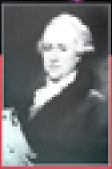
Observing and Cataloguing Nebulae and Star Clusters

From Herschel to Dreyer's New General Catalogue

WOLFGANG STEINICKE



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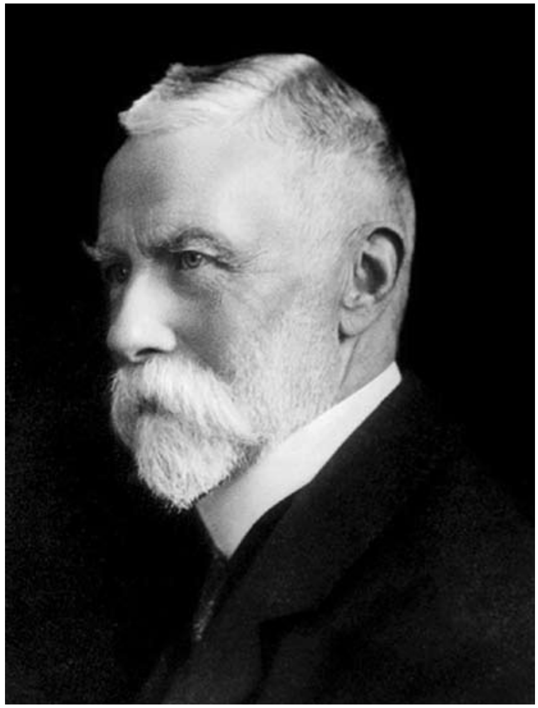
The *New General Catalogue*, created in 1888, is *the* source for referencing bright nebulae and star clusters, both in professional and amateur astronomy. With 7840 entries, it is the most-used historical catalogue of observational astronomy, and NGC numbers are commonly referred to today. However, the fascinating history of the discovery, observation, description and cataloguing of nebulae and star clusters in the nineteenth century has largely gone untold, until now.

This well-researched book is the first comprehensive historical study of the NGC, and is an important resource to all those with an interest in the history of modern astronomy and visual deep-sky observing. It covers the people, observatories, instruments and methods involved in nineteenth-century visual deep-sky observing, as well as prominent deep-sky objects. The book also compares the NGC with modern object data, demonstrating how important the NGC is in observational astronomy today.

Dr Wolfgang Steinicke, FRAS, is a committee member of the Webb Deep-Sky Society and Director of its Nebulae and Clusters section, a core team member of the international NGC/IC Project, Head of the History Section of the VdS, Germany's largest national association of amateur astronomers, and a member of the Working Group for the History of Astronomy of the Astronomische Gesellschaft. He frequently gives conference talks and courses, and contributes to astronomical magazines. This is his fourth book.



John Louis Emil Dreyer (1852–1926)

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Webb Deep-Sky Society

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521192675

First published in print format 2010

ISBN-13 978-0-511-78435-4 eBook (Adobe Reader)

ISBN-13 978-0-521-19267-5 Hardback

To my wife Gisela.

Contents

Preface

My enthusiasm for nebulae and star clusters goes back a long way – they were the targets of my first telescopic explorations of the night sky. This book treats the history of their discovery, visual observation and cataloguing. It is naturally focused on the nineteenth century – the fascinating epoch of classical astronomy, characterised by precious achromatic refractors and massive metal-mirror reflectors. Only a few astronomers searched for non-stellar objects systematically – foremost among them William Herschel and his son John. We owe to both of them the first comprehensive catalogues. The development reached its climax with the New General Catalogue (NGC) by John Louis Emil Dreyer – which is still a standard source for both amateur and professional astronomers.

Initially this immense work appeared to me as a mysterious treasure, arousing my scientific curiosity. What was behind the 7840 objects and who were the discoverers? By using the NGC, I gradually became familiar with its content. However, due to erroneous and incomplete data, it was often difficult to match the entries with the real sky. Over the years, due to my research on the historical sources and visual observing, the catalogue became a close companion. Many secrets could be disclosed – and, of course, my admiration for Dreyer increased.

The many years of investigation resulted in the 'Revised New General and Index Catalogue', which connects the original data with modern ones. In a second step, the historical background (discoverers, dates, instruments, sites) was revealed, which eventually led to the 'Historic NGC'. Both catalogues have seen many updates and are an essential basis of my recent German Ph.D. thesis at Hamburg University (Steinicke 2009). Actually, this book is an enhanced version of it and the first comprehensive popular presentation of the subject.

I want to thank the many supporters of my work – first of all my wife Gisela, who was a great help from the beginning. She worked on the indices, corrected the manuscript and was a valuable companion on many astronomical tours. Of course, special thanks must go to my friends of the NGC/IC Project, especially Harold Corwin and Malcolm Thomson. This international organisation deals with the correct identification of all objects in Dreyer's catalogues – and is, without any shadow of a doubt, very successful in this task!

During my research, I was supported by many famous institutions – I may just mention a few: Armagh Observatory, the Royal Astronomical Society, the Royal Observatory Edinburgh, the Institute of Astronomy (Cambridge), Arcetri Observatory, Birr Castle Museum and the Webb Deep-Sky Society. Special thanks go to the librarians Peter Hingley (RAS), John McFarland (Armagh Observatory), Françoise Le Guet Tully (Nice Observatory), Bertil Dorch (Danish National Library), Volker Mandel (Heidelberg-Königstuhl Observatory) and Anke Vollersen (Hamburg-Bergedorf Observatory).

Moreover, the list of important contributors is long; among them are Brent Archinal, Bob Argyle, Simone Bianchi, Wilhelm Brüggenthies, Ron Buta, Lutz Clausnitzer, Steve Coe, Glen Cozens, David Dewhirst, Wolfgang Dick, William Dreyer, Hilmar Duerbeck, Sue French, Hartmut Frommert, Steve Gottlieb, Michael Hoskin, Arndt Latußeck, John McConnell, Stewart Moore, Yann Pothier, Peter Schliebeck, William Tobin and Gudrun Wolfschmidt.

Of course, special thanks go to Steven Holt, Vince Higgs, Jonathan Ratcliffe and Claire Poole of Cambridge University Press. It was a pleasure to work with them. Last but not least, I am proud to have been supported by the late Mary Brück, who sadly died in 2008.

Wolfgang Steinicke
Umkirch, May 2010

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]

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).

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)

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.

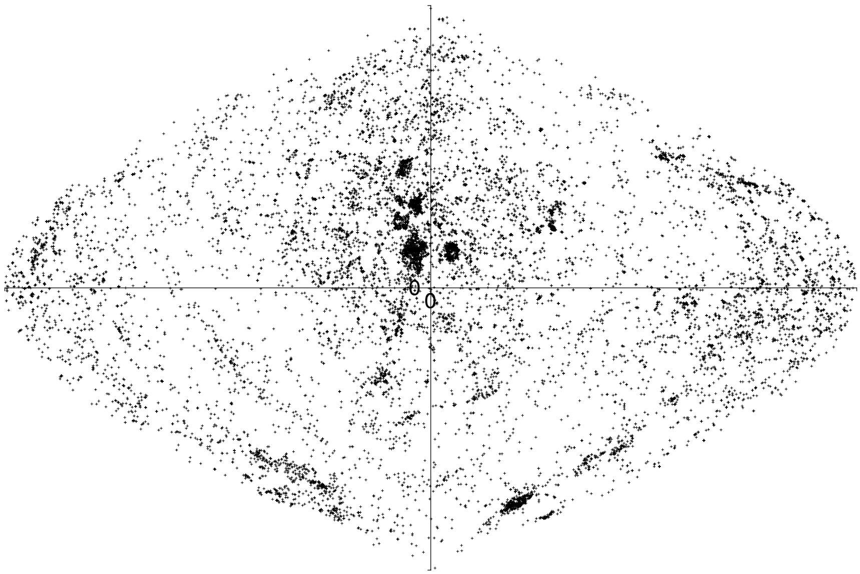


Figure 1.3. A plot of all 13 226 NGC/IC objects. The 'clusters' above centre ($\alpha = 12^h$, $\delta = 0°$) are mainly due to selection effects from photographic IC II surveys; the largest contains Virgo Cluster galaxies. The oval spot below right ($\alpha = 5^h$, $\delta = -70°$) represents objects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

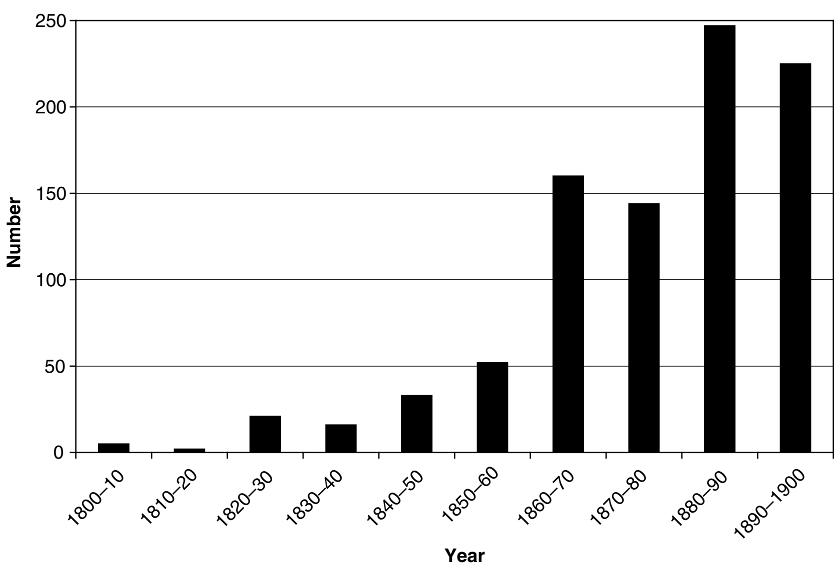


Figure 1.6. Numbers of articles on visual observations of non-stellar objects from 1800 to 1900.

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.

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

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

[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).

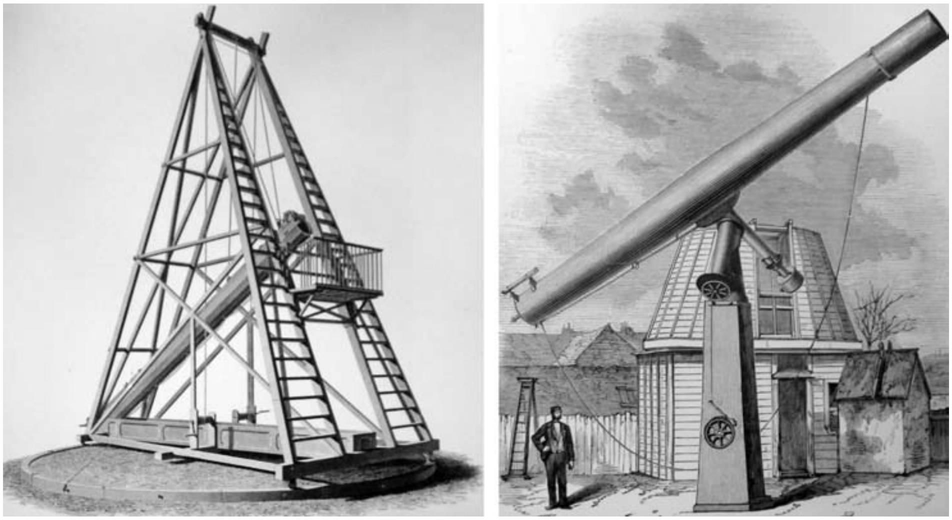


Figure 1.7. Large private telescopes. Left: the 38-cm reflector of John Ramage (erected in 1820 at Greenwich);[28] right: James Buckingham's 54-cm refractor.

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.

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

[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'.

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

stars), 'satellites' of planetary nebulae (supposed orbiting stars) and the construction of a celestial reference system based on nebular positions (e.g. Stephan at Marseille Observatory).

(7) Astrophysics. Finally, it must be stated that visual observations made to reveal the nature and evolution of nebulae and star clusters did not lead to any substantial progress. Starting from William Herschel, the basic ideas (such as the nebular hypothesis) were only slightly modified during the nineteenth century. Classical observation methods were improper as a means to get reliable statements about the physics of non-stellar objects. Neither large telescopes, with their enormous light-gathering power, nor extensive measurement campaigns to determine precise positions were able to terminate the various speculations. But the situation was changed by a simple ingenious stroke: spectroscopy.

Shortly after John Herschel's GC, the new method was systematically applied to bright, unresolved nebulae.[32] William Huggins' revolutionary studies brought astonishing results: some objects, such as planetary nebulae and the Orion Nebula, have discrete spectra and are thus gaseous. In other cases, such as the Andromeda Nebula, a continuous spectrum was detected, implying a starry nature.[33] Major contributions were also due to d'Arrest, Pickering and Copeland. Photography of nebulae was not relevant in the 1860s and 1870s. Most objects were not bright enough to be detected on the insensitive plates of the time (which had many defects). Photographic identification of nebulae (which could have been very useful for the compilation of the NGC) was out of reach. Another field, the photometry of nebulae, was still undeveloped; thus magnitudes had to be estimated visually. Useful techniques were eventually introduced in the twentieth century.

1.4 STRUCTURE, PRESENTATION AND CONVENTIONS

This work is characterised by its large amount of information and data. Altogther 2154 of the 7840 NGC objects are mentioned (see the appendix).[34] To get the necessary overview, a systematic presentation is needed. Though chronology should be a central element, it is not a sufficient guide per se. There are many interconnected aspects to the story, which must be treated in a parallel manner. These are

- observers (discoverers) and their biographies
- discovery, description and cataloguing of objects
- instruments and sites (observatories)
- observing methods and the development of astronomy during the nineteenth century

The great amount of facts can be handled only by enriching the text with a considerable number of tables, graphics and figures. There are 239 tables, presenting objects, discoveries, observers and instruments, 35 graphics[35] about statistics, historical development and magnitude distribution and 324 figures[36] showing object images, drawings/sketches, portraits, instruments and observatories.

It would certainly be useful to present the 'Historic NGC', first published by the author in 2006.[37] It contains modern data, identifications, discoverers, dates and instruments for all NGC objects. However, due to its size, it was impossible to incorporate it. Nevertheless, in connection with the original NGC, it is an essential basis of this work. Of course, both catalogues reflect the historical development and the above-mentioned major topics only in a very condensed form, so a great amount of additional information is needed. Therefore, the present work surpasses the original and the modern 'Historic NGC', using their data only as examples.

Take, for instance, the question of 'priority', i.e. who discovered an object first. Often the observers were unaware of the existing catalogues and publications, but, even if earlier data were known, some problems remained. Owing to the incomplete or erroneous nature of the data, observers were unable to discern the correct priority. To clarify the situation, a standard procedure is presented here. First, all new objects of an observer are listed in a table (if the number is not too large) showing the relevant data. Next the status of the objects must be determined. Actually, two kinds of identities are possible: (a) 'catalogue identity' – the object appears more than once in the observer's list; and (b) 'NGC identity' – the object (entry) is identical with other ones (normally

32 For the development of astrophysics, see Leverington (1995).

33 These objects were called 'white nebulae'.

34 Additionally 107 IC objects are mentioned.

35 All graphics were made by the author.

36 Most of them are from the author's archive.

37 See the author's website: www.klima-luft.de/steinicke.

associated with different observers). Afterwards it must be checked that the objects had not been found earlier by other observers. The result is a list of NGC objects for which the observer possesses the priority. It is now easy to calculate an individual's success rate, i.e. the number of non-stellar objects discovered.

Generally, the structure of the tables is uniform. The catalogue number (priority objects are in bold print), discoverer, date, type and constellation are listed.[38] A visual (integrated) magnitude is not given for pairs/groups of stars and emission/reflection nebulae (it is not an adequate measure for these types). Moreover, there are remarks, e.g. pointing to identities, other observers or names.

For observers with large numbers of discoveries, only special objects are listed: brightest/faintest, most northern/southern and first/last discovered. The distributions of objects' types and magnitudes are given both in a table and graphically. Additional notes concern the discovery of galaxy groups, clusters and special appearances (e.g. ring or edge-on galaxy). If relevant, information about further persons, relations, organisations, observations, measurements or publications is presented.

The graphics present results of statistical analyses, concerning brightness distribution, temporal development, number of discoveries, publications and instruments. The photographs of persons, telescopes and observatories are from the author's archive, the RAS and other sources. Most object images were taken from the Digitized Sky Survey (DSS), processed and labelled by the author. The orientation resembles the real sky: north up, east left; the scale is given in arcmin (′). Sketches and drawings have been copied from the original publications (sometimes the orientation is changed).

Additional structure elements are quotations, notes and references. Unfortunately, only 90 sources are given by Dreyer in the NGC. The present work contains more than 1600; mainly references to the original and secondary literature.[39] For most catalogues, lists or papers a cited object can be easily found by its designation. Many articles, especially those from the *Astronomische Nachrichten* (*AN*), are pretty short, so an exact page (or column) for the quotation is not needed.

[38] The international names and abbreviations of the constellations are used.

[39] Bigourdan gave some useful references (Bigourdan 1917b).

Of course, for longer quotations the page is given. All foreign-language texts were translated by the author. For those from previous centuries it was decided to keep the original structure and style to a large extent. However, often sentences were lengthy and dodgy, e.g. those by Tempel, written in German. In these cases the translation was a challenge. Titles of books and articles have been translated too; translations are given either in brackets, following the text, or in a footnote.

The RAS archive is a valuable source. This concerns the Herschel family (Bennett 1978) and letters and manuscripts of astronomers, such as Lord Rosse and Lassell. Other archives (if available) were consulted for those astronomers or observatories with significant contributions to the NGC. For Great Britain and Ireland some were built up by Hoskin and others: Birr Castle (Lord Rosse), Markree Castle (Cooper), Dunsink Observatory and Armagh Observatory.[40] Sadly, Dreyer's estate could not be located and it is doubted by the author that there is anything left.[41] The available information about other eminent astronomers, such as Tempel and d'Arrest, is sparse too.

The sequence of chapters generally follows the milestones defined in Table 1.2. Special sections are devoted to the discoverers contributing to the respective catalogue; one contains a detailed statistical analysis based on modern data. Looking at the table of contents, it is apparent that the number of sections (and subsections) increases with the years. This is due to the growing number of persons involved: William Herschel's three catalogues were supported only by his sister Caroline. Four discoverers contributed to the Slough and Cape catalogues (John Herschel, James Dunlop, Wilhelm Struve and Niccolò Cacciatore). In Auwers' list of new nebulae 14 persons are involved; in the GC there are 13. In the cases of the GCS and NGC we have 30 and 38 additional discoverers, respectively. Moreover, many other persons, who contributed by making measurements, corrections etc., are mentioned in the text.

[40] Bennett and Hoskin (1981) (Birr Castle); McKenna-Lawlor and Hoskin (1984) (Markree); Hoskin (1982b) (Markree und Dunsink); Buttler and Hoskin (1987) (Armagh).

[41] Dreyer's estate seems to be lost (see Section 8.1.5). Some of his documents could be inspected by the author at Armagh Observatory and are considered here. Important letters of Dreyer to Hagen were found at the Vatican Observatory (see Section 10.1.1).

All discoverers are introduced by a short biography;[42] published obituaries and other biographical sources are given. If several persons were active at an observatory, the presentation is bundled. Examples are Birr Castle, Marseille, Cambridge (Harvard), Uppsala, Chicago (Dearborn), Vienna, Melbourne and Charlottesville (Leander McCormick). If an observer contributed to more than one catalogue, separate subsections are introduced; d'Arrest, Tempel, Stephan and the observers at Harvard and Birr Castle are examples.

Chapter 10 is central, describing the structure and content of the New General Catalogue. Here all information is combined. A complete review of the NGC discoverers and their success rates is presented in Table 10.6. The problem of missing data is treated too. Finally, supplements, corrections and revisions of the NGC are critically discussed.

[42] An exception is Dreyer, who is represented by a longer biography in Section 8.1.

Chapter 11 is reserved for special themes and important objects. It starts with a comprehensive summary of nineteenth-century campaigns to determine precise positions of non-stellar objects. Next the history of nebular drawings is presented, with special emphasis on the problem of objectivity. The remaining sections deal with special objects, demonstrating the controversial character of visual observations. The popular galaxy M 51 in Canes Venatici is representative for the discussion about the reality of spiral structure, since it was first detected by Lord Rosse in April 1845. Much excitement was caused by variable nebulae, like NGC 1555 in Taurus, which was discovered in 1852 by Hind. Another case is the Merope Nebula (NGC 1435) in the Pleiades, which was found in 1859 by Tempel in Venice.

The extensive appendix contains a timeline (with 152 major events concerning the history of the NGC), abbreviations/units and data about telescopes. References and Internet sources are given. Moreover, indices concerning persons, sites (observatories) and designated objects are presented. The work is closed with a comprehensive subject index.

2 • William Herschel's observations and parallel activities

When William Herschel (Fig. 2.1) started his systematic search for non-stellar objects in autumn 1783, only about 100 were known (Messier's final catalogue had appeared two years earlier). Hence the opportunity to discover new ones with his superior telescopes was great. Herschel took advantage of it and in the end his catalogues grew to about 2500 entries – enough to analyse the nature and evolution of nebulae and star clusters by standardised methods developed by him. Generally Herschel's work is characterised by his great interest in the nature of celestial objects – perhaps a consequence of the lack of precise measurements. With his equipment, positions were determined relative to reference stars, often lying at a considerable distance. As regretted 50 years later by Auwers and d' Arrest, the precision was not high enough for using the data to determine proper motion. Thus a valuable past reference point was lost. Another crucial innovation was his coded textual description, which he introduced not only to identify the objects, but also to classify them. Herschel defined eight classes (I to VIII), which became a powerful tool with which to derive an evolutionary scenario about the nature of nebulae and clusters.

Figure 2.1. William Herschel (1738–1822).[2]

Herschel had not received a scientific education; he was self-taught and had both the limitations and the sturdy independence of an autodidact.[1] Nevertheless, he undertook systematic studies of the heavens. Herschel had therefore already dealt with 'astrophysics' (much more than with astrometry), which was strongly influenced by Newton's theory of gravity. His theories did not rest on (objective) physical experiments, but on the interpretation of (subjective) visual observations. No doubt due to his superior equipment and revolutionary mind, he was quite solitary. There was no way in which the astronomical community could repeat his observations or assess his 'natural history' vision of the heavens against accepted professional models.[3] Herschel tried to build a single series that linked 'true nebulosity' (appearing 'milky') with 'resolved' clusters. To reach this goal, a large sample of objects had to be accumulated. He introduced a 'morphological method' into astronomy.[4] Key objects (like specimens) were the Orion Nebula, 'resolved' star clusters and the planetary nebulae, the latter being primary targets of contemporary observers like Friedrich von Hahn too. However, he repeatedly changed his ideas about nebulae. Finally the objects were arranged by age, starting from much diffused nebulosity, which contracts into stars, building

1 Hoskin (1982c: 143).

2 For a comprehensive collection of Herschel portraits, see Turner A. (1988).

3 Schaffer (1980), Hoskin (1982c).

4 Later this method was repeated in the work of Fritz Zwicky; see his *Morphological Astronomy* (Zwicky 1957).

highly condensed star clusters. Herschel's method is similar to that of a naturalist, defining the life-history of a plant by pointing out specimens at successive stages of evolution. Since all stages are present at once, a natural sequence can be drawn by watching, classifying and ordering – one does not have to wait for the (slow) ageing of an individual object.

Because much has already been written about the life of William Herschel, a biography is omitted here.[5] The focus is on his observations leading to discoveries of new objects and their cataloguing. First the structure and content of his three published catalogues is presented, followed by their statistical analysis. Central aspects are the appearance of Herschel objects in the NGC and their identification. With the exception of Michael Hoskin's famous research, these issues had hitherto not been treated in the literature. William Herschel gave his name to the British 4.5-m reflector on La Palma and lately he was honoured by the European 'Herschel Space Observatory', a 3.5-m infrared telescope launched on 15 May 2009.

2.1 OBJECTS DISCOVERED PRIOR TO HERSCHEL

There are already many publications about early discoveries of nebulae and star clusters.[6] A pretty much uncovered aspect is their relevance for the NGC, which is described here. A central role is undoubtedly played by the Messier catalogue of 1781 with its 103 entries.[7] Charles Messier arranged it by the date of discovery or position measurement of the objects. It was Auwers who published in 1862 the first reduced version, sorted by right ascension for 1830 (Auwers 1862a). He included measurements by d'Arrest for 43 objects. Auwers made Messier's catalogue usable for the professional astronomer and laid the foundations, together with William Smyth, for its later popularity. The latter had already presented a sample of 65 objects in his Bedford Catalogue of 1844, with notes about history and visual observation (see Section 6.5). In 1877 Edward Holden published a list that identifies the Messier objects in John Herschel's General Catalogue (Holden 1877a). At the beginning of the twentieth century, John Ellart Gore presented comprehensive textual descriptions (Gore 1902) based on his visual observations and photographs of Isaac Roberts made in the 1890s. In 1917 Harlow Shapley and Helen Davis undertook a (successful) attempt to introduce the Messier catalogue to professional astronomers (Shapley and Davis 1917). The M- and NGC-number, equatorial coordinates (1900), galactic coordinates and type (name) are listed. However, M 91 is not identified as an NGC object; M 25 is IC 4725 (see Table 2.2).

The NGC contains 138 objects found prior to William Herschel; Table 2.1 shows their discoverers.[8] In the cases of Cassini and Pigott, Giovanni Domenico Cassini and Edward Pigott are meant. The latter saw M 64 on 23 March 1779 (Pigott 1781), i.e. a bit earlier than Bode (4 April 1779) and Messier (1 March 1780). The instruments ('Instr.') used are E = naked eye and Rr = refractor. For some discoveries the date is uncertain. 'Remarks' show the most important Messier objects and independent discoverers.[9] Amerigo Vespucci was the first northern-hemisphere observer to see the Small Magellanic Cloud (SMC), as was revealed recently (Dekker 1990). He saw it in 1501, i.e. 20 years earlier than Magellan. According to Humboldt, the Large Magellanic Cloud (LMC) was described by As-Sufi as a 'white ox'.[10] M 44 (Praesepe) and M 7 (Ptolemy's Cluster) are the second- and third-nearest NGC objects (see Table 10.17).

Actually the NGC lists 140 early objects, but two are double entries: the open cluster M 47 in Puppis and the planetary nebula M 76 in Perseus. M 47 was found

5 See e.g. Holden (1881), Ball R. S. (1895: 200–218), Dreyer (1912a), MacPherson (1919), Lubbock (1933), Buttmann (1961), Hamel (1988), Gärtner (1996) and Hoskin (1959, 2003b, 2007).

6 See e.g. Schultz (1866b), Wolf R. (1890, vol. 2: 600–609), Sawyer-Hogg (1947a–c), Duncan (1949), Gingerich (1953a, b, 1954, 1960, 1967, 1987), Glyn Jones (1967a, b, 1975, 1991), Nilson (1973: 449–455), Stoyan *et al.* (2008) and the website of Frommert: www.seds.org/messier/xtra/history/deepskyd.html.

7 Messier published three catalogues with 45, 70 and 103 objects, respectively (Messier 1774, 1780, 1781).

8 Biographical information on most of them can also be found in Johann Elert Bode's compilation in the *Berliner Jahrbuch* (Bode 1813).

9 For Ihle's discovery of M 22, see Lynn (1886a). It is remarkable that M 31 was not noticed by Tycho Brahe and Galileo; for its history and Marius' rediscovery in 1612, see Webb (1864c) and Lynn (1886b). The origin of the name Praesepe is explained by Lynn (1905a).

10 Humboldt (1850: 599); undoubtedly the SMC was seen much earlier too.

Table 2.1. *Early discoverers of NGC objects*

Discoverer	Number	Instr.	Date	Remarks
As-Sufi	1	E	905?	M 31 (Andromeda Nebula); Marius 1612[11]
Aratos	1	E	−260?	M 44 (Praesepe); Hipparch −130
Aristotle	2	E	−325?	M 39, M 41
Bevis	1	3" Rr	1731	M 1 (Crab Nebula)
Bode	4	Rr	1774–77	M 53, M 93; M 81 and M 82 (Bode's Nebulae)
Cassini	1	5" Rr	1711	M 50
Darquier	1	3.5" Rr	1779	M 57 (Ring Nebula)
de Chéseaux	6	Rr	1745?	Including M 4, M 16, M 17 (Omega Nebula), M 35, M 71
Flamsteed	1	9.7" Rr	1690	NGC 2244
Halley	2	Rr	1677–1714	M 13, ω Centauri
Hipparch	2	A	−130	Double Cluster NGC 869/884 (χ Per)[12]
Hodierna	11	Rr	1654?	Including M 6, M 33, M 34, M 36–38, M 47, M 71
Ihle	1	Rr	1665	M 22; Halley 1715
Kirch	2	Rr	1681–1702	M 5, M 11 (Wild Duck Cluster)
Koehler	3	Rr	1779	M 59, M 60, M 67
Lacaille	23	0.5" Rr	1751	Including M 55, M 83
Legentil	2	Rr	1749	M 8 (Lagoon Nebula), M 32
Mairan	1	Rr	1731	M 43
Maraldi	2	Rr	1746	M 2, M 15
Méchain	26	3" Rr	1779–82	Last object: NGC 6171 (M 107), April 1782
Messier	40	3.3" Rr	1771–81	Last object: M 80, 4.1.1781
Oriani	1	3.6" Rr	1779	M 61
Peiresc	1	Rr	1610	M 42 (Orion Nebula); Cysat 1611
Pigott	1	5" Rr	1779	M 64 (Black Eye); Bode 1779
Ptolemy	1	E	−138?	M 7 (Ptolemy's Cluster); Halley 1678
Vespucci	1	E	1501	NGC 292 (SMC); Magellan 1521

first by Hodierna and is catalogued as NGC 2422; while Messier's discovery was listed by Dreyer as NGC 2478. The case of M 76 is different: this is a bipolar nebula, whose brighter part (NGC 650) is credited to Méchain. Later William Herschel saw both 'components'; the fainter (I 193) is catalogued as NGC 651.[13] Lord Rosse even saw a 'spiral' structure.

Four Messier objects are missing in the NGC: M 24, M 25, M 40 and M 45 (Table 2.2). About M 25 Dreyer writes as follows in the introduction of the IC I: '*Two clusters in Messier's catalogue do not appear in the New General Catalogue, and may perhaps be mentioned here.*'[14] The second one is M 48; unfortunately wrong coordinates are given. This might be the reason why Dreyer did not notice that the object had already been catalogued as NGC 2548. For M 25 he changed

[11] The Andromeda Nebula was the first non-stellar object to be found with a telescope.

[12] The double cluster is usually referred as 'h + χ Persei' (with h = NGC 869 and χ = NGC 884), but, as shown quite recently, it should be only χ Per (O'Meara and Green 2003). Actually, Bayer assigned this 'star' to represent the combined light of the double cluster. Another mystery is the fact that Messier did not include the object in his catalogue (Burnham R. 1966: 1440).

[13] NGC 650/51 is known as the Little Dumbbell Nebula, a creation of Leland Copeland (Copeland L. 1960).

[14] Dreyer (1953: 243).

Table 2.2. *Missing, double and added Messier objects in the NGC*

M	NGC	Discoverer	Date	Type	V	Con.	Remarks and References
24		Messier	20.6.1764	Star cloud	2.5	Sgr	IC 4715, Barnard Aug. 1905
25		de Chéseaux	1745?	OC	4.6	Sgr	IC 4725, Bailey 1896
40		Messier	24.10.1764	2 stars	9.0	UMa	Winnecke 12.10.1863
45				OC	1.5	Tau	Pleiades
47	2422	Hodierna	1654?	OC	4.4	Pup	Messier 19.2.1771; W. Herschel 4.2.1785 (VIII 38)
	2478	Messier	19.2.1771				
48	2548	Messier	19.2.1771	OC	5.8	Hya	C. Herschel 8.3.1783 (VI 22)
76	650	Méchain	9.5.1780	PN	10.1	Per	
	651	W. Herschel	12.11.1787				I 193
91	4548	Messier	18.3.1781	Gx	10.1	Com	W. Herschel 8.4.1784 (II 120); Dreyer: NGC 4571?
102	5866	Méchain	27.3.1781	Gx	9.9	Dra	W. Herschel 5.5.1788 (I 215); Dreyer: NGC 5928
104	4594	Méchain	11.5.1781	Gx	8.3	Vir	W. Herschel 9.5.1784 (I 43); Flammarion (1917)
105	3379	Méchain	24.3.1781	Gx	9.5	Leo	W. Herschel 11.3.1784 (I 17); Sawyer-Hogg (1947c)
106	4258	Méchain	July 1781	Gx	8.3	CVn	W. Herschel 9.3.1788 (V 43); Sawyer-Hogg (1947c)
107	6171	Méchain	April 1782	GC	7.8	Oph	W. Herschel 12.5.1793 (VI 40); Sawyer-Hogg (1947c)
108	3556	Méchain	16.2.1781	Gx	9.9	UMa	W. Herschel 17.4.1789 (V 46); Gingerich (1954)
109	3992	Méchain	12.3.1781	Gx	9.8	UMa	W. Herschel 12.4.1789 (IV 51); Gingerich (1954)
110	205	Messier	10.8.1773	Gx	7.9	And	C. Herschel 27.8.1783 (V 18); Glyn Jones (1967a)

his mind in the IC II, because the cluster appears on plates taken in 1896 by Solon Bailey in Arequipa, Peru (Bailey 1908). It was now catalogued as IC 4725. M 45 (and the Hyades too) was ignored by Dreyer, though it was among the 13 non-NGC objects on Bailey's plates. He wrote, in the IC II introduction, '*the Pleiades and the Hyades I have not inserted*'.[15]

The identity of the large Sagittarius Star Cloud M 24 with IC 4715, which was photographed by Barnard in the summer of 1905 (Barnard 1908a), was not recognised by Dreyer. M 40 in Ursa Major was found independently by Winnecke in 1863. It is no. 4 in a list of new double stars published in 1869 (Winnecke 1869); see Section 6.12.2. A problematic case is M 91 (NGC 4548). For NGC 4571 Dreyer writes '*M 91??*', adding in the notes that '*M 91 must have been a comet*'. Obviously he follows Flammarion, assuming an identity of Messier's objects with the comet of 1779 (Flammarion 1917). The most controversial object is M 102, which has often been identified with the galaxy NGC 5866 in Draco, which originates from Solon Bailey.[16] Others believe the object to be a double

[15] Dreyer (1953: 287).

[16] Shapley and Davis (1917: 179); supported by Frommert (2006).

sighting of the bright galaxy M 101 in Ursa Major.[17] In the IC I notes, Dreyer gives a very different view. If Méchain's reference star is a typo, M 102 could be the galaxy NGC 5928 in Serpens: '*I assume that ι Draconis is an error for ι Serpentis*.'[18]

It is well known that the Messier-numbers M 104 to M 110 were added in the twentieth century by Camille Flammarion, Helen Sawyer-Hogg, Owen Gingerich and Kenneth Glyn Jones. All these objects are included in the NGC.

For 11 Messier objects Dreyer does not give the true discoverer. M 4 (NGC 6121), M 6 (NGC 6405) and M 8 (NGC 6523) are all credited to Lacaille, but they were found by de Chéseaux, Hodierna and Legentil, respectively. In the case of M 7 he does not mention Ptolemy, mentioning the 'modern' discoverers Halley and Lacaille. For M 36 (NGC 1960), Legentil instead of Hodierna is credited. Dreyer mentions Flamsteed and Legentil in the case of M 41 (NGC 2287), which he erroneously called 'M 14' (corrected in the IC I notes). This open cluster was first described by Aristotle. Hipparch's M 44 (Praesepe, NGC 2623) had already been seen (and named) by Aratos. Dreyer credits the galaxies M 49 (NGC 4472) and M 67 (NGC 2682) to Oriani. M 49 was found earlier by Messier; M 67, discovered by Koehler, is not at all an Oriani object. This error was made by Bigourdan too.[19] M 71 was found by de Chéseaux, not by Méchain, as Dreyer claims.

In the case of M 42 (NGC 1976) Dreyer mentions Cysat's observation of 1611, obviously following Rudolf Wolf,[20] but Peiresc had seen the Orion Nebula in 1610, as Bigourdan has shown in his paper 'La découverte de la Nébuleuse d'Orion (N.G.C. 1976) par Peiresc'.[21] Given these early observations and the fact that M 42 (3.7 mag) can even be glimpsed as a nebulous spot by the naked eye on a dark night, it is remarkable that Galileo had not found the nebula with his telescope. His 1610 map of the Sword of Orion does not show it (Gingerich 1987). This was noticed by Humboldt, who wrote '*How could the large nebula in the sword escape his attention?*'[22] Webb's idea was that '*We can only suppose that he may have mistaken it for the effect of moisture upon his eye-glass*' or '*engravers and copyists may have been in fault*' (Webb 1864c). In 1617 Galileo made another, even closer sketch of the area, which, however, shows only the principal stars with great accuracy (Graney 2007). As another reason for his failure, it was suggested recently that the nebula could have been rendered temporarily invisible by a flaring up of illumination from FU Orionis-type stars and reappeared later.[23] This, however, contradicts the observations of Cysat and Peiresc.

The pre-Herschel time ends with the observations of Méchain. Only five months after his last discovery (the globular cluster in Ophiuchus later named M 107), William Herschel took over, discovering the planetary nebula NGC 7009 in Aquarius on 7 September 1782.

2.2 STRUCTURE AND CONTENT OF THE HERSCHEL CATALOGUES

2.2.1 Herschel's sweeps and publication of the results

In Bath, Herschel had observed Messier objects with his 6.2" reflector,[24] not knowing the French catalogue at that time: the Orion Nebula (M 42) in 1774, the globular cluster M 13 in Hercules in 1779 and the Andromeda Nebula (M 31) in August 1780. He got Messier's second version (containing 70 objects) in December 1780.[25] Herschel later wrote '*As soon as the first of these volumes came into my hands, I applied my former 20-feet reflector of 12 inches aperture to them*.'[26] At that time, his largest telescope was the 'small 20 ft', a 12" reflector built in 1776 (Fig. 2.2 left).[27] By the end

17 Proclaimed e.g. by O'Meara (2006).

18 Dreyer (1953: 286).

19 Bigourdan (1917b: E140).

20 Wolf R. (1854); see also Webb (1864c: 258–266) and Lynn (1887).

21 'The discovery of the Orion Nebula (NGC 1976) by Peiresc' (Bigourdan 1916).

22 Humboldt (1850: 506).

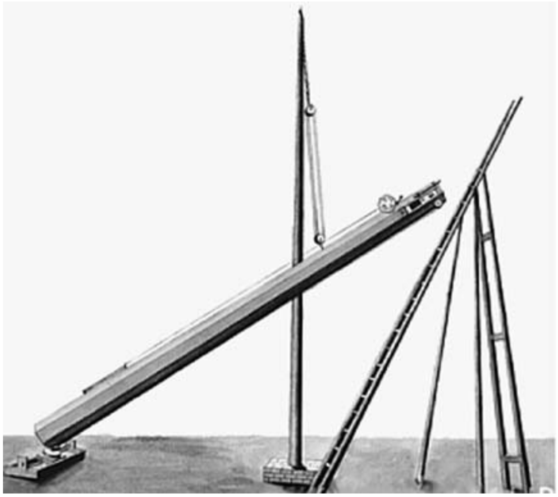
23 This idea is due to Harrison (1984); see other views by Gingerich (1987) and Herczog (1998).

24 Herschel had used this '7-foot' since 1778 in Bath. In August 1779 he started making with it a survey of all stars down to 8 mag to isolate as many double stars as he could discover, using them to determine stellar parallax. During this search, Uranus was found on 13 March 1781 (Schaffer 1981).

25 Messier (1780); Herschel wrote about it four years later (Herschel W. 1784: 439–441).

26 Herschel W. (1784: 439). See also Section 6.4.8.

27 Telescope data are listed in the appendix. On Herschel's see Steavenson (1924), Maurer (1971, 1996) and Bennett (1976a).



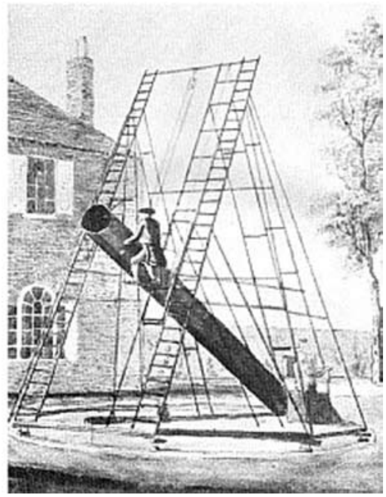


Figure 2.2. Herschel's reflectors in Datchet. Left: small 20-ft (12"); right: large 20-ft (18.7").

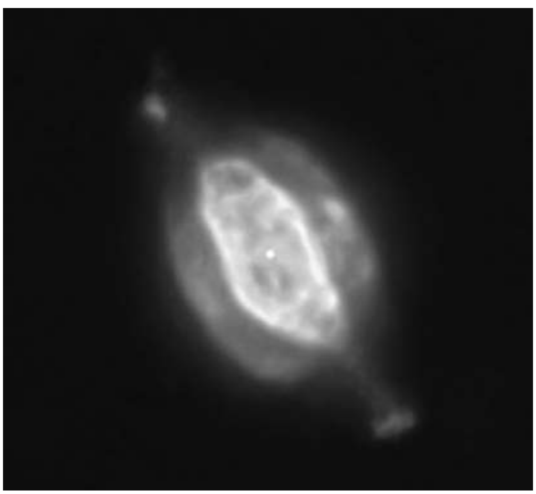


Figure 2.3. The Saturn Nebula NGC 7009 in Aquarius.[28]

of 1781 he had observed 24 Messier objects with it. However, being still absorbed with non-astronomical matter, he saw no reason for a systematic search for nebulae. In December 1781 his friend William Watson delivered him an exemplar of Messier's final catalogue with 103 objects.[29]

By the end of July 1782 Herschel moved to Datchet, where he observed Messier objects and double stars with the 12-inch. On 7 September 1782 he accidentally discovered his first nebula: NGC 7009 in Aquarius (Fig. 2.3); this is the very first non-stellar object to have been found with a reflector. However, the systematic search started a year later – motivated by observations by his sister Caroline.[30] With her small refractor, made by Herschel, she had found some non-stellar objects between August 1782 and October 1783 (see Section 2.3). Herschel was truly impressed and considered making his own observations. In spring 1783 he tested a 3.5" refractor for this task and subsequently tried the 'small 20 ft'. Since both instruments were not successful, he decided to build a larger telescope. On October 23, 1783 the 'large 20 ft', equipped with an 18.7" mirror, was ready – this was Herschel's standard telescope for his search for nebulae.[31]

Herschel effected his observations at three different sites, all near Windsor Castle.[32] From 2 August 1782 to early June 1785 he worked in Datchet (Berkshire), then moving to Clay Hall, Old Windsor. From 3 April 1786 he lived in the Observatory House on Windsor Road, Slough (Fig. 2.4). Table 2.3 gives the first and last objects discovered at the three sites. During the whole period Herschel observed on 401 nights. The numbers of objects found in Datchet and Slough are nearly equal.

[28] See also the sketches of Lamont (Fig. 6.3) and Vogel (Fig. 8.40).

[29] RAS Herschel 1/13.W.11.

[30] Hoskin (1979).

[31] Bennett (1976b), Ashbrook (1984: 127–132).

[32] See Dreyer (1912a: xxxvii).

Table 2.3. *Herschel's observing sites near Windsor and his first and last objects discovered at these sites (see the text)*

Site	Number	Date	Sweep	Object	No.	C	NGC	Type	*V*	Con.
Datchet	1079 (43%)	7.9.1782	–	IV 1	1	1	7009	PN	8.0	Aqr
		5.5.1785	409	II 425	1079	2	5990	Gx	12.3	Ser
Clay Hall	345 (14%)	17.7.1785	415	VII 18	1080	2	6823	OC	7.1	Vul
		28.3.1786	550	II 567	1424	2	5101	Gx	10.5	Hya
Slough	1076 (43%)	17.4.1786	553	II 568	1425	2	4270	Gx	12.1	Vir
		26.9.1802	1111	III 978	2500	3	3057	Gx	12.9	Dra

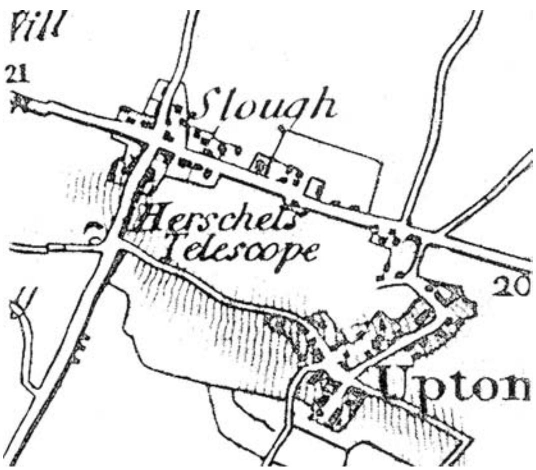


Figure 2.4. The site of Herschel's 'Observatory House' in Slough (Maurer 1996).

The 12-inch yielded only the first nebula (NGC 7009) – all later discoveries were made with the 18.7-inch.

The systematic observations ('sweeps'), were started on 28 October 1783. This night already brought a success, the first 18.7-inch discovery: II 1 (NGC 7184; Fig. 2.5), a galaxy in Aquarius.

All sweeps (1 to 1112) and discovered objects (1 to 2500) were numbered. However, these numbers are given only in Herschel's unpublished observing journals (not in his three catalogues 'C'), which are now at the RAS archive.[33] In the first 41 sweeps (up to 13 December 1783) Herschel used the telescope in 'front-view' mode,[34] standing on a platform in front of the tube. It pointed to the south (meridian) and could be moved horizontally by 30° to each side. He performed slow oscillations of 12° to 14° and made notes every 5 minutes.[35] Then the reflector was raised or lowered by 8' or 10' to repeat the procedure; 10 to 20 of them defining a sweep. Afterwards the telescope was reset to a slightly different declination (normally 2° to 3°) for another sweep. At the beginning, one sweep per night was executed, later three or four. The method, which was carried out without any assistance, turned out to be ineffective and yielded only eight nebulae, among them the galaxy NGC 253 (V 1, 30 October 1783) in Sculptor, which Caroline Herschel had already discovered on 23 September 1783 (William Herschel: '*It is Carolina's*'[36]). The main problem was caused by the frequent illumination needed to record the observation on the platform, which meant that the eye could not adapt properly.

Herschel tested alternative procedures and with sweep 46 (18 December 1783) a new standard was established. Now the south-looking telescope was moved vertically only (with the aid of an assistant); objects and reference stars passed the eye-piece due to the Earth's rotation. In every sweep three to five standard stars were observed. Herschel now used the Newtonian focus, sitting on a chair, which was fixed on a ladder at the side of the reflector (Fig. 2.2 right).[37]

33 The RAS offers a digital version (DVD) of the archive. The content is explained by Bennett (1978) (his quotation form is used here).

34 In this mode, the eye-piece points directly, i.e. without a secondary mirror, to the main mirror. The obstruction by the observer's head was negligible. The 'front-view' form is also called 'Herschelian' or 'Le Mairean' and was invented in 1728 (Mitchell O. 1851: 227–229). William Herschel tested it for his 12" and 18.7" reflectors, see his description in the notes of the first catalogue (Herschel W. 1786: 499).

35 Herschel W. (1786: 458–459); see also Hoskin (2005c) and Dreyer (1912a: xxxix).

36 RAS Herschel W. 2/1.7.

37 The platform was re-installed in September 1786, occasionally using the reflector in 'front-view' mode (Herschel

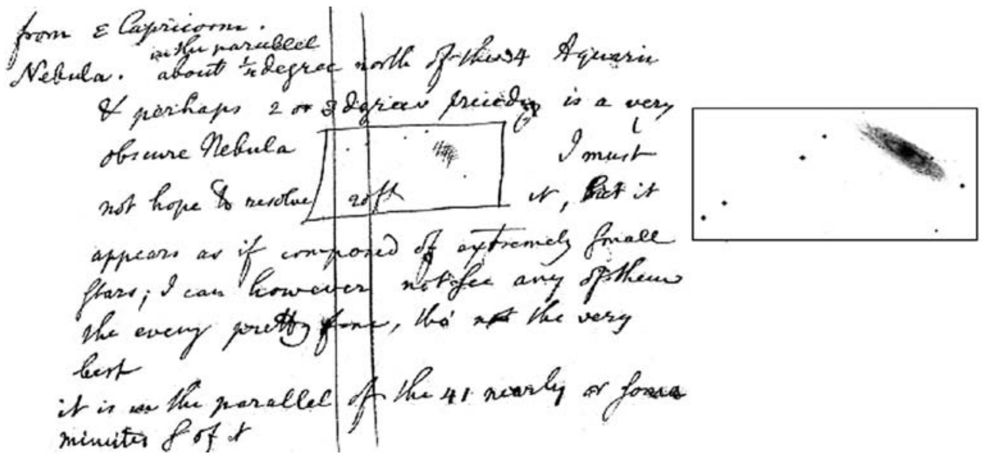


Figure 2.5. Left: Herschel's note and sketch for II 1 = NGC 7184 (RAS Herschel W. 2/1.7); right: DSS image showing the galaxy and the prominent star chain (north is up).

The observational results were shouted to Caroline Herschel, who was sitting at the window in the nearby house to record them.[38] The data were now entered in separate 'sweep-books'.[39] The first discovery with this new, effective method was II 5 = NGC 1032, a galaxy in Cetus (sweep 47, 18 December 1783).

Between 1786 and 1802 William Herschel published three catalogues in volumes 76, 79 and 92 of the *Philosophical Transactions of the Royal Society*[40] (Table 2.4), listing altogether 2500 objects. They were later revised by Dreyer and included in the *Scientific Papers of Sir William Herschel* (Dreyer 1912a); some new objects were added there (see Section 2.9).

William Herschel categorised his objects into eight classes (Table 2.5). The first five contain 'nebulae', i.e. unresolved objects, differentiated by brightness (I–III), type (IV) and extent (V). The last three classes describe 'clusters', i.e. resolved star clusters, where he distinguishes in terms of concentration and richness. As shown later, the Herschel classes are only weakly correlated with modern object types (especially for nebulae).

Table 2.6 gives the first and last objects from the three catalogues. Herschel put exactly 1000 objects in his first two catalogues (the publication of no. 1 roughly coincides with the end of the Datchet observations). His sense for numerical harmony seems to be stronger than the observational facts: it did not bother him that the discoveries made on the respective last nights landed in different catalogues. Actually, the objects III 376 and II 403 (found on 26 April 1785) were published with a time gap of three years; and even 13 years in the case of III 747 and I 216 (3 February 1788).

The title of Herschel's last catalogue promises another 500 objects. Actually his manuscript of 29 June 1802, prepared for the Royal Society, contains only 497. To get a round number, he made a last observation. The neglected near-pole regions were most promising for this task. On 26 September 1802 (sweep 1111) Herschel discovered three nebulae at a declination of +80°, added to his list as I 288, III 977 and III 978. These are the galaxies NGC 2655 (Camelopardalis), NGC 2908 and NGC 3057 (both in Draco). The three objects were communicated to the Royal Society by Caroline Herschel, who wrote that '*The reason for the addition is that, on casting up, the number of Nebulae was found 3 less than 500.*'[41]

W. 1786: 499); see also Dreyer (1912a: xlii). Herschel tried binocular vision a few times too (Dreyer 1912a: xliii).

[38] For the role of Caroline Herschel, see Hoskin (2002b) and Ashworth (2003).

[39] They were presented to the Royal Society by John Herschel in 1863 and are now in the RAS archive. The general appearance of the sweep record was explained by Dreyer (1912a: xlii).

[40] Herschel published from 1780 to 1818 in the *Philosophical Transactions* (except 1813 and 1816).

[41] Hoskin (2005c: 317).

Table 2.4. William Herschel's three catalogues

C	Title	*Phil. Trans.*	Date	Objects
1	Catalogue of one thousand new nebulae and clusters of stars	76, 457–499 (1786)	27.4.1786	1000
2	Catalogue of a second thousand new nebulae and clusters of stars	79, 212–255 (1789)	11.6.1789	1000
3	Catalogue of 500 new nebulae, nebulous stars, planetary nebulae, and clusters of stars	92, 477–528 (1802)	1.7.1802	500

Table 2.5. William Herschel's classification and object numbers in his three catalogues

Class	Description	C1	C2	C3	Sum
I	Bright nebulae	1–93 (93)	94–215 (122)	216–188 (73)	288
II	Faint nebulae	1–402 (402)	403–768 (366)	769–907 (139)	907
III	Very faint nebulae	1–376 (376)	377–747 (371)	748–978 (231)	978
IV	Planetary nebulae	1–29 (29)	30–58 (29)	59–78 (20)	78
V	Very large nebulae	1–24 (24)	25–44 (20)	45–52 (8)	52
VI	Very condensed and rich clusters of stars	1–19 (19)	20–35 (16)	36–42 (7)	42
VII	Compressed clusters of small stars and large stars[42]	1–17 (17)	18–55 (38)	56–67 (12)	67
VIII	Coarsely scattered clusters of stars	1–40 (40)	41–78 (38)	79–88 (10)	88
	Sum	1000	1000	500	2500

Table 2.6. First and last discovered objects in the Herschel catalogues

C	Date	Site	Sweep	Object	No.	NGC	Type	*V*	Con.
1	7.9.1782	Datchet	–	IV 1	1	7009	PN	8.0	Aqr
	26.4.1785	Datchet	402	III 376	1000	3821	Gx	12.8	Leo
2	26.4.1785	Datchet	402	III 377	1001	3837	Gx	12.7	Leo
	3.12.1788	Slough	889	III 747	2000	1961	Gx	10.9	Cam
3	3.12.1788	Slough	889	III 748	2001	2366	Gx	10.9	Cam
	26.9.1802	Slough	1111	III 978	2500	3057	Gx	12.9	Dra

However, Herschel discovered eight more objects in Draco and Ursa Major: three on 9 September 1802 and five during his last sweep (1112) on the 30th.[43] The final object was NGC 3063 (II 909 = no. 2508; see Table 2.22), which is only a pair of stars in Ursa Major, 2′ west of the galaxies NGC 3065 (II 333) and NGC 3066 (II 334); the object had already been found on 10 April 1785 in Datchet (Fig. 2.6). Because William Herschel did not want to exceed the magical number 500, he flatly omitted them.[44] His son John later published them in the Cape catalogue (see Section 2.9).

[42] Instead of 'faint' or 'bright' Herschel sometimes used 'small' or 'large'.

[43] For the last sweep, see RAS Herschel W. 2/3.8 (report of Caroline Herschel).

[44] He never thought about reaching another 1000 objects, for which about 50 additional sweeps would have been necessary

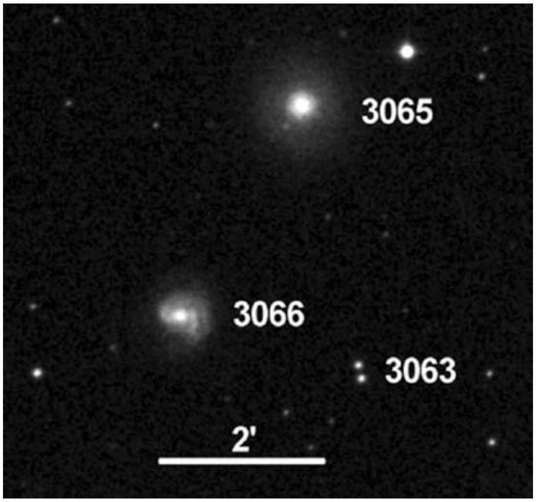


Figure 2.6. Herschel's final discovery: the star pair NGC 3063, found on 30 September 1802 (DSS).

Figure 2.7 shows the annual numbers of objects discovered. After a phase of orientation (1782–83), the years 1784 and 1785 were the most productive. The following decrease is due to the time-consuming construction of the 40-ft reflector.[45] After 1790 the number remained, except for 1793 (77 objects), below 50. Herschel was now married and had many social duties (his sister had moved to the neighbouring 'cottage'). Between 18 October 1794 and 22 November 1797 there was no sweep. At that time he concentrated on the determination of the relative brightness of stars and the secular variation of their light, measuring the magnitudes of nearly 3000 stars with astonishing accuracy compared with later photometric catalogues.

While observing the moons of Uranus, Herschel made an accidental find on 4 March 1796: I 272 = NGC 3332 (see Section 9.7.2).[46] The planet was used as a 'reference star'. This was the case too for III 934 (NGC 3080, 1 April 1894) and II 898 (NGC 3107, 22 March 1894). All of these objects are galaxies in Leo. From 22 November to 20 December 1797 Herschel searched at high declinations (74° to 80°) in the constellations Ursa Minor, Draco and Camelopardalis, discovering altogether 25 galaxies. Among them are bright objects such as NGC 4589 (I 273) with 10.7 mag.

Figure 2.8 shows the average declinations searched by Herschel. He started to the south, increasing to about 10° in 1785 (completion of the first catalogue), then going up to reach +45° in 1788 (the second catalogue). Then he moved to lower declinations. Finally, from 1897 to 1802, he focused on the near-pole regions, which was a much more difficult and time-consuming task.

It is interesting to look at Herschel's favourite constellations and observing seasons. The constellations Virgo, Ursa Major, Coma Berenices and Leo clearly dominate (Fig. 2.9). The most productive was spring, which confirms the last table: 46% of all objects were found in March/April (Fig. 2.10). The summer months, with late darkness, brought only a few. The most successful night was on 11 April 1785 in Datchet. Herschel discovered 74 objects, most of them in Coma Berenices (47). All but one (NGC 4209 = II 375, a star) are galaxies.

Table 2.7 lists Herschel's most southern and most northern discoveries. It is truly remarkable that he was able to detect the galaxies NGC 3621 (Fig. 2.11), NGC 6569 and NGC 5253.[47] Though pretty bright, they reach elevations of only 6.8°, 6.5° and 8°, respectively, in Slough!

As mentioned already, Herschel neglected the region around the northern pole. This was due to the construction of his telescope. For high declinations it had to be moved backwards beyond the zenith to the north. This was a problematic matter and sometimes the mechanism failed. Thus only a few such observations were executed, as can be seen from Caroline Herschel's

(Hoskin 2005c). Actually, the 64-year-old Herschel had not enough energy to do this. After 1802 he returned to the double stars, but, however, on 31 May 1813 he tried another sweep (1113) with a new mirror. Stopped by clouds, it lasted only half an hour (Dreyer 1912a: xliii).

45 For Herschel's largest telescope, see Dreyer (1912a: xlv–lvi), Bennett (1976a) and Hoskin (2003c).

46 The object is identical to NGC 3342 (III 5), which was found on 18 January 1784. Note the large class difference (brightness).

47 NGC 5253 was the second galaxy in which a supernova was detected (after S And in M 31 in 1885; see Section 9.20.2). On 12 December 1895 Williamina Fleming noticed a 'new star' of 8 mag on a plate exposed in March at Arequipa (Pickering E. 1895). The object was later designated Z Cen. However, in 1925 Max Wolf discovered a 12.5-mag 'nova' in NGC 4424 on a plate taken on 15 April 1895 in Heidelberg (Wolf M. 1925). The supernova was named VW Vir. The host galaxy in Virgo was found by d'Arrest (27.2.1865).

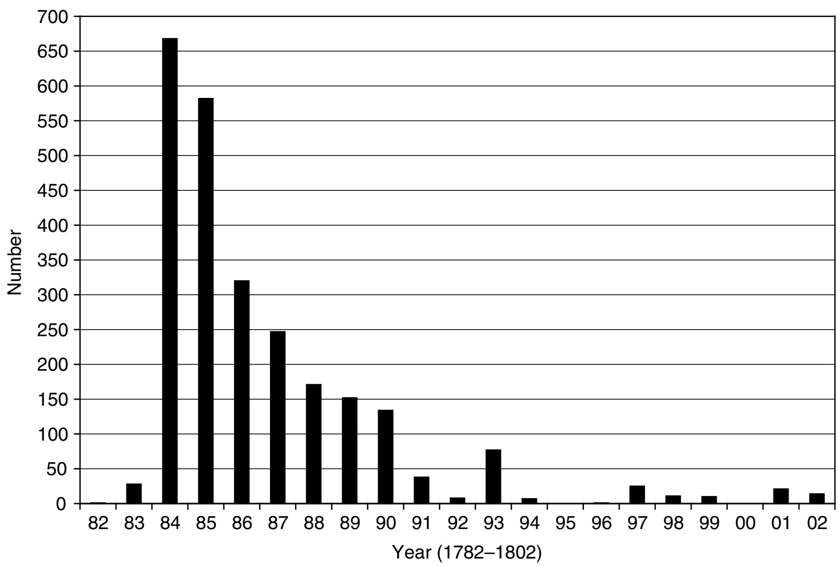


Figure 2.7. William Herschel's annual discoveries.

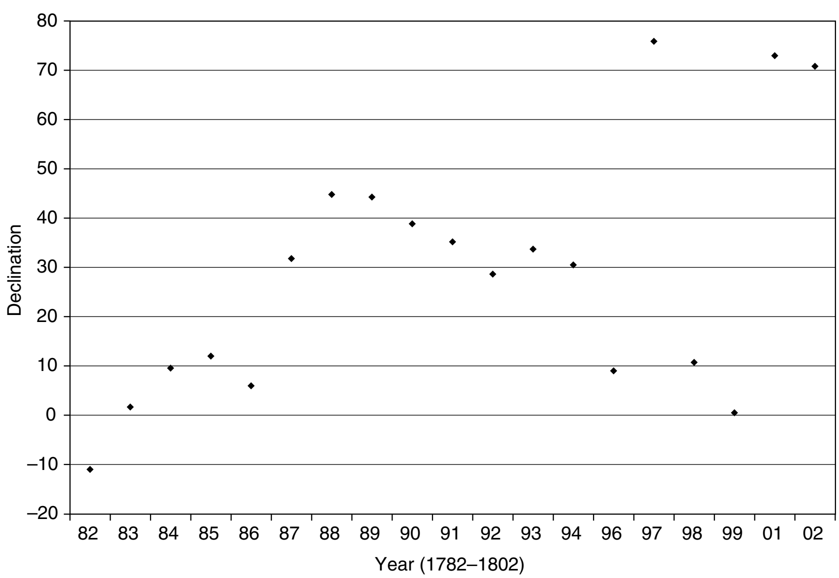


Figure 2.8. Average declinations searched by Herschel over the years.

compilation of the reference stars sorted by North Pole Distance (NPD).[48] There is not one nearer than 5° to the pole and only 12 between 5° and 10°. John Herschel later filled the gaps, discovering the most northern NGC object: Polarissima Borealis (NGC 3172).

[48] RAS Herschel C. 3/3.2; see also Hoskin (2005c).

2.2.2 Structure of the catalogues

All three Herschel catalogues have the same structure. Each class (I–VIII) has its own object table, sorted by discovery date.[49] Table 2.8 shows the meanings of the

[49] Here Herschel follows Messier, who, by the way, published his compilations in three steps too.

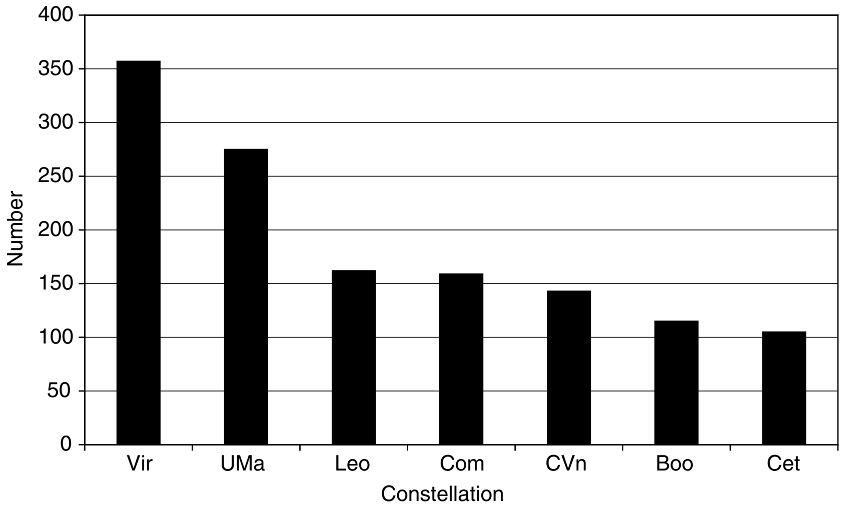


Figure 2.9. Discoveries by constellation.

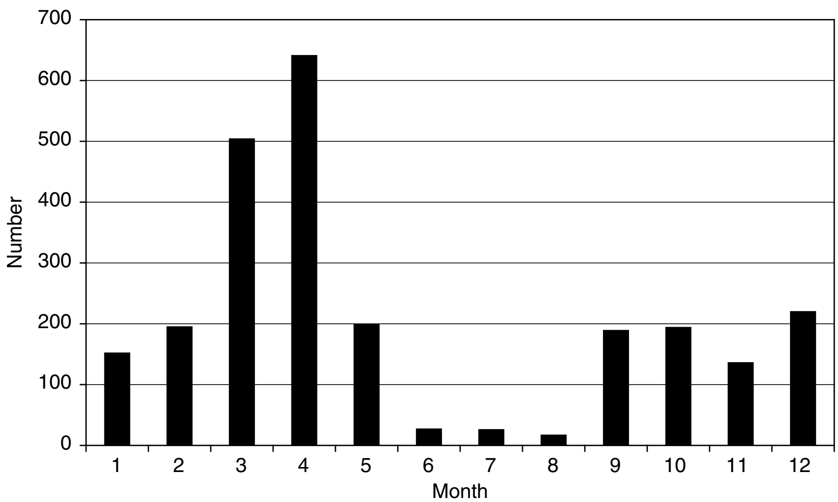


Figure 2.10. Discoveries by month.

columns. The table entries carry a running number, which is continued in the subsequent catalogue(s). II 426 is, for instance, the entry no. 426 in the table of class II objects (contained in the second catalogue in this case).

The data for distance and direction relate the object to the individual reference star. Mainly Flamsteed's *Catalogus Britannicus* of 1725 was used for this task; additional stars were taken from the catalogues of Bode, Lacaille and Wollaston.[50] Occasionally another, already catalogued nebula was used; for instance, I 100 (NGC 584) was used in the case of III 431 (NGC 586) on 10 September 1785.[51] Often the reference star is located quite far from the object; even 12.5° in the case of 85 Geminorum and II 48 (NGC 2672) in Cancer. Since Herschel did not use a micrometer, this sometimes caused wrong positions. Distances were simply determined with the aid of the (much smaller) diameter of the field of view. Herschel's standard eye-piece (focal length 39 mm) at the 18.7" reflector gave a power of 157

[50] For star catalogues see the list of Chambers (1890: 487–495).

[51] Even the 'Georgian Planet' Uranus was taken as a 'reference star' (see Section 2.2.1).

Table 2.7. *Most southern and most northern objects (site: D = Datchet, S = Slough)*

Object	NGC	Decl.	Date	C	Site	Type	*V*	Con.
II 638	5253	−31 38	15.3.1787	2	S	Gx	10.1	Cen
II 201	6569	−31 49	13.7.1784	1	D	GC	8.4	Sgr
I 241	3621	−32 48	17.2.1790	3	S	Gx	9.4	Hya
II 704	1184	+80 47	16.9.1787	2	S	Gx	12.5	Cep
III 974	6251	+82 32	1.1.1802	3	S	Gx	12.9	UMi
III 975	6252	+82 34	1.1.1802	3	S	Gx	14.8	UMi

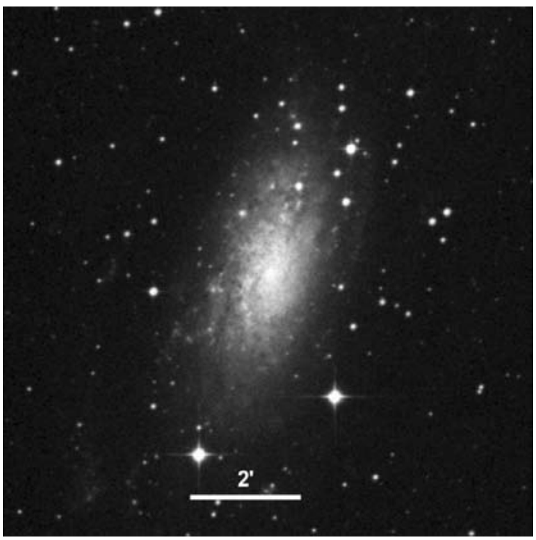


Figure 2.11. Herschel's most southern discovery, the galaxy NGC 3621 in Hydra (DSS).

with a field of view of 15' 4". Sometimes other magnifications were applied (240, 300 or 320).

Herschel's code (the last column) was the basis of nearly all textual descriptions of non-stellar objects in the nineteenth century, particularly in the catalogues of his son (SC, CC, GC) and in Dreyer's GCS and NGC. The features are characterised by simple abbreviations.[52] Examples are brightness (F = faint, B = bright), size (S = small, L = large) and form (E = elongated, R = round). Additional letters, including e (exceedingly), v (very), p (pretty) and c (considerably), give further differentiation.[53] The column also contains remarks and further information, e.g. on magnification or Caroline Herschel's observations. In the case of class IV objects (planetary nebulae) remarks can be lengthy. A few notes can be found below the tables of the first two catalogues (e.g. corrections to I 54, II 1 and II 239).

As an example, the entry for the 'faint nebula' II 5 (Table 2.9) is presented here; the galaxy NGC 1032 in Cetus (13.8 mag) was observed eight times. According to the (first) catalogue, it is located 5^s west and 46′ north of δ Ceti, which is correct. The description means pretty bright, small, little elongated, brighter middle.

Owing to identities, the number of entries in Herschel's catalogues can be reduced (Table 2.10). In 34 cases there is an identity between entries in the three catalogues. A typical example is II 57 = II 546 (both listed in the second catalogue). The object was discovered on 15 March 1784 in Datchet (II 57) and was found again on 3 March 1786 in Clay Hall (II 546). It is NGC 2872, a galaxy in Leo (11.9 mag).

One object was even listed four times: the Trifid Nebula M 20 (NGC 6514) in Sagittarius (Fig. 2.12). On 12 July 1784 (Datchet) Herschel found three individual nebulae (actually separated by dark lanes), catalogued as V 10, V 11 and V 12: '*three nebulae, faintly joined, form a triangle*'. Unfortunately his position was 30′ too far south. This error made it possible to discover the nebula a second time (26 May 1786), now catalogued as IV 41 at the correct position. Auwers was the first to notice the identity.[54] John Herschel created the popular name 'Trifid' (meaning 'threefold') in his note about the observation on 1 July 1828 in Slough (h 1991): '*very large, trifid, three nebulae with a vacuity in the midst*'.[55] Interestingly, the object was not identified with Messier's M 20 by

[52] Attempts to introduce new codes, e.g. by John Herschel and by Schultz (see Section 8.16.5), were unsuccessful.

[53] Dreyer (1953: 12–13). The most important abbreviations are collected in the appendix.

[54] Auwers (1862a: 57).

[55] Citations related to objects from the catalogues of William and John Herschel or Dreyer are referred to simply by their catalogue number.

Table 2.8. *Meanings of the columns*

Column	Content	Remarks
1	Object number	Number in the particular class
2	Discovery date	Sorting order
3	Reference star	Mainly from Flamsteed's catalogue
4	Direction (AR)	p (preceding = west), f (following = east)
5	Distance (AR)	M. S. = minute, second
6	Direction (Decl)	n (north), s (south)
7	Distance (Decl)	D. M. = degree, minute
8	Observations	Number of observations (1–8)
9	Description	Herschel code; remarks

Table 2.9. *The fifth entry of Herschel's class II*

II.	1783	Stars.		M. S.		D. M.	Ob.	Description
5	Dec. 18	82 (δ) Ceti	p	0 5	n	0 46	8	pB. S. lE. bM.

Table 2.10. *Independent objects in Herschel's catalogues*

	C1	C2	C3	Sum
Entries	1000	1000	500	2500
Catalogue identity	20	10	4	34
NGC identity	13	8	7	28
Balance	967	982	489	2438

Figure 2.12. The Trifid Nebula (M 20) in Sagittarius; drawing by Trouvelot, Harvard College Observatory (Winlock 1876).

William Herschel, John Herschel, Mason and Auwers.[56] The possible reason (besides the positional confusion) is that Messier described it as a 'star cluster'. The identification of the four Herschel nebulae with M 20 was first presented in the General Catalogue (GC 4355).

In 28 cases there is an identity with another NGC object (also contained in the Herschel catalogues). A typical example: NGC 3611 = II 521, a galaxy in Leo (11.9 mag), discovered on 27 January 1786 in Clay Hall. It is identical with NGC 3604 = II 626, found on 30 December 1786 in Slough. Another case is NGC 4664 = II 39 (Datchet, 23 February 1784), a galaxy of 10.3 mag in Virgo. Herschel saw it once again on 30 April 1786 in Slough, but now as a class I object (I 142). Dreyer, not recognising the identity, catalogued it as NGC 4665. But there is still a third

[56] M 20 is listed in the Cape catalogue as h 3718.

NGC-number: NGC 4624. Dreyer now refers to John Herschel's 'new' object h 1390, observed on 9 April 1828 in Slough.

Three cases show a 'combined' identity (already counted in Table 2.10): NGC 4124 = II 33 = II 60 is equal to NGC 4119 = II 14; NGC 4470 = II 18 = II 498 is the same as NGC 4610 = II 19; and finally NGC 4526 = I 31 = I 38 is equal to NGC 4560 = I 119. All of these objects are Virgo galaxies.

The balance gives 2438 independent Herschel objects, which is, compared with other catalogues, a high value (98%). Obviously William Herschel made a very good job of his cataloguing. Subsequent observers were less successful, despite using much better equipment.

Table 2.11. *Discoverers of independent objects in the Herschel catalogues*

Discoverer	C1	C2	C3	Sum
W. Herschel	955	967	484	2406
C. Herschel	2	5	1	8
de Chéseaux		1		1
Flamsteed	1			1
Hipparch	2			2
Hodierna	3	1		4
Mairan	1			1
Méchain	2	4	3	9
Messier	4	1		5
Oriani		1		1
Sum	970	980	488	2438

2.3 CAROLINE HERSCHEL AND OTHER DISCOVERERS

Not all 2438 independent objects can be credited to this outstanding observer. As Table 2.11 shows, 32 had been found earlier by others; mainly Méchain, Caroline Herschel and Messier.

Eight objects from the Herschel catalogues were discovered by Caroline Herschel (Fig. 2.13).[57] For her early observations in Datchet (28 August 1782 to 4 July 1783) she used a small refractor with magnification 14.5 and 3° field of view, which had been made by her brother. William Herschel told her how to use it and suggested that she observe double stars, nebulae and star clusters. Caroline was very successful, despite being not much interested in the theoretical background.

On 30 September 1782 she independently found M 27, which had remained unobserved by her brother until that time.[58] William Herschel was impressed and eventually started his own search for nebulae. Later he built two larger telescopes for his sister.[59] The first was an azimuthal 4.5" reflector with a power of 24. Caroline used this 'small sweeper' from 8 July 1783 onwards, discovering some nebulae and star clusters. From 17 March 1791 (now in Slough) she owned the 'large sweeper', a 9.2" reflector, which brought to light no new objects.[60]

Figure 2.13. Caroline Herschel (1750–1848).

[57] For Caroline Herschel's life and work, see Lubbock (1933), Kemps (1955), Kerner C. (2004), Hoskin (2002b, 2003a, b, 2007) and Wilson B. (2007).

[58] M 27 was later called the Dumbbell Nebula by John Herschel. On 24 August 1827 he wrote (h 2070, the Tarantula Nebula) that '*The central mass may be compared to a vertebra or a dumb-bell.*'

[59] For Caroline Herschel's telescopes, see Hoskin and Warner (1981) and Hoskin (2005a, b).

[60] In Slough she observed from the roof of a small detached building to the north of the dwelling house, which was used as library.

Table 2.12. *Caroline Herschel's objects (sorted by date; see the text)*

P	H	h	NGC	Date	Date (H)	C	Note (H)	Type	*V*	Con.	Remarks
1	VII 12	440	2360	26.2.1783	4.2.1785	1	CH	OC	7.2	CMa	Refractor
1	VII 27	436	2349	4.3.1783	24.4.1786	2	CH 1783	OC		Mon	Refractor
0	VI 22	496	2548	8.3.1783	1.2.1786	2	CH 1783	OC	5.8	Hya	Refractor; M48, Messier 19.2.1771
1	VII 59	2066	6866	23.7.1783	11.9.1790	3		OC	7.6	Cyg	
0	VIII 72		6633	31.7.1783	30.7.1788	2	CH 1783	OC	4.6	Oph	de Chéseaux 1745?
2			IC 4665	31.7.1783				OC	4.2	Oph	Bailey 1896
0	V 18	44	205	27.8.1783	5.10.1784	1	CH 23.9.1783	Gx	7.9	And	M 110, Messier 10.8.1773
1	V 1	61	253	23.9.1783	30.10.1783	1	CH	Gx	7.3	Scl	'It is Carolina's'
2		36	189	27.9.1783				OC	8.8	Cas	J. Herschel 27.10.1829
1	VIII 78	25	225	27.9.1783	26.2.1788	2	CH 1784	OC	7.0	Cas	
1	VIII 65		659	27.9.1783	3.11.1787	2	CH 1783	OC	7.9	Cas	
0	VII 32	174	752	29.9.1783	21.9.1786	2		OC	5.7	And	Hodierna 1654?
1	VI 30	2284	7789	30.10.1783	18.10.1787	2	CH 1783	OC	6.7	Cas	
2		2048	6819	12.5.1784				OC	7.3	Cyg	Harding Sept.? 1823; J. Herschel 31.7.1831
1	VIII 77	2182	7380	7.8.1787	1.11.1788	2	CH 1787	OC	7.2	Cep	Slough

Table 2.12 lists Caroline Herschel's discoveries, sorted by date. Except for the last (NGC 7380), all were made in Datchet. The sources are the three Herschel catalogues and the observing journals of William and Caroline Herschel.[61]

Caroline Herschel found 11 objects. The eight with priority P = 1 are contained in the Herschel catalogues; the three with P = 2 bear no Herschel designation. The remaining objects (P = 0) were found earlier by other observers. The column 'Note (H)' gives William Herschel's (incomplete) notes. All objects are listed in the NGC, except IC 4665. This large open cluster was credited by Dreyer to the Harvard astronomer Solon Bailey, who photographed it 1896 at Arequipa Observatory. It is remarkable that all 11 of Caroline Herschel's objects exist. All are open clusters, except NGC 253, the bright galaxy in Sculptor (Fig. 2.14), which comes only 15° above the horizon in Datchet.

William Herschel erroneously credits his sister for three other objects. VII 13 = NGC 2204 (CH 26 February 1783) should read VII 12 (NGC 2360); and VIII 64 = NGC 381 (CH 1783) should be NGC 189 (not observed by William Herschel). The most curious case is the prominent edge-on galaxy NGC 891 = V 19 (Fig. 2.15), which was discovered by William Herschel on 6 October 1784. In the notes following the first

[61] See also Hoskin (2005b).

Figure 2.14. NGC 253 in Sculptor, discovered by Caroline Herschel on 23 September 1783 (DSS).[62]

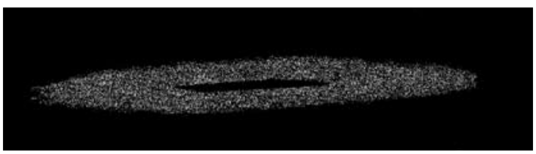


Figure 2.15. Herschel's sketch of the edge-on galaxy NGC 891 with its 'black division' (Herschel W. (1811), Fig. 12).

catalogue one reads that Caroline found the nebula on 27 August 1783. This is, however, a typo: V 18 = NGC 205 = M 110 is meant, which was seen by her on the given date (but had already been discovered by Messier on 10 July 1773). It is probable that she made a clerical error. In the catalogue one correctly reads the remark 'CH' for the entry V 18.

In Table 2.13 the other discoverers of Herschel objects are listed. Though the astronomer has looked up nearly all of the nebulae and star clusters of Messier's catalogue, it sometimes happened that an object was thought to be new. In the appendix of the *Scientific Papers of Sir William Herschel*, Dreyer compiled 'Unpublished observations of Messier's nebulae and clusters'.[63] They are based on Herschel's notes in his observing journals (his manuscripts contain a Messier list[64]). Most objects were observed with the 18.7-inch; for M 2, M 5, M 42, M 72 and M 74 the 48-inch ('40 ft reflector') was used – a rare matter.[65] Not observed were M 61, M 91 and M 102, which obviously could not be identified by Herschel. Additionally, it is not astonishing that there are no reports for M 44 (Praesepe) and M 45 (the Pleiades).

Only 2 of the 2500 catalogued objects are missing from the NGC. The emission nebula V 35 in Orion, which was discovered on 1 February 1786 in Clay Hall, was later listed by Dreyer as IC 434. For VI 8 there is no appropriate object. Dreyer has ignored Herschel's observation made in Datchet on 25 April 1784. Thus the number of independent NGC objects in the three catalogues is 2437, of which 2405 must be credited to Herschel.

2.4 HERSCHEL'S EIGHT CLASSES AND MODERN OBJECT TYPES

Next the relation between Herschel's classes and modern types is treated. Table 2.14 shows that, as expected, the classes I to III strongly correlate with galaxies (96%). Herschel could not resolve 28 globular clusters (GC) and classified them as 'nebulae' of classes I to III. In the case of very remote objects, this is comprehensible. The top scorers are the Intergalactic Wanderer NGC 2149 (I 218) in Lynx, found on 31 December 1788, and NGC 7006 (I 52) in Delphinus, found on 21 August 1784; the distances of these globular clusters are 182 000 ly and 135 000 ly, respectively.[66]

Most interesting is class IV ('planetary nebulae'), which is very inhomogeneous (see Section 2.6). In class V ('very large nebulae'), 63% of the objects are galaxies and 20% are emission nebulae. Obviously, the form did not play an essential role, since there are edge-on galaxies in this class, e.g. NGC 891 (Fig. 2.15), NGC 253 (Fig. 2.14), NGC 4565, NGC 4631 and NGC 5907, and also face-on galaxies, such as M 33, M 106, NGC 2403 and NGC 2997. The emission nebulae in class V are mostly irregular; the North America Nebula (NGC 7000, V 37), Veil Nebula (NGC 6992, V 15)

[62] See also Lassell's sketch, Fig. 7.12 left.

[63] Dreyer (1912a, vol. 2: 651–660).

[64] RAS Herschel W. 4/33.1.

[65] M 42 was the first object looked up using the '40-foot', while it was still under construction (19 February 1787). However, it is remarkable that it was so little used for observations of nebulae. The reason might be that the mirror soon tarnished and the image consequently became bad. Later, Proctor remarked that it was a matter of public notoriety in England that the 48" mirror '*bunched a star into a cocked hat*' (Wolf C. 1886b: 199). Some objects (e.g. M 31) were observed by Herschel with his 'X-feet', a chunky 24" reflector of focal length 10 ft.

[66] See Steinicke (2003e).

Table 2.13. *Objects discovered prior to Herschel (without C. Herschel; sorted by H-number; site: D = Datchet, C = Clay Hall, S = Slough)*

H	M	NGC	Date (H)	C	Site	Discoverer	Date	Type	*V*	Con.	Remarks
I 7	49	4472	23.1.1784	1	D	Messier	19.2.1771	Gx	8.3	Vir	
I 17	105	3379	11.3.1784	1	D	Méchain	24.3.1781	Gx	9.5	Leo	
I 43	104	4594	9.5.1784	1	D	Méchain	11.5.1781	Gx	8.3	Vir	Sombrero Galaxy
I 139	61	4303	17.4.1786	2	S	Oriani	5.5.1779	Gx	9.3	Vir	
I 186		5195	12.5.1787	2	S	Méchain	21.3.1781	Gx	9.6	CVn	Companion of M 51
I 193	76	651	12.11.1787	2	S	Méchain	5.9.1780	PN	10.1	Per	Component of M 76
I 215	102	5866	5.5.1788	2	S	Méchain?	April 1781	Gx	9.9	Dra	
II 120	91	4548	8.4.1784	1	D	Messier	18.3.1781	Gx	10.1	Com	
III 1	43	1982	3.11.1783	1	D	Mairan	1731	EN	6.8	Ori	
IV 61	109	3992	12.4.1789	3	S	Méchain	3.12.1781	Gx	9.8	UMa	
V 10–12	20	6514	12.7.1784	1	D	Messier	5.6.1764	EN+OC	8.5	Sgr	IV 41, Trifid Nebula
V 17	33	598	11.9.1784	1	D	Hodierna	1654?	Gx	5.5	Tri	
V 18	110	205	5.10.1784	1	D	Messier	10.8.1773	Gx	7.9	And	C. Herschel 27.8.1783
V 43	106	4258	9.3.1788	2	S	Méchain	July 1781	Gx	8.3	CVn	
V 46	108	3556	17.4.1789	3	S	Méchain	16.2.1781	Gx	9.9	UMa	
VI 22	48	2548	1.2.1786	2	C	Messier	19.2.1771	OC	5.8	Hya	C. Herschel 8.3.1783
VI 33		869	1.11.1788	2	S	Hipparch	−130	OC	5.3	Per	Double Cluster (χ Per)
VI 34		884	1.11.1788	2	S	Hipparch	−130	OC	6.1	Per	Double Cluster (χ Per)
VI 40	107	6171	12.5.1793	3	S	Méchain	April 1782	GC	7.8	Oph	
VII 2		2244	24.1.1784	1	D	Flamsteed	17.2.1690	OC	4.8	Mon	12 Mon
VII 17		2362	6.3.1783	1	D	Hodierna	1654?	OC	3.8	CMa	
VII 32		752	21.9.1786	2	S	Hodierna	1654?	OC	5.7	And	C. Herschel 29.9.1783
VIII 38	47	2422	4.2.1785	1	D	Hodierna	1654?	OC	4.4	Pup	NGC 2478, Messier 19.2.1771
VIII 72		6633	30.7.1788	2	S	de Chéseaux	1745?	OC	4.6	Oph	C. Herschel 31.7.1783

Table 2.14. *Herschel's classes and modern types*

Class	Description	Gx	EN	RN	PN	OC	GC	GxP	Star	Stars	NF	Sum
I	Bright nebulae	254	1	1	3	1	16	1		1		278
II	Faint nebulae	853	2	1	4	1	10		1		2	874
III	Very faint nebulae	934	3	1	5	2	2	4	4	8	2	965
IV	Planetary nebulae	39	7	5	20	2	2		2			77
V	Very large nebulae	31	12	3	1			1			1	49
VI	Very condensed and rich clusters of stars	2			1	28	8			2	1	42
VII	Compressed clusters of small stars and large stars					61				4	1	66
VIII	Coarsely scattered clusters of stars					69				17	1	87
	Sum	2113	25	11	34	164	38	6	7	32	8	2438

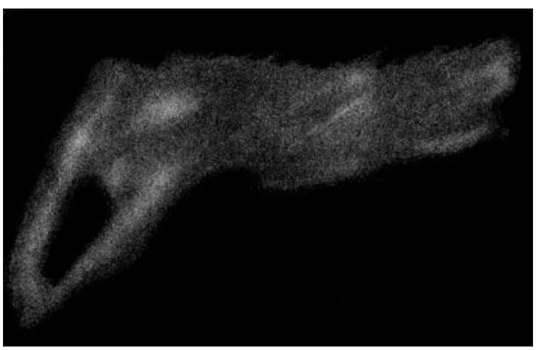


Figure 2.16. Herschel's illustration of an 'extensive diffused nebulosity' (Herschel W. (1811), Fig. 1).

Figure 2.17. The North America Nebula in Cygnus (NGC 7000), photographed by Max Wolf in 1902.

and Flame Nebula (NGC 2024, V 28) are prominent examples, though Herschel had seen only their brightest parts. His publication of 1811 contains 42 sketches demonstrating the different forms of nebulae (Herschel W. 1811). The largest object shown there was intended to illustrate one of his 52 regions with 'extensive diffused nebulosities' (Fig. 2.16), which later caused some confusion (see Section 11.6.15).

Herschel's class V and his 52 obscure regions are related, as shown by the prominent North America Nebula NGC 7000 (Fig. 2.17), located about 3° east of Deneb in Cygnus. The story is worth telling here, because it illustrates the historical development of observations. Such background information will be presented for several interesting objects in the book.

Herschel discovered the nebula during sweep 620 on 24 October 1786 in Slough; the reference star was 57 Cygni, about 1° to the west (the overexposed star at the middle right edge of Fig. 2.17). In his observation journal one reads of a '*very large diffused nebulosity, plainly visible, between 7 or 8′ l, 6′ b and losing itself gradually*'. The object was entered in the second catalogue as V 37 and the description matches that given in the journal. The position given there is near the centre of the nebula. The next journal note (same sweep) is interesting: '*All this time suspected diffuse nebulosity through the whole breadth of the sweep*'. Herschel gives two positions, one at the 'west coast of Florida' the other at the 'Californian coast'. These observations were later entered as nos. 44 and 46 in the list of 52 regions with 'extensive diffused nebulosity' (Herschel W. 1811). Number 44 is described as '*faint milky nebulosity scattered over this space, in some places pretty bright*' (diameter 2.8°) and no. 46 as '*suspected nebulosity joining to plainly visible diffused nebulosity*' (diameter 3.7°). The following text additionally gives that '*In No. 44 we have an instance of faint nebulosity which, though pretty bright in some places, was completely lost from faintness in others; and No. 46 confirms the same remark.*' On 11 September 1790 Herschel made a second observation using the same reference star (sweep 959). In the journal is noted the following: '*Faint milky nebulosity scattered over their space; in some places pretty bright. The brightest part of it about the place of my V 37.*' Again two positions are given (matching the former). There is no doubt that Herschel has discovered NGC 7000. He has seen not merely the brightest spots, but a large fraction of the whole nebula. This is astonishing, because normally this needs a filter (as would be used today).

On 21 August 1829 John Herschel looked up the object and catalogued his observation as h 2096 in the Slough catalogue. However, he was not sure about the identification, noting 'V 37?'. The position is that of his father and the description reads as follows: '*An immense nebula all around this place, but ill defined to fix the limits. RA that of V 37, from working list, not settled by the observation.*' On the basis of the three observations John Herschel listed the nebula as GC 4621 in the General Catalogue (noting 'V 37?' again) with the description '*F, eeL, diff. neb*'. This was adopted by Dreyer in the NGC (including 'V 37?' and William Herschel's position). There were only two further visual observations of NGC 7000 during the nineteenth century, which were made by Bigourdan in Paris with his 12" refractor. He could confirm the nebula on 16 August 1884 and 25 September 1889.

Now the German astronomer Max Wolf enters the scene. He photographed the nebula on 1 June 1891 with the 5" Kranz portrait lens at his private observatory in Heidelberg.[67] He reported his observation in a paper 'Ueber grosse Nebelmassen im Sternbild des Schwans'.[68] The 3-hour exposure showed '*a large and bright, exceedingly subtle plotted, fan-shaped nebula, whose brightest part hitherto was known as G.C. 4621.*' However, the term 'America' is not mentioned! Another plate was taken on 12 and 13 July 1901 with the 16" Bruce refractor on Königstuhl (exposure time 4.75 hours). It is the frontispiece of the first volume of the *Publikationen des Astrophysikalischen Observatoriums Königstuhl-Heidelberg*. The subtitle reads 'Der Amerika-Nebel im Cygnus' ['The America Nebula in Cygnus']. The same volume contains a work of Wolf's young assistant August Kopff, titled 'Die Vertheilung der Fixsterne um den grossen Orion-Nebel und den America-Nebel'.[69] Wolf himself mentions the object once more in his paper 'Über eine Eigenschaft der großen Nebel',[70] which treats the connection of nebulae and 'vacancies'. Obviously, the name occurred to Wolf while he was looking at the first (really good) image of July 1901.

In January 1903 Barnard wrote a paper on 'Diffused nebulosities in the heavens' (Barnard 1903). There one reads that the object "*was first photographed by Dr. Max Wolf some twelve years ago* [1891!] *and has lately been called by him 'America Nebula' from its striking resemblance to North America as shown on maps and globes.*" In a footnote Barnard added that "*The 'North America Nebula' would perhaps be more definite, for it is North America to which Dr. Max Wolf intends the compliment.*" This is the origin of the popular name for NGC 7000. Going back to William Herschel, it is surprising that he saw nebulosity in his eye-piece with only 15′ field of view. This is only a small fraction of the field presented in Fig. 2.17, which has a width of more than 6°. It is extremely difficult to notice any contrast in the eye-piece when the nebulosity completely covers the field of view. There is nothing known about whether Herschel had switched between different areas (with and without nebulosity) for comparison.

Classes VI to VIII are naturally dominated by open clusters (81%), followed by random star groups (12%). However, there are two galaxies in class VI: NGC 3055 (VI 4) in Sextans (VI 4, 24 January 1784) and NGC 6412 in Draco (VI 41, 12 December 1797). Herschel's 1814 publication contains another 17 sketches, among

[67] Often a wrong discovery date is given: 12 December 1890, see e.g. Vehrenberg (1983: 222). During that night Wolf took a plate of the region around ζ Orionis (Wolf M. 1891a), showing the Flame Nebula NGC 2024 and a new one, later catalogued as IC 448. Undoubtedly there was no time to turn to the Cygnus region (in a winter night!). Regarding Wolf's discoveries in Orion and Cygnus, see also Clerke (1891).

[68] 'On the large nebulous masses in the constellation Cygnus' (Wolf M. 1891c).

[69] 'The distribution of the fixed stars around the Great Orion Nebula and the America Nebula' (Kopff 1902).

[70] 'On a feature of the large nebulae' (Wolf M. 1903).

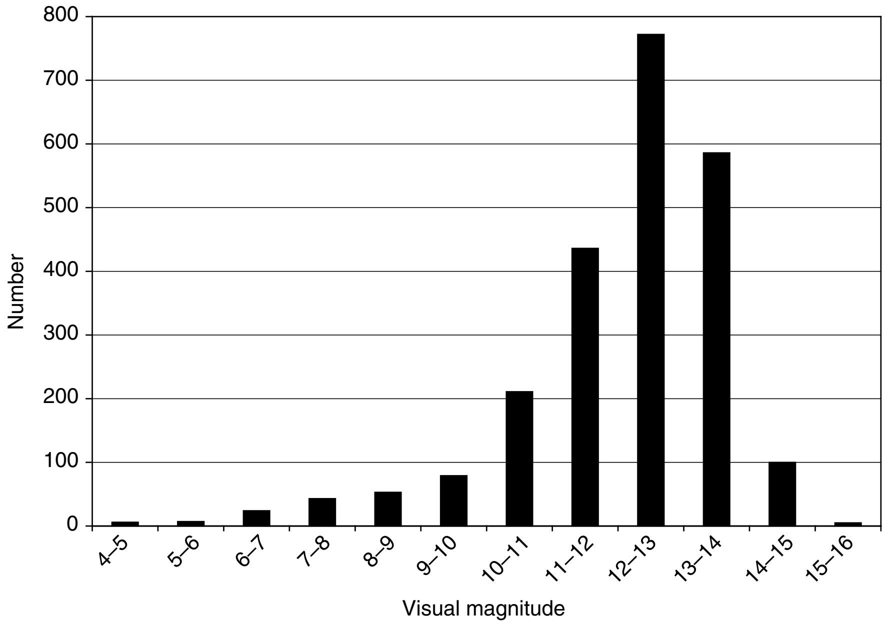


Figure 2.18. The brightness distribution of the Herschel objects.

them a few star clusters (Herschel W. 1814). Some single stars are in classes II, III and IV. In these cases, Herschel supposed there to be a nebula around the star – an erroneous perception, occasionally supported by other observers. The brightest star is NGC 5856 (IV 71) = BD +19° 2924 in Bootes with 6.0 mag. Herschel wrote that '*A star 7.6m. enveloped in extensive milky nebulosity. Another star 7m.* [BD +19° 2935?] *is perfectly free from such appearance*.' Finally, the low number of missing objects ('not found') is remarkable. As has already been stated, Herschel was a very diligent observer, correctly reporting the data with the support of his sister Caroline.

2.5 BRIGHTNESS OF THE OBJECTS

Using modern data, the brightness statistic of Herschel's objects can be derived (Fig. 2.18).[71] The mean is 12.0 mag, which is pretty bright, compared with values reported by subsequent observers, who were often observing with smaller telescopes.

The distribution reflects the situation of a widely unexplored sky prior to Herschel. The likelihood of encountering bright objects was high – certainly some fainter ones were overlooked at that time. Concerning the spatial distribution, one must consider that Herschel's sweeps primarily depended on bright reference stars (e.g. from Flamsteed's catalogue). A complete survey of the sky visible from southern England was not executed (and not planned). This can be shown by examination of the list of reference stars compiled later by Caroline Herschel.[72] There are gaps around the celestial pole (δ = 85° to 90°) and in the declination zone 42° to 52°, with no observations between right ascension 17^h to 17.5^h and 19.5^h to 21.25^h. This explains why many bright objects remained for coming discoverers.

Herschel constructed metal mirrors using an alloy of copper and tin ('speculum metal'). Modern measurements reveal a reflectivity of 63% for red light (450 nm) and even 75% for blue light (650 nm) for this material. Owing to tarnishing of the surface, the values decreased by 10% within 6 months. Therefore the mirror had to be polished frequently. Herschel (and later Lord Rosse and Lassell) used several mirrors, to allow continuous observing. Herschel's 18.7" reflector might be equal to a modern 10-inch with an aluminised glass mirror. Considering the

[71] An analogous graphic is presented for all observers with a large number of discoveries.

[72] RAS Herschel C. 3/2.3; see also Hoskin (2005c).

Table 2.15. *William Herschel's brightest and faintest objects (site: D = Datchet, S = Slough)*

Object	NGC	Date	C	Site	Type	*V*	Con.
VII 17	2362	6.3.1785	1	D	OC	3.8	CMa
VIII 5	2264	18.1.1784	1	D	OC	4.1	Mon
VIII 25	2232	16.10.1784	1	D	OC	4.2	Mon
III 735	6241	29.4.1788	2	S	Gx	15.2	Her
III 807	4549	24.4.1789	3	S	Gx	15.2	UMa
III 64	2843	21.3.1784	1	D	Gx	15.5	Cnc

unknown sky and the unfavourable site, it is truly astonishing that Herschel discovered nebulae fainter than 15th magnitude. Comparing historical and modern refractors, the difference is much smaller: the excellent instruments of d'Arrest or Tempel with 11" aperture are hardly outperformed by current achromats of equal size. Thus the discovery of so many nebulae with refractors in the nineteenth century is not surprising.

Table 2.15 lists the three brightest and three faintest objects from Herschel's catalogues. VII 17, the compact open cluster NGC 2362 around τ CMa (4.4 mag), was found by Hodierna in about 1654. NGC 2264 is the cluster around 15 Monocerotis, which is covered by faint nebulosity (Herschel saw parts as V 27 on 26 December 1785). At the south end is the famous cometary Conus Nebula.

Figure 2.19 shows the magnitude distributions for objects in classes I to III. This analysis makes sense, insofar as they are very homogeneous (98% are galaxies). The graphic suggests what Herschel meant by 'bright', 'faint' or 'very faint' in the case of nebulae: the resulting averages are 10.6 mag, 12.1 mag and 13.0 mag, respectively. However, the statistical variance is pretty high (Table 2.16). It is peculiar that the brightest objects in each class are globular clusters. Obviously, Herschel had – compared with galaxies – a different perception in these cases. Moreover, he coded equally the extreme magnitudes in classes I and II ('considerably bright' and 'pretty bright'); only class III differs ('faint', 'excessively faint').

The above-mentioned facts lead to the following conclusion: Herschel's qualitative brightness measure, as given by the class or in the object description, is only weakly correlated with modern visual magnitude. The estimation is too much influenced by the structure (and surface brightness) of the object and the individual's perception.

2.6 HERSCHEL'S CLASS IV: PLANETARY NEBULAE

For Herschel this class was a depository for objects that did not fit into other classes. It, therefore, is pretty inhomogeneous: besides true (physical) planetary nebulae (here abbreviated 'PN') there are many 'foreign bodies'. The question of how Herschel's term 'planetary nebula' came into being is interesting.

2.6.1 The origin of the term 'planetary nebula'

It is undisputed that the visual appearance of planets inspired William Herschel to call similar-looking nebulae (those collected in class IV) 'planetary'. On the other hand, Uranus was not explicitly mentioned in this context. However, the popular literature does indeed stress a connection Herschel–Uranus–planetary nebulae, quoting the similarity in colour of the planet and some PN.[73] Actually, Herschel did not report any colour for planetaries – but saw Uranus as being '*of the colour of Jupiter*' (22 October 1781), adding, on 2 October 1782, '*Planet unexpectedly appeared blueish*'.[74]

On 29 August 1782 Herschel observed M 57, the Ring Nebula in Lyra. The famous object was discovered on 31 January 1779 by Antoine Darquier. Messier, quoting his observation, wrote the following: '*pretty dull, but perfectly outlined; it is as large as Jupiter and resembles a fading planet*' (Messier 1781). For Herschel the nebulae looked '*extremely curious*' in the 6.2" reflector and his sketch shows a '*perforated nebula or ring of stars*' (Fig. 2.20).[75] The term 'planetary' is not being used.

[73] Steinicke (2007b).

[74] Herschel W. (1783: 7–8).

[75] A very similar sketch was published by Bode (1785a, Fig. 6.) Herschel's description probably gave rise to the popular name

Table 2.16. *Extreme magnitudes in classes I to III*

Class	H	NGC	Type	*V*	Con.	Code
I	I 44	6401	GC	7.4	Oph	cB
	I 113	2830	Gx	13.9	Lyn	cB
II	II 197	6544	GC	7.5	Sgr	pB
	II 26	4453	Gx	14.9	Vir	pB
III	III 143	6717	GC	8.4	Sgr	F
	III 64	2843	Gx	15.5	Cnc	eF

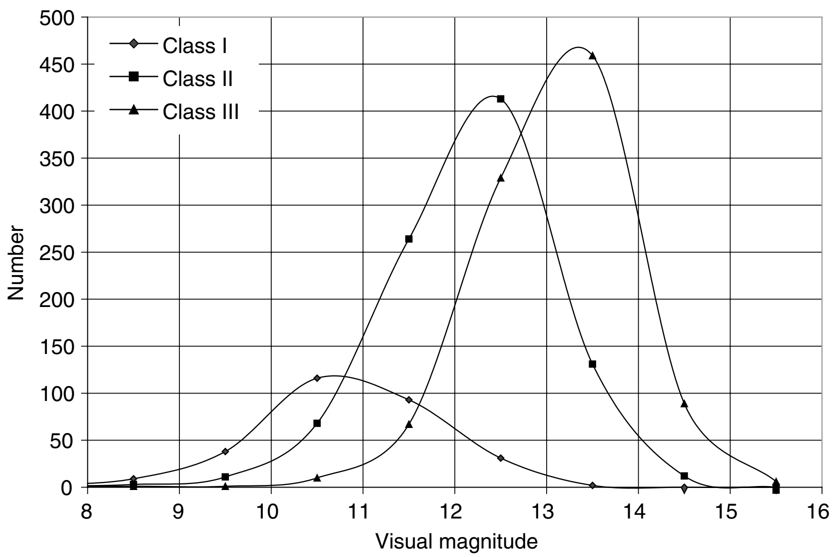


Figure 2.19. Comparison of the magnitudes in classes I to III.

Shortly thereafter, on 7 September 1782, Herschel discovered his first nebula: NGC 7009 in Aquarius[76] (named the Saturn Nebula by Lord Rosse in 1849). This object became the first one of his class IV, being published in 1786 in catalogue no. 1. In his observing journal one reads '*A curious Nebula or what else to call it I do not know. It is of a shape somewhat oval, nearly circular.*'[77] The essential sentence reads '*The brightness in all the powers does not differ so much as if it were of a planetary nature, but seems to be of the starry kind.*' Concerning its behaviour with respect to magnification, the object behaved like a planet – however, there is no hint about its blueish colour.

On 30 September 1782 Caroline Herschel independently discovered M 27 (the Dumbbell Nebula) with her small refractor. Her brother noted that it was '*very curious with a compound piece; when comparing its place with Messier's nebulae, we find it is his 27*'. M 27 is not assigned as a 'planetary nebula'. But the term appears once again on 6 October 1784, when Herschel discovered NGC 7662 in Andromeda: '*wonderful bright, round planetary, pretty well defined disc, a little elliptical*'. Once again, he did not notice the striking colour of the PN, now known as the Blue Snowball.[78]

'Ring Nebula'. On 15 July 1847 William Mitchell saw '*many stars within the compass of the ring*' with the new 15" Merz refractor at Harvard College Observatory (Bond W. C. 1847).

76 The name was created by Lord Rosse, who noted 'Saturn neb.' (h 2048) on 16 September 1849 (Parsons L. 1880: 159).

77 RAS Herschel W. 4/1.13, 231.

78 The name was created by Leland Copeland in 1960 (Copeland L. 1960).

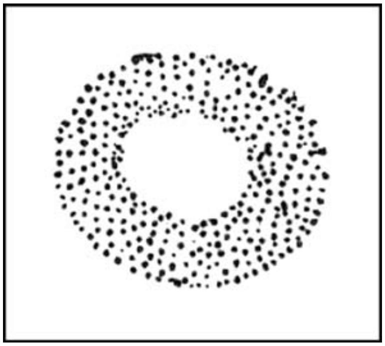


Figure 2.20. Herschel's sketch of M 57 (Herschel W. (1785), Fig. 5).

Figure 2.21. Herschel's sketch of IV 18 = NGC 7662 (Herschel W. (1811), Fig. 36).

The crucial term was first explained by Herschel in his paper 'On the construction of the heavens', written in late 1784.[79] At the beginning of the chapter 'Planetary nebulae' he notes '*a few heavenly bodies, that from their singular appearance leave me almost in doubt where to class them*'. He presents three examples: NGC 7009 = IV 1 ('*has much of a planetary appearance, uniform brightness*'), NGC 7662 = IV 18 ('*round, bright, pretty well defined planetary disc*'; Fig. 2.21) and NGC 1535 = IV 26 in Eridanus, discovered on 1 February 1784 ('*very bright, elliptical planetary, ill defined disc*'). Obviously, Herschel characterised objects as 'planetary' if they showed a round or oval disc with clearly defined edge and uniform surface brightness.

In Herschel's catalogues, class IV is titled 'Stars with burs, with milky chevelure, with short rays, remarkable shapes, &c', enlarging his definition of 1784. Perhaps he initially had the intention of listing objects with planetary discs only, but the variety of shapes forced him to use class IV for all peculiar cases. The term 'planetary' appears explicitly for 15 objects: 10 of them are PN, the rest are galaxies. Therefore, one must distinguish between 'planetary nebulae' (as members of class IV) and objects described as 'planetary', showing a smooth disc. Only the latter are related to PN. As d'Arrest pointed out: '*It is erroneous, when all 78 numbers of this fourth class IV, as is still done in new textbooks from time to time, are considered as planetary nebulae.*'[80]

In 1785 Johann Elert Bode published a short note on 'planetary-like nebulae' in the *Berliner Jahrbuch*,[81] presenting eight objects (Bode 1785b). William Herschel is not explicitly mentioned,[82] but Bode mentions observations with a telescope described as '*20-foot of 18.7-inch aperture*' and presents a sketch of M 57, which is very similar to Fig. 2.20. Moreover, part of the text looks much like Herschel's in his publication of 1785.[83] Bode wrote that '*Here I report some celestial objects, which, due to their peculiar appearance, let me strongly doubt in which class I should place them* […] *The planetary-like shape of the first two* [NGC 7009, NGC 7662] *is so strange that we hardly consider them to be nebulae, their light being so smooth and vivid, their diameter so small and definite, it is therefore very improbable that they belong to these kinds of bodies.*'[84]

The connection of Herschel and PN-colour is a strange issue. There are only two cases where colour is mentioned for class IV objects.[85] The first is IV 22 (NGC 2467) in Puppis, which was discovered on 9 December 1784: '*faint red color visible*'. Actually, this is not a PN, but a mix of star cluster and emission nebula! For IV 27 (NGC 3242), discovered on 7 February 1785, Herschel notes '*planetary disc ill defined, but uniformly bright, the light of the colour of Jupiter*'. Today

[79] Herschel W. (1785); this and further papers on the 'Construction of the heavens' have been reprinted and analysed by Michael Hoskin (Hoskin 1963).

[80] d'Arrest (1856a: 359).

[81] Often called the *Astronomisches Jahrbuch*.

[82] Occasionally Bode published unauthorized versions of Herschel's papers in the *Berliner Jahrbuch*.

[83] Herschel W. (1785: 265–266).

[84] The other six PN are NGC 6572, NGC 6886, NGC 6894, NGC 1535 and NGC 3242.

[85] Strangely, Herschel saw a 'faint red color' in the brightest part of M 31 (Herschel W. 1785: 262).

this bright PN in Hydra is known as the Ghost of Jupiter.[86] However, in comparison with the cases with distinctive blue or blue–green colour, NGC 3242 is a rather pale example.[87]

William Herschel is not the originator of the often stressed relation Uranus–PN. It sounds plausible but it is a mere myth. The explicit connection is due to his son, John. On 3 April 1834 he discovered a remarkable object with his 18¼" reflector in Feldhausen (Cape of Good Hope), which is catalogued as h 3365. This is NGC 3918, a PN with 8.1 mag in Centaurus (Fig. 2.22).

In the Cape catalogue he wrote that it was '*perfectly round; very planetary; colour fine blue;* [...] *very like Uranus, only about half as large again and blue*'.[88] All fits now: 'planetary', blue colour, appearance of Uranus. John Herschel discovered some other objects of this kind. In the case of NGC 2867 (h 3163) in Carina he believed on 1 April 1834 to have found a new planet: '*just like a small planet*'. The following day it became obvious that the object '*has not moved perceptibly and is therefore not a planet*'. The case was mentioned in a letter to William Rowan Hamilton, dated 13 June 1835,[89] in which Herschel wrote '*Indeed, the first on which I fell was so perfectly planetary in its appearance, that it was not until several observations of it at the Royal Observatory* [at the Cape], *by Mr. Mclear* [Thomas Maclear], *had annihilated all suppositions of its motion, that I could relinquish the exciting idea that I had really found a new member of our own system, revolving in an orbit more inclined than Pallas*.'

In his popular textbook *A Treatise on Astronomy* John Herschel wrote about 'planetary nebulae': '*They have, as their name imports, exactly the appearance of planets*'.[90] He was also the first to report the colour of PN. He saw NGC 7009 as being '*light blue*', NGC 7662 '*blueish white*' (both in Slough) and NGC 3242 '*sky-blue*' (in Feldhausen).[91] Nowadays it is easy to see such colours. Therefore the question of why William Herschel did not report them arises. A rather extreme possibility is that he was colour-blind in the case of faint light. For older visual observers, the colour perception can be reduced. At the beginning of William Herschel's career, when he discovered his first PN (NGC 7009) in 1782, he was already 44 years old – his son was 11 years younger when looking at this object for the first time. But another, more plausible reason is possible: mirror quality. Though of the same construction, John Herschel's telescope had a much better mirror than that used by his father, both in figure and in reflectivity. This was partly due to his skill as a chemist. Since the mirror rapidly tarnished at the Cape, Herschel got frequent practice at polishing. Therefore his reflector could have shown colour better than his father's.

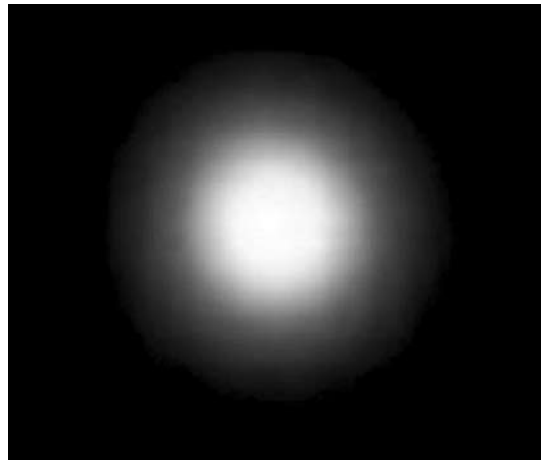


Figure 2.22. John Herschel's 'Uranus': the planetary nebula NGC 3918 in Centaurus (DSS).

2.6.2 Herschel's key object NGC 1514 and the content of class IV

William Herschel revised his ideas on the nature of nebulae several times (see also Section 6.4.8). His early observations of the Orion Nebula ('the most beautiful object in the heavens') with the 6.2" reflector in Bath

[86] Though Herschel mentions the resemblance to Jupiter, the popular name is due to Captain William Nobel, who wrote in 1886 '*a pale blue disk, looking just like the ghost of Jupiter*' (Nobel 1886). It is interesting that M 51 was described by Smyth as a '*ghost of Saturn, with his ring in vertical position*' (Smyth 1844: 302).

[87] The physical reason for PN colour is in most cases the strong O III emission line of oxygen.

[88] NGC 3918 is sometimes called the Blue Planetary Nebula.

[89] It is reprinted in Hoskin (1984); see also Jahn (1844: 79), where the year is erroneously given as 1836.

[90] Herschel J. (1833b: 378–379).

[91] Later Lord Rosse saw colour too; e.g. Struve's PN NGC 6210 (h 1970) showed an '*intense blue centre*' in the 72".

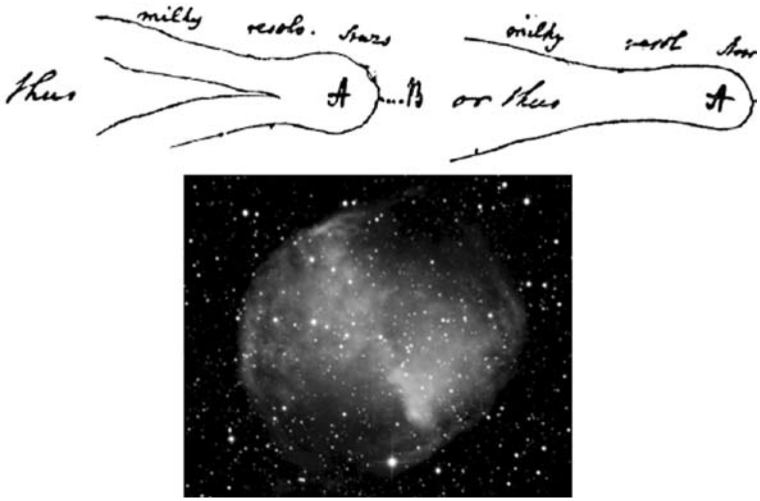


Figure 2.23. The Dumbbell Nebula (M 27) in Vulpecula. Top: William Herschel's sketch of 1784 (RAS W. Herschel 4/1.7); bottom: a modern image.

convinced him that true nebulous matter exists, which he termed '*nebulosity of the milky kind*'.[92] This was based on supposed changes in form and brightness of parts of M 42.[93] On the other hand, Herschel later could resolve some nebulae with his 12-inch. An example is the globular cluster M 30 in Capricorn, which was observed on 21 August 1783: '*Plainly resolved into very small stars. It is a difficult step, i.e. if we divide the transition from the Pleiades* [M 45] *down to the Nebula of the Orion* [M 42] *into six steps this is perhaps the 4th towards the real nebulae.*'[94] Both objects were essential species of his 'natural history' of the heavens.

On the basis of observations of the Omega Nebula (M 17) and Dumbbell Nebula (M 27) with the 18.7-inch, Herschel changed his point of view. About M 17 he wrote on 22 June 1784 that '*the milky nebulosity seems to degenerate into the resolvable kind* [...] *this nebula is a stupendous Stratum of immensely distant fixed stars*'.[95] M 27 was described on 19 July 1784 as a '*double stratum of stars of a very great extent*' (Fig. 2.23 top). One further reads that '*The ends next to us are not only resolvable nebulosity but I really do see very many of the stars mixt with the resolvable nebulosity.*'

Now Herschel arrived at the conclusion that all nebulae must be star clusters – their resolution would be a question of distance and aperture only. In 1785 he developed an evolutionary scenario: the Universe started with widely distributed stars, which slowly condensed into larger agglomerations ('stratum', 'Milky Way') by virtue of gravitational forces, eventually fragmenting into many smaller clusters.[96] The density reaches its highest degree in globular clusters, ending as planetary nebulae, which '*may be looked upon as very aged* [globular clusters] *drawing on towards a period of change, or dissolution*'.[97]

However, an observation made on 13 November 1790 led Herschel to change his theory a second (and last) time. He discovered IV 69 (NGC 1514) in Taurus: '*A most singular phenomenon! A star of about 8th magnitude, with a faint luminous atmosphere*'.[98] He did not interpret the object as 'planetary', but as a 'star with atmosphere' (Fig. 2.24). What follows was a revision of his idea that all nebulae should be clusters. The dominant central star seems to be strongly correlated with the surrounding nebula and must therefore be formed by gravitational contraction. As explained in his paper 'On nebulous stars properly so called', Herschel now was

92 Herschel W. (1784: 443).
93 Hoskin (1979), Schaffer (1980).
94 RAS Herschel W. 4/1.5.
95 RAS Herschel W. 4/1.7: 643.
96 Herschel W. (1785).
97 Herschel W. (1785: 225).
98 Herschel W. (1791: 82).

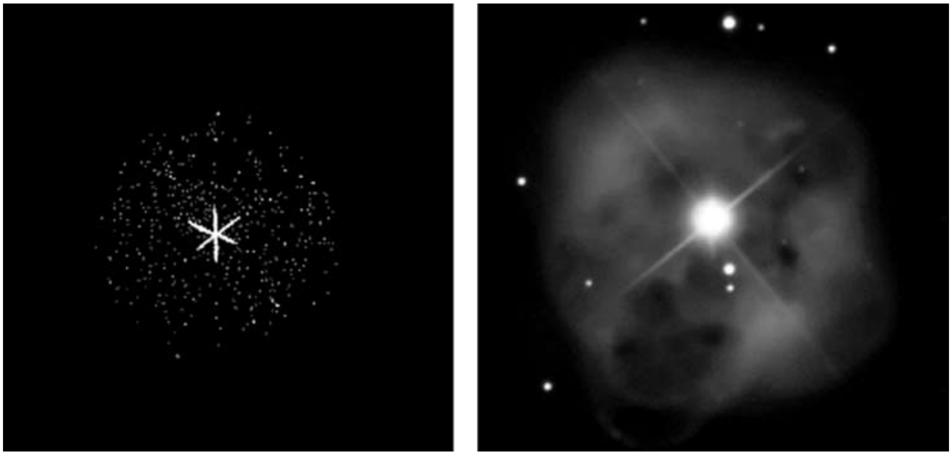


Figure 2.24. Left: Herschel's sketch of IV 69 = NGC 1514 (Herschel W. (1814), Fig. 8); right: a modern image.

convinced that at least some of the unresolved nebulae consist of a 'luminous fluid' (Herschel W. 1791). This is thought to be like an 'interstellar aether' and should not be confused with a 'gas'.[99] According to his final hypothesis, this true nebulosity would gradually condense into stars (clusters). His former picture (based on observations of M 17 and M 27) was partly reversed and his first idea (based on supposed changes in M 42) was eventually reactivated.

It is interesting to compare NGC 1514 and NGC 2392 (IV 45), the Eskimo Nebula in Gemini, found by Herschel on 17 January 1787. Because the latter holds a striking central star in a round nebulous envelope, it is astonishing that this object had not already changed his mind. However, he was surprised by the '*curious phenomenon*' and at first he could not believe it to be real: '*I suspected the glass* [eye-piece] *to be covered with damp, or my eye not yet to be in order*'. Herschel described the object as '*A star with a pretty strong milky nebulosity equally dispersed all around*.'[100] For Lord Rosse it was the prototype of a 'nebulous star' (see Section 6.4.11). He thought Herschel's NGC 1514 (h 311) to be a '*new spiral of an annular form round the star, which is central; spirality is very faint*'.[101] Thus both objects were interpreted quite differently by both observers.

Herschel accentuated his hypothesis in the publication of 1814 (Herschel W. 1814), presenting further examples of 'nebulous stars' (Table 2.17). As a connective link between them and his class IV objects, he introduced IV 73 (NGC 6826), a bright PN in Cygnus. Herschel wrote in his third catalogue that '*It is of a middle species, between the planetary nebulae and nebulous stars, and is a beautiful phenomenon*.' The reflection nebulae NGC 2167 and NGC 2170 in Monoceros are treated in Section 3.2.

Figure 2.25 shows that William Herschel's class IV contains only 20 true planetaries (PN). Most objects are galaxies (41); 13 are emission and reflection nebulae.

Examples of 'foreign' types in class IV are the emission nebula IV 41 (M 20, Trifid Nebula) in Sagittarius, globular cluster IV 50 (NGC 6229) in Hercules, galaxy IV 61 (M 109) in Ursa Major and double galaxy IV 28 (NGC 4038/39), The Antennae, in Corvus.[102] Also remarkable is IV 2, the reflection nebula NGC 2261 around the variable star R Mon in Monoceros. It is the prototype of a cometary nebula. Herschel discovered the object on 26 December 1783, describing it as 'fan-shaped'. Schmidt noticed the variability of the star in 1861; that of the nebula was first noticed by Hubble. NGC 2261 is known as Hubble's Variable Nebula (see

[99] Schaffer (1980: 90).

[100] RAS Herschel W. 2/3.6.

[101] Parsons W. 1861a: 148 and Fig. 7 (see Section 7.1).

[102] See Section 2.9. In the same night (7 February 1785) Herschel found the bright PN IV 27 = NGC 3242 in Hydra (Ghost of Jupiter). He also discovered the PN NGC 4361 in Corvus, but catalogued it as 'bright nebula' I 65.

Table 2.17. *Herschel's 'nebulous stars' (site: D = Datchet, C = Clay Hall, S = Slough)*

IV	NGC	Date	C	Site	Type	*V*	*V**	Con.	Remarks
19	2170	16.10.1784	1	D	RN		10.6	Mon	Near NGC 2167, NGC 2182
25	2327	31.1.1785	1	D	EN		9.5	CMa	
36	2071	1.1.1786	2	C	RN		10.1	Ori	In M 78 complex
38	2182	24.2.1786	2	C	RN		9.3	Mon	Near NGC 2167, NGC 2170
44	2167	28.11.1786	2	S	EN		9.3	Mon	Near NGC 2170, NGC 2182
45	2392	17.1.1787	2	S	PN	9.1	10.5	Gem	Eskimo Nebula
52	7635	3.11.1787	2	S	EN		8.7	Cas	Bubble Nebula, centre of Sh2–162
57	6301	11.6.1788	2	S	Gx	13.5		Her	
58	40	25.11.1788	2	S	PN	12.3	11.5	Cep	
65	2346	5.3.1790	3	S	PN	11.6	11.6	Mon	
69	1514	13.11.1790	3	S	PN	10.9	9.5	Tau	'A most singular phenomenon'
71	5856	24.5.1791	3	S	star		6.0	Boo	See Section 2.4
74	7023	18.10.1794	3	S	EN+OC		7.4	Cep	

Section 6.18.2). This clearly shows how problematic the assignment PN–class IV–planetary is.

Vice versa, true planetaries (PN) appear in Herschel classes I, II, III, V and VI. Examples are NGC 7008 (I 192, 'bright nebula') in Cygnus, NGC 246 (V 25, 'large nebula') in Cetus and NGC 6804 (VI 38, 'rich cluster') in Aquila.

2.7 VON HAHN'S OBSERVATIONS OF PLANETARY NEBULAE

Friedrich von Hahn was among the few contemporaries of William Herschel observing nebulae. His favourite targets were objects with planetary or annular shape. He owned a castle near Remplin in Mecklenburg, which was equipped with a considerable observatory. The main telescope was the third largest outside Great Britain.[103]

2.7.1 Short biography: Friedrich von Hahn

Friedrich von Hahn was born on 27 July 1742 in Neuhaus, Holstein, where he spent his youth. Soon his interest in philosophy and science arose. At the age of 18 he began to study mathematics and astronomy at the University of Kiel. Later Hahn, being handicapped, was largely occupied by his manor. Therefore he had to wait until the age of 50 to practise astronomy. In about 1792 he erected a private observatory. The largest instrument, an 18.7" reflector with focal length 20 ft, first saw light in 1800 (Fig. 2.26). Herschel manufactured the metal mirror; the mechanical parts were constructed by Hahn.[104] The telescope had a wooden tube and no secondary mirror ('front-view'). Together with two smaller Herschel reflectors, with apertures of 12" (1794) and 8" (1793), respectively, it was used unshielded in the garden.[105] To measure positions, Hahn purchased a circle, equipped with a 2" refractor, from Cary. From 1801 it was located in a small dome on top of a four-storeyed tower. Hahn observed the Sun, planets, variable stars and nebulae, being focused on planetaries and the Orion Nebula (Hahn 1796). His main discovery was the

[103] The two largest were used by Schroeter and Schrader.

[104] Maurer (1996: 10); optically the telescope was a duplicate of Herschel's standard reflector. It was used without a secondary mirror ('front-view'); see Bode (1808: 204).

[105] See Bode (1794: 242).

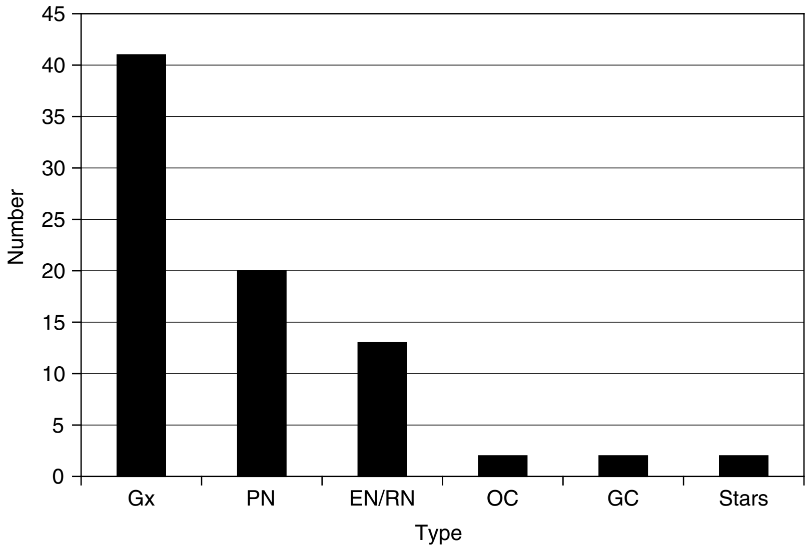


Figure 2.25. Object distribution in class IV.

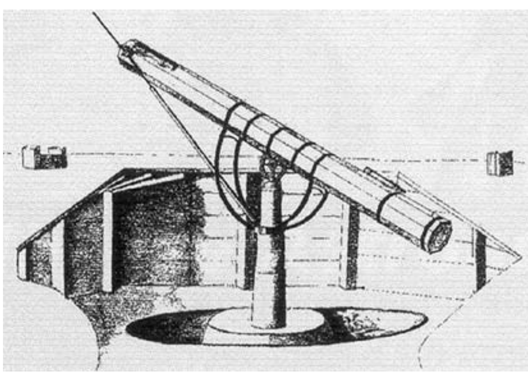


Figure 2.26. The 18.7" reflector of Friedrich von Hahn in Remplin (Fürst and Hamel 1999).

central star of the Ring Nebula M 57. He was in close contact with Johann Elert Bode, Director of the Berlin Observatory. Friedrich von Hahn died on 9 October 1805 in Remplin at the age of 63.[106]

2.7.2 Observations of planetary nebulae and the discovery of the central star in M 57

Among Hahn's primary targets were Herschel's class IV objects. The observations were published in Bode's *Berliner Jahrbuch*, titled 'Ueber den planetarischen Nebelfleck bey μ Wasserschlange'.[107] The object is IV 27 (NGC 3242), which was named the Ghost of Jupiter in the twentieth century. Hahn asked whether planetary nebulae '*would show traces of proper motion, and thus being not clusters, but singular cosmic bodies.*' He adopted Herschel's idea that planetary nebulae are the final state of globular clusters.

For the necessary positional measurements, Hahn used the Cary circle. Unfortunately, in the small instrument the objects appeared '*with very pale light* [...], *standing only very faint illumination of the wires*', which made the reading pretty difficult.[108] For finding the objects, Francis Wollaston's star catalogue of 1789 was used, which '*contains all nebulae known at its making*'. Hahn observed NGC 3242 too, using the 12-inch with powers of 240 and up. The nebula appeared '*more brilliant than the outer planets, only at higher magnification does its light decrease*'. About the appearance he notes that it was '*quite round and circular, only on one side not complete, having the shape of the moon a few days before opposition* [full moon]'. Hahn's interpretation: '*One is tempted to assume that the supposed nebula*

[106] Obituary: Bode (1806); see also Fürst and Hamel (1983, 1999).

[107] 'About the planetary nebula near μ Hydrae' (Hahn 1799).

[108] The illumination of the cross-wires in the micrometer eyepiece is meant here.

is actually a sphere with a brilliant and a dark side, where only a small part of the latter is visible.'

A year later Hahn supposed that the shape and position of NGC 3242 had changed, writing '*this nebula does not show the form which it had at the time of its discovery by Dr. Herschel* [7.2.1785]' (Hahn 1800). One further reads that '*This astronomer describes it as quite round, which is now obviously no longer the case, it resembling* [...] *the moon a few days before opposition. It seems to have waned even more and the place is different from yesteryear.*' Among Hahn's targets was the variable star Mira (o Ceti), which is mentioned in his paper too. Curiously, he suspected the object to be a planetary nebula: '*It cannot be magnified like those* [planetary nebulae]*, but it appears as a disc with little dazzling, and brighter than other stars.*'

In about 1795 Hahn examined the Ring Nebula in Lyra (M 57), which had been discovered in 1779 by Darquier in Toulouse with a 9.5-cm Dollond refractor. As early as in 1785 Bode had called attention to the object in his paper 'Ein Sternring oder ein Nebelfleck mit einer Oeffnung'.[109] He added Herschel's sketch. While observing the planetary nebula with the 12" reflector, Hahn noticed the central star. He bequeathed no date, but wrote, in 1800, '*In the famous star-ring near β Lyrae I find distinct changes. A few years ago the interior of the ring was so clear that I could distinguish in its centre a telescopic star with my 20 ft reflector. Now this telescope shows only faint fine clouds and the small star is no longer visible. A change has certainly happened*' (Hahn 1800). Hahn supposed '*It could be possible too that the transparent ring has changed its position and, relative to the sky background, infinitely beyond the ring, appears different now.*' It is remarkable that the star was seen in a 12-inch – even for today that is an extremely difficult task for such a small aperture. Nothing is said about M 57 observations with the 18-inch, which was built in 1800.[110]

It is remarkable that William Herschel did not notice the central star, despite using a reflector of similar size. It might have been visibile in the 40-ft, but his largest telescope was never pointed to M 57 (NGC 6720, h 2023). After Hahn the central star was seen by only a few observers (John Herschel was not among them).[111] The problem is the low contrast between the faint star (14.8 mag) and the interior of the ring, which is not black, but has a higher surface brightness than the sky background. To see the star, a large telescope with high magnification (enhancing the contrast) is needed. Lord Rosse always found the star 'pretty bright' in his 72" reflector (it was seen first on 5 August 1848); Angelo Secchi (about 1855) and Herman Schultz (13 August 1865) could see the central star in their 9.5" refractors.[112] However, Hermann Vogel's observation with the 27" refractor in 1884 was unsuccessful: '*The Vienna refractor shows the interior of the ring quite uniformly filled with faint nebulosity.*'[113] James Keeler could easily see the star in the 36" Lick refractor: '*with this instrument the central star was always easily visible, although it was too faint for observation with the spectroscope*' (Keeler 1892).

The first photography of the central star was achieved by Eugen v. Gothard on 1 September 1886 with a 10.25" Browning reflector in Herény, Hungary (Gothard 1886a). He noted that '*in the middle a round (possibly annular) core is visible.*'[114] Thereupon Rudolph Spitaler observed M 57 in autumn 1886 with the great Vienna refractor – and was disappointed: '*A small star near the centre was, however, not seen*' (Spitaler 1887). But on 25 July 1887, accompanied by his visitor Charles Young from Princeton, he proudly noted that '*at first glance, almost in the middle of the interior ring area, a bit northwest of the very centre, a small star was visible, just like it appears on Gothard's photography*' (Fig. 2.27). Julius Scheiner, who had imaged the planetary nebulae NGC 7009 and NGC 7662, claimed in 1892 that the "*central 'stars' are by no means stars in the usual sense of the word, but only irregularly shaped nebulous condensations*" (Scheiner 1892). This supported William Herschel's idea of 'nebulous stars'. In 1842 Arago, Director of the Paris Observatory, had already surmised that the central star (in most cases too remote to be visible) illuminates the planetary nebula, which explain its uniform light. Thus PN would be mere reflection nebulae, which is incorrect.[115]

109 'A star-ring or a nebula with an opening' (Bode 1785a).

110 The common claim that the central star was discovered with the 18-inch is wrong; see e.g. Stoyan *et al.* (2008).

111 Therefore the star remained unknown; it is, for instance, not mentioned in Smyth's observing guide (Smyth 1844).

112 Parsons L. (1880: 152), Secchi (1856a), Schultz (1874: 99).

113 Vogel (1884: 35).

114 See Section 9.15.3 (Fig. 9.58).

115 The PN gas is highly excited by the hot central star. See article 877 in *Outlines of Astronomy* (Herschel J. 1869).

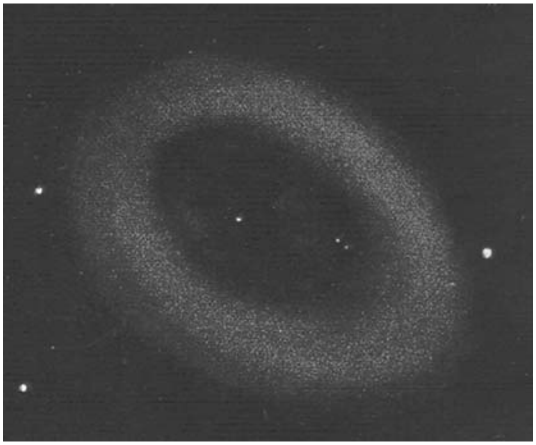


Figure 2.27. Spitaler's fine drawing of M 57 (Spitaler 1891a).

2.8 SPECIAL OBJECTS

In Herschel's papers on 'Astronomical observations', which were published in 1811 and 1814, many objects are presented.[116] He focuses on morphology and classification; individual objects were treated to demonstrate the systematic features. An interesting sample is consitituted by the double (multiple) nebulae, which were studied for the first time by Herschel and categorised by distance (Table 2.18).[117] As discoverer of physical double stars, he supposed that there was a certain similarity between these two phenomena. Therefore, double nebulae should show orbital motion too. Later John Herschel revisited the issue.

The 15 'double nebulae with joined nebulosity' (defining the closest pairs) are listed in Table 2.19. The first discovered case is NGC 5194/95 (M 51), which was seen by Méchain on 21 March 1781 (M 76 is not a true example). In nine cases we have true double galaxies, which are included in modern catalogues (Vorontsov–Velyaminov, Holmberg, Arp).[118] It is, however, remarkable that such a prominent example as NGC 4676 (II 326, 13 May 1785) in Coma Berenices, now called The Mice (Arp 242, VV 244), is not included. Herschel simply did not noticed that it is a double object, whereas his son noted on 9 April 1831 '*query if bicentral*' (the nuclei are only 37″ apart).[119]

Table 2.18. *Herschel's double and multiple nebulae*

Category	Number
Double nebulae with joined nebulosity	15
Double nebulae that are not more than two minutes from each other	23
Double nebulae at a greater distance than 2′ from each other	101
Treble, quadruple and sextuple nebulae	20/5/1

NGC 2905 is a distinctive H II region in the galaxy NGC 2903. The list also contains the planetary nebulae M 27 and M 76, interpreted by Herschel as 'double nebulae'. The smaller 'component' of M 76 was catalogued as I 193; Dreyer had considered the object as NGC 650/51. A similar case is II 316/17 (NGC 2371/72) in Gemini (Fig. 2.28 left). III 644 (NGC 5522) is nothing but a single galaxy and the 'companion' of III 45 (NGC 5174) is only a star (14.4 mag), 45″ south of the centre. The curious case of II 48, II 80 and NGC 2672/73 is treated in Section 8.16.3. Table 2.20 shows the six largest of Herschel's groups of nebulae.

It is interesting that Herschel has not included a 'quadruple', which was sketched earlier (Fig. 2.28 right): the galaxy NGC 4449 (9.4 mag) of the 'magellanic' type Sm in Canes Venatici. Unlike NGC 2371/72 (Fig. 2.28 left), for which Herschel used two entries (II 316/17), the object is listed as I 213. His sketch shows four condensations, corresponding to bright H II regions.

The quartets Arp 318 and HCG 61 are noteworthy.[120] The latter is one of Paul Hickson's 'compact groups', which was nicknamed in the twentieth century The Box (Fig. 2.29).[121] The third of Herschel's

116 Herschel W. (1811, 1814).

117 Herschel W. (1811: 285–289).

118 For these catalogues see Steinicke (2004a, Section 2) and Steinicke and Jakiel (2006, Section I.3). On the *Arp Atlas of Peculiar Galaxies*, see also Kanipe and Webb (2006).

119 The galaxy pair was eventually seen by Spitaler on 20 March 1892 with the Vienna 27" refractor (Spitaler 1893). His 'Novae' nos. 51 and 52 were catalogued as IC 819 and IC 820 by Dreyer. The identity with NGC 4676 was later detected by Carlson (1940). The name The Mice is a twentieth-century product.

120 For these catalogues, see Steinicke and Jakiel (2006).

121 See Steinicke (2001a).

Table 2.19. *Herschel's 15 'double nebulae with joined nebulosity'*

Pair	Object	NGC	Date	Type	*V*	Con.	Catalogue	Remarks
(1)	I 56	2903	16.11.1784	Gx	8.8	Leo		
	I 57	2905	16.11.1784	GxP		Leo		H II region in NGC 2903
2	I 176	4656	20.3.1787	Gx	10.1	CVn	KPG 350	
	I 177	4657	20.3.1787	Gx	12.4	CVn	KPG 350	
3	I 178 = I 179	4618	9.4.1787	Gx	10.6	CVn	Arp 23, VV 73	
	I 178 = I 179	4618	9.4.1787	Gx	10.6	CVn	Arp 23, VV 73	
(4)	I 193	651	12.11.1787	PN	10.1	Per		M 76, Méchain 5.9.1780; bipolar
		650		PN	10.1	Per		M 76, Méchain 5.9.1780; bipolar
5	I 186	5195	12.5.1787	Gx	9.6	CVn	Arp 85, VV 1	Méchain 21.3.1781
		5194	17.9.1783	Gx	8.1	CVn	Arp 85, VV 1	M 51, Messier 13.10.1773
(6)	II 80 = II 48	2672	14.3.1784	Gx	11.6	Cnc	Arp 167	With NGC 2673, J. Stoney 19.12.1848
7	II 271	741	13.12.1784	Gx	11.3	Psc	VV 175	
	II 272	742	13.12.1784	Gx	14.3	Psc	VV 175	
8	II 309	5427	5.3.1785	Gx	11.4	Vir	Arp 271, VV 21	
	II 310	5426	5.3.1785	Gx	12.1	Vir	Arp 271, VV 21	
(9)	II 316	2371	12.3.1785	PN	11.2	Gem		Bipolar
	II 317	2372	12.3.1785	PN	11.2	Gem		Bipolar
10	II 832	3895	18.3.1790	Gx	13.1	UMa	Holm 294	
	I 248	3894	18.3.1790	Gx	11.6	UMa	Holm 294	
(11)	III 45	5174	15.3.1784	Gx	12.5	Vir		
	III 46	5175	15.3.1784	Star	14.4	Vir		45″ south of galaxy centre
(12)	III 644	5522	19.3.1787	Gx	13.4	Boo		Only single galaxy
13	IV 8	4567	15.3.1784	Gx	11.3	Vir	VV 219, Holm 427	
	IV 9	4568	15.3.1784	Gx	10.9	Vir	VV 219, Holm 427	
14	IV 28.1	4038	7.2.1785	Gx	10.3	Crv	Arp 244, VV 245	The Antennae (see Table 2.22)
	IV 28.2	4039	7.2.1785	Gx	10.4	Crv	Arp 244, VV 245	The Antennae
(15)		6853	30.9.1782	PN	7.4	Vul		M 27, Messier 12.7.1764

Table 2.20. *Herschel's five quadruple nebulae and one sextuple nebula*

Objects	Date	NGC	Con.	Remarks
II 482–485	28.11.1785	833, 835, 838, 839	Cet	Arp 318
II 568–571	17.4.1786	4270, 4273, 4277, 4281	Vir	In Virgo Cluster
II 372, III 358–360	11.4.1785	4173, 4169, 4174, 4175	Com	HCG 61 (The Box)
II 371, III 356/57	11.4.1785	4134, 4131, 4132	Com	Only three galaxies
III 562–565	21.9.1786	703, 704, 705, 708	And	In Abell 262
III 391–396	27.4.1785	4070, 4069, 4074, 4061, 4065, 4076	Com	In CGCG 1202.0+2028

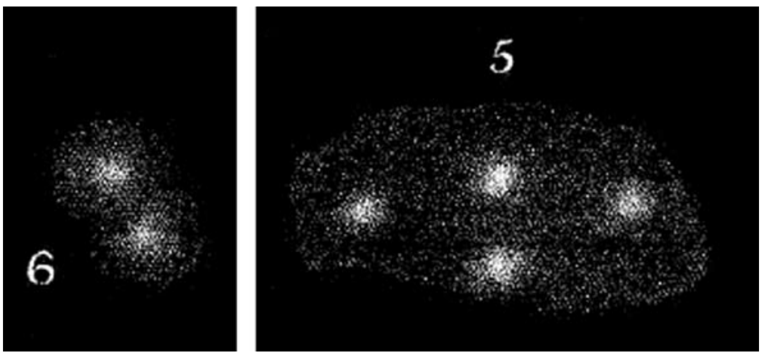


Figure 2.28. Left: Herschel's sketch of the 'double nebula' II 316/17 = NGC 2371/72; right: I 213 = NGC 4449 (I 213) shows four condensations (Herschel W. (1811), Figs. 6 and 5, respectively).

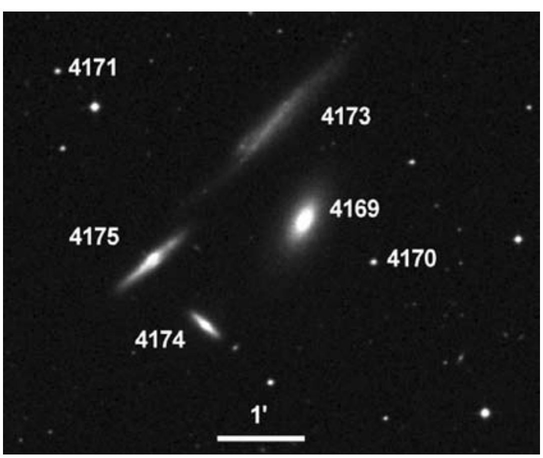


Figure 2.29. The Box in Coma Berenices: four galaxies within 8′, discovered by Herschel; the two stars NGC 4170/71 were found in 1864 by d'Arrest (DSS).

'quadruple nebulae' is only a chain of three galaxies, with NGC 4134 (12.9 mag) as the brightest (Herschel wrote '*a 4th suspected*'). The other groups are parts of galaxy clusters (the sextuple is in a cluster, which was later catalogued by Zwicky).[122]

In addition to III 562–565, Herschel discovered two other members in Abell 262: NGC 679 (III 175, 13 September 1784) and NGC 687 (III 561, 21 September 1786). The remaining five NGC galaxies of the cluster are credited to d'Arrest (three) and the Birr Castle observers Lawrence Parsons and Mitchell. The objects in the quadruple II 568–571 (Herschel's first discovery in Slough) were difficult to identify; the problem was eventually solved by Schönfeld in 1862 (see Section 8.5.4).

Herschel was successful in other Abell clusters too. He found 23 galaxies in the Coma Cluster (Abell 1656), but did not notice its very structure (see Section 8.6.4). Seven of the 21 NGC galaxies in the Leo Cluster (Abell 1367) were seen on 26/27 April 1786 (Datchet); among them was the brightest member, NGC 3842

[122] Interestingly the term 'galaxy cluster' had already been used by Webb – albeit, to describe a galactic cluster, e.g. NGC 2301 (VI 27) in Monoceros (Webb 1859: 215).

Table 2.21. *Herschel's NGC galaxies in the Leo Cluster (Abell 1367)*

Object	NGC	Date	*V*
III 376	3821	26.4.1785	12.8
III 377	3837	26.4.1785	13.3
III 378	3842	26.4.1785	11.8
III 386	3860	27.4.1785	13.4
III 385	3862	27.4.1785	12.7
III 387	3875	27.4.1785	13.7
III 388	3884	27.4.1785	12.6

(Table 2.21). The remaining ones are due to d'Arrest (five), Stephan (five) and John Herschel (four).

Herschel succeeded at making a similar find in the NGC 507 group in Pisces. On 12 September 1784 he discovered the primary member (III 159, 11.3 mag) and three others: NGC 495 (III 156), NGC 496 (III 157) and NGC 508 (III 160). The remaining NGC galaxies of the group were found by John Herschel (two), Mitchell (two) and d'Arrest (one). On 26 September 1785 Herschel discovered three NGC galaxies in the Pegasus I Cluster, among them the brightest, NGC 7619 (II 439, 11.1 mag); the others are NGC 7623 (II 435) and NGC 7626 (II 440). This cluster, containing eight NGC galaxies, is not rich enough to be listed in the Abell catalogue; the others were found by Marth (two), John Herschel (one), d'Arrest (one) and Copeland (one).

On 17 March 1787 William Herschel discovered the first ring galaxy: NGC 4774 (III 618, VV 784) in Canes Venatici, described as 'eF, vF'. The object of 14.3 mag was nicknamed the Kidney Bean Galaxy by Zwicky. Other galaxies of this rare type were found by Marth, Stephan, Tempel and Leavenworth – though none of these visual observers could detect their peculiar structure.

2.9 ADDITIONS BY JOHN HERSCHEL AND DREYER

John Herschel and Dreyer added 15 objects to the catalogues (Table 2.22). John Herschel described the first two in his Slough catalogue, others followed in the Cape catalogue and GC, assigned as 'HON' ('Herschel omitted nebula'). Eventually Dreyer added two objects. In some cases an existing H-number was split; in other cases entries were appended to the particular class (the discovery date is thus later than that of William Herschel's final entry). Most additional objects were listed by Auwers (Au) in his revision of the three Herschel catalogues (see Section 6.19).

I 28 is the double galaxy NGC 4435/38 in the centre of the Virgo Cluster.[123] William Herschel noted '*One of two, at 4 or 5″ dist. B. cL.*' John Herschel entered these two objects as h 1274 and h 1275 in the Slough catalogue; h 1275, which is the brighter component NGC 4438 (10.0 mag), was identified as I 28. But h 1274 was equated with M 86 – a serious error, which was first noticed by Auwers[124] and eventually corrected by John Herschel in the GC, which gives GC 2991 = h 1274 = I 28,1 and GC 2994 = h 1275 = I 28,2. M 86 is now correctly identified as h 1253 = GC 2961.

Already William Herschel suspected IV 28 to be a double nebula '*opening with a branch or two nebulae very faintly joined*'. It is NGC 4038/39 in Corvus, known as The Antennae (Fig. 2.30 left); the components are only 1.5′ apart (Steinicke 2003d). It is remarkable that the pair was entered in class IV ('planetary nebulae'). In the Slough catalogue John Herschel separated it into IV 28.1 (h 1052 = NGC 4038) and IV 28.2 (h 1053 = NGC 4039).

V 29.1/2 is in the Slough catalogue too, where a common h-number was used (h 1252). V 29.1 (NGC 4395) is a galaxy of 10.0 mag in Canes Venatici, which was discovered on 2 January 1786. V 29.2 (NGC 4401) is a bright H II region 2′ southeast of the centre, which was found by John Herschel on 29 July 1827 (Fig. 2.30 right). He noted (h 1252) '*Two nebulae running into one another.*'[125] Two other H II regions, NGC 4399 and NGC 4400, were contributed by Bindon Stoney at Birr Castle (13 April 1850).

The designation VIII 1B is explained in the General Catalogue (note to GC 1480): "*This nebula is entered by C.H. as VIII. 1. B, with the remark 'not in print'.*" Caroline Herschel included the object in her zone catalogue (described in the next section), because it was erroneously missing from the first published Herschel catalogue. Since the discovery date (18 December 1783) follows that of VIII 1 = NGC 2509 (3 December), John Herschel introduced the suffix 'B'. It is, however, confusing that he assigns NGC 2319 in his entry h 423 as 'VIII. 1'.

123 The pair is a member of Markarian's Chain, starting with M 84 and M 86.

124 Auwers (1862a: 77).

125 The Slough catalogue contains a sketch (Fig. 68).

Table 2.22. *Objects added by John Herschel and Dreyer (site: D = Datchet, S = Slough)*

Object	Source	h	Au	GC	NGC	Date	Site	Type	*V*	Con.	Remarks
I 28, 2	SC	1275		2994	4438	8.4.1784	D	Gx	10.0	Vir	I 28, 1 (h 1274) = NGC 4435
II 908	HON 3		*	1690	2650	30.9.1802	S	Gx	13.3	UMa	
II 909	HON 5		*	1972	3063	30.9.1802	S	2 stars		UMa	Dreyer: 'HON 5'; W. Herschel's final object
II 910	GC	1407	*	3179	4646	24.3.1791	S	Gx	13.4	UMa	II 794,2 (order changed); II 794,1 = NGC 4644
III 979	HON 6		*	2077	3210	26.9.1802	S	2 stars		Dra	Dreyer: 'HON'
III 980	HON 7		*	2078	3212	26.9.1802	S	Gx	13.7	Dra	Dreyer: 'HON'
III 981	HON 8		*	2079	3215	26.9.1802	S	Gx	13.2	Dra	Dreyer: 'HON'
III 982	HON 1		*	1679	2629	30.9.1802	S	Gx	12.3	UMa	Dreyer: 'HON'
III 983	HON 2		*	1682	2641	30.9.1802	S	Gx	14.0	UMa	Dreyer: 'HON'
III 984	SC	2296	*	5044	7810	17.11.1784	D	Gx	13.1	Peg	H.MS. (order changed)
III 985	D	1435		3224	4695	24.3.1791	S	Gx	13.5	UMa	'II 796' (order changed)
IV 28.2	SC	1053		2671	4039	7.2.1785	D	Gx	10.4	Crv	IV 28.1 (h 1052) = NGC 4038, The Antennae
IV 79	HON 4		*	1950	3034	30.9.1802	S	Gx	8.6	UMa	M 82, Bode 31.12.1774; Dreyer: '4 HON'
V 29.2	SC	1252		2962	4401	29.7.1827		GxP		CVn	H II region in NGC 4395 = V 29.1 (h 1252)
VIII 1B	SC	423		1480	2319	18.12.1783	D	Star group		Mon	VIII 1 = NGC 2509

III 984 is not in the Herschel catalogues. John Herschel recognised the object in an observing journal of his father. The Slough catalogue remarks for h 2296 'H.MS.' ('Herschel manuscript'). Dreyer introduced the designation III 984 in the *Scientific Papers of Sir William Herschel*.[126]

The eight 'HON' objects are listed in the appendix of John Herschel's Cape catalogue.[127] The abbreviation was used first in the GC and stands for 'Herschel omitted nebulae'.[128] All objects were discovered by William Herschel on 26 and 30 September 1802 in Slough. Since he had decided that his last catalogue should contain exactly 500 entries, they were omitted (see Section 2.2.2). Most of them are galaxies in the constellations Ursa Major and Draco. The story of IV 79 is remarkable. This 'planetary nebula' is identical with the bright

[126] Dreyer (1912a); see Dreyer's notes to the Herschel objects.

[127] Herschel J. (1847: 128).

[128] The GC uses 'H.O.N.', whereas Dreyer notes 'HON' in the NGC.

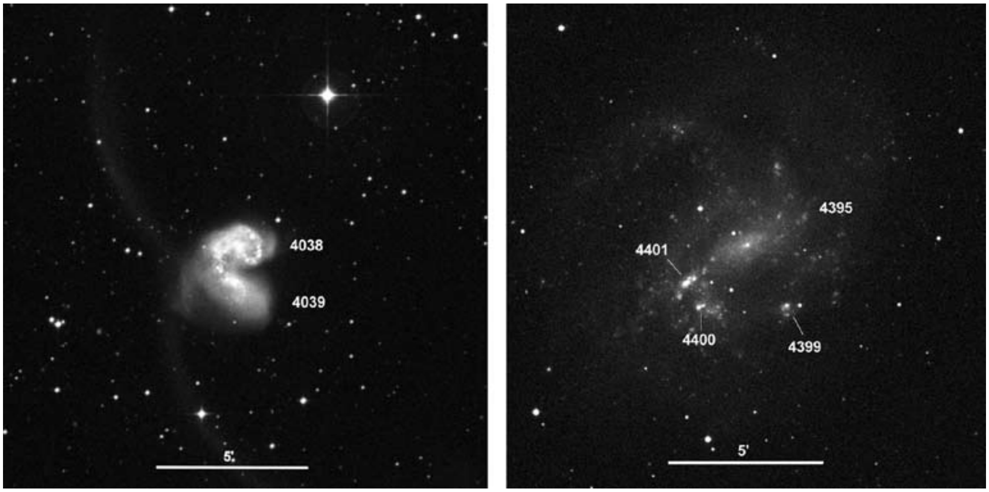


Figure 2.30. Additional Herschel objects. Left: The Antennae NGC 4038/39 (IV 28.1/2); right: NGC 4395 with the H II regions NGC 4399, NGC 4400 and NGC 4401 = V 29.1/2 (DSS).

galaxy M 82 in Ursa Major! It was discovered by Bode on 31 December 1774. The whole Herschel family is involved in this curious story (Steinicke 2007a).

For II 794 William Herschel noted two observations: 14 April 1789 (sweep 921) and 24 March 1791 (sweep 1001). The first was used for his entry in the third catalogue, described there as '*F, S*'. In the GC John Herschel now claims that these observations concern different objects. He thus introduced two new designations: II 794,1 = h 1406 = GC 3177 (NGC 4644) and II 794,2 = h 1407 = GC 3179 (NGC 4646). The first object is II 794 of sweep 921. This was not recognised by him in the Slough catalogue, where we face a confusing situation: he identifies h 1407 with II 794, but takes the object from sweep 1001. On the other hand, h 1406 is assigned as 'Nova', but this is actually the object of sweep 921, named II 794 by his father. In the NGC Dreyer used the correct GC version. In the *Scientific Papers* the case was investigated once again. Now Dreyer introduces the designation II 910, instead of II 794,2, and II 794,1 gets back its old name II 794.

III 985 is a similar case. William Herschel noted two observations from his sweeps 921 and 1001 (the same as for II 794, see above). Once again two different objects are involved, which was not noticed by him. The first, found on 14 April 1789, was named II 796 (NGC 4686) in the third catalogue; the second, observed on 24 March 1791 was not listed. It first appears in Dreyer's *Scientific Papers* as III 985 (NGC 4695). Both objects are contained in the Slough catalogue and GC too. But there is confusion concerning the identification with H-numbers: h 1428 = GC 3216 (NGC 4686) is called 'II 795' and h 1435 = GC 3224 (NGC 4695) is called 'II 796'. The NGC gives the correct version. With the designations II 910, III 984 and III 985, introduced by Dreyer in the *Scientific Papers*, the usual order (by date) was given up. This makes his version different from William Herschel's original catalogues.

2.10 LATER PUBLICATIONS AND REVISIONS OF HERSCHEL'S CATALOGUES

Johann Elert Bode published Herschel's catalogues (in German translation) with a delay of two years in the *Berliner Jahrbuch* (Bode 1788, 1791, 1804b).[129] Right ascension and declination for 1786, 1790 and 1801, respectively, are given. However, Bode kept the original order. A flaw was the lack of precise star positions used to determine absolute positions. Bode's aim was not a new reduction, but to present Herschel's discoveries to a wide (German-speaking) audience. As d'Arrest and

129 Herschel's first catalogue was also reprinted in Francis Wollaston's book *A Specimen of a General Astronomical Catalogue*, published in 1789 in London (Wollaston 1789). Bode translated other works of Herschel too; see e.g. Bode (1804a).

Auwers later pointed out, Bode's treatment is full of errors (d'Arrest 1856a; Auwers 1862a). D'Arrest wrote that, '*even if one ignores the inaccurate star positions used to determine the coordinates of the nebulae, the work is distorted by many errors*'. It therefore was hardly used.

Another treatment of the original data is due to Caroline Herschel. After her brother's death and her return to Hannover, she reduced the nebular positions for the epoch 1800.[130] The resulting catalogue was a folio-volume of 104 handwritten pages (Herschel C. 1827).[131] It was based on Flamsteed's star catalogue, which had been revised by her earlier. The objects are arranged in declination zones, starting with the circumpolar nebulae to 9° north polar distance, followed by the zones 10° to 14° and 15° to 16°, after which the zones up to the final one (121°) had a constant width of 1°. Inside a zone, the objects are ordered by right ascension. The sweep-number is given for each entry. The last two pages of the manuscript contain, among other things, errata to the three Herschel catalogues.

On 8 February 1828 Caroline Herschel received the gold medal of the Astronomical Society of London[132] '*for her recent reduction, to January 1800, of the Nebulae discovered by her illustrious brother, which may be considered as the completion of a series of exertions, probably unparalleled, either in magnitude or importance, in the annals of astronomical labour*' (South 1830). The work on the 'zone catalogue' began in Hannover in April 1824 and might have been finished in late 1827. Unfortunately it was never published and can have been seen by only a few people.[133] The catalogue was primarily intended for the use of her nephew, John Herschel. From it, 'working lists' for the Slough observations were compiled. Herschel would have had the opportunity to publish the zone catalogue, but Dreyer assumed that '*he shared the universal opinion at the time, that very few of his father's nebulae could be seen, or at least, usefully observed with any but the largest telescopes; but chiefly because he always intended to bring out a General Catalogue of all known Nebulae and Clusters, a task which the vast amount of valuable work he carried out did not allow him to complete till 1864*'.[134]

In 1826 another German edition of Herschel's catalogues was published by Wilhelm Pfaff in Leipzig (Pfaff 1826). Unfortunately, the number of errors was even larger than in Bode's version. Therefore d'Arrest criticised this work too, describing it as a '*very erroneous reprint of the unreduced nebulae catalogues*'.[135]

Herschel's catalogues, though receiving praise, were hardly used for subsequent observations. It was John Herschel's work that kept things going. His observations in Slough of a large fraction of the objects were published in 1833. The main value of the Slough catalogue is based on its reliable absolute positions and a homogeneous numbering (h). This made the old Herschel catalogues more or less obsolete. Why use the inconvenient original now that an updated version was available? Lord Rosse, for instance, referred to h-numbers exclusively (which he curiously wrote 'H').

This was partly changed by the work of Auwers, who published the first complete revision of the Herschel catalogues in 1862, titled 'William Herschel's Verzeichnisse von Nebelflecken und Sternhaufen'.[136] Auwers, of course, used the results of John Herschel. Thus he corrected not only the original catalogues, but also the Slough catalogue. Most errors were due to incorrect identifications or problems with reference stars. For instance, Auwers detected that William Herschel's Flamsteed-numbers in Lynx must be reduced by 1 for those greater than 38 (e.g. '39 Lyncis' must read '38 Lyncis'), which led to wrong positions for some objects (see Section 6.19).

The last step was made by Dreyer. Whilst working on the NGC (and later on the IC) he dealt intensively with Herschel's catalogues. He used the original notes of William and Caroline Herschel, which had been put at his disposal by the Royal Society. A most valuable source was the unpublished zone catalogue of the latter. The result of his revision appeared in the *Scientific Papers of Sir William Herschel*, edited by him in 1912 (Dreyer 1912a). This monumental work contains the original catalogues, enlarged by

130 Dreyer (1912a: lxiii–lxiv).

131 The manuscript is in the possession of the Royal Society.

132 On 15 December 1830 the name was changed to 'Royal Astronomical Society'.

133 Herschel C. (1827); compare with RAS Herschel C. 3/3.

134 Dreyer (1912a: lxiv).

135 d'Arrest (1856a: 360). Further volumes planned by Pfaff failed to appear.

136 'William Herschel's lists of nebulae and star clusters' (Auwers 1862a).

Table 2.23. *Different notation used for Herschel objects*

Author	Notation
William & John Herschel	VIII. 61
Smyth	61 H. VIII.
d'Arrest, O. Struve	H. VIII. 61
Auwers, Schönfeld, Schulz	VIII. 61
Winnecke, Rümker	H. VIII, 61
Tempel	VIII 61
Dreyer	VIII. 61, VIII 61

additional objects, cross references to the NGC and many notes.

Finally, a remark concerning the designation of Herschel objects, which appears not to be uniform in the nineteenth century.[137] This is demonstrated in Table 2.23 for object no. 61 in class VIII; the open cluster NGC 1778 in Auriga, which was discovered on 17 January 1787 in Slough.

[137] In the modern literature there is confusion too; a recent example is O'Meara (2007).

3 • John Herschel's Slough observations

Apart from William Herschel, his son John was the greatest discoverer of nebulae and star clusters (Fig. 3.1).[1] About his motivation he wrote in 1826 in Slough that '*The nature of nebulae, it is obvious, can never become more known to us than at present; except in two ways, – either by the direct observation of changes in the form or physical condition of some one or more among them, or from the comparison of a great number, so as to establish a kind of scale or graduation from the most ambiguous, to objects of whose nature there can be no doubt*.'[2] The first way had already been realised through his detailed observations of the Orion and Andromeda Nebulae[3] (Herschel J. 1826a, b). The second – the study of a large number of objects – was mastered in the years 1825–33, reproducing and extending the observations of his father.

Figure 3.1. John Herschel (1792–1871).

John Herschel published the results as 'Observations of nebulae and clusters of stars, made at Slough, with a twenty-feet reflector, between the years 1825 and 1833' in the *Philosophical Transactions of the Royal Society* (Herschel J. 1833a).[4] The professional Slough catalogue (SC) appeared in the same year as his first astronomical textbook *A Treatise on Astronomy*, which had been written for the general public. The latter volume had great influence and was later enlarged to become the *Outlines of Astronomy*, first appearing in 1849. In 1836 Herschel received the RAS gold medal for this work.[5] During the laudation held on 12 February (Herschel was absent), George Biddell Airy, Astronomer Royal and President of the RAS, delivered an overview on the status of nebular research (Airy 1836).[6] Because of the wide popularisation of John Herschel's writing and his many duties, he even surpasses the eminence of his father.[7]

For his observations John Herschel used a reflector with an aperture of 18¼", which was completed in 1820. It used two mirrors, one made by his father alone and another one cast and ground under his father's supervision (Fig. 3.2). The telescope resembles William Herschel's famous

1 A biography is omitted here; see e.g. Ball R. (1895: 247–271), Buttmann (1970), King-Hele (1992), Ring (1992) and Chapman A. (1993).

2 Herschel J. (1826a: 487).

3 On the Orion Nebula see Herschel J. (1826a); it contains a drawing made between February 1824 and March 1826. His subsequent paper treats the Andromeda Nebula (Herschel J. 1826b).

4 The acknowledgment reads '*Received July 1, – Read November 21, 1833*.' John Herschel became a fellow of the Royal Society in 1813.

5 John Herschel was a founder member of the Astronomical Society of London (which later became the RAS); see Dreyer and Turner (1923) and Whitrow (1970).

6 At the same time this was done by Joseph v. Littrow in his book *Sterngruppen und Nebelmassen des Himmels* (Littrow J. 1835).

7 His popularity remained in the twentieth century, as can be seen, for instance, in the forenames of the American astronaut Glenn, born in 1921, which are 'John Herschel'. By the way, the son of Thomas Maclear, Astronomer Royal at the Cape, was given the forenames 'George William Herschel'.

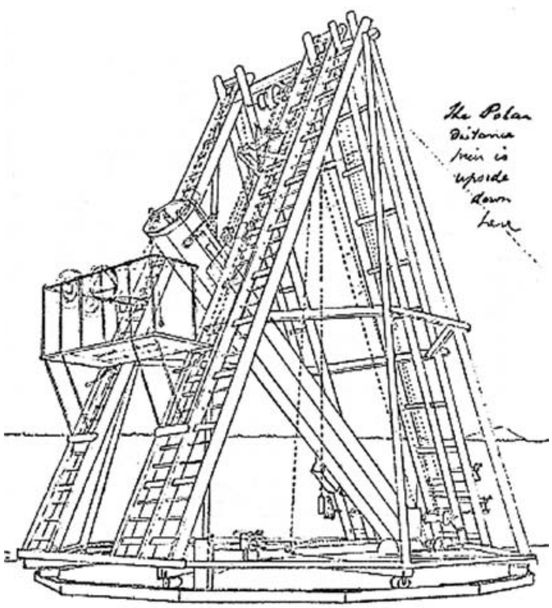


Figure 3.2. John Herschel's 18¼" reflector of focal length 20 ft that was completed in 1820 in Slough (Warner 1979).[8]

'large 20 ft' (Warner 1979). When John Herschel started observing, his intention was not so much the discovery of new nebulae and star clusters but rather he wanted to re-examine the three catalogues of his father. The main goals were identification and determination of exact positions. To realise this ambitious project, he compiled 'working lists' to direct his sweeps. They were based on Caroline Herschel's unpublished zone catalogue.[9]

John Herschel could observe a large fraction of his father's objects. Their data were partly confirmed, supplemented and corrected. Moreover he discovered many new ones. The resulting Slough catalogue contains

- known objects of William Herschel
- new objects of John Herschel
- objects that had been found earlier but not listed by William Herschel (e.g. from Messier's catalogue)
- objects discovered by others (mainly by Wilhelm Struve)

John Herschel compiled a (pretty complete) catalogue of all non-stellar objects known up to 1833. The work meant real progress and became a great success, which was due to remarkable new features: absolute positions (for 1830), order by right ascension and new designation (h). The great homogeneity rests on the fact that all objects were observed and measured by John Herschel with the same telescope. The h-number got the new standard designation (e.g. h 50 = M 31).

3.1 STRUCTURE AND CONTENT OF THE SLOUGH CATALOGUE

The text covers 147 pages; followed by 8 tables with 91 figures (drawings, sketches). The main part consists of an introduction (6 pages), the catalogue including 'Errata and addenda' (117 pages) and an appendix, which also contains the explanations to the figures (24 pages).

The catalogue lists 2306 numbered entries ('No.' is equal to h-number). Table 3.1 shows the meanings of the columns. Following the last entry (h 2306 = NGC 7827), the first one is repeated (h 1 = III 868 = NGC 12). The column 'Synonym' primarily gives William Herschel's designation. Additionally, Messier objects and those found by Wilhelm Struve are mentioned; examples are 'M 27' (h 2060) and 'Σ 885' (h 385), respectively. John Herschel's own discoveries are listed as 'Nova'. Also a few stars are referred to here, marking the centre of the nebulous object: '15 Monoc' (h 401), '50 Cassiop.' (h 179), '55 Androm.' (h 162) and 'θ Orionis' (h 360). The latter defines the prominent trapezium in the Orion Nebula.[10]

Usually, several observations are given for an object. The coordinates are mostly noted to 0.1^s (AR) and 1″(NPD); a lower accuracy is indicated. By the way, there is no NPD for the 'Nova' h 1039 ('*no PD taken*'). The descriptions rely on William Herschel's scheme. Occasionally, distance and position angle to nearby objects (nebulae, stars) or the air quality is noted. For some observations guests are mentioned: Mr Knorre (h 749), Lord Ardare and Mr Hamilton (h 1357), Mr Baily (h 1558), Capt. Smyth (h 1663) and Mr Struve (h 2081).

The last column gives the number of the sweep. Unfortunately there is no register listing the dates. They were eventually presented in 1847 as 'Synoptic table of the dates of the sweeps' in the Cape catalogue.[11]

[8] See also Hoskin (1987); Fig. 3.
[9] RAS Herschel J. 1/5.1–4.
[10] Here John Herschel had discovered a sixth star in 1830; see Section 9.6.10.
[11] Herschel J. (1847: 129–131); for some sweeps the date gives no day (there is no information in his original reports).