Chapter 1
The Discovery of Open Clusters

From a place deeply involved in stellar organizations we look out at the sidereal universe. Immediately around our minute association of sun and planets are the bright white stars of the Ursa Major cluster, with one of its members, Sirius, but a few light years distant. Much greater than such near-by groups is the local system, a star cloud that includes thousands of the surrounding bright stars and a million or so of the fainter. Still more inclusive is the Galaxy, which holds sun, clusters, and star clouds, and which, in turn, may be but one unit in a higher example of the gravitational clustering of sidereal bodies.

—H. Shapley, Star Clusters [1930]

1.1 Pre-telescopic Observations of Open Clusters

In centuries past, before the advent of artificial lighting, our ancestors had a greater familiarity with the night sky than is the case today. Knowledge of the stars was valuable; it gave power to the astrologers and priests and aided farmers and sailors. Observing from properly dark skies, they would have noted the seasonal changing of the constellations; the great arch of the Milky Way crossing the sky and the bright “wandering stars,” the planets, making their way through the constellations of the ecliptic.

Observant ancients would have noticed more. In some parts of the sky, particularly along the plane of the Milky Way, were a number of small patches of enhanced brightness, such as that in the northern part of Perseus. Some of these patches could be resolved into faint stars, such as the Praesepe in Cancer, and others were more clearly composed of stars like the Pleiades (see Figure 1.1) and Hyades in Taurus.

The prominence of these last three objects resulted in them being featured in the starlore of many societies primarily because of the compactness of each group and the brightness of the individual members, together with the fact that they are visible from both northern and southern hemispheres. This is especially true of the Pleiades. This cluster seems to have found its way into the legends of almost all ethnic groups. A detailed account of these is given by Allen [1962] and Burnham [1978], where it is said that the name we use today is of ancient Greek origin. It is either derived from the word “to sail” indicating a heliacal rising heralding the start of the navigational season, or it may be a version of the Greek word “full” or “many.” While the Pleiades would have been apparent even to primitive peoples, the first written mention of them is found in Chinese records, dating almost 4500 years ago. Certainly, they were known in Old Testament times and are specifically mentioned in the book of Job:

It is God who moves mountains, giving them no rest, turning them over in his wrath; who makes the Earth start from

its place so that its pillars are convulsed; who commands the Sun’s orb not to rise and shuts up the stars under his seal; who by himself spread out the heavens and trod on the crests of the waves; who made Aldebaran and Orion, the Pleiades, and the circle of the southern stars... (New English Bible 1970)

In the centuries after the collapse of the Roman Empire and when European culture was at its nadir, arts and sciences flourished, and astronomical references are often found in Arabian literature. For example, in a poem written by Sadi in 13th century Persia, we find the line:
The ground was as if strewn with colored enamel, and necklaces of Pleiades seemed to hang upon the branches of the trees....

In the legends of the Kiowa people of North America, the massive Devil’s Tower rock formation in Wyoming was created by the Great Spirit to protect seven Indian maidens who were being pursued by bears. The maidens were subsequently placed in the sky as the Pleiades cluster. These stars were also important in the world system of the peoples of Mexico and Central America. The west face of the Great Pyramid of the Sun at Teotihuacan is oriented towards the setting point of the Pleiades.

All over the world, from Europe and Asia, through the Americas and among the people of the Pacific islands and Australasia, the Pleiades have a place in myth and legends. Often, they are considered to be female and almost always to be seven in number; in many traditions there is also a story about a “lost Pleiad.” It has sometimes been suggested that variability in the shell-star Pleione may account for this latter aspect, but why the number seven should so often be quoted is a mystery. A person with average eyesight, at a fairly average site, can normally see between six and nine stars but some people with better eyesight, or a good observing location, can observe many more without optical aid. Maestlin, the tutor of Kepler, is said to have mapped eleven stars in 1579 prior to the invention of the telescope. Amateur astronomer William R. Dawes (1799–1868) once described as “probably the best astronomical observer in England in his day” and renowned for his keen eyesight, was clearly able to distinguish thirteen stars, and, from good sites, many modern observers have convincingly reported seeing between 12 and 14. Indeed, one of us [BA], can clearly recall making such observations himself in the days when his eyesight was better! Occasionally, some observers have claimed to be able to see as many as 18.

The star catalog of the great Greek astronomer Hipparchus (190–120 B.C.) is known to have included at least three clusters, the Double Cluster in Perseus and Praesepe (M 44), although these would have been thought of as nebulae rather than clusters. Unfortunately, no copies of this catalog have survived the passage of time. However, the revised and enlarged version compiled at Alexandria by Ptolemy (c. 83–161 A.D.) has survived as the Almagest, from the popular name of its Arabic translation. This catalog lists as nebulae, in addition to those recorded by Hipparchus, the Coma open cluster, M 7 in Scorpius, and the λ Orionis (= Collinder 69) group [Glyn Jones 1975].

In the 10th century, the Persian astronomer, Al Sûfi (903–986 A.D.), produced his Book of the Fixed Stars which included another important early star catalog based on the earlier work of Ptolemy. This included as nebulae those clusters already known, but also added the ο Velorum (IC 2391) cluster and the asterism now known as “Brocchi’s Cluster” (Collinder 399) in Vulpecula. The Book of the Fixed Stars also includes the first recorded observation of the “nebula” now known as the galaxy M 31 in Andromeda.

1.2 Galileo Examines the Nebulæ

By the time the telescope was invented, around 1608, probably nine open clusters were known, of which about four could be more-or-less resolved without optical aid. It was not long afterwards that this remarkable invention was turned toward the night sky; Thomas Harriott used one to observe the surface of the Moon as early as the summer of 1609. The first person to make systematic astronomical observations, however, was the Italian mathematician and inventor, Galileo Galilei (1564–1642), who also observed the Moon and discovered the four major satellites of the planet Jupiter. Galileo also looked at the stars and “nebulæ,” and his discoveries were published in 1610 in his book Sidereus Nuncius (The Starry Messenger). Of the Milky Way he wrote:

I have observed the nature and material of the Milky Way. With the aid of the telescope this has been examined so directly and with such ocular certainty that all the disputes which have vexed philosophers through so many ages have been resolved, and we are at last freed from wordy debates about it. The galaxy is, in fact, nothing but innumerable stars grouped together in clusters. Upon whatever part of it the telescope is directed, a vast crowd is immediately presented to view. Many are large and bright, while the number of smaller ones is quite in calculable.

Obviously, Galileo’s statement that the galaxy can be resolved into stars “grouped together in clusters” is open to interpretation and his intention may have been lost in translation. He may certainly have meant to refer to the background clumpiness of the Milky Way; however, it is possible that he did observe some genuine clusters but did not think to record specific groups in his notes.

The latter is also suggested in the first part of the following paragraph where Galileo describes his observations of the nebulae:

But it is not only in the Milky Way that whitish clouds are seen; several patches of similar aspect shine with faint light here and there throughout the aether, and if the telescope is turned upon any of them we are confronted by a tight mass of stars. And what is even more remarkable, the stars which have been called “nebulous” by every astronomer to this time turn out to be a group of very small stars arranged in a wonderful manner. Although each star separately escapes our sight on account of its smallness, or the immense distance from us, the mingling of their rays gives rise to that glow which was formerly believed to be some denser part of the aether that was capable of reflecting rays from stars or from the Sun.
Galileo’s opinion that all nebulae could be resolved into stars persisted for almost 200 years, until 1790, when William Herschel’s observations of the planetary nebula NGC 1514 and its apparent central star dispelled the idea. In his 1791 paper, *On Nebulous Stars, Properly So Called*, Herschel described his observations and theories on this object and concluded that it could only be satisfactorily explained by some kind of “shining fluid,” which was subsequently established by Huggins to be, in fact, gaseous.

### 1.3 Early Telescopic Discoveries of Open Clusters

The invention of the telescope gave an unprecedented impetus to the science of astronomy, bringing about many new discoveries. One of the first to appreciate the significance of Galileo’s work was Giovanni Batista Hodierna (1597–1660), astronomer at the court of the Duke of Montechiaro in Sicily from 1637 until his death in 1660. In 1654, Hodierna published a booklet which included several observations of nebulae and clusters, some of the objects being his own discoveries [Serio 1985; Glyn Jones 1986]. He also seems to have been the first person to attempt some kind of classification system for deep-sky objects, dividing objects into three classes: *Luminosae*—nebulae containing some naked-eye stars, *Nebulosae*—nebulae which could be resolved into stars with a telescope, and *Occultae*—nebulae which could not clearly be resolved even when observed with a telescope. In each category, Hodierna listed the objects (using the present day identifications) in Table 1.1.

In addition to the above, Hodierna mentioned quite a number of other objects, some of which have been identified with M 47, M 41, NGC 2362, NGC 2451, and objects that are possibly M 33, M 34, M 79, NGC 2169, and NGC 2175. This makes him the first known observer of nine objects, and independent discoverer of two more, a most remarkable achievement not matched for a considerable number of years. Not unexpectedly, most of the objects found were some of the brighter star clusters.

During the following century, small numbers of nebulae (mostly clusters) were discovered by several observers; for example, Gottfried Kirch (1639–1710) found the open cluster M 11 in 1681 and the globular cluster M 5 in 1702, Edmond Halley (1656–1742) found the globular clusters ω Centauri and M 13 in 1677 and 1714 respectively, and Philippe de Cheseaux (1718–1751) found IC 4665, NGC 6633, M 16, M 25, M 35, M 4 and M 71, as well as M 6 independently. However, the next listing of any significance, following that of Hodierna, was published by Nicholas-Louis de Lacaille (1713–1762), and resulted from his expedition to the Cape of Good Hope in South Africa from 1751 to 1753. The most outstanding result of this trip was a catalog of 9,776 southern stars. In addition, he found 42 nebulae and star clusters, many of which were original discoveries. Lacaille is credited with first discovery of the great globular cluster NGC 104, the “Tarantula Nebula”—NGC 2070, the bright spiral galaxy NGC 5236 (= M 83) and NGC 3372—the great η Carinae nebula. As far as open clusters are concerned, Lacaille recorded what would later be known as NGC 2477, NGC 2516, NGC 2546, NGC 2547, NGC 3228, NGC 3532, NGC 3766, NGC 4755 (“Jewel Box” cluster), NGC 5662, NGC 6025, NGC 6124, NGC 6231, NGC 6242, IC 2395, IC 2488, IC 2602, and Tr 10, many of the finest sights in the southern sky.

The later years of the eighteenth century saw an almost exponential increase in the discovery of new telescopic deep-sky objects. Many of the brighter were recorded in the landmark catalog of Charles Messier (1730–1817) and Pierre Mechain (1744–1804), which was published in 1784. The scope and history of this catalog has been well covered in other publications [Glyn Jones 1968; Mallas and Kreimer 1979; O’Meara, 2000], and observation of the Messier objects can be recommended as an excellent introduction to the study of deep-sky astronomy generally.

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**Table 1.1 Hodierna’s Categorization of Objects**

<table>
<thead>
<tr>
<th>Luminosae</th>
<th>Nebulosae</th>
<th>Occultae</th>
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<tbody>
<tr>
<td>1. Pleiades</td>
<td>1. Praesepe</td>
<td>1. “Preceding the two southern stars of Coma Berenices” (asterism)</td>
</tr>
<tr>
<td>2. Hyades</td>
<td>2. M 7</td>
<td>2. “The one following these stars, in the shape of an open rose, according to Ptolemy, and of an ivy leaf according to Copernicus” (asterism)</td>
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<tr>
<td>4. α Per cluster</td>
<td>4. M 6</td>
<td></td>
</tr>
<tr>
<td>5. M 42</td>
<td>5. ν₁, ν₂ Sagittarii (asterism)</td>
<td></td>
</tr>
<tr>
<td>6. λ Ori cluster</td>
<td>6. M 8</td>
<td></td>
</tr>
<tr>
<td>7. ζ Sco &amp; NGC 6231</td>
<td>7. M 36/M 37/M 38</td>
<td></td>
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<tr>
<td>8. “In the water of Aquarius” (unknown object)</td>
<td>8. Cr 399</td>
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<td></td>
<td>9. 88 Her</td>
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<td></td>
<td>10. σ Cap.</td>
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far as open clusters are concerned, Messier included 30 objects in his list: M 6, M 7, M 8, M 11, M 16, M 17, M 18, M 20, M 21, M 23, M 24, M 25, M 26, M 29, M 34, M 35, M 36, M 37, M 38, M 39, M 41, M 42, M 44, M 45, M 46, M 47, M 48, M 50, M 52, M 67, M 73, M 93 and M 103; Messier himself discovered at least 9 of these.

1.4 Herschel’s Classification System

Following the publication of the Messier catalog, a copy was obtained by Dr. William Watson, who sent it to his friend William Herschel (1738–1822). Herschel is one of the most remarkable figures in the history of astronomy. Born in Hanover Germany, he moved to England in November 1757; eventually settling in Bath, where he was joined by his sister Caroline. As a talented musician, Herschel soon became well established and prosperous, and was earning the not inconsiderable sum of £400 per year by 1771. Considering his subsequent distinguished career in astronomy, he did not take up a serious interest in this subject until about 1773 at the age of 35. His interest seems to have been sparked when, on buying a copy of Ferguson’s Astronomy, he “read of the many charming discoveries that had been made by means of the telescope,” and resolved to see the heavens and planets himself.

Herschel had a talent for telescope making and soon developed an international reputation for his instruments. After several years of telescope building and general observational work, Herschel set about a systematic search for double stars. He realized that, in the case of optical pairs where the components are greatly separated but along more-or-less the same line of sight, the distance of stars might be determined by trigonometric means. During this search, on March 13, 1781 he became the first person in modern times to discover a major planet and was subsequently honored by election to the Royal Society. He received an award of an annual stipend of £200 by King George III. This, together with a significant income from telescope making, enabled him to give up his musical career and concentrate full time on astronomy.

Watson sent Herschel the catalog recently published by Messier on December 7, 1781 the day of his election to the Royal Society. Herschel made a point of searching for every object on the list using a recently constructed 30-cm reflector. His enthusiasm for this work grew and with the completion of an even larger telescope (see Figure 1.2 on page 5) with a 48-cm diameter speculum mirror, he commenced a massive survey of the night sky, discovering some 2300 new objects within a period of seven years.

This significant database of observational material gave Herschel the means to classify the objects he had found. He separated them into eight categories:

I. Bright nebulae
II. Faint nebulae
III. Very faint nebulae
IV. Planetary nebulae
V. Very large nebulae
VI. Very compressed, rich clusters of stars
VII. Compressed clusters of small and large stars
VIII. Coarsely scattered clusters of stars.

Although now long superseded, the Herschel designations which resulted from this classification system proved sufficiently useful that they were often used by amateur astronomers until recent times. Indeed, Herschel’s designations were used as the primary numbering system for deep-sky objects in Norton’s Star Atlas until the 18th Edition was published in 1989.

Herschel also speculated on the origin of some of the morphological features he found in the nebulae and clusters that he discovered. In this he used the evidence of his extensive star count surveys, or gauges. Having gauged the Milky Way in various places, he concluded that the number of stars “constantly increase and decrease in proportion to its apparent brightness to the naked eye” and, supposing that the stars were of various sizes and brightnesses and almost equally distributed in space, made the following suggestions concerning the star clusters. First, in the case of a star considerably more massive than its neighbors, it would have the effect of attracting less massive stars close by, creating a globular cluster. He also suggested that open clusters (then called “irregular clusters”) were formed when a group of similarly massive stars happened to lie within a certain distance of each other causing their mutual gravitational attraction to draw them together. The variations on these forms, he felt, could be explained by combining the effects described above, and that the occurrence of several clusters in the same region of space could be caused by the same principles on a larger scale—clusters being pulled together by their mutual gravitational attraction. As a result of these clusterings of stars and of star clusters, the dark spaces or “holes” which he had found in many Milky Way fields could be explained: they had been emptied by the stars being gravitationally attracted into clusters. Even if none of these theories is correct, Herschel’s model was perhaps the first to be developed from a good observational base. In addition, he made [1785, 217] the following comment:

These clusters may be the Laboratories of the universe, if I may so express myself, wherein the most salutary remedies for the decay of the whole are prepared.

There are prophetic elements in this statement, even if it is right for the wrong reasons!

To be fair to Herschel, his views did change as shown in a paper published in the Philosophical Transactions of 1814 where he drew attention to the common phenomenon of stars being found in association with nebulosities:

The formation of these objects is extremely instructive, as it
manifests the affinity between the matter of which stars are composed and that of the most unshapen chaotic mass of nebulosity. For the vanishing chevelure of a star being equally connected, on the one hand, with the generally diffused nebulous matter, and on the other with the star itself, round which it is in a state of gradual condensation; this double union denotes the mutual gravitation of the whole mass of nebulosity and the stars towards each other; and unless this proof can be invalidated, we must admit the fact of the growing condition of stars, that are in the situation which has been pointed out.

This argument adds greatly to the probability of stars being originally formed by the condensation of the nebulous matter; for as it now appears that stars must receive an addition to their solid contents, when they are in contact with nebulosity, there is an evident possibility of their being originally formed of it. Moreover, the affinity between the nebulous and sidereal condition being established by these observations, we may be permitted to conceive both the generation and the growth of stars, as the legitimate effects of the law of gravitation, to which the nebulous matter, as proved by observation, is subject.

He clearly—and correctly—hypothesizes the likelihood of stars forming from nebulae, although he is referring to bright nebulae not dark nebulae, the existence of which had yet to be shown. It is also interesting to note his belief that after their formation, stars could continue to “grow” by absorbing material from the nebulosity.

1.5 Open Clusters in the NGC

Following Sir William Herschel, the most important contributor to the discovery of deep-sky objects was William’s son, John Herschel (1792–1871). John was a man of great talent himself and contributed to a wide range of mathematical and scientific studies. In this respect he benefited from his father’s experience, knowledge and connections and in due course, his father’s estate, when the older Herschel died in 1822. Not only did John inherit much of William’s telescopic and other equipment, but also a substantial income. Furthermore, his mother, Lady Mary Herschel, had been the widow of a wealthy merchant when she married William in 1788, and when she died in 1832, John acquired the means to pursue his interests as he wished. In particular, he took his father’s 48-cm (18¾-inch) reflector to South Africa, where he and his family stayed from 1834 to 1838, making extensive observations of southern sky nebulae, clusters and double stars. This was a significant and costly undertaking for the time. When he boarded the Mountstewart Elphinstone on November 13, 1833, he was accompanied by his wife, three children, a maid, a manservant and his mechanic, John Stone, together with three telescope mirrors, the telescope superstructure, an equatorial refractor, transit circle, clocks and other supporting equipment. On his return, it took him over eight years to write up and publish his observations in a monumental work entitled Results of Astronomical Observations made during the Years 1834, 5, 6, 7 and 8 at the Cape of Good Hope [Herschel 1847].

Later, he spent a great deal of time reducing his observations and updating and correcting his father’s work to produce A General Catalogue of Nebulae containing 5,079 objects, which was published in 1864. However, John Herschel was by no means the only astronomer studying the deep sky. Many contemporary astronomers were also engaged on the search for new nebulae and clusters. For example, in the southern hemisphere, James Dunlop, using the observatory of Sir Thomas Brisbane at Paramatta, produced a catalog of 629 southern objects, which was published in the Philosophical Transactions of 1828. (Unfortunately, John Herschel was unable to find two-thirds of Dunlop’s objects.) However, by far the greatest level of activity was in the northern hemisphere with observations by Barnard, Bond, Holden, Stone and Swift in the U.S.A.; D’Arrest in Denmark; Bigourdan and Stephan in France; Marth in Malta; Auwers, Hartwig and Schmidt in Germany; and Lord Rosse and his assistants in Britain.
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William Parsons, the third Earl of Rosse (1800–1867), had constructed by far the largest telescope of its time, a 1.83-meter (72-inch) reflector, which was sufficiently complete for observations in 1845. He built it on the grounds of Birr Castle near Parsonstown in County Offaly, Ireland. Like large telescopes today, there was a great demand on its time and, in addition to the third Earl himself (and later his son), there was a series of resident astronomers who used it, primarily George and Bindon Stoney, William Rambaut, R.J. Mitchell, S. Hunter, Sir Robert Ball, Ralph Copeland and John Louis Emil Dreyer (1852–1926, see Figure 1.3). With all this activity astronomers soon found the need for a supplement to the *General Catalogue*; this was compiled by Dreyer and published in 1878. In 1886, he compiled a second supplement and submitted it for consideration by the Royal Astronomical Society:

But considering the circumstance that Herschel’s work is practically out of print, and that the simultaneous use of three catalogues and two copious lists of corrections would be very inconvenient, the Council proposed to me to amalgamate the three catalogues into a new General Catalogue.

Dreyer accepted the proposal and in 1888 *A New General Catalogue of Nebulae and Clusters of Stars* [Dreyer 1888] was published, covering all deep sky objects known to have been discovered up to 1887. This general compilation of deep-sky objects together with its supplements, the two *Index Catalogues* [Dreyer 1895, 1908], covering nebulae and clusters discovered up to 1907, remains the preferred reference list for observers of almost all types of deep-sky objects and is particularly useful for star clusters. Since many galactic clusters are comparatively conspicuous objects, they were readily picked out by the visual observers of this era. The selection was largely intuitive; therefore, the NGC and IC catalogs contain quite a few asterisms. Perhaps the most complete modern catalog of open clusters of recent years, the 5th Edition of the *Lund Catalogue of Open Cluster Data* [Lyngå 1987], contains information on 1152 objects, 541 of which are also listed in the NGC or IC.

Because of the rather subjective nature of the selection process, a number of NGC clusters have been omitted from some modern compilations, such as the RNC [Sulentic and Tifft 1973]. The selection criteria are open to question, leaving doubt about the existence of some objects. This problem is addressed in more detail in Chapter 3.

The NGC was the last, complete, major catalog of deep-sky objects to be compiled by visual observers and to which amateur astronomers made a significant contribution. After this, the direction and techniques of astronomy changed. The science became more qualitative than quantitative as astrophysics developed to dominate the field, and photography supplanted visual observations. Indeed, the second *Index Catalogue* covering the objects IC 1530–IC 5386 was made up primarily of photographic discoveries. Using plates taken with the 41-cm (16-inch) Bruce refractor at Heidelberg Observatory, approximately 2800 new objects were found by Wolf and Schwassmann in the northern hemisphere. In the southern hemisphere, many plates were taken with the 61-cm (24-inch) Bruce refractor at the Arequipa station of Harvard College Observatory, and a detailed examination of these by Stewart and Frost added another 1130 objects.

1.6 Modern Classification of Open Clusters

Within an astonishingly short period of time, the combination of more sophisticated observational techniques and the application of new astrophysical understanding revolutionized the science and several major developments occurred in the study of star clusters.

As far as open clusters were concerned, several attempts were made to develop a satisfactory classification system. One was by P.J. Melotte [Melotte 1915a, b] who made a study of the Franklin-Adams plates (see Figure 1.4). This early all-sky survey was designed with exposures calculated to reach 16th–17th magnitude on a scale of 20mm to the degree. This enabled small clusters to be identified with a reasonable degree of certainty without large clusters losing the characteristic appearance by being presented at too large a scale. Melotte’s study resulted in the discovery of several new open clusters and a four-tier classification system:
Class I: Globular clusters, such as NGC 6205 (M 13).

Class II: Loose clusters having a regular well-defined outline. An example of this type was given as NGC 2287 (M 41).

Class III: Small, loose clusters, not well defined, and generally of a few stars only.

Class IV: Coarse clusters such as the Pleiades and Hyades.

Melotte himself acknowledged that there would be some difficulty in deciding to which class a cluster should properly belong, and apparently this system failed largely because of its vagueness. Certainly, it was never very widely used.

At Harvard, Harlow Shapley [1930] developed a classification system based on cluster “compactness” (the apparent number of stars and their concentration). It was intended to cover the entire range of stellar clusterings from multiple stars to globular clusters. The subdivisions of this system were as follows:

- **Field Irregularities**: Shapley noted that star counts indicated a great many deviations from random stellar distribution. Often, this results in an excess over what would be expected. Shapley saw no immediate need for these to be cataloged or investigated but felt that a classification system should at least acknowledge their existence.

- **Star Associations**: into this category were placed the “moving clusters,” groups of sometimes distantly spaced stars sharing the same space motion, such as the Ursa Major group.

- **Very Loose and Irregular Clusters**: Shapley suggested that this class was typified by the Pleiades and Hyades clusters, and perhaps even the α Persei group (although this might also be included in class b). Class c corresponds approximately to Melotte’s class IV.

- **Loose Clusters**: Shapley specified M 21 and M 34 as examples of this type, which he judged to be equivalent to Melotte’s Class III.

- **Compact Clusters**: roughly equivalent to Melotte’s Class II where compact clusters were subdivided into three on the basis of their richness and concentration, (M38, M37 and NGC 2477 cited as examples of each type). Shapley placed globular clusters directly after open clusters of type g and noted that several of the most compact of this type appeared to be more like globular clusters than some of the loosest globular clusters class-
fied by means other than appearance.

Shapley recognized that the above classification system was not really complete, since it was primarily dependent on the stellar density and distance of a group. He also divided open clusters into two groups on the basis of the spectra or colors of the component stars: (1) Pleiades type—where the stars are largely Main Sequence objects with the earliest spectral types being of type B and A, and (2) Hyades type—with a greater abundance of later spectral types.

The Shapley alphabetical sequence of open cluster classification was certainly more popular than that of Melotte and others of the period, and was used in Becvar’s *Atlas Coeli Catalogue* (published in 1964, and one of the most popular amateur reference catalogs of its time).

Nevertheless, the open cluster classification system which has stood the test of time was developed by Robert J. Trumpler [1930] and published in his classic paper on the open cluster system of the Galaxy. This work is essential reading for anyone with an interest in open clusters, covering the determination and importance of the distances, sizes and space distribution of these systems.

Trumpler’s study enabled him to devise a classification system which identified certain specific features of an open cluster, which could be ascertained independently of its distance. This removed the difficulty presented by most previous systems, such as that of Shapley, whereby a “loose cluster” might only appear to be loose because of its proximity. However, if placed at a uniform distance with other clusters, it might actually be more compact. The relevant features identified by Trumpler were: (i) degree of central concentration of the stars and the extent to which the cluster appears detached from the Milky Way background, (ii) the range of brightness among the component stars, and (iii) the overall number of stars contained within the cluster. For each characteristic, subdivisions were created and assigned Latin numerals, Roman numerals and lower-case letters respectively.

In the first instance, the clusters were placed in four groups according to the degree of concentration:

1. Detached clusters with strong central concentration.
2. Detached clusters with little central concentration.
3. Detached clusters with no noticeable concentration, in which the stars are more-or-less thinly but nearly uniformly scattered.
4. Clusters not well detached but merging gradually into the background and appearing like a star field condensation.

After this, the clusters were divided into three groups according to the range of brightness within the stars:

1. Most of the cluster stars of nearly the same apparent brightness.
2. Medium range in the brightness of the stars.
3. Clusters composed of bright and faint stars.

The third component in the cluster classification system is the number of members contained in the cluster, indicated as follows:

- p. Poor clusters with less than fifty stars.
- m. Moderately rich clusters with 50–100 stars.
- r. Rich clusters with more than 100 stars.

The three elements are put together in the above order; for example, M 11 (NGC 6705), the spectacular “Wild Duck” cluster in Scutum, is classified [Ruprecht, 1966, p. 37] as being of type I2r—a detached cluster with strong central condensation containing more than 100 stars of a medium range of brightness. Trumpler, using photographs showing fewer stars, classified this cluster as type II—little central condensation. (See Figure 1.7 on page 10.)

It is worth noting that during the early years of the 20th century, there were several changes in the description that these sort of clusters were given. In the previous century, they had been commonly called “irregular clusters”—which seems perfectly appropriate and descriptive—but later it became fashionable to describe them as “open clusters.” In 1925, at the suggestion of Trumpler and others, the term “galactic cluster” was introduced on the grounds that almost all could be found close to the galactic plane and to obviate confusion with the open-structured type of globular clusters. In 1967 it was all changed yet again as “open cluster” once more became the preferred term on the grounds that “galactic” implied any object belonging to the Galaxy. Therefore, our own Galaxy’s system of globular clusters is “galactic.” Also, since star clusters were now being found in other galaxies, the term should be reserved to differentiate between the clusters of our own Galaxy and those of other galaxies. However, since it could well be argued that the term “open” implies “unbound” in the gravitational sense, which is not always the case, perhaps another change is due.

### 1.7 Trumpler and the Space Distribution of Open Clusters

In addition to the important function of setting out a useful open cluster classification system, Trumpler’s 1930 paper provides an early attempt to learn something about the structure of the Galaxy from a study of the properties of open clusters. While his overall conclusions turned out to be incorrect, this is immaterial compared to the value of the other results which were produced from his remarkably comprehensive and intuitive analysis.

Trumpler knew that the dimensions of individual clusters must be quite small when compared with their distances from us; therefore, stars in a particular cluster were
effectively at the same distances (i.e., the depth of the cluster could be ignored).

Also, there is an important relationship between the absolute magnitude, $M$, of a star (the magnitude it would have at a distance of 10 parsecs (pc)) and its apparent magnitude, $m$ (the magnitude it appears to be as measured on Earth, with no correction made for distance). This relationship is calculated by means of the formula:

$$m - M = 5 \log r - 5$$  \hspace{1cm} (1.1)

where $r$ is the distance of the cluster in parsecs (pc). (The $m - M$ relationship is called the distance modulus, although to be strictly accurate, it also needs to include a term to correct for interstellar extinction. Trumpler was not aware of this at the time, however.)

To derive the absolute magnitude from this, the equation can simply be rewritten as:

$$-M = 5 \log r - 5 - m$$  \hspace{1cm} (1.2)

or, more conveniently:

$$M = m + 5 - 5 \log r$$  \hspace{1cm} (1.3)

To give a practical example, the star Sirius has an apparent magnitude of $-1.44$ and lies at a distance of 2.7 pc. Its absolute magnitude is therefore:

$$M = -1.44 + 5 - 5 \log 2.7$$  \hspace{1cm} (1.4)

$$= 3.56 - 5 \times 0.4314$$  \hspace{1cm} (1.5)

$$= 3.56 - 2.16$$  \hspace{1cm} (1.6)

$$= +1.40$$  \hspace{1cm} (1.7)

Within recent years, the mean absolute magnitudes of various spectral types of stars had been determined from trigonometric and moving cluster parallaxes, or statistically from proper motions. Since most clusters are dominated by stars of type B and A, he carried out a program of observations to determine the apparent magnitude (hence, absolute magnitude) of the B and A stars in 100 selected clusters. With this information, he then calculated the distances of the clusters and worked out their true size from the apparent size on photographs.

Comparing the size of individual clusters against their distance, he came up with the remarkable result that those close to the Sun were only about half as big as the most distant ones. Such a correlation is extremely unlikely; it would be more plausible if the size distribution was fairly random across the distance range. Either the stars in the more distant clusters were not as bright (for the same spectral type, as those locally) or, more likely, their brightness was being diminished on the way. This would make them appear to be at a greater distance, and, therefore, larger than was really the case. Trumpler had shown the existence of interstellar dust. This was supported by another discovery; that the color of stars of the same spectral type became increasingly red with distance.

Making the appropriate corrections to compensate for this, Trumpler was able to plot the space distribution of his open clusters relative to the Sun. He found some evidence of spiral structure and made a comparison with other spiral galaxies such as M 31 and M 33, noting that they contain small “knots” in the structure of the spiral arms which could reasonably be open clusters. He also noted that most spiral galaxies have at their centers a small, bright nucleus. In this regard, he suggested that the bright and spectacular cluster in Carina, NGC 3532 (see Figure 1.8), might serve this function in our Galaxy, the reason being that this object (according to his work) lay close to the local system of open clusters. This formed a flattened disk-like system about 1000 parsecs thick and 10,000 parsecs in diameter.

These conclusions could not be reconciled with the recently published conclusions of Harlow Shapley based on the space distribution of globular clusters: that the Galaxy was a much larger system over 100,000 parsecs in diameter with a center situated in Sagittarius at a distance of 20,000 to 40,000 parsecs. Trumpler [1930, 185] discussed this significant discrepancy but discounted Shapley’s findings:

...there is no noticeable feature in the distribution of open star clusters which suggests a considerable extension of the Milky Way system in the direction of Sagittarius. A careful examination of Barnard’s excellent Milky Way photographs of this region, which reach at least to the 17th, did
Fig. 1.7 The prototypical Trumpler classes for Galactic open clusters. From Trumpler [1930, plate 5].
not reveal any appreciable number of small distant undiscovered star clusters. It is hardly possible that every one of scores or hundreds of such distant clusters should be hidden from our view through absorption by dark matter. But even if we should admit such an assumption, we should still expect the visible parts of the open cluster system to show some arrangement concentric with the distant Sagittarius center.

Trumpler came to the conclusion that the globular clusters, like the Magellanic Clouds, while gravitationally bound to the Galaxy, should correctly be considered to be independent bodies. He pointed out that such a system of objects might be like some of the other clusters of extragalactic systems made up of “spiral nebulae, elliptical and globular nebulae.” He was encouraged in this view by the similar conclusions of Lundmark.

There is a certain irony in that as the discoverer of interstellar absorption, Trumpler failed to appreciate its extent and significance. Nevertheless, his results from this paper are a considerable achievement, and he should be additionally credited with deriving a better estimate for the size of the Galaxy than did Shapley (even if the latter was correct about the implications of the distribution of the globular clusters).

1.8 Modern Listings of Open Clusters

Following the publication of the NGC and IC catalogs, open clusters continued to be discovered. For example, a list of 245 clusters was produced by Melotte in 1915. However, many of these are previously discovered objects in the NGC or IC: for example; Melotte 13 and 14 are NGC 869 and 884, the Double Cluster in Perseus, and Melotte 22 is the Pleiades. In fact, only 10 objects on the Melotte list had not been numbered before, the most conspicuous one being Melotte 111, the nearby cluster that is the namesake of the Coma Berenices constellation.

More significant in terms of original discoveries is the list produced by Trumpler and included in his classic paper of 1930. Thirty-seven objects were recorded here, and most were original discoveries found on the Franklin-Adams star charts by the author. However, a number were objects mentioned by previous observers in various papers, but not specifically cataloged as new discoveries. Most of these had been noted by Barnard [1927] on his Atlas of Selected Regions of the Milky Way. Some of the clusters in the Trumpler list are quite important, in particular Tr 15 and Tr 16, because of their association with the η Carinae Nebula (NGC 3372). One of us [SH] has a particular fondness for Tr 1 which is close to the cluster M 103 in Cassiopeia, as this was the first non-NGC/IC object that he independently “discovered.”

Appendix B in, Shapley’s Star Clusters [1930], contains an important list of clusters which has been a primary source of open cluster data until recent years. It was used extensively in Becvar’s Atlas Coeli.

In January 1929, Clyde Tombaugh arrived at Lowell Observatory in Flagstaff, Arizona, to commence the search which would result in the discovery of the planet Pluto in just over twelve months. In the course of this search, Tombaugh examined a great number of plates taken with the 33-cm (13-inch) astrograph and inevitably came across many other new objects (mostly asteroids), but he also found 5 new open clusters.

These, together with many other clusters mostly from comparatively small listings, were brought together in the first “general catalog” of open clusters, the Catalogue of Star Clusters and Associations, published in 1958 (often referred to as the “Alter catalog” after its primary author [Alter, et al., 1958]). At this time the advent of the computer database was some years away, and the catalog was produced in the form of a card-index. It contained identification information, positional data, size, distance, membership, magnitude, spectral characteristics, references and notes for each object. There seems to be an unwritten scientific law that the publication of any important database results in a flurry of activity in the same field; this catalog is no exception. New discoveries resulted in eight Supplements to the catalog being published [Alter et al., 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966]. With the publication of the last Supplement, the total number of objects recorded was 1,017. Obviously, with a main catalog
and so many supplements, the system became rather unwieldy. Therefore, the entire catalog was revised [Alter et al., 1970], and a further revision and enlargement was published a decade later [Ruprecht 1981].

Another major catalog published in 1981 was the Catalogue of Open Cluster Data compiled by Gösta Lyngå Lynå at the Lund Observatory. This is often referred to as the “Lund Catalogue” [Lyngå 1981]. This has now reached its 5th Edition and, in its computer readable form, is the primary data source for open clusters. This edition of the Lund Catalogue has been a primary reference source in the compilation of the catalog in this book. The computer readable form of the Lund Catalogue comprises six files, and the main catalog records information on approximately 1150 open clusters with information about identification, position (equatorial, galactic coordinates and Palomar Observatory Sky Survey [POSS] [National Geographic Society, 1955] chart X–Y coordinates), Trumpler class, membership, diameter, distance, reddening, age, metallicity, radial velocity, magnitude, earliest spectral class for a cluster member, magnitude of the brightest cluster member, galactocentric distance, numbers of stars of selected types (e.g. Be stars, WR stars, Cepheids, shell stars etc.) and comments on particular objects. Other files include cross-references between catalogs and 527 references (a valuable database). When printed out, the catalog occupies a significant volume of paper!

From the perspective of the amateur astronomer, there are several recent sources of data: the Observing Handbook and Catalogue of Deep-Sky Objects, by Christian B. Luginbuhl and Brian A. Skiff, published by Cambridge University Press in 1990 (reprinted in 1999); The Deep-Sky Field Guide to Uranometria 2000.0, by Murray Cragin, James Lucyk and Barry Rappaport, published by Willmann-Bell Inc. in 1993; and The Night Sky Observer’s Guide, by George R. Kepple and Glen W. Sanner, published by Willmann-Bell, Inc. in 1998. Finally, we hope that the catalogs of clusters included in this volume, independently compiled by one of us [BA] from the most up-to-date sources available, will be found especially useful.

1.9 Extragalactic Open Clusters and Associations

The history of the discovery of extragalactic open clusters really goes back to John Herschel’s expedition to the Cape of Good Hope during the years 1834 to 1838. Although other observers were active in the southern hemisphere at the time and before then, Herschel’s observations were the first to combine high quality in both the observer and the
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telescope. In the case of the latter, the large 48-cm specu-
lum reflector (Figure 1.9 on page 12) was the same as that
which had been used to such great effect by the Herschels
in England. Great things were expected, and the astronoma-
cal community was not disappointed. The four-year trip
resulted in the discovery of several thousand new double
stars, clusters and nebulae; these were analyzed and pub-
lished in 1847.

John Herschel was clearly impressed by his views of
the Magellanic Clouds and devoted much observing time to
them, cataloguing 1163 objects. He described the Clouds as
follows:

The general ground of both consists of large tracts and
patches of nebulosity in every stage of resolution, from
light irresolvable, in a reflector of 18-inches aperture, up to
perfectly separated stars, like the Milky Way, and cluster-

Fig. 1.10 The field of the Large Magellanic Cloud (−13° square). From RAS [1936, plate 4].
ing groups sufficiently insulated and condensed to come under the designation of irregular and in some cases pretty rich clusters. But besides these there are also nebulae in abundance and globular clusters in every state of condensation.

It was many years before the Magellanic Clouds were recognized as galaxies like the Milky Way in their own right, but Herschel was correct in his recording of its content. He was clearly able to resolve stars in some clusters, and many of the irresolvable condensed knots he found are in fact either open or globular clusters. Modern estimates suggest that the Large Magellanic Cloud (LMC, see Figure 1.10 on page 13) contains over 6000 star clusters, and the Small Magellanic Cloud (SMC, see Figure 1.11 on

Fig. 1.11 The field of the Small Magellanic Cloud (∼13° square). The globular cluster 47 Tucanae lies just to the upper right of the SMC. From RAS [1936, plate 2].
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page 14) contains about 2000. To gain some idea of the complexity of the Magellanic Clouds and the number of clusters they contain, an examination of ESO(B) film copies #056 and #057 can be recommended, both taken with the 1.0-m. (40-inch) Schmidt camera at La Silla in Chile. Reference should also be made to the catalog of Kontizas, et al., [1990]. For the amateur astronomer some charts showing the location and identification of clusters and other objects in the Magellanic Clouds can be found in Webb Society Deep-Sky Observer’s Handbook, volume 7 [Hynes 1987]. Perhaps the best available charts for the amateur astronomer, however, are those produced by Mati Morel in Australia [Morel, 1993].

In addition to clusters found in the Magellanic Clouds, a small number of clusters and associations in other galaxies were observed by the visual astronomers who contributed to the compilation of the New General Catalogue. Perhaps the most conspicuous of these is the huge association NGC 206, which lies in one of the outer arms of the Local Group spiral, the Andromeda Galaxy (M 31 = NGC 224)—this should be visible in a 20-cm (8-inch) telescope. Also visible with a small telescope is NGC 604 (see

Fig. 1.12 NGC 604, the largest association (approximate diameter 1500 light years) in the Pinwheel galaxy = M 33. WFPC2 HST image taken January 17, 1995. The field of view is 2', with north to the upper right and east to the upper left. Hui Yang (University of Illinois) and NASA.

Fig. 1.13 Throughout this work the orientation of illustrations is indicated by an arrow as shown in this illustration.
Figure 1.12 on page 15), a massive nebulous association in the Local Group spiral galaxy M 33 (NGC 598). This galaxy also includes a number of other NGC/IC objects of a similar nature. Since then, as telescopes have increased in size and the type and quality of detectors have improved, it has been possible to search these and many other galaxies for fainter clusters and associations. Although comparatively rare in elliptical galaxies, which contain an older stellar population, they occur in great numbers in spiral galaxies which have a younger stellar population and are usually found involved with HII regions. Obviously, they are also found in larger numbers in the nearer spirals simply because they can be seen down to fainter magnitudes. About 200 associations have now been found in M 33 and a 1985 study by Hodge [1985], identified 88 stellar associations in the large nearby spiral NGC 2403; some of these can also be seen in medium-aperture amateur telescopes. At a somewhat greater distance is the beautiful spiral galaxy M 81 (NGC 3031) in Ursa Major; in this system a survey by Ivanov [1992] has produced a catalog of 180 associations. These nicely delineate the spiral arms and typically have a size of about 80 pc.

An interesting discovery [Jones 1993] is that And IV, normally classified as a dwarf galaxy of the Local Group, is almost certainly a large stellar association within the Andromeda Galaxy system. The CMD is consistent with a young stellar population, and at the distance of M 31, its size of 50 arc-seconds would indicate a real diameter of 180 pc (2 or 3 times smaller than the smallest dwarf irregular galaxies). Such a size, however, would not be unreasonable for a stellar association.