INTRODUCTION

We are very pleased to present what is the first major star atlas devoted to the observation of the "Herschel objects" – some 5,000 star clusters, nebulae, and galaxies collectively discovered by Sir William Herschel, his sister Caroline, and son Sir John. With the widespread growing popularity of viewing these wonders of the heavens by amateur astronomers today, the need for such a work clearly exists. The one classic atlas that identified some of those objects found by William Herschel, using his designations (329 of them), was *Norton's Star Atlas* in all of its first 17 editions. Sadly, all later revised and redrawn versions – initially re-titled *Norton's 2000.0* and currently back to the original *Norton's Star Atlas* – dropped these labels, to the dismay of observers. While this new atlas is primarily designed with observation of star clusters, nebulae, and galaxies in mind, it also serves as a general purpose guide for exploring all types of deep-sky objects, showing as it does many prominent double and multiple stars, variable stars, asterisms, and the majestic Milky Way itself. Additionally, it may be viewed as a companion volume to our previous work, *The Cambridge Double Star Atlas*, first published in 2009. Between these two publications, the long-standing lack of recognition accorded the discoveries of the Herschels, and those of the classic double star observers, by celestial cartographers has finally been rectified.

Who were the Herschels?

Sir William Herschel

William Herschel was without question the greatest visual observer who ever lived. Widely regarded as the "Father of Observational Astronomy," he single-handedly opened the frontiers of deep space to telescopic exploration. In the course of his grand scheme to study what he called the "construction of the heavens," he discovered literally thousands of previously unknown double and multiple stars, star clusters, nebulae, and what we know today as galaxies. Although self-taught and so technically an amateur astronomer, he transformed the world of professional astronomy – which at the time had been largely concerned with the solar system and the positions of the stars.

William was born into a musical family in Hanover, Germany, in 1739 and moved to England around 1770. Like others members of the family, his early career was that of a musician – in his case teaching and orchestrating music for the city of Bath. It was while there that he became fascinated with astronomy. ("Obsessed" would better describe it, for on occasions he would actually run home during performances to observe between acts! And later, as a full-time astronomer, he typically observed from dusk to dawn.) He set about making his own telescopes beginning with small refractors but soon turned his attention instead to reflectors, constructing entire instruments, including their speculum-metal mirrors, entirely himself. (The familiar metal-on-glass telescope mirror was not introduced until long after Herschel's death in 1822.) But he not only became the greatest telescope-maker of his day, he was also an observer the caliber of which the world had never seen before. He used these homemade instruments to "sweep" the heavens for unexplored celestial treasure, his initial "review" being undertaken with a "7-foot" Newtonian reflector at a magnification of 227×. (At that time telescopes were designated by their length rather than by their aperture.) This resulted in his first catalog of double and multiple stars. It also produced one of the greatest discoveries in the history of observational astronomy – made by a totally unknown "amateur"!

While sweeping the sky in the constellation of Gemini on the night of March 13, 1781, Herschel came across a small greenish disk of light. Careful observation showed that it was slowly moving among the stars, leading him to believe that it was a strange-looking comet. Others agreed with him and for nearly a year mathematicians attempted to calculate an orbit on that basis. All attempts failed and it was finally realized that Herschel had, in fact, found another planet! This was the first such world ever *discovered* (the five naked-eye planets having been known since antiquity) and it effectively doubled the size of the solar system. It apparently had never entered anyone's mind that there actually could be more planets lying beyond those already known. This electrifying and unprecedented discovery catapulted William Herschel to instant fame and brought him to the attention of King George III, who appointed him his private astronomer. This honor brought with it a salary sufficient to allow Herschel to give up his musical duties and spend all his time on astronomy.

Caroline Herschel

Any account of the work of William Herschel would be incomplete without mention of his devoted sister, Caroline Herschel. She assisted him both at the telescope at night and in the arduous work of recording and reducing his many discoveries in preparation for their eventual publication. This was in addition to taking care of household duties including meals (even mouth-feeding and reading to her brother as he polished his mirrors for hours on end!). She became the leading woman astronomer of her day and the first to find a comet, her record of eight discoveries having stood for nearly two centuries. She observed with a small 27-inch focus Newtonian "comet sweeper" made expressly for her by William, using it to scan the sky on her own when he was away at meetings or showing the stars to the King and his court. Thus, a number of her own deep-sky discoveries are contained in Sir William's catalog. One of the author's personal favorites is the lovely rich open cluster designated H VI-30 (or NGC 7789) in Cassiopeia, which the author named "Caroline's Cluster" many years ago in her honor.

Sir John Herschel

William Herschel married late in life, having a son named John Frederick William, or "John" for short. Like his father and his Aunt Caroline, John Herschel also became famous as an astronomer. But in addition he was a gifted mathematician and scientist in other fields; among other activities he experimented with photography and took the oldest existing photograph on a glass plate (a ghostly image of his father's 40-foot telescope). John is best known for completing his father's survey of the northern sky and (especially) then extending it to the southern sky as well. He spent four years sweeping the heavens from Cape Town, South Africa, having taken his father's favorite telescope – the "Large" 20-foot reflector – there and discovering thousands of previously unknown double stars, clusters, and nebulae. He returned to England in 1838 a national hero for this work, receiving among many other honors knighthood. John issued a compendium of his findings titled *The General Catalog of Nebulae*, and later a combined one containing all of his and his father's telescopic discoveries totaling some 5,000 in all (including a few by other observers). This work eventually became the basis for the famed *New General Catalogue of Nebulae and Clusters of Stars* (or *NGC*), which was published in 1888. Only a hint can be gleaned of the incredible life and works of this remarkable family of astronomers from the brief account given here. Those desiring to know more about the Herschels are strongly encouraged to consult the various references given below, which make fascinating reading – especially on cloudy nights!

The Herschels' telescopes

Early instruments

It will be instructive to say something about the telescopes the Herschels used to make their discoveries and to compare their performance with modern instruments. William Herschel began his telescope-making career in 1773 by experimenting with relatively small refractors. But as these were then still optically primitive compared with today's glasses, he soon turned his attention to reflectors. These could be made in larger sizes and without concern for the quality of optical glass, for they used mirrors instead of lenses. But these weren't the familiar telescope mirrors of today, as metal-on-glass optics did not appear until long after Herschel's death. Instead, they were made of speculum-metal – a hard brittle casting composed mainly of copper and tin. Herschel first made several mirrors for a 5.5-foot Gregorian reflector, but then turned to the simpler Newtonian form. All of his telescopes from that point on were long-focus Newtonians of ever-increasing size, culminating in the great 40-foot reflector (see below). He soon produced a 7-foot reflector, probably with an aperture of around 6 inches. He also made several 9-inch mirrors for a 10-foot reflector (and much later a 10-foot with a 24-inch mirror), followed by 20-foot models with 12- and 18.7-inch mirrors as described below. But his favorite early reflector was another 7-foot which contained "a most capital speculum" as he described it, of 6.2-inches aperture. This is the telescope that he used for his first "review" of the heavens and the one with which he discovered the planet Uranus. While most of the objects Herschel found in this first review with his prized 7-footer were double and multiple stars, he also found a number of his early clusters and nebulae with it. (It should be mentioned here that in his day, and long thereafter, galaxies were not yet recognized as such, being simply lumped under the category of "nebulae".)

The 20-foot telescopes

Herschel's two "workhorse" telescopes – those used for all his later various reviews of the heavens – were his 20-foot reflectors. The earlier and smaller of these in terms of aperture (referred to as the "Small 20-Foot") used 12-inch aperture mirrors, while the larger and later instrument (called the "Large 20-Foot") used 18.7-inch mirrors. Note that "mirrors" is plural, since several were needed for each telescope – the one that was currently in use, and at least one in the process of being repolished and refigured because of the rapidity with which speculum-metal tarnished! The 18.7-inch became Herschel's most useful telescope and in later years he even preferred it to the massive 40-foot one, for it was both much easier to use and the mirrors performed better (not to mention that they were also vastly easier to make and keep ready). It was in constant use on clear nights from dusk to dawn, revealing over 2,000 previously unknown star clusters and nebulae. Owing to the huge light-loss at each reflected surface of his reflectors, Herschel eventually decided to dispense with the secondary mirror in the Newtonian form. Instead, he tilted the primary mirror so that its focus could be examined off-axis directly at the front of the tube – a form he referred to as the "front-view." This concept is still used in some amateur-made telescopes today, but it's now known as the "Herschelian" in honor of its inventor. And while loss of reflectivity is not the concern today that it was in Herschel's time, moving the secondary mirror and its support out of the optical path essentially gives the unobstructed performance of a refractor combined with total freedom from the color aberrations inherent in lenses.

It has frequently been stated that a modern 6- to 8-inch telescope will show a large percentage of the objects in the Herschel catalogs (including many of William's faint and very faint nebulae), and that a good 12-inch should reveal every one of them even though most were found using the large 20-foot instrument. This is largely possible, of course, because of the much higher reflectivity of today's coated-glass telescope mirrors – and to a lesser extent because of modern eyepieces as well. (The Herschels primarily used single-lens oculars; multiple-element designs and antireflection coatings lay far in the future.) The author fully agrees with this assessment, based on half a century of viewing these wonders with telescopes of many different types ranging from 2-inches to 14-inches (and on occasion up to 30-inches – both reflectors *and* refractors) in aperture.

The great 40-foot telescope

Sir William's most ambitious telescope-making project and, indeed, the most ambitious in history up to that time, was the construction of his "Great 40-Foot" reflector with its 48-inch mirror (or 4 feet in diameter, resulting in a focal ratio of *f*/10). He received financial support for this massive undertaking from the King, as well an annual allowance for upkeep of the telescope once it was completed. Herschel actually made several mirrors for it before he finally was able to get one that would take an acceptable polish and figure. In 1787, using one of its first mirrors, Herschel climbed into the mouth of the huge tube and searched for the focus. His target was the Orion Nebula, which he described as "extremely bright" but the figure was far from perfect. On later attempts he used Saturn as his test object, discovering several new satellites while at it. Some idea of the light-grasp of this instrument can be had from this famous account of the star Sirius as seen through it:

> *. . . the appearance of Sirius announced itself, . . . and came on by degrees, increasing in brightness, till this brilliant star at last entered the field of view of the telescope, with all the splendour of the rising sun, and forced me to take the eye from that beautiful sight.*

Regular work with the telescope finally began in 1789. But Herschel was never pleased with the telescope's performance. That very few of the objects contained in the Herschel catalogue were actually discovered with the 40-foot certainly confirms this statement. How very sad for Sir William after all his labors over this great instrument! But while it was a disappointment for him, it certainly was not for the many sightseers who came to gawk at this wonder of the ages, including royalty and dignitaries of all levels, and noted scientists from the world over. Even today, the image of Herschel's mammoth 40-foot telescope remains one of the great – if not *the* greatest – icons of astronomical history, surpassed perhaps only by the Hubble Space Telescope itself. And here two very important facts need to be pointed out. First, all of Herschel's many telescopes, including the 40-foot, were mounted as simple altazimuths, being moved about the sky and tracked manually. Secondly, they were all mounted outside of his various residences in the open night air. Amazingly, for all his fame and discoveries, Sir William never had an observatory!

The Herschel designations

William Herschel's classes

Despite Sir William's pioneering discoveries in the fields of solar system and stellar astronomy, it's his deep-space explorations for which he is best-known and remembered. Some 2,500 star clusters and nebulae (which included many galaxies, again the true nature of which was unrecognized at that time) were catalogued under the following eight categories, or "classes" as he called them, with the total number of objects in each indicated in parentheses:

Class I – Bright Nebulae (288)
Class II – Faint Nebulae (909)
Class III – Very Faint Nebulae (984)
Class IV – Planetary Nebulae (78)
Class V – Very Large Nebulae (52)
Class VI – Very Compressed and Rich Clusters of Stars (42)
Class VII – Compressed Clusters of Small (Faint) and Large (Bright) Stars (67)
Class VIII – Coarsely Scattered Clusters of Stars (88)

Thus, William's entire catalogue contains a total of 2,508 *entries*, with Classes II and III accounting for 1,893 of them. (Note that the actual *number* of objects is somewhat less than this, since some three dozen were either inexplicably assigned to more than one class or were entered twice in the same class.) Such a large number of targets (with a great percentage of them being labeled faint and very faint by their discoverer, who used the largest telescopes in the world at the time to find them) has discouraged many observers from attempting to view the entire catalog. The author suggested some years ago in both *Sky & Telescope* and *Astronomy* magazines that a much more realistic goal could be had by dropping Classes II and III as largely difficult and visually less-interesting specimens, and going after the remaining 615 objects. This suggestion was the motivation for the founding of a national Herschel Club in the United States under the auspices of the Astronomical League (see the reference section on pages 42–3 for more about this).

Out of respect for Messier's work, William Herschel included relatively few of the famed "M-objects" in his own compilations. Those he did include refer to features within those objects apparently unnoticed by Messier, as well as two of the infamous "missing" M-objects (M 47 and M 48). Also included were the ones numbered from M 104 to M 110. These objects were only attributed to Messier long after Herschel's time, later historical research showing that they had indeed been seen by Messier (or one of his colleagues) but were not included in his original catalog. In Sir John's case, he *did* assign his own numbers to most of the Messier objects, as can be seen from the target list in Appendix B. Some may wonder why he included so many of Messier's discoveries along with his own. Noted astronomical historian Michael Hoskin explains it this way: "John was preparing a catalogue of clusters and nebulae for efficient use by observers and it would have been bizarre to omit the most prominent [of them]. William, by contrast, was acting the natural historian and offering new specimens he had collected."

It should be noted that none of William Herschel's objects will be found below a declination of about −33 degrees owing to the rather high latitude of his various observing sites around London. Had he been able to see even another 7 to 10 degrees further south, he would surely have laid claim to (and been thrilled by!) such wonders as the big, bright galaxies NGC 1316 and NGC 1365 in Fornax, and NGC 55 and NGC 300 in Sculptor; or the radiantly glorious open cluster NGC 2477 in Puppis; or the fascinating planetary NGC 3132 in Vela (the Eight-Burst Planetary – rival of the northern sky's famed Ring Nebula in Lyra). Instead, these were left to his son to find during his later survey of the southern sky. John did not use specific classes in his catalog of discoveries as his father had but a running number instead. (He also sometimes unintentionally gave two different numbers to the same object on different occasions.) Under the "Name/Notes" column in the target list in Appendix B, numbers are also given by John for many of William's objects, these being the ones he assigned during his re-survey of his father's discoveries. Note also those objects designated in that column by "CH." These are ones originally discovered by Caroline Herschel and later included in her brother's catalog.

"Nonexistent" objects

In a situation analogous to the saga of the famed "missing" Messier objects (which have now all been accounted for as errors in identification and/or position), there's the case of objects the Herschels discovered and catalogued but which supposedly can't be found in the sky today! Many of these "disappearances" have involved entries in William's Class VIII, which are coarsely scattered clusters of stars that were described as "poor" by him. As such, they are often difficult to pick out from the stellar background since most open clusters lie along the plane of the Milky Way's rich stratum of stars. The modern story of Herschel objects apparently having vanished from the sky really dates back to 1973 when *The Revised New General Catalogue of Nonstellar Astronomical Objects* (or *RNGC*) was published by astronomers Jack Sulentic and William Tifft. The primary reference for this comprehensive work was photographs taken for the famed National Geographical Society–Palomar Observatory Sky Survey with the 48-inch Schmidt camera on Palomar Mountain, home of the 200-inch Hale reflector. Objects that could not be identified on the large-scale plate prints were given a "type" code of "7" in the *RNGC*, meaning they are "nonexistent." (They are indicated for objects in the Appendix B target list by "NE" under "Type.") These included no fewer than 30 of the 88 clusters in William Herschel's Class VIII alone. As a point of interest, it should be mentioned here that the *RNGC* compilers also rejected a number of John Herschel's clusters as not existing in addition to those of his father. In 1975 two Canadian amateur astronomers – Patrick Brennan and David Ambrosi – began examining the sky for these missing objects using a modest 6-inch reflector. As Brennan later wrote, "Have you ever encountered a 'nonexistent' *RNGC* cluster alive and well, so to speak?" These observers found that many of the rejected Herschel clusters actually *were* visible in the eyepiece even if they weren't distinguishable on the Palomar prints, and so were not really missing after all. Based on the author's personal experience, most of the missing Herschel objects do, in fact, exist and offer observers a wonderful challenge to identify them.

Miscataloged objects

A fair number of William Herschel's discoveries were cataloged in the wrong class (and to a lesser extent those of John as well). As just one striking example, there's H IV-50 (NGC 6229) in Hercules. William considered this little object to be a planetary nebula and so it was long viewed to be such by most of the classic observers. And indeed, it does look like a typical planetary in the eyepiece. But, in reality, it's a globular cluster that apparently was beyond the resolution capabilities of his telescopes. And many other small globular clusters were assigned to Class I as nebulae. (In John's case, a number of objects listed by him as globulars are in reality tight open clusters.) Likewise, Class IV actually contains many diffuse nebulae and more galaxies than true planetaries! Such misidentifications as these are hardly unexpected, for nothing was known at the time of the actual physical nature of most of the nebulous objects seen in the eyepiece, spectroscopic analysis and astrophysics still lying in the future. The Herschels based the classification of their discoveries *solely upon their visual appearance in their various telescopes*. But all of this adds to the fascination of viewing these objects, as we attempt to verify their eyepiece impressions and to see why the Herschels placed them in the classes they did. And, while having to rely strictly on what these objects looked like to the eye resulted in a sizeable number of objects being misclassified, in other cases this reliance led to some profound insights and discoveries. One example with important historical significance involves the planetary nebula H IV-69 (NGC 1514) in Taurus, which appears as an obvious nebulous halo surrounding a 9th-magnitude star even in small telescopes. Here is Sir William's description of this object: "A most singular phenomenon! A star of about 8th-magnitude with a faint luminous atmosphere, of circular form, and about 3 minutes in diameter. The star is in the centre, and the atmosphere is so faint and delicate and equal throughout that there can be no surmise of it consisting of stars; nor can there be a doubt of the evident connexion between the atmosphere and the star." Thus he recognized for the first time the existence of "a shining fluid of a nature totally unknown to us" as he described it. Until this observation, all diffuse nebulae were thought to be simply unresolved masses of stars. This amazing deduction – *based solely on the appearance of this object in the eyepiece of the telescope* – showed nebulae to be gaseous long before the spectroscope actually proved it! Such is the power of *really seeing* what it is you are looking at in the eyepiece, as Sir William himself advised.

Finally, mention should be made that William Herschel's various discoveries originally appeared as papers in the *Philosophical Transactions* of the Royal Society of London in the late 1700s. In 1864, John Herschel published his monumental *General Catalogue of Nebulae* (or *GC*) also in the *Transactions*, its more than 5,000 entries having been found mostly by his father and himself. Based heavily on the *GC*, J.L.E. Dreyer subsequently compiled the famed *New General Catalogue of Nebulae and Clusters of Stars* (or *NGC*). Its 7,840 entries contain among them the only complete listing of all of Sir William's and Sir John's discoveries outside of the *GC* itself, providing shorthand descriptive notations that they invented. These were adopted by Dreyer, and in some cases added to in the light of more recent (at that time) knowledge.

Overlooked objects

As thoroughly as the three Herschels swept the skies (especially those visible from England), they still inexplicably missed a number of fascinating objects – all of which are visible in typical backyard telescopes today. Among these are the Helix Nebula in Aquarius, the Flaming Star Nebula in Auriga, Stephan's/Webb's Protoplanetary Nebula in Cygnus (which rivals the famed Blinking Planetary also in Cygnus – so named by the author in 1963 from its amazing behavior – which Sir William did discover), Barnard's Dwarf Galaxy in Sagittarius, and Hind's Variable Nebula in Taurus. One of the author's favorite overlooked objects is the big but dim open cluster NGC 6791 in Lyra. This amazingly rich swarm hosts over 300 stars and looks very much like a globular cluster, both visually and on photographs.

Map parameters and selection criteria

The 32 maps comprising this *Atlas* were planned, drawn and labeled by Wil Tirion, widely recognized as the world's greatest celestial "cartographer" and creator of such classic works as the magnificent *Sky Atlas 2000.0* and *The Cambridge Double Star Atlas*.

They show over 2,500 of the brighter Herschel objects suitable for viewing with typical backyard telescopes in the 2-inch to 14-inch aperture range. In addition to this introductory guide to the *Atlas*, the original target list in Appendix B and the showpiece roster below were compiled by James Mullaney based on his personal observations of thousands of Herschel objects over the past 50 years – ones using literally hundreds of telescopes of all types and sizes within the aperture range stated above. No doubt experienced observers will have favorites that are not shown, but those that are certainly include the best of the Herschels' discoveries. (All 400 objects on the Astronomical League's Herschel 400 Club target list are also included, being designated with an asterisk there.) All told, some 25,000 stars are plotted in half-magnitude steps on the maps to a visual magnitude limit of 7.5. The nominal visual magnitude cutoff for the Herschel objects themselves is 12.5. However, some fainter ones are included that have special appeal. In the case of Classes I, IV, V, VI, VII, and VIII, *every* object in each class, whatever its magnitude, is shown in order to provide observers with the complete contents of these six visually rewarding groups (those suggested by the author as the basis for creating Herschel clubs). Note that all of William Herschel's objects appear on the maps without an "H" prefix (since his classes clearly identify his discoveries), while John Herschel's have an "h" prefix. And while mentioning dim objects below the map limit, it's very important to point out here that many of the Herschel objects plotted *often have one or more fainter objects lying within the same wide, low-power eyepiece field* (ones found by the Herschels and by others)! Thus, the field of view should always be scrutinized for these in addition to the primary target itself.

A magnitude scale and color-coded key to the symbols used to denote various types of deep-sky objects appear at the top of each map. Note that the edges of the maps have blue-arrowed numbers indicating adjoining ones (with some overlap) in each direction, which will be found very helpful in navigating the *Atlas*. Also, soft lavender lines have been used to connect the principal stars in each constellation, the boundaries of which are indicated by dashed lavender lines. (Note that all of the lines used are "red-light-friendly," remaining visible when employing such illumination to preserve night vision.) These so-called "stick figures" also aid in finding your way around the sky. Many observers today use computerized ("Go-To") target acquisition, and most of the brighter Herschels plotted on the maps – particularly those given in the showpiece roster below – can be located by entering their NGC designation, common name and/or coordinates on the controller's keypad. (Again, see Appendix B for data on all objects plotted.) To many of us "purists," this modern technology takes away much of the fun of good old-fashioned "star hopping" (or "sweeping" as the Herschels did) to learn and find your way around the sky – which is really one of the primary purposes of a star atlas like this and one of the joys of leisurely stargazing!

Instrumental factors

Light-grasp, resolution and magnification

There are three types of "power" used in describing a telescope's capabilities. The one uppermost in most beginners' minds is magnification, but it is actually the least important of the three. The primary one for viewing the Herschel objects (the majority of which are faint compared with other types of celestial objects) is its *light-gathering power.* Simply stated, the larger the telescope, the more light it collects and the brighter the image it delivers. And it's paramount here to realize that *doubling the aperture of a telescope quadruples the amount of light collected*, since the area of the objective lens or primary mirror increases as the square of its diameter. Next in importance is the telescope's *resolving power*, or ability to reveal fine detail in an image. Much has been written in the literature over the years about the resolution capabilities of various apertures, particularly in regards to the splitting of close double stars. The best-known and most widely used of the various resolution criteria is the famed *Dawes' Limit*, $R = 4.56/A$, where R is the resolution in arc-seconds and A is the telescope's aperture in inches. (For much more about this see the introductory section of *The Cambridge Double Star Atlas*.) The primary factor at play in determining if a given telescope will resolve tight clusters, or show structure in a nebula or galaxy (aside from atmospheric conditions) is aperture. And in this case, when the aperture is doubled, so too is the resolution – a telescope twice as big as another one will show twice as much detail (assuming they are both of the same optical quality). In achieving optimum results here (particularly in the case of resolving fine planetary detail or splitting close double stars), the telescope should be used at what is known as its "resolving magnification." This is typically given as 25× per inch of aperture, which leads us to a telescope's *magnifying power*, or how many times bigger it makes an object than what the unaided eye sees. Observers typically employ a range of low, medium, and high powers on their instruments. Recommended magnifications for viewing a Herschel object depend on what type it is. For big scattered open clusters or extensive nebulosities (and even a few of the largest galaxies), the lowest possible power and widest field of view (which depends on eyepiece design) give the most pleasing results. The same applies in the initial sweeping for objects to find them. In the case of rich, compact open clusters and tight globulars, medium magnifications typically give the best view. The same goes for the smaller diffuse nebulae and most planetaries, and also for galaxies in general. Unless the atmosphere is steady, high powers can give a "washed-out" appearance to the image and typically greatly restrict the field of view. But they are still worth trying on all but the very largest of objects to see if any additional details are revealed.

Another factor affecting telescopic image quality aside from atmospheric conditions (see below) is that known as "local seeing" or the thermal conditions in and around the telescope itself. Heat radiating from driveways, walks and streets, houses and other structures (especially on nights following hot days) plays a significant role. This is why observing from grassy areas away from buildings gives the best results. The cooling of the telescope's optics and tube assembly is especially critical to achieving sharp images. Depending on the season of the year, it may take up to an hour or more for the optics (especially the primary mirror in larger reflectors) to reach equilibrium with the cooling night air. During this cool-down process, air currents within the telescope tube itself can play absolute havoc with image quality, no matter how good the optics and atmospheric seeing are. (This is less of a concern using refractors with their closed tubes, which in smaller apertures at least are essentially ready for immediate use.) Surprisingly, even the heat radiating from the observer's body can be a factor here if concerned with optimum resolution, particularly with reflecting telescopes having open-tubed truss-style designs. For much more on all aspects of telescopes and their use, see *A Buyer's and User's Guide to Astronomical Telescopes and Binoculars*, by the author (Springer-Verlag, London, 2007).

Optical quality and collimation

For the casual observation of the Moon, planets and brighter deep-sky wonders, a telescope of even mediocre optical quality can provide acceptable views. But for optimum viewing, good-to-excellent optical quality is essential. The condition of a telescope's optics and its all-important optical alignment can readily be determined by a simple test using a star itself. Known as the *extrafocal image test*, this involves looking at the image of a star, both inside and outside of focus, using a medium-to-high-power eyepiece. An ideal target for this purpose is Polaris in Ursa Minor (the Pole Star), which is neither too bright nor too faint, and has the great added advantage of not moving in the eyepiece as the Earth rotates, in case your instrument isn't motorized! A telescope having first-class (or "diffraction-limited") optics in perfect alignment (or *collimation* – see below) will show identical circular disks of light with a pattern of faint concentric interference rings on either side of focus as the eyepiece is racked in and out. These rings should be uniformly spaced and of even intensity. If not, this indicates zones in the optical figure – a condition known as "spherical aberration." A "shaggy" look to the rings indicates a rough polish to the glass rather than the desired smooth one. If the extrafocal images are triangular rather than circular, this shows that the objective lens or mirror is pinched in its cell. Elliptical-shaped images that rotate 90 degrees on either side of focus are the most to be feared, since they reveal the serious optical defect known as "astigmatism" or a warping of the glass itself. However, astigmatism in the observer's own eye, a bad eyepiece, and especially optical misalignment can each produce the same effect!

Optical collimation is an entire subject unto itself. The term describes that condition in which all of the optical elements in a telescope are precisely lined up on the same optical axis – something that can be achieved by examining the extrafocal image (among other methods) while adjusting the alignment. The need for and actual process of collimation depends upon the type of instrument being used. Refractors and Maksutov–Cassegrains are typically permanently collimated, and in many cases no provision is even made for adjustment. Reflectors and Schmidt–Cassegrains typically do require periodic collimation, instructions for which are normally included in the manuals provided with commercially made telescopes. For optimum resolution and image contrast, a precisely collimated telescope is an absolute must. (The ultimate reference on interpreting extrafocal images and testing/collimating telescope optics is Harold Richard Suiter's *Star Testing Astronomical Telescopes: A Manual for Optical Evaluation and Adjustment*, Willmann-Bell, Inc., Richmond VA, 2009.) And one final note here: the extrafocal image test also makes it possible to judge something of the seeing conditions, ranging from local conditions within and immediately above the telescope to the upper atmosphere itself. Undulating waves and flashing patterns of light crossing over the image can say much about the steadiness of the atmosphere, as well as the telescope's thermal state and environment. Careful focusing will reveal moving patterns seemingly "floating" at different levels above the light path and (with experience) show if disturbances are atmospheric, or are within the telescope itself or its immediate vicinity.

Observing hints

It's often claimed that the person behind the eyepiece of a telescope is far more important than the size or type or quality of the instrument itself. The truth of this adage has proven itself time and again. Typical examples are that of a skilled observer using a small telescope seeing intricate detail on a planet like Jupiter or Mars at opposition, or subtle structure in a nebula or galaxy, that completely escapes an inexperienced observer using a much larger aperture. The fact is that the eye does not work alone, but in conjunction with the most marvelous "image processor" known – the human brain! It was Sir William Herschel himself, the greatest visual observer of all time, who said that "seeing" is an art and that as observers we must properly educate our eyes to *really see* what it is we are looking at in the eyepiece. And so this section is aimed at helping you get the most out of your nightly explorations of the heavens – especially in the observation of the star clusters, nebulae and galaxies discovered by the Herschels.

Training the eye

There are several distinct areas in which the human eye/brain combination can be "educated" to see better. We begin with two of especial importance when it comes to looking at Herschel objects. The first involves the technique of using *averted* (or side) *vision* in viewing faint deep-sky targets. This makes use of the well-known fact that the outer portion of the retina of the eye – that containing the receptors called *rods* – is much more sensitive to low levels of illumination than is the center of the eye containing the receptors known as *cones*. (See the discussion below on color perception.) This explains the common experience when driving at night of objects seen out of the corner of your eye appearing brighter than they actually are if you turn and look directly at them. Averted vision is especially useful in viewing low-surface-brightness targets like nebulae and galaxies, where the increase in the apparent brightness of the image is typically more than doubled.

The second area is that of *dark adaptation*. It's an obvious fact that the eyes needs time to adjust to the dark after coming out of a brightly lit room. Two factors are at play here. One is the dilation of the pupils themselves, which begins immediately upon entering the dark and continues for several minutes. The other involves the actual chemistry of the eye, as the hormone rhodopsin (often called "visual purple") stimulates the sensitivity of the rods to low levels of illumination. The combined result is that night vision improves noticeably for perhaps half an hour or so, continuing slowly thereafter. This explains why the sky looks black on first going outside, but later appears gray as you fully adjust to the dark. In the first instance, it's a contrast effect and in the second the eye has become sensitive to stray light, light pollution, and the natural airglow of the sky itself that were not seen initially. White lighting causes the eye to lose its sensitivity while red light preserves it, which is the reason for the well-known standard practice of using red illumination for reading star maps and making notes at the eyepiece.

Another aspect of training the eye is that of *visual acuity* – the ability to see or resolve fine detail in an image or in splitting close double stars. There's no question that the more time you spend at the eyepiece, the more detail you will eventually see. Even without any real purposeful training plan in mind, the eye/brain combination will learn to search for and find ever-finer detail in what it is viewing. But this process can be considerably accelerated by a simple exercise repeated daily for a period of several weeks. On a piece of white paper, draw a circle about 3 inches in diameter. Then using a soft pencil, randomly place various markings within the circle, ranging from broad patchy shadings to fine lines and points. Now place the paper at the opposite side of a room at least 20 feet or so away, and begin drawing what you see using the unaided eye. Initially, only the larger markings will be evident, but as you repeat this process over a period of time, more and more of the markings will become visible to you. Tests have shown improvements in overall visual acuity by as much as a factor of 10 from using such a procedure!

A final important area involving the eye/brain combination is that of *color perception*. At first glance, to the unaided eye the stars all appear to be white. But, upon closer inspection, differences in tint among the brighter ones reveal themselves. The lovely contrasting hues of ruddy-orange Betelgeuse and blue-white Rigel in the constellation of Orion is one striking example visible in the evening sky around January and February. Another can be found by comparing blue-white Vega in Lyra, orange Arcturus in Bootes and ruddy Antares in Scorpius – seen best together in the evening sky in July. Indeed, the sky is alive with color once you've been trained to see it! While the rods in the edge of the eye are light sensitive, they are essentially colorblind. Thus, for viewing the tints of stars in the more prominent open clusters, the subtle coloration of the brighter diffuse nebulae, and the eerie unearthly tints of many of the planetaries, direct vision should be employed – making use of the color-sensitive cones at the center of the eye. In short, stare directly at an object to perceive its color and off to the side to see it brighter.

Sky conditions

A number of atmospheric and related factors affect the visibility and appearance of celestial objects in the telescope. In the case of resolving tight open clusters or compact globulars, or seeing detail within nebulae or galaxies, the most important of these is atmospheric turbulence or *seeing*, which is an indication of the steadiness of the image. On some nights, the air is so unsteady (or "boiling" as it's sometimes referred to) that star images appear as big puffy, shimmering balls, and detail on the Moon and planets is all but nonexistent. This typically happens on nights of high transparency – those having crystal-clear skies in which the air overhead is in a state of rapid motion and agitation. These nights are ideal for viewing faint objects like nebulae and remote galaxies. On other nights, fine detail stands out on the Moon and planets like an artist's etching and star images are nearly pinpoints showing virtually no motion. Such nights are often hazy and/or muggy, indicating stagnant tranquil air over the observer's head, making them poor for viewing "faint fuzzies." Occasionally, observers are blessed with nights of both good seeing *and* transparency (such as those typically found at many of the world's major mountaintop observatories). Such opportunities should be utilized to the fullest and often result in "all nighters" in which observing sessions begin after sunset and continue until dawn! Various "seeing scales" are employed by observers to quantify the