magnificent; thick dust belt on one side; traces of spiral detail
http://www.noao.edu/outreach/aop/observers/n7331.html					*Dust lanes most visible and resolved in this image*	
*						
NGC 7479	SBb	11.5	4′ × 3′	23049n1219	Pegasus	Prominent bar; S-shaped curved arms; dark regions between arms; dark wisps; difficult object
http://www.astronomytoday.com/images/NGC-7479.jpg					*B/W image – dark lanes and details show best*	
*						
NGC 7814	SAab	11	5′ × 2′	00033n1609	Pegasus	Fine and prominent equatorial dust belt divides bright core like an arc
http://commons.wikimedia.org/wiki/File:NGC7814HunterWilson.jpg					*Resolves galaxy well, plus nature of dust belt, showing faint double banding*	

Chapter 7

Dark Regions in Planetary Nebulae

Perhaps planetary nebulae are the least likely deep space objects in which we might think to look for dark lanes or features. However, since these nebulae are the very places where interstellar matter is created, it would seem logical that we might find evidence of it within some of them. Indeed, some of these nebulae do provide fertile ground for the inquisitive observer.

Although many planetaries appear smooth, disc-like and uniform, this is not what we should assume is the state of all of them. A large proportion of these objects are anything but conventionally shaped, with an array of varied and sometimes surprising details, such as bright irregularities, streaks, blotches, and true dark features, albeit perhaps less obviously displayed than many dark features readily seen in other types of deep space object.

In the early days of the telescope the typical blue-green ringed form of many of these nebulae gave these apparent disc-like structures an eerily similar telescopic appearance to our own Solar System's two like-hued giant gaseous planets, Uranus and Neptune. This led to the name they are known by to this day, but planetary nebulae have, of course, nothing in common with planets other than the name. Before their identities were better known, the less conventionally shaped examples were often listed as double nebulae and not as planetaries at all. Herschel was baffled (or fooled?) more than a few times, and his NGC catalog entries can be seen to reflect what science could not solve during his day.

Given all the stars visible to the unaided eye, and knowing that most will go on to become planetary nebulae in their final days, one might be forgiven for asking if more of them should be readily visible in the skies, especially since they provide the raw materials for all ongoing stellar creation. Despite the seeming rarity of these objects, are they, in fact, actually scarce in number? One must not forget that these objects are, for the most part, quite small by astronomical standards, and not all of them are as brilliantly illuminated as some of the best-known examples. Thus, not

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too many of those that are a reasonable size in the eyepiece are available to us, and we will be limited to the closest, largest and brightest – in reality, this represents merely our local neighborhood in space. Of those capable of showing sufficient dark details to merit our attention, the list shrinks further. The smallest *observable* planetaries probably lie within 100 light years, and the largest examples perhaps within no more than 1,500 light years. That is not very far in galactic terms.

There are other reasons, too, for the apparent shortage of examples to study. Significantly, because the greatest concentration of potentially eligible stars lies within the galactic thin disc, unsurprisingly, a large percentage of those that might be close enough for us to see are hidden behind the dense dark nebulae of their predecessors' own making. So, in total, while it turns out that the ratio of planetaries to the stellar population is, indeed, what one would expect, one way or the other, most of them will not be readily visible to us. Actually, there are many thousands of planetary nebulae known within the Milky Way, quite the expected number on a cosmic timescale, although most fall outside the average observer's realm. We must bear in mind that on this same timescale, their rapid rise and decline also limits the number of them on view at any time. So while not unlimited in number, interesting examples are reasonably plentiful and sufficiently striking to justify the search.

Almost all of these phenomena are the product of old dying stars with insufficient mass (less than 9′suns') to become novae or supernovae, amounting to possibly as many as 90–95% of all Population I stars. The process of their formation begins when such stars become old, a time when nuclear fusion shuts down and they exhaust their core supplies of hydrogen. Helium 'ash' (the product of hydrogen fusion) now forms the core of the star.

During the time that hydrogen fusion is coming to an end, the outward pressure from the core diminishes and further compression begins to take place, as its temperature rises in consequence. Helium fusion (which creates oxygen and carbon as by-products) then takes over, either in a gradual process in the case of larger stars, or a more sudden event (a 'helium shell flash') in lesser ones. This, in turn, creates a series of pulsations as a result of the expansion, cooling, contraction, and reheating cycles taking place in the core. As this process accelerates in dying stars, the pulse-like cycles of growing internal winds push the outer envelope of the star outwards into the bloated dimensions of classic red giants, eventually to become supergiants. In the case of our own Solar System, when that time comes for our own sun, we can expect most of the orbits of the inner planets to be consumed by fire; while Earth may indeed be spared from being engulfed, ultimately such a reprieve is only one from direct ignition. It will nevertheless be superheated into extinction, and certainly no longer exist as the watery, solid and rocky entity we know today.

In all such dying stars, as each expands, the process results in a much larger surface area, which in turn cools it. (This is why red giants have much lower surface temperatures than that of stars in the prime of life.) For a brief time the core becomes stable, but with some fusion of hydrogen as well as some direct burning of helium in the outer shell, inevitable increases in temperature begin to resume, and the collapse resumes, due to lack of internal pressure.

Eventually this process causes the star to expand again at an accelerating rate but often is interrupted by periods of cooling because of the vast sizes it reaches; the overall structure, being unstable, is unable to keep up with its own pace of evolution. The fury and speed of the expanding gaseous shell can only be imagined, as it is anything but the gentle process it may appear to be. Hubble Space Telescope scientists have estimated that wind speeds of as much as 1,000 miles per second may be typical. This cycle of expansion and contraction produces further, much larger, pulsations in the structure, resulting in variations of pressure at the core that cause a large proportion of the star's matter to be ejected outside the star's normal confines. Thus the core of the star is slowly eroded, gradually reduced in mass, layer by layer. Eventually, after a few hundred million years, its helium spent in fusion, the star's inner core becomes increasingly compressed as it finally collapses, unable to sustain its bloated dimensions against its own internal gravity.

All fusion having ceased, now both helium and hydrogen burn freely in the outer red shell as it collapses inwards, causing further decline and instability. The star is in its death throes, its huge stellar shell now cooling and receding from its grand status as a supergiant. As it does so, the inwardly falling matter and instability of the structure cause further expansions and contractions, resulting in even more basic building-block elements and compounds of multiple forms of matter being shed in layers to create the colossal, often spherical forms typical of many we immediately recognize as planetary nebulae. Thus, as its matter is stripped away, the ultimate degradation of its former glorious self begins to takes place, producing the final visible stage we recognize as planetary nebulae. The increasingly superheated core (a super-hot 'white dwarf' star of immense density of only planet-sized proportions), in turn, heats and excites the electrons of the hydrogen (HII) gas component of the expanding shell into fluorescence, only to expose an even smaller and yet more superheated core. Temperatures may reach as much as a million degrees, and the illumination of expelled molecular hydrogen begins to take place via the irradiation of the central star.

Historically, the luminous gas component in many planetaries caused considerable controversy for much of the nineteenth century, because many planetary nebulae were seen to respond uniquely in spectroscopic analysis with the appearance of the 'forbidden lines' – those apparently impossible dark absorption lines crossing the spectral band, and which earlier astronomers had vainly sought to explain as being due to a new element ('nebulium'). Once the Periodic Table of the Elements had been established in 1869 and gradually expanded to take all possible elements into account, it became increasingly clear that such an element as nebulium could not exist, so other factors had to be responsible for the absorption lines.

Early in the twentieth century, the death knell finally sounded for nebulium, as it was conclusively shown once and for all that the mystery element actually did not, and could not possibly, exist at all, with the discovery of previously unknown molecular variants. It turned out that the lines were due, in fact, to the greater presence of electrons in extremely rarified (double ionized) OIII gas densities and the special behavior (and emission lines) resulting from those circumstances surrounding their occurrence. Such conclusions had to wait until physics had caught up with observational research.

Once such a white dwarf star has completed this cycle (sometimes in as little as 10,000 years), it will begin to shrink and fade into the lowly status of a cool white dwarf star. ('Cool' is a relative term, of course.) The total life expectancy of the illuminated nebula is likely to be no more than a few thousand years at most. However, despite being at the end of its life, with total extinction the inevitable destination, this tiny dwarf star has still quite a large number of years ahead of it, as no example is yet known of any disappearing from view. The universe is simply not yet old enough.

The remaining nebula has by now, of course, ceased to be visible, and much of it will be drawn back towards the central star; we should realize, therefore, with this time scale, perhaps most of the larger (and more distant) planetaries we can observe already no longer exist! However, in spite of the inevitable contraction, almost half the mass will have been ejected and returned to the surrounding space, freed from the diminished hold of the remaining dwarf star, to be eventually drawn away by gravitational pulls of other stars, finally to blend with other remnants of planetary nebulae in the twisted forms of present dark nebulae that stud the galactic disc – that great pool of interstellar matter waiting to be reborn as new stars. Thus, we see the full circle of star creation.

Because these nebulae contain many 'heavy' elements (astronomically speaking, 'metals'), we find planetary nebulae develop only from Population I stars. In contrast, the remaining elemental makeup of 'metal poor' stars, which belong to the Population II category, eliminates any potential for future star formation as they expire. There does not seem to be evidence of any return of reusable matter to the galaxy from these old Population II stellar survivors, in complete contrast to the combined processes of Population I star demise being responsible for most of the galaxy's future. The recycled interstellar matter unsurprisingly includes gaseous compounds of ionized hydrogen, carbon monoxide as well as various more exotic compounds of oxygen and nitrogen, 'ash' types of compound including rocky silicate, calcium and carbon based compounds, as well as many other traces of more rare elements remaining from supernovae explosions, everything, in fact, for new stars and ultimately perhaps for the formation of solid planets encircling them. Of all of these compounds, though, it is primarily the ionized hydrogen that makes all illuminated nebulae visible to us. For the creation of even more exotic and unstable elements, we must depend on the more spectacular cosmic events provided by supernovae. By the common appearance of such elements on Earth we can see that, while relatively far fewer in number, supernovae are fairly widespread throughout the active star-forming regions of the galaxy.

It is probably fair to say that all planetary nebulae will have manifested dark features at some point in their life spans, especially early on in their development, due to the very nature of the matter that makes up their being – comprising the same dusty matter of the greater dark nebulae themselves. Such details are quite transient in nature, though, since these nebulae have a remarkably short existence relative to their former lengthy existence as main sequence stars. When we see such features in these nebulae, it is shortly after they have been drawn away from the central star, yet to blend into the greater nebula shell. Any obscuring matter may form into clumps by the same processes of internal gravitational forces that we find in matter everywhere, with the effects of ever-increasing density continuing to trap more dusty matter.

Eventually, the radiant energy of the central star and resulting strong winds will cause features that started out dark to break up and reform, much of it becoming visible through infrared radiation and intense heat emitted by the central star. Unfortunately, at any given time there is not an overly generous supply of planetaries that show dark features. The gaseous luminescence that we see is, unsurprisingly, the result of the same radiation-energized molecular hydrogen (HII), and sometimes double ionized oxygen.

Some of the more famous examples of planetary nebulae clearly contain remnants of what were once dark features (even lanes) that we can see quite clearly. However, they no longer appear dark, ultimately having become homogenized into the overall structure, where they may appear now as bright patches or streams of luminous gas. The matter within them has already been heated into infrared luminescence, or sometimes takes other shapes, having been pulled and twisted by various internal forces. (The ‘Dumbbell Nebula,’ M27, comes to mind, with its bright patchy linear clumping, along with its other unique irregularities, such as the elusive, curious striations concentric with the outline. These may be the visible manifestations of the expansion and contraction cycles of matter being shed from the central star.)

There is, however, still one other type of star that may become a planetary nebula, although the final outcome is far from peaceful. Among the most super-massive and brightest, these are known as ‘Wolf-Rayet stars,’ typically being 20, 30 or even 40 times the mass of the Sun, and having strong emission lines representing several common heavy elements. The cores of these stars already far exceed the Chandrasekhar limit, of course, and so their life cycles are already predetermined. However, while relatively rare at any given time in our galaxy, they are sufficiently numerous to have been counted in the hundreds.

The scale of these stars will cause them to take different paths than other less massive, though still huge, stars (of <20 but more than 9 solar masses), but the additional mass of all such stars dictates their future. The fate of all such supermassive stars means that heavy elements created by their fusion reach the stars’ surfaces in such large quantities that much of the energy from the star becomes trapped. This sets up powerful resulting pressures, characterized by extremely powerful winds, while hydrogen-, helium-, carbon- and oxygen-abundant matter is ejected at a furious pace, briefly giving the star the appearance of a conventional planetary nebula, as well as the same typical strong accompanying emission lines.

As we find elsewhere in the galaxy, it is the radiant energy of the fiercely hot star that causes the HII (molecular hydrogen) to fluoresce. However, eventually, these nebulae generally do not have the graceful decline and relatively tranquil ending of conventional planetary nebulae, as the overweight central stars finally detonate as colossal supernovae – the way of all supermassive stars. Some galaxies are made up predominantly of Wolf-Rayet stars, and so their stability must always be in question. Many of these fall into the category of ‘starburst galaxies,’ although not all such galaxies have the same underlying reasons for such a designation. Regardless, in Wolf-Rayet dominant galaxies, the large proportion of these stars will consist of those far too massive to allow an orderly galactic structure to endure.

Examples of observable Wolf-Rayet stars undergoing planetary nebula transformations include NGC 1360 in Fornax, a large structure apparently awaiting its final sudden death. Relatively smooth appearing and fairly bright, its sizeable oval outline may surprise those unaware of this lesser known nebula, but it is largely devoid of features, let alone dark ones. Another is the better known but sometimes elusive 'Thor's Helmet,' NGC 2359, in Canis Major, which is dominant in the greenish wavelengths of double ionized oxygen. Also not yet quite at supernova stage, we are witnessing the processes leading up to it soon (on a galactic timetable, of course)! Other interactions with apparent dense interstellar matter have contributed further to the strained shape of this nebula, with strands of luminous matter pulled in every direction. Dark features we can see within this turmoil are more a matter of uneven material distribution than anything else, but still it is worthy of time and attention at the eyepiece. And of course, we cannot overlook the beautiful 'Crescent Nebula,' NGC 6888, in Cygnus, another Wolf-Rayet star on its way to an unpleasant end. Although appearing as a faint crescent in the live view with mottled subtleties, detailed imagery reveals it to be a classic shell of ionized hydrogen and oxygen surrounding its massive central star, full of illuminated ash and dust streaks (and consequently dark spaces in between), driven into myriads of irregular striations by violent stellar winds.

Incidentally, because the central stars of many, if not most, planetaries may be too faint to be seen readily, it remains a standard challenge (perhaps even the primary attraction?) of every observer of planetary nebulae to try to spot these frequently highly elusive and often tiny points of light. While the challenge of seeing the central stars of planetary nebulae is hardly the fare of this writing, who among us is able to resist the challenge as long as we are observing the nebula? Certainly this writer is never able to resist and has always been amazed at the remarkably telling results that can be obtained, once again, with image intensification. It is common for the central stars of planetary nebulae, usually considered as photographic subjects only, to be readily visible at the eyepiece of these devices. If we recall the favorable manner with which stellar points respond to such devices, it is hardly surprising they are such useful tools for this purpose. (See M57, the 'Ring Nebula,' later in this chapter.)

Unusual Shaped Planetary Nebulae

In the early stages of a star becoming a planetary nebula, what is frequently so readily observable is the form with which we are perhaps most familiar – that of a small ring with a central star. This is certainly how most casual observers might always expect such objects to appear in the field of view. Regardless, what we are seeing in all planetary nebulae is the effect of the dying central star causing powerful stellar winds to push dusty and gaseous matter (of its own creation) ever outwards. From our visual impressions alone, we might thus easily assume that most planetary nebulae take the form of a flat ring (in appearance like those of Saturn), or perhaps a sphere with a star at its heart. A little time at the eyepiece soon reveals that many objects listed as planetary nebulae do not even show this ring shape at all, let alone a sphere. Although the ringed form may be an only illusion relative to our angle of sight of an actual sphere of ejected matter, and while other planetary nebulae may indeed once have once had a ringed appearance, this is in all probability not an accurate description of most of them.

Nevertheless, it is reasonable to accept that many planetary nebulae do indeed take the form of large expanding bubbles, to put it in the simplest terms. Although we can readily identify the familiar ringed planetary nebulae (appearing as a roughly circular or oval form surrounding a central star), it is possible that some appearing this way do not have a spherical structure at all. Indeed, it may be that the generally accepted model of spherical form is less common than may be suspected. In this regard, we might consider how a cylinder would look seen from top to bottom: a ring – just as spherical examples appear. (However, it is also possible that some examples of this cylindrical form of planetary, from a lengthwise orientation, might simply disappear from visibility altogether, their substance being too tenuous to register.)

Some side-on examples, such as the 'Butterfly Nebula,' NGC 6302, are readily visible in amateur scopes as something resembling a bowtie with a 'pinched' waist. Although the 'Butterfly' reveals a complex structural form, that of a relatively bright central region with two similar 'loops' on each side, this is more than likely at least partly due to its near side-on perspective of a bipolar 'cylindrical' form, with a thin tapered waist in the middle at the 'home' of the central star. It is possible to see many traces of dark material being ejected from the core of this nebula, giving the nebula a two-sided mirror image effect, with multiple dark intrusions. The central dark 'lane' we see is real, and presumably is a disc-like ring of dusty matter being ejected from the central star – a clear example of what we know is taking place in many other planetary nebulae. Other examples of bipolar planetary nebulae may reveal similar structures and dark lanes dividing these nebulae into two segments. The reader may justifiably conclude that many (although not all) bipolar examples are merely identical to spherical 'ring' forms, seen from a 90° alternate perspective, as if we are looking down from on top. Indeed, we already have determined that a cylindrical structure would indeed look similar to a spherical one.

A very clear example of this effect – seen partially edge-on – may be seen on the Hubble Space Telescope image of the 'Hourglass Nebula,' MyCn18, in the constellation of Musca (below, Fig. 7.1). Although not a candidate for ready amateur viewing, it serves an instructive purpose here and helps us to understand what we may be seeing with many planetary nebulae.

Recent studies have shown that planetary nebulae come in a great variety of shapes and sizes, although the apparent 'ring' form and bipolar examples make up many of those we can see. Beyond this, it is a plausible explanation that many of

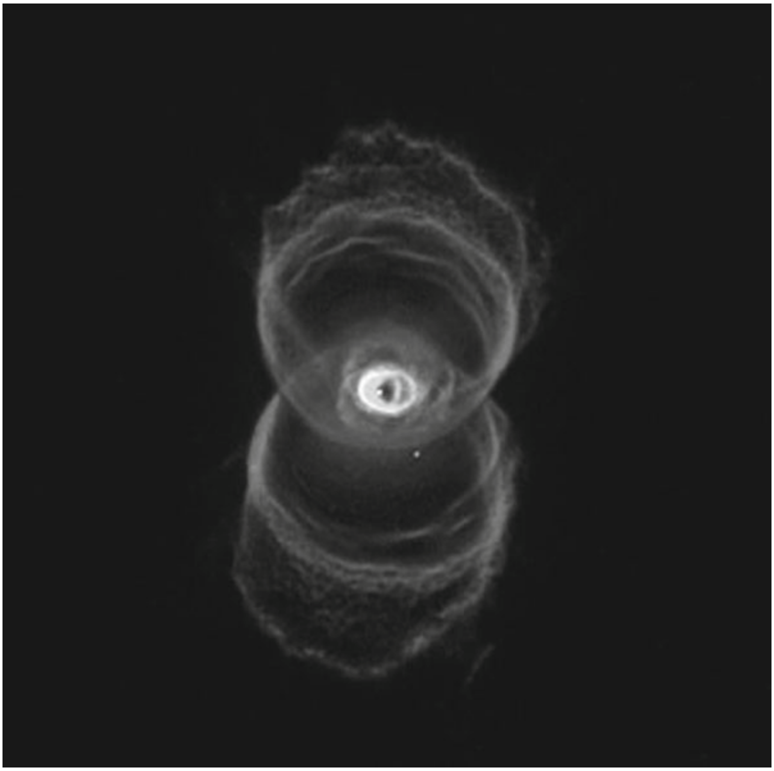

Fig. 7.1 The hourglass nebula, MyCn18 (image courtesy NASA/ESA, Raghvendra Sahai and John Trauger (JPL), and WFPC2 science team)

these different basic structures (spheres and cylinders) may, in fact, be the same thing, but seen from different perspectives. In cases where they do not fit this scenario, and where many planetaries show true bipolarity, it may be that multiple-star systems are the cause, the result of a companion star orbiting closely around the main star. This could provide just enough influence to pull matter away from the central star into an equatorial ‘disc,’ ultimately driven outwards in both directions by stellar winds away from the hot central star. However, just as likely an explanation could be different electromagnetic conditions in the expanding shells around varying sizes of stellar cores, or maybe even peculiar characteristics unique to certain stars. Yet this still does not explain all the differences we see in the appearance of all bipolar planetaries, whose irregular shapes may also be the result of solar systems of the host star, or even warped central stars.

The difficulty of finding an exact explanation for all aspects we might notice in planetary nebulae – especially bipolar varieties – underscores the complexity of these particular objects in general, where any number of possible contributing factors could have produced some of the specific characteristics we see. It seems possible that many bipolar examples may be merely younger nebulae in early stages of development, and if they are truly different to the more commonly recognized ringed form at this time, perhaps they will gradually assume that more familiar appearance. However, modern research has shown that at least some of the older 'bipolar' planetary nebulae were likely formed long ago by internal stellar winds and have survived the test of time.

Regardless, it has to be admitted that we still do not fully understand all aspects of the dynamics of planetary nebulae in general, and although many existing theories may be perfectly accurate, no one can be absolutely sure that what we know about the evolution of some applies to them all. Certainly the variety is considerable and the possible explanations even more so.

Observing Dark Features in Planetary Nebulae

Because dark features in themselves are the focus of this writing, any found within planetary nebulae, by default, become our primary focus; however, their relative rarity makes them something we cannot take for granted. Therefore, in this context, those that we can see may prove to be more interesting than the radiant portion of the spectacle itself.

Successful viewing of dark features in planetary nebulae also soon makes clear the limitations of our potential. Because these nebulae usually are too small for increasingly distant examples to reveal such features easily, we will be restricted to the closer better-known examples, by default. However, for the most part, even those dark features present within such nebulae have been given scant attention in most observers' descriptions, and they may have sometimes escaped notice altogether. In our favor, some of the closer examples are quite bright. However, the majority of these objects are typically quite small and dim, especially with live viewing. Thus, for seeing dark features and details, we always need to maximize our prospects for contrast, perhaps even more than with many other types of deep space object.

Narrowband filters help immeasurably with many of those planetary nebulae that exhibit vibrant emission components, and can throw those light frequencies into surprisingly striking contrast against any dark details that may be present, thus making them more immediately visible. Where illumination permits, high magnifications may be necessary, even preferable, in some cases to reveal detail, although in many other instances it makes little difference, or actually detracts from the view. Oddly, in other instances, the use of all filters or electronic enhancing devices may be unsuccessful, the view being best with simple direct eyepiece observations.

The study of the 'Eskimo Nebula,' NGC 2392, in Gemini (Fig. 7.2), actually a known bipolar planetary that looks like simple ringed form, demonstrates one such case in point – a planetary nebula that shows dark details readily and without any help at all, the view seeming to lose information with every attempt to enhance what we are seeing! The nebula is a favorite of many observers: here the dusty

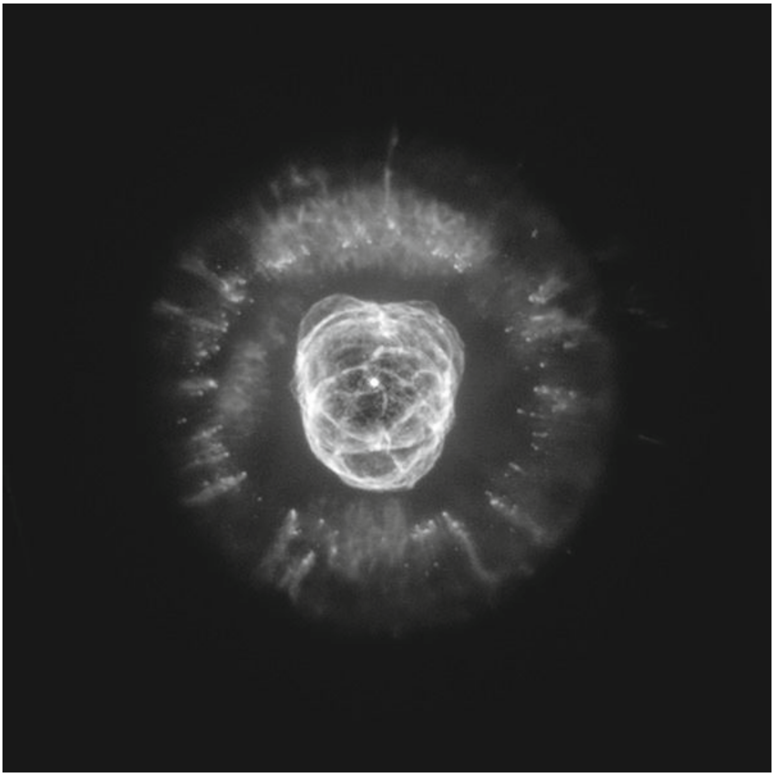

Fig 7.2 The 'Eskimo Nebula,' NGC 2392 (image courtesy NASA, ESA, Andrew Fruhter (STScl), and the ERO team (STScl + St-ECF))

ejected matter is being condensed into the bright ionized streaks (appearing much like the iris in a human eye) that may be questionable to see at the eyepiece, but which we see on detailed imagery, radiating away from the central star within the outer ring of this double ringed nebula. Fortunately just as striking are the dark inner region and voids that we can easily see for ourselves.

Unsurprisingly, because of the frequencies of light they are most responsive to, image intensifiers and, to a great extent, CCD video cameras are likely to be quite successful in revealing detail of all types in these objects, even at fairly low powers. Planetary nebulae emit strong energy in the red and infrared parts of the spectrum. Because this takes place through the excitation of ionized hydrogen that is plentiful within their makeup, it is hardly surprising that they respond so well to these electronic devices, while increasing the potential contrast. Dark details will be more likely to stand out against the illuminated portion of any subject, and they may often be significantly brightened in such enhanced views.

The phosphor screens of image intensifiers are also well suited to the excellent response of the dark adapted eye to green wavelengths, the resulting frequent brilliant characteristics of these nebulae providing a particularly good match. The brighter planetaries will usually allow surprisingly high magnifications, too, which will be helpful in resolving subtle dark features, lanes and other details. As always, experimentation is at least as pivotal here as in any other type of deep space object, but perhaps the potential range of results is even greater. And the potential for experimentation has never been greater, or the surprises more likely.

M57, 'The Ring Nebula'

Although dark features in planetary nebulae are the prime focus of this chapter, few of these are without observational challenge. When they do reveal dark features, faintness and small dimensions remain primary problems with most of them. Perhaps no more than blotchy regions within the overall structure, dark features sometimes do take the form of genuine lanes, although these are relatively rare for the visual astronomer. Inside the less luminous central portion of the celebrated Ring Nebula, M57, dark lanes have long been regularly sighted and imaged, although they might be considered more as details for imaging rather than candidates for live viewing. With good equipment and conditions, they may even be glimpsed occasionally at the eyepiece.

Although it is no surprise that images from the Hubble Space Telescope (Fig. 7.3) makes these lanes extremely clear, the author has seen them quite easily in real time with the use of an image intensifier eyepiece. This speaks volumes to the effectiveness of these devices (Fig. 7.4). Additionally, the infamous 16th magnitude central star (often reported to be invisible in telescopes as large as 60 in.!) is likely to be an easy mark with a Generation 3 or 4 image intensifier and only moderate apertures, even from the most unlikely suburban locations or in other light-polluted conditions.

The casual observer might speculate that the oval shape of M57 represents a flat structure, orientated slightly edge-on relative to our perspective. However, the distinctly circular central zone should be seen as the primary circular disc or sphere, while it seems logical that the outer regions could have taken a looser form as they are pushed outwards by stellar winds and by being further away from the influence of the central star. It would seem logical to suppose that their shape might reflect other influences also, internal or external.

However, there is no doubt that many central dwarf stars may be quite difficult to see at the eyepiece. In general, when trying to spot them when they are faint, indirect vision (looking to the side of the field of view) may help, as do some of the other methods of exposing hidden detail, as outlined in Chap. 2.

Although some commentators have stated that the use of an image intensifier negates the benefits of many of these observing techniques, this is certainly not the

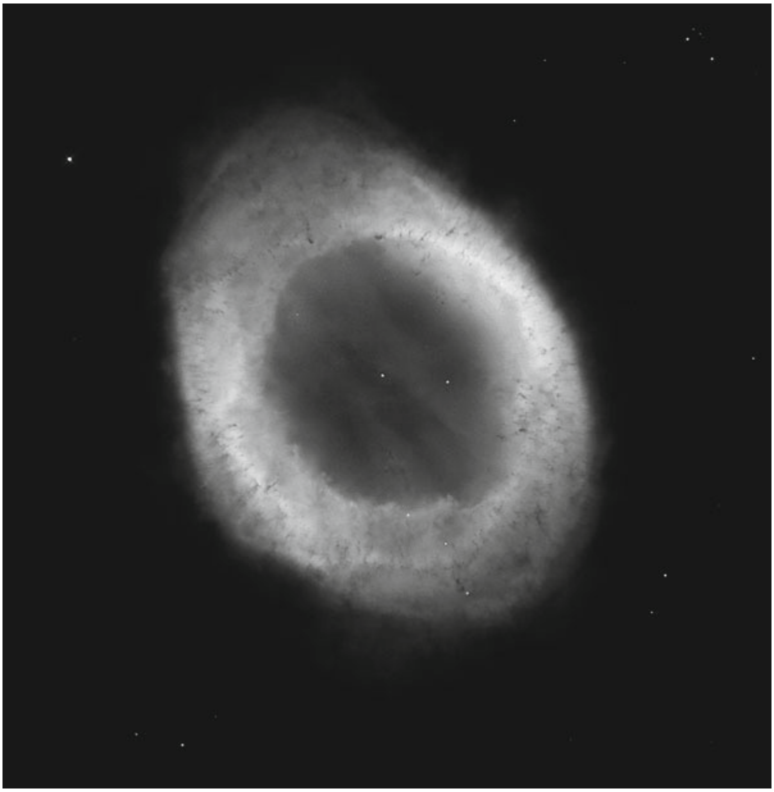

Fig. 7.3 M57 hubble space telescope image (image courtesy NASA/STCcl/AURA/ESA)

case; the sensitivity of the eye to such things remains constant with all forms of viewing. Regardless, surely it is being able to view the dark lanes of M57 that remains the ultimate prize, at least in the context of this writing. Certainly such straight bands as these are highly unusual in any planetary nebula and are even more difficult to explain as entities in themselves.

Other more typical examples of dark features within planetary nebulae may be seen in the relatively nearby (2,300 light years) 'Owl Nebula,' M97, in Ursa Major. One of the best-known planetaries, it appears in many ways as a conventional circular 'ring' type, but it acquired its unusual name following Lord Rosse's observations (once again!). Through his mighty Leviathan 72-in. telescope, Rosse remarked on two prominent dark spots within its disk that were highly reminiscent of an owl's face. Readily possible these days to see at the eyepiece of much smaller apertures than he had at his disposal – especially when aided by a narrowband filter – the owl's 'eyes' are seemingly balanced on each side of the 'face,' superimposed on the unusually bright inner regions of the nebula ring.

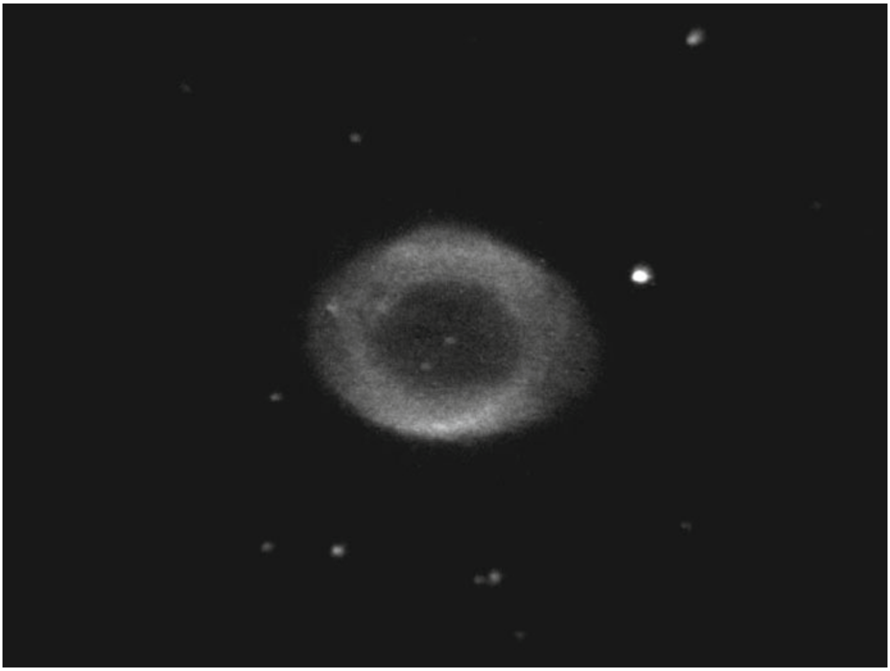

Fig. 7.4 M 57 real time image using 18-in. telescope/image intensifier (AC)

Presumably these dark clumps of matter (ejected from the 16th magnitude central star) are yet to be homogenized into the larger luminous whole, the result of stellar winds clearing uneven regions on each side of the star into relative transparency. We know now, however, that features of this type are far from unusual, with many less celebrated examples being quite common fare for the observer today. In that context, we will look at another planetary with very similar dark features, NGC 1535 in Eridanus.

NGC 1535 in Eridanus

Among many similar planetaries, the near perfectly circular NGC 1535 in Eridanus, sometimes known as 'Cleopatra's Eye,' reveals no less than three such striking dark regions arranged within an inner illuminated gaseous ring, and evenly placed around the narrow dark zone surrounding the central star – not unlike the symbol for a radiation hazard (and not an unfitting description of such a deep space object at that!). The 20″ ring itself is slightly uneven in brightness, and a second faint shell of ejected gaseous matter of approximately 45″–50″ is also observable under decent

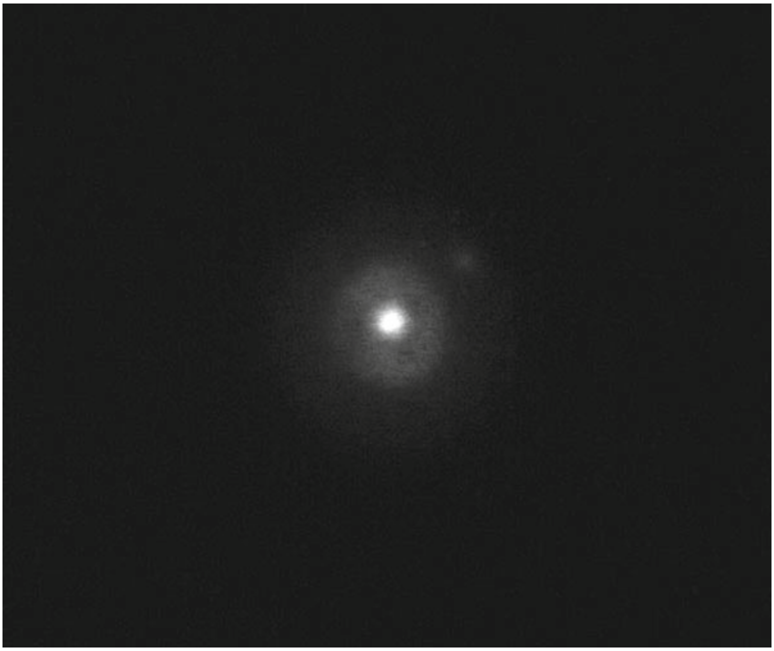

Fig. 7.5 NGC 1535 (AC)

circumstances. However, for us, it is the defining dark features that are surely the most significant components, standing out very prominently in the image above (Fig. 7.5), as they do in the eyepiece.

More detailed imagery reveals a significantly more complex structure to these dark spots, although the intensified image makes the elusive 12.2 magnitude central star far more prominent than in most other imagery; one would imagine that this star is far bigger and brighter than it is. Another even fainter star is superimposed on the outer ring, also usually possible to see in real time viewing. We know it to be external because it clearly has no effect on the structure of the nebula itself, which would otherwise be distorted in some way.

NGC 7662 in Andromeda

A further example of 'owl' type nebulae is NGC 7662 in Andromeda, better known as 'Barnard's Nebula,' which also readily reveals other strikingly unique dark details. In Fig. 7.6, the curiously variable central star (which fluctuates between 12th. and 16th magnitudes), sits prominently in the midst of an oval darker 'void,' although the star may prove difficult visually. The variability could be the result of an orbiting near-brown dwarf companion star, being encapsulated by the partly

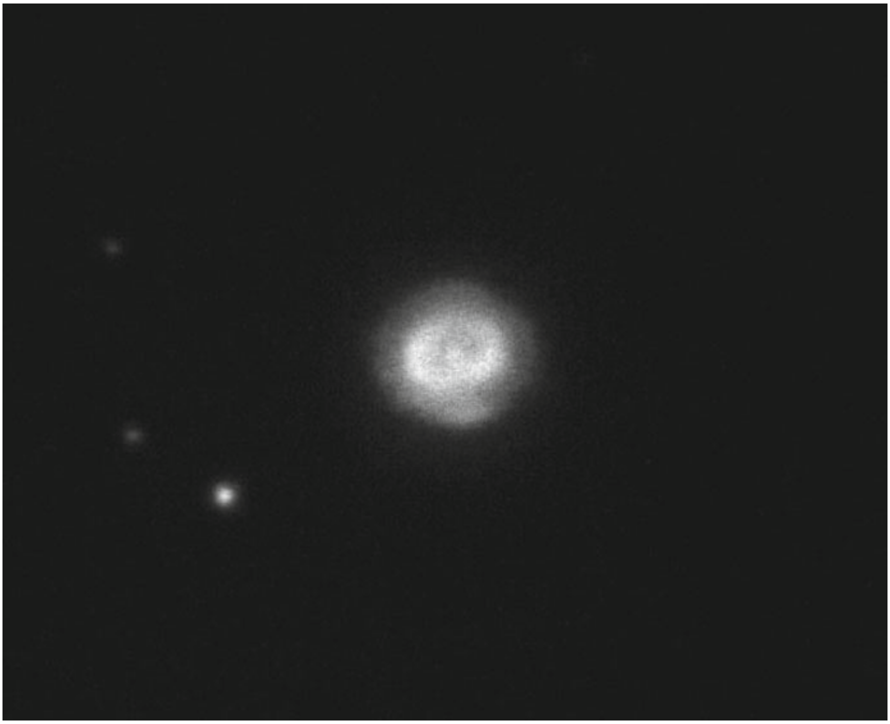

Fig. 7.6 NGC 7662 Barnard's Nebula (AC)

blotchy ejected matter in the form of at least two rings. The brightest and innermost oval ring appears partly incomplete on one side and indented on the opposite, with the central star appearing not exactly in the middle of the inner dark space. Beyond this may be seen another oval ring, quite uneven in illumination, with a bright region toward one narrower side, another similar but less prominent region on the opposite side, and even traces of some subtle small bright details around the periphery of the extremes of the oval shape, along with some additional contrasting darker detail, as the ring appears to fade and trail off into space. Beyond this outer ring, it is sometimes possible to detect an additional faint 'disc' of matter, difficult to detect on the image here.

Making Sense of the Structures of Bipolar Planetary Nebulae

The 'Little Dumbbell Nebula,' M76, in Perseus

Despite its relative faintness, the 'Little Dumbbell Nebula,' M76, in Perseus is actually a prime example of bipolar planetary nebula for us to examine in detail.

Fig. 7.7 M76, the 'Little Dumbbell Nebula' (image courtesy Vanderbei at en.wikipedia)

Being easily accessible in the northern skies and of a decent size, it will serve to illustrate many of the characteristics we see in such nebulae (Fig. 7.7); typical bipolar characteristics can be seen in its double cylindrical form, with bubble-like extensions on each side.

Fortunately, it is bright enough to reveal some of these traits at first blush, and in exceptional conditions larger apertures will also show the distinct but faint outline of the outer shell that is so conspicuous in many images. Although in many ways the image in Fig. 7.7 is quite representative of the overall impression at the telescope in the very best conditions, you are not likely to see it with such clarity and easy registration.

Despite its obvious bipolar characteristics, the elusive faintness of the outer parts of the nebula caused astronomers of old to struggle to find a precise explanation for its appearance, or even how it came by its apparently unusual shape. However, the shape is not all that unusual. Once understood as a three-dimensional entity, it suddenly appears to be a much more straightforward structure, illustrating the classic pipe-like effect commonly noted in other planetary nebulae similarly seen side-on, or partially so. With care, from our perspective, the nebula's brightest region can be appreciated to resemble two short pipe-like sections, lying on top of one another to make the rectangular-appearing main section we see from the side (refer to Guide image on page 220, Fig. 7.8b).

Although the 'Little Dumbbell Nebula' shows some obvious similarities to the cylindrical form of the 'Hourglass Nebula,' it is actually diametrically opposite in the totality of its form, and less dramatically placed with respect to the 'pipe' effect we see. The dotted lines serve as a guide to how the nebula might appear as two pipe-shaped sections on top of each other, with the bubbled double 'shells' on top of those.

Try to imagine its appearance viewed from the direction of Arrow 2, and the nebula's apparent perplexing shape that we see from our perspective begins to make more sense to the observer. Specifically, the pipe-like 'rings' occupy the central zone instead of the extremities as seen in the 'Hourglass' (shown as broken lines); the form expands beyond these 'rings' into bubble-like 'shells' (indicated by irregular broken lines) as the expanding gases are pushed away from the central star, and the shells finally extend into additional further, much fainter 'shells' (their locations shown by dotted lines), which gradually taper, somewhat conically, the entire system appearing almost double on each side of the primary central form.

Remarkably, viewed from 'above' (directly over the faces of the rings), it is conceivable that both the 'Little Dumbbell' and 'Hourglass' nebulae both might take on much the familiar 'smoke-ring' appearance we more normally associate with planetary nebulae, far different from the side view. They might appear almost interchangeable. Be patient with this nebula in order to discern detail; while highly illustrative of bipolar forms, it is not the easiest subject. In live viewing only the very best circumstances will allow a glimpse of the faint shells. However, it is possible to see many other fine details in the 'snapshot' of the 'Little Dumbbell' in Fig. 7.8. The easy registration of the faint central star is striking, as is the delicacy and subtle dark detail revealed by careful inspection of the image in general. Light filters can bring out many of the features more distinctly on this subject, especially the multiple dark features, but anything one has on hand is always worth a try.

1. A striking central dark lane – a 'bar' that extends through most of the most prominent central portion of the nebula, and probably the 'inner' circular gap between one of the pipe-like sections and the other; truly an unusually well displayed example of such a feature in a planetary nebula. It does not seem unreasonable that the cylindrical structure may be due to the effect of a companion brown dwarf, as it draws matter away from the dominant star to form a dark disc of matter, which then expands outwards in both directions by the action of stellar winds to create the cylinder and fainter outer 'bubbles.' However, this theory is purely the author's conjecture.
2. The 16.6 magnitude central star is clearly shown; it is not difficult with image intensification and moderate apertures. It is sometimes possible to distinctly see this star as binary (see [5]); however, astronomers have assured us that what

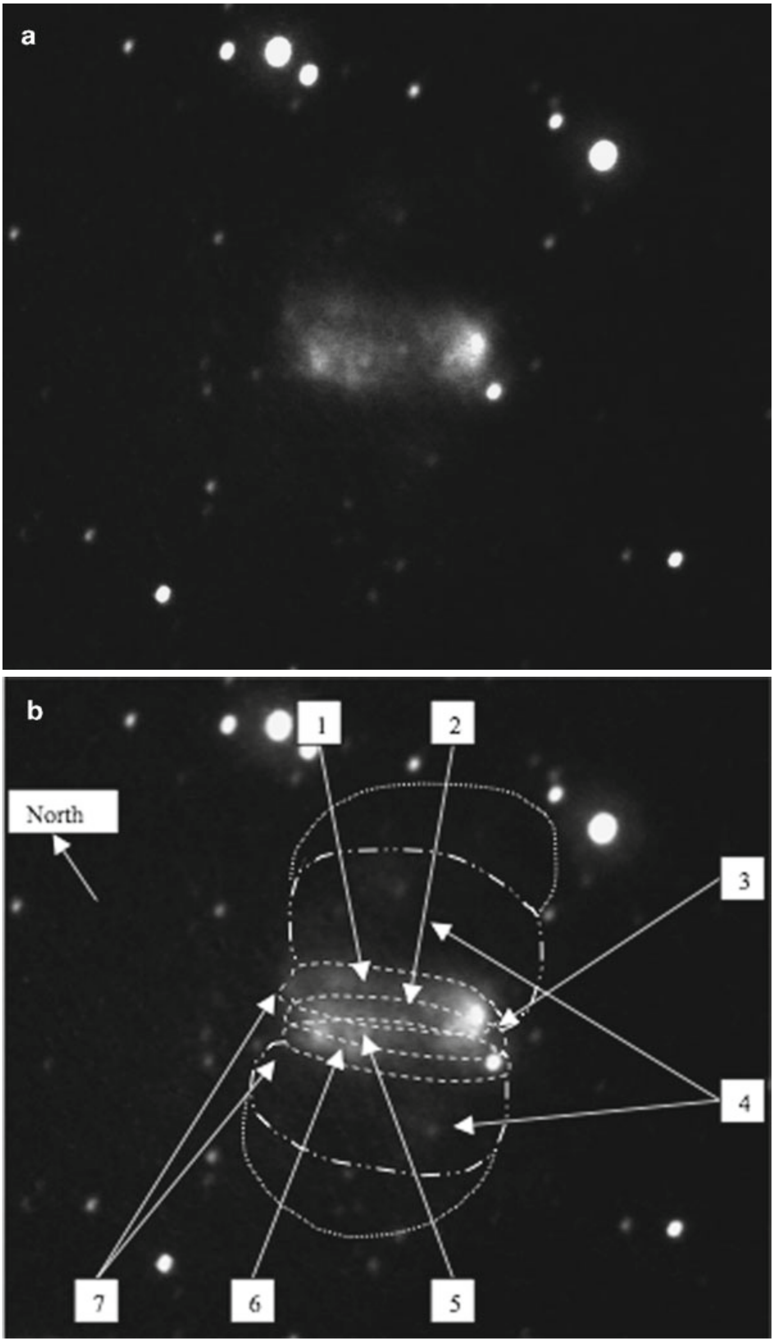

Fig. 7.8 (**a** and **b**) 'The Little Dumbbell Nebula,' M76 (AC)

we are seeing is merely an illusion, with one star actually being situated far in the background, only giving the appearance of a double system.

3. This is one of the two points where the nebula appears to divide into two parts (adjacent to the brightest knot), with matter being ejected outwards in a double arc. This may be due to the influence of stellar winds interacting on the possible companion star. The strong division is easier to spot in observatory images, but it is satisfying to see a trace of it at the eyepiece. Bear in mind that it is not an easy mark in live viewing, although still feasible to do.
4. Look closely at the two brightest knots within the surrounding outer 'shells,' which admittedly are faint but are frequently readily visible in real time. The knots are just detectable here, if not the outer shell itself.
5. The fine and tiny dark ring seeming to surround the visual double star on one side (outside the nebula) shows clearly here. Since this image was made with an image intensifier, it may not be so readily apparent with conventional viewing. This dark feature shows on detailed imagery but apparently is not related to the star.
6. Similarly, the dark pointed notch-like streak across the 'lower' ring that is quite clear in Fig. 7.8a may be detectable with larger equipment and under the best conditions.

Suggested List of Interesting Planetary Nebulae with Potentially Viewable Dark Features

Dark details in planetary nebulae are elusive objects. There are probably more examples among the listing below in which most observers will not be able discern such features, but this should not deter the effort. In most cases within these structures, dark details and features are delicate, subtle, and usually minimal. Depending on equipment and viewing expertise, looking for them may provide some interesting study, especially since it must often consist of the same dusty silicates that we find in interstellar matter.

However, the exact nature of dark features in these objects poses different questions; although they may be true features of internal dust and therefore the earliest manifestations of interstellar matter, they could also merely be gaps in the structure, or partially translucent parts of it.

There may be a few celebrated planetaries included in the listing that do not have any particularly notable dark features, but excluding them out of hand might have seemed confusing; by including them we have at least raised, however briefly, the prospect for something unexpectedly being visible.

Each object is listed with, where applicable or available, its *catalog number* first (NGC or other), next its *magnitude*, object *type*, a short *description* of interesting features in parenthesis, angular *size*, *coordinates*, and the *constellation* in which it can be found.

Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 246	Planetary	12	200″	00470s1153	Cetus	Mottled dark interior
http://www.skyshooter.net/IMAGE%20FOLDER/Nebulas/NGC246.jpg					*Dark inner details well shown*	
*						
NGC 650/1 (M76) The 'Little Dumbbell Nebula'	Planetary	11	60″	01424n5134	Perseus	See text
http://www.noao.edu/outreach/aop/observers/m76block.jpg					*Excellent reference image*	
*						
NGC 1360	Planetary	9.5	6′ × 4′	03333s2551	Fornax	Diffuse oval planetary, probably in state of contraction; 11.5 m. central star; with faint dark lane-like region & small ejected trail of HII gas; Wolf-Rayet central star
http://stardustobservatory.org/image.php?id=175					*Predominant blue color shows well*	
*						
NGC 1501	Planetary	13	55″ × 48″	04070n6055	Camelopardalis	Much dark mottling; 13.5 m. central star
http://mexicanskies.com/constellations/ngc1501pollux.jpg					*Dark mottling well revealed*	
*						
NGC 1514	Planetary	11.5	100″	04092n3047	Taurus	Bipolar; with bright 10 m. central star, likely a double causing 'bubbles' around its circumference; dark mottling.
http://www.noao.edu/outreach/aop/observers/n1514block.jpg					*Good reference image*	
*						
NGC 1535 'Cleopatra's Eye'	Planetary	10	20″	04142s1244	Eridanus	With two shells (inner one with dark mottling); 11.5 m. central star.
http://www.noao.edu/outreach/aop/observers/n1535blocks.jpg					*Blue color is accurate*	
*						

IC 418 *'Spirograph Nebula'*	Planetary	10	30″ × 25″	0527s1242	Lepus	Complex, tangled, finely 'knitted' appearance; brilliant in field of view; double shell with darker region between
http://hubblesite.org/newscenter/archive/releases/2000/28/					*Superlative color image, showing great detail*	
*						
NGC 1952 (M1) *'Crab Nebula'*	Supernova remnant	9	5′ × 3′	05345n2201	Taurus	Resolution of tendrils possible with sufficient aperture; many dark details, and two conspicuous dark inlets
http://wallpapers.free-review.net/49_~_Crab_Nebula.htm					*Outstanding image that shows the pulsar and the surrounding shock waves*	
*						
NGC 2371/2	Planetary bipolar	12.5	50″ × 30″	07256n2929	Gemini	Faint but interesting bipolar, two bright zones give the impression of double ends, hence double designation; has two ansae on each side not unlike NGC 7009
http://en.wikipedia.org/wiki/File:NGC_2371.jpg					*Ansae as shown will be challenging to glimpse*	
*						
Sh2-274 *'Medusa Nebula'*	Planetary	11.5	10′	07290n1315	Gemini	Unusual very old crescent-shaped nebula, with dark streaks and details. Careful inspection seems to show that the nebula is presented almost edge-on – an unevenly lit cylindrical appearance
http://www.astroimager.net/Page-180-CCD-152.html					*B/W image well resolved*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 2392 'Eskimo Nebula'	Planetary Bipolar	8	40″	07292n2055	Gemini	Bipolar elements partly superimposed in central region; 10 m. central star; high powers and conventional, unfiltered viewing show it best; bipolar aspect not clear; mottled dark inner ring and bright & dark streaks visible
http://apod.nasa.gov/apod/image/0312/eskimo2_hst_big.jpg					*Hubble image shows intricate details and darker inner mottling*	
*						
NGC 2359 'Thor's Helmet' (Gum 4)	Emission Nebula/ Planetary Wolf-Rayet caused bubble	–	8′ 6′	07186s1312	Canis Major	One bright lobe and four others; dark region to one side
http://www.ruppel.darkhorizons.org/IMAGES/ngc2359SHO.jpg					*Good image for showing dark details*	
*						
NGC 3132 'Eight Burst Nebula' aka 'Southern Ring Nebula'	Planetary	8.2	84″ × 52″	10069s4026	Vela	Bright; appears similar to 'Ring Nebula,' M57, with 10 m. central, not illuminating, star. Disturbances between these two stars caused concentric rings; dark inner details more obvious at the eyepiece
http://www.celestiamotherlode.net/catalog/images/screenshots/extrasolar/NGC_3132_EightBurstNebula__Killeen.jpg http://heritage.stsci.edu/1998/39/big.html					*Perhaps the most revealing image for preparing the observer at the eyepiece* *Hubble image shows true illuminating central star (next to bright star)*	
*						

NGC 3242 'Eye Nebula' aka the 'Ghost of Jupiter'	Planetary	8.9	40″	10248s1838	Hydra	Startling appearance with dark zones
http://www.astrosurf.com/antilhue/ngc3242.htm					*Perhaps the most useful image in revealing dark details around central 'eye' region*	
*						
NGC 3587 (M97) 'The Owl Nebula'	Planetary	11	3.5′	11148n5501	Ursa Major	Surface brightness very low; dark features.
http://www.kopernik.org/images/archive/m97.htm					*Good preparatory image with dark 'eyes' realistically portrayed*	
*						
NGC 4361	Planetary	10.5	80″	12245s1848	Corvus	With 13 m. central star; may be a difficult object for observing dark details in outer disc
http://www.lunarplanner.com/Images/Deep%20Space/Corvus-Neb-NGC4361.jpg					*Fine image, revealing mottling in outer periphery*	
*						
NGC 5189	Planetary	–	2.5′ ×1.3′	13334s6558	Musca	Spiral appearance; more like a backward 'S.' Much dark detail; twisted form possibly due to binary system; edge-on perspective; many mottled dark details
http://www.airglow.de/html/nebulae/ngc5189.html					*Clarifying image for visual analysis*	
*						
NGC 5307	Planetary	12	15″ × 10″	13510s5110	Centaurus	Curiously twisted, almost spiral form, presumed caused by binary star system; use higher powers; some dark mottling may be apparent
http://apod.nasa.gov/apod/image/9712/ngc5307_hst_big.jpg					*Reveals twisted form. Image intensifiers may show some of this*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
IC 4406	Planetary	11	60″ × 30″	14224s4409	Lupus	Perfect example of side-on planetary with cylindrical form, although will likely be seen live more as a disc
http://apod.nasa.gov/apod/image/0807/ic4406_hst_big.jpg					*Very clear image, although dark details are limited to each end fading into background; this serves more to demonstrate common planetary form seen from side*	
*						
NGC 6058	Planetary	12	25″ × 20″	16044n4041	Hercules	Typical ringed appearance of many planetaries; this example also has a very faint outer ring as well as a further rectangular outline; bright central star
http://www.capella-observatory.com/ImageHTMLs/PNs/NGC6058.htm					*Subtle dark details shown*	
*						
NGC 6164-5	Planetary bipolar	10	1.7′ × 2.5′	16171s6051	Norma	Huge central Wolf-Rayet star – likely to become a supernova. Bipolar likely caused by magnetic field
http://panther-observatory.com/gallery/deepsky/doc/NGC6164_F9_HA_c80.htm					*B/W image; well-shown characteristics and dark zones*	
*						
NGC 6210	Planetary bipolar	9.7	20″ × 16″	16447n2345	Hercules	With 12.5 m. central star/some dark detail; oval shape and jets shooting from shell
http://www.spacetelescope.org/images/screen/opo9836f.jpg					*Live viewing will likely be disappointing for dark details*	
*						
NGC 6302 the 'Butterfly' or 'Bug Nebula'	Planetary bipolar	9	2′ × 1′	17134s3706	Scorpius	Classic irregular bipolar shape, superficially like a flattened figure '8' in some views; true dark lane through narrow center region
http://www.spacetelescope.org/images/screen/heic0910h.jpg					*A remarkable image*	
*						

NGC 6309	Planetary bipolar	11.5	20″ × 10″	17141s1255	Ophiucus	With 14 m. central star; two dark lanes dividing whole; one more prominent than the other
http://www.noao.edu/outreach/aop/observers/n6309.html					*Detailed true-to-form image*	
http://www.saratogaskies.com/image.pl?i=68#					*As it will likely appear in live view*	
*						
NGC 6543 'Cat's Eye Nebula'	Planetary bipolar	8.6	22″ × 16″	17586n6638	Draco	Exceptional; helical structure partly resolved; probably result of binary star system; Wolf-Rayet visible central star.
http://www.universetoday.com/wp-content/uploads/2009/02/ngc6543cross.jpg					*Interesting stereo image, showing structure well; any dark detail visible is likely to be subtle and small, but will reinforce sense of helical structure.*	
http://dayton.hq.nasa.gov/IMAGES/LARGE/GPN-2000-000955.jpg					*Hubble image; composite image at three wavelengths.*	
*						
NGC 6567	–	11.5	11″ × 7″	18137s1905	Sagittarius	Within M24 Sagittarius Star Cloud;15 m. central star; some dark detail.
http://www.blackskies.org/images/pnbst/pnbst3/n6567.jpg					*Small B/W image showing some detail; reference imagery scarce.*	
*						
NGC 6572 'The Emerald Nebula'	Planetary bipolar?	9.5	15″ × 12″	18121n0651	Ophiucus	12 m. central star; twisted oblong appearing main core; similar structure to M76?
http://www.noao.edu/outreach/aop/observers/n6572bodners.jpg					*Shows detail and structure well, and some dark inner features.*	
http://web.pd.astro.it/sabbadin/ngc6572_nii_low.gif					*Interesting rotating computer model showing three-dimensional apparent bipolar form.*	
*						

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Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6720 (M57) 'Ring Nebula'	Planetary	9	80″ × 60″	18536n3302	Lyra	Exceptional; marvelous object; subtle parallel dark streaks inside ring visible, as well as faint 16 m. central star.
http://www.noao.edu/image_gallery/images/d3/02678a.jpg						*For preparing the eye for internal dark detail, perhaps this is the best image.*
http://apod.nasa.gov/apod/image/0911/ring_hst_big.jpg						*Perhaps the most startling image of M57 ever.*
*						
NGC 6772	Planetary	13	60″	19146s0242	Aquila	Irregular, slightly oblong ring with dark center and other details; v. faint 18.2 m. central star.
http://www.skyfactory.org/deepskycatalogue/NGC6772.html						*Very useful B/W image, showing variety of dark zones, including small very dark eye-shaped region surrounding central star.*
*						
NGC 6781	Planetary	12.5	105″	19184n0633	Aquila	Round, with 15.5 m. central star; some dark inner details.
http://www.saratogaskies.com/ngc6781-full.jpg						*Stereotypical planetary with uneven dark interior.*
*						
NGC 6818 'Little Gem Nebula'	Planetary	10	22″ × 15″	19444s1409	Sagittarius	15 m. central star difficult; mottled disc framed by triangle of stars; near galaxy NGC 6822–1.2 m.
http://www.kopernik.org/images/archive/n6818.htm						*The best preparatory image, if not the most detailed.*
*						
NGC 6826 'Blinking Nebula'	Planetary	8.8	25″	19448n5031	Cygnus	Round, with 11 m. central star; v. good at high power.
http://www.johnastro.info/astrophotography/nebula/060717_c15_blinking_nebula.html						*A good image for preparing the eye for live views; subtle dark details revealed.*
*						

NGC 6853 (M27) 'Dumbbell Nebula'	Planetary	8	8′ × 5′	19596n2243	Vulpecula	Exceptional; fine detail and concentric zones.
http://www.noao.edu/education/ir.asp/images/01244lg.jpg					*Shows filamentary structure horizontally and vertically; many 'stars' that appear to be diagonally crossing center are actually clumps and tendrils of HIV gas.*	
http://www.astrophoto.net/m27.htm					*Typical of subject; helpful standard image.*	
*						
NGC 6888 'Crescent Nebula'	Planetary	8	18′ × 15′	20127n3821	Cygnus	Finely detailed Wolf-Rayet formed nebula; many striations; challenging visual object.
http://apod.nasa.gov/apod/ap090915.html					*A very finely resolved image via the Isaac Newton Telescope.*	
*						
NGC 6891	Planetary	10	15″ × 7″	20152n1242	Delphinius	Tiny object; 11 m. central star; unlikely to provide much detail in live views, but does show dark mottled detail.
http://www.nightskyinfo.com/archive/ngc6891_6905/ngc6905.jpg					*Dark detail best show on this image; different structural information may be seen on alternate image below.*	
http://i131.photobucket.com/albums/p301/glactus/space%20album%20eight/NGC6891-2.jpg					*Alternate.*	
*						
NGC 6894	Planetary	13.5	41″	20164n3034	Cygnus	Interesting little nebula with dark indentations and bright zones on surrounding ring.
http://www.spiegelteam.de/ngc6894.htm					*Extraordinary image.*	
*						

(continued)

(continued)

Object	Type	Magnitude	Angular size	Coordinates	Constellation	Comments
NGC 6905 *'Blue Flash Nebula'*	Planetary	12	44″ × 38″	20224n2005	Delphinius	Disc, with 14 m. central star; partially framed by four prominent stars. Named after central star; appears and vanishes with direct or indirect vision (as do several others).
http://www.astrosteve.com/nebula_blueflash.aspx					*Good informative image, showing subtle inner dark details, as well as dark outer extensions.*	
*						
NGC 7008	Planetary	12	85″ × 70″	21006n5433	Cygnus	May appear heart-shaped in many live views, but appearance is due to uneven brightness of outer ring; full of subtle dark detail, much of which will be challenging to see live.
http://apod.nasa.gov/apod/image/0808/ngc7008_hagercollab.jpg					*Shows many subtle dark features.*	
*						
NGC 7009 *'Saturn Nebula'*	Planetary	8	25″	21042s1122	Aquarius	Exceptional, celebrated nebula, but not for showing dark detail in live viewing.
http://www.noao.edu/outreach/aop/observers/n7009ehrhorn.jpg					*Detailed image; little dark detail except at each side of oval.*	
*						
NGC 7026	Planetary bipolar	12	25″ × 16″	21063n4751	Cygnus	Appears visually like smudged elongated rectangular double nebula because of dividing dark lane and wider dark regions on each side; 15 m. central star hard to see; bright star adjacent.
http://www.astrophotos.net/pages/PLANETARY/NGC%207026.htm					*Decent, revealing image, though unexceptional, better for live viewing expectation.*	
*						

NGC 7027	Planetary bipolar	9	18′ × 11′	21071n4214	Cygnus	Prominent star and two separate lobes on one side; many dark lanes, including dividing central lane.
http://stars.astro.illinois.edu/sow/n7027.html					*Informative analysis of object with images.*	
*						
NGC 7293 'Helix Nebula'	Planetary	6.5	25′	22294s2050	Aquarius	Spread out, but visible in moderate apertures, along with central star; seen slightly edge-on as partial cylinder, many inner dark details; needs dark skies.
http://apod.nasa.gov/apod/image/0708/helixdeep_hambsch.jpg					*Shows structure well.*	
*						
NGC 7354	Planetary	13	30″	22404n6117	Cepheus	Much inner detail and dark features; small ansae on each side; 16.5 m. central star.
http://www.sidleach.com/ngc7354.htm					*Finely detailed image.*	
*						
IC 1470	Poss. Planetary	12	70″ × 45″	23052n6015	Cepheus	Fan-like irregular shape.
http://www.astrophotos.net/pages/Nebula/IC%201470.htm					*Difficult object for seeing lanes, but some fine lanes and details are present, as can be seen on this image.*	
*						
NGC 7635 'Bubble Nebula'	Poss. Planetary	–	15′ × 8′	23205n6112	Casseopeia	Winds from 8 m. central star created and illuminates this nebula, within nebulous field.
http://www.princeton.edu/~rvdb/images/NJP/ngc7635-DD-Gamma-LRGB.jpg					*Wonderful image, with many intricate dark details.*	
*						
NGC 7662	Planetary	8.5	32″ × 28″	23259n4233	Andromeda	Barnard's celebrated nebula; exceptional detail.
http://www.spiegelteam.de/CCD-Aufnahmen/ngc7662.jpg					*Remarkable image; dark details will be more like subtle zones in live viewing.*	

Chapter 8

A Few Last Words

If observing dark structures and features within subjects in deep space promotes anything, perhaps it is an increased awareness of how closely interrelated all of the known workings of the cosmos actually are – even if we have never consciously connected all the 'dots' through what we knew all along. If we are primarily observers, 'mere' astronomical sightseers, a detailed understanding of the inner workings of what we are observing, while not always a requirement, could surely only lead to greater enjoyment. Maybe it will provide pause to rethink the way we observe already familiar sights and help us to see them anew, a prospect indeed to far greater satisfaction from our time under the stars (Fig. 8.1).

What we know of the universe seems always intertwined with the processes that cause dark to become light: essentially the conversion of matter to energy and matter to other forms of matter. One way or the other, everything we relate to and perceive is on these terms. The universe is a work in progress, its structure and appearance in a constant state of change, even if this is barely perceptible in the tiny time frame of a human lifespan. This gargantuan machine will continue until the time when all ongoing cosmic evolution as we know it reaches total exhaustion.

Needless to say, this evolution has been ongoing since the advent of the 'Big Bang,' an event that required the first few million years just for light to be able to escape into space itself. Thus was the beginning of the evolution of the elements and energy, even the apparently unlikely advent of human life, and all that allows us to look inwards at ourselves and out to the universe and stars we descended from. There is an apparent inevitability of all things – alternate back and forth like a cosmic-scale concertina.

For those who argue that science and religion are leading to the same thing, it is perhaps more realistic to consider that here is where they part company. Where science sees creation in inevitable cosmic terms and that something can come from nothing without further explanation, religious philosophers ask instead, "But what

A. Cooke, *Dark Nebulae, Dark Lanes, and Dust Belts*,
Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4614-1186-4_8,

Fig. 8.1 The author's 18-in. telescope ready for a night of observing in dark sky country at the Borrego resort in the California desert, which has facilities for astronomy (AC)

created creation?" This is something best left well alone here; although it will always remain a topic for debate, it is fair to say no one may ever know the answers for sure, despite those who say they do.

The matter distributed throughout the cosmos is also something to ponder. It manifests itself primarily in what we see as huge illuminated clumps that still reflect the vibrations of the Big Bang, something that is accompanied by a faint glow that permeates the entire universe. This is the only model for the existence of this 'cosmic microwave background,' that glow left over from the Big Bang, itself. Those clumps of matter comprise the structures we know as galaxies – vast evolving manifestations of highly organized mass and energy, all reacting to the twin forces of gravity and compression. Despite their huge size, individual galaxies are tiny parts of the whole, to be counted in the hundreds of billions, and although existing in a range of manifestations no less varied than the human face, are about as far from random in appearance as we could possibly expect. Even irregular and peculiar galaxies are logically structured – in their own ways. Although exactly how the original primordial matter came about from apparently nothing and evolved into such fantastic structures may be always far from understood, an ingredient common to all of them is their composition of typically hundreds of billions of stars. (It seems the unit of a billion is standard fare in space.)

But although stars are the main visible manifestation of a galaxy's mass, blended across the far reaches of space to appear as a homogeneous whole, who among the uninitiated would have ever suspected what one of these structures actually represents? Thus, the astronomers of old can hardly be chastised for assuming what they saw were nebulae *within* the Milky Way – the only universe they knew. It took the 100-in. 'Hooker' telescope to show that galaxies were actually made up of stars, *other* Milky Ways.

We know that the mass of all that is contained in the universe is subject to an all-powerful force – something we perceive more as a result of its existence rather than its tangibility. In simple terms we explain what we witness and experience as "gravity," but such simple language barely implies its real effect of bending the fabric of space-time. Regardless, there is not enough visible mass in the universe to explain the physics of galaxies, nor apparently even sufficient unseen dark matter and dark energy ultimately to pull the universe back together for one more shot at creation. If this is an accurate scenario, it seems that we are destined to expand into obscurity and ultimate darkness, once our star-making factories are spent. However, until that time arrives, it seems that the unwritten law of the universe dictates that even almost totally vacuous matter is destined to bunch together ultimately to become compressed into ever-denser matter. Gravity again. Thus the ongoing processes of creation proceed, at least for the time being. The same forces of gravity, and resulting forces of compression, will accompany the beginning of the cycle, just as they do at the end. The beacons of energy that accompany the beginning or end of life for stars represent the lifeblood of our existence. Regardless of which fate awaits each star, one way or the other, all stars recycle their matter back into the cosmos as forms of energy and elements. Without these events there could have been no life on Earth – and no life anywhere else in the universe.

Thus, we return to what might have appeared to be those 'inert' looking dark clouds of gas and dust populating so much of the space within galaxies. They turn out to be more central to the life force of the universe than perhaps we may ever have previously contemplated. It is enlightening to see on some of the best images – those that show everything in extremely contrasted terms – there is usually much in the form of dark nebulous matter appearing amazingly thick in dust; perhaps the sheer quantity of matter available for star formation is made suddenly more apparent, especially as we consider the clouds' almost unimaginable size. And although that matter in the most compressed form of stars may be not viewed as more than a pinpoint, these 'points' may be several millions of miles in diameter, or even very much larger.

However, we cannot assume that all visible dark matter in the cosmos has the same potential for future generations of creation; some may have other characteristics, makeup and possible future role; maybe other interstellar matter will simply never condense in sufficient quantities and densities to live again, while other regions are inappropriate for star making. But it does seem that dark stuff of one kind or another can be found almost everywhere, if we just take the trouble to look for it, even if we must look for it as indirectly silhouetted against brighter backdrops. And perhaps it may have finally become clear to us that not all dark spaces

Fig. 8.2 The author setting up the camera, adapter and image intensifier for imaging

are created equal, since there are many shades and variations in the degrees of darkness that we see; usually many seem present within just one object.

Because our eyes are incapable of accumulating light as in time exposure imaging, at times it is difficult to be sure whether we are actually observing dark features, merely a lack of illumination, or just the depths of seemingly endless space. Indeed, sometimes we may even have the illusion that some features are darker than the surrounding space itself, but this can only be due to the presence of slightly illuminated and extremely tenuous matter in the region. However, when it comes down to what it is that motivates us to spend countless hours in the dark hoping to glimpse a tiny fragment of detail we have never seen before within an object long familiar, we should never overlook the one element outside the periodic table that drives us – the human element. Of this is born inquisitiveness, and perhaps looking for such tiny details, outside the norm, will drive us even further (Fig. 8.2).

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Additional Website Resources

International Supernovae Network. The network endeavors to help contacts and share information among supernovae enthusiasts both amateurs and astronomers worldwide. www.supernovae.net/isn.htm.

List of supernovae pages on the web: A comprehensive, categorized list of supernovae and supernovae remnant web pages and resources. rsd-www.nrl.navy.mil/7212/montes/sne.html.

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