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Nicolas-Louis de La Caille, James Dunlop and John Herschel
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An analysis of the First Three Catalogues of Southern Star Clusters and Nebulae

Thesis submitted by

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in June 2008

for the degree of Doctor of Philosophy

in the Faculty of Science, Engineering and Information Technology

James Cook University

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STATEMENT ON THE CONTRIBUTION OF OTHERS

The following have assisted in the production of this thesis.

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Finally, I would like to thank my wife and three daughters for their patience and support throughout.

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[1] Wolfgang Steinicke's *Revised NGC/IC*, *Historic NGC* and biographical data about NGC/IC Observers, can be found at <http://www.klima-luft.de/steinicke/index_e.htm>

[2] Robert Erdmann's *Historically Corrected NGC* and *Digitized Sky Survey* (DSS) Images of NGC Objects, can be found at <http://www.ngcic.org/>

[3] Digitized Sky Survey, *The Space Telescope Science Institute*, 2007, <http://archive.stsci.edu/dss/acknowledging.html>, accessed 20 January 2008.

ABBREVIATIONS

AAO	Anglo-Australian Observatory
cf	cumulative frequency
Dec	Declination
DSFG	Deep Sky Field Guide
DTU	Desktop Universe
Dun	Dunlop
D*	double star
ESO (B)	European Southern Observatory, blue sensitive plates
GC	globular cluster
Gxy	galaxy
Hers	Herschel
IC	Index Catalogue
Lac	Lacaille
LMC	Large Magellanic Cloud
Mag	Magnitude
MWSC	Milky Way star clouds
Neb	Nebula
NGC	New General Catalogue
NPD	north polar distance
np	north preceding
NSW	New South Wales
OC	open cluster
PN	planetary nebula
RA	Right Ascension
RAS	Royal Astronomical Society
SEM	standard error mean
SERC (J)	Science and Engineering Research Council, green sensitive plates
sf	south following
SMC	Small Magellanic Cloud
SPD	south polar distance
V	visual
’	minutes or arc-minutes
”	seconds or arc-seconds

ABSTRACT

"If men like [John] Herschel are to spend the best years of their lives in recording for the benefit of a remote posterity the actual state of the heavens…what a galling discovery to find amongst their own contemporaries men [James Dunlop] who … from carelessness and culpable apathy hand down to posterity a mass of errors …[so] that four hundred objects out of six hundred could not be identified in any manner … with a telescope seven times more powerful than that stated to have been used!"[4]

The denigration of James Dunlop and his catalogue of 629 southern nebulae and clusters produced in 1826 originated with John Herschel and was continued by others of his day. Was this criticism justified? Was James Dunlop guilty of "carelessness and culpable apathy"? Were there "four hundred objects out of six hundred" which could not be identified, and if so, was there an explanation for this large shortfall?

This question led to a search within Dunlop's 1826 catalogue to rediscover, if possible, some of the missing objects and to reinstate Dunlop, if justified, as a bona fide astronomer. In doing this, Dunlop's personal background, education and experience became relevant, as did a comparison with the catalogue of 42 southern nebulae and clusters produced by Nicolas-Louis de La Caille in 1751-2, and the 1834-8 catalogue of 1708 southern nebulae and clusters by John Herschel, who found the Dunlop catalogue so galling.

To place the three southern catalogues in their historical context, a brief overview of these and the first three northern catalogues was made. Biographical information, descriptions of their equipment and comments on their observing techniques were included, where obtainable, for each of the authors of the three southern catalogues.

However the main objective of this thesis was to determine which of the 629 objects in the Dunlop catalogue exist and then using these objects in a revised Dunlop catalogue, to statistically analyse and compare it with the content of the Lacaille and Herschel catalogues. In order to identify and compare the catalogues, positions given for an object by each astronomer were precessed to J2000.0 coordinates. These modern positions for

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[4] James David Forbes, 'Results Results of Astronomical Observations made during the years 1834, 5, 6, 7, 8 at the Cape of Good Hope, being a completion of a telescopic survey of the whole surface of the visible heavens commenced in 1825', *The Quarterly Review*, 85, 1849, pp 1-31.

an object could then be plotted onto modern photographic star atlases and digital images of the sky, to determine the accuracy of the original positions.

Analysis of the three non-stellar catalogues included the determination of the radial distance of each object from its “correct” position and diagrams of both difference in Right Ascension and difference in Declination against Right Ascension and Declination, in order to identify any trends. Each catalogue contained some copy or printing errors, but these were omitted from the statistical calculations performed. The results for the three catalogues, from the astrometric perspective, showed that the Herschel catalogue contained the most accurate positions, followed closely by the Lacaille catalogue with no obvious or systematic trends in their inaccuracies. In contrast, the Dunlop catalogue showed some clear trends in the positional inaccuracies which, regardless of mitigating circumstances, to some extent warranted John Herschel’s criticism.

Finally an examination of the completeness of each catalogue was undertaken to determine the thoroughness of each astronomer. Firstly the effective aperture and theoretical magnitude limit for each telescope was calculated. Next the non-stellar objects were grouped into five types, open clusters, globular clusters, diffuse nebulae, planetary nebulae and galaxies, and a single working magnitude limit[5] was found for each catalogue. A number of indicators were used to determine the working magnitude limit.

The number of faint objects of each type which were seen, and the number of bright objects which were missed by the three astronomers, was assessed. In both the Dunlop and Herschel catalogues galaxies gave the best indicator of the working magnitude limit. Globular clusters provided the best working magnitude limit for Lacaille.

In answer to the question, ‘Was the Dunlop catalogue as bad as John Herschel claimed?’ the reply must surely be that although there are definite problems within the catalogue, chiefly missing objects and positional inaccuracies, generally this catalogue achieved much of what Dunlop intended, that is, a comprehensive list of bright nebulae and clusters in the southern sky. Although partially justified, John Herschel and others have not granted to James Dunlop the recognition he deserves.

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[5] The working magnitude limit is the magnitude at which the observer starts to miss more than half the objects in the best available reference catalogue.

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CHAPTER 1 - A BRIEF SURVEY OF THE CATALOGUES OF SIX EARLY OBSERVERS OF CLUSTERS AND NEBULAE

J L E Dreyer finished the *New General Catalogue of Nebulae and Clusters of Stars* (NGC) in 1888.[6] It listed most of the star clusters and nebulae known at the time. The majority of these nebulae turned out to be galaxies, although this was not recognised until 1924. The NGC was mainly based on the observations of Sir William and Sir John Herschel. William used an 18.5-inch reflecting telescope to search the sky above Slough, west of London, for 20 years (1782 to 1802). His son John continued this work from Slough (1823 to 1832) and from Cape Town, South Africa (1834 to 1838). By the end of 1838 a total of 4,465 NGC clusters, nebulae and galaxies had been found. According to Bob Erdmann[7] eight people discovered 10 or more of these objects as listed in Table 1.1.

Table 1.1: The number of NGC objects found by 1838.

Discoverer	**Number of Objects**
William Herschel	2408
John Herschel	1676
James Dunlop	225
Charles Messier	41
Pierre Méchain	25
Nicolas-Louis de La Caille	22
Giovanni Hodierna	11
Caroline Herschel	11
26 other observers	46
Total	**4465**

The individual contribution of the first six people in the above table, those who found more than 20 objects, will be looked at in more detail below. Three of these searched from the northern hemisphere, two from the south and one from both the northern and southern hemispheres. Charles Messier and Pierre Méchain observed from Paris and William Herschel observed from London in the northern hemisphere. Nicolas-Louis de La Caille (Lacaille) observed from Cape

[6] J. L. E. Dreyer, ‘A New General Catalogue of Nebulae and Clusters of Stars, being the Catalogue of the late Sir John F. W. Herschel, Bart’, *Memoirs of Royal Astronomical Society*, Vol. 49, 1888.

[7] The NGC/IC Project, *The Historically Corrected New General Catalogue*, 2007, <http://www.ngcic.org/public_HCNGC/HCNGC.htm>, accessed 3 August, 2007.

Town and James Dunlop observed from Sydney in the southern hemisphere. John Herschel observed from both hemispheres, from London and Cape Town.

The search for non-stellar objects progressed slowly at first. By 1731 only 35 non-stellar objects (clusters and nebulae) were known and 12 of these were known before Galileo first used a telescope in 1609.[8] Giovanni Hodierna, an enthusiastic follower of Galileo catalogued an additional 11 objects (M6, M33, M34, M36, M37, M38, M47, NGC 752, NGC 2362, NGC 6231, and NGC 6530)[9] before 1654 from Sicily.[10] Hodierna, a Roman Catholic Priest, taught mathematics and astronomy in his home town of Ragusa, Sicily. In 1655 he became court mathematician. Hodierna observed the Sun, Moon, comets, planets (including eclipses of their moons) and asteroids. The asteroid 21047 was named after him. “His deepsky discoveries occurred within a larger project he endeavored, compiling a sky atlas, "Il Cielo Stellato Diviso in 100 Mappe," a work he never completed.”[11] The first preserved drawing of the Orion Nebula was drawn by Hodierna.

Plate 1.1: Giovanni Hodierna[12] discovered non-stellar objects before 1654.

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[8] SEDS (Students for the Exploration and Development of Space), *Discovery table of the Deep Sky Objects*, 2005, <http://www.seds.org/messier/xtra/history/dis-tab.html>, accessed 3 August, 2006.

[9] Klima-Luft, *Historic NGC – Explanation, Dr Wolfgang Steinicke*, 2009, <http://www.klima-luft.de/steinicke/index_e.htm>, accessed 19 October, 2009.

[10] G.F. Serio, L. Indorato and P. Nastasi, ‘G.B. Hodierna's Observations of Nebulae and his Cosmology’, *Journal for the History of Astronomy*, Vol. XVI, 1985, pp. 1-36.

[11] SEDS, *Giovanni Battista Hodierna (April 13, 1597 - April 6, 1660)*, 2007, <http://messier.lamost.org/seds/seds.org/messier/en/xtra/Bios/hodierna.html>, accessed 19 October, 2009.

[12] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/hodierna.htm>, accessed 3 August, 2006.

Table 1.2: All clusters and nebulae found by 1782.

Discoverer	Number of Objects
Charles Messier	41
Pierre Méchain	25
Nicolas-Louis de La Caille	22
Giovanni Hodierna	11
Phillippe de Chéseaux	6
21 other NGC observers	32
Other non-NGC observers	17
Total	**154**

By 1782 the number of known objects had grown to 154 as listed in Table 1.2. This increase was principally due to the work of four men:

1. Phillippe de Chéseaux found 6 objects in 1745-46,
2. Lacaille found 22 objects in 1751-52,
3. Messier found 41 objects between 1764 and 1781 and
4. Méchain found an additional 25 between 1779 and 1782.

1.1 NICOLAS-LOUIS De La CAILLE

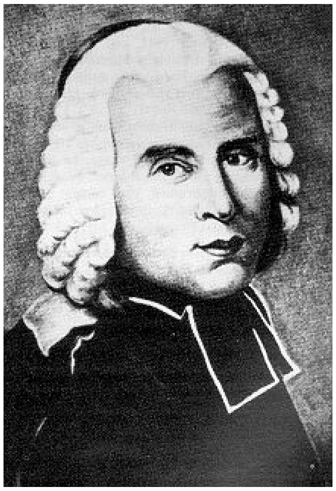

Plate 1.2: Abbé Nicolas-Louis de La Caille[13] was the first to catalogue southern non-stellar objects.

The first of the six main observers was the Frenchman Abbé Nicolas-Louis de La Caille (1713-1762) who arrived at Cape Town, South Africa on April 19, 1751. During the next two years he made a catalogue of 9,776 stars that included 42 nebulae and clusters. Lacaille discovered the nebulae and clusters between August 23, 1751 and July 18, 1752. He divided his list of nebulae and clusters into three parts; nebulae without stars, nebulae with stars, and clusters. There are 14 objects in each part. Today the 42 Lacaille objects are classified as 23 open clusters, 7 globular clusters, 4 diffuse nebulae and one galaxy. There are no planetary nebulae and the other 7 objects are asterisms or stars. Messier later included seven Lacaille objects in his catalogue, namely: M4, M6, M7, M8, M22, M55 and M83.

The remaining objects were too far south for Messier to see. Lacaille was the first person to make a list of southern non-stellar objects.[14] His list included 22 new objects. It was to be 74 years before Dunlop made the next search for southern clusters and nebulae.

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[13] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/lacaille.htm>, accessed 3 August, 2006.

[14] Edmond Halley made a list of 341 southern stars in 1677 including one non-stellar object, Omega Centauri.

1.2 MESSIER

Plate 1.3: Charles Joseph Messier[15] began a catalogue of non-stellar objects six years after Lacaille completed his catalogue.

Charles Joseph Messier (1730-1817) was also a Frenchman. His main interest was comet hunting and he made his famous catalogue of 109 objects to avoid confusing clusters and nebulae with comets. His first entry, M1, was made on September 12, 1758 and his last, M104, was made on May 11, 1781. Most observations were made in 1764, 1780 and 1781.

His catalogue, published in *Connaissance des Temps*, was in three parts in 1771, 1783 and 1784. Messier only discovered 41 of the 109 objects in this catalogue. The other objects were found by others, including his friend Méchain (Section 1.3). However Messier did observe all 109 objects himself using telescopes up to 8 inches in diameter. "Messier used over a dozen telescopes, but none larger than his favourite, a 104-power Gregorian reflector. This instrument had a length of 32 inches and an aperture of 7½ inches. Bailly computer that this was equivalent to a refractor about 28 feet long and with an effective aperture of about 3½ inches!"[16]

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[15] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/messier.htm>, accessed 3 August, 2006.

[16] J.H. Mallas and E. Kreimer, *The Messier Album*, Cambridge, 1978, p. 6.

1.3 MECHAIN

Plate 1.4: Pierre Francois André Méchain[17] discovered some objects in the Messier catalogue.

Pierre Francois André Méchain (1744-1804) like Messier was a French comet hunter. He found 25 new objects between June 1779 and April 1782 and these were included in the Messier catalogue. His discoveries completed the Messier Catalogue’s 109 objects. The final catalogue contains 39 galaxies, 29 globular clusters, 26 open clusters, 8 diffuse nebulae and 4 planetary nebulae. It also includes 1 double star, 1 asterism and 1 duplication.

By 1782 there were in total 154 objects[18] known. Five people discovered most of them; Messier 41 objects, Méchain 25, Lacaille 22, Hodierna 11 and Leys de Chéseaux[19] 6 objects. William Herschel was about to make this number pale into insignificance.

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[17] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/mechain.htm>, accessed 3 August, 2006.

[18] Kenneth G. Jones, *The Search for the Nebulae*, Cambridge, 1975, p. 81, 83.

[19] Philippe Loys de Chéseaux (1718-51) observed near Lausanne in Switzerland in 1745-46.

1.4 WILLIAM HERSCHEL

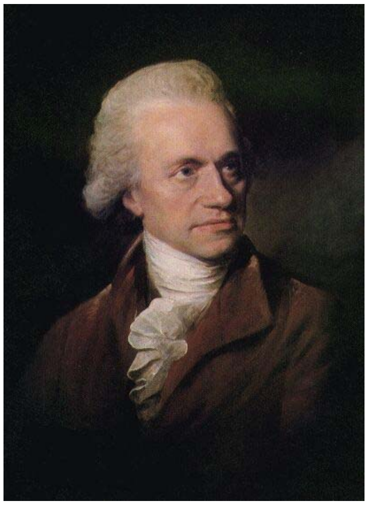

Plate 1.5: William Herschel[20] compiled a catalogue of more than 2000 non-stellar objects with help from his sister, Caroline Herschel.[21]

Sir William Herschel (1738-1822) began his career as a musician first in Germany and afterwards in England. He became interested in astronomy while working in Bath, England and discovered the planet Uranus on March 13, 1781.

He also made three catalogues of non-stellar objects. The first catalogue contained 1000 objects which were found between September 7, 1783 and April 26, 1785. The next catalogue also contained 1000 objects, found between April 26, 1785 and December 3, 1788 while the third catalogue contained 510 objects found between December 3, 1788 and September 30, 1802. Most of the objects were found between 1784 and 1790.

William observed from several places including Bath, then Datchet after August 1782, Clay Hall after June 1785 and Slough (near Windsor) from April 1786, using a large 18.5-inch aperture telescope. During most of these years, Sir William Herschel was supported by King George III of England.

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[20] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/herschel_w.htm>, accessed 3 August, 2006.

[21] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/herschel_c.htm>, accessed 3 August, 2006.

Herschel divided his objects into 8 classes as shown in Table 1.3.

Table 1.3: Number of Each Type of Object Found by William Herschel

Type	Number of Objects
I bright nebulae	288
II faint nebulae	910
III very faint nebulae	985
IV planetary nebulae	78
V very large nebulae	52
VI very compressed and rich clusters	42
VII compressed clusters of mixed magnitude	67
VIII coarsely scattered clusters	88
Total	**2510**

Herschel tended to miss large open clusters with his 18.5-inch aperture telescope because it had a small field of view. Later he ignored them.[22] Only 40 of the type IV objects proved to be planetary nebulae, not 78 as he thought. Thirty of the 2510 objects were in the southern part of the sky that Dunlop later surveyed (south of Declination –28°), the most southerly being at Declination –35°. Dunlop only saw seven of these southern Herschel objects. William Herschel's original discoveries included 2135 galaxies, 158 open clusters, 42 nebulae, 38 globular clusters and 35 planetary nebulae.

Caroline Herschel assisted her brother William and independently found 9 open clusters and 2 galaxies, including the magnificent galaxy NGC 253, between 1783 and 1787.[23]

By October 1802 the sky north of Declination –30° had been thoroughly explored by Messier, Méchain and William Herschel while the far southern sky had only been examined by Lacaille with a small 0.5-inch aperture telescope. The southern region was yet to be systematically explored by James Dunlop and John Herschel.

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[22] He thought at first that all objects were made of stars. When he found that some were made of gas he lost interest in recording open clusters. See Section 4.3.1.

[23] Caroline Herschel's Deep Sky Objects, <http://www.seds.org/messier/xtra/similar/cher.html>, accessed 31 July, 2006.

1.5 JAMES DUNLOP

Plate 1.6: James Dunlop[24] produced the first major catalogue of southern non-stellar objects in 1826.

The Scotsman James Dunlop (1793-1848) produced a catalogue of 629 southern nebulae and clusters, between April 27, 1826 and November 30, 1826 using a 9-inch aperture telescope at Parramatta, NSW. Dunlop produced a much longer list of objects than Messier despite the fact that he searched a smaller area of sky. Originally it seemed a great success, but Sir John Herschel was able to find only 211 of the 629 objects in Dunlop's *A Catalogue of Nebulae and Clusters of Stars in the Southern Hemisphere observed in New South Wales*.[25] Herschel admitted however that he did not attempt to observe all of the 629 objects. Not counting the Lacaille objects, there were 196 Dunlop objects included in John Herschel's catalogue.

Why were there so many missing objects from the Dunlop catalogue? This thesis will show that Dunlop actually found many more objects than John Herschel attributed to him, including a number of objects that are not in the NGC. The remainder of his 629 objects are mainly asterisms, faint double stars and repeat observations. According to Wolfgang Steinicke,[26] Dunlop was the first to see 225 NGC objects, including 95 open clusters, 46 galaxies, 41 globular clusters, 39 nebulae and 4 planetary nebulae. This thesis credits Dunlop with the discovery of 310 objects, including 36 possible Dunlop objects, as listed by type in Table 6.1. Dunlop may have seen the objects listed as possible, but this is not certain.

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[24] State Library of NSW, *The Picture Gallery*, 2006, <http://www.sl.nsw.gov.au/exhibitions/picture2/4.cfm>, accessed 3 August, 2006.

[25] James Dunlop, 'A Catalogue of Nebulae and Clusters of Stars in the Southern Hemisphere observed in New South Wales', *Philosophical Transactions of the Royal Society*, Vol. 118, 1828, p. 113-151.

[26] Wolfgang Steinicke, Astronomy, *Historic NGC – Explanation*, 2008, <http://www.klima-luft.de/steinicke/index_e.htm>, accessed 3 August 2008.

1.6 JOHN HERSCHEL

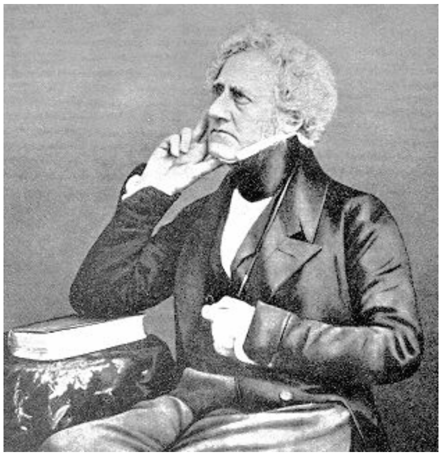

Plate 1.7: John Frederick William Herschel[27] was the first to catalogue more than 1000 southern non-stellar objects.

Sir John Frederick William Herschel (1792-1871), the only child of Sir William Herschel, was the third person to search for southern non-stellar objects. He started by re-observing 1781 of his father's 2518[28] northern objects from Slough, England and in the process discovered 525[29] new objects. Next he catalogued 1708, mainly southern objects, from Claremont near Cape Town, South Africa, between March 5, 1834 and January 22, 1838 using his father's 18.5-inch[30] aperture telescope.

Over 300 of these objects were in the Large Magellanic Cloud (LMC) where he sometimes gave several numbers to a single large object. In the LMC Dunlop found 37 open clusters, 25 globular clusters and 22 nebulae and Herschel found a further 136 open clusters, 50 globular clusters and 49 nebulae.

In the Small Magellanic Cloud (SMC) Dunlop found 5 open clusters, 3 globular clusters and 8 nebulae. Herschel found another 15 open clusters, 1 globular cluster and 2 nebulae.

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[27] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/herschel_j.htm>, accessed 3 August, 2006.

[28] Sir John found 8 objects that his father had seen but not included in his lists of 2510 objects.

[29] Bob Erdmann credits him with 605 objects north of Declination –25° and 1148 objects south of –25°.

[30] Sir John called it an 18.25-inch telescope, but William called it an 18.75-inch telescope.

In both Magellanic Clouds, Dunlop found a total of 100 objects and John Herschel discovered an additional 253 objects, often by giving several numbers to an object that had only one Dunlop number.

John Herschel completed the first major survey of the whole sky with a large telescope in 1838. His catalogue made at Cape Town, *Results of Astronomical Observations made during the years 1834, 5, 6, 7, 8 at the Cape of Good Hope, being a completion of a telescopic survey of the whole surface of the visible heavens commenced in 1825* (Cape Catalogue) included 1708 clusters and nebula and 3183 double stars.

Most of the bright non-stellar objects were now catalogued.

1.7 SUMMARY

The number of non-stellar objects included in the catalogues compiled by each of the above six observers is shown in Table 1.4. It includes non-stellar objects from both the northern and southern hemispheres. Messier and Méchain worked closely together and are listed together in Table 1.4 because, although Méchain did not produce his own catalogue, his discoveries were included in the Messier catalogue.

Three of the six astronomers observed from the southern hemisphere, two in Africa and one in Australia. These three, Nicolas-Louis de La Caille, James Dunlop and John Herschel, and the catalogues of non-stellar objects they produced, are discussed in greater detail in the following chapters.

Table 1.4: Number of non-stellar objects catalogued by six early observers.

Years	Observer	Number	Location
1751-1752	Lacaille	42	Cape Town
1758-1782	Messier & Méchain	109	Paris
1783-1802	W Herschel	2518	London
1826	Dunlop	629	Sydney
1825-1833	J Herschel	525	London
1834-1838	J Herschel	1708*	Cape Town

* Includes 135 William Herschel and 206 Dunlop objects according to Herschel.

The major early catalogues of the southern sky, up to the time of John Herschel were:

1. Edmond Halley (1656-1742) made a catalogue of 341 stars from St Helena between 1676 and 1678.
2. Nicolas-Louis de La Caille (1713-1762) made a catalogue of 9776 stars and a catalogue of 42 nebulae and clusters from Cape Town in 1751 and 1752.
3. Sir Thomas Makdougall Brisbane (1773-1860) made a catalogue of 7385 stars between 1822 and 1825 with help from Charles Rümker and James Dunlop.
4. James Dunlop (1795-1848) made a catalogue of 629 clusters and nebulae and a catalogue of 253 double stars from Sydney in1826.
5. Sir John Herschel made the last major visual catalogue of 1708 southern nebulae and clusters and he also catalogued double stars from the Cape between 1834 and 1838.

According to *The Historic NGC*[31] there are 1248 NGC clusters, nebulae and galaxies south of Declination –30.0^o. Four men were the first to record most of these objects: John Herschel (982 objects), James Dunlop (223), Nicolas-Louis Lacaille (20) and William Herschel (13). A summary of the 1248 NGC objects, by type of object, and their first observer is found in Table 1.5.

Table 1.5: NGC objects found before 1838 south of Declination –30^o.

Discoverer	**Years**	**OC**	**GC**	**Neb**	**PN**	**Gxy**	**Total**
John Herschel	1834-1838	263	9	43	16	651	982
James Dunlop	1826	120	28	25	4	46	223
Nicolas-Louis de La Caille	1751-1752	14	4	2			20
William Herschel	1784-1793	3	4			6	13
Charles Messier	1771-1780		4				4
Giovanni Hodierna	Before 1654	2					2
Amerigo Vespucci	1501					1	1
Claudius Ptolemäus	138 B.C.	1					1
Edmond Halley	1677		1				1
Niccolò Cacciatore	1826		1				1
Total		**403**	**51**	**70**	**20**	**704**	**1248**

The next two southern catalogues were made after the NGC was published in 1888. Between 1898 and 1905 DeLisle Stewart and Royal Frost[32] each made catalogues by taking and analysing 4-hour photographic plates using the Harvard 24-inch 11.2-foot focal length refractor at Arequipa, Peru. Their observations were published as part of the Index Catalogue (IC) which contains 830 clusters, nebulae and galaxies south of Declination –30^o.

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[31] Historic and modern NGC/IC data, *The Historic NGC*, 2009, <www.klima-luft.de/steinicke/ngcic/Expl_Hist_NGC.htm>, accessed 13 December, 2009.

[32] 'Nebulae discovered at the Harvard College Observatory', *Annals of Harvard College Observatory*, Vol. 60, 1908, p. 151-192.

CHAPTER 2 – NICOLAS-LOUIS de La CAILLE, a Precursor to the Work of Dunlop

2.1 LIFE SKETCH OF LACAILLE (1713-1762)

Plate 2.1: Monument to Lacaille at his birthplace in Rumigny, France.[33]

Biographical information in the following sections on Lacaille's life was principally obtained from the book *Lacaille: Astronomer, Traveler*, by David S Evans[34]. Previous to Nicolas-Louis de La Caille, Edmond Halley (1656 – 1742) catalogued 341 stars from the island of St Helena in the Atlantic Ocean (15°55'S, 5°44'W). He completed this catalogue in 1677. Halley's interest was not just astronomy. It also included the major problem of the time which was navigating at sea. His star catalogue was designed to help in this regard. In 1714 the British Board for the Discovery of Longitude offered prize money of £20,000 for an accurate method for measuring longitude at sea. Although Evans indicates that Lacaille was not interested in personal wealth, his prize may have provided some impetus for Lacaille, as for the next 47 years there was competition amongst astronomers until the money was finally awarded.

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[33] G Cozens, 2006.

[34] David S. Evans, *Lacaille: Astronomer, Traveler*, Tucson, 1992,

Lacaille's father, Charles Lewis La Caille (1679-1731) and his mother Barbe Rebuy had 10 children, 6 daughters and 4 sons. Six children died young, three girls and three boys. The other 3 girls become nuns and Nicolas-Louis became an astronomer.

Plate 2.2: Location of Lacaille's house at Rumigny.[35] The current building was erected in 1825.

Nicolas-Louis de La Caille was born in March or December 1713 at Rumigny (65 km north of Reims and 175 km NE of Paris), France. His education began with his mechanically minded father tutoring him. At age sixteen, Nicolas-Louis attended the college of Mantes-sur-Seine, where he studied humanities. He studied rhetoric for the next two years in Paris, but his interests included history, antiquities, mythology and Latin poetry. His father's death when he was eighteen left Nicolas-Louis with large debts. After completing his philosophical studies in Paris, he went on to three years of theology, intending to become a priest.

It was during his theological studies that Lacaille became interested in mathematics, especially Euclid's *Elements*, which he studied on his own. He also taught himself astronomy. Lacaille passed his examinations with distinction, but when he failed to answer the Vice-Chancellor's questions satisfactorily, he was denied his Master of Arts, and this turned him from theology. He was never ordained.

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[35] G Cozens, 2006.

Plate 2.3: Collège Mazarin, now the Institut de France,[36] where Lacaille studied and later taught, and a satellite image showing its location across the Seine River from the Louvre.[37]

Lacaille spent the next year at Paris Observatory working with Cassini II and Maraldi II. For some reason, Lacaille lost the esteem of Cassini II, but in July 1739, Lacaille and Cassini III began a geodetic survey of a 930 km long meridian from Perpignan, on the French Mediterranean Coast (near Spain) to Dunkirk on the English Channel, to establish the circumference of the earth. Their results were published as *Le Méridien de l'Observatoire Royal de Paris*, in 1744. Later Lacaille moved to the Collège Mazarin (Plate 2.3) where he studied the earth's orbit, parallaxes, planetary orbits, comets and stars. He also wrote textbooks on mathematics, practical astronomy, mechanics and optics for the college. It was during this time that Lacaille became interested in the work of Father Feuillée who observed from the Canary Islands in 1724. This probably inspired his later trip (1751-1754) to the Cape of Good Hope.

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[36] G Cozens, 2006.

[37] Google Earth, *Digital Globe*, 2006.

2.2 LACAILLE'S WORK IN THE SOUTHERN HEMISPHERE

Lacaille set himself several goals for his stay in the southern hemisphere. He wanted to find the exact positions of the fixed stars, especially first, second and third magnitude stars near the ecliptic; the length of a simple seconds pendulum to provide a value for gravity at that location and hence information on the shape of the Earth; the longitude and latitude of important places, especially Cape Town; measure an arc of the meridian; and measure the parallaxes of the Moon, Mars and Venus which he did in conjunction with astronomers in Europe.[38] Lacaille made plans with other astronomers for simultaneous observations of solar system objects to determine their distances from the Earth, before he left for the Cape.

The authorities at the Cape were reluctant at first to allow Lacaille to observe there, because he was a French Catholic, while they were Dutch Protestants. Previously there were problems with a German astronomer, Peter Kolbe who had invented false stories against these authorities. However, Lacaille left Paris on October 20, 1750 and sailed from L'Orient on November 21, 1750 on *Le Glorieux*. His trip was to span three years and eight months.

The ship was uncertain of its position on the way from France to Africa, but a lunar eclipse on December 13, 1750 (totality from 5:30 to 7:11 UT) showed they were 4^{o} off course. They stayed at Rio de Janeiro from January 25 to February 25, 1751 where Lacaille did experiments on magnetism and pendulums. He also determined Rio de Janeiro's longitude using the moon's position with respect to the stars as an accurate clock. *Le Glorieux* arrived off Cape Town on April 19, and Lacaille presented himself to the governor the next day. A leading citizen by the name of Bestbier gave Lacaille the use of his house. He spent the next six weeks in May and June constructing an observatory.

2.2.1 LACAILLE'S OBSERVATORY

Lacaille's observatory was at the lower end of Strand St, in Cape Town behind Jan Lourens Bestbier's house. The governor, Ryk Tulbagh helped with the building of the observatory, which was only 2.5 metres above sea level. A commemorative plaque, seen in Plate 2.4, was placed near the site of Lacaille's observatory.

The observatory was a 4.1 m square with the corners pointing north, east, south and west and the instruments were set out as shown in Figure 2.1. The sector was placed on the western pedestal, the sextant on the eastern pedestal and the quadrant on the northern pedestal. A bed,

[38] Evans, *Lacaille*, pp. 78, 81.

table and chairs filled the southern part of the crowded room. The door was near the southern corner on the western side and there was a window in the southeast wall. The wooden roof was covered with a tarpaulin.

On this site L'Abbe De LaCaille carried out his astronomical observations in the years 1751 – 1752 A.D.

Plate 2.4: The plaque and its wording, on Strand St, Cape Town, near the site of Lacaille's observatory. [39]

2.2.2 INSTRUMENTS IN LACAILLE'S OBSERVATORY

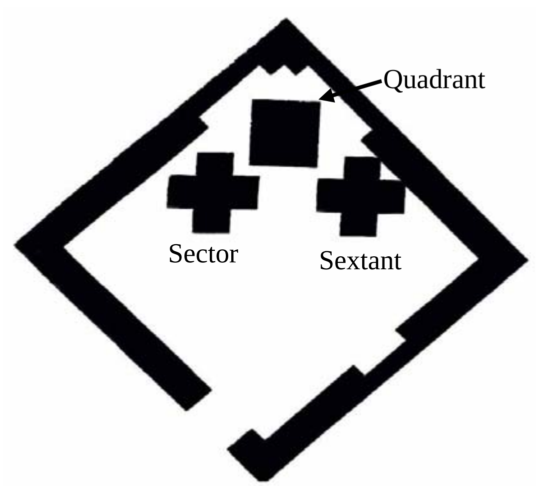

Figure 2.1: Plan of Lacaille's 1751 observatory on Strand St, Cape Town, showing the location of the instruments.[40]

The instruments used in Lacaille's observatory are listed below:

1. A sector, with 1.95 m radius.

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[39] Astronomical Society of Southern Africa, *Lacaille Photo Gallery*, 2006, <http://www.saao.ac.za/assa/html/his-astr-lacaille-gallery.html>, accessed 7 August, 2006.

[40] Evans, *Lacaille*, p. 112.

2. A sextant, with 1.95 m radius, which was equipped with two telescopes perpendicular to each other. The focal lengths of the telescopes were 2.11 m and 1.79 m. The observations for the determination of refraction were apparently made with the sextant.
3. A quadrant, of 0.97 m radius with a telescope attached. This was the main instrument used for the star catalogue.
4. A clock made by Julien le Roy.
5. Telescopes of various sizes, with focal lengths 14, 15 and 18 feet. Unfortunately their apertures are not known. The 14-foot telescope was used to examine parts of the Milky Way and the Magellanic clouds.

Lacaille's aim was to replace the catalogue of 341 southern stars made by Edmund Halley in 1677 with a better one. He used a quadrant telescope, 75.7 cm in length with a three degree field of view to make his star catalogue. The observations for the star catalogue were made "with a clock regulated to the revolutions of the stars and with a telescope equipped with different reticles. This telescope had a length of 32 pouces [866 mm]. It was applied parallel to the fixed telescope of a quadrant of 3 pieds [974 mm] radius, very heavy and of a very solid construction. The object glass of the telescope had a focal length of 26 pouces 3 1/8 lignes [712 mm]: its aperture was 6 lignes [13.5 mm]. The focal length of the eyepiece was 3 pouces and 3 lignes [88 mm] to give the telescope an extended field, very clear, and free from parallaxes at its edges. The field was almost 3 degrees."[41] This gave eight times magnification.

An expert workman by the name of Poitevin maintained and modified the instruments.

2.2.3 OBSERVATIONS

The weather in Cape Town was much better than in Europe. Lacaille categorised the year's weather as follows: one fifth was cloudy, one fifth variable, one fifth calm and clear, and the remaining two fifths were clear with a strong, south-easterly wind (September to March).[42]

Because of the strong winds, Lacaille viewed through a 10 cm opening in the roof of his observatory. The proposed catalogue required one hundred nights of uninterrupted viewing, for six hours at a time, to complete. Each clear night he observed a section of sky covering 6 h in Right Ascension and 2.7^{o} in Declination. Two bright stars were observed during each session to establish accurate positions for the fainter stars in the catalogue. "He used a clock star, usually Sirius, to check on the performance of his clock. He always observed a reference star for which

[41] Evans, *Lacaille*, p. 118.

[42] Evans, *Lacaille*, p. 82.

the Right Ascension had been determined by observations of corresponding altitudes on the same or nearby day…. The clock was illuminated by a feeble light provided by a dark lantern placed opposite."[43] "As soon as a star entered or left the plates of the reticle, the observer, closing his right eye, which was only used to look in the telescope, and keeping his left eye open, turned a little to present a little paper to the light of the dark lantern at the clock. He recorded his observation on it and quickly returned to the telescope."[44]

To systematically cover the whole area, Lacaille divided the sky into twenty-five zones, between the south celestial pole and the Tropic of Capricorn (23°18'16"S). The stars' positions were determined using a clock and four different copper rhomboid reticles in his telescope. The first was used for zones 1 and 2 near the pole; the second, the small reticle (35 mm in diameter) was used for zones 3 to 7; the third, the large reticle (70 mm in diameter) was used for zones 8 to 21 and the fourth (also 70 mm in diameter but reversed) was used for zones 22 to 25 which were north of the zenith. Silk threads formed a cross in the middle of the rhomboid field, as shown in Figure 2.2.

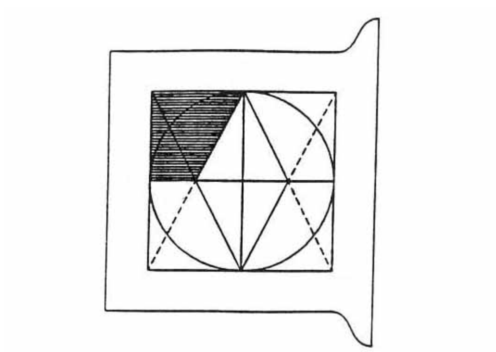

Figure 2.2: A diagram of the large reticle, one of four used to make the star catalogue. Different reticles were used for different Declination zones of the sky.[45]

Lacaille began observing in June 1751 but discovered errors in his observations made between June 1 and August 21, 1751 and these objects were re-observed. He started again on August 23, 1751 and by July 18, 1752 had catalogued all the stars he could easily see, totalling 10,035. This took 100 sweeps and 76 nights. It can be estimated that Lacaille was observing to approximately magnitude 7.7 when the total number of stars is compared with the 1997 Hipparcos-Tycho

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[43] Evans, *Lacaille*, p. 121.

[44] Evans, *Lacaille*, p. 122.

[45] Evans, *Lacaille*, p. 112.

catalogue[46] which contains 9,409 stars to magnitude 7.6 and 10,353 stars to magnitude 7.7 south of Declination –23°. The formula m = 9.1 + 5logD in inches[47] gives Lacaille's half-inch aperture telescope a limiting magnitude of 7.6 which corresponds well with the estimate from the Hipparcos catalogue. Some would argue for a magnitude limit of 9.0 for a half-inch aperture[48] but a magnitude limit of 7.6 is probably more realistic.

2.2.4 PUBLICATION OF THE LACAILLE STAR CATALOGUES

Lacaille's raw observations of 10,035 stars were published in two parts. He reduced the data for eleven of the twenty-five zones, namely zones 6-16 (Declination 47° to 77° south), and produced a catalogue of 1942 naked eye stars to an estimated magnitude limit of 6.8. (The Hipparcos Catalogue has 1858 stars to magnitude 6.8 in this Declination range.) The first catalogue containing 1942 bright stars was published posthumously in 1763, a year after Lacaille died, as *Coelum Australe Stelliferum.* It was edited by J D Maraldi. "The remaining stars were reduced in 1844 and published as *A Catalogue of 9766 Stars in the Southern Hemisphere for the Beginning of the Year 1750 from observations of Lacaille* in 1847,"[49] eighty-five years after his death.[50] This was decades after Brisbane completed his Parramatta catalogue. The British Association for the Advancement of Science paid £200 for Lacaille's second publication. A Mr Wallace did the reductions and John Herschel wrote the preface.

2.2.5 SOUTHERN CONSTELLATIONS DEFINED BY LACAILLE

Lacaille constructed a chart before leaving the Cape that introduced fourteen new constellations. He placed 1,000 stars in his fourteen new constellations and rejected a constellation called *Robur Carolinum* (Charles' Oak), which Edmond Halley had introduced in 1677 "to pay homage to the king of England."[51] This was because nine of its twelve stars were already in ancient catalogues. Maybe French English rivalry also paid a part.

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46 European Space Agency, ESA, *The Hipparcos and Tycho Catalogues*, 1997, <http://vizier.u-strasbg.fr/cgi-bin/VizieR?-source=I/239>, accessed 20 October, 2006. These catalogues are complete to magnitude 7.3 and 11.0 respectively.

47 J.B. Sidgwick, *Amateur Astronomer's Handbook*, London, 1961, p. 27.

48 Bradley Schaefer, 'Telescopic Limiting Magnitudes', *Publications of the Astronomical Society of the Pacific*, vol 102, 1990, p. 212-229. To calculate the limiting magnitude for any telescope, see Schaefer's internet site, *Determining the Limiting Magnitude of a Telescope*, 1998, <http://www.go.ednet.ns.ca/~larry/astro/maglimit.html>, accessed 16 November, 2006.

49 Evans, *Lacaille*, p. 125.

50 A copy of this catalogue can be found at the web address for the *Service Bibliothèque de l'Observatoire de la Côte d'Azur* at <http://www.obs-nice.fr/biblioca/Sommaireanglaishtml.html>, accessed 3 August, 2006.

51 Evans, *Lacaille*, p. 130.

The New Constellations were:

1. Apparatus Sculptoris (the Sculptor's Tools)
2. Fornax Chemica (the Chemical Furnace)
3. Horologium (the Clock)
4. Reticulus Rhomboidalis (the Rhomboidal Net)
5. Caela Sculptoris (the Sculptor's Chisel)
6. Equuleus Pictoris (the Painter's Easel)
7. Pyxis Nautica (the Mariner's Compass)
8. Antlia Pneumatica (the Air-Pump)
9. Octans (the Octant)
10. Circinus (the Compasses)
11. Norma, alias Quadrans Euclidus' (Euclid's Square)
12. Telescopium (the Telescope)
13. Microscopium (the Microscope)
14. Mons Mensae (Table Mountain)

2.2.6 OBSERVATIONS OF NEBULAE AND CLUSTERS

While determining the positions of stars for his catalogue, Lacaille also noted the positions of some double stars and nebula. He produced a catalogue of 42 nebulae, which was published in 1755 on his return to France in *Memoires de l'Academie Royale des Sciences*, 1755, pp 286 – 296.

The following is an extract from his journal article, *Sur les étoiles nébuleuses du Ciel Austral* or *On the Nebulous Stars of the Southern Sky* by L'Abbé de La Caille. (See Appendices A and B)

> "The Stars which are called nebulous offer to the eyes of Observers so varied a spectacle that their exact and detailed description could occupy an Astronomer for a long time and cause philosophers to make many curious reflections. As strange as are those nebulae that we can see in Europe, those that are in the vicinity of the southern Pole concede them nothing either in number or form. I am going to outline here an account and a list: this essay may help those who have the equipment and leisure to study them with long telescopes. I would have greatly wished to give something more detailed and instructive for this article but, other than ordinary telescopes of 15 to 18 feet [4.57 m to 5.49 m] focal length, those that I had at the Cape of Good Hope were not adequate or convenient for this kind of research. Those who would take the trouble to examine what occupied me during my visit to that country will easily see that I did not have enough time to make these kinds of observations.
>
> "I first observe that three kinds of nebulae can be distinguished in the heavens; the first is no more than a whitish, ill-defined area, more or less luminous and of a very irregular shape: these patches are quite similar to the nuclei of faint, tail-less comets. [Most turned out to be globular clusters.]

“The second class of nebulae comprises Stars which are only nebulous in appearance to the naked eye, but when seen in the telescope, show up as a cluster of distinct Stars, although very close to each other. [Usually open clusters.]

“The third class is that of Stars which are actually accompanied by or surrounded with white patches or by nebulae of the first class.

“I have found a large number of these three types of nebulae in the southern part of the sky but I do not flatter myself that I have observed them all; especially those of the first and third classes, because they can scarcely be seen except out of the twilight and in the absence of the Moon. However, I believe that the list I give here is passably complete in regard to the more outstanding in these three classes.

“In frequent examination with a 14-foot [4.27 m] telescope of the areas of the milky way where its whiteness is most noticeable, and comparing them with the two clouds commonly called the Magellanic Clouds and which the Dutch and the Danes call the Clouds of the Cape, it is obvious that the white portions of the sky resemble one another so perfectly that one believes, without too much conjecture, that they are of the same nature, or, if you like, that these clouds are no more than detached portions of the milky way which are themselves composed merely of parts often interrupted. It is not certain that the whiteness of these portions could be caused, as is commonly supposed, by clusters of small Stars, more closely packed than in other parts of the sky, for with such attention as I have observed the better defined extremities, whether of the milky way or of the clouds, I have not seen anything there with a 14-foot telescope, other than a whiteness against the background of the sky, without seeing there more stars than elsewhere, where the background becomes darker.

“I will not venture further than to suggest that the nebulae of the first class are no more than small portions of the Milky Way, spread throughout different regions of the sky and that the nebulae of the third class are only Stars which are found relative to us, in a straight line as we observe these luminous patches.

“The list which I am going to give here is an extract from the Catalogue of Southern Stars which I put before the Academy: I was not able to distinguish in the Catalogue, the different nebulae except by brief notes which are explained in the discourse which I have included here; but in order to satisfy the curiosity of those who may find these notes too vague, I will give here a short description of each nebula in particular.”[52]

A list of the 42 objects in this catalogue can be found in Section 2.7.

[52] Jones, *Search for Nebulae*, p. 45.

2.2.7 OTHER ASTRONOMICAL OBSERVATIONS BY LACAILLE

2.2.7.1 Diameter of the Earth

With his star catalogue completed, Lacaille turned his attention to measuring an arc of the meridian, to determine the shape of the Earth. Between September 9 and October 23, 1752, Lacaille measured an arc 135.8 km long with the southern end at his Cape Town observatory and the northern end at Klipfontein (the modern town of Aurora). This involved measuring the angles in two large triangles and two small triangles and also measuring the altitude of stars from the two ends of the arc, as shown in Figure 2.3.

Lacaille took two friends, two wagons, one drawn by six horses and the other by ten oxen, and eight slaves with him. From Klipfontein on September 24, he measured the angles to two signal fires on two mountains, Riebeek Kasteel (NE of Malmesbury) and Kapokberg (on the southern edge of Darling). On October 14, from Riebeek Kasteel Mountain, he measured the angle to a fire at Klipfontein and also the angle to his observatory at Cape Town. On October 16, Lacaille made similar measurements from Kapokberg Mountain to Klipfontein and Cape Town. Between October 17 and 21, he measured a base line 12.6 km long across flat ground just north of Kapokberg using pine rods 5.85 m long. He also measured the angles from the eastern and western ends of this line to Kapokberg and Riebeek Kasteel.

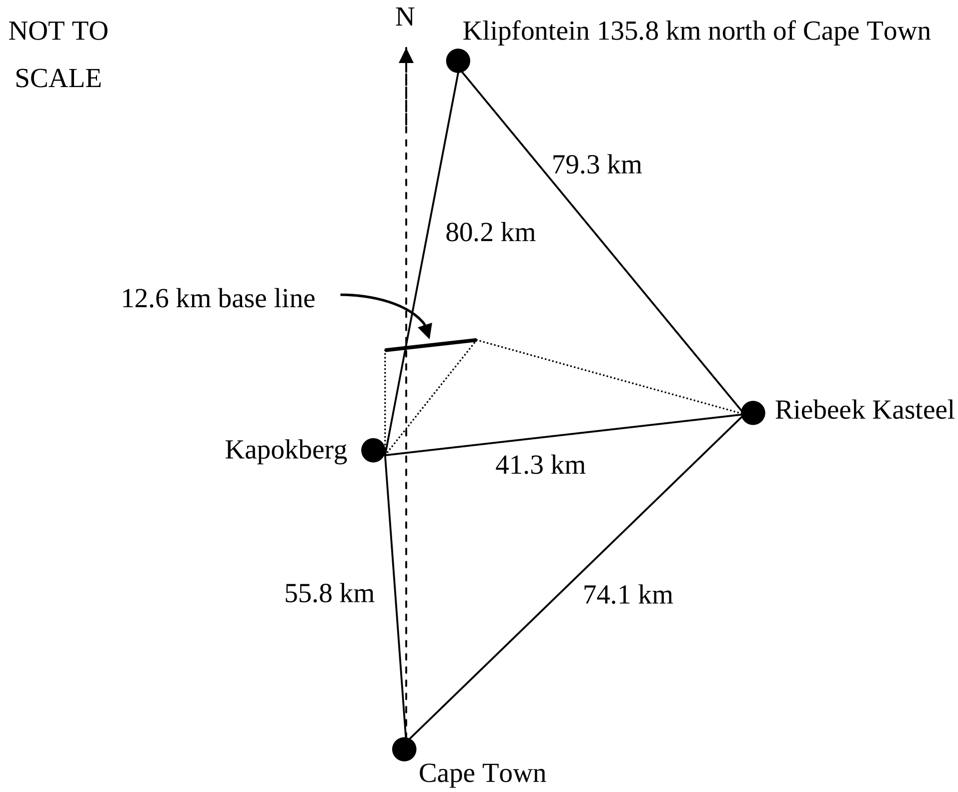

Figure 2.3: Lacaille's arc of the meridian triangles.

By measuring the angular altitude of stars he calculated that the celestial angle between Cape Town and Klipfontein was 1°13’17.3” and this meant that one degree equalled 111.165 km. Klipfontein was 5.1 km east of the meridian line through Cape Town. Plate 2.5 contains recent satellite images of the places where the four vertices of the triangles were located.

Northern end of arc, Klipfontein/Aurora

West, Kapokberg south of Darling

East, Riebeek Kasteel

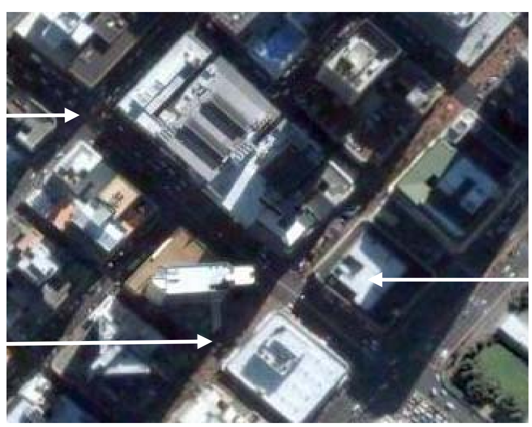

Plate 2.5: Satellite photographs of the vertices of the meridian triangles.[53]

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[53] Google Earth, *Digital Globe,* 2006.

When Lacaille arrived back at Cape Town, he discovered that the arc was not in accordance with northern hemisphere measurements. His measurements incorrectly indicated that the Earth is pear-shaped. He decided there was no error in the six angles of the two large triangles, so he suspected an error in the base line. He remeasured it on November 3 with a chord 58.5 m long but found no error. However his problem primarily arose from the mountain's effect on his plumb line, as first suggested by the surveyor Colonel Sir George Everest. Everest arrived "at an estimate that the sums of the deviations of the plumb-line at Lacaille's two stations must be 8".99"[54] due to the presence of Table Mountain, Devil's Peak and Lion's Head. Lacaille's meridian length was also later (1841) confirmed to be in error when Maclear from the Royal Observatory at the Cape found a difference of 36 m in the 135.8 km arc from Cape Town to Klipfontein. "He thus verifies Everest's total effect of the plumb line deviations but attributes the greater part to the close mountains at Klipfontein not to Table Mountain."[55] Sir Thomas Brisbane also planned to measure an arc of the meridian when he came to Australia in 1821 (see Section 3.2.1). Modern measurements give the earth's average radius as 6367.44 km, making one degree equal to 111.133 km.

2.2.7.2 Longitude at Sea

Another of Lacaille's goals was to determine longitude at sea using the moon's motion through the stars. Sailing ships leaving coastal waters needed to navigate in open oceans. This prompted the British to offer £20,000 for an accurate method for measuring longitude at sea.

Several people suggested using the moon's motion through the stars, including Sieur de St. Pierre (1674), Bouguer and Halley. Lacaille adapted Halley's suggestion for finding longitude using the moon's position with respect to bright stars. "The moon makes a circuit of the sky with respect to the star background in 27.322 days."[56] This can be used to "establish the longitude with an uncertainty equal to the rotation of the Earth in two minutes, that is, half a degree or roughly 30 nautical miles on the equator."[57] There were two major problems: neither the star positions nor the motion of the moon were known with sufficient precision to make the method workable. Two more complications had to be considered: the moon's position varies depending on the observer's location on earth and the moon's position varies depending on its distance from the earth. Lacaille studied refraction, made star catalogues and observed the

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[54] Evans, *Lacaille*, p. 152.

[55] Evans, *Lacaille*, p. 162.

[56] Evans, *Lacaille*, p. 167.

[57] Evans, *Lacaille*, p. 167.

moon's orbit in an attempt to solve these problems. He used a graphical method to make it easier for ship's captains to calculate their longitude.

In 1761, just one year before Lacaille died, John Harrison introduced the marine chronometer which he developed over many decades and this gradually made the lunar method of determining longitude obsolete. With this invention, longitude could be accurately measured at sea, and Harrison received the £20,000 prize money. However the high cost of chronometers meant the lunar method of determining longitude was still used for many years.

2.2.7.3 Cartography

Lacaille left Cape Town on March 8, 1753 and arrived at Mauritius on April 18, 1753. While on the voyage he tested his new method for determining longitude at sea, using the distance of stars from the moon. During the next nine months he made an accurate map of the coastline of Mauritius. On January 16, 1754 Lacaille sailed to the nearby island of Réunion where he made longitude and latitude determinations from January 17 until February 27, 1754. On his return voyage to France, Lacaille visited Ascension Island (St Helena) from April 15 to 20, 1754. This was the place where Halley made his star catalogue in 1677. Lacaille arrived back in L'Orient, France on June 4, 1754.

2.3 LACAILLE'S WORK BACK IN FRANCE

The next few years were spent working with his observations from the Cape and in revising his textbooks on mathematics, astronomy and optics. "In 1759 he wrote up his graphical method for the determination of the longitude at sea, by the method of 'lunars,' that is the position of the moon with respect to certain bright stars."[58]

In February 1762 Lacaille had a recurrence of an illness which he experienced at the Cape. On March 19 he was bled by a physician but died on March 21, aged 49, probably as a result of the bleeding. He was buried at the Collège Mazarin in Paris, but his remains were later moved.

Lacaille is honoured by a monument at Rumigny, by a plaque in Cape Town and by a bas-relief bust at Curepipe in Mauritius. Two streets were also named after him, one in Cape Town and one in Mauritius.

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[58] Evans, *Lacaille*, p. 51.

CHAPTER 3 - JAMES DUNLOP, Messier of the Southern Hemisphere

3.1 LIFE SKETCH OF DUNLOP[59] (1793 – 1848)

Plate 3.1: James Dunlop (1793-1848).[60]

Biographical information in the following section on James Dunlop's life was primarily obtained from the work by John Service, James Dunlop's nephew.

3.1.1 EARLY LIFE IN SCOTLAND 1793 – 1821

James Dunlop was born at Dalry (34 km south-west of Glasgow, Scotland) on October 31, 1793 six years after Australia became a convict settlement. His father John was a handloom weaver. John and his wife Janet Boyle had seven children, James being the fourth child. In 1819 his

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[59] A biography of James Dunlop was written by John Service. His father, Dr David Dunlop Service, was James Dunlop's nephew. John Service came to Australia in January 1884.
John Service, *Thir Notandums*... to which is appended a Biographical Sketch of James Dunlop, Edinburgh, 1890, p. 163.

[60] State Library of NSW, The Picture Gallery, 2005, <http://www.sl.nsw.gov.au/exhibitions/picture2/4.cfm>, accessed 3 August, 2006.

father died after an eleven year illness and James left for Australia two years later. His mother, said to be a clever woman, died in 1830, three years after James returned to Scotland in 1827.

When James was fourteen years old he moved six kilometres to Beith where he lived with his father's twin brother, Robert, and worked for Mr Fauld in a thread factory. The locations of the towns where James lived and worked are underlined in Plate 3.2.

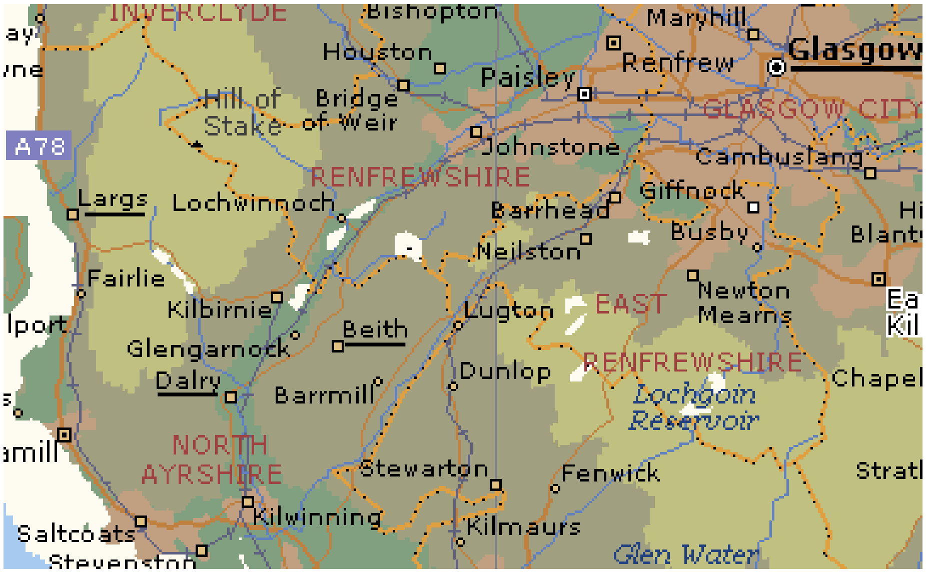

Plate 3.2: Map showing the area south-west of Glasgow including Largs where Brisbane built his observatory, Dalry where Dunlop was born and Beith where Dunlop worked.[61]

James was not well educated. His biographer, John Service notes, "He had been a short time at school in Dalry, and when he went to Beith, he attended a night-school in the Strand... But, beyond these meagre opportunities for education, he received no scholastic training whatever..."[62] James had a "natural aptitude and love"[63] for mechanics and "when he was seventeen years of age, he was constructing lathes and telescopes and casting reflectors for himself..."[64] He made a telescope four feet long and six or nine inches in diameter. The only help he received was from his 14 year old brother John, who sometimes held a candle for him.

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61 Microsoft, *Encarta Interactive World Atlas*, 2001, Version 10.00.00.0808, Software.

62 Service, *Notandums*, p. 134, 135.

63 Service, *Notandums*, p. 135.

64 Service, *Notandums*, p. 135.

James married his cousin Jean Service on June 25, 1816. They had no children. In 1818 James, aged 24, left his job as a warehouse foreman in Beith and returned to Dalry to become a handloom weaver like his father.[65]

The Patrick family of Trearne introduced James to Sir Thomas Brisbane (1773-1860) in 1820, which led to Dunlop's trip to Australia and his three catalogues of 7385 stars, 629 clusters and nebulae, and 253 double stars. Brisbane, a former soldier, was soon to become the sixth governor of NSW. He was interested in astronomy because of its value in navigation and time keeping. During his life Brisbane established three observatories; the first was built at Largs in 1808.[66] Plate 3.3 shows photographs of the remains of this observatory.

Plate 3.3: Remains of Brisbane's first observatory at Largs.[67]

Brisbane was planning to build his second observatory in NSW and employed Dunlop to care for and repair the mechanical appliances and instruments. He also employed a German, Christian Carl Ludwig (Charles Stargard) Rümker (1788-1862) as the astronomer and

[65] More information on handloom weavers' conditions and wages in the 1800s is at Spartacus Educational, <http://www.spartacus.schoolnet.co.uk/PRhandloom.htm>, accessed 28 November, 2006.

[66] K. Weitzenhoffer, 'General Thomas Brisbane's astronomical adventures', *Sky & Telescope*, 84, 1992, p. 620.

[67] G Cozens, 1998.

mathematician. Dunlop packed Brisbane's instruments and sailed from Leith (Edinburgh) on March 7, 1821 bound for London.

3.1.2 DUNLOP'S WORK IN AUSTRALIA – 1821-1827

On May 18, 1821 Brisbane aged 47, Rümker 33 and Dunlop 27 sailed from England on the *Royal George*. They arrived in Sydney five-and-a-half months later on November 7, 1821, having sailed via Rio de Janeiro in South America.

Brisbane built his observatory next to Government House at Parramatta. It was completed in April 1822[68] but observations began on March 11, 1822 according to Dunlop's letter of resignation dated August 18, 1847.[69] Plate 3.4 and Plate 3.5 are photographs of the remains of the observatory beside Government House. Both photographs show transit mounting stones, which were apparently erected just before Dunlop retired. An error in the placement of the obelisk was apparently made when it was erected in 1880.

Plate 3.4: Old Government House Parramatta, from the transit mounting stones.[70]

A discussion on the correct position of the original transit instrument can be found in Section 3.2.6.

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[68] Service, *Notandums*, p. 140.

[69] Service, *Notandums*, p. 197.

[70] G Cozens, 1987.

Plate 3.5: The obelisk marks the alleged position of the original transit instrument in the observatory, with a transit mounting in the foreground.[71]

The following satellite image, Plate 3.6 shows the locations of the observatory, Government House, Dunlop's house and St John's Church. Plate 3.7 gives a map of Sydney and Parramatta.

Plate 3.6: Satellite image of Parramatta showing the location of Brisbane's observatory, Government House, the site of Dunlop's house and observatory and St John's Church.[72]

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[71] G Cozens, 1987.

[72] Google Earth, *Digital Globe*, 2006.

Plate 3.7: Map showing Sydney and Parramatta (top left) 24 km to the west.[73]

One year later on June 16, 1823 Rümker left the observatory after several disputes with Brisbane. Up to this time Rümker had observed between 2000 and 2300 stars.[74] In the absence of Rümker, the untrained Dunlop continued making observations. Brisbane taught him to use the instruments and he completed *A Catalogue of 7385 Stars, chiefly in the Southern Hemisphere* (also called the Parramatta Catalogue) by March 2, 1826. Plate 3.8 is an image of the published catalogue.[75] This copy, signed by Brisbane, was advertised for $5500 in 2006.

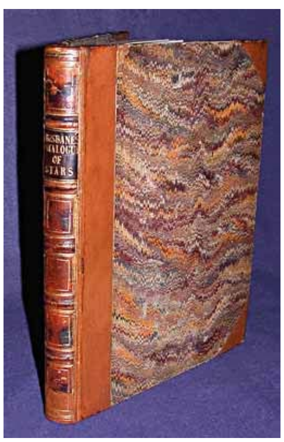

Plate 3.8: *A Catalogue of 7385 Stars, chiefly in the Southern Hemisphere*. This catalogue was produced by Brisbane from observations made by Dunlop and Rümker.[76]

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[73] Microsoft, *Encarta Interactive World Atlas*, 2001, Version 10.00.00.0808, Software.

[74] Service, *Notandums*, p. 186.

[75] William Richardson, *A Catalogue of 7385 Stars, chiefly in the Southern Hemisphere prepared from observations made in the years 1822, 1823, 1824, 1825 and 1826 at the observatory at Parramatta, New South Wales, founded by Lieutenant General Sir Thomas Makdougall Brisbane*, London, 1835.

[76] Hordern House, <http://www.hordern.com/stockimages/large/199406_456_01.jpg>, accessed 25 November, 2006.

Dunlop prepared star maps of the Large Magellanic Cloud (which he called Nebula Major), the Small Magellanic Cloud (which he called Nebula Minor), and the area around Eta Carinae (which he called Eta Argus) using the mural circle. Dunlop also started work on his double star catalogue in 1825. Prior to this he made preliminary catalogues of clusters and nebulae in 1824.

Brisbane returned to England on December 1, 1825[77] and Dunlop left the Parramatta Observatory with its accurate instruments and clocks on March 7, 1826, two months before Rümker's return on May 10, 1826. Dunlop moved to Mrs Elder's house on the north side of Hunter Street, Parramatta, half way between Marsden Street and St John's Church. The house no longer exists, however Plate 3.9 is a drawing of this house, and Plate 3.10 shows the white multi-storey building that replaced it, with St John’s church and its 1819 twin towers in the foreground.

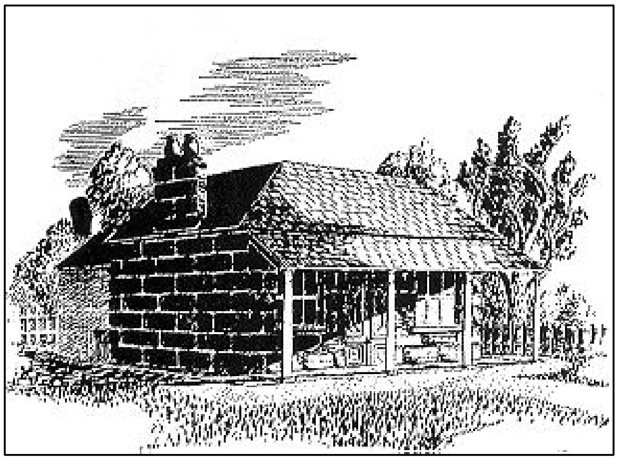

Plate 3.9: Dunlop catalogued clusters, nebulae and double stars with his 9-inch reflecting telescope from the back yard of this house, in 1826.[78]

Dunlop spent the first month or more watching a bright magnitude 6 comet (Comet Pons 1825 IV[79]) from this house (latitude 33.82°S and longitude 151.00°E). After this he produced two catalogues, the first of 629 clusters and nebulae and the second of 253 double stars. Dunlop

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[77] J. D. Heydon, 'Brisbane, Sir Thomas Makdougall (1773 - 1860)', Vol 1, Melbourne University Press, 1966, pp 151-155, in *Australian Dictionary of Biography – online edition*, 2006, <http://www.adb.online.anu.edu.au/biogs/A010141b.htm>, accessed 28 November, 2006.

[78] Collinridge Rivett, *Parramatta Bicentenary: Australia*, Parramatta, 1988, Illustration 27.

[79] Cacciatore discovered the globular cluster NGC 6541 in Corona Australis on March 19, 1826 probably near Comet Pons which passed 6541 on 28/3/1826. SEDS (Students for the Exploration and Development of Space), 2005, <http://www.seds.org/~spider/spider/MWGC/n6541.html>, accessed 28 November, 2006.

worked on the double star catalogue when the moon was bright. Full moons in 1826 occurred on May 22, June 20, July 19, August 18, September 16, October 16 and November 15. Concurrently he worked on the non-stellar catalogue on dark nights between April 27 and November 30, 1826.

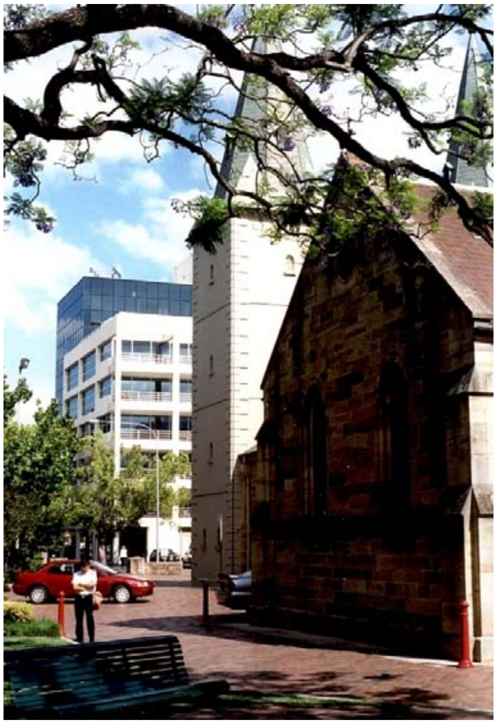

Plate 3.10: The white multi-storey building behind St John's Church was built on the site of Dunlop's house.[80]

On the first night, April 27, he observed four open clusters NGC 3532, IC 2714, Mel 105 and NGC 3766. Herschel missed two of these four objects and many others that Dunlop saw. Dunlop observed the Small Magellanic Cloud (SMC) on four nights between August 1 and September 6. The Large Magellanic Cloud (LMC) was studied on seven nights between August 3 and November 6. He observed three galaxies on November 24 namely NGC 1317, 1350 and 1365. On his last night, November 30, he saw the faint globular cluster NGC 2298.

Dunlop used a 9-inch aperture, 9-foot long reflecting telescope he made himself and an achromatic telescope of 46 inches focal length.[81] The 9-inch telescope had a magnitude limit of approximately 13 and a very poor resolution of about 5 arc-seconds. See Section 5.3.2.3 regarding Dunlop's 9-inch telescope.

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[80] G Cozens, 2002.

[81] He used the 3.25-inch achromatic telescope, and the 9-inch reflector.

3.1.3 BACK IN SCOTLAND – 1827-1831

Dunlop left Sydney on February 4, 1827. Back in Scotland, he worked for Brisbane again at his third observatory at Makerstoun, 62 kilometres SE of Edinburgh (latitude 55.57^{o}N and longitude 2.52^{o}W) and six kilometres upstream from Kelso on the Tweed.[82] Plate 3.11 is a map of the area. Dunlop's 9-inch telescope was probably left at Makerstoun.[83] Plate 3.12 shows photographs of Brisbane’s third observatory and house next to the Tweed River.

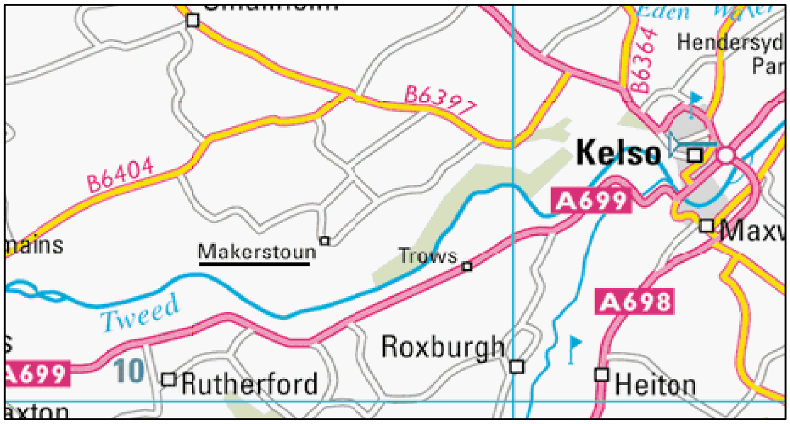

Plate 3.11: Brisbane built his third observatory at Makerstoun, Scotland, on the Tweed River, 6 km west of Kelso.[84]

Brisbane and Dunlop worked together for the next four years and also travelled together on the continent where they visited astronomers and observatories. Dunlop reduced and arranged his observations of southern clusters and nebulae during this time, probably between August and November 1827. This task was very poorly executed as shown in Table 5.9, Section 5.2.3.2. The catalogue of 629 objects was presented to the Royal Society on December 20, 1827 and was published in the Royal Society's Philosophical Transactions. An extract containing only 37 objects was published in the Edinburgh Journal of Science, vol. X, in 1829. A catalogue of 253 double stars was presented to the Royal Society on May 9, 1828. The catalogue of 7385 stars was reduced by William Richardson of the Royal Observatory at Greenwich and published in 1835.

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[82] In 1819 Brisbane married the only daughter of Sir Makdougall, baronet of Makerstoun, and succeeded to that estate.

[83] Service, *Notandums*, p. 187.

[84] Multimap.com, 2006, <http://www.multimap.com/map/home.cgi?client=public&lang=&advanced=&db=GB>, accessed 28 November, 2006.

Plate 3.12: Brisbane's third observatory, according to the owner Lady Mary Biddulph, and his house on the Tweed River at Makerstoun, Scotland.[85]

On February 8, 1828 the president of the Royal Astronomical Society of London,[86] Sir John Herschel presented gold medals to Brisbane, Dunlop[87] and Caroline Herschel. At that time, Sir John praised Dunlop for his zealous, active, industrious and methodical work, and also said Dunlop "must be regarded as the associate rather than the assistant of his employer; and their difference of situation becomes merged in their unity of sentiment and object."[88] Herschel also said that the "optical power of Lacaille's telescope was far too feeble to afford much insight into the physical constitution of the objects determined with it"[89] and added, "the astronomers of Europe may view with something approaching to envy, the lot of these their more fortunate brethren."[90] Interestingly, it seems Dunlop was not present for the presentation of the gold medal, possibly due to his low social class, as Herschel asked James South to "transmit to him [Dunlop] also this our medal."[91] South became president of the Royal Astronomical Society after Herschel.

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[85] Photographs by G Cozens, 1998.

[86] Service, *Notandums*, p. 153.

[87] A reproduction of the medal is on display at the Sydney Observatory.

[88] Service, *Notandums*, p. 155.

[89] Service, *Notandums*, p. 155.

[90] Service, *Notandums*, p. 157.

[91] Service, *Notandums*, p. 157.

Between 1827 and 1831 Dunlop visited relatives in Ayrshire. The Blair Museum near Dalry kept some of Dunlop's curios including an embalmed head.[92] In a letter dated April 22, 1831, issued from Government House NSW, Dunlop was appointed Superintendent of Parramatta Observatory with a salary of £300 per year, replacing Rümker.

Rümker returned to England in the middle of 1829 to purchase instruments to measure an arc of the meridian in NSW, to buy a transit circle and to publish his results. He lost his job because of a dispute with Brisbane over original records of observations and a separate dispute with Sir James South over the exorbitant price[93] of a transit circle, which Rümker refused to purchase from him.[94] Rümker never returned to Australia, but instead became superintendent of the Nautical School at Hamburg and Director of the Hamburg Observatory in 1830.

3.1.4 BACK IN AUSTRALIA 1831 – 1848

James and Jean[95] Dunlop left London on June 14, 1831 on *The Mary* and arrived back in Sydney five months later on November 11, 1831 after an eventful journey "including a fire, a row among the convicts, and an attempted duel between the doctor and the mate."[96] Governor Darling had departed the colony, Colonel Lindsay was acting governor when they arrived and Governor Bourke was about to become governor. Their house was to have been built next to the observatory, but when Dunlop arrived construction had not even started. The contract for the house was signed on May 17, 1832 and the building was finished in December 1832, one year after Dunlop arrived. It was 36 feet 3 inches by 27 feet with four rooms and cost the government in London nearly £470.[97] In the absence of an astronomer at Parramatta, white ants and the elements were destroying Brisbane's observatory and its precious books.

Dunlop began work at Parramatta, observing and recording new projects including the preparation of a working catalogue of 300 principal stars and the discovery of several new nebulae (names unknown). He continued sending observations to the Royal Astronomical Society in England and his observations of Mars were published in March 1835. Dunlop also

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[92] Service, *Notandums*, p. 164.

[93] South paid 400 for the transit circle and tried to sell it to Rümker for 650 pounds.

[94] G.F.J. Bergman, 'Christian Carl Ludwig Rümker (1788-1862) - Australia's First Government Astronomer', *Journal of the Royal Australian Historical Society*, 46, 1960, p. 268.

[95] On James Dunlop's commemorative stone (1848) at Kincumber church she calls herself Jane.

[96] Service, *Notandums*, p. 168.

[97] Vernon W.E. Goodin, 'Paramatta Observatory - The story of an absurdity', *Journal of the Royal Australian Historical Society*, 33, 1947, p. 183.

observed lunar occultations and the eclipses of Jupiter's satellites.[98] He received a medal from the King of Denmark for finding a magnitude 4 comet in Virgo in September 1833 (the medal took twelve years to reach him) and also a medal from the Royal Institute of France in 1835.

John Service writes “Sir John Herschel was at the Cape 1834-38, and went there evidently with the intention of glorifying himself as the Observer in the Southern Hemisphere.”[99] Herschel was unable to find some of Dunlop's double stars and he is quoted as saying Dunlop “saw Double Stars from subjective reasons.”[100]

Herschel's comments may have led to an incident on a Parramatta River steamer. The Rev W B Clarke, an eminent geologist, and James Dunlop were not the best of friends. Dunlop was known to ridicule Clarke's articles on “Winds and Earthquakes”[101] published in the Sydney Herald. One day when the two were travelling on a Parramatta Steamer, Clarke offended Dunlop by asking Dunlop if he saw the stars double. The argument became heated with Dunlop threatening to throw Clarke overboard and the Captain had to intervene.

Dunlop’s observations were recorded in books dating from January 1832 to June 1840. He made about 4000 star observations in 1832 and 1833. In late 1835 Dunlop observed the return of Halley's Comet at magnitude 1 (perihelion November 16, 1835).[102]

Another of Dunlop’s activities was to keep rainfall records from January 1832 to September 1838, with the averages shown in Table 3.1. John Service notes that three separate records of the rainfall at Parramatta have been found “and no one of them agrees with another.”[103]

Table 3.1: Parramatta’s Average Rainfall in mm from 1832 to 1838.

Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
95	62	105	75	88	54	95	99	61	45	66	64

98 Service, *Notandums*, p. 176.

99 Service, *Notandums*, p. 177, italics in the original.

100 Service, *Notandums*, p. 177.

101 Service, *Notandums*, p. 209.

102 J. Dunlop, *Sydney Monitor*, September 19, 1835.

103 Service, *Notandums*, p. 187.

Dunlop also recorded the unusual occurrence of snow one inch deep at Parramatta on Tuesday June 28, 1836.[104]

In addition Dunlop pursued other interests, including assisting several explorers. In November 1831 and again in 1834 and 1835, Dunlop assisted Sir Thomas Mitchell with his preparations for exploratory expeditions. In 1839 Lieutenant Wilkes visited Dunlop after a trip to the south polar seas. By then Dunlop was “nearly blind with sore eyes”[105] and this limited his astronomical observations. In July 1841 Dunlop carried out experiments with Sir James C Ross using rockets to establish an accurate latitude and longitude for Garden Island. Ross travelled to Parramatta with the governor by the usual transport of the day; a barge to Parramatta and a carriage back to Sydney.

By 1835 Dunlop's health was failing. He was still in poor health after an attack of dysentery when his wife wrote to her sister on July 20, 1837. His health problems were compounded by tetanus, as a result of being bitten on the thumb by a native cat. On October 23, 1839 Governor Gipps wrote to Brisbane that “Dunlop the Astronomer is very ill, and will not I fear last long.”[106] The comment was however somewhat premature as Dunlop lived nine more years. For his health's sake, Dunlop travelled in 1841 and 1845[107] to a property he owned at Bathurst, 195 kilometres (120 miles) west of Parramatta. One dark night early in 1843, Dunlop broke his leg when he fell over a log in the Parramatta Domain.[108] By October 1843 he was suffering from a “sort of torpor”[109] every morning at 2 a.m. as well as “indigestion and some deranged action of the heart.”[110]

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[104] The Sydney Herald reported on the same incident in an article headed ‘A Stranger’ "For the first time in the memory of the oldest inhabitants, snow fell in Sydney on the morning of Tuesday last. (27 June 1836) About 7 O’clock in the morning, a drifting fall covered the streets nearly one inch in depth". Weather Zone, *Snow in Sydney*, 2004, <http://www.weatherzone.com.au/cgi-bin/ultimatebb.cgi?ubb=get_topic;f=13;t=002988>, accessed 28 November, 2006.

[105] Service, *Notandums*, p. 188.

[106] Service, *Notandums*, p. 189.

[107] Service, *Notandums*, p. 193.

[108] Service, *Notandums*, p. 192.

[109] Service, *Notandums*, p. 192.

[110] Service, *Notandums*, p. 193.

On August 18, 1847 Dunlop wrote a letter of resignation. The *Sydney Morning Herald* announced his resignation on November 9, 1847.[111] A testimonial was to have been held in his honour but it was postponed and never occurred because the governor's wife, "Lady Mary Fitzroy was thrown from her carriage in the grounds of Government House and killed."[112]

Dunlop retired to Boora Boora, NSW (latitude 33.47°S, longitude 151.37°E) on Brisbane Water between Gosford and Kincumber, in October 1847. A house still stands on the original foundations of Dunlop's house and is occupied by John Dunlop Heuston, a descendant of John Dunlop, the brother of James. The hill nearby is named Dunlop Hill.

Plate 3.13 is a map showing Gosford on Brisbane Water and Kincumber to the southeast and Plate 3.14 is a satellite image of Kincumber showing the location of Dunlop's house and the church where he is buried.

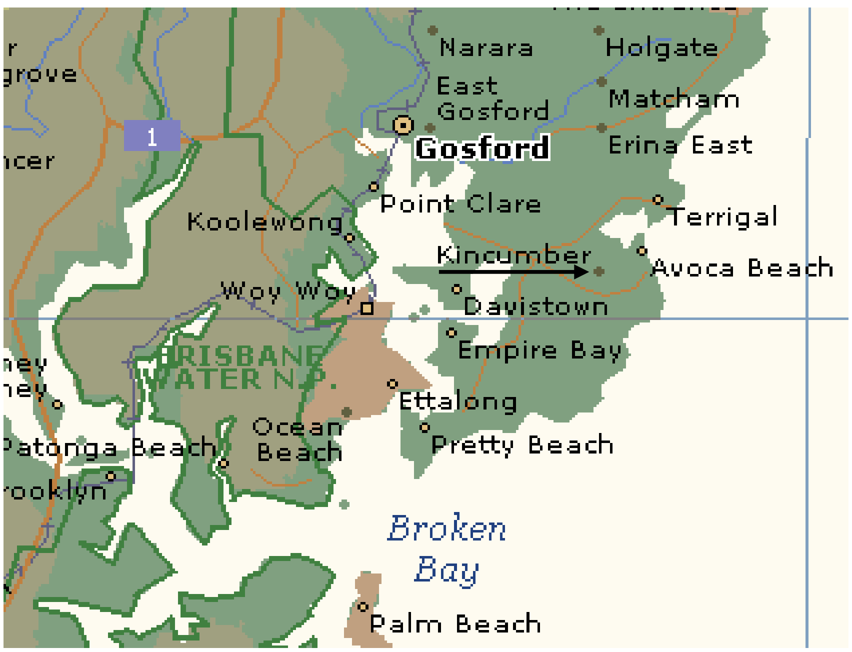

Plate 3.13: Dunlop retired to Kincumber on Brisbane Water, 11 km south east of Gosford, NSW.[113]

[111] Service, *Notandums*, p. 200.

[112] Service, *Notandums*, p. 201.

[113] Microsoft, *Encarta Interactive World Atlas*, 2001, Version 10.00.00.0808, Software.

Dunlop’s house, Boora Boora St Paul’s Anglican Church

Plate 3.14: Satellite image of Kincumber showing Dunlop's house on Brisbane Water and St Paul’s Anglican Church where he is buried.[114]

The photo in Plate 3.15 shows the current house built on the foundations of Dunlop’s house at Boora Boora, overlooking Brisbane Water.

Plate 3.15: John Dunlop Heuston, a relative of James Dunlop now lives at Boora Boora, the site of Dunlop's original house.[115]

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[114] Google Earth, *Digital Globe*, 2006.

[115] G Cozens, 1987.

Late in August 1848 Dunlop and a friend strayed from the track and were lost, while walking home from Gosford one night. The winter night in the bush and "the cold and exposure told severely on Mr Dunlop's already shattered constitution."[116] He died on September 23, 1848 of Urinary Calculus (Kidney Stones) aged 54. He is buried at St Paul's Anglican Church**,** Kincumber, with his wife Jane, who died 11 years later. The inscription on the headstone of James Dunlop's grave is shown in Plate 3.16. A stone at the entrance to St Paul's Church also reminds people of his work.

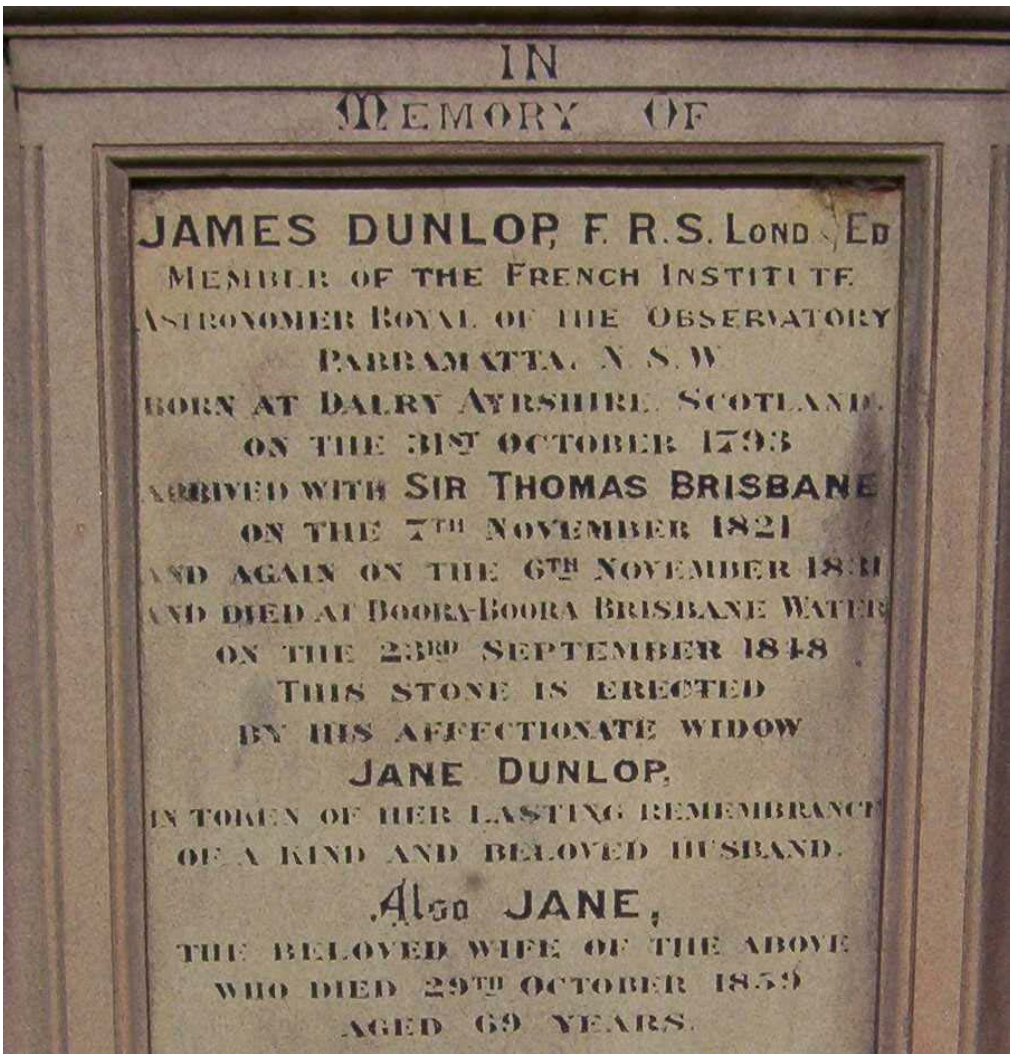

Plate 3.16: Head stone on James Dunlop's grave (1793 – 1848) at St Paul's Church, Kincumber, NSW.[117]

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[116] Service, *Notandums*, p. 203.

[117] G Cozens, 2004.

After his death, Dunlop was described by his contemporaries in many different ways, some contradictory. He was slender and not tall (5 feet 8 inches or 5 feet 10 inches), had a swarthy pale complexion, was dark haired, had a rather long nose and piercing dark eyes. He wore a blue coat with brass buttons on it, smoked and snuffed, and had a broad Scottish accent. Some said he was eccentric, peculiar, strange, and was not good at explaining things while others said he was intelligent and much respected. It was said he hated all ceremony but was hospitable and generous, loved poetry, and had a good sense of humour.

Dunlop's life contributed greatly to southern astronomy even though he “laboured with little encouragement from the colonial authorities.”[118]

[118] Service, *Notandums*, p. 211.

3.2 HISTORY OF THE PARRAMATTA OBSERVATORY

3.2.1 ESTABLISHMENT OF THE PARRAMATTA OBSERVATORY

Plate 3.17: Sir Thomas Brisbane (1773-1860) established the Parramatta Observatory in 1822 with Charles Rümker as his astronomer and James Dunlop as an assistant.[119]

Sir Thomas Brisbane[120] established an observatory at Parramatta for several reasons. Firstly, in 1795 he was almost shipwrecked "one night off the coast of Africa due to a navigator's error in computing longitude."[121] This led to an interest in navigation and methods for determining time.[122] As a consequence, he decided to make a catalogue of 30,000 southern stars down to magnitude 8, as a guide for navigation.[123] However, there are only 13,700 stars brighter than magnitude 8.1 south of -30^{o} Declination so Brisbane's plan was optimistic.[124] Lacaille had already catalogued nearly 10,000 stars in 1751-52 but this catalogue was not printed in full until

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[119] National Library of Australia, *Digital Collections Pictures*, <http://nla.gov.au/nla.pic-an9454279>, accessed 29 November, 2006.

[120] More information on Brisbane can be found at: Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1518.html>, accessed 30 November, 2006.

[121] Weitzenhoffer, 'Brisbane's adventures', p. 620.

[122] S.D. Saunders, *Astronomy in Colonial New South Wales: 1788 to 1858*, Sydney, 1990, p. 151.

[123] Saunders, *Colonial NSW*, p. 192.

[124] L.E. Brotzman, and S.E. Gessner, *Astronomical Data Centre CD-ROM*, Selected Astronomical Catalogs 1, NASA, Greenbelt, 1991. This contains the SAO catalogue of 259,000 stars.

1847. Lacaille's partial catalogue of 1942 stars was published in 1763 and Brisbane no doubt wanted to improve on this. Another reason for his interest in astronomy was to help with surveying and determining the shape of the earth.[125] Lacaille had measured an arc of the meridian and this suggested that the earth was pear-shaped.[126] Brisbane wanted to check Lacaille's results by using a pendulum and by measuring an arc of the meridian.[127] [128]

In 1815 after the battle of Waterloo, Brisbane had protected the Institut de France (Collège Mazarin) from the allied armies and later, when he was a member of the occupation forces, the French rewarded him with their friendship and knowledge.[129] Brisbane was impressed with their ideas and wanted "to raise the standard of practice of measurements such as time and position... [and] to communicate to his countrymen in Britain what he regarded as outstanding mathematical and scientific achievements by French practitioners and philosophers."[130] By setting up an observatory in the southern hemisphere, Brisbane aimed to elevate British astronomy.

There were four main periods in the history of the Parramatta Observatory from the time it was first built by Brisbane in 1821:

1. Rümker as Brisbane's astronomer with Dunlop as technical assistant – 1821-1823
2. Dunlop as Brisbane's astronomer – 1823 - 1826
3. Rümker as Government Astronomer – 1826 -1829
4. Dunlop as Superintendent – 1831 -1847.

These periods are detailed below.

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[125] Saunders, *Colonial NSW*, p. 147.

[126] Saunders, *Colonial NSW*, p. 154.

[127] Saunders, *Colonial NSW*, p. 154.

[128] Lacaille's pear-shaped earth turned out to be an error caused by the mountains near his arc of the meridian attracting the plumb bobs. That was confirmed by Maclear at the Cape in the 1860s and is referenced in Saunders, *Colonial NSW*, p. 316.

[129] Saunders, *Colonial NSW*, p. 152.

[130] Saunders, *Colonial NSW*, p. 171.

3.2.2 RÜMKER AND DUNLOP 1821 – 1823

On Rümker's 33rd birthday, May 18, 1821 Brisbane, Rümker[131] and Dunlop sailed from England for NSW. They arrived in Sydney five-and-a-half months later on November 7, 1821. Brisbane lived in Government House at Parramatta when he arrived because Governor Macquarie was still living in Government House in Sydney. Macquarie left three months after Brisbane's arrival.[132]

Plate 3.18: The German Charles Luis Rümker (1788-1862) was Brisbane's astronomer until June 1823.[133]

Parramatta was better suited as an observatory site because there was less smoke. The observatory was built 100 yards from Government House at Parramatta, (latitude 33.81°S, longitude 150.99°E), 15 miles (24 km) west of Sydney, in 1821 and 1822. It was two hours by horse, coach or boat from Sydney.[134] Brisbane funded the observatory[135] until he left on December 1, 1825. The building was small compared with other observatories of the time[136] and it was not designed to be long lasting. Rümker was employed as the astronomer, with a salary of £200 per annum[137] and Dunlop was employed as the technical assistant. His wage is

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[131] More information on Rumker can be found at: Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1524.html>, accessed 30 November, 2006.

[132] Saunders, *Colonial NSW*, p. 179.

[133] Raymond Haynes, Roslynn Haynes, David Malin and Richard McGee, *Explorers of the Southern Sky: A History of Australian Astronomy*, Cambridge, 1996, p 40.

[134] Saunders, *Colonial NSW*, p. 179.

[135] C.A. Liston, *New South Wales under Governor Brisbane, 1821-1825*, Sydney, 1980, p. 22. Brisbane's salary was £2000 per annum.

[136] Saunders, *Colonial NSW*, p. 323.

[137] F. Watson, (ed), *Historical Records of Australia*, Series I, XI, Sydney, 1913, p. 480.

unknown. Brisbane employed the German astronomer Rümker because of a lack of trained astronomers in England. Astronomy was not taught in English universities at the time.[138]

The solstice in December 1821 was observed and the observatory at Parramatta was completed in April 1822.[139] Observations began on March 11, 1822 according to Dunlop[140] but May 2, 1822 is given in the preface to *A Catalogue of 7385 Stars, chiefly in the Southern Hemisphere*.

One month later, on June 2, Dunlop recaptured Encke's comet (magnitude 4.6) at the position calculated by Rümker. It was near the Orion/Gemini border and set 1h 40m after sunset and only 17 minutes after the end of astronomical twilight. Dunlop did not realise at first that it was a comet.[141] Plate 3.19 shows the calculated position of Encke's Comet when Dunlop and Rümker recovered it on June 2, 1822.

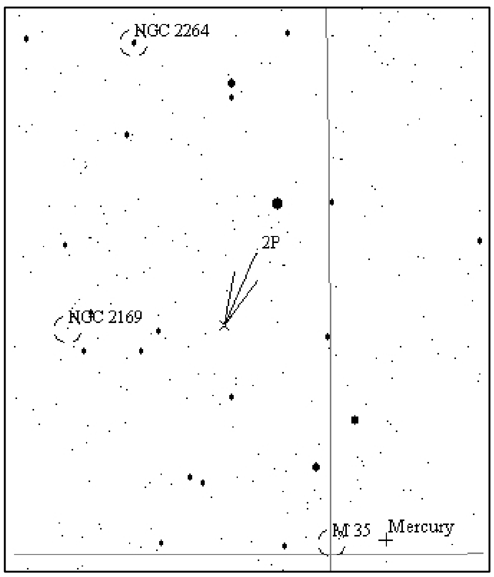

Plate 3.19: Encke's comet was near M35 and Mercury when recovered, according to modern astronomy software. [142]

This was only the second recovery of a comet, the first recovery being that of Halley's Comet by Johann Georg Palitzsch[143] on Christmas Day, 1758. The Astronomical Society of London gave

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[138] Saunders, *Colonial NSW*, p. 172.

[139] Service, *Notandums*, p. 140.

[140] Service, *Notandums*, p. 197.

[141] According to a letter by Rümker, who was having tea with the governor when Dunlop found the comet.

[142] Project Pluto, *Guide 8*, 2006, CD-ROM software.

Rümker £100 and a silver medal for this achievement.[144] Fearon Fallows (1789-1831), the first director of the Cape Observatory, had planned to search for the Encke's Comet, but was too sick to see it.[145] In fact Fallows produced very little in his seven years (1821-1828) at the Cape.[146]

Brisbane and Rümker observed a transit of Mercury on November 3, 1822 and a solar eclipse on August 16, 1822 (London time).[147] [148] By January 17, 1823, according to Saunders, Rümker had re-observed most of Lacaille's 9776 stars.[149] This seems unlikely, as it was less than a year since they started observing and Lacaille's full catalogue was not available to them. Also in a letter supplied to *The Monitor*, Dunlop wrote, "During the time he [Rümker] was in the Observatory, I think the number of stars observed from the commencement till his departure on this day (16th June 1823) cannot exceed 2000 or 2300 at most."[150]

Five months later on Monday June 16, 1823 Rümker suddenly left the observatory after a several disagreements with Brisbane He then moved to his farm, *Stargard* (near Picton, south west of Sydney), where he lived for nearly three years until his return to the observatory as Government Astronomer on May 10, 1826.

3.2.3 DUNLOP 1823-1826

During Rümker's absence, James Dunlop[151] continued the observations even though he was inexperienced and untrained. Brisbane taught him to use the instruments and he completed the catalogue of 7385 stars by March 2, 1826, although he may have had some difficulty once Brisbane left for England on December 1, 1825. The astrometry was poor because Dunlop used the mural circle instead of the transit instrument. He probably did this because he had no

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[143] Ridpath, *Encyclopedia of Astronomy*, p. 87.

[144] Saunders, *Colonial NSW*, p. 189.

[145] Saunders, *Colonial NSW*, p. 187.

[146] Saunders, *Colonial NSW*, p. 271.

[147] Saunders, *Colonial NSW*, pp. 191, 2.

[148] *Guide* 8 puts the transit of Mercury on November 5, and the partial eclipse at 8:47 am on November 17, 1822. The eclipse was total north of Cairns and 67% in Sydney.

[149] Saunders, *Colonial NSW*, p. 192, quoting *Transactions of the Royal Society of Edinburgh*, 10, 1826, p. 112.

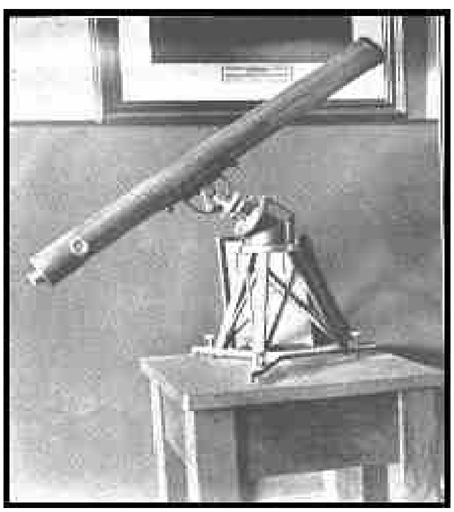
[150] Service, *Notandums*, p. 186.

[151] More information on Dunlop can be found at: Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1527.html>, accessed 30 November, 2006.

assistant. William Richardson of the Royal Observatory at Greenwich later made the computations for the 7385 stars, constructed the catalogue and published it in 1835,[152] twelve years before Lacaille's full catalogue was published.

Plate 3.20: The Scotsman James Dunlop (1793-1848) became the astronomer at the Parramatta Observatory when Rümker left in June 1823.[153]

In 1824 Dunlop started making lists of clusters and nebulae while still working on the star catalogue. After Brisbane left Parramatta, Dunlop continued preparing star maps of the Nebulae Major (LMC), the Nebulae Minor (SMC) and the area around Eta Argus (Carinae), using the mural circle. He also began work on a double star catalogue using the 3.25-inch (82 mm) achromatic telescope of 46 inches focal length.



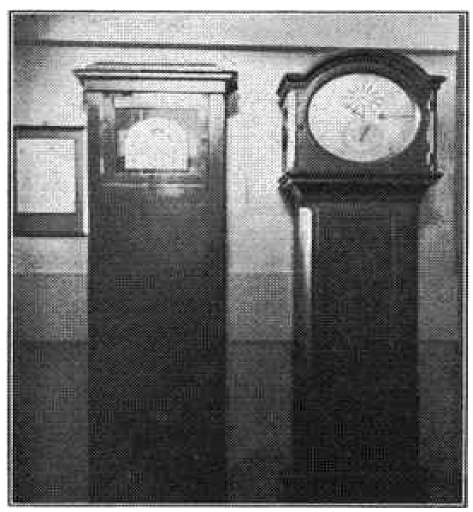


Plate 3.21: The 46-inch equatorial telescope and two Parramatta clocks: local time (left) and sidereal time (right);[154] now at the Sydney Observatory.

[152] Richardson, *7385 Stars.*

[153] SPACETEC, *NGC/IC Observers*, 2005, <http://www.klima-luft.de/steinicke/ngcic/persons/dunlop.htm>, accessed 30 November, 2006.

Dunlop left the Parramatta Observatory, and its accurate instruments and clocks, shown in Plate 3.21, in March 1826, two months before Rümker returned as Government Astronomer.

3.2.4 RÜMKER 1826-1829

Governor Darling, who replaced Brisbane as governor of NSW in 1826, unofficially appointed Rümker as Government Astronomer and on Wednesday May 10, 1826 Rümker returned to the observatory. Rümker's pay was tentatively set at £400 per annum on December 21, 1827 but this was reduced to £300 per annum. This was only half that paid to the astronomer at the Cape.[155]

From 1826 to 1828 Rümker worked on a catalogue of stars. He also published a table to help find the time of night using the position of the Southern Cross.[156] A zenith circle arrived at the observatory in October 1825 to help measure an arc of the meridian.[157] This project was officially approved on July 4, 1826. However the zenith circle was never unpacked.

Rümker left for England on January 6, 1829 for three reasons: to purchase rods and cylinders[158] for a survey of an arc of the meridian, to purchase a transit circle to replace the worn out transit instrument, and to publish 152 pages of results. A transit circle could measure Right Ascension and Declination while the transit instrument could only measure Right Ascension.

For almost three years, from January 1829 to November 1831, the Parramatta Observatory was without an astronomer, and apparently was left without a caretaker.

3.2.5 DUNLOP 1831-1847

James Dunlop was appointed to replace Rümker in November 1830 after Rümker's dismissal was orchestrated by Sir James South and Brisbane. Dunlop left Scotland and arrived back in Sydney on November 11, 1831. Colonel Lindsay was acting governor but Governor Bourke was soon to be governor. The observatory was "in a deplorable condition, - the Instruments were literally buried in ruins, the plaster from the ceiling was fallen down and one of the slides in the

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[154] Southern Astronomical Delights, Southern Astronomers and Australian Astronomy, *A History of Parramatta Observatory*, 2006, <http://homepage.mac.com/andjames/Page032.htm>, accessed 30 October, 2006.

[155] Saunders, *Colonial NSW*, p. 258.

[156] Bergman, *Rümker*, p. 262.

[157] Saunders, *Colonial NSW*, p. 241.

[158] Saunders, *Colonial NSW*, p. 257.

roof standing open to admit rain, a great portion of the books are totally destroyed."[159] There were problems with the transit instrument, the mural circle and Hardy's clock. White ants were also destroying the observatory and the books.

Dunlop prepared a working catalogue of 300 principal stars with observations written in ink, not on slate as before.[160] Service includes a letter from Dunlop to Brisbane, written early in 1832, where he says he reduced the observations daily at first. Dunlop goes on to say, "The constants and co-efficients which I employ in the reduction are very nearly the same as those of the Astronomical Society Catalogue."[161] He also allowed for refraction. Several new nebulae were discovered with a 7-inch Newtonian telescope with 70 times power. A 5-inch reflector was also used.[162] James Dunlop continued sending observations to the Royal Astronomical Society including observations of the magnitude, colour and brightness of 400 southern stars. The Royal Astronomical Society printed these records on June 14, 1833. He used the transit instrument and the mural circle in late 1832 to study Mars but his results were not published until March 13, 1835. In 1838 Dunlop observed lunar occultations and eclipses of Jupiter's satellites.[163]

The number of volumes produced by Dunlop while at Parramatta is not clear. John Service says that he made observations in eight large books beginning in January 1832 and running to June 1840, and he adds there were also four small books, which ran from August 1832 to April 1838. In his letter of resignation however, Dunlop says there were five volumes and six or seven smaller volumes.[164]

Dunlop achieved much at first, making about 4000 star observations in 1832 and 1833. From 1836-1840 his workload increased with duties as curator of the museum at the Sydney Mechanics' School of Arts.[165] By 1839 Dunlop was nearly blind and in need of an assistant and money for repairs to the instruments and observatory. Thomas Maclear (1794-1879) at the Cape observatory had up to three skilled assistants, including Piazzi Smyth and G R Smalley.[166] John

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[159] Service, *Notandums*, p. 169.

[160] Service, *Notandums*, p. 172.

[161] Service, *Notandums*, p. 173.

[162] Service, *Notandums*, p. 187.

[163] Service, *Notandums*, p. 176.

[164] Service, *Notandums*, p. 198.

[165] Saunders, *Colonial NSW*, p. 344.

[166] Saunders, *Colonial NSW*, p. 325.

Herschel who had the necessary influence in London supported Maclear but Brisbane was not able to give Dunlop the support he needed.[167] Because of the lack of assistants Dunlop never copied his records and thousands of his observations were never sent to England.[168] It was during 1835 that Dunlop's health started to deteriorate.

Meanwhile in England there was concern over the lack of reports from Parramatta and Dunlop was ordered to prepare an annual report every April starting in 1847.[169]

By 1847 the observatory had fallen into disrepair as a result of Dunlop's illness and a lack of money. A commission of three men (P P King, J A Gordon and R Rodgers) was appointed on April 14, 1847 to investigate the observatory. It reported on June 26, 1847[170] that the main problem was damage to the walls and floor caused by white ants and damage to the instruments caused by holes in the roof. On August 18, 1847[171] Dunlop wrote a letter of resignation and recommended that a new observatory be built in what is now North Sydney, away from the smoke of the city and within sight of the harbour. Before he left, Dunlop packed the Parramatta instruments into boxes.

3.2.6 AFTER 1847

The Colonial Office in London decided to close the Parramatta Observatory on March 31, 1848.[172] The British Government could see no need for two observatories in the south even though there were five observatories in England.[173] Meanwhile the observatory at Parramatta was demolished, probably before the above decision was made. Dunlop's house was all that remained when Parramatta Park was opened to the public on August 6, 1858.[174] It too was eventually demolished in 1876 and an obelisk was erected in 1880 to commemorate the observatory. The obelisk and inscription are shown in Plate 3.22.

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[167] Saunders, *Colonial NSW*, p. 354.

[168] Saunders, *Colonial NSW*, p. 330.

[169] Saunders, *Colonial NSW*, p. 362.

[170] Service, *Notandums*, p. 194.

[171] A copy of the letter can be found at: Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1543.html>, accessed 30 November, 2006.

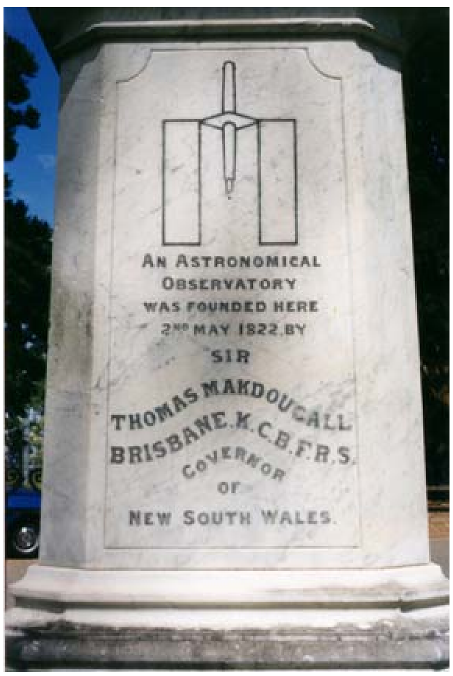
[172] Saunders, *Colonial NSW*, p. 303.

[173] Saunders, *Colonial NSW*, p. 359.

[174] Goodin, *Absurdity*, p. 173.

Today, only the obelisk and two stone piers remain. The obelisk purports to mark the spot where the transit instrument stood. However the stone piers, which probably held the transit instrument, are 26.7 feet (8.14 m) away from the obelisk. It seems that the obelisk may be in the wrong place. There are two possible scenarios for the locations of the obelisk and stone piers:

1. The obelisk is in the correct place and the existing piers are not the original ones. Service in 1890 notes that, "The two piers now standing near the obelisk were those erected for a new telescope which was sent out to Dunlop about the end of his time but never used. They stand outside of what was the old observatory, the foundations of which can now be traced."[175]
2. The transit piers are in the correct place and the obelisk is in the wrong place. In his article for the Royal Australian Historical Society, *Parramatta Observatory - the Story of an Absurdity*, Vernon W.E. Goodin supports this view.[176]



AN ASTRONOMICAL
OBSERVATORY
WAS FOUNDED HERE
2ND MAY 1822 BY
SIR
THOMAS MAKDOUGALL
BRISBANE, K.C.B. F.R.S.
GOVERNOR
OF
NEW SOUTH WALES

Plate 3.22: The obelisk in Parramatta Park marks the alleged site of the transit instrument.[177]

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[175] Service, *Notandums,* p. 213.

[176] Goodin, *Absurdity*, p. 177.

[177] G Cozens, 2004. K.C.B. stands for Knight Commander of the Order of the Bath, and F.R.S. for Fellow of the Royal Society.

In 1855 an amount of £7,000 was allocated for building the present observatory in Sydney (on the south side of the harbour), which included a time-ball, for ships to set their chronometers. The Government Astronomer was to be paid £400 and his assistant £200 per annum.

3.3 THE INTER-RELATIONSHIP BETWEEN DUNLOP, RÜMKER AND BRISBANE

3.3.1 BACKGROUND

Brisbane and Dunlop both came from Scotland; they had a common culture and they understood each other. Brisbane was the master and Dunlop his obedient assistant. Rümker was German; he didn't belong to the English class system and he considered himself the equal of Brisbane, at least as an astronomer. Brisbane tended to favour Dunlop and Rümker was jealous of this and his own reputation as an astronomer.

Rümker had many talents. He graduated as a master-builder in Berlin in 1807;[178] he taught maths in Hamburg in 1808; he was a midshipman in the British East India Company and a helmsman in the Merchant Navy. He was also artistic. In 1813 he was seized by a press-gang and ended up as a navigation teacher on five British ships between 1813 and 1819. The captain of one of these ships, Peter Heywood, became Rümker's close friend and later informed him of Brisbane's plans for an observatory in NSW. (Heywood was one of the Bounty mutineers.[179]) Some of Rümker's observations were published in the Edinburgh Philosophical Journal in 1819[180] and this made Brisbane aware of Rümker.

3.3.2 IN AUSTRALIA

When Sir Thomas Brisbane arrived in Sydney on November 21, 1821, Governor Lachlan Macquarie met Brisbane's suite,[181] and in Macquarie's Journal, Rümker is mentioned but there

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[178] He may have helped build the Parramatta Observatory.

[179] Queensland Museum, *The Bounty Mutineers*,
< http://www.qm.qld.gov.au/features/pandora/story/02_story.asp >, accessed 7 April, 2010.

[180] The published article was headed “Mr Rumker’s determination of the Longitude of La Valette by Astronomical Observations. Solar Eclipse, May 5, 1818” and was part of a letter to Robert Jameson. These observations were carried out at Malta. A copy of his article can be found in *The Edinburgh philosophical journal*, *Volume 1*, Royal Society of Edinburgh, Wernerian Natural History Society, <http://books.google.com.au/books?id=WkhkAAAAMAAJ&pg=PA280&lpg=PA280&dq=observations+at+Malta+in+the+Edinburgh+Philosophical+Journal+of+1819&source=bl&ots=vCvL9KJZR6&sig=rc5U2C3bQKiniZ0QOH0e0DPsNT4&hl=en&ei=zcPnSpviDaKK6AO6xLjoBQ&sa=X&oi=book_result&ct=result&resnum=2&ved=0CBEQ6AEwAQ#v=onepage&q=observations%20at%20Malta%20in%20the%20Edinburgh%20Philosophical%20Journal%20of%201819&f=false>, accessed 28 October, 2009.

[181] Bergman, *Rümker*, p. 251.

is no mention of Dunlop. “He was probably regarded as not very much more than a servant.”[182] At this time, Brisbane was 48, Rümker 33 and Dunlop 28 years old.[183] Dunlop was not only Brisbane's servant, he was also very much his junior and his subject when Brisbane became governor of NSW.

Brisbane praised Rümker at first for his mathematical and observational ability. Rümker calculated the position of Encke's Comet, which was recovered by Dunlop on June 2, 1822. He also re-observed some of Lacaille's 9,776 stars. Brisbane gave Rümker a land grant of 1000 acres on July 9, 1822 near Picton, 75 kilometres south of Parramatta. Rümker called his property *Stargard* after his birthplace about 100 km north of Berlin, Germany. The town of Redbank was later built on Rümker's farm.

3.3.3 RÜMKER LEAVES THE OBSERVATORY

On June 16, 1823, a year after the land grant, Rümker left Parramatta and moved to his farm where he built a crude house. There he discovered three comets, using a four-foot telescope from a hill now called Reservoir Hill.[184] One was Comet Rümker 1824I magnitude 3.9 in July 1824.

One reason for Rümker’s parting was a clash with Brisbane over professional matters. They disagreed over the timing of an eclipse of the moon on January 26, 1823 (London time). This eclipse occurred on January 27, between 2:34 am and 4:14 a.m. NSW time. Brisbane argued the time was “eight digits”, while Rümker said it was “nine digits” and both refused to compromise.[185] There was also a dispute between them regarding credit for scientific work, whether it should go to the employer Brisbane, or the astronomer Rümker.

Another reason for Rümker's departure was his dislike of the Governor's sport of shooting. On one occasion Rümker was forced to join a shooting party where Brisbane shot a magpie. Rümker said in his German accent, “I was so shocked at dat I trow down my shot belt vat he

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[182] Bergman, *Rümker*, p. 251.

[183] Their birthdays were 23/7/1773, 18/5/1788 and 31/10/1793 respectively.

[184] Bergman, *Rümker*, p. 260.

[185] Bergman, *Rümker*, p. 254.

made me bring and stamp about like mad. I never like him since."[186] The Governor was not impressed. Sir Thomas, as an experienced general, expected obedience, not temper tantrums.[187]

3.3.4 DUNLOP AND RÜMKER

There was also friction between Rümker and Dunlop. In a letter in 1830 Rümker complained, "Mr Dunlop before his departure declared publicly that he was going home to put me down." Rümker claimed in the same letter that "I all ways behaved openly and kindly towards Mr Dunlop, who has not acted in the same manner towards me."[188]

Both were apparently easily excited as later incidents show. Dunlop clashed with Clarke on board a Parramatta steamer and Rümker threw the publisher of his books down the steps of his house.[189] Neither Rümker nor Dunlop mentions the other in their scientific works.[190]

After Rümker's departure, Brisbane wrote to Lord Bathurst on November 15, 1823 to try to reduce Rümker's 1000 acre land grant to 200 or 300 acres. However Bathurst thought Rümker was a good farmer and he reprimanded Brisbane for trying to do this. During 1823 and 1824 Brisbane made several attempts to retrieve the original volumes of observations that Rümker had taken to *Stargard* when he left the observatory, but Rümker did not hand these over. On August 9, 1824 Brisbane wrote to Rümker at *Stargard* to ask if he would carry out a measurement of an arc of the meridian in NSW. Rümker did not reply. Brisbane may have been trying to bring about reconciliation or he may have written because there was no one else in the colony qualified to do the job.

3.3.5 THE DISPUTE BACK IN ENGLAND

Brisbane returned to England on December 1, 1825. Rümker returned to the Parramatta Observatory on May 10, 1826 and was officially appointed Government Astronomer on December 21, 1827. Back in England, Brisbane was still unhappy with Rümker. In mid 1828 he visited the Royal Society and proposed that Dunlop replace Rümker as Government Astronomer.[191] This news filtered back to Sydney.

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[186] Bergman, *Rümker*, p. 255.

[187] Bergman, *Rümker*, p. 255.

[188] C. Rümker, 'Letter', *MS Q569*, State Library of NSW, 1830, p. 121.

[189] Bergman, *Rümker*, p .255.

[190] Bergman, *Rümker*, p. 255.

[191] Bergman, *Rümker*, p. 266.

A dispute developed when Brisbane wanted Rümker to hand over three books of observations he had made. Brisbane wanted the "original observations"[192] but it was not clear what this meant.[193] The dispute started while Rümker was in Australia and came to a head when he was back in England. Rümker left Australia on January 6, 1829 and planned to return to Australia but never did so. In February 1834[194] he sold his 600 cattle, 40 pigs and 10 horses and ten years later, on September 14, 1844 he sold his farm, which had grown to 4000 acres, to Mr Lumsdaine.[195]

While in England, Rümker clashed with Sir James South[196] who tried to sell him a Troughton reversible four-foot transit circle[197] with a 3.5-inch aperture and a five-foot focus, which South had purchased for £400 from Stephen Groombridge. When the government consented to the purchase, South raised the price to £650,[198] and Rümker refused to buy it even though the government would have paid.[199] He ordered a new transit circle instead from Jones for £400 and was told he was silly to spite "a man of wealth and interest, whose patronage [he] ought to have

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192 Rümker thought the original observations were the notebooks he had copied from slates but Brisbane thought they were the copies made in heavy bound books. The first copy was sent to the Royal Society in 1825 and was mislaid. A second copy was made in 1828 and given to the Royal Society in July 1829. Rümker also handed over his original notebooks in December 1829. South then removed these from Richardson, who was reducing them to see, by comparing the original with the copies, if there was any "COOKERY." Bergman, *Rümker*, pp. 266, 271.

193 Bergman, *Rümker*, p. 271.

194 Bergman, *Rümker*, p. 265.

195 Rümker's original grant of 1000 acres was increased by 1000 acres on December 22, 1828, and by 2000 acres on January 1, 1829, after his return to the Parramatta Observatory and before his departure on January 6, 1829.

196 South was "President of the Royal Astronomical Society, Fellow of the Royal Society and King's own Astronomer." Bergman, *Rümker*, p. 266.

197 Henry C. King, *The History of the Telescope*, New York, 1955, p. 234.

198 Bergman, *Rümker*, p. 268.

199 South had some other shady transactions. He refused to pay E. Troughton £800 for a mounting he made for South in about 1829. Troughton took South to court and won the case, whereupon South smashed the mounting. Another example of South's tendency to financially exploit people occurred in 1833. He purchased a circle for £50 and Simms renovated it for £140. South then sold it for "the apparently exorbitant sum of £400." King, *Telescope*, p. 236.

courted - which alone paves the way in England to situations and offices."[200] This spelled the end of Rümker's association with British scientific society.

There was an ensuing dispute over the "original observations" between the President of the Royal[201] Society, Mr Davies Gilbert who supported Rümker and the President of the Royal Astronomical Society, Sir James South who supported Brisbane. This dispute even reached the newspapers. While still in England, Rümker lost his job as Government Astronomer at Parramatta Observatory on June 3, 1830 and Dunlop was appointed in November to replace him. James South seems to have wanted Rümker removed even more than did Brisbane. Rümker was of course unhappy with both his dismissal and with Dunlop's appointment. Rümker wrote a letter[202] in an attempt to reverse the decision to appoint Dunlop as astronomer to NSW. In the letter Rümker says, "You seem inclined to think me rather a theoretical than practical astronomer. Indeed Sir you have not yet seen my observations, and I think you are prejudiced against me by other persons - but what is Mr Dunlop. To theory he can not pretend and if a man can for 3 months together trace a body [a comet in 1825)] across the skies from star to star and so mistake them all, those of the first magnitude included, as to be out 40^o in their positions, and never find out his mistake then you may verily say that his good stars have forsaken him and if knowledge of the stars make the astronomer he does not deserve that name."[203] Rümker's opinion of James Dunlop's ability as an astronomer could not be clearer.

3.3.6 RÜMKER RETURNS TO GERMANY

From England Rümker returned to Germany where he later became Director of the School of Navigation in Hamburg. At that time a Mr Metz was Director of the Hamburg Observatory. He had been appointed temporary director until the arrival of Rümker but refused to give up his house and job to Rümker.[204] Rümker and Metz came to blows in front of their students and Rümker was granted both jobs, Director of the School of Navigation and Director of the Hamburg Observatory.

In 1832, Rümker published his own version of the Parramatta Catalogue. In the preface he praised Brisbane's liberality and dedicated the catalogue to Sir Thomas. The two became

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[200] Bergman, *Rümker*, p. 269.

[201] It became the Royal Astronomical Society in December 1830.

[202] The letter implies it is written to the president of the Astronomical Society, who in 1830 was Sir James South.

[203] Rümker, 'Letter', p. 122.

[204] Bergman, *Rümker*, p. 277.

reconciled and corresponded until Brisbane's death in January 1860. In 1854 the President of The Royal Astronomical Society, Sir George Airy, gave Rümker the gold medal of the Society "for his extensive observations chiefly of comets, and a catalogue of twelve thousand stars."[205]

Rümker's housekeeper, Maria L B Melcher bore him an illegitimate son, George Friedrich Wilhelm Rümker[206] in December 1832. He also became an astronomer, working at Durham, England 1853-1856, then at Hamburg Observatory 1857-1900, becoming director in 1862. Charles Rümker married an Englishwoman, Mary Ann Crockford in November 1848. She too was an astronomer and had discovered a comet the previous year.

By 1857 Rümker's health was declining and he moved to Lisbon, Portugal where he lived until his death on December 21, 1862. He was buried in the cemetery of the St George English Church at Estrella, Lisbon (latitude 38.72^{o}N, longitude 9.16^{o}W).

Plate.3.23: The author at Rümker's grave at St George English Church, Estrella, Lisbon, Portugal.[207]

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[205] H.C. Russell, 'Astronomical and Meteorological Workers in New South Wales, 1778-1860,' *Australasian Association for the Advancement of Science*, 1888, vol. 1, pp. 45-94, quoted in Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1526.html>, accessed 8 December, 2006.

[206] The name bears some similarity to John Frederick William Herschel, whose father was also German. Rümker was probably an admirer of both William and John Herschel. John Herschel and Rümker were both opposed to James Dunlop.

[207] G Cozens, 2006.

The inscription on Rümker's grave reads:

TO THE MEMORY OF THE LATE CHARLES LOUIS CHRISTIAN RÜMKER
BORN IN NEU BRANDENBURG MECKLENBURG STRELITZ
DEPARTED THIS LIFE ON THE 21ST DEC 1862 AGED 73 YEARS
MANY YEARS IN HMS ASSISTED AT THE CLOSE OF THE FRENCH WAR
AS OFFICER IN THE FLEET THEN STATIONED IN THE MEDITERRANEAN
AND ALSO UNDER LORD EXMOUTH AT THE BOMBARDMENT OF ALGIERS
AND SERVED AS NAVAL TEACHER IN THE BENBOW MONTAGUE
QUEEN CHARLOTTE AND ALBION
AND 9 YEARS COLONIAL ASTRONOMER AT AUSTRALIA
25 YEARS SUPERINTENDENT OF THE HAMBURG OBSERVATORY
AND NAUTICAL SCHOOL
THIS STONE WAS ERECTED BY HIS WIDOW

3.3.7 CONCLUSION

Originally, Brisbane favoured Dunlop, but in later years became critical of him. Brisbane also had a falling out with Rümker, yet later the two became reconciled, while Dunlop and Rümker continued to dislike each other. Rümker looked down on Dunlop as an inferior. Rümker said, "Mr Dunlop's astronomical career is comparatively nothing and his abilities in my opinion accordingly."[208] The Parramatta Catalogue would probably have been a great success if these three men had worked unitedly together.

[208] Rümker, 'Letter', p. 121.

3.4 A DESCRIPTION OF THE PARRAMATTA OBSERVATORY, ITS INSTRUMENTS, EQUIPMENT AND THE TELESCOPES USED FOR THE DUNLOP CATALOGUES

3.4.1 THE PARRAMATTA OBSERVATORY BUILDING

The drawings of the north and east sides of the Parramatta Observatory shown in Plate 3.24 were made by W B Clarke and are from the introduction to the book *A Catalogue of 7385 Stars, chiefly in the Southern Hemisphere*, observed by Rümker and Dunlop for Governor Brisbane.

"The Parramatta Observatory was a curious looking structure,"[209] a square 28 feet by 28 feet (8.5 m) with semicircular bulges of 11 feet (3.4 m) diameter on the north and south sides. The ceiling was also 11 feet high. The roof was flat with two domes 11 feet in diameter above the two semi-circular bulges. Four pillars inside the building supported each dome. Building materials included timber and canvas in the domes. A diagram of the layout of the Parramatta Observatory can be seen in Figure 3.1.

[209] Service, *Notandums*, p. 140.

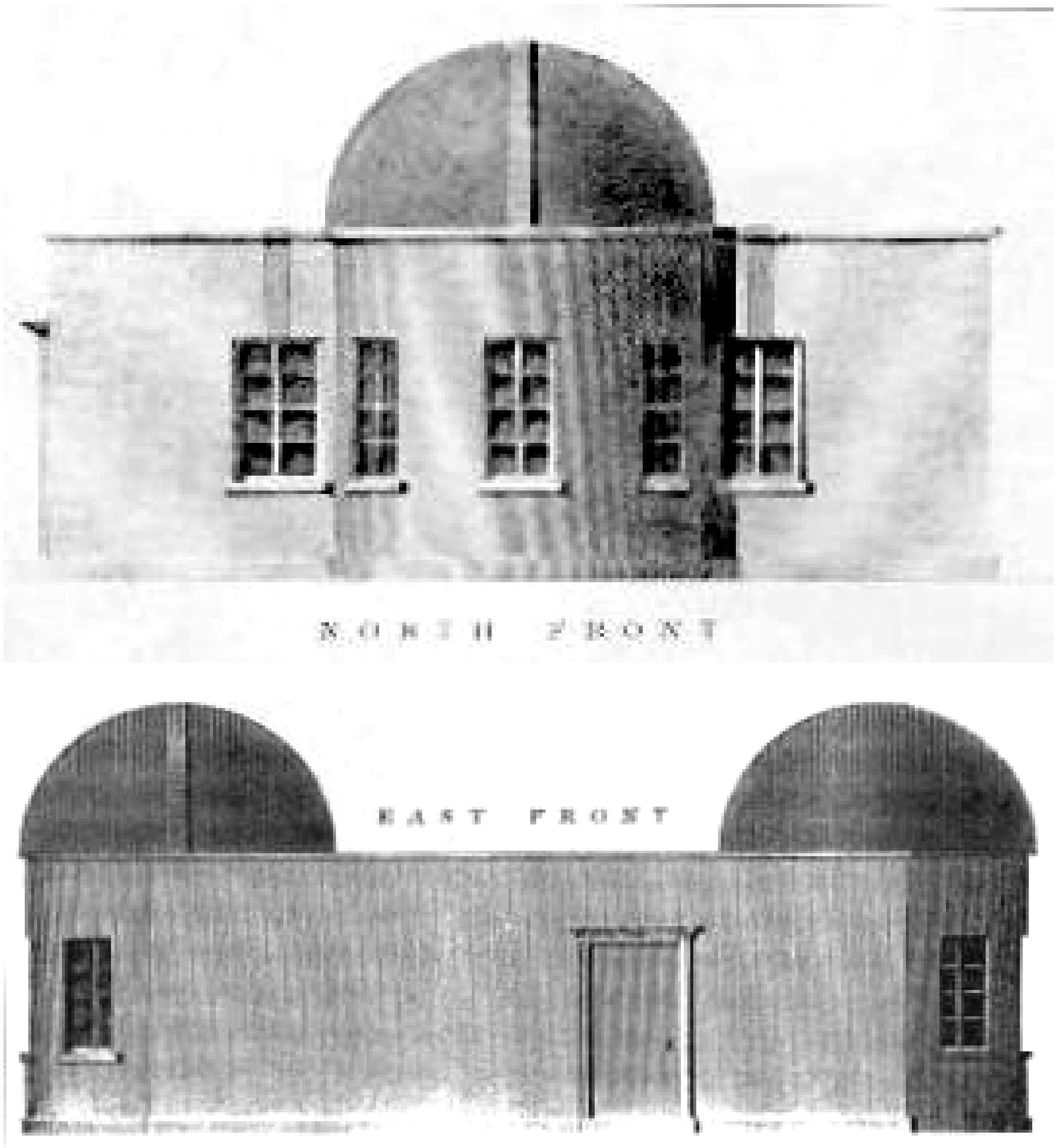

Plate 3.24: The northern and eastern walls of the Parramatta Observatory.[210]

3.4.2 THE MAIN INSTRUMENTS OF THE PARRAMATTA OBSERVATORY

The six main instruments[211] in the observatory were:

1. A 5.5-foot transit instrument (TI) by E. Troughton, aperture 3.75-inches, used to find Right Ascension (RA)

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[210] Richardson, *7385 Stars*, p 55.

[211] N. Lomb, 'The instruments from Parramatta Observatory', *Historical Records of Australian Science*, 2004, Vol. 15, pp. 211-222.

2. A 2-foot mural circle (MC) with a 2 foot telescope by E. Troughton, normally used to find Declination but used by Dunlop to also find RA
3. A 46-inch equatorial achromatic refracting telescope (AT) by Banks, aperture 3.25-inches located under the southern dome
4. A 16-inch repeating circle (RC) by Reichenbach located under the northern dome
5. A sidereal clock (SC) by Hardy
6. A mean time clock (MTC) by Breguet.

Brisbane's observatory at Parramatta was better equipped than the observatory Fearon Fallows used at the Cape.[212]

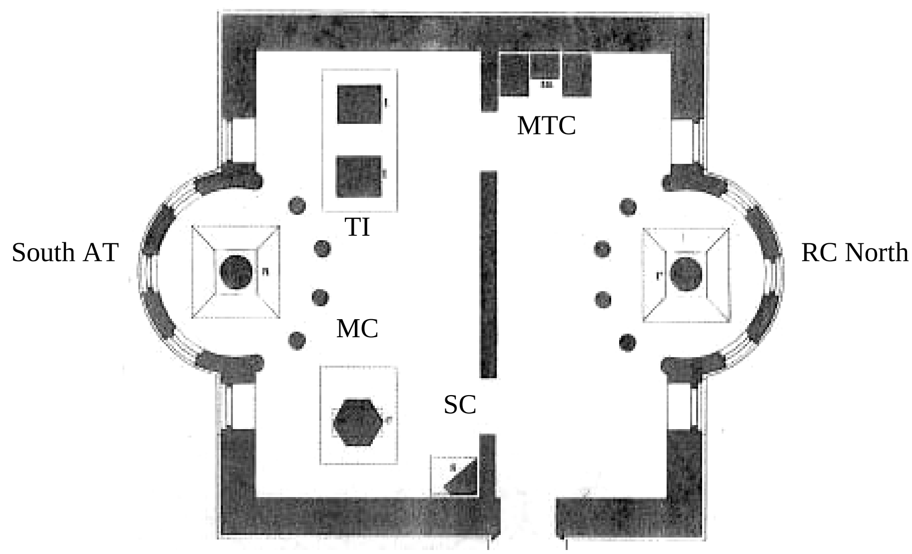

Figure 3.1: The Parramatta Observatory, showing the position of the instruments.[213]

Most of the observing took place in the southern room. Both the transit instrument (TI) and the mural circle (MC) were able to see from the northern horizon to the southern horizon through slits and windows in the three walls. There were five windows on both the north and south sides of the building, with three in the semi-circular parts of the walls and one on each side. There were no windows in the east and west walls.

Dunlop mainly used three of the instruments; the 2-foot mural circle, the 46-inch equatorial achromatic telescope and the sidereal clock by Hardy. Photographs of the 46-inch equatorial telescope and two of the Parramatta clocks, showing local and sidereal time are shown in Plate 3.21, Plate 3.27 and Plate 3.29.

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[212] Saunders, *Colonial NSW*, p. 183.

[213] Richardson, *7385 Stars*, p. 55.

The transit instrument was designed to find Right Ascension and the mural circle was designed to find Declination. When observing for the Parramatta Catalogue of 7,385 stars, Dunlop mainly used the mural circle for both Right Ascension and Declination.[214] The transit instrument was not accurate but had he persevered with it, the errors would have been less than those obtained with the mural circle.

When Brisbane left NSW on December 1, 1825 he sold the instruments to the Colonial Government for £1614. Some of the prices for the observatory equipment are listed in Table 3.2.

Table 3.2: Instruments sold by Brisbane to the NSW Government.

Instrument	Pounds (£)
Four clocks	490
Mural Circle	200
Repeating Circle	130
Transit Instrument	105
Equatorial telescope	60
Astronomical books (300 volumes)	353

These costs were large compared to a typical annual wage. Miners and gardeners were paid £100 per annum in 1801.[215] There was very little inflation during this period and wages were still about the same fifty years later. On average, the clocks thus cost more than a year's wage. All the original instruments are now owned by the Powerhouse Museum and are on display at the Sydney Observatory, at The Rocks, near the Harbour Bridge. Sydney Observatory also owns a copy of *A Catalogue of 7385 Stars, chiefly in the Southern Hemisphere*.

Brisbane had to wait three years to receive his money. The payment was authorised on September 10, 1827 and he finally received the money from the Colony, not London, at the end of 1828.[216] Brisbane was a generous man, offering to donate the instruments if the government failed to pay for them.[217]

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[214] Richardson, *7385 Stars*, p. vii.

[215] Saunders, *Colonial NSW*, p. 137.

[216] Saunders, *Colonial NSW*, p. 243.

[217] Saunders, *Colonial NSW*, p. 242.

3.4.2.1 The Transit Instrument and Transit Circle

Olaus Romer at Copenhagen invented the transit instrument in 1684. Edward Troughton (1753-1835) made one for John Pond at Greenwich in about 1813.[218] Brisbane purchased a new 5.5-foot transit instrument from Troughton just before leaving England in 1821.[219] A photo of this transit instrument and the celestial globe Brisbane shipped to Sydney can be seen in Plate 3.25.

A transit instrument has several lines across its field of view. The sidereal time is recorded as a star crosses each line and averages are taken. By comparing Brisbane's catalogue with Johnson’s St Helena catalogue, Richardson found that the Parramatta transit was out by 3.45 arc-seconds at south polar distance 10^o – 15^o and this error reduced to 0.30 arc-seconds at south polar distance 115^o – 120^o. However, errors of 1 minute or even 2 minutes in Right Ascension did occur.[220]

Plate 3.25: The 5.5-foot Transit Instrument[221] and Brisbane's celestial globe are at the Sydney Observatory.[222]

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[218] King, *Telescope*, p. 236. 233.

[219] Saunders, *Colonial NSW*, p. 180.

[220] Edward J. Stone, *Catalogue of 12,441 Stars, for the Epoch 1880; from Observations Made at the Royal Observatory, Cape of Good Hope, during the years 1871 to 1879*, London, 1881, p. 556.

[221] The transit instrument is currently on display at Sydney Observatory, as part of the Powerhouse Museum’s collection. See the Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258792>, accessed 13 December, 2006.

Prior to this Troughton had made a four-foot reversible transit circle (a transit circle is sometimes called a meridian circle[223]) for Stephen Groombridge[224] in 1806. Groombridge sold this to James South, which he later tried to sell to Rümker. Troughton started making a second transit circle but never finished it because for "no apparent reasons"[225] he did not like this type of instrument. Transit circles have the advantage of being able to measure both Right Ascension and Declination at once and Brisbane would have been better equipped with one. The Parramatta Observatory did get a Jones transit circle in 1835 that Rümker had ordered to replace the transit instrument. Dunlop assembled it but found it was badly made and inaccurate. It had only three microscopes for measuring Declination, not four, and the graduations were also poorly made. P P King said it was "in every way faulty,"[226] badly divided and difficult for one person to use.[227] Dunlop rarely used it.

Dunlop also seldom used the transit instrument with its 3.75-inch refracting telescope. In 1839 Lieutenant Wilkes found that air and water were dissolving its pillars and they were sinking and unsteady.[228] In 1847, P P King found the transit instrument leaning in a corner "like a walking stick covered with cobwebs of 6 years' accumulation"; the pillars and foundations stood "in a sort of well with four or five feet of water in it" and they were "twisted out of the meridian."[229] Eleven years later, William Scott used the same Troughton transit instrument at the new Sydney Observatory in 1858 and 1859, while the Jones transit circle was being repaired in London. He also found that it had great defects, including irregular pivots and a weak axis,[230] and these were some of the reasons for the errors in Right Ascension in the Parramatta Catalogue.

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[222] Both images from: Glenda Thompson, 'Sir Thomas Brisbane: Comets over the colony', *Australian Women's Weekly*, Halley in Australian Skies, 1985, pp. 41, 42.

[223] Sir John F.W. Herschel, *Outlines of astronomy*, London, 1851, p. 103.

[224] Groombridge found the famous runaway star "Groombridge 1830" with this transit circle. This star's proper motion is 7 arc-seconds per annum. King, *Telescope*, p. 234.

[225] King, *Telescope*, p. 236. 234.

[226] Saunders, *Colonial NSW*, p. 308 quotes a letter from P.P. King to W.H. Smyth, 1847.

[227] Service, *Notandums*, p. 197.

[228] Service, *Notandums*, p. 197. The obelisk allegedly replaced this.

[229] Saunders, *Colonial NSW*, p. 363.

[230] Saunders, *Colonial NSW*, p. 194.

3.4.2.2 The Mural Circle

E. Troughton completed a six-foot mural circle for Greenwich in 1812.[231] The Parramatta "mural circle of two-feet diameter was exactly similar to the Greenwich circle"[232] and a two foot telescope was attached. Brisbane used this mural circle in his first observatory at Largs, Scotland before taking it to NSW.[233] Plate 3.26 shows an image of part of this mural circle.

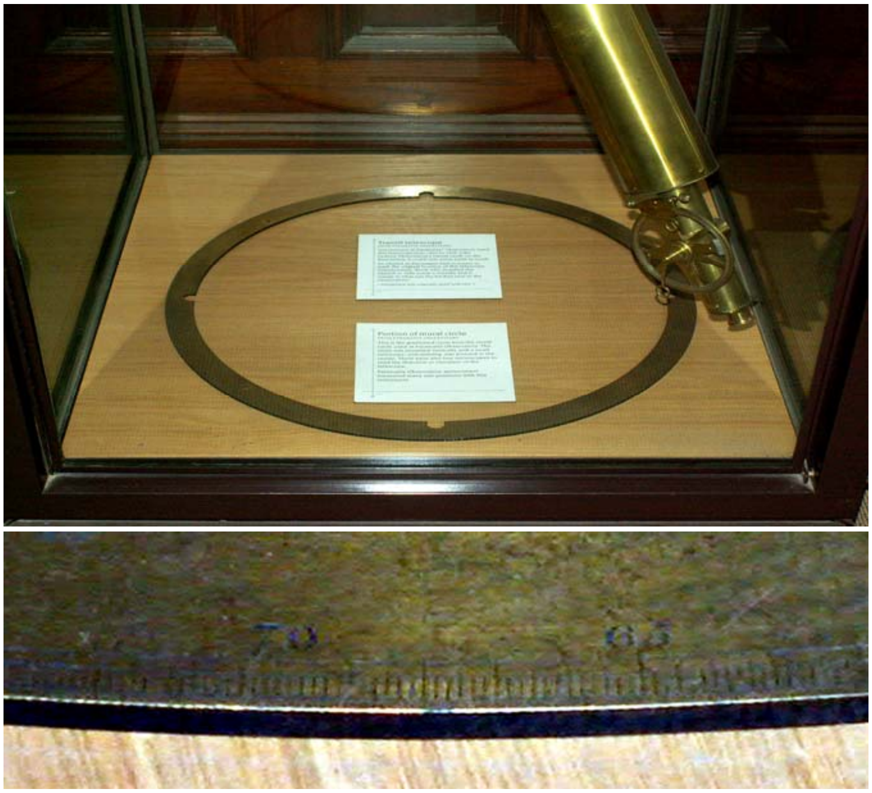

Plate 3.26: Part of the 2-foot diameter mural circle and an enlargement of the circle showing 1 degree = 6 divisions.[234]

A mural circle is calibrated to measure distances from the pole. Four microscopes were provided, all 45^{o} from the horizontal, to read the scale on the circle and reduce errors in the graduations. It was mounted on only one pier, not two like a meridian circle. A mural circle "cannot be reversed, and its axis is not symmetrically supported, it is not suited to the accurate

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[231] King, *Telescope*, p. 233.

[232] Saunders, *Colonial NSW*, p. 184.

[233] Saunders, *Colonial NSW*, p. 180.

[234] G Cozens, 2006. The mural circle is currently on display at Sydney Observatory, and is part of the Powerhouse Museum collection. See the Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258792>, accessed 13 December, 2006

determination of Right Ascensions."[235] Despite this, Dunlop used the mural circle to determine the Right Ascension of many stars, with errors ranging from 2.49 seconds to 1.15 seconds.[236] The south polar distance determined with the mural circle was much more reliable than the Right Ascension but there were still a bewildering[237] number of errors in both Right Ascension and Declination.

The two-foot diameter mural circle is made of brass, stone, and glass. The circle is divided into two, each half being divided and numbered from 0-180 on the outside edge as shown in the enlargement of Plate 3.26.[238]

It would be difficult for Dunlop, by himself, to find stellar positions using both a transit instrument and a mural circle. To do this, first the sidereal time would have to be noted as the star crossed several transit wires. Then he would have to hurry to the mural circle, move it to point to the same star, and record the readings from the four microscopes before returning to the transit instrument to catch the next star as it drifted by. Alternatively he could observe the Right Ascension and Declination separately and match them later.

3.4.2.3 The Banks Equatorial Achromatic Telescope

The 46-inch focal length, 3.25-inch equatorial refracting telescope was made by Banks[239] and brought to NSW by Brisbane for use in the Parramatta Observatory.[240] It was fitted with several micrometers, including a position micrometer by Banks, a double image micrometer based on Amici's principle and a third micrometer that Dunlop made himself.[241] These were used to measure small angles. In the introduction to his *Double Star Catalogue* Dunlop says:

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[235]W. Chauvenet, *A Manual of Spherical and Practical Astronomy*, 2 Vols, London, 1896, ii, p.282.

[236] Stone, *Catalogue of 12,441 Stars*, p. xxii.

[237] Stone, *Catalogue of 12,441 Stars*, p. xxii.

[238] A fuller description of the component parts of the mural circle can be found at the Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258796&search=mural+circle&images=&c=&s=>, accessed 13 December, 2006.

[239] Banks was an instrument maker to King George IV.

[240] This telescope is currently on display at Sydney Observatory and is part of the Powerhouse Museum Collection. See Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258735>, accessed 14 December, 2006.

[241] James Dunlop, 'Approximate Places of Double Stars in the Southern Hemisphere', *Memoirs of the Astronomical Society of London*, 3, 1828, p. 258.

> "In the case of the stars marked with an asterisk,[242] their positions, distances, Declination, &c., are the result of micrometrical measurements with the 46-inch achromatic telescope mounted on the equatorial stand which you left with me: the micrometers were constructed by myself, consisting of a parallel line micrometer, the screws of which I bestowed great pains upon, and which I consider very excellent and uniform; also a double image micrometer on AMICI's principle, which I sometimes used, particularly when the stars were nearly of equal magnitudes (I always found some uncertainty in the measurements, when the stars were of very unequal magnitudes): the position micrometer was made by BANCKS, and belongs to the telescope."[243]

Plate 3.27: The 3.25-inch aperture, 46-inch focal length, Banks equatorial achromatic telescope, and mounting detail, now located at the Sydney Observatory.[244]

Dunlop used the Banks 3.25-inch refracting telescope to find the position, distance and Declination of 119 of his 253 double stars. Most of these were observed after Brisbane left NSW between December 1, 1825 and May 10, 1826 when Rümker took over the observatory. Rümker however implies that Dunlop had the use of this telescope in 1826. He says, "These nebulas now were observed with the same telescope of Banks and neither by his [Dunlop's] own nor yet by the work of his hand."[245]

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[242] 119 stars were marked with the asterisk.

[243] Dunlop, 'Double Stars', p. 258.

[244] G Cozens, 2006.

[245] Rümker, 'Letter', p. 123.

3.4.2.4 The Repeating Circle

The 16-inch repeating circle was made by Reichenbach in Germany between 1804 - 1814.[246] It is "mounted with two 1.5-inch refractor telescopes, each 555mm [22 inches] in length. [It] includes counterbalances and tripodal stand with adjustable feet."[247] Plate 3.28 is an image of the repeating circle.

"Geographical positions [were] deduced from zenith distances using the repeating circle."[248] The repeating circle reduced the errors of graduation and the observer errors by repeating the angle to be measured many times.[249] The repeated measurements were then averaged. It was also used to measure the angle between stars.[250] Rümker said, "The repeating circle has never been attempted by Mr Dunlop for the very best reasons possible"[251] meaning Dunlop did not know how to use it.

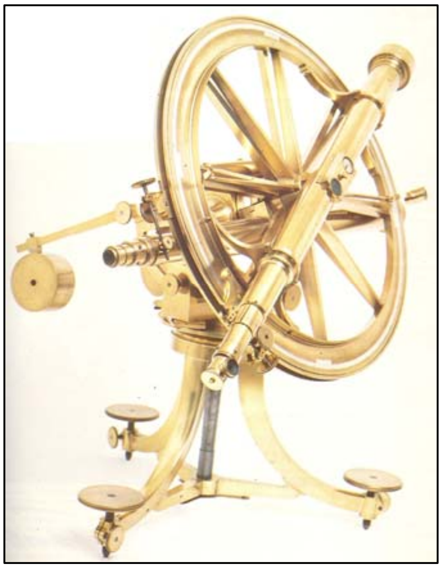

Plate 3.28: The 16-inch repeating circle by Reichenbach now located at the Sydney Observatory.[252]

[246] Lomb, 'Instruments of Parramatta Observatory', p. 212.

[247] See Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258793&search=repeating+circle&images=&c=&s=>, accessed 14 December, 2006.

[248] Saunders, *Colonial NSW*, p. 193.

[249] Herschel, *Outlines*, p. 118.

[250] Thompson, 'Comets', p. 43.

[251] Rümker, 'Letter', p. 123.

[252] Thompson, 'Comet', p. 43.

3.4.2.5 The Hardy Sidereal Clock

Invented and made by William Hardy in England around 1820, this "longcase astronomical regulator clock"[253] gives sidereal time. The clock casing is not original. A close-up of its face can be seen in Plate 3.29.

Dunlop used this clock with the Mural Circle for the measurement of most star positions. The 24-hour circle is small and would be difficult to read in the dark.

Plate 3.29: The face of the Hardy sidereal clock at Sydney Observatory. Note the 24 hour circle. This was the main clock used by Dunlop at the observatory.[254]

3.4.2.6 Breguet Mean Time Clock

This clock was purchased by Governor Brisbane in 1818[255] from Breguet & Sons in France and was used to keep local time. It uses a "double weight driven gear train with a double adjustable escapement, which is directly connected to the pendulum."[256] Plate 3.30 shows the face of the mean time clock.

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[253] Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258756&search=Parramatta+Observatory&images=&c=&s=1>, accessed 14 December, 2006.

[254] G Cozens, 2006.

[255] Lomb, 'Instruments of Parramatta Observatory', p. 218.

[256] Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=258776&search=breguet+clock&images=&c=&s=>, accessed 14 December, 2006.

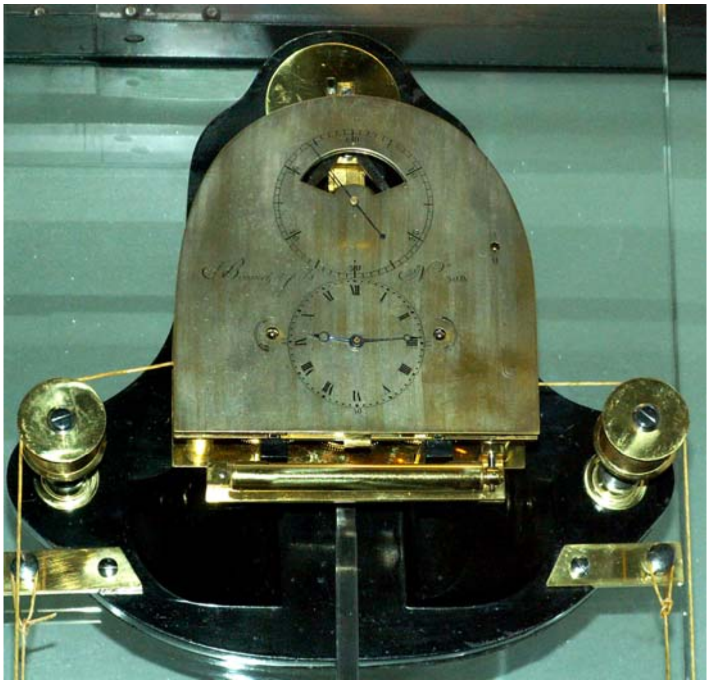

Plate 3.30: The Breguet mean time clock, now at the Sydney Observatory.[257]

Dunlop mainly worked in the south room of the Parramatta Observatory, and did not use this clock on a regular basis as it was housed in the north room.

3.4.3 THE OBSERVATORY'S OTHER EQUIPMENT AND BOOKS

Apart from the six main instruments described above, Parramatta Observatory had the following instruments.[258]

1. One astronomical clock by Barraud
2. One astronomical clock by Grimaldi
3. A mountain barometer by Troughton
4. A 30-inch portable transit collimator

There were also a number of books. When Brisbane left Parramatta in 1825 he sold over 300 volumes to the NSW government. Some of the books at Parramatta Observatory in 1847 are listed below, including the German astronomer, Johann Elert Bode's (1747-1826), 1801 'Uranographie', which was probably used as the main star atlas. In this book "the positions of more than 17,000 stars are given, as well as just about every constellation ever invented, and no

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[257] G Cozens, 2006.

[258] See Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1545.html>, accessed 21 December, 2006.

less than 2500 nebulae that had been discovered and catalogued by William Herschel... truly the grandest star atlas ever produced."[259] It had twenty double-page plates, one of which is shown in Plate 3.31.

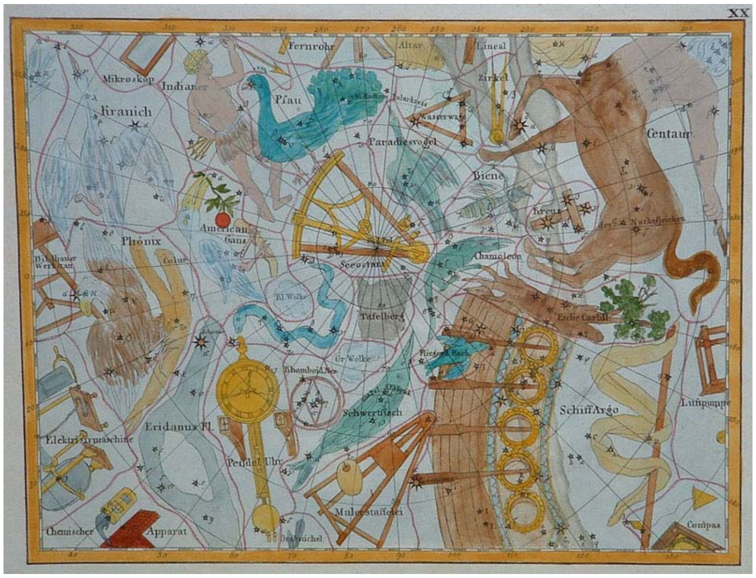

Plate 3.31: A plate from Bode's 1801 *Uranographia*.[260] This was similar to the atlas used by James Dunlop.

Some of the Parramatta Observatory books were:

1. Astronomy de La Caille
2. Traité d'Optique par La Caille
3. La Caille's Astronomy, by Robertson
4. 37 Philosophical Transactions
5. Piazzi's Catalogue
6. Francoeur's Urauographie
7. Bode's Uranographie (maps)
8. Bode's Jährbuch
9. 104 Connaissance des Temps.

As well as these books, the observatory possessed the Cape of Good Hope Observations, the Parramatta Catalogue and five volumes of observations made by Dunlop, partly reduced.[261]

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[259] Linda Hall Library of Science, Engineering and Technology, *Johann Bode Uranographia*, 2006, <http://www.lhl.lib.mo.us/events_exhib/exhibit/exhibits/stars/bodb.htm>, accessed 21 December, 2006.

[260] Mapwoman, *Antiquarian Maps, Prints and Books*, 2006, <http://www.mapwoman.com/images/maps_ce/CE003.jpg>, accessed 21 December, 2006.

3.4.4 DUNLOP'S NINE INCH REFLECTOR

In March 1826 James Dunlop left the Parramatta Observatory and began observations from Mrs Elders' house in Parramatta using a 9-inch telescope that he made. It was here that Dunlop made most of the observations for his two catalogues, *A Catalogue of Nebulae and Clusters of Stars in the Southern Hemisphere observed in New South Wales* (Appendix C), and *Approximate Places of Double Stars in the Southern Hemisphere, observed at Parramatta in New South Wales* (Appendix E).

The house where he lived and worked is no longer standing. It was located near St John's Church, which is shown in the satellite photograph of Parramatta in Plate 3.32, with a marker also indicating the approximate location of Mrs Elders' house.

Plate 3.32: Location of the house in Parramatta where Dunlop made his catalogues of clusters and nebulae, and double stars.[262]

Dunlop probably took his 9-inch telescope back to Scotland with him;[263] its current whereabouts is unknown. However, the following description of Dunlop's telescope appears in the introduction to his catalogue of 629 clusters and nebulae:

> "The observations were made in the open air, with an excellent 9-feet reflecting telescope, the clear aperture of the large mirror being nine inches. This telescope was occasionally fitted up as a meridian telescope, with a strong iron axis firmly attached to the lower side of the tube nearly opposite the cell of the large mirror, and the ends of the axis rested in brass Y's, which were screwed to blocks of wood let into the ground about 18 inches, and projecting about 4

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261 Australian Science and Technology Heritage Centre and Bureau of Meteorology, *Federation and Meteorology*, 2001, <http://www.austehc.unimelb.edu.au/fam/1541.html>, accessed 21 December, 2006.

262 Google Earth, *Digital Globe*, 2006.

263 Service, *Notandums*, p. 187.

> inches above the ground; one end of the axis carried a brass semicircle divided into half degrees and read off by a vernier to minutes. The position and index error of the instrument were ascertained by the passage of known stars. The eye end of the telescope was raised or lowered by a cord over a pulley attached to a strong wooden post let into the ground about two feet: with this apparatus I have observed a sweep of eight or ten degrees in breadth with very little deviation of the instrument from the plane of the meridian, and the tremor was very little even with considerable magnifying power."

The descriptions in the Dunlop catalogue of clusters and nebulae refer to the use of some high magnifying powers, namely 170 times (16 mm eyepiece in Dunlop 250) and 260 times (10.5 mm eyepiece in Dunlop 389). With these eyepieces his field of view would have been very small. He also used a low power eyepiece for sweeps across the sky. This eyepiece had a 45 arc-minute field of view. The 'open air' would have caused problems with dew on the eyepiece. This would make stars appear nebulous at times. Dunlop no doubt used a ladder to reach the eyepiece of his nine foot long telescope when it was more than about five foot above the ground.

The 'large' mirror was made of speculum, which would tarnish. "Speculum is an alloy of copper and tin formerly used in reflecting telescopes to make the main mirror, as it could be cast, ground and polished to make a highly reflective surface."[264] A similar 9-inch telescope with a speculum metal mirror, that William Herschel made and used, was donated to the Sydney Observatory. Speculum mirrors were heavier than today's mirrors. Silver on glass mirrors were not used until 1856.[265] These too tended to tarnish, but they were found to reflect 50% more light than a speculum metal mirror.[266] Compared to aluminium on glass mirrors used today, two speculum mirrors would only reflect about 57% of the light as the following data shows. William Herschel calculated that a new speculum mirror absorbed 33% of the light, hence reflecting 67%.[267] Today's aluminium mirrors reflect about 89% of the visible light.[268] For the two reflections from the primary and secondary mirror, aluminium is 76% better than speculum (i.e. $\frac{0.89^2}{0.67^2} = 176\%$).

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[264] Powerhouse Museum Collection, <http://www.powerhousemuseum.com/collection/database/?irn=231971&search=speculum+mirror&images=&c=&s=>, accessed 20 December, 2006.

[265] King, *Telescope*, p. 262.

[266] King, *Telescope*, p. 261.

[267] King, *Telescope*, p. 137.

[268] King, *Telescope*, p. 382.

Further calculations suggest that a 9-inch speculum mirror was approximately equal to a 6.8-inch aluminium mirror, since $d^2 \times 0.89^2 = 9^2 \times 0.67^2$, gives $d = 6.78$. This means Dunlop's 9-inch mirror had the limiting magnitude of a modern 6.8-inch aluminium mirror. His theoretical limiting magnitude was about 13.2 (limiting magnitude $= 9.1 + 5\log D$ where *D* is in inches).[269] John Herschel identified 211 of the 629 clusters and nebulae in the Dunlop catalogue. Of these at least twelve objects were fainter than magnitude 12, indicating that his magnitude limit was fainter than 12. See section 5.3.2 for more accurate calculations.

To be used as a meridian telescope, its ‘strong’ axis would have to run precisely east west, and be exactly level. Adjusting the brass Y’s at the eastern and western end of the axis probably achieved this. If the wooden posts under the Y's moved even slightly with time, the telescope would no longer follow the meridian.

‘One end of the axis carried a brass semicircle divided into half degrees and read off by a vernier to minutes’ but this may have been poorly divided.

The ‘strong wooden post’ with the pulley for adjusting the eye end of the telescope must have been 10 feet high and located next to the telescope when it pointed to the zenith. This would allow the telescope to move north and south along the meridian.

3.4.4.1 Possible Equipment Problems for Dunlop

A number of potential problems with the 9-inch telescope Dunlop used after he left the observatory were alluded to in the above section. These included:

1. Observing in the open air caused the eye piece and/or mirror to fog
2. Ensuring the telescope’s axis did not deviate from the east-west alignment
3. Ensuring the axis remained exactly level
4. The accuracy of the vernier scale.

However Dunlop faced other problems including not having an assistant and possibly not having a suitable chronometer. To solve this he may have borrowed one of the four accurate clocks from the observatory. Apparently he used a sidereal clock to time a conjunction of Venus and Jupiter during this time.

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[269] Sidgwick, *Handbook*, p. 26.

Dunlop's observatory was at latitude 33° 49' south (33.82°S) so that the Declination –33.8° was overhead. His survey of the sky covered the area from the South Celestial Pole (33°49' above the horizon) to the most northerly object in his catalogue at south polar distance 61° 55' which is equal to Declination 28° 5' S, nearly 6° north of the zenith. Thus the telescope needed to sweep at least 62° of arc from the south celestial pole to Declination 28° 5' S. He probably observed below the south celestial pole too. The longitude of his observatory was 151.002°E.

The following figures give some idea of the resolving power of Dunlop's telescopes and his accuracy as an astronomer. On May 13, 1826, he was able to resolve the bright pair of stars comprising Alpha Crucis, using the Parramatta Observatory's 46-inch focal length refractor. These were recorded as 5.42 arc-seconds apart.[270] In his double star catalogue, the closest double stars Dunlop saw were listed as 2 arc-seconds apart. Some of his close doubles are listed in Table 3.3.

Table 3.3: The magnitudes and separations for some close double stars, according to Dunlop.

Star name	58 Pic (Δ24)	53 Arg (Δ33)	146 Arg (Δ50)	v^2 Cen (Δ152)	328 Cen (Δ173)
Magnitudes	6 & 10	6 & 8	5 & 8	6 & 13	7 & 10
Separation (arc-sec)	2	2	2	2	2

John Herschel found that v^2 Cen is not a double star.

According to the *Guide* 8 Star Chart,[271] some of the Dunlop double stars are less than 6 arc-seconds apart. Table 3.4 lists the distance and magnitude data from *Guide* 8 and the Dunlop figures for the same double stars. The asterisk (*) indicates that Dunlop used the Parramatta Observatory's 3.25-inch, 46-inch focal length refractor. The other double stars were seen through his 9-inch reflector. There seems to be no correlation between the accuracy of Dunlop's estimations of distances or magnitudes and the telescope he used. Dunlop's estimates of distance (in arc-seconds) and magnitude were sometimes quite good.

[270] Robert Burnham, *Burnham's Celestial Handbook*, 3 vols, New York, 1978, 1, p. 729.

[271] *Guide* 8's double star separations are based on Hipparcos satellite data.

Table 3.4: Comparisons between distances (in arc-seconds) and magnitudes of some double stars from the Dunlop double star catalogue.

Dunlop Number	***Guide 8* (1826) (Hipparcos)**		**Dunlop**	
	Distance (arc-sec)	Magnitude	Distance (arc-sec)	Magnitude
5	8	5.7 + 5.8	2.5*	6.7 + 6.7
22	9.5	7.2 + 7.8	5.534*	6.7 + 7
23	2.9	7.2 + 7.4	3	7 + 7
70	4.1	5.2 + 7.0	5.49*	6 + 9
81	4.6	5.8 + 8.2	4	6 + 8
141	1.8	5.2 + 6.5	3 or 4*	6 + 9
168	6.7	8.5 + 8.7	5	8 + 8.9
190	9.6	7.9 + 9.7	3	7 + 8

3.5 CRITICISMS OF THE DUNLOP CATALOGUES

Towards the end of his life, and even after his death, Dunlop and his catalogues received substantial criticism. Firstly Brisbane criticised him for not producing sufficient results at the Parramatta Observatory in the 1830s. Also Dunlop was criticised by a number of astronomers after the publication of his three catalogues, of 629 clusters and nebulae, 253 double stars and 7385 stars. Chief among these was John Herschel, who was unable to find many of the non-stellar objects in the clusters and nebulae catalogue. Herschel also said that many of the double stars were not actually doubles, and that the Dunlop star catalogue was inaccurate. Forbes, who was indebted to Herschel, published a review of the Herschel catalogue and this review was easily and widely available. Forbes echoed and embellished Herschel's criticisms of Dunlop. The last major critic of Dunlop's work was Baron de Vos Steenwijk who found inaccuracies during his analysis of the Dunlop/Rümker star catalogue in the 1920s.

These criticisms are detailed below.

3.5.1 JOHN HERSCHEL

John Herschel began his southern sky survey more than seven years after Dunlop completed his 1826 catalogue of non-stellar objects. Herschel's *Results of Astronomical Observations Made during the Years 1834, 5, 6, 7, 8 at the Cape of Good Hope* (Appendix G) contained 1708 nebulae and clusters. This number included 89 that John previously saw from Slough, about 35 kilometres west of London. He goes on to explain:

> "Of the objects remaining, 135 are nebulae and clusters of my Father's catalogues, now, for the first time, re-observed; 9 are Messier's, 5 of which are identical with objects catalogued by Mr. Dunlop; and 206 others have also been identified, with more or less certainty (indicated by the absence or presence of the sign ?), with objects observed by Mr. Dunlop, and described in his Catalogue of Nebulae. The rest[272] of the 629 objects, comprised in that catalogue, have escaped my observation; and as I am not conscious of any such negligence in the act of sweeping as could give rise to so large a defalcation, but, on the contrary, by entering them on my working lists (at least, until the general inutility of doing so, and loss of valuable time in fruitless search, thereby caused it to become apparent), took the usual precautions to ensure their rediscovery; and as I am, moreover, of [the] opinion that my examination of the southern circumpolar region will be found, on the whole, to have been an effective one, I cannot help concluding that, at least in the majority of those

[272] 418 objects = 66.5%

> cases, a want of sufficient light or defining power in the instrument[273] used by Mr. Dunlop, has been the cause of his setting down objects as nebulae where none really exist. That this is the case, in many instances, I have convinced myself by careful and persevering search over and around the places indicated in his catalogue."[274]

Herschel only found 211 of Dunlop's 629 non-stellar objects. He was disappointed because he thought "the cream of the southern hemisphere had already been skimmed" by Dunlop, according to Agnes Clerke (1901, p.160)[275]

John Herschel also criticised the Dunlop *Double Star Catalogue*, and the catalogue of 7385 stars. Regarding the *Double Star Catalogue* John said, "A great many mistakes appear to have been committed in the catalogue ... either in the places, descriptions, or measures of the objects set down in it."[276] Herschel also criticised the Parramatta catalogue of 7385 stars. He said the Right Ascension was often out by –2 seconds and the catalogue could not be trusted.[277] This was due to both instrumental and observer error.[278] At that time "science favoured the rich and powerful"[279] and mistakes by those from lower classes were not accepted. British science was deeply entrenched in the class system.[280] Shirley Saunders notes that Dunlop's reputation was largely destroyed by comments made by the reviewers of John Herschel's work.

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[273] The original footnote says, "A 9-inch Newtonian reflector, of 9 feet focal length, which, in point of light, would correspond to about one-seventh of that used in my [John Herschel] sweeps. That such was its construction, I conclude from the mention of the *large mirror* in Philosophical Transactions, 1828, p.113."

The one-seventh comes from $(9^2 \times 0.60^2) / (18.5^2 \times 0.60) = 0.142 = 1/7$ assuming 60% reflectivity for speculum and that Sir John did not use a secondary mirror.

[274] J. Herschel, *Astronomical Observations*, p. 3.

[275] Brian Warner, 'Sir John Herschel at the Cape of Good Hope', *Transactions of the Royal Society of South Africa*, 49, 1994, p. 22.

[276] Saunders, *Colonial NSW*, p. 311.

[277] Saunders, *Colonial NSW*, p. 196.

[278] Saunders, *Colonial NSW*, p. 198.

[279] Saunders, *Colonial NSW*, p. 226.

[280] Saunders, *Colonial NSW*, p. 247.

3.5.2 JAMES DAVID FORBES[281]

J D Forbes was one of the reviewers of Herschel's work. He wrote in The Quarterly Review in 1849 regarding the Dunlop catalogue of nebulae:

> "Here is a sad tale and warning: for errors like Mr. Dunlop's not only deprive the more conscientious labours of their author of almost all their value, but they inflict a grave and positive injury upon the science which they pretend to promote. If men like Herschel are to spend the best years of their lives in recording for the benefit of a remote posterity the actual state of the heavens, in order that their changes may be examined and pronounced upon, what a galling discovery to find amongst their own contemporaries men who, without any wish to invent (we do not mean to charge Mr. Dunlop with that), but merely from carelessness and culpable apathy hand down to posterity a mass of errors, bearing all the external semblance of truth; - a quintessence of error so refined, that four hundred objects out of six hundred could not be identified in any manner, after only eight years, by the first observer of the day, and with a telescope seven times more powerful than that stated to have been used! We can add nothing to an exposure so humiliating."[282]

Dunlop died in 1848 so he would not have read this criticism. Forbes not only criticised the Dunlop catalogue of southern clusters and nebulae but his double star catalogue, his stellar catalogue and his later works also received similar negative comments.

In his review of Sir John's double star catalogue made at the Cape, J D Forbes says:

> "Dunlop, through negligence, indolence,[283] or something worse, has failed to be the elder Herschel of Antarctic Astronomy. The discrepancies are so great and frequent, that we can have scarcely any confidence in those whose agreement with the recent observations is sufficient to allow us to suppose that they might possibly be correct."[284]

3.5.3 BARON DE VOS VAN STEENWIJK

In 1923 the Dutchman, Baron de Vos Steenwijk[285] re-reduced the Parramatta stellar catalogue. He noted that "the observations between 1823 and 1825, made by Dunlop, were in many cases incomplete" and that "Dunlop recorded hundreds of stars which do not really exist."[286]

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[281] Forbes was a physicist and professor of Natural Philosophy at the University of Edinburgh, 1833 – 1859.

[282] Saunders, *Colonial NSW*, p .312.

[283] This was not the cause of Dunlop's errors.

[284] Saunders, *Colonial NSW*, p. 311.

[285] Dudley Holdings, 2007, <http://www.dudleyobservatory.org/Collections/pdf_files/Book_Listingr.pdf>, accessed 11 April, 2010.

3.5.4 BRISBANE

Brisbane showed little interest in Dunlop's work after Dunlop returned to Parramatta in 1831. It was not until two years later that Brisbane asked if Dunlop had sent back any observations.[287] The Astronomer Royal (1835-1881) George Airy wrote in 1841 that Dunlop's recent observations were even poorer than expected and that he was "a ninny for sending them [to England] at all."[288]

In 1842 Brisbane went with fellow astronomer Francis Baily to see John Herschel and obtain his support to either give Dunlop an assistant or remove him from his job because there were not sufficient or adequate observations being sent back from the Parramatta Observatory.[289] But Sir John was out and Brisbane did not pursue the matter. Towards the end of the 1840s Brisbane joined in the general criticism of Dunlop. He was mainly criticising Dunlop's lack of productivity in the 1830s, but his criticism also reflected on Dunlop's earlier catalogues. On February 26, 1846 Brisbane said his appointment of Dunlop was "a mistake."[290] Saunders notes that, "Brisbane had no appreciation of the lack of support and difficulties faced by Dunlop and advocated his dismissal so that 'a real working man [could be] sent out in his place.'"[291] Brisbane hoped that "something is in hand to revive the Parramatta Observatory and to dismiss the culpable Director thereof."[292] However by 1846 Dunlop was too sick to revive it.

3.5.5 CONCLUSION

The legacy of criticism of Dunlop's work, particularly his catalogue of non-stellar objects has meant that his catalogues were not, and are still not utilised by other astronomers. There are three major reasons for this:

1. There was no one in the southern hemisphere to use it in the years between its publication and the publication of the Herschel catalogue
2. Observers preferred to use John Herschel's larger and more accurate catalogue
3. The Dunlop catalogue is difficult for more recent observers to obtain and use.

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[286] Bergman, *Rümker*, p. 256.

[287] Saunders, *Colonial NSW*, p. 328.

[288] Saunders, *Colonial NSW*, p. 357.

[289] Saunders, *Colonial NSW*, p. 359.

[290] Saunders, *Colonial NSW*, p. 358.

[291] Saunders, *Colonial NSW*, p. 360. Brisbane to Smyth, April 13, 1846.

[292] Saunders, *Colonial NSW*, p. 360. Smyth to Airy, June 9, 1846.

However the criticisms of Dunlop’s work were not all justified. Major problems for him included a lack of financial and personnel support, a homemade telescope with poor resolving power and a lack of accurate equipment. He was an inexperienced observer who did not have the educational or financial advantages of John Herschel.

In defence of Dunlop’s work his catalogues are actually better suited to amateur astronomers with smaller telescopes. His descriptions are of interest to those with 6 to 10-inch telescopes because Dunlop's telescope was of a similar size and had a similar limiting magnitude. The descriptions are also important because they were the first made of many bright far southern objects, including genuine objects that John Herschel failed to see.

Although there are many positional discrepancies and apparently non-existent objects included (probably double stars or asterisms), there are numerous original objects which were first seen by him, including a number which were missed by Herschel. When Herschel’s better quality catalogue became available not long after, and with the criticism of Dunlop so widely known, the Dunlop Catalogue was no longer used. No new surveys of the southern skies were made for about a century, so the Herschel catalogue became and remained the standard by default.

A Catalogue of Nebulae and Clusters of Stars in the Southern Hemisphere observed in New South Wales failed because it contained many errors and because the influential John Herschel and his friends discredited it publicly. Other Dunlop critics tended to compare him to both William and John Herschel, with their larger 18.5-inch telescope. In fact it would be fairer to compare Dunlop (using a 9-inch telescope) to Messier whose telescopes were of a similar size[293] and Messier only catalogued 109 objects. Unfortunately, astronomers have continued to ignore James Dunlop and his contribution to southern astronomy.

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[293] Mallas & Kreimer, *Messier Album*, p. 6.

CHAPTER 4 – SIR JOHN FREDERICK WILLIAM HERSCHEL, The follow-on from Dunlop

4.1 LIFE SKETCH OF JOHN HERSCHEL (1792-1871)

Plate 4.1: John Herschel[294] in 1845 after his time at the Cape and his father William Herschel (right).[295]

Biographical information in the following section on John Herschel was mainly obtained from the book by G Buttmann, called *The Shadow of the Telescope: A Biography of John Herschel*.

4.1.1 WILLIAM HERSCHEL, JOHN'S FATHER

Eleven years before John's birth, Frederick William Herschel (1738 – 1822) discovered the planet Uranus on March 13, 1781[296] while surveying the sky with a homemade 6-inch diameter reflector from his garden in Bath, England. William had become interested in

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[294] The image was obtained from: John J O'Connor, & Edmund F Robertson, The MacTutor History of Mathematics archive, *Biographies – John Herschel*, 1999, <http://www-history.mcs.st-andrews.ac.uk/PictDisplay/Herschel.html>, accessed 25 January, 2007.

[295] Slough Borough Council, *Sir William Herschel*, 2007, <http://www.slough.gov.uk/mytown/articles/2235.asp>, accessed 25 January, 2007.

[296] Uranus was mag 5.6 at Right Ascension 2000: 05h 49m 06s, Declination: +23 38'

astronomy while he was director of the Bath orchestra, and this discovery brought him great fame as an astronomer.

Five years later, in April 1786, King George III appointed William as the Royal Astronomer. John's father and his aunt, Caroline Herschel (1750-1848), moved to Slough,[297] where William was paid £200 per year and Caroline £50 per year to assist her brother. William made telescopes at Slough and sold them all over Europe. He also made two telescopes for himself; a 20-inch aperture and a 48-inch aperture reflecting telescope. With Caroline's help he used these to make catalogues of double stars, star clusters and nebulae.

William (aged 49) married Mary Pitt (aged 38), nee Baldwin on May 8, 1788 and John Frederick William Herschel was born in their home, *Observatory House*, at Slough, on March 7, 1792. As a child, John had little contact with other children. During the day, he had to maintain silence while his father slept, as William made his astronomical observations at night. Under Caroline's guidance, John developed an interest in chemical experiments, which they carried out at her house.

Plate 4.2: John's drawing of *Observatory House* at Slough[298] and William's coat of arms showing Uranus and the 40 ft telescope.[299]

William's home and observatory were at *Observatory House* (demolished 1962) on Windsor Road near Herschel Street. A monument honouring William Herschel stands in Herschel

[297] In August, 1782 he moved to Datchet and June 1785 to "Clay Hall" near Windsor.

[298] The image was obtained from: Slough Museum, *Family Life*, <http://www.sloughmuseum.co.uk/family_life.htm>, accessed 17 January, 2007.

[299] The image was obtained from: Escutcheons of Science, *Sir William Herschel*, <http://home.att.net/~numericana/arms/herschel.htm>, accessed 17 January, 2007.

Street close to the former position of the 40 ft telescope. Its location is shown on the map in Plate 4.3. The twelfth century, St Laurence's Church was William’s parish church until his death in 1822, aged 84. He was buried in a vault just inside the chancel.

Plate 4.3: Map of Slough[300] showing the location of the monument that marks the site of the 40 ft telescope at *Observatory House* and the monument to William Herschel.[301] Also shown is the location of St Laurence’s Church.

Plate 4.4: St Laurence's Church[302] where William is buried and the stained glass window by Andrew Taylor commemorating William Herschel.[303]

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[300] Multimap, *Great Britain & NI, Slough*, 2007, <http://www.multimap.com>, accessed 25 January, 2007.

[301] The image was obtained from: Slough Borough Council, *Sir William Herschel*, 2007, <http://www.slough.gov.uk/mytown/articles/2235.asp>, accessed 17 January, 2007.

4.1.2 JOHN'S EDUCATION

In May 1800 at the very young age of 8, John was a boarding pupil at Eton (one mile south of Slough) for a short period. "One day his mother, no doubt overanxious about his somewhat delicate health, saw her son inveigled into a boxing match by an older and stronger boy and knocked to the ground."[304] He was withdrawn from Eton and sent to a private school at Hitcham, where a private tutor was also provided. John was not proficient at mathematics at this stage of his life, but at age 21 became a Fellow of the Royal Society after a "brilliant mathematical investigation."[305]

John, aged 17, enrolled in the University of Cambridge in October 1809 and studied mathematics and physics in St John's College. He was an exceptional student, the best candidate doing Mathematical Tripos (becoming Senior Wrangler) within the Bachelor of Arts degree. He developed close friendships with George Peacock (1791-1858) and Charles Babbage (1792-1871). They started the Analytical Society, in 1812. "The object of this society was to make known in England the modern methods of infinitesimal calculus developed chiefly in France and Germany and to replace the rather cumbersome notation of Newton's 'calculus of fluxions' by the more elegant usages practiced on the Continent. This ambitious project by the three undergraduates was to achieve remarkable success within five years."[306] Herschel and Peacock translated a book on calculus by the French mathematician Lacroix in 1816. They supplemented this in 1820, with two volumes containing examples of the French methods, and Newton's notation was soon displaced.

During his vacations John did experiments in his own small laboratory at Slough. Chemistry at the time was undergoing major changes due to the work of Humphry Davy and Joseph Louis Gay-Lussac. He showed great enthusiasm for new ideas. In January 1814, against his father's wishes, John decided to become a lawyer and moved to London to study at Lincoln's Inn. William wanted John to become a clergyman, because "clerical duties would provide more leisure for the pursuit of private hobbies and scientific interest than any other profession

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[302] G Cozens, 2006.

[303] The image was obtained from: Andrew Taylor, The Herschel Window, 2000, <http://www.aptglasspainter.com/10020/info.php?p=7&pno=0>, accessed 17 January, 2007.

[304] Gunther Buttmann, *The Shadow of the Telescope*, New York, 1965, p. 9.

[305] Buttmann, *Shadow*, p. 9.

[306] Buttmann, *Shadow*, p. 11.

could offer."[307] Much of John's time in London was spent pursuing chemistry and mineralogy under the influence of William Hyde Wollaston and Edward Daniel Clarke. By the summer of 1815, John decided to quit law because of poor health and a lack of interest. He returned to St John's at Cambridge as a sub-tutor and examiner in mathematics where he spent eight to twelve hours a day "examining 60 or 70 blockheads."[308] He took the degree of Master of Arts in July 1816, but his life was about to take a new turn.

4.1.3 JOHN TAKES UP ASTRONOMY

"In the summer of 1816 John accompanied his father on a trip to Dawlish, a popular resort on the Devonshire coast just north of Torquay. William Herschel, who was then in his seventy-eighth year, had for some time suffered from various ailments brought on by advancing age and had been compelled to restrict his astronomical observations more and more."[309] In October 1816, soon after the holiday together, John decided to become his father's astronomical assistant. He wrote, "I am going, under my father's directions, to take up the series of his observations where he has left them and continuing his scrutiny of the heavens with powerful telescopes."[310] John thus began the work for which he is best remembered, revising and continuing his father's life work.

William, who had made or attempted to make 2160 telescope mirrors, taught John to grind and polish mirrors. He also taught John to sweep the sky. "These 'sweeps' or surveys were carried out by systematically observing all noteworthy objects – star clusters, nebulae, double stars, and so forth – in successive zones of the sky; the results were recorded in a catalogue. From personal experience the son came to appreciate the incredible physical exertions that the father's years of night watches had entailed."[311]

However John never devoted himself exclusive to astronomy. His other interests included physics, chemistry, geology and mathematics as well as travel, but the study of light was his first love. He became interested in polarisation and birefringence (double refraction); he studied the interference of light and sound waves; and he investigated "spherical and

[307] Buttmann, *Shadow*, p. 15.

[308] Buttmann, *Shadow*, p. 18. This shows some arrogance on John's part.

[309] Buttmann, *Shadow*, p. 19.

[310] Buttmann, *Shadow*, p. 20.

[311] Buttmann, *Shadow*, p. 22.

chromatic aberrations of compound lenses."[312] In 1819 he discovered that "sodium thiosulphate has the property of dissolving silver salts rapidly and completely."[313] Twenty years later this contributed to the invention of photography. John also did mathematical research and contributed an article on the history of mathematics to the Edinburgh Encyclopaedia.

Another interest was the study of the solar spectrum. John, like his father, believed "that the sun was a dark body surrounded by a luminous envelope."[314] Later in South Africa John carried out a major study of the sun.

On January 12, 1820 John Herschel, with his friends Babbage, South, Colebrooke, Pearson and Baily established the Astronomical Society, (which became the Royal Astronomical Society in 1831.) Sir Joseph Banks, then president of the Royal Society opposed the establishment of the Astronomical Society and persuaded its first president Edward Seymour to resign. William Herschel was eventually persuaded to be president and when Banks died in June 1820, the opposition ceased.

William catalogued 800 double stars and was particularly interested in binary stars. He found fifty binary stars by 1804. In 1816, soon after he decided to carry on his father's work, John resolved to extend and improve this catalogue. He began working with James South in 1821, and together they made a catalogue of double stars using two refractors, one 5-foot and the other 7-foot in focal length with 3.75-inch and 5-inch apertures respectively. South's refractors were made by Edward Troughton and were ideal for measuring double stars as they could measure position angles to one arc-minute. Together they searched for any movement in the double stars since William first measured them. By the end of 1823, Herschel and South had catalogued 380 double stars. South went to France with his 7-foot refractor in 1825 and catalogued a further 458 double stars. In 1828 the French astronomer Felix Savary used William Herschel's measurements to calculate the first orbit of a binary star, Xi Ursae Majoris, "followed in 1829 by a solution from [John] Herschel (1832)."[315]

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312 Buttmann, *Shadow*, p. 26.

313 Buttmann, *Shadow*, p. 27.

314 Buttmann, *Shadow*, p. 25.

315 Brian D. Mason, Harold A. McAlister, William I. Hartkopf, & M. M.Shara, 'Binary star orbits from speckle interferometry. 7: The multiple system XI Ursae Majoris', *The Astronomical Journal*, 1995, vol. 109, no. 1, p. 332-340, in SAO/NASA Astrophysics Data System (ADS), American Astronomical Society, <http://adsabs.harvard.edu/full/1995AJ....109..332M>, accessed 11 April, 2010.

4.1.4 EUROPEAN TRAVELS, 1821 - 1826

During the summer of 1821 John made the first of several trips to the continent, accompanied by Babbage. There they met with other scientists doing similar experiments on physical optics in France, Switzerland and Italy. During his travels John measured the temperature, the altitude (with a barometer) and made drawings with his camera lucida. This pocket sized instrument, invented by Herschel's friend Wollaston in 1807, consisted of two inclined sheets of plain glass arranged so that "the image of an object produced by it is seen by the eye as if lying on a sheet of paper placed beneath and the image can be traced out on the paper."[316]

In the summer of 1822 he made a second trip to Europe, touring Holland and Belgium. His father died on August 25, 1822 while John was in Europe and his Aunt Caroline later returned to Hanover, Germany. That same year John described a new method for calculating occultations of the stars by the moon and provided tables to determine the places of fundamental stars.

John's third continental trip to France, Italy and Sicily began in April 1824. Within eight hours of his arrival in Paris, he met with Arago, Laplace, Humboldt, Thénard, Gay-Lussac, Poisson and Fourier. He also visited Guiseppi Piazzi who was famous for making a catalogue of 7500 stars and discovering the first asteroid, Ceres (now a dwarf planet). In Munich, Joseph von Fraunhofer presented him with a large prism of flint glass, which he later used to study photochemistry. The six and a half month journey concluded with a visit to Aunt Caroline at Hanover, before his return to England in October 1824. He also made a short journey to France in the autumn of 1826 where he used the actinometer he had invented to measure radiation from the sun.

Between 1825 and 1833 John Herschel produced two great catalogues. The first contained 2306 nebulae and clusters including 525 newly discovered objects, and also included 100 drawings of remarkable objects. The second was a six-part catalogue of double stars, containing 5075 pairs. This was an amazing feat considering that clear, moonless nights are rare in England. Some nights he was very discouraged as the following quote from his notes shows. "Two stars last night, and sat up till two waiting for them… Ditto the night before. Sick of star-gazing – mean to break the telescope and melt the mirrors."[317]

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[316] Buttmann, *Shadow*, p. 113.

[317] Buttmann, *Shadow*, p. 51.

John now concentrated on measuring position angles between double stars. He wanted to measure the parallax shift and hence the distance to the stars. In 1826 Herschel published a paper entitled "On the parallax of the fixed stars" which contained a table giving the approximate annual parallaxes for some 70 double stars.[318] Two astronomers measured stellar parallaxes by the late 1830s. Thomas Henderson, in Cape Town, measured the first stellar distance by the parallax method (to Alpha Centauri), but he did not publish it timeously.[319] Friedrich Bessel accurately measured the distance to 61 Cygni, publishing first in 1838.[320]

In July 1825, John helped supervise a whole detachment of artillery, deployed to measure the difference in longitude between Paris and Greenwich, using rockets. The measurement for Paris was calculated to be 2°20'24", out by only 10.5" according to modern measurements. However John tried to avoid paid employment like this and he was fortunate to be able to do so, because "his father had left him a very considerable fortune, which enabled him not only to fill all material needs but to finance his sometimes quite expensive scientific enterprises without requiring a professional salary."[321]

Herschel was elected president of the Astronomical Society in February 1827, but found this seriously interfered with his research. "He wanted above all to keep his personal freedom and scientific independence, and not to have the scope of his private researches restricted by any official and public engagements."[322] He was offered academic positions at Cambridge and the University of London, but refused both. "It was partly out of vanity that he would prefer his contribution to knowledge to be regarded as that of an amateur rather than a professional scientist,"[323] preferring he said to "loiter on the shores of the ocean of sciences and pick up such shells and pebbles as take my fancy for the pleasure of arranging them and seeing them look pretty."[324]

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318 Buttmann, *Shadow*, p. 53, quoting *Philosophical Transactions*, 1826, pp. 256-280.

319 Astronomical Society of Southern Africa, *Historical Section – Henderson*, 2004, <http://www.saao.ac.za/assa/html/his-astr_-_henderson_t.html>, accessed 18 January, 2007.

320 Charles Coulston Gillispie, *Dictionary of Scientific Biography*, New York, 1970, p. 101.

321 Buttmann, *Shadow*, p. 67.

322 Buttmann, *Shadow*, p. 55.

323 Buttmann, *Shadow*, p. 56.

324 Buttmann, *Shadow*, p. 56.

John did much for the adoption, in England, of the wave theory of light. This was at odds with Newton's particle theory. His 1827 treatise on *Light*, written for an encyclopaedia, was translated into French in 1830 and into German in 1831. He also wrote a book called *Preliminary Discourse on the Study of Natural Philosophy*, which gave a general introduction to the nature and method of science and short surveys of astronomy, physics, chemistry, geology and mineralogy. The book also included much of Herschel's philosophy of life.

4.1.5 MARRIAGE AND CHILDREN

Herschel's friends, Whewell, Grahame, Peacock and Babbage were all involved in scientific pursuits and apart from them he had few social contacts outside of science. He was becoming a "crotchety and eccentric old scholar"[325] and Grahame, urging him to marry, introduced him to a widow by the name of Mrs Alexander Stewart. On March 3, 1829, when John was about to turn 37 years old, he married 18 year old Margaret,[326] one of Mrs Stewart's two daughters. She was almost twenty years younger than John. A portrait of Margaret Brodie Stewart (1810-1864) can be seen in Plate 4.5.

Plate 4.5: Margaret Brodie Stewart (after Alfred Edward Chalon 1829), wife of John Herschel. [327]

In the late 1820s John decided to travel to the southern hemisphere to make a catalogue of the southern skies. However the expedition was delayed because his mother, Mary, was dying. She died on January 4, 1832 and was buried at St Laurence's Church, Upton with her

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[325] Buttmann, *Shadow*, p. 67.

[326] Margaret was born August 16, 1810.

[327] The Herschel Society of Japan, *Portraits – John's children*, 2005, <http://www.ne.jp/asahi/mononoke/ttnd/herschel/p-text/jchildren-e.html>, accessed 25 January, 2007.

husband. John's first child, Emilia Mary was born on March 31, 1830 and his second daughter, Isabella was born in 1831, both before his mother's death. His first son, William James was born in 1833, six months before they left for Cape Town. Altogether John and Margaret had twelve children. John and Margaret's other children were Margaret Louise (1834), Alexander Stewart (1836), Colonel John (1837), Maria Sophie (1839), Amelia (1841), Julia Mary (1842), Matilda Rose (1844), Francisca (1846) and Constance Ann (1855).

After the death of his mother, John and his family moved from London back to the old family home at Slough. In June 1832 he paid a farewell visit to Aunt Caroline in Germany.

4.1.6 CAPE TOWN, 1834 - 1838

Herschel planned to collect all his father's published papers, written over 40 years, into a single volume, but this was not done until 1912 when J L E Dreyer published them in two volumes called *The Scientific Papers of Sir William Herschel*. Instead Herschel decided to explore the southern sky with the 20-foot reflector. He considered travelling to Parramatta but decided to go to Cape Town instead for a number of reasons, including the fact that Margaret's brother was there. The Royal Society and the British Admiralty offered to help with this expedition but Herschel refused because he did not want to compromise his independence.

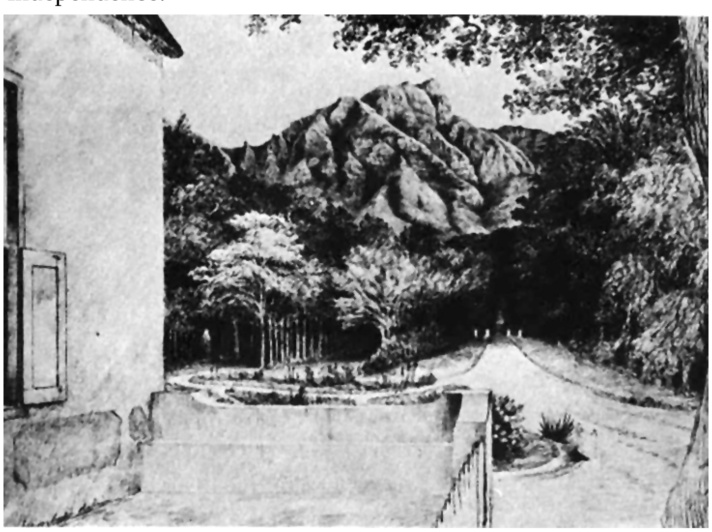

Plate 4.6: A highly finished camera lucida sketch by John Herschel of Devil's Peak, from the front of his home *Feldhausen*.[328]

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[328] Astronomical Society of South Africa, *Feldhausen Photo Gallery*, 2006, <http://www.saao.ac.za/assa/html/his-pl-obs_-_feldhausen_-_gall.html>, accessed 30 July, 2007.

On November 13, 1833 John Herschel and his family sailed from Portsmouth on the *Mountstuart Elphinstone*, bound for Cape Town. The journey took nine weeks. They arrived on January 16, 1834 and spent several days unloading their apparatus and baggage and moving into a large property called *Feldhausen*, ten kilometres southeast of Cape Town on the eastern side of Table Mountain. Images of the house and surrounds can be seen in Plate 4.6 and Plate 4.7. Orchards and a grove of trees surrounded it. The weather there was much better than in England, especially in winter.

Plate 4.7: *Feldhausen*, the Cape Town home of John Herschel, in later years just before it was demolished.[329]

Herschel's assistant, John Stone, helped him set up two telescopes; the 18.5-inch aperture 20-foot long reflector and the 5-inch aperture 7-foot refractor. On February 22, Herschel looked at the triple star Alpha Crucis and the nebula Eta Argus (Carinae) for the first time using the 20-foot, but the 7-foot was not used until May 2. Section 4.2 contains more information on the two telescopes. Thus John became the first person to explore the southern sky using a large telescope.

[329] Astronomical Society of South Africa, *Feldhausen Photo Gallery*, 2006, <http://www.saao.ac.za/assa/html/his-pl-obs_-_feldhausen_-_gall.html>, accessed 30 July, 2007.

On March 5, Herschel began regular sweeps. He searched for star clusters, nebulae and double stars in a series of zones 3° long in Declination. In four years he catalogued 1708 clusters and nebulae and 2102 double stars in the southern sky. He also studied the structure of the Milky Way by counting a total of 68,948 stars in 3000 areas of the sky. His father William believed that there were a vast number of cosmic gaseous masses "a shining fluid, of a nature totally unknown to us,"[330] but John thought all nebulae were made up of stars. As a result John sometimes catalogued several parts of one nebula with different numbers instead seeing the nebula as a single object. The invention of the spectroscope proved William correct.

John made an astrometer to measure the magnitudes of 191 bright stars by comparing them with the light of the moon. He also arranged the naked eye stars by magnitude using his step method. To do this, he divided the star charts made by the German astronomer Johann Bode into triangular fields and "all stars visible to the naked eye were arranged in sequences. This was done by writing down a list of stars having very marked differences in brightness between them, leaving enough space between successive entries so that more stars could be interpolated."[331]

William Herschel correctly thought the Milky Way was a lens-shaped system, but John thought it was ring-like. He noted some dark patches in the Milky Way, such as the Coal Sack, and he discovered a large number of nebulae outside the Milky Way, but did not know that these were distant galaxies. He also made detailed catalogues of the Magellanic Clouds, which he called the Cape Clouds. John listed 244 objects in the small cloud and 919 objects in the large cloud. All the catalogues he made were arranged by Right Ascension. He preferred north polar distance (NPD) to Declination.

A map made of the area around the Orion nebulae contained 150 stars and a map of the area around Eta Argus included 1216 stars. The star Eta Argus was fourth magnitude according to Halley and second magnitude according to others but it suddenly brightened at the end of 1837 to be equal to Alpha Centauri (magnitude –0.1). By January 20, 1838 it had faded to the magnitude of Rigel (magnitude 0.1) and by April 14, it was similar to Aldebaran (magnitude 0.8). Thomas Maclear, who was the director of the Cape Observatory at Cape Town, thought

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[330] Buttmann, *Shadow*, p. 103.

[331] Buttmann, *Shadow*, p. 96.

it was only slightly fainter than Sirius (magnitude –1.5[332]) at its maximum in early 1843. Herschel also observed this very unusual occurrence between 1834 and 1838.

Maclear and Herschel worked jointly on a number of projects, including measuring the difference in longitude between *Feldhausen* and the Cape Observatory (5.5 km apart). Maclear provided Herschel with the exact positions of a number of fundamental stars and Herschel helped Maclear with financial support for tidal and meteorological observations, especially at the solstices and equinoxes.

John observed Halley's Comet between October 28, 1835 and May 5, 1836. It was magnitude 2.4 when he first saw it and magnitude 12.7 at the end. He moved the 7-foot telescope to the sand hills on the Cape Town flats, south-east of the city, and cut down some oak trees near the 20-foot telescope in order to study the comet. It was visible in the evening sky until November 10 (elongation 33^{o} from the sun) and in the morning sky after January 26 (elongation 66^{o} from the sun). Herschel speculated on the cause of the comet's tail, and made the radical (and correct) proposal that it was due to positive and negative charges.

He also tracked the positions of Saturn's satellites including two faint moons that were discovered by William in 1789, and subsequently lost.

Herschel made drawings to record the positions of sunspots by projecting the sun with a power of 105 or 179, and he speculated on the cause of them, believing sunspots were holes in the solar atmosphere, which allowed a view of the dark solid core. He inherited his belief in the dark core from his father.

As already mentioned three children were born in Cape Town, Margaret Louisa on September 10, 1834, Alexander Stewart on February 5, 1836 and John on October 29, 1837. On Sundays the family attended church at the nearby village of Rondebosch. Herschel developed an interest in botany and collected tuberous and bulbous plants to take back to England. Using his camera lucida he drew the plants and his wife coloured the drawings. Herschel's other interests included poetry and music and he played the flute and violin. On June 15, 1836 he was visited by Charles Darwin who described him as "a very modest man, rather shy and even gauche[333] in society, despite his lively intellect."[334]

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[332] David Frew calculated this to be visual magnitude minus 1.0. D.J. Frew, 'The Historical Light Curve of Eta Carinae', *Journal of Astronomical Data*, 2004, vol.10, number 6.

[333] Meaning: lacking social experience or grace.

While Herschel was at Cape Town, the *New York Sun* published a series of false articles about his "discoveries" on the moon. These included paradise-like woods and meadows, hills and valleys and moon men and women. It was some time before Herschel found out about these articles and denied them. On March 11, 1838 the Herschel family left Cape Town for England on the *Windsor*. The voyage, including a stop over at St Helena, took nine weeks. A stone obelisk, seen in Plate 4.8, commemorating their stay was later erected at *Feldhausen*, in the grounds of the current Grove Primary School, 7 km south of Cape Town (latitude 33.98^{o}S, longitude 18.46^{o}E). John believed his time at the Cape was the happiest time of his life.

Plate 4.8: Stone obelisk marking the site of the 20-foot telescope in the grounds of the Grove Primary School[335] and the satellite image showing its location.[336]

4.1.7 ENGLAND, 1838 - 1840

Back at England Herschel visited Lord Glenelg, Secretary of State for the Colonies regarding education in South Africa. While in Cape Town, Herschel had campaigned for public education, demanding "fundamental improvement in the social and economic position of teachers and the creation of a secure professional status."[337]

On June 28, 1838, Herschel was made a Baronet, at the time of the coronation of Queen Victoria. Soon after this John paid another visit to Caroline Herschel in Hanover and also met with other scientists on the Continent. In London he discussed constellation reform with the Astronomer Royal, George Biddell Airy. John proposed a "complete rearrangement of the

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[334] Buttmann, *Shadow*, p. 117.

[335] G Cozens, 2006.

[336] Google Earth, *Digital Globe*, 2006.

[337] Buttmann, *Shadow*, p. 114.

constellations in the southern sky."[338] "Herschel's plan was not accepted by astronomers on the Continent, and he withdrew it,"[339] but in 1928, the IAU (International Astronomical Union) used a similar method to draw constellation boundaries for the whole sky.

In October 1838 Herschel dined with the Queen and Lord Melbourne at Windsor Castle and they discussed a planned trip to the south magnetic pole. Herschel was a member of a committee convened to study geomagnetism and meteorology, using geomagnetic stations established at St Helena, Van Diemen's Land, Cape Town and Madras in 1840 and 1841. Another forty-seven stations were set up in other countries. These found a correlation "between disturbances of the compass needle and events in the solar atmosphere, after the discovery of the eleven-year periodicity of sunspot numbers."[340] As part of this project voyages were made to the north and south magnetic poles.

Herschel reluctantly became involved in many official duties and willingly became president of the Royal Astronomical Society. While president he wrote a preface for *A catalogue of 9766 stars in the southern hemisphere, for the beginning of the year 1750, from the observations of the Abbé de Lacaille, made at the Cape of Good Hope in the years 1751 and 1752*. The catalogue was published after the data from Lacaille's observations were finally reduced under the superintendence of Thomas Henderson. The University of Oxford gave John an honorary doctorate in June 1839, and he was a member of the Board of Management of the British Museum and the Board of Visitors of the Royal Observatory at Greenwich.

Between 1839 and 1844 Herschel investigated photography and photochemistry using his understanding of physics and chemistry. He was the first to use the words 'positive' and 'negative' for the images. He also used glass plates, coated in silver nitrate and later silver bromide. These had a greater sensitivity to light and could be exposed in a few seconds. He realised that susceptible paper, a good lens and a chemical fixer were needed to produce pictures. His discovery that sodium thiosulphate dissolves silver salts and fixes the image was included in subsequent patents made by others. On January 30, 1839 Herschel took a picture of the 40-foot telescope at Slough using paper coated with silver carbonate solution. On July 9, 1839 he made a picture of the solar spectrum.

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[338] Buttmann, *Shadow*, p. 122.

[339] Buttmann, *Shadow*, p. 123.

[340] Buttmann, *Shadow*, p. 125.

January 1, 1840, found the Herschel family assembled inside the tube of the dismantled 40-foot telescope while John read a poem written by him for the occasion. Leaving some grinding and polishing tools inside, the tube was closed, sealed and left in the grounds of *Observatory House*. John's 20-foot reflector lay in the cellar at Slough and was never used again. It was eventually displayed at the Royal Observatory at Greenwich.

4.1.8 HAWKHURST, 1840 - 1871

Herschel decided to move from Slough in 1840 because of the increasing urbanisation and because he wanted a refuge where he could reduce his Cape Observations. Also *Observatory House* had become too small for his family of seven children (Maria Sophia was born after their return from South Africa). In April 1840, he purchased a house called *Collingwood* at Hawkhurst, 70 km southeast of London, an "isolated country house in Kent where he spent the remainder of his life."[341] Here he set up the 5-inch aperture 7-foot refracting telescope on a small observing platform on the roof.

John observed a solar eclipse on July 8, 1842. The path of totality passed just south of both Lisbon and Vienna. He thought the three large prominences were enormous cloud formations. This supported his father's model of the sun. He proposed a permanent watch over sunspot activity and Warren de la Rue began photographing the sun systematically in 1858 from England. John used "a cylindrical vessel of sheet-zinc 3.75 inches in diameter and 2.4 inches deep, filled with dark-coloured water"[342] to measure the heat output from the sun.

While at *Collingwood*, John discovered that Betelgeuse was a variable star. He observed the great magnitude zero comet of March 1843 and magnitude 5.7 Biela's Comet early in 1846.

Herschel also spent many hours analysing the results of four hundred nights observing at the Cape. By 1844, with his health failing from continued trouble with rheumatism and bronchitis, he wrote, "I feel my health rapidly breaking and I have many and distinct warnings that what I have to do I must do quickly, that *time* is the stuff of which life is made."[343]

His *Results of Astronomical Observations Made during the Years 1834, 5, 6, 7, 8 at the Cape of Good Hope; Being a Completion of a Telescopic Survey of the Whole Surface of the*

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[341] Buttmann, *Shadow*, p. 129.

[342] Buttmann, *Shadow*, p. 110.

[343] Buttmann, *Shadow*, p. 156.

Visible Heavens, Commenced in 1825, (Appendix G) was finally completed on March 7, 1847, on his 55th birthday and published in London that year. The book contained seven chapters as outlined below:

1. 1708 nebulae and star clusters, 919 objects in the Large Magellanic Cloud and 244 in the Small Magellanic Cloud
2. 2102 double stars seen with the 20-foot telescope and 1081 double stars seen with the 7-foot telescope
3. Brightness estimates for 2341 stars
4. Star gauges (counts) done with the 20-foot telescope
5. A description of Halley's Comet from October 1835 to May 1836
6. A summary of observations of seven satellites of Saturn and
7. Observations of sunspots.

The book earned Herschel another Copley Medal in 1847. A copy of the book was sent to Aunt Caroline in Hanover, a year before she died aged 98.

Visitors to *Collingwood* included Encke in 1840, Bessel in 1842, and Airy, Babbage, Whewell, Peacock and Pritchard. He also hosted a meeting on July 10, 1847 between rivals Urbain Jean Joseph Leverrier (1811-1877) and John Couch Adams (1819-1892) after both allegedly made independent predictions for the position of Neptune. On September 23, 1846 Johann Gottfried Galle (1812-1910) at Berlin Observatory found Neptune at the position predicted by Leverrier while John Challis at Cambridge Observatory and George Airy at Greenwich Observatory apparently did not search for it at the position given by Adams.[344]

Herschel was now devoting most of his time to writing and he authored a 700 page book, *Outlines of Astronomy*, which was printed in at least thirteen editions between 1849 and 1902. He also wrote an article on meteorology, which was printed in the eighth edition of the *Encyclopaedia Britannica* and in 1845 published two papers on fluorescence.

The year 1847 saw him elected president of the Royal Astronomical Society (RAS) for the third time but his role was largely as a figurehead because his name gave the RAS prestige.

As mentioned earlier his family grew from seven to twelve children while at *Collingwood* with the births of Amelia (1841), Julia (1842), Matilda Rose (1844), Francisca (1846) and Constance Anne (1855). Constance wrote *The Herschel Chronicle* in 1938, a biography of

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[344] The circumstances surrounding the discovery of Neptune are still disputed.

the Herschel family, which contained documents on William and Caroline Herschel. John turned 63 the year Constance was born.

In December 1850, probably because of financial need, Herschel decided to take up public office, and he was appointed Master of the Mint, a post that was once held by Sir Isaac Newton. He attempted to introduce decimal currency but did not succeed. During this time he lived in London while his family remained 70 km away at *Collingwood*. He no longer had time for his scientific pursuits and, suffering from bronchitis, rheumatism and gout, he took opium to relieve the pain. Late in 1854 he suffered a nervous breakdown and resigned from the mint in April 1856.

Back at *Collingwood* he continued his solar observations and attended a meeting in Aberdeen on terrestrial magnetism in 1859. This was "his last major public appearance."[345] He also produced the *General Catalogue* which contained almost all the nebulae and star clusters discovered before 1863, a total of 5079 objects. To do this he had to reduce fifty thousand separate objects. This was printed in the *Philosophical Transactions* in 1864 and enlarged in 1888 by Dreyer to become the *New General Catalogue of Nebulae and Clusters* (NGC), which is still used today. He also produced a catalogue of 10,300 double stars, which was published after his death and a more detailed catalogue of double stars, which was never published.

John Herschel died May 11, 1871 at *Collingwood*, aged 79 and was buried in Westminster Abbey. A contemporary wrote in an obituary, "He touched nothing that he did not adorn."[346]

[345] Buttmann, *Shadow*, p. 184.

[346] Buttmann, *Shadow*, p. 190.

4.2 JOHN HERSCHEL'S TELESCOPES

4.2.1 THE TWENTY FOOT REFLECTOR

The 20-foot [6.1 m], 18.5-inch telescope with its standard 39 mm eyepiece had a power of 157 times and a field of view of 15 arc-minutes 4 seconds. This telescope was said to have an aperture of 18.75 inches by William, and 18.25 inches by John. The average of these two numbers is used throughout this thesis.

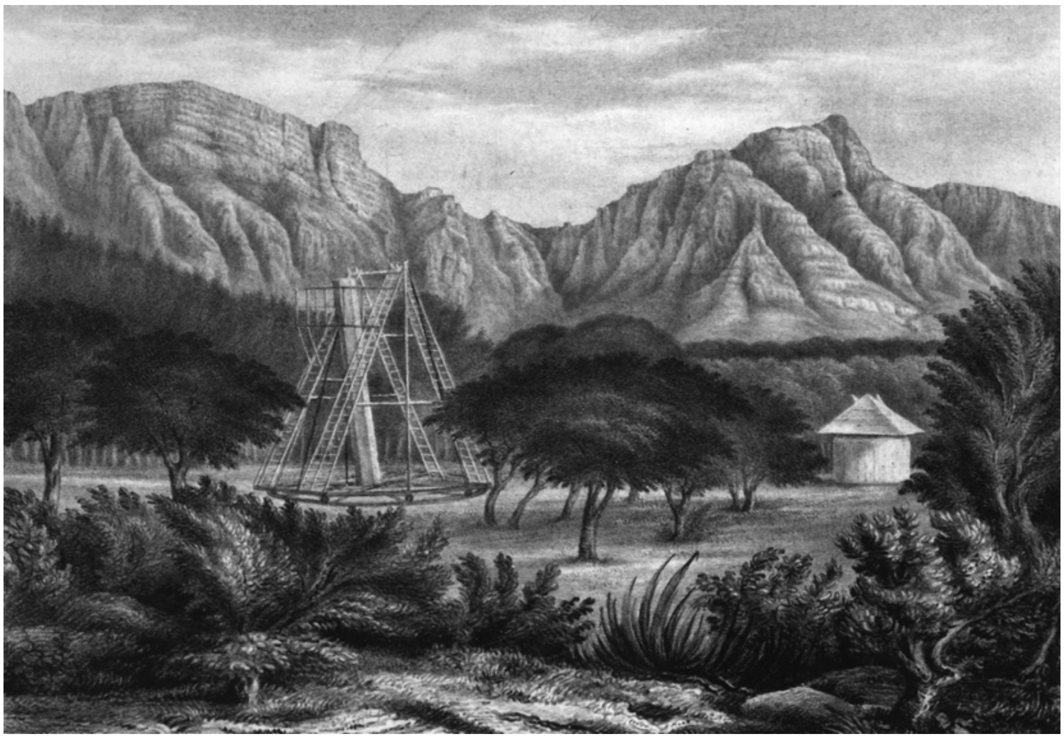

Plate 4.9: The 18.5-inch aperture, 20-foot reflector at the Cape and the building housing the 5-inch aperture, 7-foot refractor.[347] Table Mountain is shown in the background.

"Like most of the Herschel telescopes, the 20-foot reflector was constructed on the Newtonian principle, but without a secondary… It was suspended by a system of ropes from a framework mounted on movable rollers. A movable platform gave the observer access to the eyepiece in any position. There was no secondary mirror; the Herschel's looked straight down the tube. Of the three interchangeable mirrors constructed for this telescope, William

[347] National Maritime Museum, *Collections and Research*, <http://www.nmm.ac.uk/collections/prints/viewPrint.cfm?ID=PAD1906>, accessed 4 February, 2007. This drawing by John Herschel was the front-piece in his *Results of Astronomical Observations Made… at the Cape of Good Hope*.

Herschel had made one, another had been ground and polished by father and son together, and John Herschel had produced the third on his own. All three mirrors had the same aperture of 18.5-inches and the same focal length of 20 feet, so that they were identical in their optical performance."[348] Salt spray sometimes spoiled the mirror within a week and it had to be repolished. John estimated that the 20-foot telescope could see 5.3 million stars in both hemispheres using a power of 180 times.

As stated in Section 3.4.4, William Herschel calculated that a new speculum mirror absorbed 33% of the light and hence reflected 67%[349] while modern aluminium mirrors reflect 89% of the visible light.[350] This means John's 18.5-inch had the same magnitude limit as a 16.8-inch aluminium mirror since there was no secondary in Herschel's telescope. See Section 5.3.2 for more detailed calculations.

4.2.2. THE SEVEN FOOT REFRACTOR

Charles Tulley made this refractor using 5-inch blanks provided by Sir James South. John was able to split the double star Eta Coronae Borealis with it. This pair was 1.03 arc-seconds apart when Struve discovered it in 1826.

The 7-foot telescope was set up in a small building with a sliding roof and used from May 2, 1834 onwards. With this telescope, using powers from 100 to 500 times and a micrometer to measure their separations, John measured and catalogued 417 double stars.

This telescope was later used as a finder on the 30-inch Helwan telescope in Egypt.[351]

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[348] Buttmann, *Shadow*, p. 91.

[349] King, *Telescope*, p. 137.

[350] King, *Telescope* p. 382.

[351] King, *Telescope* p. 200.

4.3 THE OBSERVING TECHNIQUE USED BY HERSCHEL COMPARED TO THAT USED BY DUNLOP

John Herschel began observing under his father's tutelage and thus his technique was similar to that used by William. When searching for non-stellar objects, Dunlop's observing technique was sometimes similar to that used by both William and John Herschel. They swept back and forth for several degrees along the meridian. Both William and John found the Right Ascension by timing reference stars and non-stellar objects as they crossed the wires in the eyepiece. They found the polar distances using ropes and a scale or a semicircle divided into degrees.

4.3.1 WILLIAM HERSCHEL'S OBSERVING TECHNIQUE

William Herschel modified his main 20-foot telescope several times. In the early days when he first started making his catalogue, William would oscillate his telescope through an arc of 12^o or 14^o in breadth (Right Ascension) in 4 to 5 minutes of time.[352] Then he lowered or raised the telescope 8 or 10 arc-minutes in polar distance and repeated this. A sweep was 10, 20 or 30 oscillations and it was heavy work pushing the telescope from side to side. When he found a nebula or cluster he drew a diagram of the stars visible in the finder and in the telescope. He would have lost his dark adaptation each time he did this, and it was time consuming.

On December 13, 1783 William Herschel began using a new method. This time he moved the telescope vertically with the help of an assistant. His sister, Caroline Herschel wrote his descriptions of the astronomical objects and she repeated them aloud. Five days later he started using his telescope as a transit instrument (moving it along the meridian) and on December 24, 1783 he added a sidereal clock.[353] A further improvement was made when a rope and scale on an index board were introduced for measuring the altitude of the telescope. From the altitude William was able to establish the north polar distance (NPD) of an object. He found that moving the telescope 2^o in altitude translated to 24 inches on the index board. This gave reasonably accurate measures of polar distance for that time. At the beginning he read the index board himself, later adding a rope so that his assistant could do this. A bell rang at the end of each vertical sweep along the meridian. In June 1784 a quadrant was introduced for measuring altitude but there were still errors of 4 or 5 arc-minutes in polar

[352] William Herschel, 'Catalogue of One Thousand New Nebulae and Clusters of Stars', *Philosophical Transactions*, 76, 1786, p. 261.

[353] W. Herschel, 'Nebulae and Clusters', p. 262.

distance (Declination). Another improvement was made on September 24, 1785 by incorporating a small rope passing tangentially from the front of the telescope to the assistant's desk. This removed the problem of the larger telescope support ropes changing length due to changes in humidity.

To prevent the telescope from moving horizontally during the meridian sweeps, vertical iron plates, springs and rollers were used. The accuracy was now 3 or 4 arc-minutes in polar distance and 10 or 12 seconds of time in Right Ascension.

On September 22, 1786 William Herschel started using the 18.5-inch telescope without the secondary mirror. "By looking into the telescope at the front without the small reflecting mirror, [he] found the image as good as at the side; [and] the light … incomparably more brilliant."[354] With two mirrors his telescope was approximately equivalent to a 13.9-inch aluminium mirrored telescope, but with one mirror it was equivalent to a 17.0-inch Newtonian telescope.[355] However, the shadow from his head would slightly reduce this.

An example of one of his observations is sweep number 729, which was made on April 15, 1787. The sweep was $2^{o}10'$ broad from north polar distance $90^{o}5'$ to north polar distance $92^{o}15'$ and went from Right Ascension 12 hours 19 minutes to Right Ascension 13 hours 40 minutes. The objects seen in this sweep are listed in Table 4.1 with their NGC identifications added. The stars Gamma and p Virginis were used as zero stars. The time given is sidereal time.

For each object Herschel wrote a description and gave its position with respect to a zero star of known Right Ascension and north polar distance, for example the stars Gamma and p Virginis in the table. He avoided using bright stars as reference stars because they spoiled his dark adaptation. NGC 5345 was described as "vvS. mbM. 90 (p) Virginis p. 0' 37" n. 0^{o} 4'." [356] [357]

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[354] J.L.E. Dreyer, *The Scientific papers of Sir William Herschel*, 2 vols, London, 1912, i, p. xlii.

[355] These numbers are calculated as follows:

$$\frac{\sqrt{18.5^2 \times 0.67^2}}{\sqrt{0.89^2}} = 13.9 \quad \text{and} \quad \frac{\sqrt{18.5^2 \times 0.67}}{\sqrt{0.89^2}} = 17.0$$

assuming 67% reflectivity for speculum and 89% reflectivity for aluminium.

[356] Very, very small, much brighter in the middle. The star p Virginis precedes NGC 5345 by 0'37" and is 0^{o} 4' north of it.

Table 4.1: A William Herschel record, sweep number 729.

Time (h m s)	**NPD** (deg min)	**Object Notes**
12 19 0	90 05	Began
12 26 2	90 17	Gamma Virginis
12 31 32	91 34	NGC 4684
12 32 28	92 12	NGC 4691
12 37 0	90 02	NGC 4753
13 14 27	90 33	NGC 5183,4
13 36 18	91 12	NGC 5327
13 37 7	90 05	NGC 5334
13 38 18	90 24	NGC 5345
13 39 25	90 28	p (90) Virginis
13 40 0	90 05	Left off

Herschel "started with the idea that all nebulae were composed of stars, and he therefore included clusters, even scattered ones, in his observations."[358] When he found that some nebulae (e.g. IV 69 = NGC 1514, a magnitude 10 planetary nebula 1.8' diameter) contained "some kind of luminous fluid"[359] he "lost interest in the scattered clusters, and after 1790 he only catalogued nine of them."[360] His small field of view (15') also made it hard for him to see large clusters.

The telescope was not always used as a transit instrument. William Herschel was able to point the telescope to any part of the sky and could follow an object for 15 minutes of time.

4.3.2 JOHN HERSCHEL'S OBSERVING TECHNIQUE

John Herschel's technique for cataloguing the positions of non-stellar objects was the reference star method used by his father William. He used the Parramatta star catalogue for reference stars until he found that it was inaccurate by a few seconds in Right Ascension. He

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357 Dreyer, *W Herschel*, i, p. xlii.

358 Dreyer, *W Herschel*, i, p. xliv.

359 Dreyer, *W Herschel*, i, p. xliv.

360 Dreyer, *W Herschel*, i, p. xliv. This should be 12 open clusters after 1790 according to Bob Erdman. NGC/IC Project, *The Historically Corrected New General Catalogue*, 2006, <http://www.ngcic.org/public_HCNGC/HCNGC.htm>, accessed 26 November, 2006.

then asked Thomas Maclear (HM Astronomer at the Cape) to give him accurate positions for some stars and Maclear did this for 670 stars.[361]

Herschel swept back and forth along the meridian and noted the time when reference stars, double stars, clusters and nebulae crossed the meridian line in his eyepiece. Most sweeps were 3^{o} long in north polar distance (e.g. NPD 126^{o} to 129^{o}). He normally did one sweep per night but he started a new sweep if there was cloud or if he stopped to examine an object more closely. He completed a total of 381 sweeps during his time at *Feldhausen*. These sweeps varied in length, with several hours of Right Ascension being typical.

Sir John wanted to examine objects several times but did not achieve this goal. He wrote:

> "In going a second time over the same ground, or even a third, in the richer regions of the heavens, it would have been very unadvisable to have arrested the sweeping process at each nebula detected in the first course of sweeps for the purpose of re observing it; since, by so doing, the escape of every other object of interest (whether nebula, cluster, or double star), situated in the same zone, and within two or three minutes in Right Ascension, or even more, if the object re-observed were in any way interesting, would have been infallibly insured. With such an instrument as that which I employed, the place of an object cannot be determined with precision otherwise than by including it in a zone with sufficient zero stars to form a connected series: and to have carried out this process with that especial view (however desirable a thing in itself) would have required at least two, and probably three years of additional observation."[362]

4.3.3 JAMES DUNLOP'S OBSERVING TECHNIQUE

There is a general lack of information regarding the observing techniques used by Dunlop. However he seemed to have used three different methods to establish the Right Ascension and south polar distance (SPD). Both William and John Herschel always used north polar distance (NPD).

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[361] J.F.W. Herschel, *Results of Astronomical Observations Made During the Years 1834,5,6,7,8, at the Cape of Good Hope*, London, 1847, p. ix.

[362] J. Herschel, *Astronomical Observations*, p. 4.

Firstly, with the 9-inch telescope he swept back and forth along the meridian[363] in sweeps of varying length in SPD. As he swept he noted the time using a sidereal clock[364] when clusters and nebulae crossed the meridian. He also noted the south polar distance for each object using a vernier scale attached to the telescope. This method was similar to the one he learned while working at Parramatta Observatory.

In the introduction to his catalogue of 629 clusters and nebulae (Appendix C), Dunlop describes his observing technique using the 9-inch telescope fitted up as a meridian telescope on an iron axis. "One end of the axis carried a brass semicircle divided into half degrees and read off by a vernier to minutes. The position and index error of the instrument were ascertained by the passage of known stars...With this apparatus I have observed a sweep of eight or ten degrees in breadth [SPD] with very little deviation of the instrument from the plane of the meridian."[365]

Secondly, Dunlop occasionally used William Herschel's reference stars and clock method to obtain the Right Ascension of objects. When cataloguing the Large Magellanic Cloud he swept back and forth parallel to, but not along the meridian, and he also allowed the sky to drift by without moving his telescope. On September 27, 1826 the reference star theta Doradus was used for one drift but he misidentified the star. He also used reference stars to give the position of a comet he observed between March 11, 1826 and May 25, 1826.[366] This was Comet Pons (1825 IV), which was magnitude 6.2 in Corona Australis on March 11 and magnitude 7.6 in Virgo on May 25. Rümker scoffed at Dunlop's lack of knowledge of the stars at the time Dunlop was appointment as astronomer to Parramatta Observatory in 1830.

Dunlop's third method utilised the setting circles on the 3.25-inch diameter equatorial telescope to give the Right Ascension and Declination. This telescope was used to measure 119 of the 253 double stars in his double star catalogue. He may have found positions of

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[363] He sometimes swept off the meridian. On 27/9/1826 he says, "This ends the sweeps out of the meridian." He was studying the LMC at the time. James Dunlop, Reel M1709, microfilm, Australian Joint Copying Project, 1983, p. 333.

[364] On August 1, 1826 he used a sidereal clock to time a conjunction of Venus and Jupiter. Dunlop, Reel M1709, p. 256. This clock was put forward 1 min on 29/8/1825 and was also put forward 1 min on 3/10/1825. In summer it was more accurate. Adding or removing mercury could change the speed of the clock. Dunlop, Reel M1709, p. 252.

[365] Dunlop, 'Nebulae and Clusters', p. 113.

[366] Dunlop, Reel M1709, p. 375.

some clusters and nebulae with the same telescope. On July 2, 1826[367] he observed Beta Toucani with the 3.25-inch refractor so it seems he used both the refractor and a sidereal clock after Rümker returned to the observatory on May 10, 1826. He also used the refractor on May 13 and 18. However Rümker says in his letter of 1830 that since May 5, 1826, "Mr Dunlop has not been in the observatory."[368] He may have taken a clock and the refractor to his house in Hunter Street, Parramatta.

In the introduction to the double star catalogue, Dunlop gives some more clues to his observing technique (Appendix E). He says:

> "In presenting this list of double stars, it may be necessary for me to make some apology for its imperfect state, as regards the true apparent distance and position of a great many of the double stars, the situation of which it points out in the heavens. You are aware that during your administration of the government of the colony of New South Wales, my time and attention were wholly devoted, in your employ, to the Parramatta observatory in the miscellaneous observations which occurred; and principally in observing the Right Ascensions and polar distances of the fixed stars, thereby collecting materials towards the formation of a catalogue of the stars in that hemisphere (which materials have been presented by you to the Royal Society of London): and your departure from the colony alone prevented me from pursuing that branch further. Finding myself in possession of reflecting telescopes,[369] which I considered capable of adding considerably to our knowledge of the nebulae and double stars in that portion of the heavens, I resolved to remain behind to prosecute my favourite pursuits, in collecting materials towards the formation of a catalogue of the nebulae and double stars in that hemisphere, and any other object which might have attracted my attention. The nebulae being a primary object with me, I devoted the whole of the favourable weather in the absence of the moon to that department, and the moonlight,[370] in general, was allotted to the observations of double stars; a portion only of which I have been able to subject to the various measurements necessary for the accurate determinations of their relative distances and positions...In the case of those stars which are not marked with an asterisk[371], their positions and distances are only estimations while passing through the field of the 9-feet telescope: in the various sweeps, the Right Ascension and Declinations are also those which were indicated by the

[367] Dunlop, 'Double Stars', pp. 259, 267.

[368] Rümker, 'Letter', p. 124.

[369] Note the plural.

[370] Some full moons in 1826 were: May 21, June 19, July 18, August 17, September 16, October 15, and November 14.

[371] 134 stars.

> same instrument fitted up and described as a meridian telescope, in my paper on the nebulae of the southern hemisphere."[372]

Regardless of his observing method, Dunlop would have lost his dark adaptation when he stopped to write descriptions of each object, unless like Lacaille, he closed one eye while writing notes. There is no record of him doing this in any of his notes. William Herschel overcame this problem by having his sister Caroline act as his scribe. John Herschel may have written his own notes although he did have an assistant (John Stone) to operate the telescope.

It is interesting to note that the Parramatta Observatory was only 10 arc-minutes north of Herschel's observatory at *Feldhausen*, South Africa. Their positions are shown in Table 4.2. The observatories were however about 11,000 great circle kilometres apart.

Table 4.2: Comparison of the positions of the two southern observatories.

	Latitude (south)	**Longitude** (east)	**Latitude** (decimal)[373]	**Longitude** (decimal)	**Elevation** (m)
Feldhausen	33°58'57"	18° 27'43"	-33.983	18.460	48
Parramatta	33°48'51"	151°01'34"	-33.813	150.995	29

[372] Dunlop, 'Double Stars', p. 257.

[373] Decimal values and elevations above sea level were obtained from Google Earth, *Digital Globe*, 2006.

CHAPTER 5 – AN ANALYSIS OF THE THREE EARLY CATALOGUES OF NEBULAE AND CLUSTERS

5.1 IDENTIFICATION METHODOLOGY

This section describes the four methods used to identify the objects in the three catalogues of nebulae and clusters made by Lacaille, Dunlop and John Herschel. The aim was to examine objects near the positions given in the three catalogues, to see if they matched the descriptions given. Emphasis was placed on identifying the objects listed in the Dunlop catalogue as this catalogue was reported to have a large number of errors, and because of this, Dunlop was criticised and discredited by his peers (see Section 3.5).

Summaries of the four methods used are given below.

1. The coordinates given in the original catalogues were converted to J2000 and the objects were plotted as accurately as possible on an *Uranometria 2000.0*[374] star atlas. Using this atlas to locate each object, photos were taken of Schmidt plates at the Anglo-Australian Observatory (AAO), Epping, NSW. These glass plates and Mylar copies were taken by the UK/AAO Schmidt Telescope Unit near Coonabarabran, NSW, and by the European Southern Observatory Telescope near La Silla, Chile. The photos of the Dunlop objects included the surrounding area and were high quality images. However the positions were not exact. This process was time consuming because of difficulties in finding the right plate and finding the position on the plate.
2. The Project Pluto's *Guide* CD-ROM star atlas[375] and text definition files were used to plot the original coordinates very accurately. The software converted these automatically to J2000. This was combined with *RealSky*[376] images (from the Digital Sky Survey) and the descriptions were compared with images of nearby objects. This method proved best for identifying compact objects such as globular clusters, planetary nebulae and galaxies because it gave highly accurate positions. However the *RealSky* images were sometimes unsatisfactory because *RealSky* south was made

[374] Wil Tirion, Barry Rappaport and George Lovi, *Uranometria 2000.0*, 2 vols, Richmond, Virginia, 1988.

[375] B. Gray, *Guide Star Chart*, Version 8, (CD-ROM), Project Pluto, Bowdoinham, ME, 2006.

[376] Association of Universities for Research in Astronomy, Inc (AURA), *RealSky*, (CD-ROM), San Francisco, 1997.

from blue sensitive plates and does not show open clusters, emission nebulae or Magellanic Cloud objects well because many of these objects are dominated by Hα emission.

3. Next *Desktop Universe*[377] was used to search for Lacaille and Dunlop asterisms and double stars because these do not show up well on *RealSky* images. The images were then compared with the descriptions. This method was also the best for identifying open clusters and diffuse nebula. The positions were not exact however, and the resolution of the images was inferior to *RealSky,* but the magnitude limit of *Desktop Universe* was closer to Dunlop's limit.
4. Lastly a microfilm of Dunlop's original handwritten notes was used as it included extra information that was not part of his published catalogue. The coordinates given made it possible to study each drift observation made by Dunlop in the Magellanic Clouds. Plotting each drift on a detailed star atlas was the best way to search for and identify objects in the Magellanic Clouds. The microfilm also gave extra information regarding other objects and helped identify errors in the typed catalogue.

Each method is explained below, using the Dunlop catalogue as an example.

5.1.1 *URANOMETRIA 2000.0* AND SCHMIDT PLATES

5.1.1.1 *Uranometria 2000.0*

Uranometria 2000.0[378] is a computer drawn star atlas of scale 196 arc-seconds per mm. The atlas is in two volumes, one for the northern sky and one for the southern. There is also a third related volume *The Deep Sky Field Guide to Uranometria 2000.0* (DSFG).[379] The northern and southern volumes contain a total of 473 maps each 10^{o} by 13^{o}. These maps show approximately 332,500 stars to visual magnitude 9.5. The deep sky objects shown include 930 open clusters, 185 globular clusters, 380 bright nebulae, 160 dark nebulae, 525 planetary nebulae and 6,700 galaxies. All non-stellar objects in the NGC Catalogue are included as well as objects from other catalogues. The Epoch, Equator and Equinox of *Uranometria* are J2000.0.

In 1988 the southern part of *Uranometria 2000.0* became available and this provided one method to check the Dunlop catalogue. The original Dunlop catalogue in South Polar

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[377] Main Sequence Software, *Desktop Universe*, (CD-ROM), Ottawa, Canada, 2002.

[378] Tirion, *Uranometria*.

[379] Murray Cragin, James Lucyk, and Barry Rappaport, *The Deep Sky Field Guide to Uranometria 2000.0*, Richmond, Virginia, 1993.

Distance (SPD) order, with 1827 coordinates was precessed to the year 2000 and sorted by Right Ascension. This process gave the 629 Dunlop entries for Equator and Equinox J2000.0. The accuracy of the precession routines used (typically better than 5 arc-seconds), is several orders of magnitude better than the accuracy of the Dunlop positions (which are typically 9 arc-minutes). Each object was then marked on the *Uranometria 2000.0* atlas with a cross (X) and its corresponding number from the Dunlop catalogue written next to it, as shown in Plate 5.1. A list of possible identifications of the Dunlop objects was then compiled.

The position of an object, as recorded in the Dunlop catalogue, marked with a cross and labelled with its corresponding number.

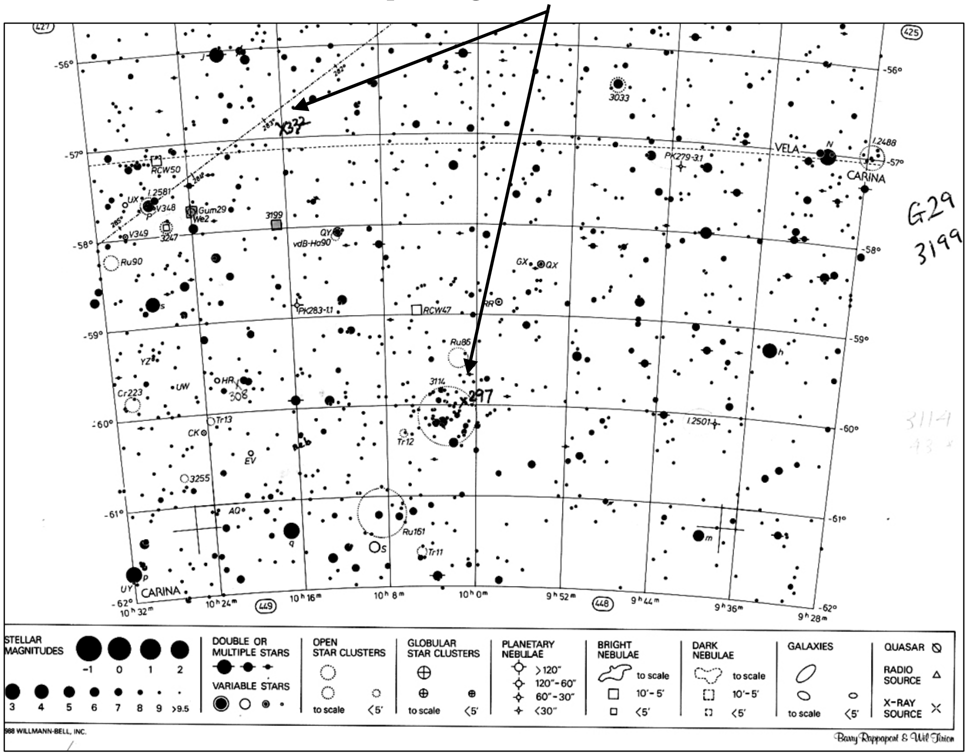

Plate 5.1: A section of the *Uranometria 2000.0* star atlas.

The search of the southern edition of *Uranometria 2000.0* was successful in locating bright objects in non-crowded fields. However the search was not successful for non-stellar objects in the Large and Small Magellanic Clouds where objects are too close together for a definite identification to be made. Another difficulty in identifying objects came from the omission of some moderately bright IC objects in *Uranometria 2000.0*. For example the magnitude 11.6 galaxy IC 1633 is not shown.

A list was made of objects in the Dunlop catalogue located within 1 degree of a non-stellar object in *Uranometria 2000.0*. The 472[380] objects in this list were then compared to photographic sky surveys. Plate 5.2 shows NGC 5128 marked on *Uranometria 2000.0* and labelled as 482, its number in the Dunlop catalogue.

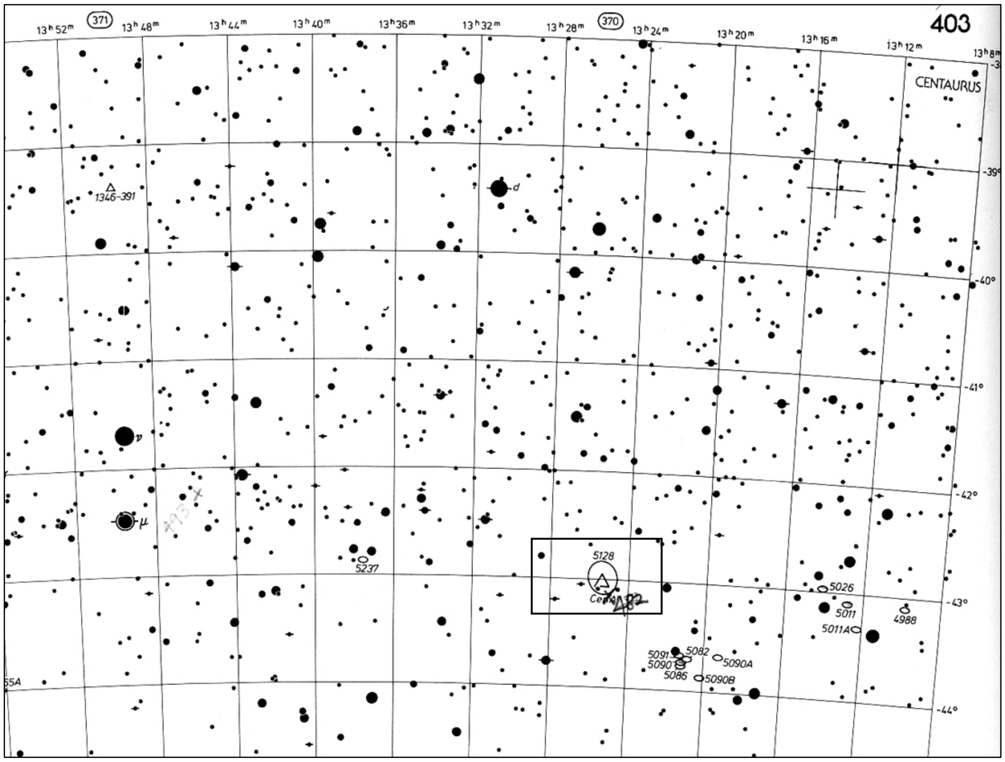

Plate 5.2: A section of *Uranometria* showing NGC 5128. The small rectangle covers approximately the same 75' wide area as the UK Schmidt image in Plate 5.3.

5.1.1.2 Schmidt Telescope Photographic Plates

The Anglo-Australian Observatory at Epping, NSW, has two complete photographic surveys of the southern sky. The first was taken by the 1.0 metre Schmidt Telescope at the European Southern Observatory, near La Silla, Chile. It is called the ESO (B) survey[381] because it was taken on blue sensitive plates. The resulting 606 photographic plates are each 300 mm by 300 mm and 5.5^{o} by 5.5^{o} with a nominal scale of 67.52 arc-seconds per mm. They show stars to blue (B) magnitude 21.5.

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[380] There were 403 within 0.5 deg and 269 within 0.2 deg.

[381] The ESO (B) catalogue is available from NASA's Astronomical Data Center on *Selected Astronomical Catalogs*, Vol. I.

The second survey, the SERC (J)[382] survey, was taken by the 1.24 metre UK Schmidt Telescope at Siding Spring, NSW, using green sensitive plates. This survey also contains 606 photographic plates from Declination –17.5° to –90°. Each plate is 356 mm by 356 mm and covers 6.6° by 6.6° of the sky with a scale of 67.14 arc-seconds per mm. These SERC (J) plates show stars to (J) magnitude 22.5. Table 5.1 compares the plates for these two surveys.

Table 5.1: Comparison of plates from ESO (B) and SERC (J) surveys.

	ESO (B)	**SERC (J)**
Sensitivity	B blue	J green
Magnitude limit	21.5	22.5
Size (mm)	300 x 300	356 x 356
Size (degrees)	5.5 x 5.5	6.6 x 6.6
Scale (arc-seconds/mm)	67.52	67.14

These photographic survey plates were used to photograph the Dunlop objects for comparison and possible positive identification. Two hundred and thirty-five photographs were taken with the coordinates of the Dunlop object near the centre of each photograph.

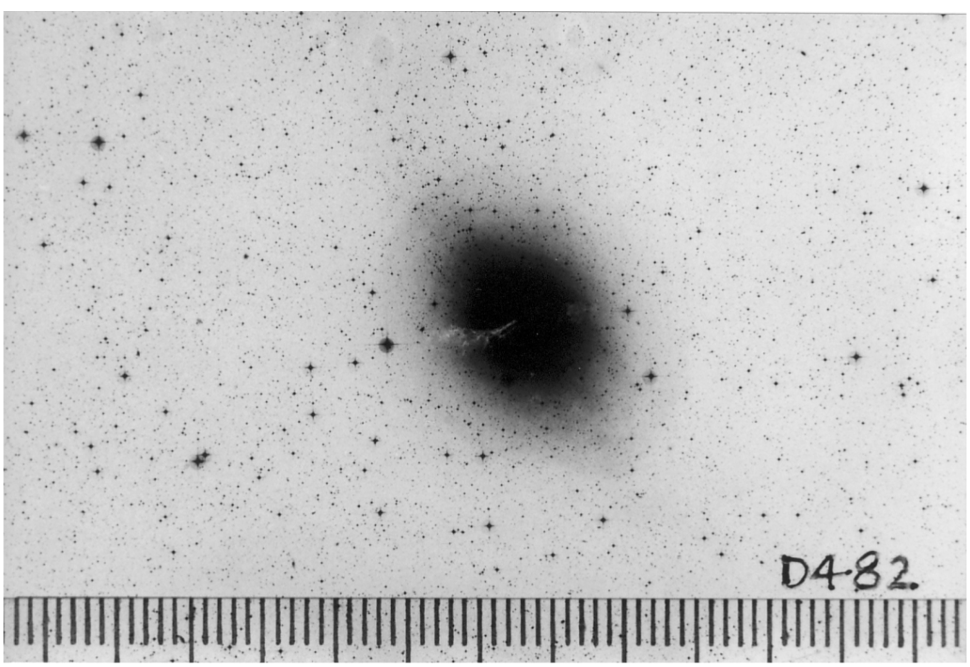

Plate 5.3: Photograph from the Schmidt plate, SERC (J), of NGC 5128, Dunlop 482.

[382] The UK Science and Engineering Research Council. J has green wavelength sensitivity.

Each photograph covered an area of about 70 arc-minutes by 50 arc-minutes to magnitude 21 or 22. A ruler was also placed on the edge of each photograph so that both scale and size could be more easily calculated. Generally the SERC (J) plate was used for the photograph, but sometimes the correct plate could not be found and the ESO (B) plate was used. Plate 5.3 showing NGC 5128 is 75 arc-minutes wide. The photograph of the SERC (J) plate covers approximately the small rectangle in Plate 5.2.

Using a printed star atlas and photographic copies taken of high quality Schmidt plates was a painstakingly slow method for identifying objects from a catalogue. Where the catalogue description and coordinates matched accurately and there were no other nearby non-stellar objects, identification was relatively easy and conclusive. However with many of the objects in the Dunlop catalogue identification was inconclusive.

At the time this work was undertaken, this method was the best available. When digital atlases became available they were more complete than *Uranometria* and allowed identifications to be made on a computer.

5.1.2 *GUIDE* CD-ROM STAR ATLAS AND *REALSKY* DIGITIZED SKY SURVEY

In 1993, electronic, computer based star atlases on CD-ROM became available. These atlases display stars to magnitude 13.5 and in some places 15. The scale can be varied on the computer screen or in the hard copy print out. One of these, the *Guide CD-ROM Star Chart*[383] (1993-2006) was used for this research. This CD-ROM shows 15 million stars from the Hubble Guide Star Catalog.[384] It also includes 190,000 galaxies, 1,200 open clusters, all galactic globular clusters and all nebulae from pole to pole, not just the NGC and IC catalogues.

Computer based star atlases meant that the Dunlop positions could be entered, the area of sky located with great precision and the search made to a deeper magnitude. The *Guide* program converted the Dunlop coordinates from 1827 to J2000 and displayed the positions on the atlas as shown in Plate 5.4.

A one degree field with a magnitude 13 limit was searched around each object's position. This process resulted in a second, more accurate and complete list of possible Dunlop objects being compiled than was possible with *Uranometria*. The Magellanic Clouds were included

[383] Gray, *Guide*.

[384] This was prepared for the Hubble Space Telescope.

at this time, but the Dunlop positions were not always accurate enough for definite identifications to be made for objects in the Clouds because they are so crowded with clusters and nebulae. Section 5.1.4 explains how the Magellanic Clouds were studied.

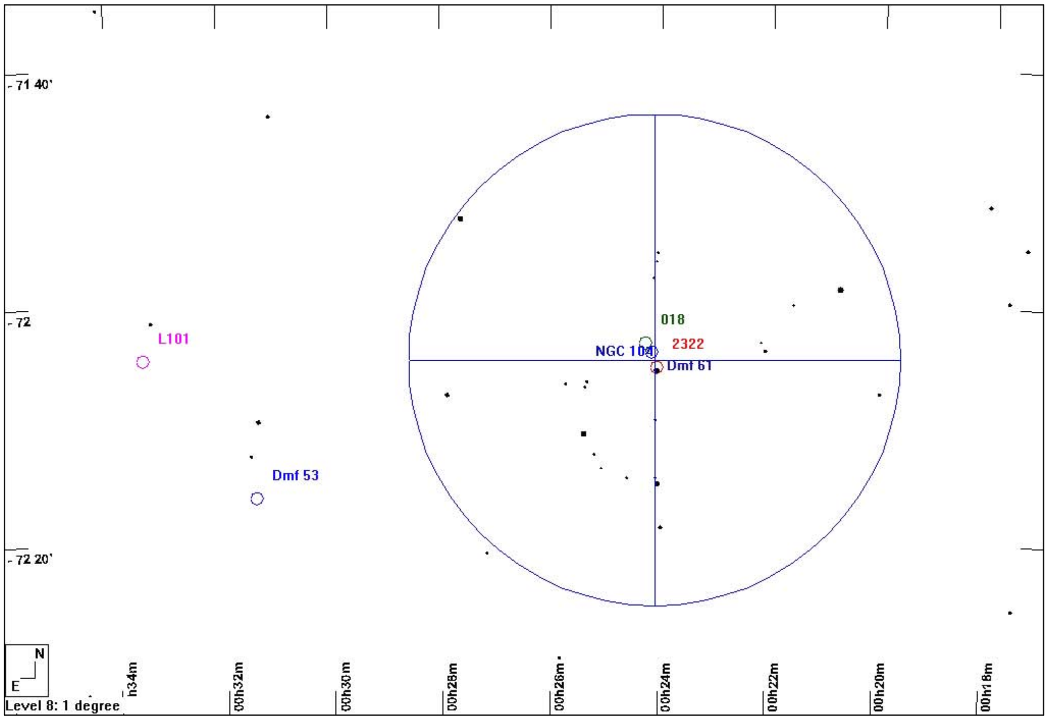

Plate 5.4: *Guide Star Chart* showing NGC 104, Lacaille I.1 (L101), Dunlop 18 and Herschel 2322. The labels Dmf 53 and Dmf 61 refer to the microfilm of Dunlop's notes.

In 1997 this second more accurate list and atlas was combined with digital photographs of the sky using the *RealSky* Digitized Southern Sky Survey.[385] However this survey lacked the resolution of the high quality photographic plates from the Schmidt telescopes because it is compressed by a factor of 100. The southern section of *RealSky* is based on the SERC (J) plates. *RealSky* has an angular resolution of 1.7 arc-seconds and a limiting magnitude of about 20.

Superimposing the *Guide Star Chart* with the *RealSky* images allowed for easier identification of Lacaille, Dunlop and Herschel objects as seen in Plate 5.5. Using *Guide* and *RealSky* together meant that matching the original descriptions with the images (particularly globular clusters, planetary nebulae and galaxies) was possible, allowing the identification of more objects.

[385] AURA, *RealSky*.

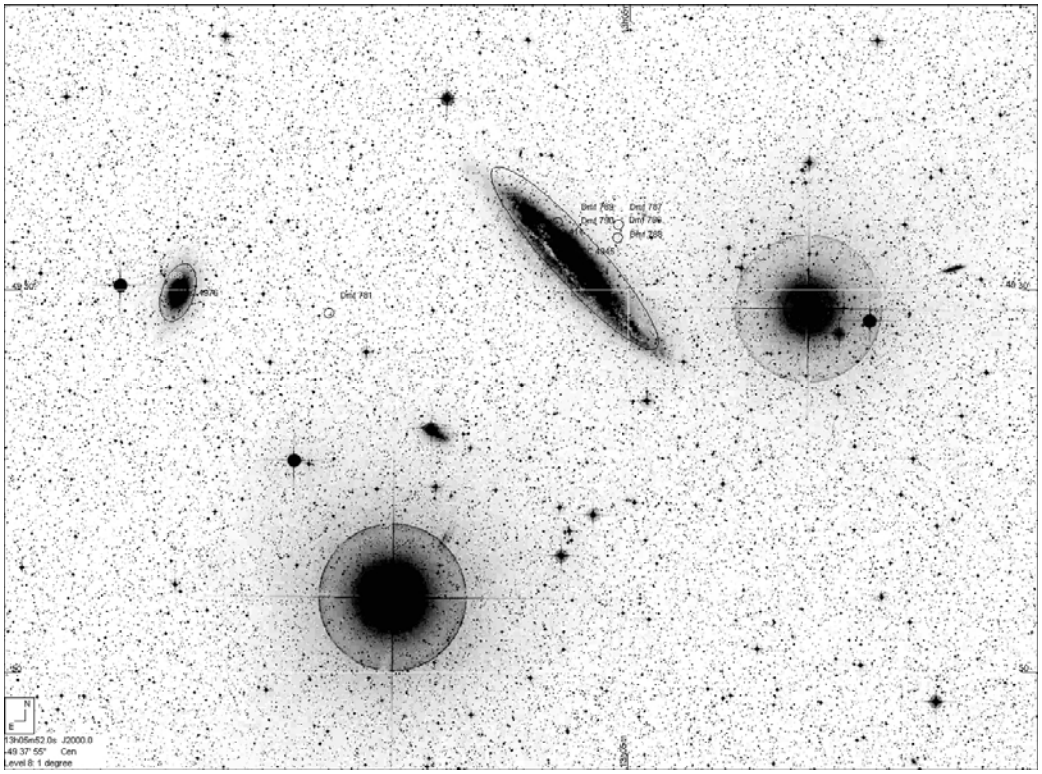

Plate 5.5: The elongated galaxy NGC 4945 using *Guide* merged with *RealSky*.

Open clusters, asterisms and wide double stars are not obvious on the original photographic plates or in *RealSky* because bright stars are similar in size to fainter stars. Unfortunately nebulae also do not show up well on the southern part of *RealSky* because it is not based on the red sensitive plates and the 100 times compression made many nebulae inconspicuous. As many of the objects in both the Large and Small Magellanic Clouds are nebulae it was difficult to match descriptions with *RealSky* images for these objects.

To overcome these problems images with a magnitude limit similar to Dunlop's limiting magnitude were needed, that is to magnitude 13 rather than magnitude 20.

5.1.3 *DESKTOP UNIVERSE*

August 2002 saw the release of *Desktop Universe*, a colour photographic survey of the sky, imaged in RGB colour and digitally "stitched together with astrometric precision, resulting in a single, seamless view of the entire sky."[386] With *Desktop Universe* the screen can be zoomed from 180° to 0.5° wide, although the latter only shows fuzzy stars. *Desktop Universe*

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[386] Diffraction Limited, *About Main-Sequence Software Inc*., 2004, <http://cyanogen.com/products/dtu_aboutmssi.htm>, accessed 7 February, 2007.

displays about one million clusters, nebulae and galaxies including Messier, NGC, IC and PGC[387] objects. Double stars and open clusters are not conspicuous in *RealSky*, and *Desktop Universe* was better suited for identifying these because the fields are not crowded with faint stars. Also in *Desktop Universe* emission nebulae stand out better because they are shown in colour.

Desktop Universe displays 10 million stars with a resolution of 12 arc-seconds per pixel compared to the 1.7 arc-seconds per pixel available with *RealSky*; this means the image is less clear than in *RealSky*. Plate 5.6 and Plate 5.7 demonstrate this for NGC 6397 using *RealSky* and *Desktop Universe* and these show that *RealSky* is better suited for resolving globular clusters. Plate 5.8 and Plate 5.9 compare the open cluster NGC 3114 and Plate 5.10 and Plate 5.11 compare the nebula NGC 3199. Both open clusters and nebulae are more conspicuous using *Desktop Universe*.

Matching the original descriptions written by the discoverers with the *Desktop Universe* image again helped with identification of objects. The limiting magnitude for *Desktop Universe* is 14, so the image on the screen is similar to what Dunlop would have seen through his 9-inch telescope with its limiting magnitude of about 13. However *Desktop Universe* is not suitable for faint galaxies in the Herschel catalogue.

[387] *Catalogue of Principal Galaxies.*

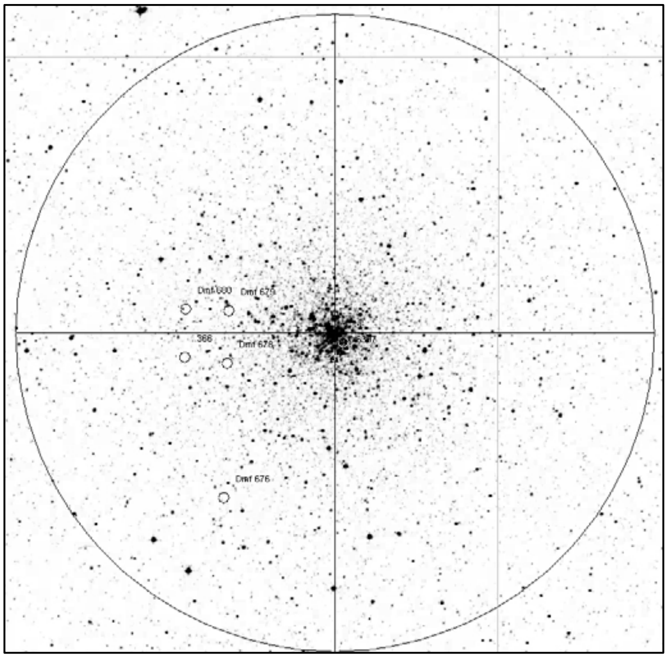

Plate 5.6: The globular cluster NGC 6397 using *Guide* and *RealSky*.

Plate 5.7: NGC 6397 using *Desktop Universe* with approximately the same 25' wide field as Plate 5.6.

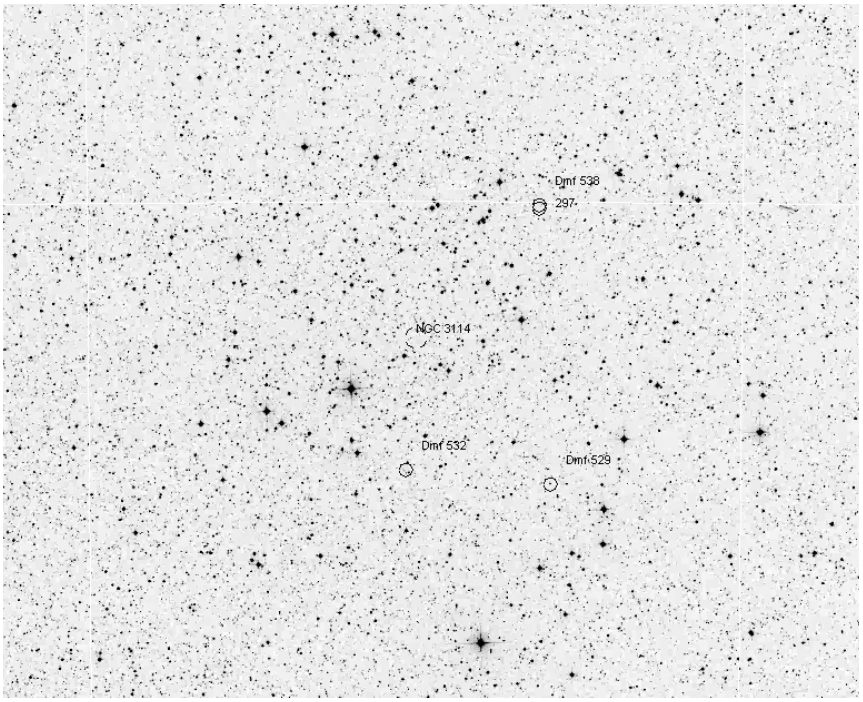

Plate 5.8: The open cluster NGC 3114 in *RealSky* with 50' wide field.

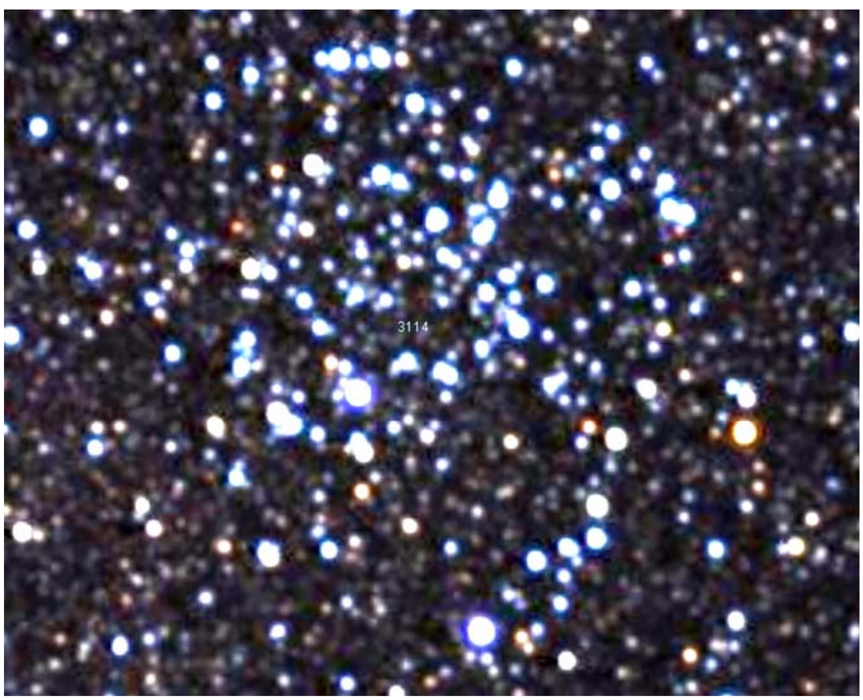

Plate 5.9: NGC 3114 in *Desktop Universe* is more conspicuous.

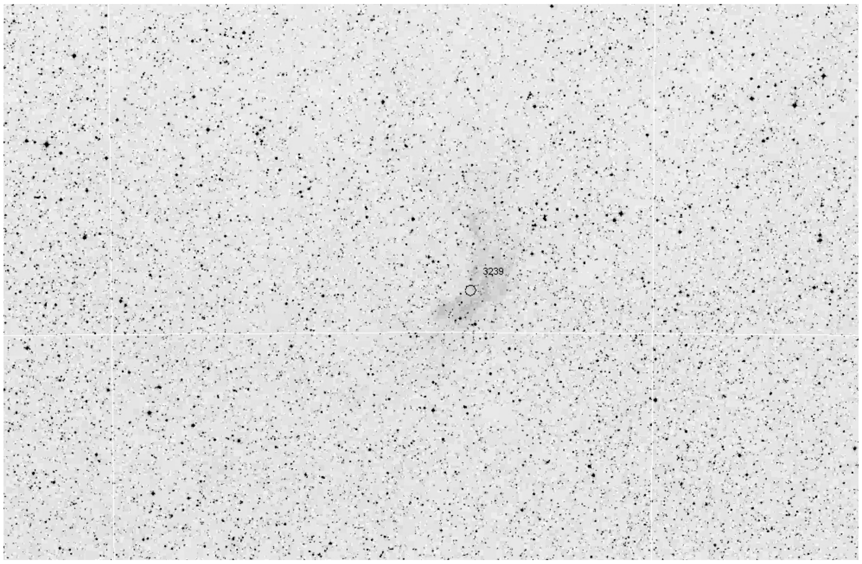

Plate 5.10: *RealSky* image of the nebula NGC 3199 with 60' wide field.

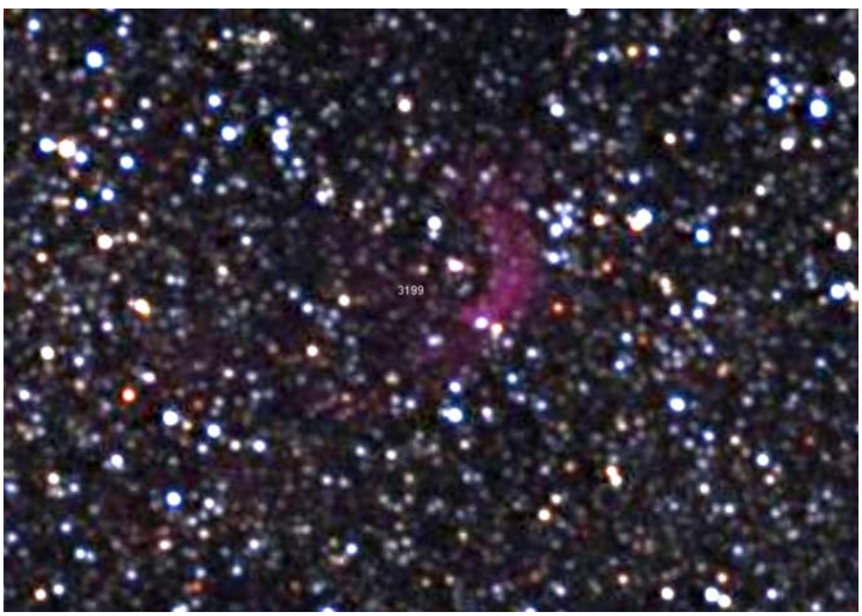

Plate 5.11: NGC 3199 is more obvious in *Desktop Universe*.

By comparing *Guide* positions and the original descriptions with *Desktop Universe* many of the missing open clusters and nebulae in the Dunlop catalogue were identified. However in the Large and Small Magellanic Clouds it was still difficult to conclusively identify the myriad of closely packed objects and a further refinement of method was needed. Plate 5.12 and Plate 5.13 show a crowded section of the LMC 1.0^{o} by 0.5^{o}. The labels are from the Dunlop catalogue and microfilm notes (labelled Dmf).

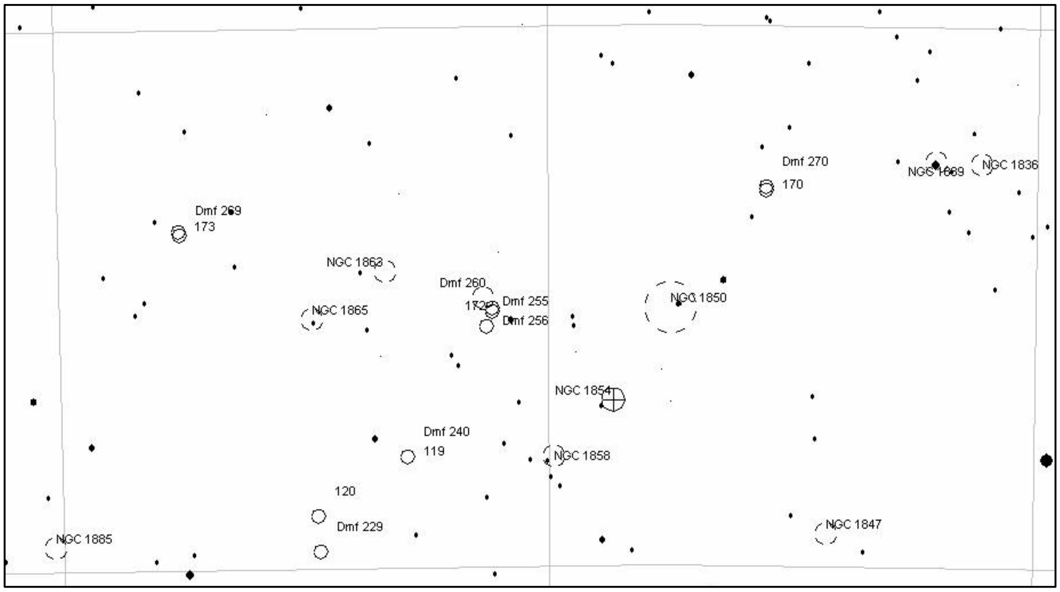

Plate 5.12: *Guide* 8 for part of the LMC showing many non-stellar objects.

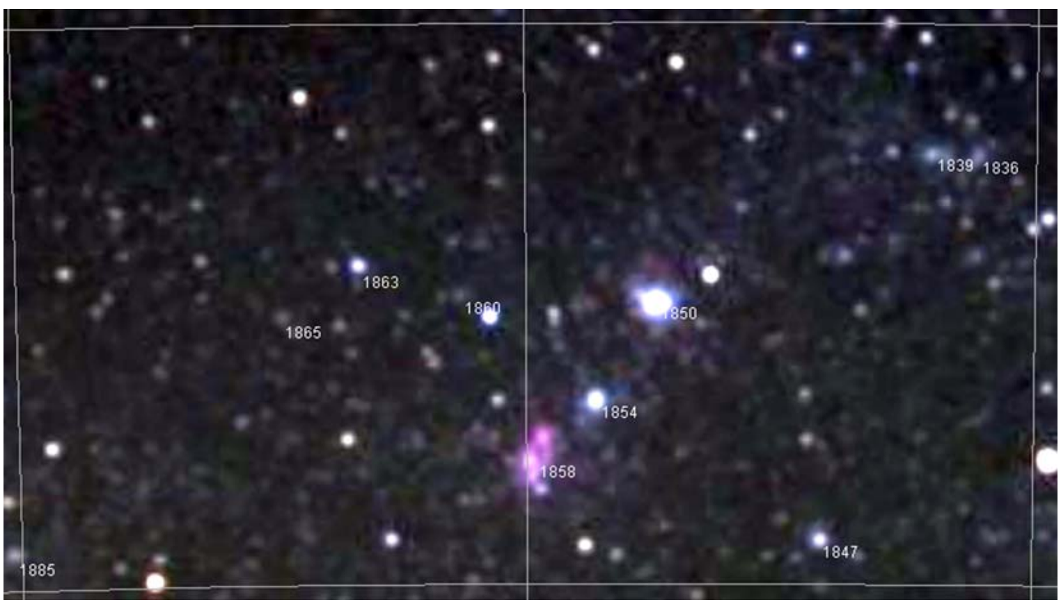

Plate 5.13: *Desktop Universe* of the same area (1^o by 0.5^o) of the LMC as shown in Plate 5.12.

5.1.4 MICROFILM OF DUNLOP’S HANDWRITTEN NOTES

To solve the problem of relatively inaccurate positions and crowded fields in the two Magellanic Clouds, a microfilm[388] copy of Dunlop’s 1826 handwritten notes was obtained from the National Library in Canberra. A sample is shown in Plate 5.14.

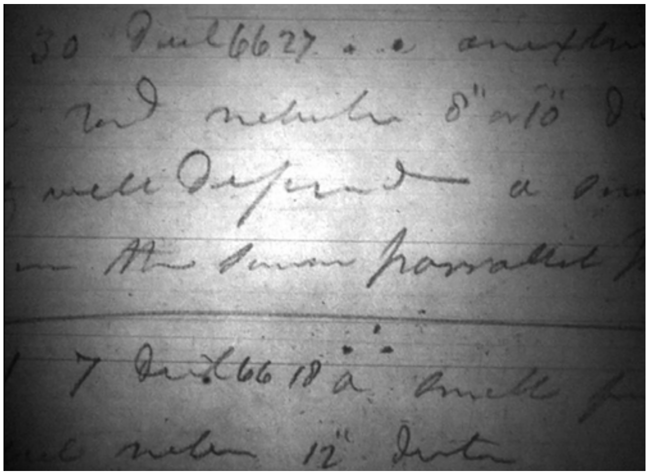

Plate 5.14: A sample from the microfilm of Dunlop's hand written notes.

This microfilm contains 740 pages of original descriptions and notes written by Dunlop, and includes dates for most of the observations, none of which were available in the typed catalogue. It also gives some unreduced observations for the Large and Small Magellanic Clouds. A summary of the contents of the microfilm is given in Table 5.2.

Table 5.2: Summary of the microfilm of Dunlop’s notes.

Section	Main Contents	Page
6.21	Double stars 1824	1
6.22	Notes 1824 & 1825	130
6.3	Comet 1825 & 1826	170
6.41	The LMC & SMC	268
6.42	Notes Nov 1826	335
6.43	Nebulae 1826	378
6.44	Nebulae 1826	445
6.5	Notes 1827 to 1829	541
7	Notes	602

[388] The microfilm is available from the National Library in Canberra. Australian Joint Copying Project, Reel M1709. Section 6.41 of the microfilm contains unreduced observations of the LMC, one of these is given in this chapter.

8	The 1824 catalogues	621
9	Circle Observations	669
10	Definitions & 1828 notes	684
11	Notes & Tables	718
	End	740

Dunlop's survey of the Large and Small Magellanic Clouds was analysed night-by-night, sweep-by-sweep and drift-by-drift. Each sweep and drift was marked on a separate star chart. A list of the Dunlop LMC and SMC objects was then compiled. Copies of the Schmidt plates on Mylar of the Large and Small Magellanic Clouds were also borrowed from the UK Schmidt telescope at Coonabarabran to help produce this list.

The microfilm was also used to determine the identity of some objects outside the Magellanic Clouds as the date of observation (not included in the printed catalogue) and the original, unreduced position were given by Dunlop. Utilising both the extra data available on the microfilm and the descriptions in the printed catalogue (also given in the microfilm) allowed for greater certainty in determining an object's identity. This was particularly valuable when identifying objects with large positional discrepancies to ensure that a correct identification was made, and not a chance coincidence with another similar object.

5.1.5 ANALYSIS OF DUNLOP'S IDENTIFICATIONS IN THE MAGELLANIC CLOUDS

5.1.5.1 The Large Magellanic Cloud (LMC)

In August 1826 Dunlop turned his attention to the Magellanic Clouds. He was unable to sweep along the meridian because the LMC transited after the beginning of morning twilight until late October and so he moved his telescope off the meridian. In November he was finally able to study the LMC on the meridian before morning astronomical twilight began. Table 5.3 gives the dates when he studied the LMC. He completed five sweeps, either on or off the meridian, and six drifts between August and November.[389] Of the five sweeps he made of the LMC, his first and last were particularly productive.

Dunlop's drifts did not cover the LMC completely, and he failed to properly search the southern part, with only two objects recorded below Declination $–71^{o}$. The LMC is inclined from north-preceding (np) to south-following (sf). Dunlop often started his drifts at Declination $–70^{o}$ and rarely made drifts south of that. As a result of this inconsistent search of

[389] See Section 4.3.3 for more information on Dunlop's observing technique.

the LMC, many objects were recorded twice in his notes but with different coordinates. Consequently, many objects were then listed twice in his printed catalogue.

Table 5.3: Dates when Dunlop studied the Large Magellanic Cloud.

Date 1826	Number of Sweeps	Number of Drifts	Astronomical twilight begins	LMC transits
3-Aug	1		5:20 am	8:35 am
24-Sep	1	2	4:20 am	5:15 am
25-Sep		1		
27-Sep		3		
3-Oct	1		4:05 am	4:35 am
5-Nov	1		3:20 am	2:25 am
6-Nov	1			

Table 5.4 summarises the sweeps and drifts by date from the microfilm and lists the NGC identifications of the objects recorded, with duplications included.

Table 5.4: Dunlop objects in the LMC showing drift number and arranged by date.

Note: Where there is no drift number, Dunlop searched using a sweep.

NGC	Date	Drift	NGC	Date	Drift	NGC	Date	Drift	NGC	Date	Drift
1704	3-Aug		1921	24-Sep	1	1865	25-Sep		2027	27-Sep	3
1711	3-Aug		1939	24-Sep	1	1917	25-Sep		2035	27-Sep	3
1748	3-Aug		1943	24-Sep	1	1953	25-Sep		2041	27-Sep	3
1763	3-Aug		1951	24-Sep	1	1966	25-Sep		2117	27-Sep	3
1770	3-Aug		1986	24-Sep	1	2001	25-Sep		2130	27-Sep	3
1818	3-Aug		2005	24-Sep	1	2042	25-Sep		2135	27-Sep	3
1831	3-Aug		2019	24-Sep	1	2070	25-Sep		2154	27-Sep	3
1850	3-Aug		2046	24-Sep	1	2093	25-Sep		1711	3-Oct	
1858	3-Aug		2057	24-Sep	1	2100	25-Sep		1755	3-Oct	
1866	3-Aug		2058	24-Sep	1	2118	25-Sep		1770	3-Oct	
1870	3-Aug		2065	24-Sep	1	1704	27-Sep	1	1866	3-Oct	
1894	3-Aug		2079	24-Sep	1	1751	27-Sep	1	1831	5-Nov	
1910	3-Aug		2113	24-Sep	1	1772	27-Sep	1	1866	5-Nov	
1922	3-Aug		2122	24-Sep	1	1801	27-Sep	1	1947	5-Nov	
1955	3-Aug		1702	24-Sep	2	1898	27-Sep	1	1755	6-Nov	

2004	3-Aug		1711	24-Sep	2	1939	27-Sep	1	1760	6-Nov	
2014	3-Aug		1712	24-Sep	2	1943	27-Sep	1	1763	6-Nov	
2035	3-Aug		1727	24-Sep	2	1986	27-Sep	1	1769	6-Nov	
2070	3-Aug		1772	24-Sep	2	2005	27-Sep	1	1770	6-Nov	
2074	3-Aug		1835	24-Sep	2	2019	27-Sep	1	1846	6-Nov	
2100	3-Aug		1872	24-Sep	2	2058	27-Sep	1	1850	6-Nov	
2122	3-Aug		1898	24-Sep	2	2065	27-Sep	1	1852	6-Nov	
2160	3-Aug		1910	24-Sep	2	2079	27-Sep	1	1866	6-Nov	
1805	24-Sep		1916	24-Sep	2	1966	27-Sep	2	1873	6-Nov	
1818	24-Sep		2005	24-Sep	2	2001	27-Sep	2	1936	6-Nov	
1856	24-Sep		2037	24-Sep	2	2042	27-Sep	2	1945	6-Nov	
1869	24-Sep		2055	24-Sep	2	2070	27-Sep	2	1974	6-Nov	
1871	24-Sep		2074	24-Sep	2	2093	27-Sep	2	1978	6-Nov	
1873	24-Sep		2080	24-Sep	2	2100	27-Sep	2	2014	6-Nov	
2002	24-Sep		2084	24-Sep	2	1869	27-Sep	3	2030	6-Nov	
2004	24-Sep		1836	25-Sep		1871	27-Sep	3	SL553	6-Nov	
2070	24-Sep		1850	25-Sep		1873	27-Sep	3	2035	6-Nov	
1711	24-Sep	1	1854	25-Sep		1968	27-Sep	3	2041	6-Nov	
1751	24-Sep	1	1856	25-Sep		2004	27-Sep	3	2157	6-Nov	
						2011	27-Sep	3	2164	6-Nov	

As mentioned in Chapter 4.3.3, Dunlop used the star Theta Doradus as a reference point to calculate the position of objects for the third drift on September 27, 1826. However because he misidentified the reference star, this drift was the most difficult to study.

Dunlop's notes on the microfilm for this third drift are reproduced in Table 5.5. This table shows his unreduced observations as listed in the microfilm. This table borrows abbreviations from Herschel and the NGC, as explained in the footnote below. The Sidereal or Mean time (they are nearly the same on September 27) is given in hours, minutes and seconds (taken from the microfilm), as is the position in the field, which gives the north-south distance from the centre of his field in arc-minutes. The last column gives the NGC or other identification.

Table 5.5: Dunlop's third drift through the LMC on 27 September 1826.

Sidereal Time			Position in Field	Description of Object[390]	Identification
Hr	Min	Sec	(arc-min N or S)		
0	2	0	0	5 neb in square see another page	
0	10	28	-2	vS F R neb f vF*	
0	11	45	18	Cl vS st 3'x1.5'	SL298
0	12	23	19	F E neb 30"d	
0	13	20	-1	vS R neb 8"d F	
0	15	20	0	3 vS neb in obliq tri p vB yellow *	Theta Dor
0	15	55	-2	B* n of Cl* + many S F neb in B neby	NGC 1871
0	21	24	6	S F E neb	
0	24	30	-8	S F neb p D + neb 20"RA f 2's	
0	28	30	0	vS F neb RA12"?37"?	
0	28	57	-2	2 vS F neb sf vS*	
0	30	0	-19	curve of 6 F neb & S st mixt rich	NGC 1968
0	31	42	0	(Fld 0?) eF R neb 30"d	
0	33	10	0	2 S F ill def neb	
0	33	22	-3	pB R neb 30"d F edges	NGC 2004
0	35	30	-20	vS Cl vS st in B neb irrF	NGC 2011
0	37	30	15	S R neb p S*	NGC 2027
0	38	30	-22	pL F ill def neb iF	NGC 2035
0	39	2	17	pB well def R neb 25"d	NGC 2041
0	41	0	-15	F R S neb	
0	42	33	11	vS D neb p S* both 8"d	
0	45	20	-6	pB ray 2'x1' f S* b in p part of ray	
0	46	55	4	F C neb 20"d + 3 S * in it	
0	50	27	-14	F neb f pB S*	NGC 2117
0	55	10	-1	S R F neb 15"d pos?	NGC 2130
0	56	40	-11	F S neb 15"d f vS*	NGC 2135
1	0	10	5	S R neb 20"d slbM	NGC 2154
				This ends the sweeps out of the meridian	
				The night is very fine	

[390] Abbreviations are as follows: (this scheme was borrowed from Herschel and the NGC.)

eF vF F b pB B vB extremely faint, very faint, faint, brighter, pretty bright, bright and very bright

vS S pL L vL very small, small, pretty large, large and very large

C E obliq tri irrF R compressed, extended, oblique, triangle, irregular figure and round

illdef s l M ill defined, suddenly, little, middle

D neb neby Cl double, nebula, nebulosity and cluster

p f d * preceding, following, diameter, star

pos ? n position, uncertain, north

The objects in Table 5.5 were plotted by the author on a star atlas as shown in Plate 5.15. Both Dunlop and proposed NGC numbers are shown. Dunlop 182 refers to three NGC objects, but only NGC 1871 is listed in Table 5.5.

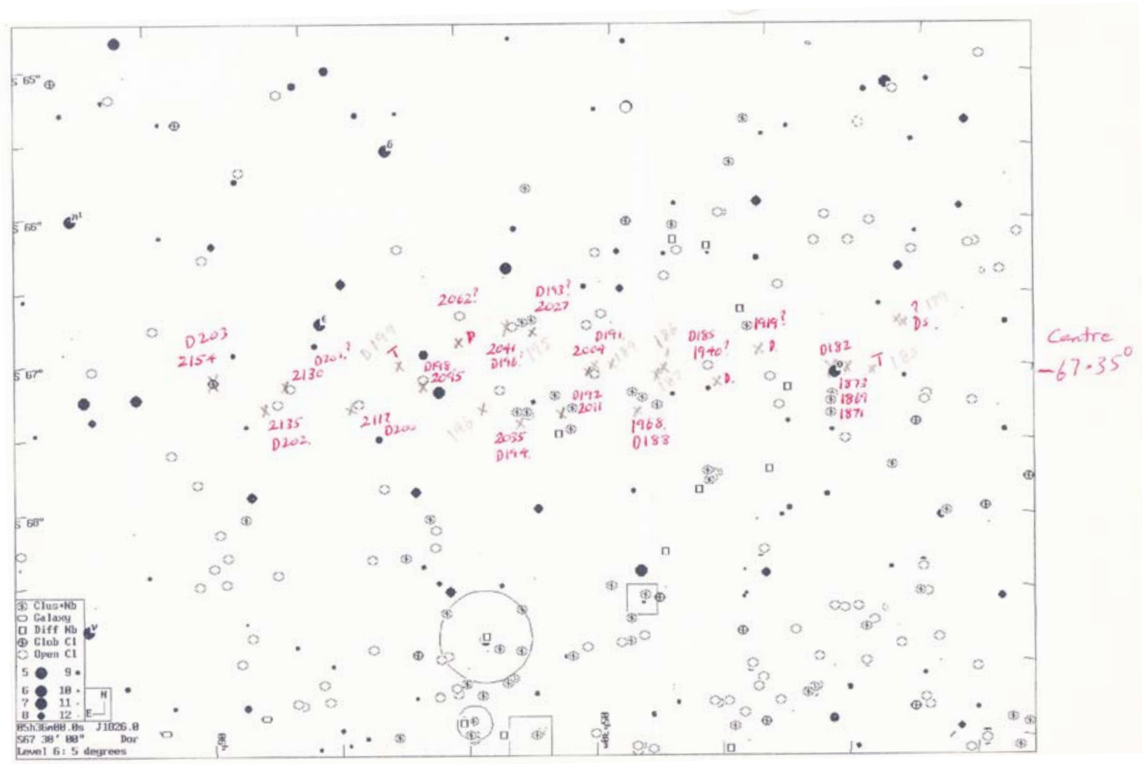

Plate 5.15: Identification of objects discovered by Dunlop in the LMC on 27 September 1826, drift 3.

5.1.5.2 The Small Magellanic Cloud (SMC)

When Dunlop began his study of the SMC on August 1, 1826 there was no problem with having to search off the meridian as it transited well before the start of astronomical twilight. The dates when Dunlop studied the SMC are shown in Table 5.6.

Table 5.6: Dates when Dunlop studied the Small Magellanic Cloud.

Date 1826	Number of Sweeps	Number of Drifts	Astronomical twilight starts	SMC transits
1-Aug	1		5:20 am	4:05 am
2-Sep		1	4:50 am	2:00 am
5-Sep		4		
6-Sep		2		

He completed one sweep and seven drifts. Unfortunately the unreduced drifts are not all available in his notes on the microfilm, and as a result the drifts on September 5, are the most difficult to study.

The main objects in the SMC were found during the first sweep. Fainter objects were then added from the drifts done in September. He saw some surprisingly faint objects such as NGC 222. Table 5.7 summarises the sweeps and drifts by date from the microfilm and lists the NGC or other identifications of the objects recorded, with duplications included. There were not as many repetitions of objects in the SMC as in the LMC.

By using the microfilm and following the drift paths in both the LMC and SMC on photographic plates, the objects in the Dunlop catalogue were gradually identified. Duplicated objects were more easily discovered using this method and the faint doubles and asterisms were easier to identify.

Table 5.7: Objects found in the SMC sorted by date.

Note: Where there is no drift number, Dunlop searched using a sweep.

NGC	Date	Drift		NGC	Date	Drift		NGC	Date	Drift
104	1-Aug			330	2-Sep	1		H 30	5-Sep	3
222	1-Aug			H 63	2-Sep	1		H 36	5-Sep	3
261	1-Aug			I1612	2-Sep	1		371	5-Sep	4
330	1-Aug			f 376	2-Sep	1		395	5-Sep	4
346	1-Aug			419	2-Sep	1		416	5-Sep	4
362	1-Aug			330	5-Sep	1		361	6-Sep	1
371	1-Aug			H 63	5-Sep	1		411	6-Sep	1
395	1-Aug			419	5-Sep	1		I 1665	6-Sep	1
419	1-Aug			L 43	5-Sep	2		458	6-Sep	1
456	1-Aug			L 51	5-Sep	2		419	6-Sep	2
460	1-Aug			346	5-Sep	2		456	6-Sep	2
465	1-Aug			249	5-Sep	3		460	6-Sep	2
L104	1-Aug			261	5-Sep	3		465	6-Sep	2
602	1-Aug			H 19	5-Sep	3				

5.2 ASTROMETRY, UNCERTAINTY IN POSITIONS

5.2.1 INTRODUCTION

In this section the positions of objects recorded in the catalogues of Lacaille, Dunlop and Herschel are compared with modern positions from the *European Southern Observatory ESO/Uppsala Survey of the ESO (B) Atlas.*[391] This accurate catalogue was made by measuring the positions of objects on 606 photographic plates taken with the ESO 1 metre Schmidt telescope. The ‘difference in position’ referred to in this chapter, is equal to the ESO position minus the position given in each of the three catalogues.

The comparisons between the original catalogued positions (precessed to J2000) and the ESO catalogue established a search radius and identified trends in the positional differences. The comparisons also showed the accuracy of each observer’s work and suggested possible problems with their equipment and/or method of observation.

5.2.2 DATES WHEN OBSERVATIONS WERE MADE

5.2.2.1 Nicolas-Louis de La Caille

Lacaille started observing on August 6, 1751 and finished observing eleven months later on July 18, 1852. During this time he made 106 sweeps on 79 nights for his catalogue of 9,776 stars. The 42 clusters and nebulae were discovered between August 23, 1751 and July 18, 1752, and were catalogued separately.

5.2.2.2 James Dunlop

Dunlop catalogued his 629 clusters and nebula in just seven months, between April 27, 1826 and November 24, 1826. He found new objects on sixty different nights, three at the end of April, fourteen in May, ten in June, nine in July, nine in August, eight in September, four in October and three in November 1826. However he observed on 77 nights and sometimes observed the same object more than once. Table 5.8 gives the number of objects recorded on each of these nights. He made a total of 1059 observations. The seven objects seen after November 24 were discovered earlier.

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[391] The ESO (B) catalogue is available from <http://cdsarc.u-strasbg.fr/viz-bin/Cat?VII/34C>

Table 5.8: Dates when Dunlop observed in 1826.

Date	Objects	Date	Objects	Date	Objects
27-Apr	4	16-Jun	2	26-Aug	7
29-Apr	9	23-Jun	2	28-Aug	2
30-Apr	20	24-Jun	3	29-Aug	6
1-May	5	25-Jun	13	31-Aug	19
3-May	9	26-Jun	16	2-Sep	20
7-May	19	28-Jun	20	3-Sep	16
8-May	29	30-Jun	15	5-Sep	45
9-May	22	1-Jul	4	6-Sep	17
10-May	10	3-Jul	9	24-Sep	78
11-May	1	7-Jul	4	25-Sep	17
12-May	6	8-Jul	11	27-Sep	126
13-May	20	10-Jul	9	28-Sep	5
14-May	13	12-Jul	6	29-Sep	1
24-May	1	14-Jul	11	3-Oct	10
25-May	11	24-Jul	7	4-Oct	10
26-May	12	25-Jul	7	5-Oct	1
28-May	15	28-Jul	28	21-Oct	1
29-May	7	29-Jul	2	27-Oct	1
30-May	2	30-Jul	6	29-Oct	11
1-Jun	7	31-Jul	42	5-Nov	16
2-Jun	9	1-Aug	20	6-Nov	34
3-Jun	7	2-Aug	18	22-Nov	1
4-Jun	10	3-Aug	32	24-Nov	4
5-Jun	23	4-Aug	29	30-Nov	6
9-Jun	6	5-Aug	6	29-Dec	1
13-Jun	2	21-Aug	3		

5.2.2.3 John Herschel

Herschel began his observations on March 5, 1834 and made his last sweep on January 22, 1838; a period of nearly four years. He made 380 sweeps on 341 nights; ninety-six nights in 1834, one hundred and twenty nights in 1835, eighty-one nights in 1836, forty-three nights in 1837 and only one night in 1838.

5.2.3 TYPING AND COPYING ERRORS

5.2.3.1 Nicolas-Louis de La Caille

There is one copy error in the Lacaille catalogue. The position for NGC 104 (47 Tuc) is out by 10 minutes of time or 43 arc-minutes. He gave the RA as 00:22:54 but it should have been 00:12:54.

5.2.3.2 James Dunlop

Analysis of the original notes made by Dunlop (obtained on microfilm) resulted in the discovery of some errors in the published catalogue. These are most probably due to transcription but should have been detected by accurate proof reading. Dunlop was living in England at the time his printed catalogue was produced and it seems likely that he read his notes to someone who at times misunderstood his Scottish accent (eg 13 and 30, 15 and 50). Other errors seem to be purely typographical. Table 5.9 contains a list of the transcription errors in the published catalogue.

Table 5.9: Typing errors in Dunlop's published catalogue.

Dunlop Number	Microfilm Position	Typed Catalogue	Object ID
1	RA 4h 30' 0"	4h 13' 0"	
44	RA 1h 6' 2"	1h 6' 22"	N419
45	RA 1h 7' 15"	1h 7' 50"	
275	RA 14h 48' 10"	14h 18' 10"	
312	SPD 31d 58'	31d 38'	N5138
331	RA 4h 12' 30"	5h 12' 30"	N1553
357	RA 14h 50'	14h 15'	N5593
425	SPD 41d 12'	42d 12'	N6861
491	RA 9h 27' 16"	9h 7' 16"	
525	RA 18h 50' 30"	17h 50' 30"	
562	RA 3h 27' 39"	3h 37' 39"	N1365
628	RA 13h 28' 3"	13h 15' 3"	M 83

5.2.3.3 John Herschel

There are, no doubt, some typing or copying errors in this large catalogue. However Herschel often gives several positions and descriptions for objects because they were recorded more than once during his stay at the Cape. He advises the reader of his catalogue to choose the best description because it was probably written on the best viewing night. Herschel commented on the positions that were probably in error, when the positions did not agree.

5.2.4 UNCERTAINITY IN POSITION

The quality of the work of Lacaille, Dunlop and Herschel was ascertained by comparing the positions of objects as recorded in their catalogues of clusters and nebula with positions obtained from modern catalogues. For comparisons with the Lacaille catalogue, *Guide* 8 was used because the majority of the Lacaille objects are open clusters and he usually gave the position for the brightest star, rather than the centre of the object. In the Dunlop and Herschel catalogues this is less of an issue and their catalogues were compared to positions obtained from the ESO/Uppsala Survey of the ESO (B) Atlas.[392] The ESO (B) position was used for all Dunlop and Herschel objects even though it is noted that this may not be the most accurate measure for some objects because sometimes they also used a bright star for the position instead of the centre of an open cluster. Visually determining the position of a large or nebulous object is quite subjective and the notes and catalogue of Dunlop and Herschel do not give sufficient information on how the position was determined or even if the same method was consistently used.

The differences are in the sense ESO (B) position minus observer position. Each catalogue was analysed separately, and accuracies were plotted to demonstrate any trends or anomalies.

5.2.4.1 Astrometry of Nicolas-Louis de La Caille's Catalogue

The Abbé de La Caille catalogue, *Sur les étoiles nébuleuses du Ciel Austral* or in English, *On the Nebulous Stars of the Southern Sky* (Appendices A and B) contains 42 objects. The evaluation of the accuracy of the Lacaille catalogue presented in this section includes all 42 non-stellar objects. All objects have been identified, with most located between RA 07 and 20 hours and only 5 objects are outside this area.

The positions recorded in the Lacaille catalogue are for equinox 1752. Calculations and comparisons were made after precession to equinox J2000 using the *Guide* 8 star atlas.[393] There is no inclusion of proper motion. With so few objects in the Lacaille catalogue, the analyses were made considering the objects as one data set, without distinction between the different types of non-stellar objects (there are 25 open clusters, 6 globular clusters, 4 nebulae, 1 galaxy, no planetary nebulae and 6 asterisms in the catalogue). All objects are south of Declination -24^{o}. The Eta Carinae nebula was divided by Lacaille into two sections, both of which were included under nebulae.

Firstly the radial distance from the Lacaille position was determined for each of the 42 objects. The differences are shown in Figure 5.1 from smallest to largest. NGC 104 is not shown on this figure, because its position in the catalogue has a copy error of 10 minutes of time.

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[392] A. Lauberts, *The ESO/Uppsala Survey of the ESO (B) Atlas*, Germany, 1982.

[393] Gray, *Guide*.

The smallest radial difference, 0.2 arc-minutes, from the Lacaille position is NGC 6523, an open cluster and nebula with an accompanying bright star. For this object, and for other open clusters with conspicuous bright stars, the position of this star, as given in the *Guide* 8 star atlas, was used for comparison with the Lacaille position.

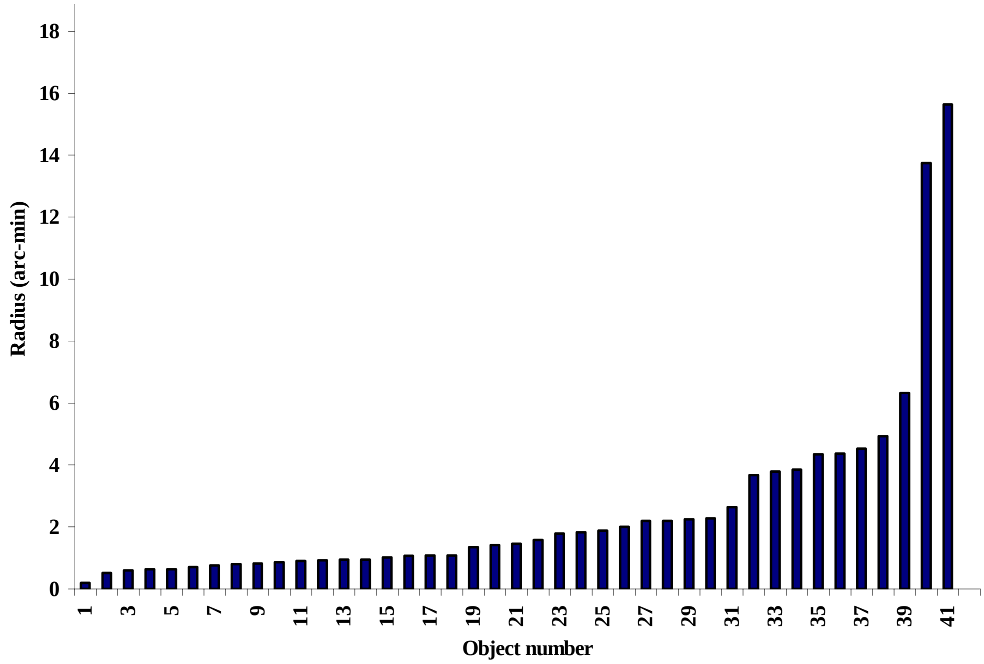

Figure 5.1: Radius from *Guide* 8 position to Lacaille position.

Analysis of the difference between the *Guide* 8 position and the Lacaille position showed that 90% of the objects (38/42) are within 5 arc-minutes, with 33% (14/42) within 1 arc-minute, but only 2% (1 object) was within 0.5 arc-minutes. Apart from the copy error of 10 minutes of time, the two largest differences in the data set are 15.6 arc-minutes for the open cluster NGC 2477 and 13.7 arc-minutes for the open cluster Trumpler 10. Most stars in NGC 2477 are of similar magnitude and hence no bright star was used for its coordinates. For the remaining 39 objects, those less than 7 arc-minutes from the *Guide* 8 position, the mean, standard error mean (SEM) and standard deviation for the radial distances were calculated to be 1.9, 0.24 and 1.5 arc-minutes respectively. The SEM was found by dividing the standard deviation of the data set by the square root of the count.

Further astrometric comparisons were made on the Lacaille catalogue. The difference between the Lacaille position and the *Guide* 8 position was measured in the sense *Guide* 8 minus Lacaille, and the following five standard graphs drawn to determine Lacaille's accuracy and any possible trends:

1) The Target diagram, a plot of differences in Right Ascension with differences in Declination

2) The plot of differences in Right Ascension with Right Ascension
3) The plot of differences in Declination with Right Ascension
4) The plot of differences in Right Ascension with Declination
5) The plot of differences in Declination with Declination.

These figures were drawn with the difference in Right Ascension and difference in Declination shown to ± 5 arc-minutes. This range matches the range used for Herschel, but not that used for Dunlop (± 30 arc-minutes).

1) The Lacaille Target diagram

In Figure 5.2 a 'scatter' or 'target' graph was used to show simultaneously the difference in Declination and the difference in Right Ascension.

This figure shows that the difference in RA is usually negative and less than 5 arc-minutes and the difference in Declination, although more scattered, is also usually less than 5 arc-minutes. It also shows that the Lacaille positions are remarkably accurate for the time, the aperture of his telescope and the types of object observed.

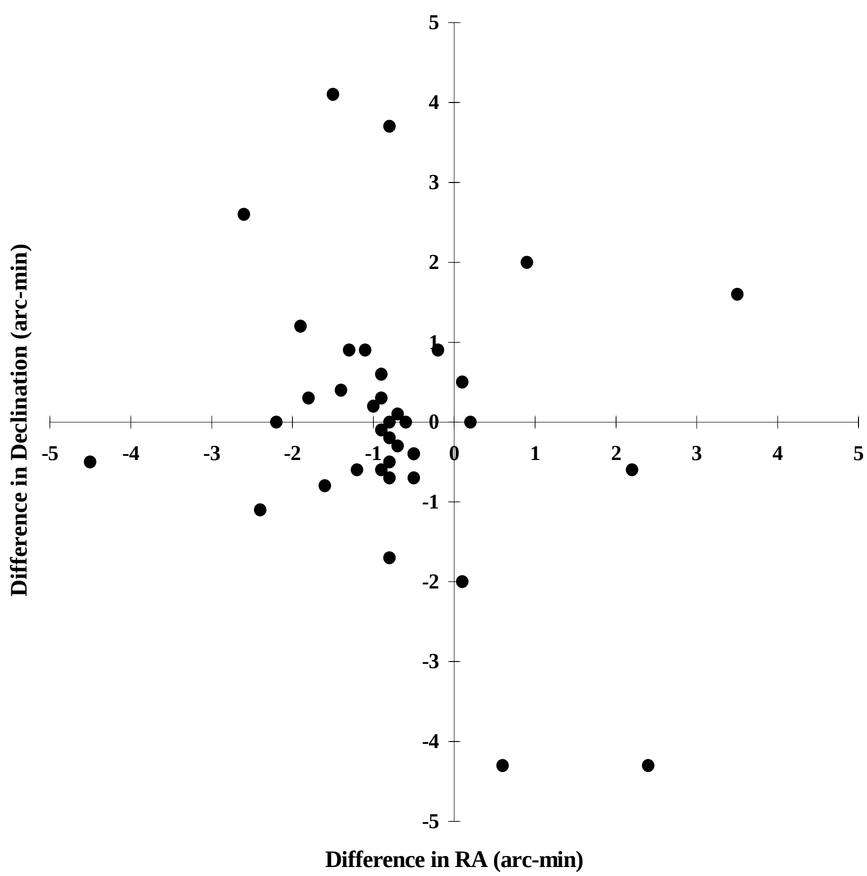

Figure 5.2: The Lacaille Target diagram (in the sense *Guide* – Lacaille).

There is an obvious bias in the positions towards a negative difference in RA, as the above figure shows. This bias suggests there is a time difference from the Lacaille position to the correct position, which is usually late. Explanations for this discrepancy are speculative, but two reasons are suggested. Firstly, Lacaille's clock could have been inaccurate, with it set slightly behind the correct time. This explanation is unlikely as Lacaille, almost certainly would have set his clock accurately using stars with precise coordinates. A second explanation could be a delay between the time when Lacaille observed the object and when he read and recorded the clock's time in his notes.

2) Differences in Right Ascension as a function of Right Ascension

Figure 5.3 gives the difference between the *Guide* 8 Right Ascension and the Lacaille position, as a function of Right Ascension.

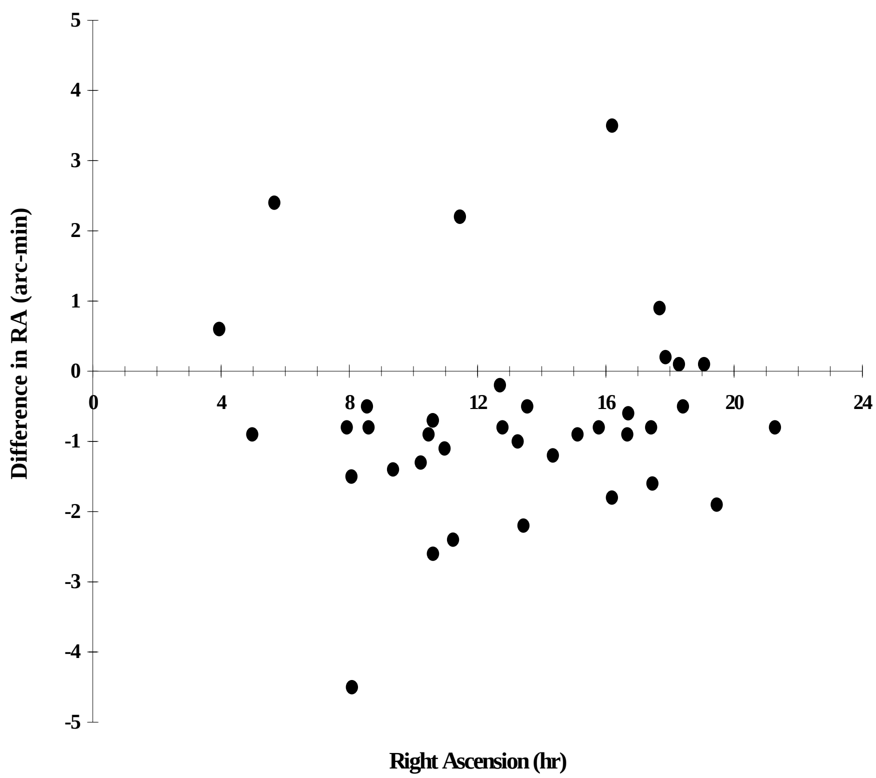

Figure 5.3: The distribution of the differences in Right Ascension (in the sense *Guide* – Lacaille) as a function of Right Ascension.

The differences in RA in the Lacaille catalogue are small after the three objects greater than 7 arc-minutes radial distance from the modern position are removed. The mean for RA is -0.5 ± 0.28 (SEM) arc-minutes and the standard deviation is 1.8 arc-minutes. There is an obvious bias in the positions as the above figure shows. This small bias is however unlikely to be the result of either misalignment of the telescope or clock inaccuracy.

The Lacaille catalogue only contains one object from the Magellanic Clouds. Most of the Lacaille objects are located in the southern Milky Way region between RA 08 and 18 hours.

3) Differences in Declination as a function of Right Ascension

The differences in Declination are also small. Using the same 39 objects less than 7 arc-minutes (radial distance) from the correct position, the mean difference in Declination is 0.0 arc-minutes, the SEM is ± 0.26 arc-minutes and the standard deviation is 1.6 arc-minutes. Generally the spread in differences in Declination is slightly less than the difference in RA, and there is no bias. There is no evidence of any curve, indicating that there are no systematic errors.

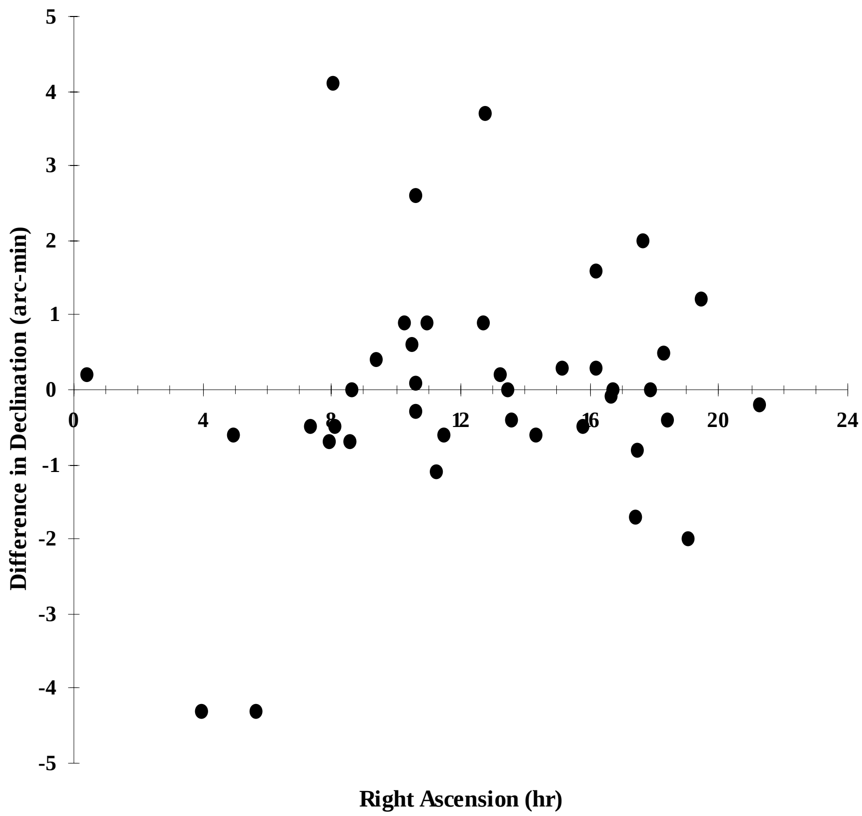

Figure 5.4: The distribution of the differences in Declination (in the sense *Guide* – Lacaille) as a function of Right Ascension.

4) Differences in Right Ascension as a function of Declination

Figure 5.5 shows the difference between the Right Ascension from *Guide* 8 and that determine by Lacaille, as a function of Declination.

A regression line drawn on the figure revealed that the difference in RA decreases by 0.65 arc-minutes from Declination -30^{o} to Declination -70^{o}. The mean difference, SEM and standard deviation are –0.5, 0.28 and 1.8 arc-minutes respectively for the 39 objects.

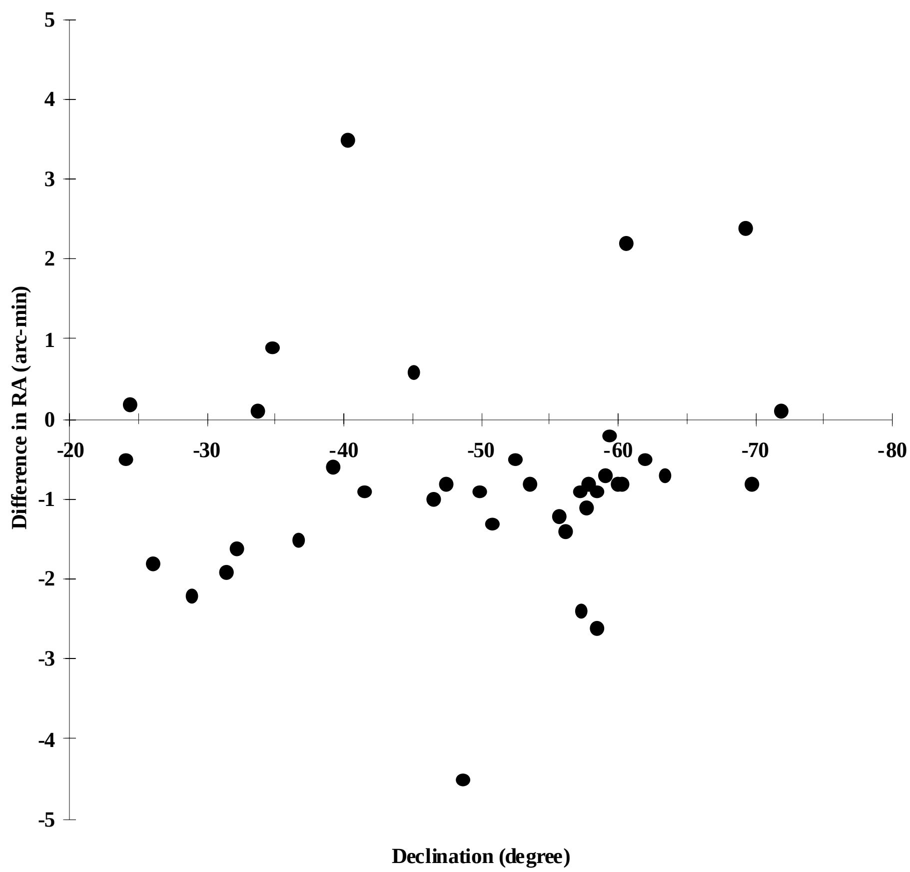

Figure 5.5: The distribution of the differences in RA (in the sense *Guide* – Lacaille) as a function of Declination.

Again it is noted that there is an apparent negative bias in the above figure in the difference in RA, suggesting a time delay. The fact that Lacaille was more accurate as the telescope moved further south supports the time delay theory because objects nearer the pole move more slowly.

5) Differences in Declination as a function of Declination

Figure 5.6 plots the difference between the Declination from *Guide* 8 and that determined by Lacaille, as a function of Declination.

The spread of the data is random with no obvious trends. The mean, SEM and standard deviation are 0.0, 0.26 and 1.6 arc-minutes respectively for the 39 objects.

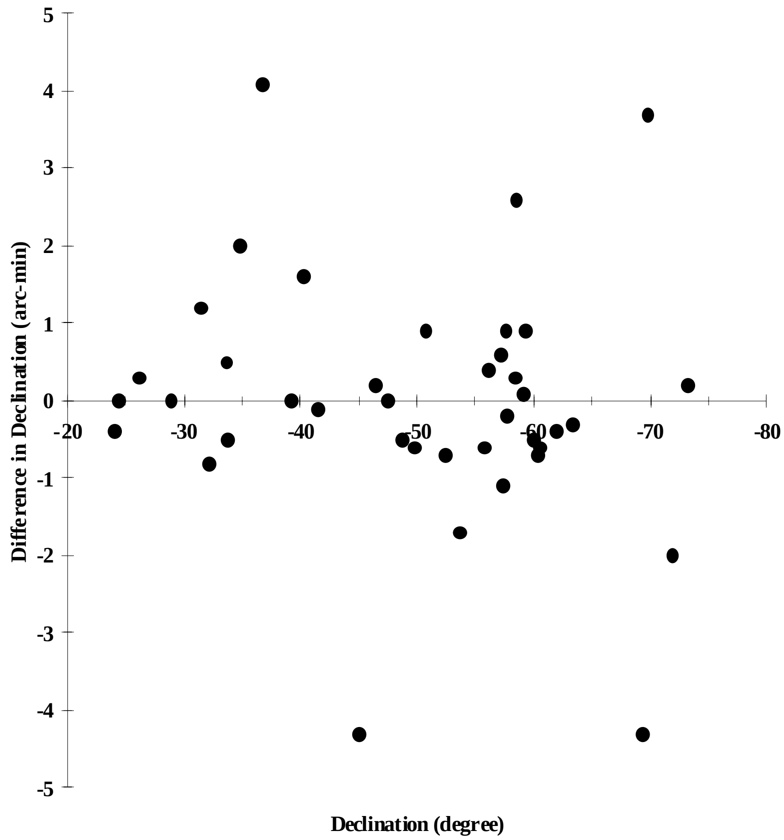

Figure 5.6: The distribution of the differences in Declination (in the sense *Guide* – Lacaille) as a function of Declination.

When the Lacaille catalogue was analysed by comparing the dates he observed with the accuracy of his positions, it was noted that Lacaille's accuracy improved over time. His early observations have the largest errors. It is not surprising that Lacaille's accuracy improved as he gained experience in using his instruments.

5.2.4.2 Astrometry of the Dunlop Catalogue

Dunlop's printed catalogue, *A Catalogue of Nebulae and Clusters of Stars in the Southern Hemisphere observed in New South Wales*, contains 629 entries (Appendices C and F). A description of the observing technique used by Dunlop is found in Section 4.3.3.

The positions given in the Dunlop catalogue are for equinox 1827.0. Analysis was carried out at equinox J2000 after precession to that date using the *Starlink* precession program COCO.[394] No allowance for proper motion was made. The modern positions were acquired

[394] Starlink Project, 2004, <http://www.starlink.rl.ac.uk>, accessed 20 July, 2004.

from the ESO (B) Atlas, which was obtained from the internet[395] where data is available for both B1950 and J2000 equinox (Appendix D).

Of the 629 objects in the original catalogue 404 objects were identified (compared to 211 identified by John Herschel). The 404 objects consist of 368 non-stellar objects (including 36 possible Dunlop objects) and 36 other objects (faint double stars or asterisms that Dunlop was unable to resolve with his telescope and some repeat entries). The collection of non-stellar objects in the Dunlop catalogue was dealt with as one unit and no attempt was made to separate the non-stellar objects into star clusters, nebulae or galaxies. (Only non-stellar objects, apart from D1, were included in the combined catalogue in Section 6.4 and Appendix J.) The astrometric comparisons presented are for 354 objects south of Declination –30^o and includes a number of asterisms. The asterisms included are those where the description given by Dunlop clearly matches an asterism in *Desktop Universe*, as described in Section 5.1.

Of the 629 objects, 225 were not included in this comparison as they could not be identified. For the remaining 404 objects (including some with uncertain identifications) differences in position were calculated in the sense ESO (B) – Dunlop. It became apparent that there were some very large discrepancies between the precessed Dunlop position and that given in the ESO (B) catalogue. These differences were much greater than those encountered in either the Lacaille or Herschel positions. Of these 404 objects, 50 (12% of the sample) were rejected because they are more than 30 arc-minutes from the ESO (B) position, leaving 354 objects.

The radial distance of the Dunlop position from the ESO (B) position was determined for all 404 objects. These differences were ranked from smallest to largest then plotted. Only those within 30 arc-minutes are shown in Figure 5.7. The radial distances between the ESO (B) position and the Dunlop position show that 88% (354/404) of objects are within half a degree (30 arc-minutes), with 20% (81/404) within 5 arc-minutes, 45% (182/404) within 10 arc-minutes, 67% (269/404) within 15 arc-minutes and 79% (318/404) within 20 arc-minutes. The remaining 12%, as mentioned above, contain large errors; many due to typing errors or errors caused by the wrong identification of a reference star in the Large Magellanic Cloud. These errors are detailed in Section 5.2.3.

Figure 5.7 suggests that a 40 arc-minute diameter field is an acceptable search diameter for Dunlop objects. Interestingly the field of the eyepiece Dunlop used when making his

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[395] Centre de Données astronomiques de Strasbourg, Catalogue Selection Page, <http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/34C>, accessed 8 February, 2007.

catalogue was similar, about 45 arc-minutes. However some objects are out by 1 degree in Declination and this requires a 2 degree diameter search field.

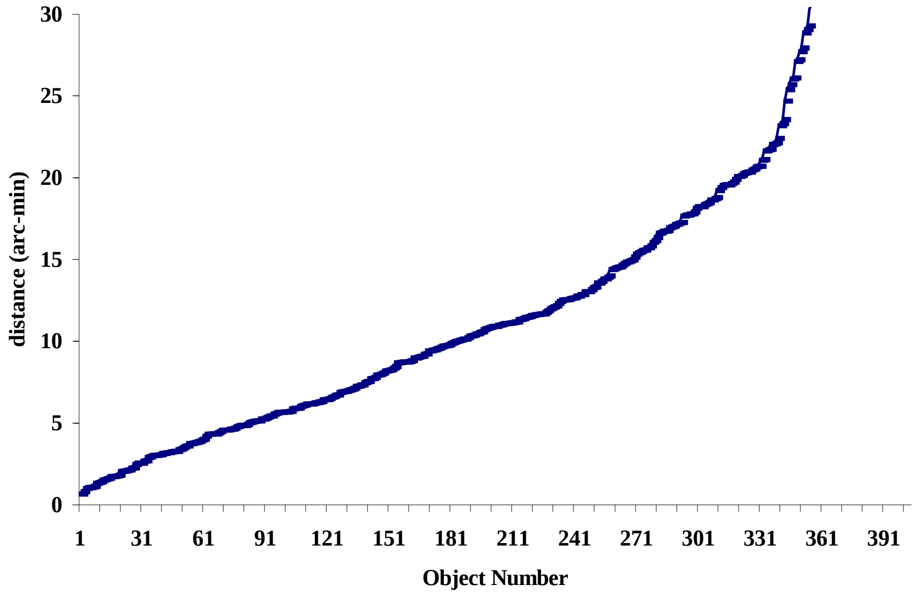

Figure 5.7: Radial distances of 354 objects from the modern ESO (B) positions.

NGC 1910, a nebula in the Large Magellanic Cloud has one of the smallest radial differences between the ESO (B) catalogue and the Dunlop position, one arc-minute. Unlike Lacaille, Dunlop rarely used the brightest star within a nebula or cluster as the position recorded.

The mean, standard error mean (SEM) and standard deviation for the radial distances were calculated using the 318 objects within 20 arc-minutes of the ESO (B) position. The mean is 9.13 ± 0.29 (SEM) arc-minutes and the standard deviation is 5.10 arc-minutes.

The same five standard figures were drawn for the Dunlop positions. Mean values were plotted with the SEM shown as error bars. The raw data was also plotted on the same figure.
A further four diagrams were drawn to reveal other trends as the Dunlop catalogue contained the greatest inaccuracies.

There are a number of possible reasons for the apparent errors in the catalogue. Difficulties with his equipment, his clock, setting circle or mounting could result in errors in RA or Declination (South Polar Distance). If his telescope did not point to the pole when the South Polar Distance read zero, his Declination would be in error. If his telescope did not run north-south along the meridian the RA would vary from the correct reading.

The four additional diagrams are:

6) The plot of date versus difference in RA
7) The plot of date versus difference in Declination
8) The plot of the range in daily difference in RA against date
9) The plot of the range in daily difference in Declination against date.

All of the above graphs were drawn using a range of ± 30 arc-minutes for both difference in RA and difference in Declination. This range was necessary to display a significant sample of the identified Dunlop objects and is indicative of the much larger positional errors in the Dunlop catalogue compared to both Lacaille and Herschel, where ± 5 arc-minutes was used.

1) The Dunlop Target diagram

In Figure 5.8 a 'scatter' or 'target' graph was used to show simultaneously the difference in Declination and the difference in Right Ascension. The Dunlop position, after precession, is shown relative to the position in the ESO (B) catalogue in the sense ESO (B) minus Dunlop. This figure shows widely scattered points, with some quite large errors in both RA and Declination. There is a poor cluster of points towards the centre and the errors are substantial. It seems there must be either equipment and/or procedural errors in the Dunlop positions.

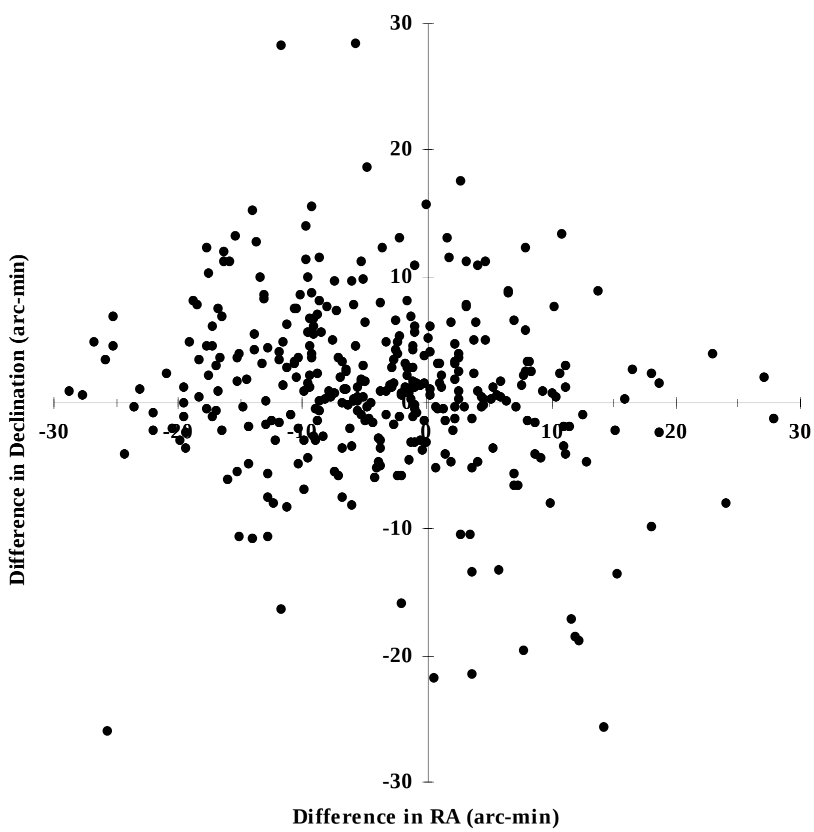

Figure 5.8: The Dunlop Target Diagram (in the sense ESO – Dunlop).

There is an obvious bias in the positions with the upper left quadrant containing most objects, indicating that the majority of objects have a negative difference in RA and a positive difference in Declination. For the 318 objects, there is a significant mean difference in RA of –3.46 (7.5 sigma) and mean difference in Declination of 1.62 arc-minutes (5.4 sigma). The Standard Error Mean for RA is 0.46 and for Declination is 0.30 arc-minutes. The standard deviations are 8.20 and 5.28 arc-minutes respectively. There is great variation in RA, which could be the result of a clock error, a delay in recording the observation and/or a lack of cross hairs in the eyepiece.

2) Difference in RA as a function of RA

Figure 5.9 illustrates the difference between the ESO (B) Right Ascension and the RA given by Dunlop, as a function of Right Ascension.

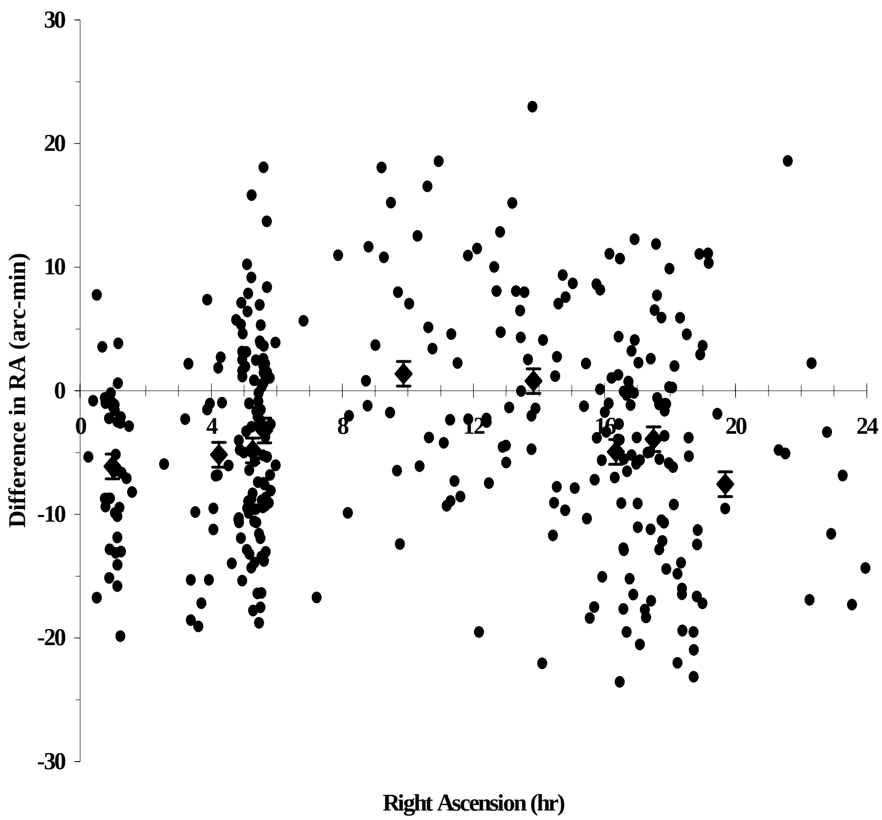

Figure 5.9: The distribution of the differences in Right Ascension (in the sense ESO – Dunlop) as a function of Right Ascension.

As noted, the differences in RA for the Dunlop positions are quite scattered. Of the 404 identified objects 32% (130/404) have a RA within 5 arc-minutes from the modern position and 73% (294/404) within 15 arc-minutes of the ESO position.

The difference in RA is generally negative for RA less than 08 hours, then positive between RA 08 and RA 16 hours, and finally negative above RA 16 hours. Dunlop's early observations were made in the area of positive difference, between RA 08 and RA 16 hours.

It may be possible to fit a sinusoidal curve to the above figure as the differences may be due to errors in his clock. This is explored more fully when the difference in RA is compared to the date of observation.

Figure 5.9 contains groups of data at approximately RA 01 and RA 05 hours. The groups represent concentrations of non-stellar objects within the Small and Large Magellanic Clouds respectively. The grouping around RA 16 hours is made up of objects near the centre of the Milky Way. There are only a few objects at RA 07 hours and between RA 21 to 23 hours, reflecting a lack of bright non-stellar objects in these areas.

3) Difference in Declination as a function of RA

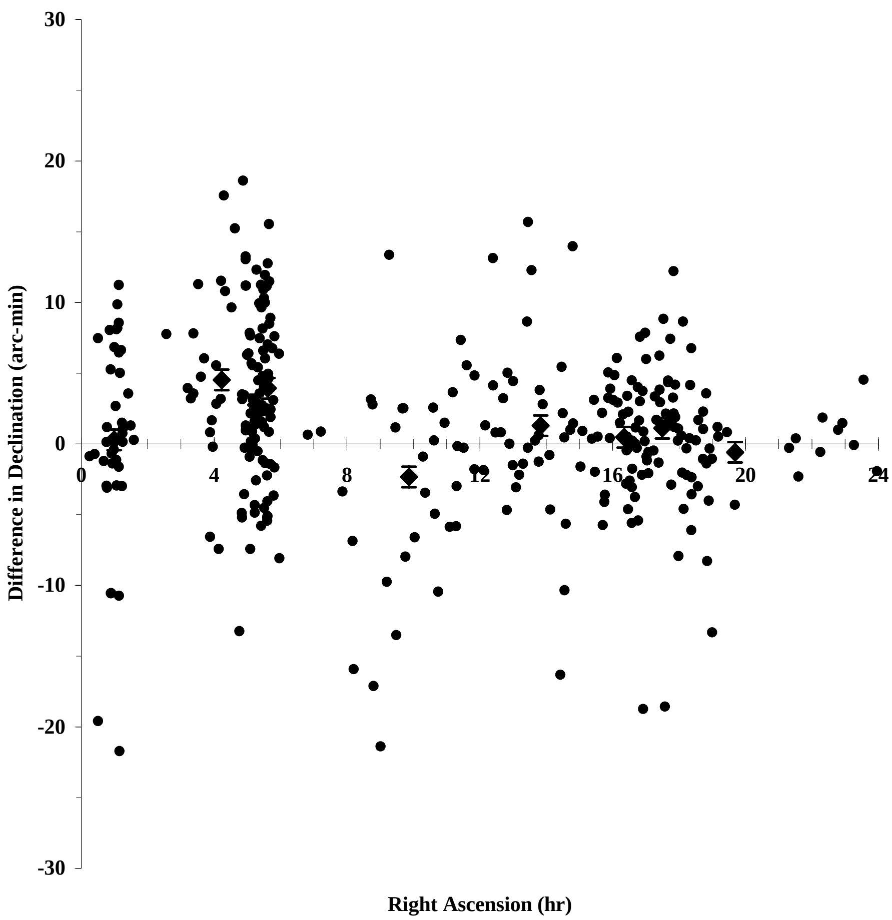

Figure 5.10: The distribution of the differences in Declination (in the sense ESO – Dunlop) as a function of Right Ascension.

Figure 5.10 shows the difference between the ESO Declination and that determined by Dunlop, as a function of Right Ascension.

The Dunlop Declinations are generally more accurate than the Right Ascensions. Fifty-seven percent (229/404) are within 5 arc-minutes and 82% (332/404) within 15 arc-minutes in Declination. For the 318 objects with a radial distance less than 20 arc-minutes from the ESO (B) position, the mean difference in Declination is 1.62 arc-minutes, the SEM is ± 0.30 arc-minutes and the standard deviation is 5.28 arc-minutes.

The Magellanic Clouds are again conspicuous at approximately RA 01 hour and 05 hours.

4) Difference in RA as a function of Declination

Figure 5.11 illustrates the difference between the ESO (B) Right Ascension and that determined by Dunlop, as a function of Declination.

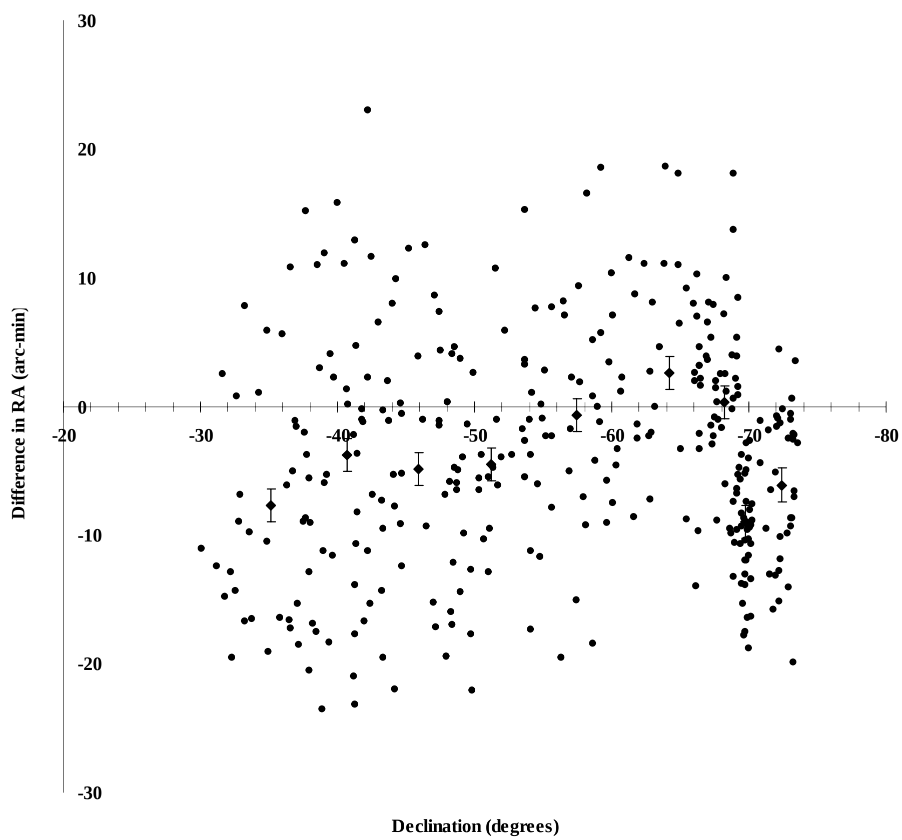

Figure 5.11: The distribution of the differences in RA (in the sense ESO – Dunlop) as a function of Declination.

Generally the difference in RA is negative except at Declination –65°. Again the Magellanic Clouds are conspicuous around Declination –65° and –70°. In the LMC and SMC Dunlop worked off the meridian, and this caused errors.

5) Difference in Declination as a function of Declination

Figure 5.12 illustrates the difference between the ESO Declination and that determine by Dunlop, as a function of Declination. Once more there is a clear positive off-set to the difference in Declination. This difference is greatest between Declination –65° and –70° which resulted from errors in the positions of a number of objects in the Large Magellanic Cloud when it was searched off the meridian.

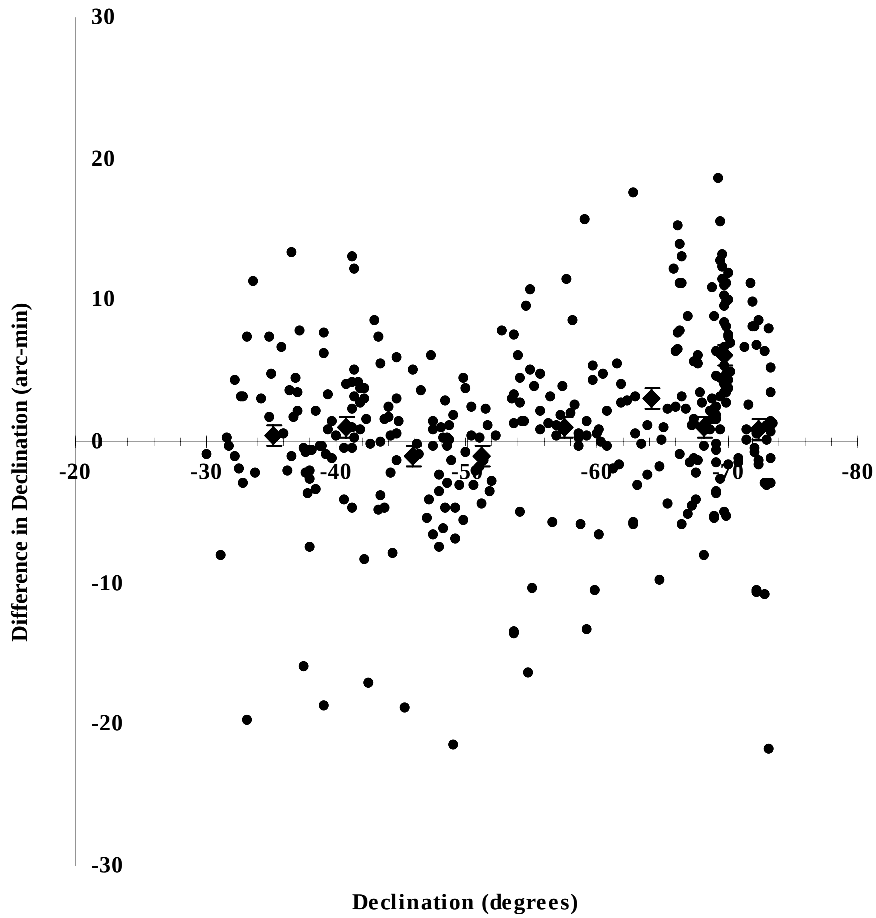

Figure 5.12: The distribution of the differences in Declination (in the sense ESO – Dunlop) as a function of Declination.

As stated previously, further analysis was carried out on the Dunlop data because of the large positional inaccuracies evident. Difference in Right Ascension and Declination were compared with the date of observation in 1826. The mean was calculated for each month, from full moon to full moon and error bars for each month were plotted on the graphs. The range in daily difference in Right Ascension and Declination was also graphed to determine if any trends were evident. Again, all comparisons were made with data precessed to equinox J2000.

6) Difference in RA as a function of Date

Figure 5.13 illustrates the difference between the ESO (B) Right Ascension and that determined by Dunlop as a function of the date observed.

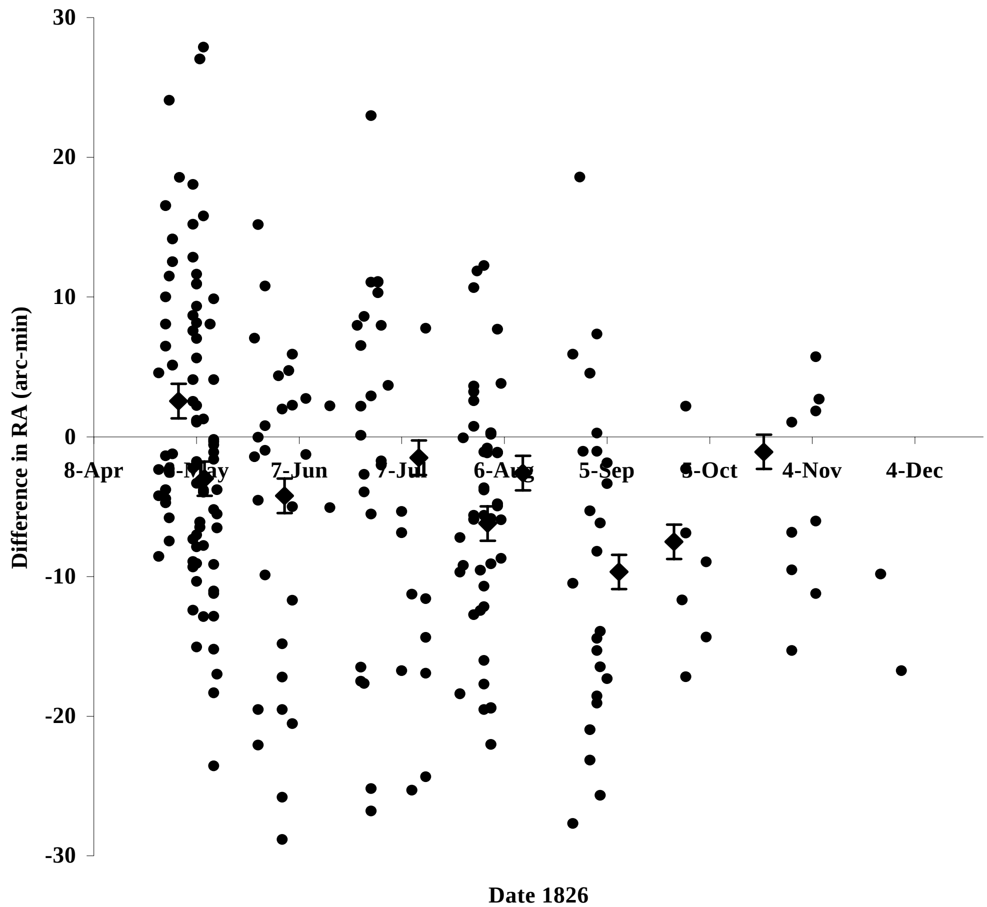

Figure 5.13: Difference in RA as a function of the observation date in 1826.

By comparing the difference in RA with the date of the observation any regular error in the clock used by Dunlop becomes evident. The figure shows that although the mean difference in RA is mostly negative, his early observations have a positive mean. Generally the mean values decrease and there are very few positive differences towards the end of Dunlop's observations.

In early July and the middle of October, the mean difference in RA is closest to correct. If there were problems with Dunlop's clock gaining or losing, the times at which it was corrected would be expected to have the least errors. Dunlop seems to have reset the clock in early July, early August and the middle of October. By omitting the mean value in early September when Dunlop was observing off axis, there does appear to be a repeated, gradual decrease in difference in RA between these dates. This could indicate an inaccurate clock which gradually gained time.

7) Difference in Declination as a function of Date

Figure 5.14 illustrates the difference between the ESO (B) Declination and that determined by Dunlop, as a function of the date observed.

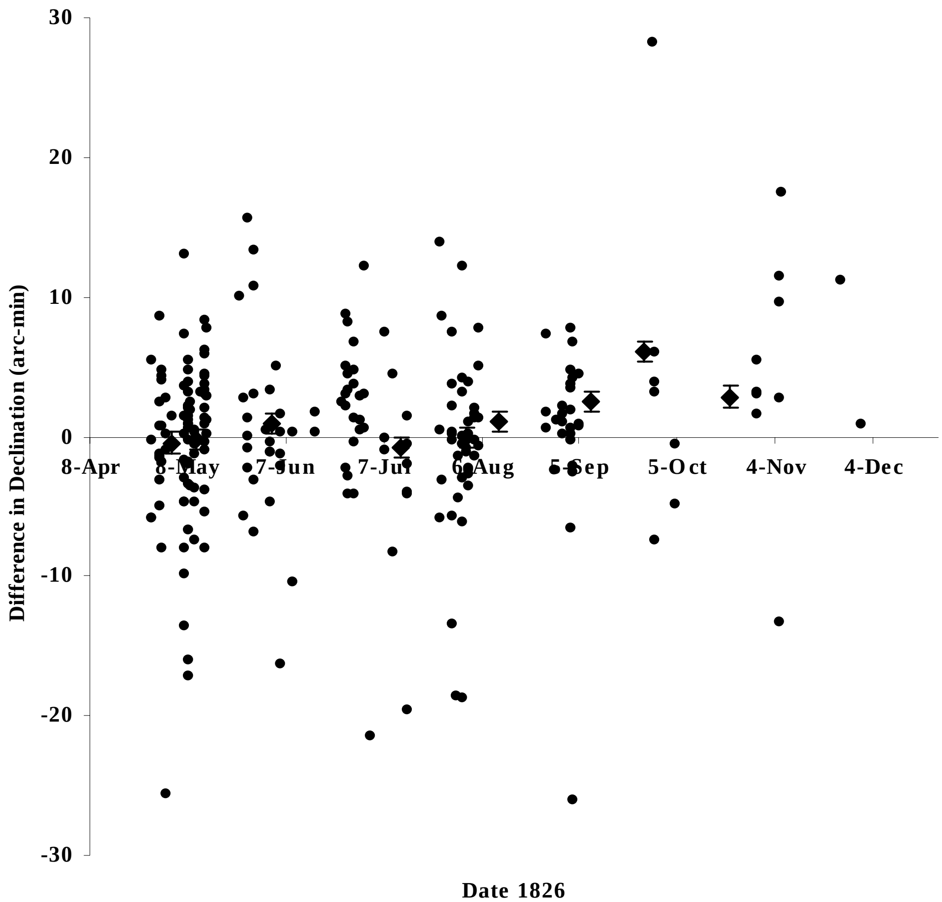

Figure 5.14: Difference in Declination as a function of observation date in 1826.

The figure shows that the mean difference in Declination is close to zero with a fairly small standard error (shown as error bars on the figure) up to about the middle of August when there was a change to a positive mean. During his early observations, Dunlop was relatively accurate in determining Declination considering that he was only using a vernier scale. In September Dunlop began working off the meridian in the Large Magellanic Cloud. From this time on the Declination readings were less accurate. When Dunlop resumed sweeping along the meridian, his Declination readings continued to be too far south.

8) Range in Daily Difference in RA

The difference between the Right Ascension Dunlop recorded and the ESO (B) catalogue position shows large variations on any one night. These variations are illustrated in Figure 5.15 for the 61 nights he observed, as listed in Table 5.8. The maximum and minimum differences are shown at the end of the vertical lines. On a number of nights Dunlop only recorded one observation, and for these nights there is only one dot with no vertical line.

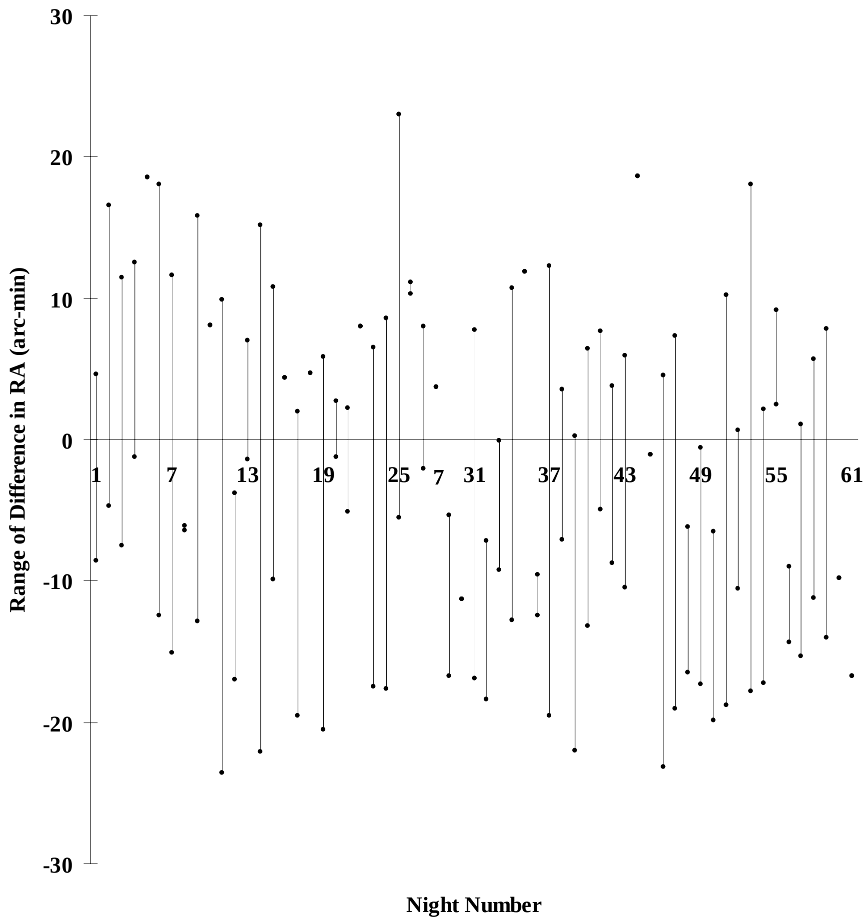

Figure 5.15: Plot of the range in daily difference in RA, for the 61 nights of observations.

On May 26 the difference in RA varied by 37.2 arc-minutes, which is the largest variation on any one night. The range of difference in RA exceeds 30 arc-minutes on 11 of the 61 nights. The nightly variation of difference in RA outweighs any difference in RA seen as a function of date, RA or Declination, and strongly indicates that the errors in RA were not caused by a clock error.

There is an obvious negative slope within the daily range bars up to day 21, repeated again up to about day 50, then starting again. This pattern follows that outlined above where the clock gradually gains, is reset and then gradually gains again.

9) Range in Daily Difference in Declination

Figure 5.16 shows the range for the difference in Declination for each of the 61 nights Dunlop observed, as listed in Table 5.8. The maximum difference and minimum difference values are shown at the end of the vertical lines. Only one dot with no vertical line is shown on the nights when Dunlop made only one observation.

The daily range in the Declination difference is evidently less than the daily range in the RA difference. As stated above, Dunlop's range in RA difference exceeds 30 arc-minutes on 11 nights, but the difference in Declination exceeds 30 arc-minutes on only 3 nights. The greatest difference in Declination for any one night, 31.0 arc-minutes, occurred on July 31.

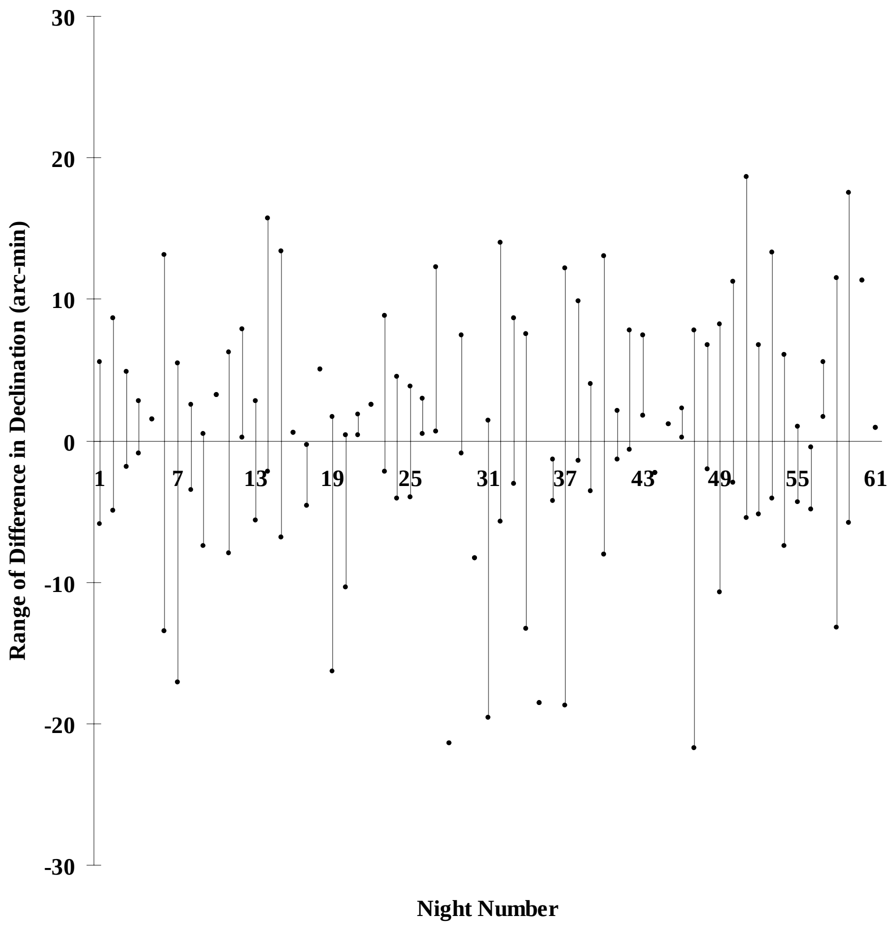

Figure 5.16: Plot of the range in daily difference in Declination, for the 61 nights of observations.

As described earlier, Dunlop recorded some positions in the Large and Small Magellanic Clouds by drifting, with the telescope stationary, rather than sweeping. On September 27, 1826 he completed three drifts off the meridian through the LMC. On the third drift he wrongly identified the star near the start of his drift. The star was Theta Dor (RA 2000 5h 13m 45.5s, Declination –67^{o}11'8") but he misidentified it as SAO 249316 (RA 2000 5h 34m 39.7s, Declination –68^{o}12'18"). This was an error of about 2.23^o. These errors are not included in the above graphs as they are more than 30 arc-minutes from the ESO (B) position.

5.2.4.3 Astrometry of the John Herschel Catalogue

John Herschel's catalogue, *Results of Astronomical Observations made during the years 1834, 5, 6, 7, 8 at the Cape of Good Hope, being a completion of a telescopic survey of the whole surface of the visible heavens commenced in 1825* (Appendices G, H and I) contains a total of 1708 nebula and clusters. Chapter 4.3.2 gives details of the observing technique used by Herschel to make this catalogue.

The positions recorded in the catalogue are for equinox and equator 1830.0. All comparisons were made at equinox J2000 after precession to that date using the *Starlink* precession program COCO.[396] Differences in position were calculated in the sense ESO (B) minus Herschel.

The comparisons presented are for all non-stellar objects in the Herschel catalogue south of Declination –17^o. As with the other catalogues, no attempt was made to differentiate these objects into star clusters, nebulae or galaxies. The collection is treated as one data set. There are 448 open clusters, 58 globular clusters, 62 nebulae, 30 planetary nebulae, 1009 galaxies and 89 other objects, making a total of 1696 objects south of Declination –17^o.

The Herschel sample was not constrained to south of Declination –30^o even though –30^o was used for both the Lacaille and Dunlop data. However when completeness is examined, the Herschel data is constrained to south of –30^o to enable a direct comparison to be made with the work of Lacaille and Dunlop. Of the 1696, 1524 were used in this analysis because only that many are listed in the ESO (B) catalogue. Of these 1524 objects, 30 were rejected in this comparison (leaving 1494) because they were more than 20 arc-minutes from the ESO (B) position; this represents 2% of the sample. The 20 objects with the largest radial differences in position, more than 30 arc-minutes from the ESO (B) position, are discussed separately in Section 5.2.5.

[396] Starlink Project, 2004, <http://www.starlink.rl.ac.uk>, accessed 20 July, 2004.

Again five standard diagrams were used to determine Herschel's astrometric accuracy. The figures do not show objects with difference in RA greater than 5 and less than –5 arc-minutes. There are 73 objects outside these limits. The largest difference in RA is –110 arc-minutes but the remainder are within 33 arc-minutes.

Forty-nine objects have a difference in Declination greater than 3 or less than –3 arc-minutes, with four objects being out by one degree in Declination. Another four objects are out by more than half a degree.

The Herschel catalogue is remarkably free from errors as the figures demonstrate. The differences from the ESO (B) positions are so small that the range for difference in RA and Declination can be plotted to ± 5 arc-minutes. In contrast, the range for difference in RA and Declination for the Dunlop data was plotted to ± 30 arc-minutes.

1) The Herschel Target diagram

Figure 5.17 shows that the Herschel positions are surprisingly accurate, especially in Right Ascension.

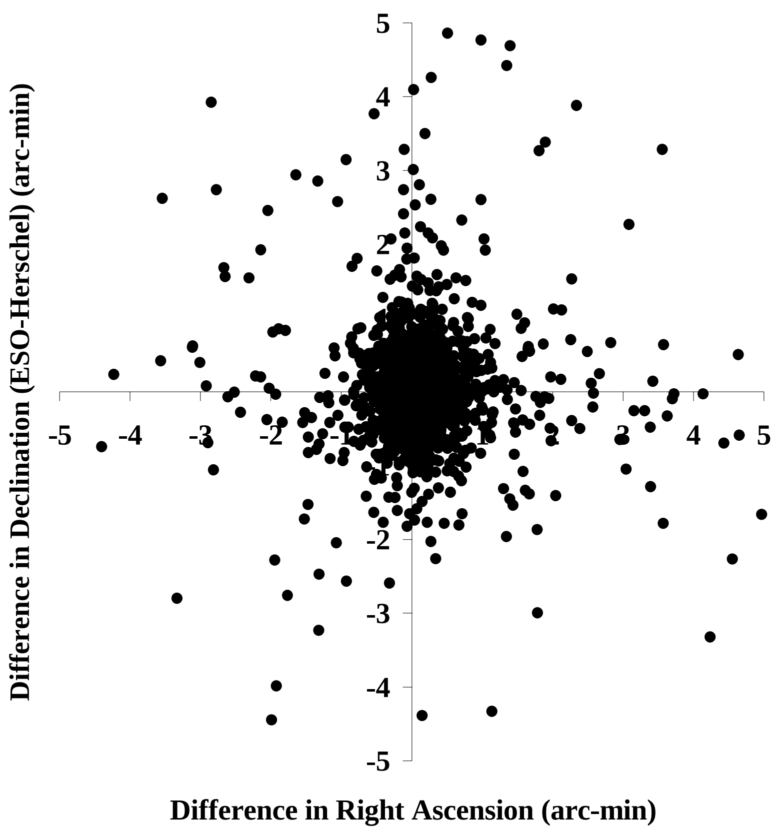

Figure 5.17: The Herschel Target diagram (in the sense ESO – Herschel).

Figure 5.18, Figure 5.19 and Figure 5.20 are the histograms in 1 arc-minute increments of the positional differences (again ESO (B) – Herschel) for:

(i) the radial distance profile of the distribution

(ii) difference in Right Ascension and

(iii) difference in Declination.

(i)

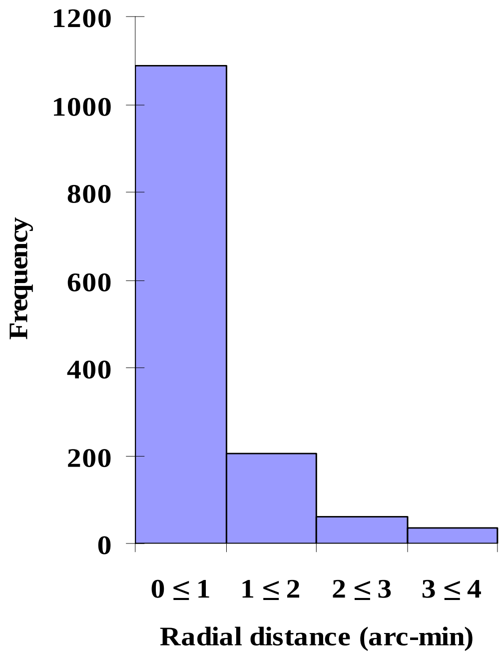

Figure 5.18: Histogram of the radial differences in position.

(ii)

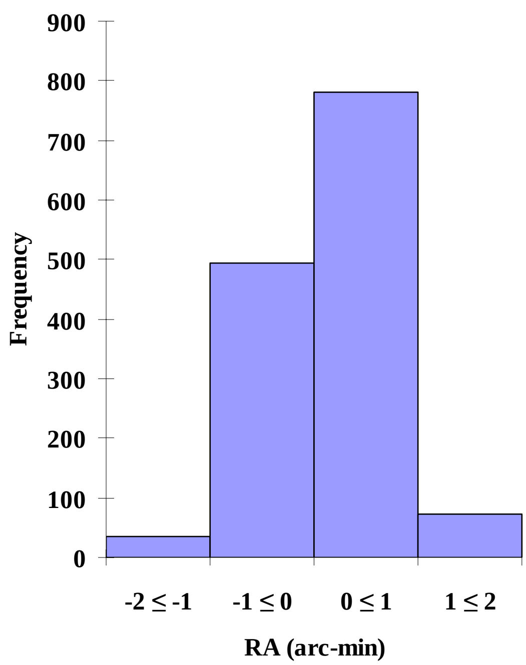

Figure 5.19: Histogram of positional differences in RA (ESO – Herschel).

(iii)

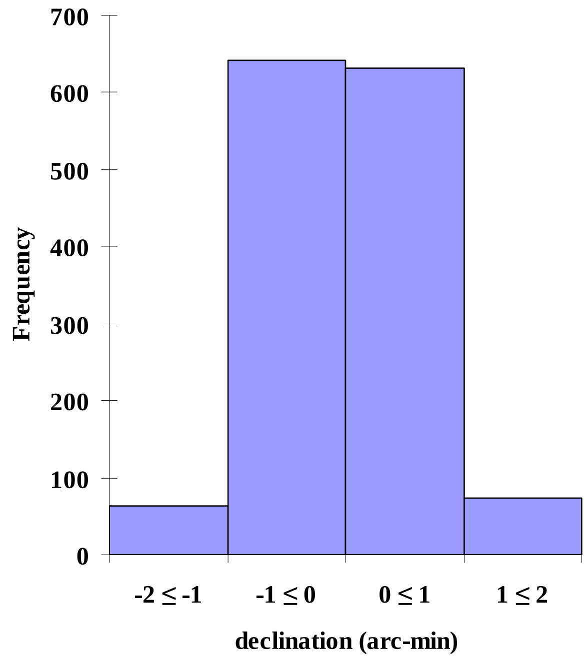

Figure 5.20: Histogram of positional differences in Declination (ESO – Herschel).

Analysis of the radial distance between the ESO (B) position and the Herschel position shows that 42% of the objects (645/1524) are within 0.5 arc-minutes, 71% (1089/1524) are within 1 arc-minute, 92% (1409/1524) are within 5 arc-minutes. Only 30 objects (2%) are more than 20 arc-minutes from their ESO position. The largest difference in the data set is 110 arc-minutes. See Section 5.2.5. The mean, SEM and standard deviation for the radial distance are 1.3, 0.06 and 2.4 arc-minutes respectively for the 1494 objects less than 20 arc-minutes from the correct position.

2) Difference in RA as a function of RA

Figure 5.21 shows the difference between the ESO (B) Right Ascension and that determined by Herschel as a function of Right Ascension.

The difference in RA in the Herschel catalogue is very small, 1274 of the 1524 objects (84%) are less than or equal to one arc-minute from the modern position. Ninety five percent (1450/1524) are within 5 arc-minutes of the ESO position. There is no obvious bias in the positions. The mean difference in RA is 0.15 ± 0.06 arc-minutes and the standard deviation is 2.2 arc-minutes for the 1494 objects within 20 arc-minutes of the ESO (B) position.

It is apparent that the data is concentrated into groups. The groups at approximately RA 01 and 06 hours represent concentrations of objects in or near the Small and Large Magellanic Clouds respectively. The grouping between 10 to 14 hours represents objects in the Southern

Milky Way in the Crux-Centaurus region. The lack of objects with differences outside ± 2 arc-minutes between RA 20 and 24 hours reflects the lack of open clusters in that part of the sky. It is difficult to give precise positions for open clusters and consequently there are many open clusters in the above graph between RA 00 and 20 hours with differences greater than 2 arc-minutes.

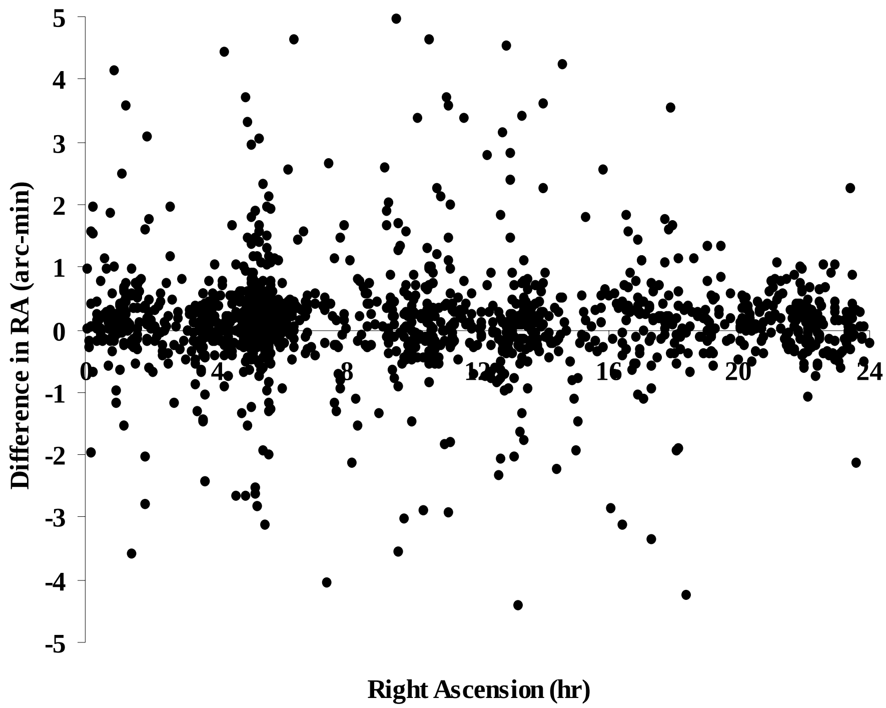

Figure 5.21: The distribution of the differences in Right Ascension (in the sense ESO – Herschel) as a function of Right Ascension.

3) Difference in Declination as a function of RA

Figure 5.22 gives the difference between the ESO (B) Declination and that determine by Herschel, as a function of Right Ascension.

The difference in Declination is also very small. Eighty four percent (1272/1524) are within one arc-minute and 97% (1474/1524) are within five arc-minutes in Declination. After removing the 30 objects with radius greater than 20 arc-minutes from the ESO (B) position (leaving 1494 objects), the average difference in Declination is 0.03 arc-minutes, the SEM is ± 0.04 arc-minutes and the standard deviation is 1.6 arc-minutes. Fourteen objects are more than 30 arc-minutes out in Declination and eight of these are 1 degree out in Declination. There may have been a copy error when the Declination was recorded. Generally the difference in Declination is however slightly greater than the difference in RA. There is no evidence for systematic error.

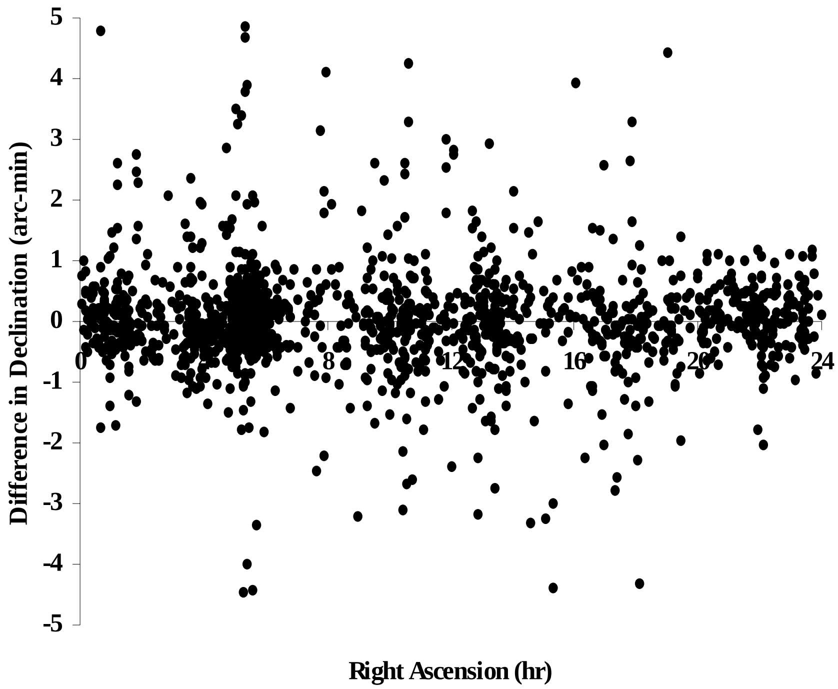

Figure 5.22: The distribution of the differences in Declination (in the sense ESO – Herschel) as a function of Right Ascension.

4) Difference in RA as a function of Declination

Figure 5.23 gives the difference between the ESO (B) Right Ascension and that determine by Herschel, as a function of Declination. No obvious trend is visible in this data set.

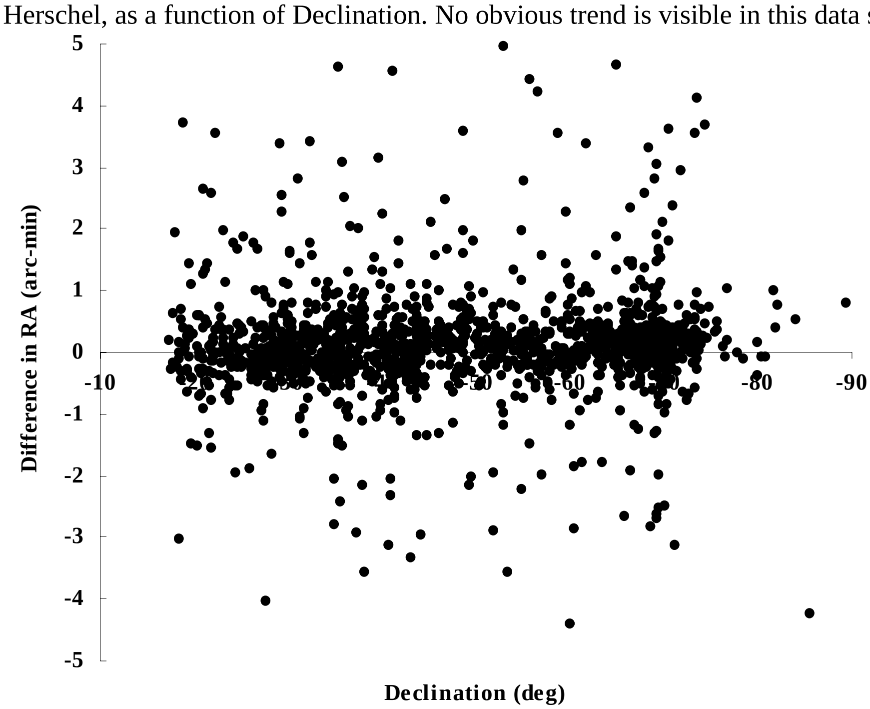

Figure 5.23: The distribution of the differences in RA (in the sense ESO – Herschel) as a function of Declination.

5) Difference in Declination as a function of Declination

Figure 5.24 gives the difference between the ESO (B) Declination and that determine by Herschel, as a function of Declination. Again no trend is evident in this data set.

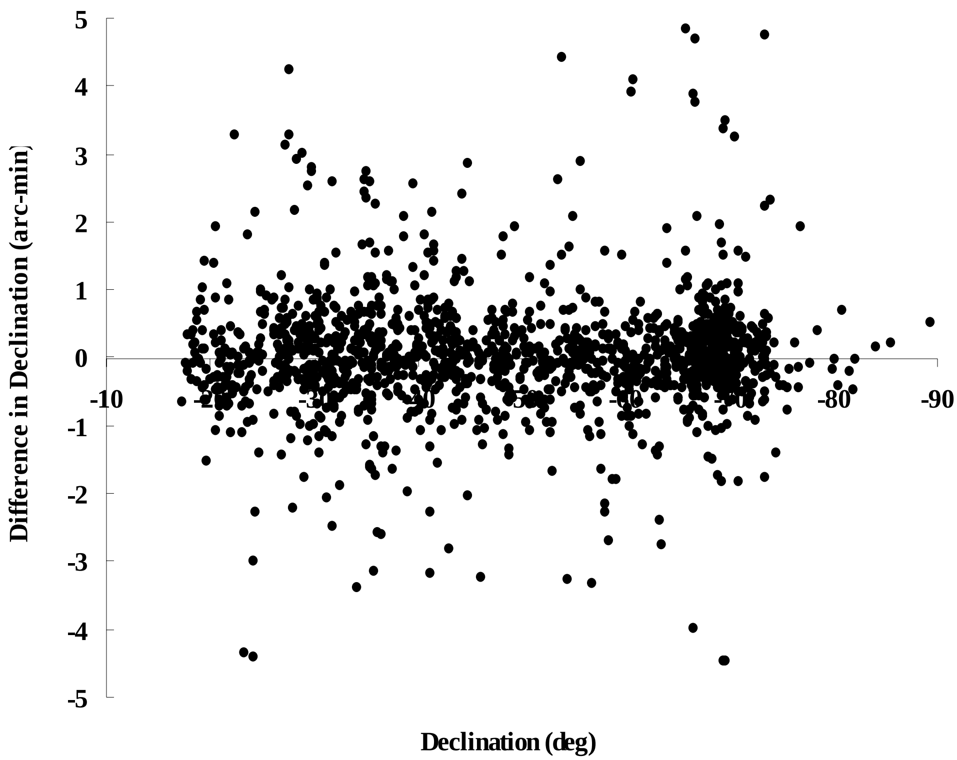

Figure 5.24: The distribution of the differences in Declination (in the sense ESO – Herschel) as a function of Declination.

5.2.5 OBJECTS WITH LARGE DIFFERENCES IN POSITION

Each of the three catalogues contain some objects with large errors in their position, either Right Ascension, Declination or both, which calculate to a large difference in their radial distance from the ESO (B) position. This section considers objects with positional differences greater than 30 arc-minutes.

As outlined above, both the Lacaille and Herschel catalogues were generally remarkably accurate, and significantly their catalogues contain only a small number of objects with a large error in radial position. However, as Table 5.10 summarises, the Dunlop accuracy again falls short when compared to either the Lacaille or Herschel accuracy.

Table 5.10: A Comparison of the number of objects with large uncertainty in radial position.

	Number of Objects in the catalogue	Number of Objects analysed or found	Number of Objects with Large Radial differences in position	Percentage of Analysed Objects
Lacaille	42	42	1	2.4%
Dunlop	629	404	35	8.7%
Herschel	1708	1524	20	1.3%

5.2.5.1 Nicolas-Louis de La Caille

The Lacaille catalogue contains only one object which has a radial distance greater than 30 arc-minutes from the ESO (B) position. This is the globular cluster NGC 104 (47 Tuc) and the radial error is 43.1 arc-minutes due to a copying error of 10 minutes of time in the RA. The difference in Declination is 0.2 arc-minutes.

5.2.5.2 James Dunlop

The accuracy of the Dunlop data is inferior to the Lacaille or Herschel data. Although 50 objects have a positional distance greater than 30 arc-minutes from the ESO (B) position, 15 of these 50 objects are not in the NGC catalogue, so in this section, only 35 are listed. These are listed in increasing order of their radial distance from the ESO (B) position in Table 5.11.

Table 5.11: Dunlop objects with large uncertainty in radial position.

Dunlop Number	NGC Number	Type of Object	difference in RA	difference in Dec	Radial distance (arc-min)
626	2489	OC	30.17	-3.05	30.3
207	1313	Gxy	-11.68	28.28	30.6
616	2243	OC	-31.81	10.08	33.4
607	6652	GC	-33.95	-2.48	34.0
447	5882	PN	-34.08	8.30	35.1
606	6563	PN	-25.67	-25.92	36.5
621	613	Gxy	-36.99	1.39	37.0
477	7590	Gxy	-36.81	-3.95	37.0
629	6316	GC	-36.11	8.42	37.1
532	1808	Gxy	-12.40	39.17	41.1
429	1527	Gxy	-6.13	-54.86	55.2

332	3199	Neb	8.27	-60.05	60.6
335	6087	OC	-1.43	-60.79	60.8
425	6861	Gxy	4.97	-63.19	63.4
320	1533	Gxy	9.82	62.65	63.4
451	6902	Gxy	1.21	70.80	70.8
610	3621	Gxy	-27.00	69.09	74.2
242	2035	Neb	-10.14	-79.76	80.4
205	1313	Gxy	81.10	9.71	81.7
562	1365	Gxy	-128.84	5.05	128.9
201	2130	OC	-117.38	57.12	130.5
182	1871	OC	-134.87	41.14	141.0
191	2004	OC	-133.33	56.50	144.8
194	2035	Neb	-132.28	58.99	144.8
203	2154	OC	-133.09	57.51	145.0
184	1940	OC	-100.95	104.10	145.0
188	1968	Neb	-131.33	61.83	145.2
200	2117	OC	-131.83	61.62	145.5
198	2095	OC	-133.31	60.54	146.4
192	2011	OC	-134.04	59.83	146.8
202	2135	OC	-134.31	62.19	148.0
628	M83	Gxy	160.0	-2.00	160.0
196	2041	OC	-134.03	89.74	161.3
193	2027	OC	-135.03	105.41	171.3
331	1553	Gxy	-502.36	25.23	503.0

The 35 objects include 14 open clusters, 13 galaxies, 4 diffuse nebulae, 2 globular clusters and 2 planetary nebulae. There are also 14 objects in the LMC, 12 of which have large discrepancies in both Right Ascension and Declination due to the misidentification of a reference star. They have the Dunlop numbers, 201, 182, 191, 194, 203, 184, 188, 200, 198, 192, 202, and 196.

Five objects have copying errors. Their Dunlop numbers are 629, 425, 562, 628 and 331, with 331 having by far the largest discrepancy due to the RA being out by 1 hour. More detailed explanations of these copy errors are found in Section 5.2.3.2.

Six objects have inaccuracies in Declination of approximately one degree which are not copying errors. They are Dunlop numbers 429, 332, 335, 320, 541 and 610. It could be assumed that Dunlop made a mistake in either reading or recording the Declination for these objects. There are five objects with a difference in Right Ascension of approximately 30 arc-minutes. These are 626, 616, 607, 621 and 477. Three Herschel objects also have the Right Ascension inaccuracies of around 30 arc-minutes.

Dunlop numbers 207 and 205 are repeats of Dunlop number 206 which has an accurate position. Dunlop number 532 is a repeat of the more accurate Dunlop number 549.

The two remaining objects are planetary nebulae. Dunlop number 447 is identified as NGC 5882 although it is suggested here that this object was too small for Dunlop to see and the object was not included in the combined catalogue. This object will be further discussed in the next section on magnitude limits. The planetary, Dunlop number 606, is both large enough (50 arc-seconds in diameter) and bright enough (magnitude 10.8) for Dunlop to have seen, and his description matches NGC 6563. However both the Right Ascension and Declination have significant differences from the ESO (B) position.

Although it appears that the Dunlop catalogue contains a high proportion of objects with large positional discrepancies, if both the copying errors and the objects whose positions were based on the wrong reference star are omitted from the list, only 18 objects remain, or 4.5% of the total catalogue, which is closer to the percentages in both the Lacaille and Herschel catalogues. These 18 objects are classified by the error(s) they contain as found in Table 5.12. For the purposes of this table, RA is considered accurate up to approximately 10 arc-minutes.

Table 5.12: Summary of differences in RA and Declination for 18 Dunlop objects with radial positions greater than 30 arc-minutes from the ESO (B) position.

Difference from the ESO position	**Number of Objects**	**Dunlop number for these objects**
Right Ascension errors of ~ 30 arc-minutes, (Declination accurate)	6	626, 616, 607, 447, 621, 477
Right Ascension errors > 60 arc-minutes, (Declination accurate)	1	205
Both RA and Declination errors	5	207, 606, 532, 610, 193
Declination errors of ~ 60 arc-minutes, (RA accurate)	4	429, 332, 335, 320
Declination errors > 60 arc-minutes, (RA accurate)	2	451, 242
Total	**18**	

5.2.5.3 John Herschel

As stated previously, of the 1696 objects south of Declination -17^o, only 1524 are listed in the ESO (B) catalogue. Thirty of these objects have a radial distance greater than 20 arc-minutes from the ESO (B) position and 20 have a radial distance greater than 30 arc-minutes from the ESO (B) position. In Table 5.13 these 20 objects are listed by increasing radial distance. There are 12 galaxies and 8 open clusters. Other types of objects were all within 30 arc-minutes of the position.

Table 5.13: Herschel objects with large uncertainty in radial position.

Herschel Number	NGC Number	Type of Object	difference in RA	difference in Dec	Radial distance (arc-min)
3966	7456	Gxy	0.62	30.10	30.11
3890	7130	Gxy	0.93	-30.18	30.19
2364	324	Gxy	0.27	-30.47	30.47
3112	2520	OC	32.00	2.19	32.07
3687	6374	OC	32.84	0.63	32.85
2959	2094	OC	2.82	-33.11	33.23
3369	3960	OC	-33.16	2.91	33.28
3558	5488	Gxy	-37.05	19.55	41.89
3184	2982	OC	-2.96	43.37	43.48
3471	4994	Gxy	0.00	-50.01	50.01
3805	6849	Gxy	56.95	0.86	56.95
3892	7140	Gxy	-0.19	58.82	58.82
2462	824	Gxy	-1.06	-59.12	59.13
2957	2088	OC	0.29	59.47	59.47
3796	6805	Gxy	-0.11	60.06	60.06
2917	2036	OC	-2.50	-60.21	60.26
3952	7355	Gxy	0.54	60.65	60.66
3974	7507	Gxy	0.44	-60.69	60.69
3140	2669	OC	13.99	61.07	62.65
3294	3366	Gxy	-109.77	1.19	109.78

The inaccuracies were categorised for the 20 objects in Table 5.13. It was found that six were out by approximately one degree in North Polar Distance. For these 6 objects, the difference in RA is quite small. The Herschel numbers for the six objects are: 3892, 2462, 2957, 3796, 3952 and 3974.

Two objects, 3184 and 3471 have discrepancies in Declination between 30 and 60 arc-minutes and another two objects, 2364 and 3890 have a difference in Declination of almost exactly 30 arc-minutes. However for these four objects the RA is fairly accurate. The exact reason for this is unknown, but it could be as simple as misreading the Declination at the time of observation or subsequently during their reduction and/or printing. One other object, 3966, also has a difference in Declination of around 30 arc minutes. This is a repeat of the galaxy, Herschel 3967, which has accurate coordinates in his catalogue.

Two open clusters in the LMC have large discrepancies in their Declinations. They are Herschel 2917 and 2959, with discrepancies of –60.21 and –33.11 arc minutes respectively.

Only two objects have significant discrepancies in both Declination and Right Ascension. They are Herschel 3140, an open cluster and 3558, a galaxy. For 3140, it is suggested here that because the Right Ascension difference is 14 arc-minutes and the Declination difference is 61 arc-minutes from the NGC object, 3140 may actually be IC 2391. The description in the original Herschel catalogue matches this object. However the radial distance from the ESO (B) position of IC 2391 is still quite large at 75 arc-minutes.

Unlike 3140, the description for the galaxy 3558 matches NGC 5488 according to Herschel's notes. Again differences in Right Ascension, Declination and radial distance are sizeable at 37, 20 and 42 arc-minutes respectively.

Finally, of the 20 objects that have a radial discrepancy of more than 30 arc-minutes from the ESO (B) position, five have large discrepancies in their Right Ascension, while the Declinations are relatively accurate. The five include three open clusters; Herschel numbers 3112, 3369 and 3687. Herschel 3687 is a repeat of the open cluster Herschel 3698, which has the correct position in the Herschel catalogue. In his notes, Herschel recognised a problem with 3369 commenting that the minute Right Ascension value was doubtful. For all three open clusters, the Right Ascension is out by approximately 32 or 33 arc-minutes. This suggests there may have been a problem in his method of recording Right Ascension or a mathematical error.

The two remaining objects with large errors in their Right Ascension are galaxies with Herschel numbers 3294 and 3805. Herschel 3294 is out by 110 arc-minutes and Herschel again recognised a problem when he made a note that the Right Ascension was doubtful. Like 3112, the reason for the discrepancy (56.95 arc-minutes) in 3805 is uncertain. Perhaps this too was an error in his reading of the time or in subsequent calculations.

A summary of the differences in Right Ascension and Declination for the 20 objects with a radial distance greater than 30 arc-minutes from the ESO (B) position is given in Table 5.14. The Right Ascension or Declination is regarded as accurate when the error is less than 3 arc-minutes.

Table 5.14: Summary of differences in RA and Declination for 20 Herschel objects with radial distance greater than 30 arc-minutes from the ESO (B) position.

Difference from the ESO position	Number of Objects	Herschel number for these objects
Large RA discrepancy, (Declination accurate)	5	3805, 3369, 3294, 3112, 3687
Both RA and Declination discrepancy	2	3558, 3140
Declination discrepancy of ~ 30 arc-minutes, (RA accurate)	4	3966, 3890, 2364, 2959
Declination discrepancy of between 30 and 60 arc-minutes, (RA accurate)	2	3184, 3471
Declination discrepancy of ~ 60 arc-minutes, (RA accurate)	7	3892, 2462, 2957, 3796, 2917, 3952, 3974
Total	**20**	

5.2.6 CONCLUSION

Each of the astronomers, Lacaille, Dunlop and Herschel, produced catalogues of non-stellar objects, which had some errors in the recorded positions. For any of the discrepant objects, the error could have been due to one or more possible reasons. These include:

1. Equipment inaccuracies – the time on the clock, uneven vernier marks, lack of cross hairs in the eye-piece
2. Observational methods – misalignment of telescope (not parallel to the meridian), misalignment of the telescope to the south celestial pole, using the telescope off axis (parallel to, but not along the meridian), not having the object in the centre of the field of view, the time taken to form a description of an object, a delay in reading and/or recording the clock
3. Practical problems – lack of an assistant, the time involved in climbing up and down a ladder, copying errors, errors in calculations when the raw data was reduced and typographical errors in the published catalogue.

The copying errors were not included and it was found that generally both the Lacaille and Herschel catalogues showed remarkably few errors and no systematic trend.

In contrast, the analysis of the Dunlop positions compared to the ESO (B) catalogue showed much greater differences and some clear trends. These included possible problems with his equipment (a clock that gained), procedural problems during observation (working off the meridian and misalignment of his telescope), and practical problems (copying errors). It should be noted however that Dunlop worked under very different and adverse circumstances to the other two astronomers. Dunlop was restricted to his home-made telescope and a borrowed clock, he probably did not have any financial backing, and his catalogue was completed in a very short time, perhaps because of the lack of financial support. Although Lacaille and Dunlop both worked independently without assistants, the Dunlop catalogue contains many more entries than the Lacaille catalogue and an assistant would undoubtedly have decreased some of the difficulties experienced by Dunlop. Had he been able to revisit his observations, check his original notes and make corrections, his catalogue may not have had as many inaccuracies.

Table 5.15 summarises the percentages for the radial inaccuracies in position for each catalogue. It shows that for Lacaille and Herschel, most objects (90% or more) were within 5 arc-minutes of the ESO (B) position. For both catalogues an acceptable search diameter would be within 10 arc-minutes. However for the Dunlop catalogue, most objects (79%) are within 20 arc-minutes. Hence an acceptable search diameter to confirm the object is 40 arc-minutes, which is an area 16 times greater than that for either Lacaille or Herschel.

Table 5.15: Comparison of radial distance discrepancies in position for the 3 catalogues.

Radius	**< 1 arc-minute**	**< 5 arc-minutes**	**< 15 arc-minutes**
Lacaille	33%	90%	95%
Dunlop	1%	20%	67%
John Herschel	71%	92%	97%

For each non-stellar object in a catalogue, the decision to match it to a ‘modern’ object is dependent on the description of the object in the original catalogue, the acceptable search radius determined for each catalogue and/or other good reasons, such as copy errors (for example of one degree in Declination). However, in reality some objects are not easily matched and there is uncertainty regarding identification. For these objects, an understanding of the bias in the catalogue can help determine the validity of an object’s identification. This is especially true for the Dunlop catalogue. The figures drawn for the Dunlop data have helped to identify some of these biases.

Table 5.16 summarises the mean, standard error mean and standard deviation for discrepancies in Right Ascension and Declination, and the mean for the radial difference in position for each catalogue. In this table, for Lacaille 39 objects within 7 arc-minutes of the "correct" position were included; for Dunlop 318 objects within 20 arc-minutes (318/404 or 79%) of the ESO (B) position were included and for Herschel 1494 objects within 20 arc-minutes of the ESO (B) position were included.

Table 5.16: Comparison of mean, standard error mean and standard deviation for the radial distance, difference in RA and difference in Declination for the 3 non-stellar catalogues.

	Mean			Standard Error Mean			Standard Deviation		
arc-min	**Lac**	**Dun**	**Hers**	**Lac**	**Dun**	**Hers**	**Lac**	**Dun**	**Hers**
Radial difference	1.9	9.13	1.3	0.24	0.29	0.06	1.5	5.10	2.4
Difference in RA	–0.5	–3.46	0.15	0.28	0.46	0.06	1.8	8.20	2.2
Difference in Declination	0.0	1.62	0.03	0.26	0.30	0.04	1.6	5.28	1.6

Both Lacaille and Herschel produced catalogues which were remarkably accurate for their time especially considering the equipment they used. Both took considerable time to complete their catalogues, ensuring their accuracy. Both received just recognition for their work.

On the other hand, Dunlop produced a catalogue which contains many inaccuracies and it is not of the same standard as the other two catalogues, regardless of mitigating circumstances. The Dunlop catalogue was severely criticised by John Herschel because of its inaccuracies and it would seem that to some extent that criticism was justified.

5.3 MAGNITUDE LIMITS AND COMPLETENESS

5.3.1 INTRODUCTION

In this section the quality of the data in the Lacaille, Dunlop and Herschel catalogues is evaluated by determining a theoretical limiting magnitude and a working magnitude limit[397] for each telescope and hence the completeness of each catalogue. The process used for this analysis included the following steps:

(i) Calculate the equivalent aperture (diameter) of a modern, aluminium mirrored Newtonian telescope, for the principal telescopes used by Herschel and Dunlop, so that comparisons with known magnitude limits could be used. This was not done for Lacaille's telescope, as he used a refracting telescope.

(ii) Calculate the theoretical limiting magnitude for the principal telescopes used by Herschel, Dunlop and Lacaille, using the telescope's aperture. Although the theoretical limit of a telescope is for stars, it provides an upper limit for the magnitudes of the non-stellar objects in the three historical catalogues.

(iii) List the faintest magnitude for each type of non-stellar object in each catalogue.

(iv) Compare the content of the historical catalogues with modern catalogues to:

1. Determine the magnitude to which each catalogue is reasonably complete, that is the working magnitude limit.
2. Compile a list of bright objects that were missed but that could have been found.
3. Compile a list of the faintest objects found in order to verify that they were seen.

No attempt was made by Lacaille, Dunlop or Herschel to give magnitudes for the non-stellar objects recorded in their respective catalogues. Notes, written at the time of observation by each astronomer, contain descriptive information, but no numerical estimate of the object's brightness. For example, the description in the Dunlop catalogue of number 337 (NGC 1261) states, "A very bright round nebula, about 1.5' [arc-minutes] diameter, pretty well defined and gradually bright to the centre. A small star north following." Herschel's description of the same object, number 2517 in his catalogue, states, "pretty Bright; Round; very gradually brighter in the Middle; 3 arc-minutes diameter; resolved into stars of magnitude 15. A very faint nebula (??) precedes." In his description, Herschel gives an estimate of the magnitude of the resolvable stars, but he does not include an overall magnitude for this globular cluster.

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[397] See Uranometria 2000.0, p. III where this term is used.

An appraisal of the catalogues in association with modern photographic material such as the Southern Schmidt Surveys of the ESO[398] and the UKSTU,[399] clearly allows classification of the objects into open clusters, globular clusters, nebulae, planetary nebulae and galaxies. The content of each catalogue is shown in Table 5.17 as listed in the combined catalogue.

Table 5.17: Content of the Lacaille, Dunlop and Herschel catalogues by object type, not including the Magellanic Clouds.

Object	Lacaille	Dunlop	Herschel
Number of Open Clusters	25	93	133
Number of Globular Clusters	7	39	44
Number of Diffuse Nebulae	2	5	21
Number of Planetary Nebulae	0	4	20
Number of Galaxies	1	59	748

To correctly compare the three historical catalogues, this section concentrates on the area of sky common to all three, south of Declination –30^{o} and outside the Magellanic Clouds. The number of objects in each catalogue in this region is shown in Table 5.18.

Table 5.18: Content of the Lacaille, Dunlop and Herschel catalogues by object type, south of Declination –30^{o} and not including the Magellanic Clouds.

Object	Lacaille	Dunlop	Herschel
Number of Open Clusters	25	93	131
Number of Globular Clusters	5	36	41
Number of Diffuse Nebulae	1	4	20
Number of Planetary Nebulae	0	4	20
Number of Galaxies	0	57	714

5.3.2 EQUIVALENT DIAMETERS AND THEORETICAL LIMITING MAGNITUDES OF THE THREE HISTORICAL TELESCOPES

To determine the equivalent diameter of Herschel's 18.5-inch and Dunlop's 9-inch telescopes the number and type of mirrors needs to be considered. Detailed calculations are shown below in 5.3.2.1.

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[398] European Southern Observatory

[399] United Kingdom Schmidt Telescope Unit

The theoretical limiting magnitude is defined as the faintest star which can be seen by a particular telescope. Theoretical limiting magnitudes were calculated for the main telescopes used by Lacaille, Dunlop and Herschel.

Even when the theoretical limiting magnitude is known, it does not mean that all objects to that magnitude are visible. There are many factors which influence the ability of a telescope to capture light, including the size of the mirror, the type of telescope (refractor or reflector), the darkness of the sky, the stillness of the atmosphere (seeing), the observer's altitude and the type of astronomical object being viewed. With optimal conditions, stars as faint as the theoretical limiting magnitude should be visible in a well collimated telescope. Harold Suiter lists 23 aberrations, obstructions, misalignments and processing errors that can degrade an image, which he labels the "wobbly stack".[400]

The concept of magnitude implies that the same amount of light can be seen from any astronomical objects quoted as having the same magnitudes. While this seems reasonable, the light emitted from stars originates from a very compact point. For other objects like open clusters, globular clusters, planetary nebulae and galaxies, the light derives from a much larger area and will therefore be more difficult to discern. Thus while the stars at the theoretical magnitude limit of a telescope may be visible, non-stellar objects at the same magnitude are not usually visible.

In the same telescope, different types of non-stellar objects have different limiting magnitudes depending on a number of factors, including size and surface brightness. For non-stellar objects, the surface brightness is better than magnitude for predicting an object's visibility. Surface brightness can be calculated using the formula $SB = m + 2.5\log\sqrt{\pi ab}$ where *m* is the magnitude of the object and $\sqrt{\pi ab}$ is the "effective" circular area.[401] However for the purposes of this thesis, the surface brightness was not used, but a working magnitude limit was determined for each catalogue. Although there are many factors which affect the

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400 H.R. Suiter, *Star Testing Astronomical Telescopes: A Manual for Optical Evaluation and Adjustment*, Richmond, Virginia, 1994, p.36.

401 L.M. Lubin & A. Sandage, 'The Tolman Surface Brightness Test for the Reality of the Expansion. III. *Hubble Space Telescope* Profile and Surface Brightness Data for Early-type Galaxies in three High-Redshift Clusters', *The Astronomical Journal*, 2001, vol 122, p. 1071-1083, <http://www.iop.org/EJ/article/1538-3881/122/3/1071/201174.text.html>, accessed 3 October, 2007.

visibility of non-stellar objects, only one working magnitude limit was used for all types of objects within each historical catalogue for the determination of completeness.

As the historical catalogues are of non-stellar objects, the calculated theoretical limiting magnitude was used only to establish an upper limit and the working magnitude limit was used to evaluate the completeness of each catalogue.

5.3.2.1 Detailed Calculations on Speculum Mirror Reflectivity

In 1946 S Tolansky and W K Donaldson wrote "The reflectivities of electrodeposited speculum (a copper-tin alloy containing preferably 45% of tin) and of speculum prepared by evaporation in vacuo have been determined over the range 4500-6500 A. The reflectivity of the freshly polished electrodeposited alloy containing 45% of tin, which is the ideal composition from the viewpoint of maximum resistance to tarnishing, varies from 63% at 4500 A [Å] to 75% at 6500 A [Å]. After keeping for six months in a damp atmosphere the reflectivity decreases by 10% in the red region [to 65%] and by 2% in the blue region [to 61%]."[402] Calculations using the average of the above percentages (61% and 65%) suggest that Dunlop's mirror was equivalent to a 6.5-inch and Herschel's mirror was equivalent to a 16.8-inch aluminised mirror after six months in a damp atmosphere. There is no printed record of the extent of tarnishing or of Dunlop repolishing his mirror, but he probably did so.

A more detailed calculation is shown in Table 5.19. The reflectivity of a speculum mirror depends on the wavelength of the light. Herschel's speculum mirror contained copper and tin in the ratio 12:5 or 29% tin, not 45% as described above. No information on the composition of Dunlop's speculum mirror is available. Calculations for reflectivity for both Herschel's and Dunlop's mirrors used the 45% tin speculum mirror because no information on the reflectivity of a 29% tin mirror is available.

Table 5.19 predicts that Herschel's 18.5-inch speculum mirror was theoretically equivalent to a 17.1-inch aluminium mirrored Newtonian telescope in the blue part of the spectrum and to an 18.2-inch telescope in the red part of the spectrum when freshly coated. Similarly, Dunlop's 9-inch speculum mirror was theoretically equivalent to a 6.6-inch aluminium Newtonian telescope in blue light and a 7.7-inch in red light when freshly coated. Thus the limiting magnitude for blue reflection nebulae is fainter than for red emission nebulae for a freshly coated speculum mirror. However red emission nebulae would not appear brighter to

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[402] An abstract of the article can be found at: IOP (Institute of Physics), *Journal of Scientific Instruments*, 2007, <http://www.iop.org/EJ/abstract/0950-7671/24/9/308>, 22 August 2007.

an observer because the dark adapted eye is not able to detect faint red light. Table 5.19 also shows (in bold print) that the equivalent aluminium Newtonian telescope would be a 16.8-inch for Herschel and a 6.5-inch for Dunlop (average for 450 and 650 nm) after six months in a damp atmosphere.

Table 5.19: Reflectivity and magnitude limit for 45% tin speculum mirror telescopes.

HERSCHEL'S TELESCOPE with no secondary mirror / **Wavelength (nm)**	**Mirror Diameter (inches)**	**Reflectivity Speculum[403] (%)**	**Reflectivity Aluminium (%)**	**Diameter of Equivalent Newtonian Telescope (inches)**	**Magnitude Limit**
450 (blue)	18.5	63	86	17.1	15.3
650 (red)	18.5	75	88	18.2	15.4
450 (after 6 months)	18.5	61	86	**16.8**	**15.2**
650 (after 6 months)	18.5	65	88	**16.9**	15.2

DUNLOP'S TELESCOPE with secondary mirror / **Wavelength (nm)**	**Mirror Diameter (inches)**	**Reflectivity Speculum (%)**	**Reflectivity Aluminium (%)**	**Diameter of Equivalent Newtonian Telescope (inches)**	**Magnitude Limit**
450 (blue)	9	63	86	6.6	13.2
650 (red)	9	75	88	7.7	13.5
450 (after 6 months)	9	61	86	**6.4**	**13.1**
650 (after 6 months)	9	65	88	**6.6**	13.2

Table 5.19 also gives the magnitude limits for telescopes, using the formula $m = 9.1 + 5 \log D$. In blue light after six months in a damp atmosphere, a magnitude limit of 15.2 is calculated for Herschel's telescope and 13.1 for Dunlop's telescope. These values are used as their theoretical limiting magnitudes for stars.

5.3.2.2 Herschel's 18.5-inch Reflecting Telescope

As shown in Section 5.3.2.1, John Herschel's telescope is equivalent to a 16.8-inch Newtonian telescope with a theoretical magnitude limit of 15.2. The second edition of

[403] The values are included in the abstract of the article by Tolansky and Donaldson at: IOP (Institute of Physics), Journal of Scientific Instruments, 2007, <http://www.iop.org/EJ/abstract/0950-7671/24/9/308>, 22 August 2007.

Hartung's Astronomical Objects for Southern Telescopes suggests slightly fainter magnitude limits of 15.3 for a 16-inch telescope and 15.6 for an 18-inch telescope.[404]

This theoretical limiting magnitude is evidenced in his double star catalogue. One double star John Herschel recorded (Herschel 2684) has both stars with equal magnitudes of 14.5.[405] The two closest southern double stars Herschel catalogued are 0.5 arc-seconds (magnitudes 6.4 and 7.1) and 0.6 arc-seconds apart (magnitudes 7.3 and 8.3).[406] This indicates that his resolution was approximately 0.5 arc-seconds, and probably limited by the atmosphere.

5.3.2.3 Dunlop's 9-inch Reflecting Telescope

As shown in Section 5.3.2.1, Dunlop's telescope was similar to an aluminium mirrored Newtonian 6.5-inch reflector, with a theoretical magnitude limit of 13.1.

Further evidence to support this limit was found in his printed descriptions. Dunlop seems to refer to a star which, according to modern measurements has a magnitude of 13.1. Table 5.20 lists in Dunlop order, the faintest stars recorded in his catalogue of nebulae and clusters and gives their modern magnitudes. Asterisms in the Dunlop catalogue also help to establish the magnitude limit of his telescope as their stars have known magnitudes.

Table 5.20: Magnitude of the faintest stars in the Dunlop catalogue of nebulae and clusters.

Dunlop Number	Faintest Star Seen
D 1	magnitude 12.6
D 67	magnitude 12.9 stars in a globular cluster probably resolved.
D 244	magnitude 12.6 star in open cluster seen
D 269	magnitude 12.3 seen
D 270	magnitude 12.8 not clear
D 305	magnitude 12.3 seen
D 319	magnitude 12.3
D 328	magnitude 12.6 seen

[404] D. Malin and D.J. Frew, *Hartung's Astronomical Objects for Southern Telescopes*, Melbourne, 1995, p. 89.

[405] Data from *Washington Catalog of Visual Double Stars.* Guide 8.0 gives magnitude 13.6 for both stars.

[406] Data from *Washington Catalog of Visual Double Stars.*

D 529	magnitude 13.1 uncertain identification
D 565	magnitude 12.4
D 576	magnitude 12.8 not clear
D 615	magnitude 12.8 not clear
D 616	magnitude 12.8 star seen in open cluster
D 618	magnitude 12.6 seen

The resolution of Dunlop's telescope is also significant, and the quality of the 9-inch telescope can be established by comparing the closest doubles in his double star catalogue[407] with the corresponding entries in the Washington Double Star Catalog.[408] This comparison reveals the resolving ability of the 9-inch telescope to be about 4 arc-seconds, whereas Herschel's 18.5-inch telescope could resolve stars to about 0.5 arc-seconds. Dunlop's poor resolution was probably due to the poor quality of his eyepieces or the use of low magnifying powers while sweeping.

Four of the closest double stars in the Dunlop double star catalogue, sorted by separation, are shown in Table 5.21, which includes the separation and the magnitudes of the two stars.

Table 5.21: The closest doubles in the Dunlop double star catalogue.[409]

Dunlop Number	Separation (1826) (arc-second)	Magnitudes of the two stars
23	3.0	7.0 + 7.4
81	4.0	5.9 + 8.0
168	5.0	8.3 + 8.6

The binary star Dunlop 23 was probably not discovered with the 9-inch reflecting telescope but with the 46-inch focal length refractor. In his double star catalogue Dunlop includes objects found with both the refractor and the reflector telescopes and marks with an asterisk those found using the refractor. Although there is no asterisk against Dunlop 23, it is possibly a mistake in the catalogue as it seems unlikely Dunlop resolved this binary with his 9-inch reflector. He also gives an accurate position angle which suggests he used the refractor.

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407 J. Dunlop, *Approximate Places of Double Stars, in the Southern Hemisphere, observed at Paramatta in New South Wales*. There are 253 pairs in this catalogue.

408 C.E. Worley, and G.G. Douglass, *Washington Catalog of Visual Double Stars*, Washington, 1984.

409 Data from *Washington Catalog of Visual Double Stars.*

Harold H. Peterson,[410] stated that using a 3-inch diameter telescope and 45 times magnification, the resolution limit was independent of the companion star's brightness up to the ninth magnitude. After that the detection of the increasingly fainter companion required wider separations. Peterson was able to resolve double stars with a separation of 3 arc-seconds or more using a 3-inch diameter telescope.

Norton's Star Atlas[411] suggests that a 1-inch diameter telescope should have a resolution of 4.56 arc-seconds and an 8-inch diameter telescope a resolution of 0.57 arc-seconds. According to Dawes' formula,[412] the resolution of Dunlop's telescope should be less than 1 arc-second. Thus Dunlop's resolution was very poor, being similar to or worse than a 1-inch telescope. Inferior quality eye pieces are probable reasons for the telescope's poor resolution.

5.3.2.4 Lacaille's Half Inch Refracting Telescope

As the Lacaille telescope was a refractor, no equivalent Newtonian was determined. The theoretical magnitude limit for Lacaille's half inch telescope can be found using the formula $m = 9.1 + 5 \log D$, where D is the aperture of the telescope in inches. This gives a limiting magnitude of 7.6, similar to the magnitude limit (7.6 or 7.7) determined by comparing his star catalogue with modern star catalogues as described in Section 2.2.3. Hartung implies a limiting magnitude of 7.8 for a half inch telescope.[413] A theoretical magnitude limit of 7.6 is used for comparison purposes for the Lacaille catalogue. According to the Dawes' limit formula[414], the resolution of his telescope was about 10 arc-seconds.

5.3.3 MODERN CATALOGUES USED FOR COMPARISON WITH THE HISTORICAL CATALOGUES

A number of modern catalogues specialising in one type of object were obtained and used to determine a working magnitude limit for each historical catalogue. The modern catalogues chosen contain the best current data available. They were:

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[410] Leif Robinson, *The "Sky and Telescope" Guide to the Heavens*, Cambridge, Massachusetts, 1980, p.28. The original article by H. Peterson appeared in *Sky and Telescope*, September 1954, page 396.

[411] Norton, p. 108.

[412] Robinson, p. 27.

[413] Malin and Frew, p. 89.

[414] Dawes' limit formula gives the maximum resolving power of a telescope. It is $R = 4.56/D$ where D is in inches and R is in arc-seconds.

1) *The Lynga Open Star Catalogue*[415]
2) *Catalog of Parameters for Milky Way Globular Clusters*[416]
3) The *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae*[417]
4) The *Catalogue of Principal Galaxies*.[418]

The *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae* does not assign magnitude values to planetary nebula, but the visual magnitude can be calculated[419] from the flux values provided in this catalogue. All references to the magnitudes of planetary nebulae in this chapter quote these calculated magnitude values.

The working magnitude limit for the reference catalogues is the magnitude of the peak (mode) shown in the histograms below. These magnitude values and the number of objects south of Declination -30^{o} (not including objects in the Magellanic Clouds) are listed in Table 5.22.

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[415] G. Lynga, *Open Cluster Data*, 5th Ed., CDS, 1987, <http://cdsarc.u-strasbg.fr/viz-bin/Cat?VII/92A>, accessed 20 July, 2005.

[416] William E. Harris, 'Catalog of Parameters for Milky Way Globular Clusters', *Astronomical Journal*, 122, 1996, p. 1487. The catalogue can be found on the CDS web site, <http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/202>, accessed 1 July, 2005.

[417] Agnes Acker, James Marcout, Francois Ochsenbein, Bjorn Stenholm, Romuald Tylenda, Constant Schohn, *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae*, Munich, 1992.

[418] G. Paturel, P. Fouque, L. Bottinelli, L. Gouguenheim, 'Catalogue of Principal Galaxies', *Astronomy and Astrophysics Supplement Series*, 80, 1989, p. 299-315. The catalogue can be found on CDS web site, <http://vizier.u-strasbg.fr/cgi-bin/VizieR-5?-out.all=1&-source=VII/119&-c=PGC+046957>, accessed 20 October, 2005.

[419] Kent Wallace provides this information on the web site; D. Snyder, *Planetary Nebulae Observer's Home Page*, 2005, <http://www.blackskies.org/intro.html#Files >, accessed 5 November, 2005. Most were calculated by Owen Brazell in his WEBB society article using Jack Marling's formula:
$M_v = -2.5[\log_{10}(\text{Flux } H_\beta) + \log_{10}(1.04+0.77\text{Flux He } 469\text{nm} + 0.985\text{Flux OIII } 496+501\text{nm})]-13.50$, where the H_β Flux is given in ergs/sec.cm^2 and F469, F501 and F96 are the ratios of these nebula line strengths compared to the H_β line.

Table 5.22: Number of non-stellar objects south of –30^o Declination in the modern catalogues cutside the Magellanic Clouds.

Type of Object	Name of Catalogue	Number of objects south of Declination –30^o	Working Magnitude
Open Cluster	The Lynga Open Star Catalogue	221	9.0
Globular Cluster	Globular Clusters in the Milky Way	54	8.5
Planetary Nebula	The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae	212	15.0
Galaxy	The Principal Galaxy Catalogue	8837	14.5

5.3.3.1 *The Lynga Open Star Catalogue*

Although the catalogue *Optically Visible Open Clusters and Candidates* by Dias,[420] is currently the most complete, it does not include magnitudes for open clusters. For this reason the *Lynga Catalogue* was used for comparisons.

Open clusters are defined in the Encyclopædia Britannica as "any group of young stars held together by mutual gravitation. Open clusters contain from a dozen to many hundreds of stars, usually in an unsymmetrical arrangement."[421] The visibility of open clusters depends on a number of factors including the telescope's field of view and the cluster's size, concentration, detachment, brightness as well as the brightness range of its component stars and the number of stars in the cluster. For this reason, using open clusters as a guide for the determination of a telescope's limiting magnitude is problematic.

The *Lynga Catalogue* contains 221 open clusters to magnitude 13. The objects were categorised into half magnitude groups (0.25 – 0.75, 0.75 – 1.25, etc) and a histogram was drawn as shown in Figure 5.25. The magnitude of the peak (or mode) is 9.0. Thus the Lynga Catalogue is only suitable for determining a working limit up to magnitude 9.0 and is not suitable for either the Herschel of Dunlop catalogues.

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[420] W.S. Dias, B.S. Alessi, A. Moitinho, J.R.D. Lepine, 'Optically Visible Open Clusters and Candidates', *Astronomy and Astrophysics,* 389, 2002, p. 871-873. The catalogue can be found on CDS web site, <http://cdsarc.u-strasbg.fr/viz-bin/Cat?B/ocl>, accessed 20 July, 2005.

[421] Encyclopædia Britannica, *Open Cluster*, 2009.
<http://www.britannica.com/EBchecked/topic/429616/open-cluster>, accessed 30 September, 2009.

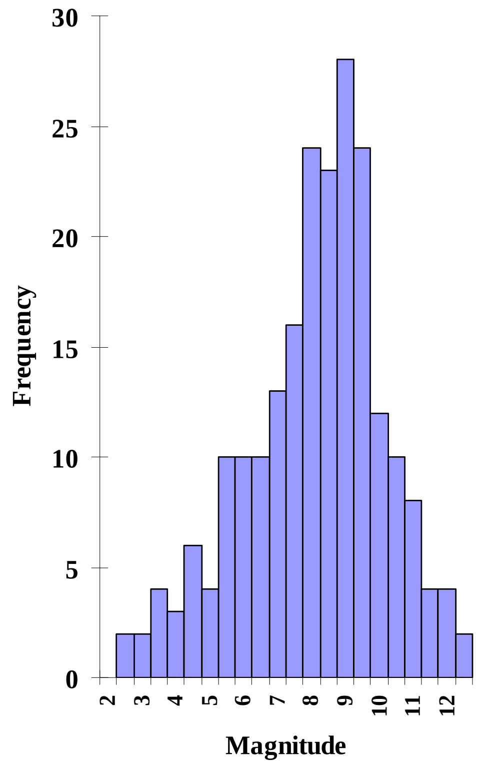

Figure 5.25: Histogram of the number of open clusters by half magnitude for the *Lynga Catalogue*.

5.3.3.2 *Catalog of Parameters for Milky Way Globular Clusters*

Fifty-four southern globular clusters to magnitude 14.5 are included in Harris' *Catalog of Parameters for Milky Way Globular Clusters*[422] but there is a lack of faint objects. As with open clusters, the globular clusters were categorised into half magnitude groups and a histogram was drawn to find the magnitude of the peaks as shown in Figure 5.26. There are two peaks (bimodal), at magnitudes 6.5 and 8.5, and the faintest magnitude (8.5) is used. The use of globular clusters for determining a working limit is only feasible up to magnitude 8.5, and consequently the Harris catalogue is not suitable for determining the working magnitude limit for either the Dunlop or Herschel catalogues.

[422] W.E. Harris, 'Catalog of Parameters for Milky Way Globular Clusters', *Astronomical Journal*, vol. 112, 1996, p. 1487.

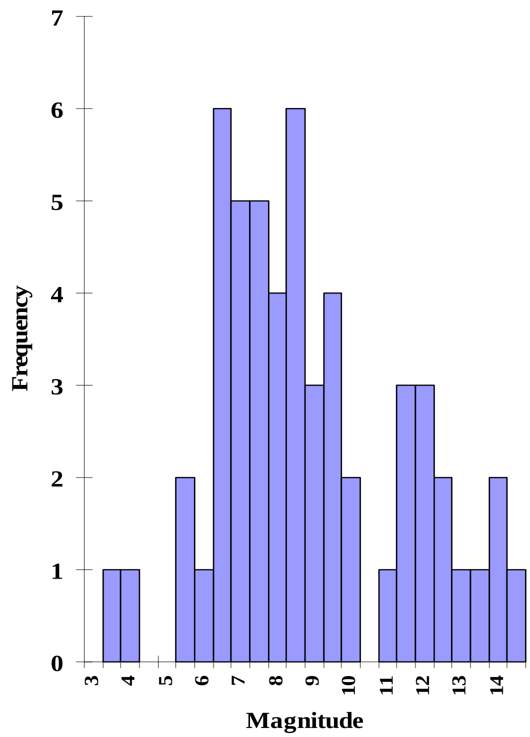

Figure 5.26: Histogram of the number of globular clusters by half magnitude for the Harris catalogue.

Comparisons with the reference catalogues of open clusters and globular clusters are only suitable for the determining a working magnitude limit for the Lacaille catalogue.

5.3.3.3 The *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae*

Less than 40 planetary nebulae were known in the whole sky prior to 1864 when William Huggins[423] first used a spectrograph to study them. Williamina Fleming,[424] Rudolph Minkowski, Guillermo Haro, Karl Henize and others used spectroscopy to harvest large numbers of southern planetary nebulae from 1891 onwards.

Magnitude values for planetary nebula were, until recently, given as whole numbers and were consequently not very precise. This changed recently when the majority of planetary nebulae

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[423] William Huggins, ‘On the Spectra of some of the Nebulae’, *Philosophical Transactions of the Royal Society of London*, 154, 1864, pp. 437-444.

[424] Wolfgang Steinicke, *Astronomie-Homepage*, <http://www.klima-luft.de/steinicke/ngcic/persons/fleming.htm>, 28 August 2007.

had more precise magnitudes derived for them based on the fluxes in the *Strasbourg-ESO Catalogue* (S-ESO).[425]

The *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae* contains 212 southern planetary nebulae, to magnitude 17.5. These were categorised into half magnitude groups and a histogram was drawn as shown in Figure 5.27. The magnitude of the histogram's peak for planetary nebulae is 15, which is adequate for determining working magnitude limits for the three historical catalogues. However Lacaille and Dunlop did not record sufficient planetary nebulae in their catalogues, and the relatively small numbers of planetary nebulae in the Herschel catalogue reduces the reliability of using planetary nebulae for determining his working magnitude limit.

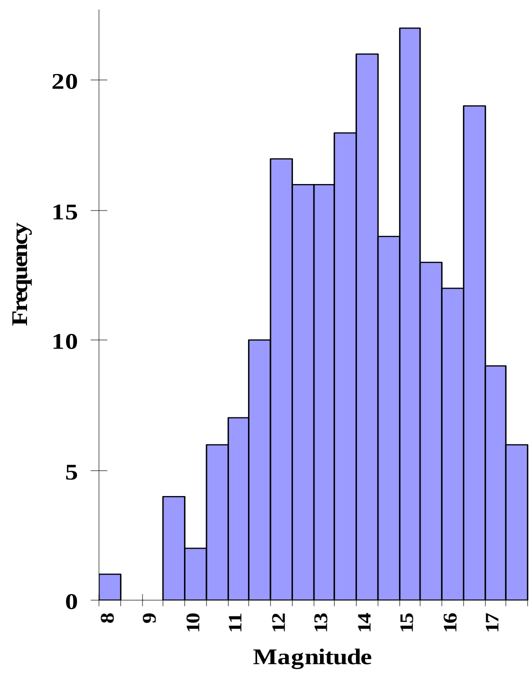

Figure 5.27: Histogram of the number of planetary nebulae by half magnitude in the *Strasbourg-ESO Catalogue*.

Also most planetary nebulae are very small and they are easily overlooked especially when sweeping at low power. Their visibility depends on the magnification used and the observer's alertness and experience, because planetary nebulae are difficult to detect even when the observer knows their location. Consequently planetary nebulae are not suitable for ascertaining a working magnitude limit for any catalogue.

[425] Acker, *S-ESO*.

5.3.3.4 The *Catalogue of Principal Galaxies* (PGC)

The PGC (1989) expanded to become the HyperLEDA[426] catalogue in 2003 with 983,261 galaxies. The PGC contains total B magnitudes (bt), not visual magnitudes. To calculate the visual (V) magnitude, an estimate was obtained by adjusting from a B (blue or photographic) magnitude to a V magnitude using the formula V = B – 0.8. This adopted colour index is typical of bright galaxies[427] and is close (within 0.1 magnitude) to the mean of galaxies in the PGC.

The LEDA catalogue includes the total B magnitudes (bt), the total B-V colour (bvt), and the effective B-V colour (bve). Visual magnitudes were calculated using the total B magnitude (bt) minus the effective B-V colour (bve) or minus the total B-V colour (bvt), depending on which values were available.

Although the LEDA catalogue is more recent and accurate, it does not provide bvt and bve data for 217 Herschel galaxies, but it does provide this data for all the Dunlop galaxies. The PGC also provides data for all Dunlop galaxies, but does not provide bt data for 16 Herschel galaxies. For this reason, the magnitude analyses for the Herschel and Dunlop catalogues used the data obtained from the PGC rather than the LEDA catalogue. However LEDA data was used for the determination of the magnitude of the faintest galaxies seen by both Herschel and Dunlop, as described in Sections 5.3.4, 5.3.5.1 and 5.3.6.1.

There are 8407 entries in the PGC to V magnitude 15.0 south of Declination –30°, including the two Magellanic Clouds and 6 dwarf galaxies. Galaxies are the best non-stellar objects for determining working magnitude limits because of their sheer numbers. It is known from photographic plates that the number of galaxies increases rapidly as magnitudes become fainter. At magnitudes fainter than Herschel's theoretical magnitude limit the PGC is no longer complete (the mode occurs at V magnitude = 14.5). Yet at V magnitudes brighter than 14 the PGC galaxy count continues to increase while there is a clear fall in the number of galaxies catalogued by both Herschel and Dunlop, as Figure 5.28 shows.

The 8407 PGC galaxies were grouped by half magnitudes and a histogram was drawn to find the peak as shown in Figure 5.29. The PGC histogram peaks at V magnitude 14.5 and is

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[426] G. Paturel, C. Petit, Ph. Prugniel, G. Theureau, J. Rousseau, M. Brouty, P. Dubois, and L. Cambrésy, LEDA Database for physics of galaxies, *HyperLEDA*, 2003, <http://leda.univ-lyon1.fr/>, accessed 18 November, 2009.

[427] C.W. Allen, *Astrophysical Quantities*, 2nd ed, London, 1973.

adequate to determine a working magnitude limit for the catalogues of Dunlop and Herschel. At magnitude 14.5 there are more galaxies than those recorded in the PGC, but this does not change the following analysis.

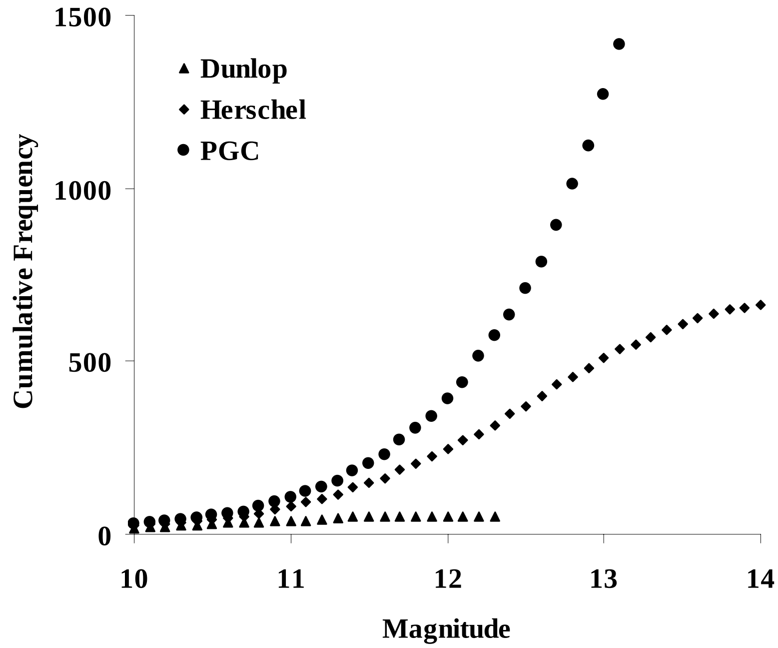

Figure 5.28: Cumulative frequency as a function of magnitude for galaxies recorded by Dunlop, Herschel and the *Catalogue of Principal Galaxies*.

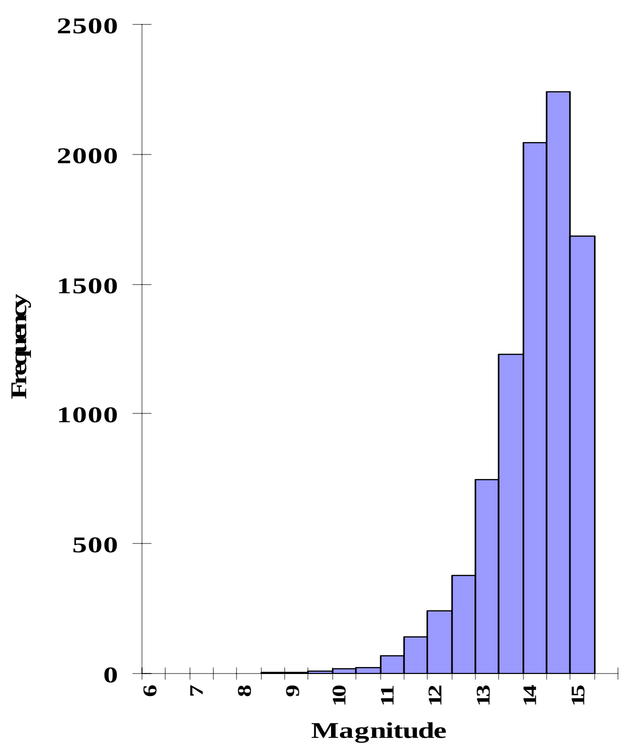

Figure 5.29: Histogram of the number of galaxies by magnitude for the PGC.

To assess the completeness of each historical catalogue, their contents were compared with one of the above reference catalogues to determine a working magnitude limit for each. A list by type of bright objects missed and faint objects seen was then compiled.

5.3.4 THE FAINTEST OBJECTS OF EACH NON-STELLAR TYPE FOUND IN THE CATALOGUES

The magnitudes of the faintest open cluster, globular cluster, planetary nebula and galaxy catalogued by Lacaille, Dunlop and Herschel are shown in Table 5.23. There is no listing for diffuse nebula. For the faintest galaxies, V magnitude values were calculated from the *Catalogue of Principal Galaxies* (PGC)[428] and also obtained from the more recent *LEDA Galaxies* (LEDA)[429] catalogue as a galaxy was the faintest object seen by each observer. Using the PGC data, the faintest Herschel galaxy was fainter than the theoretical limit of his telescope, which is unlikely. The V magnitudes obtained from LEDA are more accurate.

Table 5.23: Magnitudes of the faintest open cluster, globular cluster, planetary nebulae and galaxy catalogued by Lacaille, Dunlop and Herschel.

TYPE OF OBJECT	LACAILLE	DUNLOP	HERSCHEL
Open Cluster	7.4	11.8	12.6
Globular Cluster	6.9	9.3	12.6
Planetary Nebula		11.6	13
Galaxy – from PGC	7.6	12.3	15.3
Galaxy – from LEDA	7.1	12.7	14.5
Star (theoretical limit)	7.6	13.1	15.2

The magnitudes of the faintest object could be considered an absolute magnitude limit. The differences between the theoretical magnitude limit and the faintest LEDA galaxies catalogued by Lacaille, Dunlop and Herschel are 0.5, 0.4 and 0.7 respectively. Herschel disputed Dunlop's discovery of NGC 1483 (LEDA magnitude 12.7, PGC 12.3), however the position and description match the object and it is listed as a possible Dunlop object.

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428 Paturel, *Catalogue of Principal Galaxies*.

429 Paturel, *LEDA Galaxies with DENIS Measurements Catalog*.

5.3.5 THE HERSCHEL CATALOGUE

As outlined in Section 5.3.3, a comparison of the Herschel catalogue with the *Catalogue of Principal Galaxies* provided the best method for determining a working magnitude limit.

5.3.5.1 Galaxies in the Herschel Catalogue

There are 995 galaxies in the Herschel catalogue apart from the Magellanic Clouds, with 685 south of Declination –30°. Magnitude estimates for each were calculated using the PGC after identification and after an adjustment from the B colour to a visual magnitude.

Table 5.24: Cumulative frequency percentages of galaxies catalogued by Herschel and the PGC, south of Declination –30°.

V Magnitude	PGC	Herschel	
	cf	cf	cf %
≤ 5	2	0	0%
≤ 6	3	0	0%
≤ 7	5	1	20%
≤ 8	8	3	37%
≤ 9	16	9	56%
≤ 10	31	24	77%
≤ 11	107	80	75%
≤ 12	395	248	63%
≤ 13	1272	509	40%
≤ 14	3885	663	17%
≤ 15	8407	685	8%

The two brightest galaxies in the PGC, the Large and Small Magellanic Clouds were not recorded in the Herschel catalogue as individual galaxies. However many non-stellar objects within both Magellanic Clouds were listed separately by Herschel. The brightest galaxy in the Herschel catalogue is NGC 5128 with a V magnitude of 6.6 and the faintest galaxy is NGC 2007 at V magnitude 14.5. It is next to NGC 2008, V magnitude 14.1. This value is consistent with the telescope and circumstances of the observations.

Table 5.24 shows that Herschel was very adept (75%) at finding galaxies brighter than magnitude 11, and even at magnitude 12 he continued to catalogue more than half (63%). At fainter magnitudes the percentage found drops off markedly.

The following analyses were carried out to determine the magnitude at which Herschel started to miss a large number of faint galaxies during his observations in order to determine a working magnitude limit. Five indicators were used:

1) The histogram of the number of galaxies as a function of magnitude (Figure 5.30)
2) The graph of the log of the cumulative frequency of the galaxies observed, ± the square root of the cumulative frequency, as a function of magnitude (Figure 5.31)
3) A comparison of the log of the accumulated number of galaxies between the Herschel catalogue and the PGC (Figure 5.32), and on the same graph
4) A comparison of the log of the accumulated number of galaxies and a straight line with gradient 0.6, representing the increase in density of galaxies assuming a homogeneous universe (Figure 5.32)
5) The V magnitude at which 50% of the galaxies in the PGC were catalogued, that is, at fainter magnitudes more than half of the galaxies were missed.

The first indicator shows the distribution of Herschel galaxy magnitudes as a histogram in Figure 5.30 using V magnitude values derived from the PGC. The more accurate LEDA catalogue was not used because about half of the Herschel galaxies do not have V magnitude values. The histogram peaks at magnitude 12.5, while the number of galaxies in the PGC continues to increase. This suggests a working magnitude limit of 12.5, more than two magnitudes below Herschel's theoretical limit of 15.2.

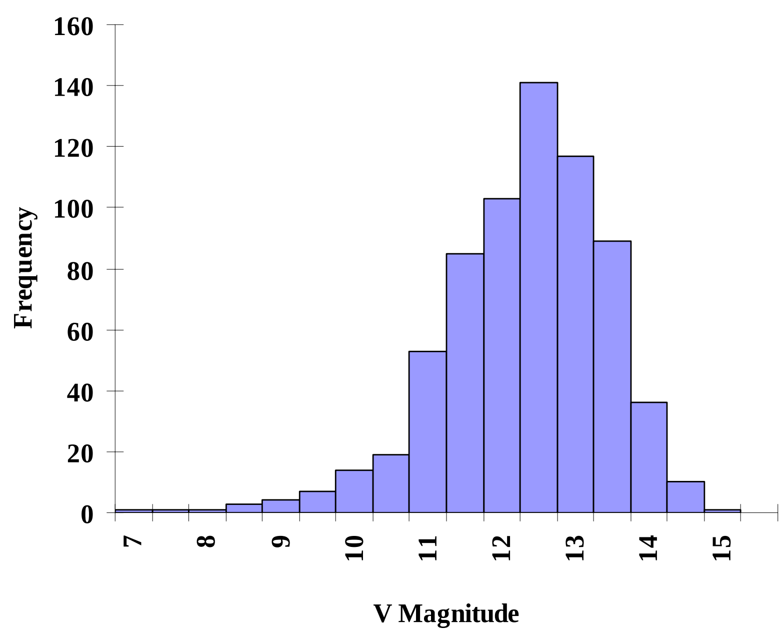

Figure 5.30: Histogram of the number of galaxies by half magnitude for the Herschel catalogue.

The second indicator used for ascertaining a working magnitude limit, a graph of the log of the accumulated number of galaxies observed ± the square root of the cumulative frequency as a function of magnitude, is shown in Figure 5.31 with upper and lower limits resulting from Poisson (root n) statistics.

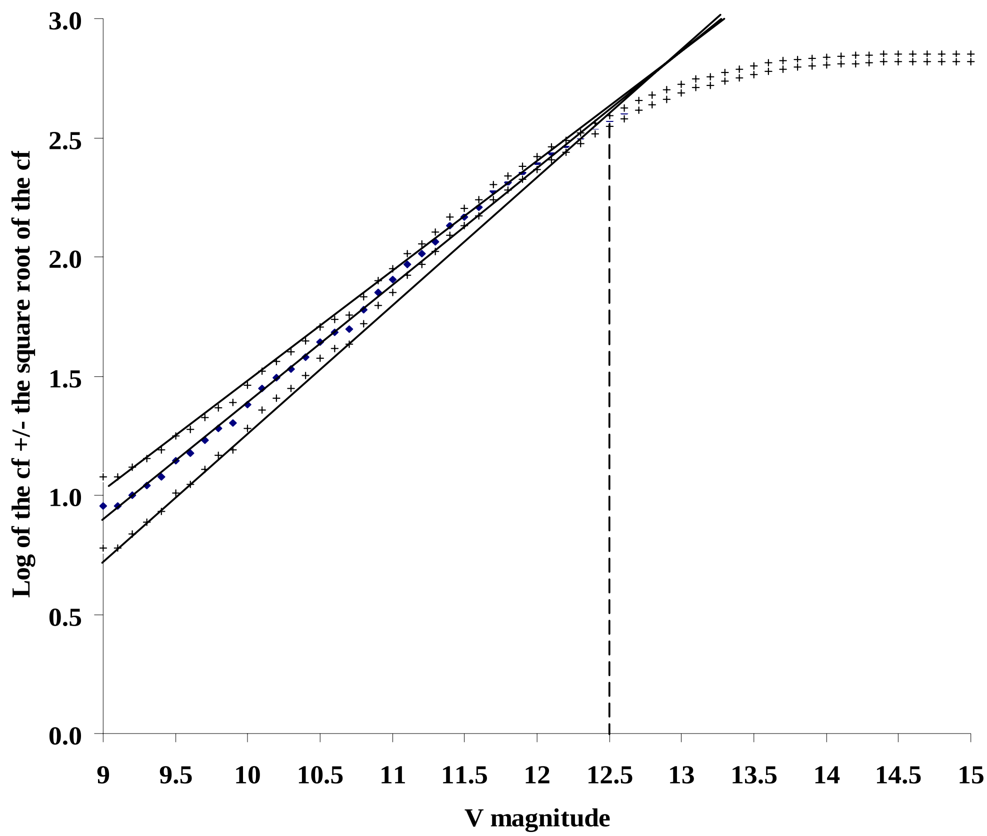

Figure 5.31: Distribution of log of the cumulative frequency with Poisson upper and lower limits as a function of V magnitude for Herschel galaxies.

On this figure three straight lines of best fit were drawn for the log of the cumulative frequency, the upper and lower limits. The working magnitude limit occurs where the data leaves the region bounded by these three lines. The dotted line on the figure shows this occurring at magnitude 12.5.

The third and fourth indicators are shown on the same graph in Figure 5.32. It compares the log of the cumulative frequency of the Herschel and PGC galaxies, for all galaxies south of Declination –30^{o} and brighter than magnitude 15.

Two differences in the curves are evident. There is general agreement between Herschel and the PGC in the shape of the curves for bright galaxies but the two curves diverge where

Herschel begins to miss fainter galaxies. This divergence occurs at about V magnitude = 13.0. This gives a third estimate for a working magnitude limit.

Figure 5.32 also includes the fourth indicator, an analysis with respect to a straight line with gradient = 0.6. This straight line represents the increase in density of galaxies that would occur in a homogeneous universe with a homogenous mixture of galaxy types. It can be shown that the increase in the number of galaxies at successively fainter magnitudes is a factor of four, and thus the slope of the logarithmic line for such a universe is 0.6.

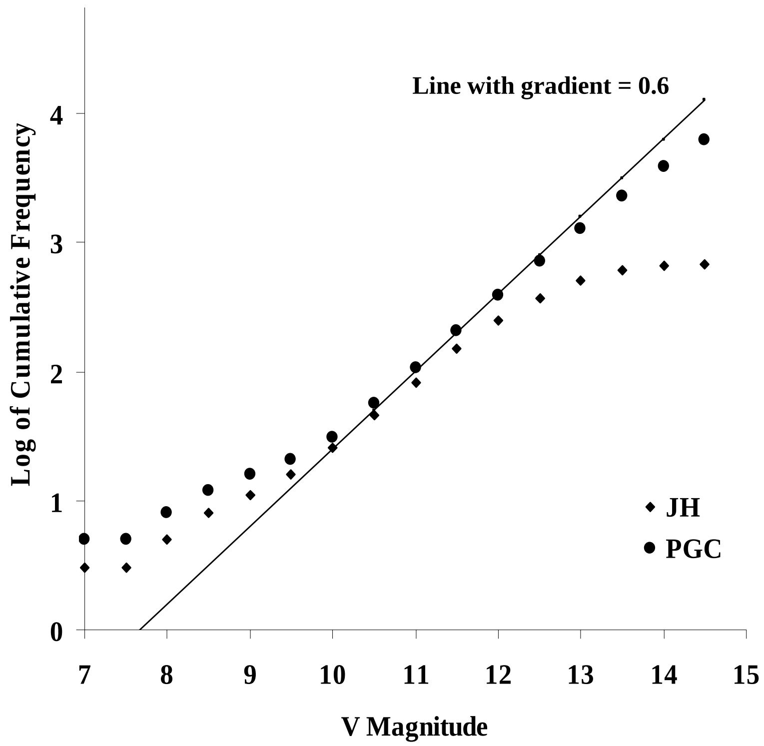

Figure 5.32: Distribution of log of the cumulative frequency as a function of V magnitude for the Herschel and PGC galaxies.

When a line of best fit for the log of the cumulative frequency was drawn over the PGC data points between magnitudes 10 and 13, its gradient was found to be 0.567. This is very similar to the theoretical 0.6 slope but is more realistic because it does not assume a homogeneous universe. The divergence between the line and the Herschel data again becomes significant at about V magnitude = 13.0, which corresponds with the previous estimate.

The fifth indicator was determined from a spreadsheet of magnitudes comparing the Herschel and PGC galaxies. At magnitude 12.7 Herschel catalogued 50% and missed 50% of the PGC galaxies. At fainter magnitudes more than half the PGC galaxies were missed by Herschel.

In conclusion, the average of the first four estimates for the V magnitude (12.5, 12.5, 13.0 and 13.0) where Herschel started to miss galaxies indicates a working magnitude limit of 12.75. At V magnitude 12.5, Herschel catalogued 53% of the galaxies listed in the PGC and at V magnitude13.0 he catalogued only 42%. The fifth indicator (12.7) is consistent with the average of the first four working magnitude limits. Thus the working magnitude limit for the Herschel catalogue is 12.7.

5.3.5.2 Other Objects in the Herschel catalogue

As with galaxies, analyses were carried out to compare the corresponding reference catalogue with the open clusters, globular clusters and planetary nebulae in the Herschel catalogue. The number of each type of object in the Herschel catalogue is found in Table 5:17 and Table 5:18. Table 5.25 compares the number of objects at different magnitudes from the reference catalogues with the Herschel catalogue.

Table 5.25: Cumulative frequency percentages of open clusters, globular clusters and planetary nebulae catalogued by Herschel.

Magnitude	Lynga Open Clusters	Herschel Open Clusters		Harris Globular Clusters	Herschel Globular Clusters		S-ESO Planetary Nebulae	Herschel Planetary Nebulae	
	cf	**cf**	**cf %**	**cf**	**cf**	**cf %**	**cf**	**cf**	**cf%**
≤ 5	23	9	39%	2	2	100%			
≤ 6	36	19	53%	4	4	100%			
≤ 7	61	32	52%	12	12	100%			
≤ 8	96	47	49%	24	23	96%			
≤ 9	146	73	50%	32	31	97%	1	1	100%
≤ 10	188	85	45%	39	36	92%	5	4	80%
≤ 11	208	92	44%	41	37	90%	10	7	70%
≤ 12	219	98	45%	46	39	85%	23	15	65%
≤ 13							33	17	52%
≤ 14							49	18	37%

John Herschel listed 129 open clusters outside the Magellanic Clouds in his catalogue, 98 of which are south of Declination –30^{o}. They range in magnitude from 3.0 to 12.6.

When Herschel made his catalogue of non-stellar objects, he was apparently frustrated because Dunlop had already catalogued most of the bright globular clusters in the southern sky. Not including the Magellanic Clouds, 36 of the 40 globular clusters listed in the Herschel catalogue were also in the Dunlop catalogue. There are only three globular clusters in the Herschel catalogue with magnitudes fainter than the faintest seen by Dunlop (see Table 5.35). The faintest globular cluster seen by Herschel is Herschel 3688 or NGC 6380, at magnitude 11.3. Two globular clusters, NGC 6352 (magnitude 8.0) and NGC 5824 (magnitude 9.1), were missed by Herschel but seen by Dunlop.

The modal magnitude for open clusters, globular clusters and planetary nebulae for the Herschel catalogue compared to those of the reference catalogues are listed in Table 5.26. The table confirms that galaxies provide the best data for the determination of Herschel's working magnitude limit of 12.7.

Table 5.26: Peak or modal magnitudes for open clusters, globular clusters and planetary nebulae in the Herschel catalogue compared to the reference catalogues.

MODAL MAGNITUDES	Open Clusters	Globular Clusters	Planetary Nebulae
Reference Catalogue	Lynga = 9.0	Harris = 8.5	S-ESO = 15.0
Herschel Catalogue	8.5	6.5 and 8.5	11, 11.5 and 12

5.3.5.3 Completeness of the Herschel catalogue

Using a working magnitude limit of 12.7, the number of open clusters, globular clusters, planetary nebulae and galaxies brighter than or equal to this magnitude which were missed by Herschel can be found.

Table 5.27: Number of open clusters, globular clusters, planetary nebulae and galaxies included and missed in the Herschel catalogue compared to the working magnitude limit of 12.7.

The Herschel catalogue – working magnitude limit of 12.7	Open Clusters	Globular Clusters	Planetary Nebulae	Galaxies
Number Missed, Brighter than Working magnitude Limit	25	10/49 20%	16/63 25%	432/896 48%
Number Seen, Fainter than Working magnitude Limit	0	0	2	253

Similarly, the objects fainter than 12.7 that were seen by Herschel can be determined. These are shown in Table 5.27. Percentages are not given for open clusters because only the open clusters recorded in at least one of the three historical catalogues are included in this comparison.

A list of the bright open clusters, globular clusters and planetary nebulae missed by Herschel is found in Section 5.3.8. A sample of the 432 bright galaxies missed is also included. Similarly, all the faint open clusters, globular clusters and planetary nebulae which were seen by Herschel are listed, while only a sample of the 253 faint galaxies is given.

5.3.6 THE DUNLOP CATALOGUE

As with the Herschel catalogue, galaxies provided the best data for finding a working magnitude limit.

5.3.6.1 Galaxies in the Dunlop Catalogue

There are 53 galaxies in the Dunlop catalogue outside the Magellanic Clouds, 51 being south of Declination -30^{o}. Dunlop did not record the Large or Small Magellanic Clouds separately as galaxies, although objects in the Clouds were included. The brightest galaxy observed by Dunlop in the analysis area is NGC 5128 with V magnitude 6.6 and the possible faintest is NGC 1483 with V magnitude 12.3 (using V = B – 0.8, from the PGC) or V magnitude 12.7 according to LEDA.

Again five indicators were employed to establish a working magnitude limit for the Dunlop catalogue:

1. A histogram of the number of galaxies as a function of magnitude (Figure 5.33)
2. A distribution of the log of the accumulated number of galaxies observed $\pm$ the square root of the cumulative frequency, as a function of magnitude (Figure 5.34)
3. A comparison between the Dunlop catalogue and the PGC of the distribution of the log of the accumulated number of galaxies as a function of magnitude, and on the same figure (Figure 5.35)
4. A comparison of the distribution of the log of the accumulated number of galaxies and a 0.6 gradient straight line, representing the increase in density of galaxies assuming a homogeneous universe (Figure 5.35)
5. The V magnitude at which 50% of the galaxies in the LEDA catalogue were catalogued that is, at fainter magnitudes more than half of the galaxies were missed.

The first indicator is shown in Figure 5.33 as a histogram of the distribution of the number of galaxies catalogued by Dunlop by half magnitudes (0.25 – 0.75, 0.75 – 1.25 etc) using data obtained from the LEDA catalogue. The magnitude values in this catalogue are more accurate than the PGC because the B – V magnitude value is given rather than assuming a mean B – V value of 0.8. Of the 53 galaxies in the Dunlop catalogue, 52 have this information recorded in the LEDA catalogue. The peak of the histogram occurs at magnitude 10.5 giving the first working magnitude limit.

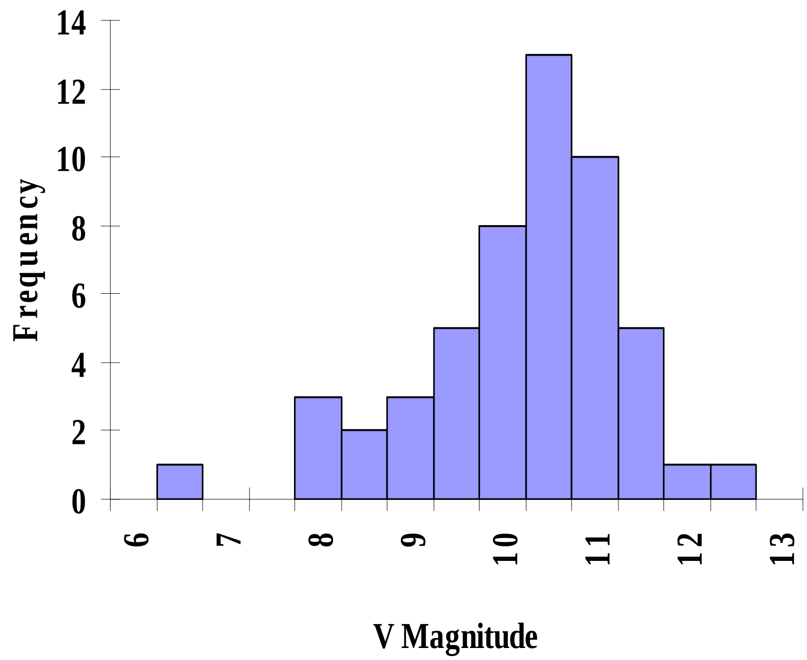

Figure 5.33: Histogram of the number of galaxies by half magnitude for the Dunlop catalogue.

The second indicator used for determining a working magnitude limit is the graph of the log of the accumulated number of galaxies observed ± the square root of the cumulative frequency as a function of magnitude. Figure 5.34 shows the cumulative frequency for galaxies fainter than magnitude 9, with upper and lower limits obtained from Poisson (root n) statistics. Lines of best fit were drawn for the upper and lower limits. The working magnitude limit was the point where the data leaves the region bounded by the three lines. This is shown as a dotted line at approximately magnitude 11.4.

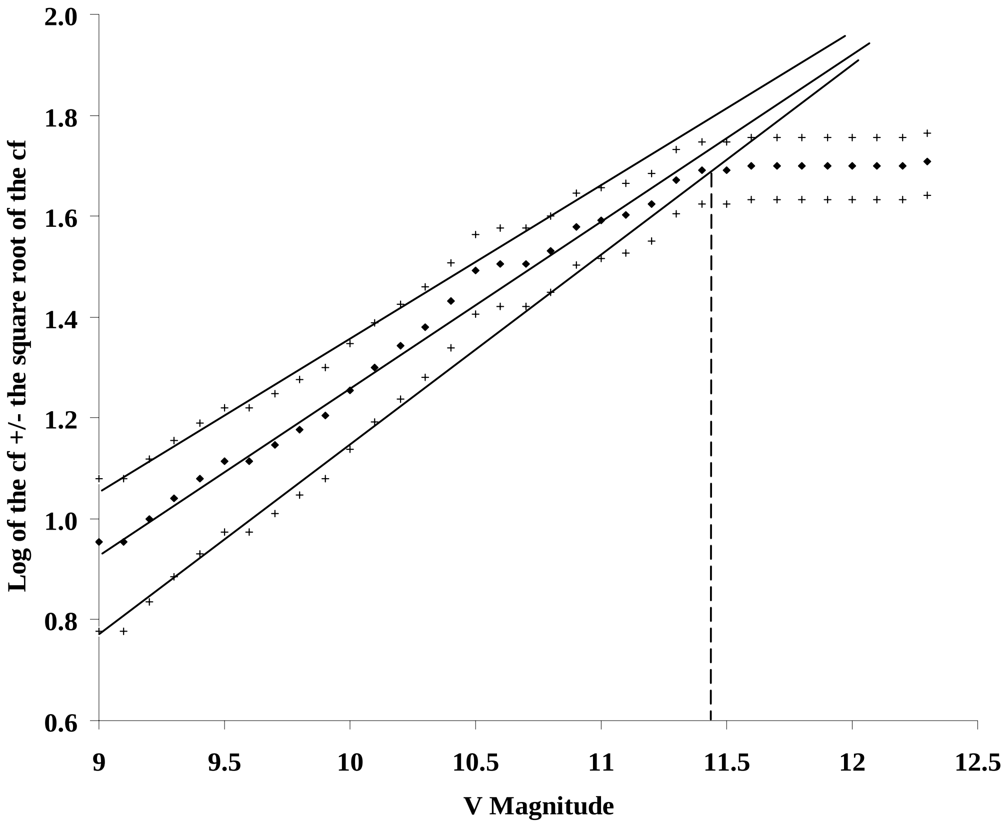

Figure 5.34: Distribution of log of the cumulative frequency with Poisson upper and lower limits as a function of V magnitude for the Dunlop galaxies.

The third and fourth indicators were drawn on the same graph Figure 5.35. The graph shows a comparison of the Dunlop galaxy counts with the log of the accumulated number of galaxies in the LEDA catalogue for all galaxies south of Declination –30°. Differences in the curves are evident. The point where Dunlop started missing the fainter galaxies is where the two curves diverge indicating the working magnitude limit. The divergence occurs at about V magnitude = 11, the point where the Dunlop curve begins to flatten out. Hence the third estimate for a working magnitude limit for the Dunlop catalogue is approximately 11.

Figure 5.35 also shows a straight line with gradient = 0.6, representing the increase in density that would occur in a homogeneous universe with a homogenous mixture of galaxy types. This is the fourth indicator used for determining a working magnitude limit.

The divergence between this line and the Dunlop curve becomes significant at approximately V magnitude = 11, again giving a working magnitude limit of approximately 11.

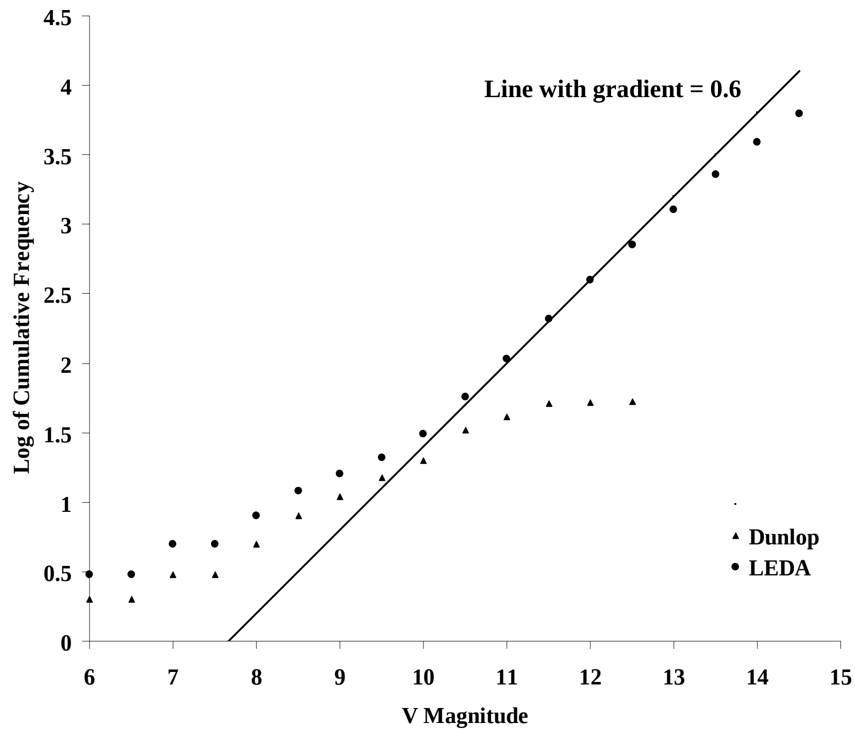

Figure 5.35: Distribution of log of the cumulative frequency as a function of V magnitude for the Dunlop and LEDA galaxies.

The final indicator used a spreadsheet to determine the magnitude at which Dunlop catalogued 50% and missed 50% of the galaxies in the LEDA catalogue. This occurred at V magnitude 10.8.

The five estimates for the working magnitude limit as determined above are 10.5, 11.4, 11, 11 and 10.8, with a mean of 10.9. The last indicator, the 50% method produced the most accurate result. Thus the working magnitude limit for the Dunlop catalogue is determined to be 10.9.

5.3.6.2 Other Objects in the Dunlop catalogue

Open clusters, globular clusters and planetary nebulae were also analysed for the Dunlop catalogue. Table 5:18 showed that the Dunlop catalogue contains 93 open clusters, 36 globular clusters and 4 planetary nebulae south of Declination -30^{o} outside the Magellanic Clouds. Table 5.28 gives the cumulative frequency percentage for each type compared to their respective reference catalogues. All entries for these objects are less than or equal to magnitude 12.0.

Table 5.28: Cumulative frequency percentages of open clusters, globular clusters and planetary nebulae catalogued by Dunlop.

Magnitude	Lynga Open Clusters	Dunlop Open Clusters		Harris Globular Clusters	Dunlop Globular Clusters		S-ESO Planetary Nebulae	Dunlop Planetary Nebulae	
	cf	cf	cf %	cf	cf	cf %	cf	cf	cf%
≤ 5	23	10	43%	2	2	100%			
≤ 6	36	18	50%	4	4	100%			
≤ 7	61	26	43%	12	12	100%			
≤ 8	96	35	35%	24	24	100%			
≤ 9	146	56	36%	32	32	100%	1	0	0%
≤ 10	188	63	33%	39	35	90%	5	1	20%
≤ 11	208	67	32%	41			10	2	20%
≤ 12	219	73	33%	46			23	4	17%

As the table shows, Dunlop was remarkably good at finding globular clusters. Perhaps this was because globular clusters look similar to comets, with which he was familiar. Dunlop saw all of the globular clusters to magnitude 9.0, and 35 of the 39 to magnitude 10 (90%). Dunlop's proficiency with finding globular clusters exceeds Herschel's to magnitude 9.3.

Planetary nebulae catalogued by Dunlop were sometimes described by him as "faint small nebula." It seems probable that the large number of faint double stars and asterisms included in his catalogue were seen by him as possible planetary nebulae because of the poor quality of his telescope. These too were often described as "faint nebula".

Dunlop may have included four planetary nebulae in his catalogue, but only two are certain, namely NGC 5189 at magnitude 9.5 and NGC 6563 at magnitude 10.8. The diameters of these two planetary nebulae are 140 arc-seconds and 47 arc-seconds respectively. He may have seen the planetary nebulae in the open cluster NGC 2818 with magnitude 11.5 and diameter 50 arc-seconds, and may also have seen NGC 6326, but this is less likely because although it has magnitude 11.1, its diameter is only 12 arc-seconds. Two other planetary nebulae were included in the star catalogue Dunlop made while working for Brisbane at the Parramatta Observatory. When Dunlop made this star catalogue,[430] he noted that star 3807 was a "fine blue star," but he did not know it was a planetary nebula. Herschel recognised

[430] Richardson, *7385 Stars.*

this to be a blue planetary nebula (NGC 3918) he had observed, according to his 1835 letter to Maclear.[431] Herschel also notes in the same letter that Dunlop recorded star 3085 as "Dusky Yellow – a fine Planetary disc" and Herschel realised that this was the planetary nebula now known as NGC 3132.

The modal magnitude for open clusters, globular clusters and planetary nebulae for the Dunlop catalogue compared to those of the reference catalogue are listed in Table 5.29. As only 4 planetary nebulae were seen by Dunlop, the mode is irrelevant.

Table 5.29: Peak or modal magnitudes for open clusters, globular clusters and planetary nebulae in the Dunlop catalogue compared to the reference catalogues.

MODAL MAGNITUDES	Open Clusters	Globular Clusters	Planetary Nebulae
Reference Catalogue	Lynga = 9.0	Harris = 8.5	S-ESO = 15.0
Dunlop Catalogue	9.0	6.5 and 8.5	

Again it is evident that the working magnitude limit of 10.9 for the Dunlop catalogue derived from the galaxy data is the best estimate.

5.3.6.3 Completeness of the Dunlop catalogue

Using a working magnitude limit of 10.9 for the Dunlop catalogue, the number of open clusters, globular clusters, planetary nebulae and galaxies which were missed and brighter than or equal to magnitude 10.9 can be found. Similarly, the number of each type of object fainter than 10.9, but catalogued by Dunlop, can be determined. These are shown in Table 5.30. Percentages are not given for open clusters because only open clusters recorded in at least one of the three historical catalogues are included in this comparison.

A list of open clusters, globular clusters, planetary nebulae and galaxies brighter than magnitude 10.9 and missed by Dunlop is found in Section 5.3.8. Also, all objects fainter than magnitude 10.9 seen by Dunlop are listed.

[431] B. & N. Warner, *Maclear & Herschel Letters & Diaries at the Cape of Good Hope 1834-1838*, Cape Town, 1984, p. 108.

Table 5.30: Number of open clusters, globular clusters, planetary nebulae and galaxies included and missed in the Dunlop catalogue compared to the working magnitude limit of 10.9.

The Dunlop catalogue – working magnitude limit of 10.9	Open Clusters	Globular Clusters	Planetary Nebulae	Galaxies
Number Missed, Brighter than Working magnitude Limit	32	5/41 12%	4/15 27%	46/94 45%
Number Seen, Fainter than Working magnitude Limit	6	0	2	14

5.3.7 THE LACAILLE CATALOGUE

Unlike Herschel and Dunlop, Lacaille did not list any galaxies (or planetary nebulae) in his catalogue south of Declination –30^{o}. Thus to determine a working magnitude limit for Lacaille means that either open clusters or globular clusters must be used. Lacaille includes 25 open clusters but only 5 globular clusters in this area of the sky.

Open clusters are not satisfactory for determining working magnitude limits because the Lynga magnitude values are not reliable. More recent open cluster catalogues cannot be used either because no magnitude values are provided for clusters, only for individual stars. The combination of variable characteristics and variable circumstances for viewing open clusters also disqualifies them for the determination of a working magnitude limit.

Although there are very few globular clusters in the Lacaille catalogue, their magnitude values are much more reliable and they are more like the Herschel and Dunlop galaxies than open clusters. This leaves globular clusters as the preferred object type for determining a working magnitude limit.

5.3.7.1 Globular Clusters in the Lacaille Catalogue

The Lacaille catalogue contains seven globular clusters, five of which are south of Declination –30^{o}. These southern globular clusters range in magnitude from 3.7 to 6.9. The theoretical magnitude limit for stars for Lacaille's telescope is magnitude 7.6 which is approximately one magnitude fainter than the naked-eye magnitude limit. Messier believed that Lacaille saw M69 (NGC 6637) at magnitude 7.6, but this is unlikely because the position given by Lacaille is incorrect for M69 but correct for a nearby asterism. Also M69, at Lacaille's theoretical magnitude limit, is too faint for him to see.

The indicators used on the galaxy data for the Herschel and Dunlop catalogues cannot be used for the globular cluster data in the Lacaille catalogue because there are so few entries. However the 50% method, the magnitude at which Lacaille catalogued 50% of the reference globular clusters was found to be magnitude 6.4. In the Herschel and Dunlop catalogues this indicator was the most precise and was similar to the average derived from the other indicators. The working magnitude limit used for the Lacaille catalogue is 6.4.

5.3.7.2 Other objects in the Lacaille Catalogue

Apart from globular clusters, only open clusters could be analysed from the Lacaille catalogue. Table 5.31 gives the cumulative frequency percentages for open clusters and globular clusters in the Lacaille catalogue.

Table 5.31: Cumulative frequency percentages of open clusters and globular clusters catalogued by Lacaille.

Magnitude	Lynga Open Clusters	Lacaille Open Clusters		Harris Globular Clusters	Lacaille Globular Clusters	
	cf	cf	cf %	cf	cf	cf %
≤ 5	23	12	52%	2	2	100%
≤ 6	36	16	44%	4	3	75%
≤ 7	61	19	31%	12	5	42%
≤ 8	96	22	23%	24		

Lacaille recorded three open clusters that Dunlop and Herschel did not catalogue, namely IC 2602, IC 2391 and Trumpler 10 although all three are in Dunlop's hand written notes.

There are 22 open clusters in the above table. The modal magnitude is 5.5. At magnitude 5.3 Lacaille catalogued 50% of the open clusters in the *Lynga* Catalogue and missed 50%. This confirms that for Lacaille's catalogue, globular clusters provide a better working magnitude limit of 6.4.

There are no planetary nebulae in the Lacaille catalogue as the brightest planetary nebula (magnitude 8.2) is fainter than Lacaille's theoretical limit for stars. However John Herschel wrote in a letter to Thomas Maclear in 1835[432] that the Lacaille star 1046[433] was the same as the Dunlop star 3807[434] and that both were the same as the planetary nebula now known as NGC 3918. It is remarkable that Lacaille may have seen this magnitude 8.2 planetary nebula, even though he thought it a star.

Lacaille found only one galaxy, M 83, at V magnitude 7.1 (according to LEDA). Its Declination is –29.87°, just outside the analysis area. This was the third galaxy to be discovered with a telescope after M33 and M32. Hodierna probably found the first, M 33, from Sicily one hundred years earlier.

5.3.7.3 Completeness of the Lacaille catalogue

Using 6.4 as the working magnitude limit for the Lacaille catalogue, a list of bright objects Lacaille missed and faint objects he saw was compiled. The complete list is found in Section 5.3.8. Table 5.32 gives the number of these objects, by type.

The faint planetary nebula listed is that attributed to Lacaille by Herschel. The faint galaxy is M83 with V magnitude 7.1 and Declination –29° 52' just north of Declination –30°. The galaxy NGC 5128 with V magnitude 6.6 was missed by Lacaille. It is brighter than M83 but fainter than his working magnitude limit. He also failed to record NGC 253 with V magnitude 7.2 and Declination –25° 17'. This too is outside the analysis area, but within the area he searched.

Table 5.32: Number of open clusters, globular clusters, planetary nebulae and galaxies included and missed in the Lacaille catalogue compared to the working magnitude limit 6.4.

The Lacaille catalogue – working magnitude limit of 6.4	Open Clusters	Globular Clusters	Planetary Nebulae	Galaxies
Number Missed, Brighter than Working magnitude Limit	10	4/8 50%	0	0
Number Seen, Fainter than Working magnitude Limit	4	1	1	1

[432] Warner, p. 108.

[433] J.D. Maraldi (ed), *Coelum australe stelliferum*, Paris, 1763.

[434] Richardson, *7385 Stars*.

5.3.8 BRIGHT OBJECTS MISSED AND FAINT OBJECTS SEEN BY EACH OBSERVER

This section contains tables of bright objects missed and faint objects seen by Lacaille, Dunlop and Herschel by type of object. The working magnitude limit for each catalogue (Lacaille = 6.4, Dunlop = 10.9, Herschel = 12.7) was used to determine the above categories.

5.3.8.1 Galaxies

Table 5.33 lists a sample of galaxies to magnitude 11.0, south of Declination –30^{o} which were missed by Dunlop and/or Herschel. These galaxies are brighter than their working magnitude limits (Dunlop = 10.9, Herschel = 12.7) and thus could have been seen. The table gives the Dunlop or Herschel number for the galaxies they found. Also listed are the modern identification, the V magnitude, and the length of the major axis of each galaxy. The table is arranged by V magnitude from brightest to faintest.

Table 5.33: A sample of bright galaxies missed by Dunlop and Herschel to magnitude 11.0.

Dunlop	Herschel	Identification	V Magnitude	Major Axis (arc-minute)
608	missed	NGC 7793	8.9	9.6
missed	2495	NGC 1097	9.5	9.4
missed	2569	NGC 1399	9.6	7.4
missed	3492	NGC 5102	9.7	8.6
missed	2629	NGC 1549	9.8	4.4
missed	3134	NGC 2640	10.0	2.2
missed	3649	NGC 6221	10.0	3.9
missed	3965	NGC 7424	10.1	10
missed	2571	NGC 1404	10.2	3.4
missed	missed	ESO 383-87	10.2	4.6
missed	3924	NGC 7213	10.2	3.7
missed	missed	IC 1459	10.2	5.1
546	missed	IC 5332	10.2	8.4
missed	missed	IC 5152	10.3	5.5
missed	3097	NGC 2442	10.4	5.4
missed	2640	NGC 1574	10.5	4
missed	3757	NGC 6684	10.5	4.1
missed	missed	IC 5052	10.5	5.9
missed	2539	NGC 1340	10.6	6.1
missed	2585	NGC 1448	10.6	7.5
missed	3872	NGC 7090	10.6	7.3
missed	missed	IC 5267	10.6	5.4
missed	2535	NGC 1326	10.7	4.3
missed	2624	NGC 1537	10.7	3.9
missed	missed	ESO 132-16	10.7	4.6
missed	missed	ESO 401-25	10.7	1.5
missed	missed	IC 5201	10.7	7.8
missed	3156	NGC 2822	10.8	3.4

missed	3205	NGC 3059	10.8	3.8
missed	3319	NGC 3557	10.8	4
missed	3498	NGC 5121	10.8	1.9
missed	3518	NGC 5206	10.8	3.8
missed	missed	IC 4296	10.8	3.4
missed	missed	ESO 41-8	10.8	4.4
missed	missed	ESO 138-10	10.8	5.6
missed	3814	NGC 6868	10.8	3.6
missed	3919	NGC 7205	10.8	4
missed	missed	IC 5271	10.8	2.6
missed	4000	NGC 7713	10.8	4.5
missed	2355	NGC 289	10.9	5.4
missed	2561	NGC 1379	10.9	2.4
missed	3231	NGC 3136	10.9	3.3
missed	3456	NGC 4936	10.9	3.2
missed	missed	ESO 270-17	10.9	11.4
missed	3605	NGC 5938	10.9	2.8
missed	missed	IC 4662	10.9	2.9
missed	3817	NGC 6876	10.9	3
missed	3963	NGC 7418	10.9	3.8
	missed	NGC 1947	11.0	3.4
	missed	IC 4633	11.0	4
	missed	ESO 185-54	11.0	3.5
	missed	IC 5325	11.0	2.8

Herschel may have seen NGC 1947, magnitude 11, but his Declination was 1 degree out. This galaxy is also in the microfilm of Dunlop's notes, but was not included in his catalogue. There are a further 412 galaxies between V magnitude 11.0 and 12.7 not listed above, which Herschel missed.

A sample of galaxies, fainter than their working magnitude limits, but seen by Dunlop and/or Herschel is found in Table 5.34. The relevant galaxies (those fainter than the working magnitude limit) are displayed in bold print, with those brighter than the working magnitude limit in grey. The table is arranged by V magnitude from brightest to faintest. Three of these galaxies are possible Dunlop objects (D 427, D 451 and D 510).

Table 5.34: Faint galaxies seen by Dunlop and a sample of faint galaxies seen by Herschel to magnitude 15.0.

Dunlop	Herschel	Identification	V Magnitude	Major Axis (arc-second)
438	2600	NGC 1493	11.0	3.6
494	3563	NGC 5530	11.0	4.2
263	3870	NGC 7083	11.1	3.6
547	2529?	NGC 1317	11.2	2.8
594	2944	NGC 2090	11.2	5
348	2609	NGC 1515	11.3	5.1
510	3428	NGC 4709	11.3	2.3
425	3811	NGC 6861	11.3	3

255	missed	IC 5250	11.3	3.1
477	3980	NGC 7590	11.3	2.6
480	2597	NGC 1487	11.4	3.3
347	3996	NGC 7689	11.4	2.8
451	3897	NGC 6902	11.5	5.6
437	missed	IC 1633	11.6	2.9
427	2595	NGC 1483	12.3	1.6
224 faint galaxies seen by Herschel between V magnitude 12.3 and 14.0 are not shown.				
	2408	NGC 526	14.0	0.9
	2433	NGC 644	14.0	1.3
	2441	NGC 698	14.0	0.9
	2999	NGC 2152	14.0	1.1
	3912	NGC 7178	14.0	1.1
	3937	NGC 7262	14.0	0.7
	3946	NGC 7299	14.0	0.7
	2332	NGC 159	14.1	1.4
	2445	NGC 727	14.1	1.1
	2664	NGC 1669	14.1	0.8
	2659	NGC 1660	14.1	1
	3029	NGC 2200	14.1	1
	3051	NGC 2233	14.1	0.9
	3462	NGC 4950	14.1	0.8
	3535	NGC 5291	14.1	1
	2317	NGC 88	14.2	0.8
	3494	NGC 5108	14.2	1.2
	3790	NGC 6784	14.2	0.8
	2390	NGC 427	14.3	1
	3415	NGC 4661	14.3	0.7
	3486	NGC 5086	14.3	0.4
	3875	NGC 7095	14.3	0.8
	3952	NGC 7355	14.3	1
	2415	NGC 572	14.4	0.8
	2450	NGC 754	14.4	0.5
	2879	NGC 1995	14.4	0.9
	3941	NGC 7278	14.4	0.8
	3338	NGC 3620	14.5	2.7
	3803	NGC 6845	15.0	2.3

5.3.8.2 Globular Clusters

Dunlop and Herschel catalogued most of the southern globular clusters. Table 5.35 lists the globular clusters south of Declination –30^{o} but brighter than their working magnitude limit that were missed. These are shown in grey print. Also listed are the modern identification and the magnitude of each. The table is sorted by magnitude from brightest to faintest.

Lacaille was the only one to catalogue a globular cluster fainter than his working magnitude limit (NGC 4833). Dunlop and Herschel did not list any fainter than their working magnitude limit probably because faint globular clusters are more difficult to see than galaxies with the same magnitude. Three globular clusters are recorded in Dunlop's hand written notes (NGC 5946, 6522 and 6624) but are not included in his printed catalogue.

Table 5.35: Globular clusters found or missed by Lacaille, Dunlop and Herschel to magnitude 12.4.

Lacaille	Dunlop	Herschel	Identification	Magnitude
missed	295	3778	NGC 6752	5.4
missed	265	3152	NGC 2808	6.2
missed	473	3726	NGC 6541	6.3
missed	62	2375	NGC 362	6.4
1.04	164	3444	NGC 4833	6.9
	417	missed	NGC 6352	8.0
	611	missed	NGC 5824	9.1
	missed	3731	NGC 6558	9.3
	missed	3723	NGC 6528	9.6
	missed	missed	IC 4499	9.8
	missed	3708	NGC 6453	10.1
	missed	missed	Rup 106	10.9
		missed	E 3	11.4
		missed	Terzan 3	12.0
		missed	Terzan 7	12.0
		missed	Ton 2	12.2
		missed	Arp 2	12.3
		missed	Terzan 8	12.4

5.3.8.3 Open Clusters

Lacaille, Dunlop and Herschel missed a large number of open clusters as shown in Table 5.36. Only open clusters that were seen by at least one of the three observers are listed. The table gives the identification found in their respective catalogues, with 'mf' in the Dunlop column indicating the object was included in his handwritten notes (on the microfilm). The word 'missed' indicates that the object is brighter than the observer's working magnitude limit and thus could have been seen. The modern identification, magnitude and diameter are also given. The table is arranged by magnitude from brightest to faintest.

Table 5.36: Open clusters missed by Lacaille or Dunlop or Herschel.

Lacaille	Dunlop	Herschel	Identification	Magnitude	Diameter (arc-minute)
2.09	mf	missed	IC 2602	1.6	100
2.05	mf	missed	IC 2391	2.6	60
missed	297	3224	NGC 3114	4.4	35
3.03	mf	missed	IC 2395	4.6	18.6
2.06	490	missed	Trumpler 10	5.0	29
missed	413	3642	NGC 6193	5.3	14
missed	missed	3689	NGC 6383	5.5	20
missed	seen	3323	NGC 3572	5.6	5
missed	272	3407	NGC 4609	5.7	4
missed	326	3622	NGC 6087	5.7	14
missed	431	3555	NGC 5460	5.9	35
missed	missed	3140	NGC 2669	6.1	20
missed	360	3619	NGC 6067	6.1	14

missed	missed	3673	NGC 6322	6.3	5
	missed	3636	NGC 6169	6.6	12
	missed	3656	NGC 6250	7.0	10
	missed	3094	NGC 2439	7.0	9
	missed	3638	NGC 6178	7.2	5
	missed	3702	NGC 6416	7.2	14
3.04	330	missed	IC 2488	7.4	18
	402	missed	IC 4651	7.5	10
	missed	3332	NGC 3590	7.5	3
	missed	3395	NGC 4463	7.7	3.5
	missed	3643	NGC 6200	7.7	14
	missed	3171	NGC 2910	7.8	4
	missed	3120	NGC 2567	7.9	7
	missed	3631	NGC 6152	8.1	25
	258	missed	Melotte 101	8.2	15
	281	missed	IC 2714	8.2	14
	missed	3703	NGC 6425	8.2	10
	missed	3707	NGC 6451	8.2	7
	missed	3177	NGC 2925	8.3	10
	missed	3142	NGC 2670	8.5	7
	missed	3194	NGC 3033	8.6	4
	missed	3310	NGC 3496	8.7	8
	missed	3655	NGC 6249	8.8	5
	missed	3373	NGC 4052	8.8	9
	380	missed	Ruprecht 119	8.8	8
	310	missed	Trumpler 17	8.9	5
	271	missed	Melotte 105	9.0	5
	missed	3137	NGC 2659	9.2	5
	609	missed	NGC 2658	9.2	6
	missed	3388	NGC 4337	9.4	4
	missed	3386	NGC 4230	9.4	8
	missed	3443	NGC 4815	9.5	5
	missed	3123	NGC 2580	9.7	3.5
	391	missed	Collinder 307	9.7	5
	455	missed	Lynga 14	9.7	3
	missed	3693	NGC 6396	9.8	3
	missed	3138	NGC 2660	9.8	3.5
	missed	3512	NGC 5168	10.3	4
	missed	3219	NGC 3105	10.4	2
	missed	3133	NGC 2635	10.7	1
		missed	Collinder 198	11.2	5
	358	missed	Trumpler 23	11.2	9
	308	missed	Trumpler 13	11.3	5
		missed	Lynga 4	11.4	3
	537	missed	Trumpler 25	11.7	8
	372	missed	Ruprecht 78		3
	299	missed	Ruprecht 164		5
	325	missed	Loden 372		6
	290	missed	Ruprecht 95		4

The four open clusters at the end of the list without magnitudes were catalogued by Dunlop, and thus could have been seen by Herschel.

Table 5.37 provides a list of all the open clusters fainter than the working magnitude limits (6.4, 10.9, and 12.7) which were seen by Lacaille, Dunlop and Herschel. The relevant open clusters are displayed in bold print, with those brighter than the working magnitude limit in grey. No open clusters fainter than Herschel's working magnitude limit were found by him because the table only includes objects seen by one or more of the three observers.

Table 5.37: Open clusters fainter than the working magnitude limits found by Lacaille, Dunlop and Herschel.

Lacaille	Dunlop	Herschel	Identification	Magnitude	Diameter (arc-second)
3.08	342	3573	NGC 5662	6.6	29
1.07	273	3531	NGC 5281	7.1	7
1.10	520	3654	NGC 6242	7.3	9
3.04	330	missed	IC 2488	7.4	18
	334	3615	NGC 6005	11.1	5
	358	missed	Trumpler 23	11.2	9
	308	missed	Trumpler 13	11.3	5
	489	3141	NGC 2671	11.6	6
	537	missed	Trumpler 25	11.7	8
	522	3672	NGC 6318	11.8	4

5.3.8.4 Planetary Nebulae

Table 5.38 provides information on all the planetary nebulae found and missed by Dunlop and Herschel south of Declination -30^{o} and larger than 12 arc-seconds in diameter to magnitude 13.2. Lacaille is omitted as he found no planetary nebulae apart from NGC 3918 which he catalogued as a star. NGC 5979 is included (diameter 8 arc-seconds and magnitude 11.8) because it was seen by Herschel. Again the word 'missed' indicates that the object is brighter than the observer's working magnitude limit (10.9 or 12.7). The modern identification, magnitude and diameter are also listed. The table is sorted by magnitude from brightest to faintest.

Table 5.38: All planetary nebulae found or missed by Dunlop and Herschel compared to their working magnitude limits.

Dunlop	Herschel	Identification	Magnitude	Diameter (")
missed	missed	NGC 6302	9.7	44.5
missed	missed	IC 4406	10.2	35
missed	missed	NGC 6153	10.6	24
missed	3242	NGC 3211	10.7	16
381	3675	NGC 6326	11.1	12.5
564	3154	NGC 2818	11.5	50
	missed	Fg 1	11.6	16
	missed	IC 4637	11.7	18.5
	missed	Lo 5	11.7	215

	3610	NGC 5979	11.8	8
	missed	Mz 2	12.0	23
	missed	Mz 1	12.0	26
	missed	IC 4663	12.1	13
	missed	He 2-141	12.3	14
	missed	BlDz 1	12.3	82
	missed	IC 4642	12.4	16.5
	missed	He 2-207	12.6	35
	missed	K 1-23	12.6	42
	missed	Sp 1	12.6	72
	missed	K 1-22	12.6	180
	3374	NGC 4071	13	63
	3617	NGC 6026	13.2	40

5.3.8.5 Bright or Diffuse Nebulae

Four diffuse nebulae are listed in the Lacaille catalogue. They are NGC 2070, the Tarantula Nebula in the Large Magellanic Cloud; two parts of NGC 3372 also called the Eta Carinae Nebula; and M8, the Lagoon Nebula. Eta Carinae and M8 are bright enough to see with the naked eye but the Tarantula Nebula is a difficult naked eye object. Lacaille did not miss any bright diffuse nebulae.

There are 53 diffuse nebulae in the Dunlop non-stellar catalogue. However, only four are outside the Magellanic Clouds. They are the Eta Carinae nebula (NGC 3372) and two nebulae near Eta Carinae, NGC 3199 and NGC 3324. The Declination given by Dunlop for NGC 3199 was 1 degree north of the ESO (B) position, but the description and diagram in his notes are accurate. There is also evidence in his notes that he may have seen NGC 3581.

Three bright red emission nebulae outside the Magellanic Clouds were not included in the Dunlop catalogue. They were IC 2948, NGC 3581 and NGC 6188. These are visible in 20 x 80 binoculars and could have been visible through his 9-inch reflector.

Dunlop recorded two dark nebulae, Bernes 157[435] in Corona Australis and Barnard 283 in Scorpius is also alluded to. These were amongst the first dark nebulae recorded. The first catalogue of dark nebulae[436] was made one hundred years later by E E Barnard in 1927.

The Herschel catalogue contains 64 bright diffuse nebulae, 43 in the Magellanic Clouds and 21 others. Six of the 21 are parts of the same object, namely NGC 3576, 3579, 3581, 3582,

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[435] C.A. Bernes, 'Catalogue of Bright Nebulosities in Opaque Dust Clouds', *Astronomy and Astrophysics Supplement Series*, 29, 1977, p. 65.

[436] E.E. Barnard, *Catalogue of 349 Dark Objects in the Sky, A Photographic Atlas of Selected Regions of the Milky Way*, Washington DC, 1927.

3584 and 3586. Herschel often gave several numbers to a single nebula, especially in the Large Magellanic Cloud.

Diffuse nebulae have been loosely classified into 'very bright' and 'bright' categories in two separate photographic catalogues made using H-alpha filters, one by Colin Gum[437] and the other by Rogers, Campbell and Whiteoak.[438] Comparing these catalogues with the diffuse nebulae recorded by Herschel shows that he missed a number of nebulae classified as 'bright', including three IC nebulae, namely IC 2872, 2948 and 4628. He also missed 15 'bright' nebulae from the Gum catalogue and 19 'bright' nebulae from the Rogers, Campbell and Whiteoak catalogue. He did not miss any classified as 'very bright'. However objects that show up well on red sensitive plates are not always visible to the naked eye.

5.3.9 DATA SUMMARY AND CONCLUSION

Table 5.39 summarises the catalogues of Lacaille, Dunlop and Herschel, and includes the theoretical magnitudes and working magnitude limits calculated for each telescope, and the magnitudes of the faintest objects catalogued.

Table 5.39: Summary of the telescopes, the magnitude limits and faintest object seen for the three historical catalogues.

	Lacaille Catalogue	Dunlop Catalogue	Herschel Catalogue
Diameter and Type of Telescope	0.5 inch Refractor	9.0 inch Reflector	18.5 inch Reflector
Equivalent Modern Newtonian Telescope		6.5 inch	16.8 inch
Theoretical Magnitude Limit for Stars	7.6	13.1	15.2
Working magnitude Limit	6.4	10.9	12.7
Magnitude of Faintest Galaxy	7.1	12.7	14.5

437 C.S. Gum, 'A Survey of Southern H II Regions', *Memoirs of the RAS*, 67, 1955, p. 155.

438 Rodgers, Campbell, Whiteoak, 'A Catalogue of H Alpha-Emission Regions in the Southern Milky Way', *Monthly Notes of the RAS*, 121, 1960, pp. 103-110.

The number of bright objects that were missed (brighter than the working magnitude limit) and the number of faint objects that were seen are summarised by type in Table 5.40.

Table 5.40: Number of missed objects brighter than working magnitude limit and objects seen fainter than working magnitude limit, by type of object.

		Open Clusters	Globular Clusters	Planetary Nebulae	Galaxies
Lacaille	Bright Objects Missed	10	4 (50%)		
	Faint Objects Seen	4	1	1	1
Dunlop	Bright Objects Missed	32	5 (12%)	4 (27%)	46 (46%)
	Faint Objects Seen	6	0	2	15
Herschel	Bright Objects Missed	25	10 (20%)	16 (25%)	432 (48%)
	Faint Objects Seen	0	0	2	253

Table 5.40 shows that when the working magnitude limits are taken into account, Dunlop missed a smaller percentage of globular clusters than Herschel (12% compared to 20%). He also missed fewer galaxies than Herschel when percentages are considered (46% compared to 48%).

The aim of Section 5.3 was to determine the magnitudes where each catalogue is reasonably complete, their working magnitude limits. Galaxies contained the best data for determining the working magnitude limits for the Herschel and Dunlop catalogues, while globular clusters were best for determining Lacaille’s working magnitude limit. The second aim was to compile a list of bright objects that were missed but that could have been seen and a list of the faint objects that were found, using the working magnitude limit as the cut-off point. This was done for open clusters, globular clusters, planetary nebulae and galaxies, with comments on diffuse nebulae.

CHAPTER 6 – CONCLUSION

This thesis set out to evaluate and compare the three earliest astronomical catalogues of non-stellar objects in the southern skies, to describe the historical events and circumstances relevant to the production of the catalogues, and to include some biographical information about each of the three astronomers who spent many nights observing and recording the objects in their catalogues. A corollary of this analysis was to determine if the strong criticism and dismissal of James Dunlop's catalogue of southern nebulae and clusters was justified and whether Dunlop's reputation as an astronomer and his contribution to southern non-stellar discoveries should receive greater recognition.

The earliest catalogue, *Sur les étoiles nébuleuses du Ciel Austral* or *On the Nebulous Stars of the Southern Sky* was produced by Abbé de La Caille at Cape Town, South Africa between August 1751 and July 1752 and contains 42 objects (Appendices A and B). The second catalogue of 629 objects was made at Parramatta, Australia by James Dunlop between April and November 1826, and was called *A Catalogue of Nebulae and Clusters of Stars in the Southern Hemisphere observed in New South Wales* (Appendices C and F). John Herschel also observed from Cape Town and produced the third catalogue entitled *Results of Astronomical Observations made during the years 1834, 5, 6, 7, 8 at the Cape of Good Hope, being a completion of a telescopic survey of the whole surface of the visible heavens commenced in 1825* (Appendices G and I), which contains 1708 southern non-stellar objects observed between 1834 and 1838.

For all three catalogues there are positive commendable points and there are also negative points. The advantages and disadvantages of the three catalogues are outlined below.

6.1 THE LACAILLE CATALOGUE

This ground-breaking catalogue, produced before the famous Messier catalogue, contains only 42 non-stellar objects. With the exception of a few objects, the positions given are remarkably accurate, with 90% of objects within 5 arc-minutes of the *Guide* 8 position. The mean radial distance from the *Guide* 8 position was found to be 1.9 arc-minutes with a standard error mean of 0.24. A copy error of 10 minutes of time created the largest positional inaccuracy. Lacaille included M83 (magnitude 7.1) in his catalogue, one of the first telescopic galaxies recorded.

Although Lacaille spent a full year making his catalogue, and thus theoretically had the opportunity to survey all the southern sky, he recorded only 42 non-stellar objects and missed a number of bright objects which could have been visible through his telescope. The 42 entries included some asterisms, which Lacaille presumably believed to be non-stellar objects because he observed with a very small telescope and low magnification.

6.2 THE DUNLOP CATALOGUE

This problematic catalogue of 629 objects contains more than 200 objects which cannot be easily identified. Of those that were identified, many contain large positional errors, typically 20 arc-minutes, and only 79% of identified objects are within a 20 arc-minutes of the correct position. The mean radial distance of an object from its ESO (B) position was calculated to be 9.13 arc-minutes with a standard error mean of 0.29. One consequence of the large positional inaccuracies is the inclusion of some repetitions in the Dunlop catalogue, that is, two positions are given for the same object. However identification of objects with incorrect positions was made easier because of the accurate, detailed descriptions Dunlop included in his notes.

This thesis did not analyse all the original Dunlop notes which are available on microfilm, as this was beyond the scope of this work. A more complete examination of the microfilm would reduce the number of unidentified objects in the Dunlop catalogue of nebulae and clusters and further support Dunlop’s important contribution to southern astronomy.

Although Dunlop observed for less than a full year, his catalogue is remarkably complete, containing all the bright southern globular clusters and most of the open clusters and galaxies brighter than his working magnitude limit (10.9). The faintest object recorded by Dunlop was a galaxy of magnitude 12.3 (according to the PGC), which is 0.8 of a magnitude brighter than the calculated theoretical limiting magnitude of his telescope, magnitude 13.1. Had Dunlop spent more time making his catalogue, perhaps even a number of years as Sir John Herschel did, it is possible that many of his erroneous positions could have been checked and corrected. Similarly if the equipment Dunlop used, particularly his telescope and clock, were of a higher quality, it is likely that the large number of inaccurate positions could have been reduced. He was constrained by a lack of money and the printed catalogue does not accurately reflect his written notes.

Like the Lacaille catalogue, the Dunlop catalogue contains many asterisms and it also contains faint double stars which do not belong in a catalogue of clusters and nebulae. Like Lacaille, Dunlop probably searched using a very low power, and the resulting poor resolution would have caused many objects to appear as non-stellar.

Historically Dunlop was the first astronomer to map the Magellanic Clouds, and approximately one third of his catalogue is devoted to objects within these two galaxies. Considering his telescope and its resolution, Dunlop catalogued a significant number of non-stellar objects in this rich area of the southern sky.

Of the three catalogues, the Dunlop catalogue was the only one produced without adequate financial support or encouragement, using substandard equipment by an untrained astronomer. Without the necessary backing and practical assistance which benefited both Lacaille and Herschel in their endeavours, and under the time constraints which a lack of funds must have created, the dedication of James Dunlop to the exploration of the southern skies is commendable

Dunlop found and recorded more objects than Messier in a smaller area of the sky, in a much shorter period of time while using a telescope that was only slightly larger. It is true that the Dunlop catalogue contains many incorrect positions and objects which are not nebulae or clusters (double stars and asterisms), however a thorough and complete inspection of his catalogue reveals an astonishingly rich content with numerous discoveries for which Dunlop has not received adequate credit. In this respect, John Herschel's criticism not only tarnished Dunlop's reputation, but ensured that the honour and acclaim for the discovery of most southern non-stellar objects was attributed to Herschel himself.

6.3 THE HERSCHEL CATALOGUE

This definitive catalogue contains many more objects than the above two catalogues, including a small number in the northern sky. Both the astrometry and limiting magnitude calculations indicated the impressive accuracy of the work done to produce this catalogue. Ninety-two percent of the southern objects were within 5 arc-minutes of their ESO (B) position. The mean radial distance from the ESO (B) position was calculated to be just 1.3 arc-minutes with a standard error mean of 0.06. The most common positional inaccuracies were 1 degree in Declination, which indicates either a copying error or a misreading of the instrument. With its large numbers of faint galaxies and very accurate positions for all types of non-stellar objects, this catalogue formed the basis for the southern part of the *New General Catalogue* (NGC) of nebulae and clusters which was produced in 1888.

Lacaille, Dunlop and Herschel all catalogued a galaxy as their faintest object. The faintest galaxy recorded by Herschel is magnitude 15.0 (using the PGC and V = B – 0.8), which is very close to 15.2, the calculated theoretical limiting magnitude of his telescope.

There are however some objects in the Lacaille catalogue which Herschel omitted, and there are a number of other bright objects which were missed by Herschel, including some recorded in the Dunlop catalogue. All three catalogues contain objects discovered by other people. Appendix J lists the objects catalogued by Lacaille, Dunlop and Herschel, and includes the name of the discoverer, the year discovered and other data for each object.

It is known that Herschel had access to the Dunlop catalogue, and that he used it for a time, but became frustrated with the large number of missing objects and positional errors it contained so much so that he discarded, criticised and publicly discounted it.

Herschel spent a number of years producing and refining his catalogue, so that many objects were observed more than once. This is confirmed in the catalogue where it often contains several different descriptions for the same object. Entries for the Large Magellanic Cloud are reasonably complete, but for the Small Magellanic Cloud this catalogue contains fewer entries than the Dunlop catalogue. Herschel often dissected an object in the Magellanic Clouds, assigning several numbers to one Dunlop object. The *New General Catalogue* followed Herschel in this regard and this artificially boosted the number of objects in his catalogue. As a result, one Dunlop object sometimes has several NGC numbers. For example Dunlop 175 was divided into 5 objects by John Herschel. These are now known as NGC 1929, 1934, 1935, 1936, 1937. In his catalogue, Dunlop's description of object 175 says "the nebulous matter has several seats of attraction, or rather it is a cluster of small nebulae with strong nebulosity common to all." However NGC 1929 is faint and was probably not seen by Dunlop. For Dunlop 175, only NGC 1934, 1935, 1936, 1937 are listed as Dunlop objects in the Combined Catalogue.

Herschel's wealth, personal prestige and influence in England no doubt sealed his reputation as 'the' astronomical observer of the southern skies, as his catalogue was the most complete and accurate available at the time. It is unfortunate that he did not fully acknowledge his forerunners and their contributions to the cataloguing of the southern sky.

6.4 COMBINED CATALOGUE

Objects from the Lacaille, Dunlop and Herschel catalogues were combined into one table using:

1. All 42 entries in the Lacaille catalogue
2. All identified non-stellar objects, plus a sample of asterisms, Milky Way star clouds (MWSC), double stars and dark nebulae from the Dunlop catalogue

3. All non-stellar objects south of Declination –29° in the Herschel catalogue.

Data given in this table of 1398 objects includes the Lacaille, Dunlop and Herschel number(s), the NGC or IC number, other identifications assigned to the object, the name of the first discoverer and the year of discovery, the type of object, the constellation in which it is located, its visual magnitude, its size in arc-minutes (or arc-seconds in the case of planetary nebulae), the Right Ascension in decimal hours and Declination in decimal degrees. The complete table can be found in Appendix J.

Ascertaining the original discoverer of each object in this combined table allowed for a final count of the number of southern objects found by each observer, with special interest in those first seen by Lacaille, Dunlop and Herschel. A summary of this information is found in Table 6.1.

Table 6.1: Number of southern objects, by type, originally discovered by each observer.

Discoverer	OC	GC	Neb	PN	Gxy	Ast	MWSC	D*	star	Dark Neb	Total
J Herschel	229	15	55	16	688	11	8				1022
Dunlop	134	44	61	4	53	9	2	1		2	310
Lacaille	22	4	3		1	4			1		35
W Herschel	2	6			10						18
Charles Messier		4									4
Giovanni Hodierna	2		1								3
Others	1	4			1						6
Total	**390**	**77**	**120**	**20**	**753**	**24**	**10**	**1**	**1**	**2**	**1398**

The table shows that John Herschel first saw by far the greatest number of southern objects 1022/1398 (73%), but it also clearly demonstrates that James Dunlop made a significant contribution 310/1398 (22%) to southern sky discovery. Lacaille’s contribution 35/1398 (2.5%) although smaller, is important.

John Herschel was able to identify only 211 objects in the Dunlop catalogue, which is well below the 368 identified objects listed in Appendix J. Herschel, and others since, failed to acknowledge the important role Dunlop played in southern sky exploration. The “sad tale and warning"[439] expressed by J D Forbes, criticising Dunlop and his catalogue was unjust and ill informed.

This thesis however is not the final word on the topic of southern sky discovery, as the identity of some Dunlop objects is still debatable, awaiting further discussion and a full analysis of his original notes.

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[439] Saunders, *Colonial NSW*, p .312.

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