1 • Introduction

1.1 THE SIGNIFICANCE OF THE NEW GENERAL CATALOGUE

Besides the point-like stars, the sky offers a large number of objects showing an extended structure. Except for a few, they are not visible without the aid of a telescope. In terms of their optical appearance, there are star clusters (resolvable objects) and nebulae (unresolvable objects). In 1862 Eduard Schönfeld, an astronomer at Mannheim Observatory, gave the following definition:[1] '*Nebulae or nebulous patches are celestial objects, which do not contrast with the sky background as shining points, like individual stars, but present the impression of a more or less extended and diffuse area of light.*'[2]

Long before the invention of the telescope, the open clusters of the Pleiades and Praesepe and the diffuse spot of the Andromeda Nebula were known. Later the telescopic exploration of the sky brought many more cases to light. Soon it became evident that some nebulae are disguised clusters of stars; the best examples are globular clusters, the compact and star-rich versions of open clusters. Other objects, such as the bright nebulae in Orion and Andromeda, could not be resolved, even with the largest telescopes. However, in 1864 the new astrophysical method of spectroscopy revealed that the Orion Nebula is a mass of gas (mainly hydrogen and helium). On the other hand, the Andromeda Nebula is a galaxy, consisting of many hundreds of billions of stars, which was eventually proved in the twentieth century.[3]

Nebulae and star clusters are 'non-stellar' objects.[4] In terms of the criteria of form, individuality, physical relation and existence, the following types are meant by this term (Fig. 1.1 shows examples):

- open clusters and globular clusters (here often subsumed as 'star clusters')
- emission nebulae, reflection nebulae and dark nebulae (commonly known as galactic nebulae, which includes remnants of novae and supernovae)
- planetary nebulae
- galaxies (including quasars)

Galaxies are by far the dominating non-stellar objects (see Table 10.12). Their forms and types are manifold.[5] Star clusters, galactic nebulae and planetary nebulae are Milky Way objects.[6]

This definition is quite helpful to rate the success of a discoverer. The measure is the percentage of non-stellar objects. This is relevant, because often visual observation could not decide whether a nebula is real or whether the 'nebulous' impression was only simulated by a pair or small group of stars; the latter is a common phenomenon with a small telescope. Sometimes a subsequent observation shows a blank field; the object could have been a comet or the position was wrong. Thus the following cases must be determined in the discoverer's balance:

- stellar object: single star, star pair, star pattern (asterism)
- part of an object (e.g. galaxy)

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1 Schönfeld (1862b: 48).

2 The terms 'nebula' and 'nebulous patch' (in German: *Nebel* and *Nebelfleck*) were mostly used synonymously; occasionally 'nebula' describes a spacious, diffuse object (such as the Orion Nebula) and 'nebulous patch' a small, confined object (such as a faint galaxy).

3 A comprehensive review was given by Wolfschmidt (1995).

4 In amateur astronomy these are 'deep-sky objects', i.e. targets beyond the solar system; see Steinicke (2004a).

5 Here the ordinary Hubble classification is used, see Sandage (1961) and Sandage and Bedke (1994); the later scheme of de Vaucouleurs is explained in Buta *et al.* (2007). For fine images of galaxies see also Ferris (1982).

6 For star clusters see Archinal and Hynes (2003); for galactic nebulae see Coe (2006); for planetary nebulae see Hynes (1991).

Figure 1.1. The globular cluster M 13 in Hercules, the open cluster M 44 (Praesepe) in Cancer and the emission nebula M 42 (Orion Nebula).[7]

- comet
- lost object (existence unknown); declared here as 'not found' (NF)

The best-known discoverers of nebulae and clusters are Charles Messier, William Herschel and his son John. Many others have fallen into oblivion. The same is true for published object lists; only the Messier catalogue (M), the New General Catalogue (NGC) and the Index Catalogue (IC) are still in use.

Unrivalled in general use – in both amateur and professional astronomy – is the M-number, designating bright, large non-stellar objects. The standard reference for smaller, fainter objects is still the NGC. The transition from Messier's catalogue to the NGC is a quantum leap: from 103 to 7840 objects! Attempts to establish an intermediate step or alternatives failed; being restricted to amateur astronomy, they had no influence. Examples are Patrick Moore's Caldwell catalogue of the 'best' 103 non-Messier objects (Moore 1995) and the 'Herschel 400' list with William Herschel's 'best' objects.[8]

Today M–NGC–IC is the primary sequence used to designate non-stellar objects (beyond it, the realm of special catalogues begins). The Andromeda Nebula is designated M 31; its NGC-number (NGC 224) being secondary. The North America Nebula in Cygnus, which is not contained in the Messier catalogue, is known as NGC 7000 (see Fig. 2.17). The nearby Pelican Nebula bears no NGC-number and is designated IC 5070.

Figure 1.2. John Louis Emil Dreyer (1852–1926); about 1874.[9]

The New General Catalogue, published in 1888 in the *Memoirs of the Royal Astronomical Society*,[10] is inseparably connected with the name of John Louis Emil Dreyer[11] (frontispiece and Fig. 1.2) – the central person

[7] Images of non-stellar objects presented without mentioning a source are from the author's archive. A nice collection was presented by Vehrenberg (1983).

[8] There is a 'Herschel 2500' list of all objects discovered by him. Because the original catalogues were used, the data are not reliable.

[9] The late Dreyer can be seen on the frontispiece.

[10] Dreyer (1888b).

[11] This is the English version, which will be used here; the Danish is Johan Ludvik Emil Dreyer and the German Johann Louis Emil Dreyer.

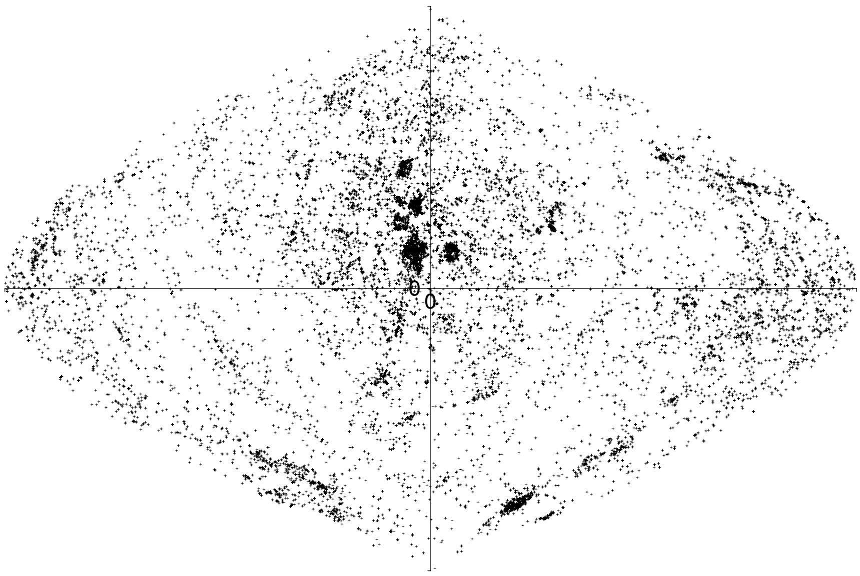

Figure 1.3. A plot of all 13 226 NGC/IC objects. The 'clusters' above centre ($\alpha = 12^h$, $\delta = 0°$) are mainly due to selection effects from photographic IC II surveys; the largest contains Virgo Cluster galaxies. The oval spot below right ($\alpha = 5^h$, $\delta = -70°$) represents objects in the Large Magellanic Cloud.

of the present work. Dreyer might be much less well known than his predecessor Charles Messier. This is due to the strong connection of name and catalogue: while the Messier catalogue is commonly known, there never was a 'Dreyer catalogue'. But Dreyer's merit for astronomy is much larger: he listed all of the non-stellar objects known up to the end of 1887, with all data necessary for their identification (position, description, source). The NGC is a standard work, which had (and still has) an enormous influence on observational astronomy.

Studying the Messier catalogue, with 103 objects and a moderate number of discoverers (23), is a manageable task – but the NGC with 7840 entries and more than 100 discoverers, is not![12] This is the reason why there have been many publications on the history of the Messier catalogue, but hitherto none about the NGC claiming to be comprehensive. The present work is the first.

Owing to the large number of contributing observers, instruments and sites, the NGC seems to be pretty inhomogeneous, but it has a common basis: all objects (except one) were found visually. This is different for its two supplements with altogether 5386 entries. The first, the Index Catalogue (IC I), appeared in 1895 and the Second Index Catalogue (IC II) came out in 1908.[13] Already the IC I contains objects that had been found by photography, but in the IC II this was the dominating method. The photographic surveys (e.g. by Max Wolf) focused on certain areas of the sky. Thus the object distribution in the IC is very inhomogeneous (Fig. 1.3).

Modern catalogues, resulting from digital ground-based or orbital surveys, differ very much from the NGC/IC – especially in size: the latest contains more than 100 million records! Individual objects have no value, being lost in the statistical analysis. There is a large range of catalogues based on special selections:

- object type (e.g. galaxy, planetary nebula, star cluster)
- sky area (e.g. Milky Way region, constellation)
- spectral range (e.g. blue, visual, infrared)

The NGC is much different. The total number of entries is large – but not too large. Thus it is manageable, which has important consequences for current observations: Dreyer's catalogue still offers

[12] For catalogues it is better to speak about entries rather than objects. There are, for instance, many NGC numbers for which no object exists (at any rate, not at the given place).

[13] Dreyer (1895, 1908). The combined catalogue is often abbreviated NGC/IC.

No.	G. C.	J. H.	W. H.	Other Observers.	Right Ascension, 1860·0.	Annual Precession, 1880.	North Polar Distance, 1860·0.	Annual Precession, 1880.	Summary Description.	Notes.
					h m s	s	° ′	″		
1	1	...	...	d'A	0 0 4	+3·07	63 4·3	−20·1	F, S, R, bet ✱ 11 and ✱ 14	
2	6246	...	...	Ld R*	0 0 6	3·07	63 6·0	20·1	vF, S, s of G.C. 1	
3	5080	...	...	m 1	0 0 6	3·07	82 28	20·1	F, vS, R, alm stell	
4	5081	...	...	m 2	0 0 16	3·07	82 23	20·1	eF	
5	...	...	...	St XII	0 0 37	3·08	55 25·0	20·1	vF, vS, N = ✱ 13, 14	
6	...	...	...	Sw II	0 1 5	3·08	58 15·6	20·1	eF, vS, cE	
7	2	4014	...	...	0 1 14	3·07	120 41·2	20·1	eF, cL, mE, vgvlbM	
8	5082	...	...	O Struve	0 1 17	3·08	66 59	20·1	vF, N in n end	
9	5083	...	...	O Struve	0 1 27	3·08	67 0	20·1	F, R, ✱ 9, 10 sf	
10	3	4015	...	...	0 1 28	3·06	124 38·9	20·1	F, cL, vlE, glbM	
6999	5981	...	...	m 432	20 53 38	3·60	118 36	13·8	eeF, vS	
7000	4621	2096	V 37?	...	20 53 48	2·14	46 13·1	13·8	F, eeL, dif nebulosity	
7001	4622	2095	...	...	20 53 55	3·08	90 44·6	13·9	eF, S, E 0°	

Figure 1.4. The first ten entries of the New General Catalogue, to which NGC 6999–7001 are appended (Dreyer 1888b).

the primary targets (mainly galaxies). Their moderate brightness allows astrophysical studies with medium-sized telescopes; and with the biggest, like the Very Large Telescope (VLT) or the Hubble Space Telescope (HST), extremely detailed observations are possible. Thus NGC-numbers are part of the astronomer's daily routine. The catalogue might be the most used in modern observational astronomy. It therefore has both historical and astrophysical importance. The New General Catalogue marks the transition from (old) astronomy to (new) astrophysics, represented by spectroscopy, photography and photometry.[14] Dreyer has created the last 'visual' catalogue containing all types of non-stellar objects in the whole sky.

1.2 MOTIVATION AND METHOD

The New General Catalogue and both Index Catalogues were published as a book by the Royal Astronomical Society (RAS) in 1953.[15] Enthusiasm for the printed NGC – if there is any – might not result from its physical appearance. At first glance the work has the brittle charm of a phone book (Fig. 1.4). Without previous astronomical knowledge it will soon be shelved.

Present-day amateur astronomers interested in observing nebulae and star clusters are familiar with the term 'NGC', but its objects rate as 'faint' and thus difficult to observe. Consequently, the visual observer dealing with them does not rank as a 'beginner'. This implies that NGC objects do not possess the same popularity as Messier objects. While M 1, M 13, M 31, M 42 and M 57 belong to the standard repertoire of amateurs, naturally only a few NGC-numbers circulate. Table 1.1 presents a (subjective) sample of popular objects – most of them are better known through their common names. About 95 NGC objects bear a (more or less official) proper name. Unfortunately, since the late twentieth century there has been a certain inflation of new names, mostly created by American observers and based on photographic images.

The majority of the NGC objects are anonymous; but, of course, the unknown makes the catalogue interesting – and motivates investigations. If one takes, for instance, NGC 7000 (the North America Nebula in Cygnus; see Fig. 2.17), the following question arises: what is hidden behind the preceding and following entries, NGC 6999 and NGC 7001? Dreyer gives only the bare minimum of information (Fig. 1.4): cross references, position and coded description. For NGC 7001 one reads 'eF, S, E 0°', meaning 'excessively faint, small, extended 0°', which describes an extremely faint and small object, elongated north–south. To find its place on a modern star chart, the coordinates must be precessed to the epoch 2000 (declination results from 'North Pole Distance'). Thus it is not easy to get on the right track. Fortunately the necessary work has

14 Concerning the instrumental aspects, see Staubermann (2007).

15 This publication is used here as the NGC/IC standard reference, cited as 'Dreyer (1953)'. Unchanged editions were printed in 1962 and 1971.

Table 1.1. *Examples of popular NGC objects without Messier-numbers*[16]

NGC	Discoverer	Date	Type	V	Con.	Remarks
104	Lacaille	1751	GC	4.0	Tuc	47 Tucanae
253	C. Herschel	23.9.1783	Gx	7.3	Scl	Silver Dollar Galaxy; Figs. 2.14 and 7.12 left
292	Vespucci	1501	Gx	2.2	Tuc	Small Magellanic Cloud
869	Hipparch	−130	OC	5.3	Per	Double Cluster (with NGC 884)
891	W. Herschel	6.10.1784	Gx	10.1	And	Edge-on galaxy with absorption lane; Fig. 2.15
1435	Tempel	19.10.1859	RN		Tau	Merope Nebula; Fig. 11.31
1499	Barnard	3.11.1885	EN		Per	California Nebula; Fig. 9.58
1555	Hind	11.10.1852	RN		Tau	Hind's Variable Nebula; Fig. 11.17
2237	Swift	1865	EN		Mon	Rosette Nebula (with NGC 2238/39/46); Fig. 9.14
2261	W. Herschel	26.12.1783	RN		Mon	Hubble's Variable Nebula; Fig. 6.56
2392	W. Herschel	17.1.1787	PN	9.1	Gem	Eskimo Nebula; Fig. 6.16
3242	W. Herschel	7.2.1785	PN	7.7	Hya	Ghost of Jupiter
3372	Lacaille	1751	EN		Car	Eta Carinae Nebula; Fig. 11.26
4038	W. Herschel	7.2.1785	Gx	10.3	Crv	The Antennae (with NGC 4039); Fig. 2.30 left
4565	W. Herschel	6.4.1785	Gx	9.5	Com	Edge-on galaxy; Fig. 7.12 right
4755	Lacaille	1751	OC	4.2	Cru	Jewel Box
5128	Dunlop	29.4.1826	Gx	6.6	Cen	Centaurus A; Fig. 4.12
6543	W. Herschel	15.2.1786	PN	8.1	Dra	Cat's Eye Nebula; Fig. 6.6 right
6822	Barnard	17.8.1884	Gx	8.7	Sgr	Barnard's Galaxy; Fig. 9.56
6888	W. Herschel	15.9.1792	EN		Cyg	Crescent Nebula; Fig. 8.56 centre
6992	W. Herschel	5.9.1784	EN		Cyg	Veil Nebula (with NGC 6960/95)
7000	W. Herschel	24.10.1786	EN		Cyg	North America Nebula; Fig. 2.17
7009	W. Herschel	7.9.1782	PN	8.0	Aqr	Saturn Nebula; Figs. 2.3, 6.3 and 8.40 right
7293	Harding	Sept.? 1823	PN	7.3	Aqr	Helix Nebula; Fig. 4.3
7331	W. Herschel	5.9.1784	Gx	9.5	Peg	
7662	W. Herschel	6.10.1784	PN	8.3	And	Blue Snowball; Fig. 2.21
7789	C. Herschel	30.10.1783	OC	6.7	Cas	

already been done: the author's 'Revised New General and Index Catalogue'.[17] This work shows that NGC 6999 and NGC 7001 are galaxies in the constellations Microscopium and Aquarius with 14.0 mag and 13.5 mag, respectively (Fig. 1.5).

The fascination of the NGC is thus partly due to its mysterious, almost cryptic data. Each entry offers an object, whose discovery story and physical nature must be revealed. There are cases, where one literally grasps at nothing. Cautiously noting 'not found' (NF), the term leaves open whether the object is non-existent or perhaps real at another place. Anyway, whomsoever wants to uncover the secrets of the NGC must consult the real sky by visual observing or – which is much easier – inspecting a photographic sky map, such as the Digitized Sky Survey (DSS).

[16] The abbreviations are explained in the appendix.

[17] See the author's website: www.klima-luft.de/steinicke. The modern data are also used in many 'planetarium programs' showing a digital image of the sky.

Figure 1.5. The galaxy NGC 7001 in Aquarius (DSS).[18]

However, for a definite identification of an NGC object, this is not sufficient. In many cases the historical sources must be taken into account, i.e. the original notes of the observers. Here the catalogue holds secrets too: who was 'Mr. Wigglesworth', owner of an observatory where 'J. G. Lohse' discovered 18 objects? Who were the Harvard astronomers Austin, Langley, Peirce, Searle, Wendell and Winlock? What is meant by the 'Melbourne observations' or by a source called 'Greenwich IX yr C', noted for NGC 2392?[19] Of course, Dreyer could count on the knowledge of the nineteenth-century observers, but today these names and terms say very little. Thus modern astronomers are pragmatic and mainly interested in astrophysical data. Nevertheless, it is fascinating to fathom out the stories behind the NGC entries.

Many non-stellar objects were catalogued prior to the NGC, e.g. in John Herschel's General Catalogue (GC) of 1864. Therefore the present work must check the cross references to the GC and other catalogues. The deeper one digs, the more Dreyer's achievement in creating a homogeneous catalogue from a large number of different observations and sources becomes clear. Never having been able to overview the relevant sky areas, this was like a 'blind puzzle'. The compilation of the NGC at the desktop was a hard and error-prone task, especially concerning the different qualities of observations and records. Today there are (digital) photographic maps to verify the identity of the objects, but, even with the aid of computers and the Internet, this is not straightforward!

For the modern analysis of the NGC it was useful to divide the catalogue into subsets corresponding to the individual observers and their different data qualities. To track the cross references, an analogous procedure was applied for the earlier catalogues. For Messier's catalogue this analysis has already been made, but in the case of the NGC new ground was broken. The method was as follows: cut the NGC and its forerunners into pieces, sort them by applying various filters and join the results. This leads to new insights about the catalogues involved, concerning their substance and historical evolution. One of the many results is that some of Dreyer's data must be revised. There are errors concerning discoverers, sources and identifications of objects or identities between them. The same is true for William and John Herschel – but both had the benefit that they discovered or observed most of their catalogued objects themselves. Thus the Herschel data are more homogeneous than the records Dreyer had to deal with.

The goal of this work is extracting primary structures from the various sources to picture the motivation and importance of the observations of nebulae and star clusters in the nineteenth century.[20] In Dreyer's New General Catalogue the consideration has had to be focused. Individual nebulae and star clusters play an important role, but, in the face of their large number, they can be presented only as examples – nevertheless, more than 2000 NGC objects are mentioned.

1.3 MILESTONE CATALOGUES OF NON-STELLAR OBJECTS AND MAJOR TOPICS

This work is focused on the nineteenth century, but the origins date earlier. The most important persons were

[18] Most images of deep-sky objects are from the Digitized Sky Survey (DSS); see http://archive.eso.org/dss/dss.

[19] See Section 10.1.1 for the answer.

[20] A contemporary and comprehensive outline of nineteenth century astronomy is due to Agnes Mary Clerke (Clerke 1893).

Table 1.2. *Milestone catalogues leading to the NGC*

Author	Milestone	Abbr.	Reference	Entries	New	Suppl.
Messier	Messier catalogue	M	Messier (1781)	103	103	7 (1921–66)
W. Herschel	Three catalogues	H	Herschel W. (1786, 1789, 1802)	2500	2427	8 (1847)
J. Herschel	Slough catalogue	SC (h)	Herschel J. (1833a)	2307	473	6 (1847)
J. Herschel	Cape catalogue	CC (h)	Herschel J. (1847)	1714	1421	
W. Parsons	Birr Castle (1861 publ.)	LdR	Parsons W. (1861a)	989	295	
Auwers	List of new nebulae	Au	Auwers (1862a)	50	46	
J. Herschel	General Catalogue	GC	Herschel J. (1864)	5057	419	22 (1864)
d' Arrest	Siderum Nebulosorum	SN	d' Arrest (1867a)	1942	307	
Dreyer	GC Supplement	GCS	Dreyer (1878a)	1166	1149	6 (1878)
Dreyer	Birr Castle (1880 publ.)		Parsons L. (1880)	1840	94	
Dreyer	New General Catalogue	NGC	Dreyer (1888b)	7840	1700	49 (1888)

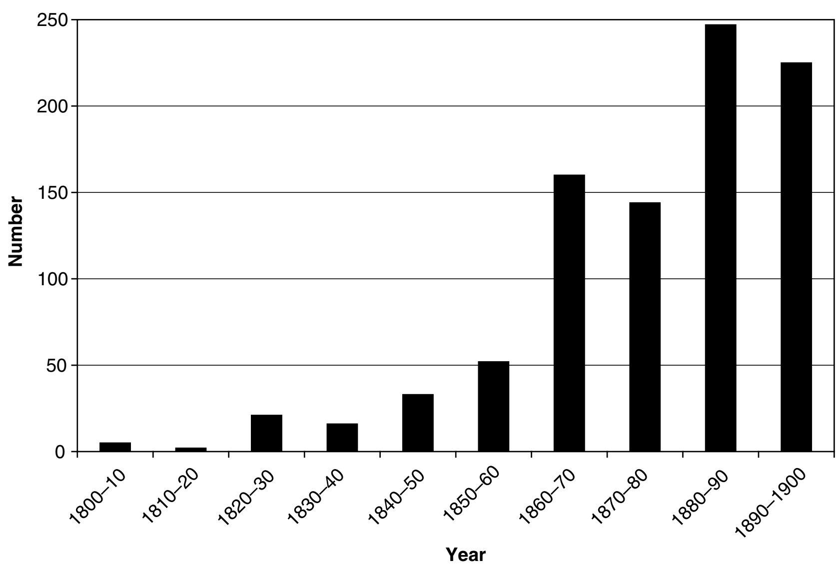

Figure 1.6. Numbers of articles on visual observations of non-stellar objects from 1800 to 1900.

undoubtedly Charles Messier and William Herschel. The three catalogues of the latter defined the decisive basis of John Herschel's observations at Slough and Feldhausen (Cape of Good Hope). The resulting Slough and Cape catalogues are among the milestones which form the backbone of this work (Table 1.2). In the column 'Abbr.' the usual catalogue abbreviation is given; 'New' shows the number of new (independent) objects, compared with earlier works (see particular sections); 'Suppl.' gives the number and year for objects added later.

Besides these major catalogues there exists a considerable number of other publications related to occasional visual observations and discoveries of non-stellar objects. Figure 1.6 shows the increase in number of articles during the nineteenth century.

The period 1860–70, during which new, ambitious observers entered the scene, such as d'Arrest, Auwers, Schönfeld, Schmidt and Winnecke, is remarkable. Additionally, John Herschel's General Catalogue was an impetus. Another climax, with numerous observations by Stephan, Swift, Tempel and Barnard, came in 1880–90. Particularly productive years were 1886 with 54 publications (e.g. by Barnard and Swift), 1862 with 39 (e.g. on variable nebulae), 1885 (34) and 1883 (27). The growth culminated with Dreyer's New General Catalogue, initiating many activities. The aftermath, leading to amendments of the NGC (from the Index Catalogues to the modern revisions), is treated here too.

Besides the milestones, some important topics that cannot be timed are treated. They are essential parts of the development and concern objects, observers, methods and instruments. The topics are

(1) **discovery:** visual, photographic, spectroscopic
(2) **cataloguing:** observation, data processing
(3) **description and condition**: brightness, form, neighbourhood
(4) **nature and evolution**: resolvability, classification, change
(5) **telescopes and observers**: reflector–refractor, amateur–professional
(6) **astrometry**: position, reference system, proper motion, double nebulae, satellites
(7) **astrophysics**: spectroscopy, photography, photometry

(1) Discovery. This is fundamental, since the NGC and its forerunners were created to list not only known objects but also newly discovered ones. The most successful discoverers (see Fig. 10.3) were William Herschel (2416 objects), John Herschel (1691), Albert Marth (582), Lewis Swift (466), Edouard Stephan (420) and Ludwig d'Arrest (321).

Nearly all NGC objects were found by visual observation (7817). The year 1877 marks the beginning of new methods: 22 objects were discovered with the aid of a (visual) spectroscope or objective prism; 15 by Edward Pickering and 7 by Ralph Copeland. Photography of nebulae was still not established at that time.[21] Only one object was found: the Maia Nebula (NGC 1432) in the Pleiades, by the brothers Henry. Later, astrophysical methods massively affected the Index Catalogue.

[21] The photography of the Sun, Moon, planets and bright stars was already advanced.

Many discoveries were made while observing other types of objects, e.g. single, double and variable stars, minor planets and comets (important cases are mentioned in the text). It is remarkable that many visual observers were 'lone fighters'.

(2) Cataloguing. Generally, there are two types of catalogue, in which the objects are those discovered either by a single observer or by different observers. Examples for the first type are William Herschel's three catalogues, the lists of Dunlop, Marth, Swift and Stephan and the Birr Castle observations. The Messier catalogue, GC, GCS (Dreyer's supplement to the GC), NGC and IC are examples of the second type, which is usually claimed by its author to be complete up to a certain date.

Catalogues of nebulae and star clusters differ in structure, arrangement, epoch and many other aspects. Messier and William Herschel sorted the entries by discovery date; Dunlop arranged the objects found in the southern hemisphere by 'South Pole Distance' (SPD).[22] John Herschel's Slough catalogue introduced right ascension (AR) as the ordering element, which became the standard. A mixed type is constituted by 'zone catalogues' listing the objects in declination zones (ordered by AR within zones). Examples are Caroline Herschel's reduction of her brother's data and the work of Johann Georg Hagen.[23] Early catalogues of non-stellar objects did not use a standard epoch (the twentieth century established 1900, 1950 and 2000). Smaller lists were often referenced to the epoch of observation. John Herschel (SC, CC) and Auwers used 1830; the epoch of the GC (1860) was adopted by the GCS, NGC and IC. Most catalogues give absolute positions (coordinates), but others only relative ones, e.g. those of William Herschel, Herman Schultz and Guillaume Bigourdan. John Herschel and Dreyer spent much time to standardise the case. However, the situation for star catalogues was even worse: the nineteenth century saw a large number of position lists, differing by limiting magnitude or sky area. Some NGC discoverers, such

[22] Most classic catalogues (up to the IC II of 1908) use 'North Pole Distance' (NPD) instead of declination ($\delta = 90° – \text{NPD}$). One modern list is sorted by NDP: Patrick Moore's Caldwell catalogue (Moore 1995).

[23] The 'Deep sky field guide' (DSFG) of *Uranometria 2000.0* is a modern zone catalogue, listing about 30 000 non-stellar objects (Cragin and Bonanno 2001).

as Harding, Chacornac, Hind, Cooper and Peters, created their own star catalogues. With the advent of the Bonner Durchmusterung (epoch 1855), consisting of a catalogue and an atlas, a certain standard was defined.[24] The first star catalogue with astrophysical data was the Henry Draper Catalogue (HD) of 1918.

(3) Description and condition. A continuous cause for discussion was the description of objects. Basically, the astronomers could gauge the sky only visually. To record their impressions concerning the brightness and structure of an object, and share the results with others, texts and sketches were the only media – a subjective matter, depending on ability, experience and talent. To objectify it, William Herschel developed a standardised (coded) description. Anyway, due to the uncertainty of the data, many objects could not be identified correctly. This led to a high error rate in the historical catalogues. Not until the twentieth century did a transition from qualitative to quantitative data for nebulae and star clusters (e.g. integrated/surface brightness, size, type) take place.

When a nebula or cluster is observed visually, the vicinity is relevant. This concerns not only the star field (e.g. for orientation) but also other non-stellar objects, which may be associated with the nebula or cluster. There are double and multiple nebulae. In these cases, William Herschel assumed an analogy with double (multiple) stars that was based on gravitational interaction. Concerning clusters of nebulae, it is interesting to ask whether such agglomerations were recognised by the nineteenth-century observers or even interpreted as hierarchical structures. A fascinating case is the rich galaxy cluster in Coma Berenices.

(4) Nature and evolution. On the basis of their observations, William and John Herschel thought about the nature and evolution of nebulae and star clusters. Helpful tools were classification and standardised description. William Herschel defined eight classes, which are barely related to modern object types. Key issues about the cosmogony of nebulae were resolvability and change. The question was whether all nebulae are star clusters, in which case a sufficient aperture would eventually unmask them. Otherwise, true (unresolvable) nebulae should exist, supposed to consist of a luminous 'gas' or 'fluid'. Such matter would naturally condense into stars by virtue of gravitational attraction. Thus changes of brightness and shape of nebulae should be detectable over a sufficient period of time. A popular idea was the 'nebular hypothesis', which had both enthusiastic advocates and strong opponents. The key object was the Orion Nebula, where William Herschel believed already to have seen change – a controversial matter. Other dubious cases were Hind's Variable Nebula (NGC 1555) and the Merope Nebula (NGC 1435); for the latter, even its existence was doubted.[25] Moreover, observers were confronted with strange things like planetary and spiral nebulae (such as M 51), whose features were not understood. The structure of the latter was interpreted – in the sense of the nebular hypothesis – as revolving nebulous matter.

(5) Telescopes and observers. The 'reflector–refractor' relation was a permanent issue in the nineteenth century. These two optical systems normally lived in peaceful harmony and had their typical users: amateur and professional astronomers, respectively,[26] but occasionally there was heated discussion about the pros and cons of each system.

According to George Biddell Airy, the reflector was '*almost exclusively the instrument of amateurs*' – the owners were wealthy, independent amateur astronomers.[27] Examples are William and John Herschel, William Lassell, John Ramage (see Fig. 1.7 left), William Parsons (Lord Rosse) and his son Lawrence. They had the freedom to observe nebulae and to deal with questions about their physical nature – omitting accurate measurements. A large reflector, such as Lord Rosse's 72-inch, was ideally suited. However, in professional astronomy such instruments were rare. Though two big reflectors were erected in Marseille and Melbourne in the 1860s, the breakthrough did not come until the early twentieth century; a trendsetter was Ritchey's 60-inch, which was installed in 1908 on Mt Wilson.

Through Fraunhofer's inventions, the refractor became the privileged instrument of professional

[24] For the history of star catalogues and charts see Tirion *et al.* (1987: xv–xlii).

[25] See Chapter 11 for details. The text contains other interesting examples (see the table of contents), e.g. 55 And, NGC 1333, BD –0° 2436, GC 80, NGC 1988, II 48, NGC 7027, NGC 6677/79 and the trapezium in M 42.

[26] See the interesting list of private British observatories (Anon 1866b).

[27] Airy (1849). Concerning the Victorian epoch, Allan Chapman created the term 'grand amateur' (Chapman A. 1998); see also Ashbrook (1984: 32–37).

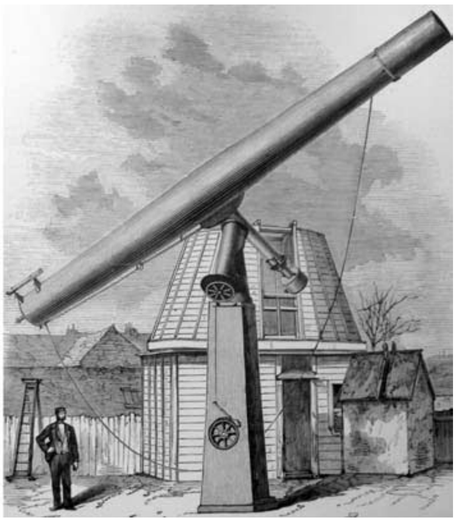

Figure 1.7. Large private telescopes. Left: the 38-cm reflector of John Ramage (erected in 1820 at Greenwich);[28] right: James Buckingham's 54-cm refractor.

astronomy in the nineteenth century. One of the first to benefit was Wilhelm Struve with the 9.6-inch in Dorpat.[29] With a refractor mounted equatorially and equipped with precise setting-circles and micrometers, accurate positional measurements could be made. Owing to their classical education, most observers at university, royal and government observatories worked in the field of astrometry. Their assistants had to concentrate on astrometry – time-consuming routine work producing large amounts of data. Practical skills and patience were needed, to ensure their careers. The primary targets were minor planets and comets (measuring relative positions at the refractor) as well as single or double stars (measuring absolute positions with the meridian-circle).[30] As a by-product, new nebulae were occasionally detected.

[28] In 1823 Ramage cast a 21" mirror with focal length 25 ft in Aberdeen, but the appropriate telescope was never built (Anon 1836; Dick T. 1845: 308–311).

[29] A duplicate was the Berlin refractor (erected in 1835), which was used by Galle and d'Arrest for the discovery of Neptune in 1846. For telescope data see the appendix.

[30] The relative position gives the coordinate differences between object and reference star. From the known star position for a certain epoch the absolute position (right ascension, declination) of the object can be determined; this calculation is called 'reduction'.

Only a few amateurs used large refractors; among the four front-runners, three were British. In 1856 the Italian Ignazio Porro had erected a 52-cm refractor in Paris. In 1862 James Buckingham built a 54-cm refractor (with optics by Wray) on Walworth Common (Fig. 1.7 right). Even larger, but optically defective and only short-lived, was John Craig's instrument with 61-cm aperture (built by Chance/Gravatt), which was installed in 1852 in Wandsworth. The largest was owned by Robert Newall in Gateshead: a 63-cm refractor, made by Cooke in 1869. It strongly suffered from the bad weather at the site.

(6) Astrometry. For instrumental and personal reasons, the precise measurement of nebular positions was a slowly growing matter. It depended on the will and authority of the director to interrupt the routine observations and turn the refractor onto nebulae. By measuring relative positions between the object and a nearby reference star it was hoped to determine its proper motion. Such data could yield information about the cosmic order (distances) of the nebulae. Frequent observations over a long period of time were necessary. However, the diffuse appearance of a nebula limited the precision.[31] Much work was done by Laugier, d'Arrest, Auwers, Schönfeld, Vogel, Rümker, Schmidt and Schultz. Related fields were the investigation of double nebulae (claiming a similarity to double

[31] The determination of a parallax was therefore impossible.