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JAMES DUNLOP'S HISTORICAL CATALOGUE OF SOUTHERN NEBULAE AND CLUSTERS

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Abstract: In 1826 James Dunlop compiled the second ever catalogue of southern star clusters, nebulae and galaxies from Parramatta (NSW, Australia) using a 23-cm reflecting telescope. Initially acclaimed, the catalogue and author were later criticised and condemned by others—including Sir John Herschel—and both the catalogue and author are now largely unknown. The criticism of the catalogue centred on the large number of fictitious or 'missing' objects, yet detailed analysis reveals the remarkable completeness of the catalogue, despite its inherent errors. We believe that James Dunlop was an important early Australian astronomer, and his catalogue should be esteemed as the southern equivalent of Messier's famous northern catalogue.

Keywords: James Dunlop, southern sky catalogue, clusters, nebulae, galaxies

1 INTRODUCTION

The first southern catalogue of clusters and nebulae was produced by the Frenchman, Nicolas Louis de Lacaille (1713–1762), from Cape Town in 1751-1752 with a tiny half-inch aperture (1.3-cm) refractor (see Lacaille, 1755). The second catalogue was compiled by James Dunlop (1828), who observed from Sydney in 1826 with a nine-inch aperture (23-cm) speculum-mirror reflector. Sir John Herschel, who observed firstly from London between 1825 and 1833, and then from Cape Town between 1834 and 1838, made the third catalogue of southern clusters and nebulae, using an 18.5-inch aperture (47-cm) speculum-mirror reflector (see Herschel, 1847).

Prior to 1654, Giovanni Battista Hodierna (1597–1660), observing from Sicily, catalogued 11 NGC objects (Hodierna, 1654). Charles Messier (1730–1817) and Pierre Méchain (1744–1804) later compiled their famous catalogue of 109 bright clusters and nebulae from Paris, between 1758 and 1782 (e.g. see Messier, 1781; Méchain, 1783). Together they found 66 new NGC objects. Messier used many telescopes, including a 7.5-inch aperture (19-cm) speculum-mirror reflector. Sir William Herschel (John's father), with his sister Caroline's help, went on to compile a very large catalogue of more than 2,500 clusters and nebulae, from London, between 1782 and 1802, using an 18.5-inch (47-cm) aperture speculum reflector (Herschel, 1786; 1789; 1802). Thus, by 1802, the sky visible from the northern hemisphere was well catalogued, while the far southern sky was still largely unknown.

As noted above, James Dunlop (Figure 1) compiled the second southern catalogue, which was titled *A Catalogue Of Nebulae And Clusters Of Stars In The Southern Hemisphere, Observed At Parramatta In New South Wales.* In 1828, after the publication of this catalogue, Dunlop was awarded the Gold Medal of the Astronomical Society of London by the President, Sir John Herschel. Upon awarding the Medal, Herschel praised Dunlop for his zealous, active, industrious and methodical work, and his recognition seemed assured. Instead, this catalogue of 629 objects was largely ignored by later observers for a number of reasons, but primarily because the positions given for the objects were not accurate (with average offsets of 9′) and because about half of the listed objects were supposedly 'missing'.

Furthermore, six years later, when Herschel began observing the southern skies from Cape Town, South Africa, he became frustrated by the inaccuracy of Dunlop's positions, and only succeeded in identifying 211 (34%) of the objects in the catalogue. In the introduction to his own catalogue of southern nebulae and clusters, included in his monumental *Results of Astronomical Observations Made During the Years 1834, 5, 6, 7, 8, at the Cape of Good Hope,* Herschel (1847) dismisses Dunlop's catalogue:

> I cannot help concluding that, at least in the majority of those cases, a want of sufficient light or defining power in the instrument used by Mr. Dunlop, has been the cause of his setting down objects as nebulae where none really exist.[1]

Figure 1: James Dunlop, 1793–1848 (courtesy: http://en.Wikipedia.ord/wiki/James_Dunlop).

Criticism of Dunlop continued during the following years. Herschel's friend, James David Forbes (1849), published a damning article in *The Quarterly Review* that was critical of Dunlop:

> 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 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.

In this paper we provide brief biographical data about James Dunlop and discuss his reflecting telescope before critically examining his catalogue.

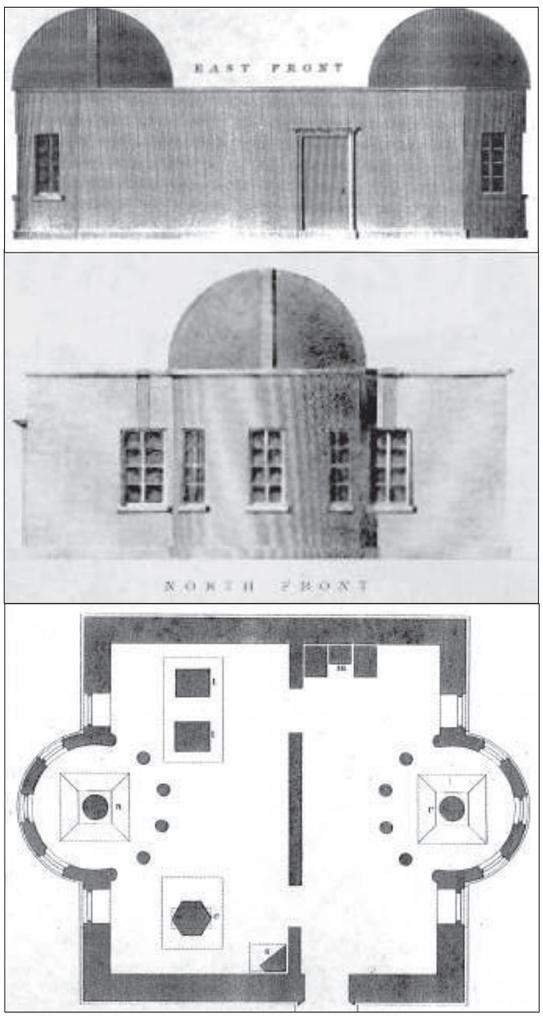

Figure 2: Side elevations and plan view of the Parramatta Observatory (after Richardson, 1835).

2 JAMES DUNLOP

In his biography of James Dunlop, John Service (1890) notes that Dunlop was born in Dalry, Scotland, in 1793. He came from a working-class family and was poorly educated. At age 14 he began work in a thread factory in the neighbouring town of Beith, and it was there that

> ... his natural aptitude for mechanics was … developed. During his intervals of leisure he constructed turning lathes, telescopes, and reflectors from such materials as his limited means afforded. The ingenuity he displayed attracted the attention of his employers and fellow workmen, who discerned in him the dawning of a distinguished scientist. (Service, 1890: 69).

While Service can be forgiven for seeing the makings of a 'distinguished scientist' in his illustrious ancestor, what specifically interests us is the reference to the manufacture of telescopes and especially 'reflectors'. In her biography of Dunlop, Salmon (1911: 627) provides further details:

> When he was only seventeen years of age, he was constructing lathes and telescopes, and casting reflectors for himself; and in a dark closet of a cellar under one of the factory stairs, he made a telescope four feet long and six or nine inches in aperture. His brother John, a boy of fourteen, helped him to the extent of holding the candle whilst Jamie did the work. When the instrument was completed they took it up to an attic and had a look at "Cock-my-lane" on the Dalrig Hills. His employer, Mr. Faulds, came up to have a look, and was astonished at the wonderful "skyglass."

What this reveals is that as a teenager Dunlop was making successful reflecting telescopes with speculum mirrors, and it was this aptitude and his mechanical skills and training that brought him to the attention of fellow Scot, Sir Thomas Brisbane (1773–1869), who was a dedicated amateur astronomer and maintained a well-equipped private observatory at Largs (Allison-Mow, 2004).

Brisbane was subsequently appointed Governor of New South Wales, and he decided to set up a private observatory in Australia so that he could explore the southern skies (see Saunders, 1990). He also decided to employ Christian Carl Rümker (1788–1862), a German astronomer (Bergman, 1960), to carry out astronomical observations, and James Dunlop to maintain the astronomical instruments

In November 1821 Brisbane, Dunlop and Rümker arrived in Sydney, and they soon began erecting an observatory near Government House. 'Parramatta Observatory', as it was known (Figure 2), was completed in May 1822, and Rümker then began compiling a southern star catalogue while Dunlop assisted him and attended to the instruments.[2]

Friction soon developed between Brisbane and Rümker, and the untrained Dunlop took over observations for Brisbane's catalogue of southern stars when Rümker left in June 1823. Bergman (1960) notes that tension had also developed between Rümker and Dunlop because Rümker thought that Brisbane favoured Dunlop. Brisbane was also having problems as Governor, and at the end of 1825 he returned to Scotland, leaving Dunlop to continue working on the star catalogue, which he completed in February 1826. In April of that year Dunlop left the Parramatta Observatory, and Rümker resumed working there.

Dunlop moved to a nearby house in Parramatta, where he began observing southern clusters and nebulae. No doubt he had noticed many of these objects while working on the Parramatta star catalogue with a 3.75-inch (9.5-cm) aperture transit instrument, many more than the mere 42 entries in Lacaille's 1755 catalogue of southern clusters and nebulae.

This inspired Dunlop to compile a larger catalogue to supersede Lacaille's catalogue, and for this he used a 9-inch (23-cm) aperture, 9-foot (274-cm) long reflecting telescope with a speculum mirror which he had made. The current whereabouts of this telescope is not known. The clock which Dunlop used to record the times of his observations may have been one of the four clocks brought to Australia by Brisbane (though there is no documentation on this).

Apparently Dunlop had no financial support and no assistant during the seven months he spent on his catalogue. He worked constantly and determinedly, in the end observing and recording a total of 629 clusters and nebulae (Dunlop, 1828; some of these objects are also discussed in Dunlop 1829b). At the same time he also produced a catalogue of 253 double stars (Dunlop, 1829a), observing these on the nights when the Moon was too bright for him to search for clusters and nebulae.

Early in 1827 Dunlop returned to Scotland, where he once again worked for Brisbane, serving as astronomer in his Makerstoun Observatory near Kelso (see Morrison-Low, 2004). His catalogue of clusters and nebulae was reduced during this time, and was published by the Royal Society (of London) in 1828.

Almost ten years to the day after Dunlop first arrived in Australia, he returned to Sydney as "...superintendent of the Government Observatory at Parramatta, with a salary of £300." (Salmon, 1911: 627).[3] Dunlop remained in this post from 1831 until 1847, when a review of the run-down facility led by Captain Phillip Parker King (see Orchiston, 1988) resulted in its closure. Dunlop then retired to his farm near Gosford, N.S.W., and just one year later he was dead. He was buried at the Kincumber Anglican Church.

3 DUNLOP'S TELESCOPE

In compiling his catalogue of southern nebulae and clusters James Dunlop used a telescope he built while maintaining the instruments at the Parramatta Observatory. This telescope had a speculum mirror of 23-cm aperture (d_s), and we can convert this to the equivalent of a modern aluminium-coated mirror (d_m) in a Newtonian reflector by using the formula

$$d_m = \sqrt{(pr_s \times sr_s \times d_s)/(pr_m \times sr_m)} \quad (1)$$

where pr_s and pr_m are the primary reflectivity of a speculum mirror and a modern mirror, respectively, and sr_s and sr_m are the secondary reflectivity of a speculum mirror and a modern mirror, respectively. Speculum was made with different percentages of copper and tin, and in calculating the equivalent modern telescope a 45% tin speculum was assumed. The composition of the speculum mirror in Dunlop's telescope is not known, but 45% tin speculum tarnished more slowly than other mixes. The calculation also assumes that after six months in a damp atmosphere, speculum has a reflectivity of ~63% (Tolansky and Donaldson, 1947)[4] and aluminium a reflectivity of 87%. Upon feeding these figures into Equation 1, we obtain the results listed in Table 1. As a general statement, we can say that Dunlop's mirror was equivalent to a modern mirror of about 16.6-cm aperture.

Determining the equivalent modern telescope to Dunlop's telescope is useful because it allows the limiting magnitude of the telescope to be determined, as this information is available for modern telescopes. The limiting apparent visual magnitude for stars for a modern 16.6-cm Newtonian (and for Dunlop's 23-cm telescope) is conservatively 13. Knowing the limiting magnitude of Dunlop's telescope, we can determine the completeness of his catalogue.

In his printed catalogue, Dunlop mentions using powers of 170× in his descriptions of D250 and D290 and he mentions a power of 260× for D389. These eyepieces would be approximately 16 mm and 10.5 mm focal length respectively since his telescope's focal length was 274 cm. In his handwritten notes there is evidence that his 'sweeping' eyepiece had a field of 45′. By comparison, Herschel used a 39 mm focal length eyepiece with a power of 157× and a field of view of 15′.

Dunlop was about 1.73m tall (Service, 1890: 207), so he must have used a ladder to climb up to the eyepiece when viewing objects located more than 35° or 40° above the horizon. He used candle light to record the time, the south polar distance and a description of each object seen as he swept back and forth across the southern sky.

Table 1: Reflectivity and magnitude limits for a 45% tin speculum mirror telescope.*

λ (nm)	d_s (cm)	pr_s (%)	pr_m (%)	d_m (cm)	m_v limit
450	23	61	86	16.3	13.1
650	23	65	88	16.8	13.2

* After 6 months

4 THE DUNLOP CATALOGUE

Dunlop's catalogue lists most of the bright non-stellar objects in the far southern sky, including the following distinctive types of objects:

Globular Clusters: NGC 104 (47 Tuc), 2808, 5139 (ω Cen), 6397, 6541 and 6752;
Nebulae: NGC 2070 (Tarantula), 3199, 3324, 3372 (η Car);
Open Clusters: NGC 2547, 3114, 3293, 3532, 4755 (κ Cru) and 6231;
Planetary Nebulae: NGC 2818A (in an open cluster), 5189, 6563; and
Galaxies: NGC 55, 300, 1291, 1313, 1316, 1553, 4945, 5128 (Cen A), 6744 and 7793.

Images and Dunlop's descriptions of globular clusters, galactic nebulae and galaxies can be seen on picasaweb (Cozens, 2009). The images are 28 × 28′ in size (except where the caption says 'wide'), with north at the top.

Two pages from the printed catalogue are shown in Figures 3 and 4. The objects in it were arranged by south polar distance (SPD) from declination –77° to –28°. Many entries in Dunlop's catalogue have not been positively identified, but it seems that no one has systematically worked through the whole catalogue to ascertain if more objects could be identified since Herschel identified 211 of these objects back in the 1830s. Using modern digital star atlases with accurate positions, and using Dunlop's original hand-written notes (available on microfilm) and other images, the first author has identified many new objects.

VIII. *A catalogue of nebulæ and clusters of stars in the southern hemisphere, observed at Paramatta in New South Wales, by* JAMES DUNLOP, *Esq. In a letter addressed to Sir* THOMAS MAKDOUGALL BRISBANE, *Bart. K.C.B. late Governor of New South Wales. Presented to the Royal Society by* JOHN FREDERICK WILLIAM HERSCHEL, *Esq. Vice President.*

Read December 20, 1827.

THE following nebulæ and clusters of stars in the southern hemisphere were observed by me at my house in Paramatta, situated about 6″ of a degree south and about 1ˢ.78 of time east of the Brisbane Observatory. 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 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 a considerable magnifying power. I made drawings or representations of a great number of the nebulæ and clusters at the time of observation, several of which are annexed to this paper; and also very correct drawings of the Nebulæ major and minor, together with a representation of the milky nebulosity surrounding the star η Robur Caroli. The places of the

Figure 3: The Second page from Dunlop's catalogue of southern nebulae and clusters of stars.

These include 187 objects outside the Magellanic Clouds (78 open clusters, 34 globular clusters, 50 galaxies, 4 planetary nebulae, 3 nebulae, 12 asterisms and 4 other objects) and about 150 objects in the Large and Small Magellanic Clouds, giving a grand total of 335 objects. A further 37 objects in the catalogue were entered more than once, with two different co-ordinate positions. Table 2 lists the 187 objects; some objects are uncertain, and these are marked with an asterisk. The remaining objects seem to be faint double stars. Apparently Dunlop was unable to distinguish between small nebulae and faint (magnitude 11-13) double stars with his poor quality eyepieces. It is not possible to identify most of the double stars because in each instance there are generally several within 20′ of the Dunlop position.

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small stars in the Nebulæ major and minor, and also those accompanying the η Robur Caroli, I ascertained by the mural circle in the year 1825, at which time I was preparing to commence a general survey of the southern hemisphere. These stars being laid down upon the chart, enabled me to delineate the nebulosity very accurately.

The nebulæ are arranged in the order of their south polar distances to the nearest minute for 1827, and in zones for each degree in the order of their right ascension. The column on the right hand shows the number of times the object has been observed.

The reductions and arrangement have been principally made since my return to Europe; and I trust this catalogue of the nebulæ will be found an acceptable addition to that knowledge which the Brisbane observatory has been the means of putting the world in possession of, respecting that important and hitherto but little known portion of the heavens.

No.	Æ h	m	s	S.P.D. °	′	Description of the Nebulæ and Stars.	No.of Obs.
1	4	13	0	12	14	A very small faint round nebula, about 12″ diameter, with a very minute star south following dist. 1′	1
2	0	33	6	15	41	A faint nebula, about 1½′ long, irregular figure, rather branched. This is involved in the margin of the Nebula minor	1
3	0	41	8	15	59	A small round nebula, about 12″ diameter	1
4	0	42	19	15	56	A faint round nebula, about 30″ diameter	1
5	0	47	12	15	46	A small faint nebula, about 10″ or 12″ diameter	1
6	0	47	39	15	36	A faint nebula, about 20″ diameter	1
7	1	9	32	15	46	A faint round nebula, 35″ diameter, with a small star near the south margin, but not involved	1
8	1	10	23	15	48	A small oval nebula, about 10″ diameter	1
9	1	12	37	15	44	A faint nebula, about 1½′ diameter, of an irregular round figure	2
10	1	13	43	15	51	An elliptical nebula, about 1′ long and 40″ broad, with three minute stars in it	1

Figure 4: The third page from Dunlop's catalogue of southern nebulae and clusters of stars.

The catalogue contains other problems, principally positional inaccuracies of 10-20′. Dunlop took just seven months to compile this catalogue, and he did not allow enough time to check it properly. By comparison, Messier took 24 years to make his catalogue of just 109 objects. Nonetheless, Dunlop's catalogue is very significant as it is the first catalogue of southern galaxies and of objects in the two Magellanic Clouds.

John Herschel failed to rediscover many of the objects in the Dunlop catalogue, including more than 20 open clusters, 2 globular clusters and 4 galaxies. This wealthy English amateur (see Chapman, 1993) spent 46 months assembling his catalogue, using a much larger and better-quality telescope. Although Herschel (1847) states that he searched diligently for objects in Dunlop's catalogue, these omissions suggest

otherwise. Some Dunlop objects missed by Herschel are listed in Table 3.

The following are descriptions from the Dunlop catalogue of a sample of objects.

D16 in the SMC is now known as Lindsay 104. Dunlop wrote "A very faint nebula of a round figure, about 2′ diameter, with a small star in the north margin." Herschel missed this object.

D175 in the LMC is now identified as NGC 1929, 34, 35, 36 and 37. Dunlop wrote "A pretty large rather faint nebula, about 5′ diameter, irregular figure, partly resolvable into stars of mixt magnitudes. The nebulous matter has several seats of attraction, or rather it is a cluster of small nebulae with strong nebulosity common to all." Herschel listed five objects here; Dunlop saw several of them.

D271 is the open cluster Melotte 105. Dunlop wrote: "A rather bright nebula, about 2.5′ or 3′ long and 1′ broad, in the form of a crescent, the convex side preceding; no condensation of the nebulous matter towards any point. This is easily resolvable into many stars of some considerable magnitude, arranged in pretty regular lines, with the nebula remaining, which is also resolvable into extremely minute stars. This is probably two clusters in the same line, Figure 10." Herschel missed this open cluster. Figure 5 shows Dunlop's drawings, including Melotte 105 in Dunlop's Figure 10.

D332 is the nebula NGC 3199. Dunlop wrote "A very faint ray of nebula, about 2′ broad, and 6′ or 7′ long, joining two small stars at the south following extremity, which are very slightly involved, but their lustre is not diminished from that of similar small stars in the field. The north extremity also joins a group of small stars, but they are not involved. Figure 15." Figure 5 includes Dunlop's Figure 15. Dunlop's position was 1° north of the nebula but his description and diagram match. It would not have been easy for Dunlop to read the south polar distance scale with a candle while trying to maintain his night vision.

Table 3: Some Dunlop objects not catalogued by Herschel.

Dunlop	Current ID	Notes
D330	IC2488	Open cluster also in Lacaille's catalogue
D437	IC 1633	Galaxy
D281	IC 2714	Open cluster
D402	IC 4651	Open cluster
D255	IC 5250	Galaxy
D546	IC 5332	Galaxy probably seen by Dunlop
D611	NGC 5824	Globular cluster
D417	NGC 6352	Globular cluster
D608	NGC 7793	Galaxy
D391	Cr307	Open cluster
D224	Har 6	Open cluster
D244	Har 8	Open cluster
D258	Mel 101	Open cluster
D271	Mel 105	Open cluster
D430	Mrk 18	Open cluster
D372	Ru 78	Open cluster
D299	Ru 164	Open cluster
D308	Tr 13	Open cluster
D310	Tr 17	Open cluster
D358	Tr 23	Open cluster
D537	Tr 25	Open cluster

D417 is the globular cluster NGC 6352. Dunlop wrote "A rather faint nebula, of an irregular round figure, 4′ diameter, slightly branched; easily resolvable into stars, with slight compression of the stars to the centre." Herschel missed this object.

D480 is the magnitude 11.9 galaxy NGC 1487. Dunlop wrote "A very faint ill-defined nebula, with two or three very small stars in it, and a small star following." This is probably the faintest galaxy in Dunlop's catalogue, and the two nearby stars would have helped him see it.

D564 is the open cluster and planetary nebula NGC 2818/2818A. Dunlop wrote "A pretty large faint nebula of a round figure, 6′ or 8′ diameter; the nebulosity is faintly diffused to a considerable extent. There is a small nebula in the north preceding side, which is probably a condensation of the faint diffused nebulous matter; the large nebula is resolvable into stars with nebula remaining."

Table 2: Identified Dunlop objects, outside of the Magellanic Clouds.

Abbreviations used in this Table:

Dun #	Dunlop number
Name	The NGC number is generally given, unless otherwise indicated
IC	Index Catalogue
Lac, H, D	Lacaille, William Herschel, Dunlop repeat object
Type	The type of object
GC	Globular Cluster
OC	Open Cluster
PN	Planetary Nebula
Gxy	Galaxy
MW	Milky Way star cloud
Em Neb	Emission Nebula
m_v	Visual magnitude (where known)
Size	In ′ except PN which are in ″
RA and Dec	J2000 position from the ESO(B) catalogue and other sources, given in fractions of an hour or a degree
Offset	Distance from the correct position to Dunlop's position ′

Dun	Name (NGC/IC)	Notes	Type	Const	m_v	Size	RA 2000	Dec 2000	Offset (')
1		GSC9368335, copy error	D*	Men	12.5	0.9	4.411	-77.33	60.1
18	104	47 Tuc	GC	Tuc	4.0	50.0	0.401	-72.07	1.1
62	362		GC	Tuc	6.8	12.9	1.054	-70.83	1.6
67	4372		GC	Mus	7.2	18.6	12.436	-72.70	25.4
68	6101		GC	Aps	9.2	10.7	16.430	-72.20	4.4

69	6777	Lac I.13	Ast	Pav	8.0	2.0	19.447	-71.50	2.1
164	4833		GC	Mus	6.9	13.5	12.993	-70.88	4.7
206	1313	D 205, D 207	Gxy	Ret	9.2	9.1	3.304	-66.48	3.9
224		Harvard 6	OC	Mus	10.7	5.0	12.633	-68.42	10.0
225	6362		GC	Ara	8.1	10.7	17.532	-67.03	11.0
244		Harvard 8	OC	Mus	9.5	4.0	13.300	-67.12	8.2
252	5189		PN	Mus	9.5	140"	13.559	-65.97	14.6
255	IC 5250		Gxy	Tuc	11.1	3.1	22.788	-65.05	3.5
258		Melotte 101	OC	Car	8.2	15.0	10.703	-65.10	27.1
262	6744		Gxy	Pav	8.8	20.0	19.163	-63.85	11.2
263	7083		Gxy	Ind	11.4	3.9	21.596	-63.90	18.7
264	1559		Gxy	Ret	10.7	3.5	4.294	-62.78	17.8
265	2808		GC	Car	6.2	13.8	9.201	-64.85	20.5
271		Melotte 105	OC	Car	9.0	5.0	11.328	-63.48	4.6
272	4609		OC	Cru	6.9	5.0	12.705	-62.98	8.7
273	5281		OC	Cen	5.9	8.0	13.777	-62.90	2.1
281	IC 2714		OC	Car	8.2	15.0	11.289	-62.72	6.3
282	5316		OC	Cen	6.0	13.0	13.899	-61.87	3.1
289	3766		OC	Cen	5.3	12.0	11.602	-61.62	10.2
290*		Rup 95	OC	Cen		5.0	9.727	-61.13	8.6
291	4103		OC	Cru	7.4	6.0	12.111	-61.25	11.6
292	4349		OC	Cru	7.4	15.0	12.403	-61.87	4.8
295	6752		GC	Pav	5.3	20.4	19.181	-59.98	10.3
296	1672		Gxy	Dor	10.2	6.6	4.762	-59.23	14.4
297	3114		OC	Car	4.2	35.0	10.042	-60.12	9.6
299		Rup 164	OC	Cen		2.0	11.514	-60.73	2.2
300	4439		OC	Cru	8.4	4.0	12.475	-60.10	7.5
301	4755	kappa Cru	OC	Cru	4.2	10.0	12.893	-60.33	4.6
302	5617		OC	Cen	6.3	10.0	14.496	-60.70	2.5
304	6025		OC	TrA	5.1	12.0	16.062	-60.50	5.9
306	1543		Gxy	Ret	10.3	4.9	4.212	-57.73	11.7
308*		Trump 13	OC	Car	11.3	5.0	10.397	-60.13	29.3
309	3372	eta Car	Em Neb	Car	3.5	120.0	10.730	-56.98	11.0
310		Trump 17	OC	Car	8.9	5.0	10.940	-59.20	18.6
311	4852		OC	Cen	8.9	11.0	13.004	-59.62	7.3
312	5138	copy error	OC	Cen	7.6	7.0	13.455	-59.02	15.7
313	5606		OC	Cen	7.7	3.0	14.463	-59.62	10.6
314		Lac III.9	Ast	Cir	8.1	2.3	15.377	-59.20	1.3
315		5 stars	Ast	Nor		1.6	15.550	-58.67	18.4
316		arc of stars	Ast	Ara		4.0	16.733	-58.60	0.8
319		kite shaped asterism	Ast	Tuc		2.0	22.321	-57.13	2.9
321	3293		OC	Car	4.7	6.0	10.597	-58.23	16.7
322	3324		Em Neb	Car		5.0	10.623	-58.62	5.1
323	3532		OC	Car	3.0	55.0	11.107	-64.40	7.2
324		Lac II.11, line of 7 stars	OC	Car		55.0	11.383	-58.32	15.0
326	6087	D 335	OC	Nor	5.4	12.0	16.314	-57.93	7.3
329		Lac III.14	Ast	Ind	8.4	4.4	21.518	-56.92	5.1
330	IC 2488		OC	Vel	7.4	18.0	9.460	-56.98	2.1
331	1553	Copy error	Gxy	Dor	9.4	4.5	4.270	-55.78	503.0
332	3199	1 deg error in dec	Em Neb	Car		22.0	10.290	-57.92	60.6
333	5715		OC	Cir	9.8	5.0	14.725	-57.57	9.4
334	6005		OC	Nor	10.7	3.0	15.930	-57.43	15.6

337	1261		GC	Hor	8.3	6.9	3.204	-55.20	4.6
338	1566		Gxy	Dor	9.8	7.0	4.333	-54.93	10.9
339	1617		Gxy	Dor	10.7	4.3	4.528	-54.60	11.4
342	5662		OC	Cen	5.5	30.0	14.587	-56.55	9.0
343	5999		OC	Nor	9.0	3.0	15.869	-56.47	8.8
347*	7689		Gxy	Phe	11.7	2.9	23.554	-54.08	17.9
348	1515		Gxy	Dor	11.4	5.2	4.068	-54.10	11.6
349	3960		OC	Cen	8.3	6.0	11.843	-55.67	5.4
350		curve of stars	Ast	Lup		2.7	14.550	-55.10	10.7
351	5823		OC	Cir	7.9	12.0	15.092	-55.60	7.9
355	3330		OC	Vel	7.4	6.0	10.646	-54.12	6.2
356	5749		OC	Lup	8.8	7.0	14.815	-54.48	7.7
357	5593	copy error	OC	Lup		7.0	14.428	-54.78	20.1
358		Trump 23	OC	Nor	11.2	9.0	16.013	-53.53	3.6
359	6031		OC	Nor	8.5	2.0	16.126	-54.00	6.2
360	6067	D 361	OC	Nor	5.6	12.0	16.220	-54.22	1.8
362*		Norma star cloud	MW	Nor		180.0	16.350	-53.12	45.8
364	6208		OC	Ara	7.2	15.0	16.824	-53.72	8.2
366	6397		GC	Ara	5.3	25.7	17.678	-53.67	5.7
367		bunch of stars	Ast	Tel		2.2	18.994	-53.68	7.4
374	6253		OC	Ara	10.2	5.0	16.985	-52.70	8.7
376	6584		GC	Tel	7.9	7.9	18.311	-52.22	5.9
379	6115		OC	Nor	9.8	3.4	16.407	-51.93	4.8
380		Rup 119	OC	Nor	8.8	8.0	16.471	-51.50	10.9
381*	6326		PN	Ara	11.1	15"	17.346	-51.75	27.7
386	3228		OC	Vel	6.0	5.0	10.363	-51.72	7.0
388	5286		GC	Cen	7.4	9.1	13.774	-51.37	4.9
389	5927		GC	Lup	8.0	6.0	15.467	-50.67	10.5
391		D 392, Cr 307	OC	Ara	9.7	5.0	16.589	-51.00	5.5
397	2972	NGC 2999	OC	Vel	9.9	4.0	9.671	-50.32	6.9
400	6167	D 401	OC	Nor	6.7	7.0	16.576	-49.77	13.9
402	IC 4651		OC	Ara	6.9	10.0	17.414	-49.93	4.6
406	7049		Gxy	Ind	10.6	4.2	21.317	-48.55	4.8
409	1527	D 429*	Gxy	Hor	11.0	3.7	4.140	-47.88	10.1
410	2547		OC	Vel	4.7	20.0	8.178	-49.27	12.0
411	4945		Gxy	Cen	8.9	20.0	13.091	-49.47	3.4
412	6134		OC	Nor	7.2	6.0	16.463	-49.15	6.1
413	6193	also saw NGC 6200	OC	Ara	5.2	14.0	16.689	-48.75	6.6
417	6352		GC	Ara	7.8	7.1	17.425	-48.42	17.3
425*	6861	1 deg dec copy error	Gxy	Tel	11.2	2.8	20.122	-48.37	63.4
426	1433		Gxy	Hor	10.1	6.5	3.700	-47.22	18.2
430		Mrk 18, Cr 205	OC	Vel	7.8	2.0	9.009	-48.98	21.7
431	5460		OC	Cen	5.6	35.0	14.124	-48.33	6.2
437	IC 1633		Gxy	Phe	11.4	2.6	1.165	-45.92	6.3
438	1493		Gxy	Hor	11.4	3.5	3.958	-46.20	1.1
440	5139	omega Cen	GC	Cen	3.7	36.3	13.447	-47.48	4.3
442	6204		OC	Ara	8.2	5.0	16.769	-47.02	16.1
445	3201		GC	Vel	6.9	18.0	10.294	-46.40	12.6
454	6216	NGC 6222	OC	Sco	10.1	4.0	16.824	-44.72	6.0
455*		Ly 14 or NGC 6249	OC	Sco	9.7	3.0	16.918	-45.23	22.4
456	6259		OC	Sco	8.0	10.0	17.013	-44.65	10.9
457	6388		GC	Sco	6.8	8.7	17.605	-44.73	1.5

458		line of stars	Ast	Sco		15.0	17.726	-44.10	9.5
460	6496		GC	Sco	8.6	6.9	17.984	-44.27	12.7
466	1512		Gxy	Hor	10.6	8.9	4.065	-43.35	11.0
468	2982	Ru 80	OC	Vel		12.0	9.700	-44.02	8.4
469	5643		Gxy	Lup	10.5	4.6	14.545	-44.17	7.8
473	6541		GC	CrA	6.3	13.0	18.134	-43.70	5.0
475	7552	Grus-Quartet	Gxy	Gru	10.7	3.4	23.270	-42.58	6.9
476	7582	Grus-Quartet	Gxy	Gru	10.6	5.0	23.306	-42.37	24.7
477	7590	Grus-Quartet	Gxy	Gru	11.6	2.7	23.315	-42.23	37.0
477	7599	Grus-Quartet	Gxy	Gru	11.4	4.4	23.323	-42.26	37.0
480	1487	Faintest galaxy	Gxy	Eri	11.9	2.0	3.930	-42.37	15.4
481	3680		OC	Cen	7.6	12.0	11.428	-43.23	10.4
482	5128		Gxy	Cen	6.8	25.7	13.425	-43.02	10.8
483	6192	D 470	OC	Sco	8.5	7.0	16.673	-43.37	3.8
487	1291	NGC 1269	Gxy	Eri	8.6	9.8	3.288	-41.11	4.5
489	2671		OC	Vel	11.6	4.0	8.770	-41.87	3.0
490		Tr 10, copy error	OC	Vel	4.6	15.0	8.777	-42.57	20.7
499	6231		OC	Sco	2.6	15.0	16.900	-41.80	3.7
507	55		Gxy	Scl	8.3	32.4	0.252	-39.22	5.4
508	1851		GC	Col	7.1	11.0	5.235	-40.03	15.8
509		stars in an F shape	Ast	Cen		29.0	12.400	-41.22	13.3
510	4696	D511 = NGC 4709?	Gxy	Cen	10.5	4.5	12.814	-41.30	13.7
514	6124		OC	Sco	5.8	40.0	16.427	-40.67	1.4
518	7410		Gxy	Gru	10.6	5.5	22.917	-39.65	11.7
519	986		Gxy	For	11.0	3.9	2.559	-39.03	9.8
520	6242		OC	Sco	6.4	9.0	16.927	-39.50	4.2
521	6268		OC	Sco	9.5	6.0	17.036	-39.72	2.5
522	6318		OC	Sco	11.8	5.0	17.270	-39.42	18.6
530	300		Gxy	Scl	8.3	21.9	0.915	-37.67	8.7
531	1792		Gxy	Col	10.2	5.2	5.088	-37.97	14.9
535	2477		OC	Pup	5.8	27.0	7.872	-38.55	11.5
536	6139		GC	Sco	9.1	5.5	16.461	-38.85	23.6
537		Tr 25	OC	Sco	11.7	8.0	17.408	-39.02	12.8
545		stars in a T shape	Ast	Gru		12.0	22.700	-38.10	116.4
546*	IC 5332	1 deg error in dec	Gxy	Scl	10.4	8.9	23.574	-36.10	71.3
547	1317		Gxy	For	11.2	2.8	3.379	-37.10	15.7
548	1316		Gxy	For	8.5	12.0	3.378	-37.20	20.1
549	1808	D 532	Gxy	Col	10.0	6.5	5.129	-37.50	9.0
552	5986		GC	Lup	7.6	9.8	15.768	-37.78	5.2
556	6281	D555 is 32' in pa252	OC	Sco	5.4	8.0	17.078	-37.98	5.6
557	6441		GC	Sco	7.2	7.8	17.837	-37.05	2.7
559		Bernes 157	Dark neb	CrA		80.0	19.050	-37.15	40.6
562	1365	copy error	Gxy	For	9.6	11.2	3.560	-36.13	128.9
563	2546		OC	Pup	6.3	41.0	8.207	-37.63	16.1
564	2818	Data is for PN	OC & PN	Pyx	11.6	35"	9.269	-36.62	17.2
568	6400		OC	Sco	8.8	12.0	17.670	-36.93	4.6
573	6723		GC	Sgr	6.8	11.0	18.993	-36.62	17.2
574	1380		Gxy	For	10.2	4.8	3.608	-34.97	19.6
578	2298		GC	Pup	9.3	6.8	6.816	-36.00	5.7
590	134	D 599	Gxy	Scl	10.5	8.5	0.506	-33.23	18.3
591	1350		Gxy	For	10.7	5.2	3.519	-33.62	15.0
594	2090		Gxy	Col	11.3	4.9	5.784	-34.25	3.3

597*	6444		OC	Sco		12.0	17.826	-34.82	26.1
600	1532		Gxy	Eri	10.6	11.1	4.201	-32.87	7.5
604		5 stars	Ast	Sco		2.5	16.883	-33.65	16.6
605		Star cloud and Dark nebula B283	MW & Dark nebula	Sco		85.0	17.817	-33.87	95.9
606*	6563		PN	Sgr	10.8	54"	18.201	-33.87	36.5
607	6652		GC	Sgr	8.5	3.5	18.596	-32.98	34.0
608	7793		Gxy	Scl	9.2	9.3	23.964	-32.58	14.5
609	2658		OC	Pyx	9.2	12.0	8.724	-32.65	3.3
611	5824		GC	Lup	9.1	6.2	15.066	-33.07	27.9
612*	6405	M6 or NGC 6416	OC	Sco	4.2	25.0	17.668	-32.22	13.6
613	6637	M 69, not Lac I.11	GC	Sgr	7.6	7.1	18.523	-32.33	27.2
614	6681	M70	GC	Sgr	7.8	7.8	18.720	-32.28	19.6
616	2243		OC	CMa	9.4	5.0	6.493	-31.28	33.4
617	3621	H I 241, D 610	Gxy	Hya	9.2	12.3	11.305	-32.80	9.4
619	6569	H II 201	GC	Sgr	8.4	5.8	18.227	-31.82	14.8
620	6809	M55	GC	Sgr	6.3	19.0	19.667	-30.95	25.7
621	613	H I 281	Gxy	Scl	10.1	5.5	1.572	-29.42	37.0
622	2997	H V 50	Gxy	Ant	9.6	8.9	9.761	-31.18	14.7
623	5253	H II 638	Gxy	Cen	10.7	5.0	13.666	-31.63	2.5
624	6715	M54	GC	Sgr	7.7	9.1	18.918	-30.47	28.9
626	2489	H VII 23	OC	Pup	7.9	8.0	7.938	-30.05	30.3
627	6266	M62	GC	Oph	6.4	14.0	17.020	-30.10	11.1
628	5236	M83, copy error	Gxy	Hya	7.6	11.0	13.617	-29.87	159.8
629	6316	H I 45	GC	Oph	8.1	4.9	17.277	-28.13	37.1

5 ASTROMETRY

The first consideration in analysing the Dunlop catalogue was the discrepancies in the positions given for the identified objects. In the printed catalogue the Right Ascension and Declination of each object was given in 1827 coordinates. Before analysis these coordinates were converted to J2000. Analysis was carried out at equinox J2000 after precession to that date using the Starlink precession program COCO. No allowance for proper motion was made. The J2000 positions were then compared to accurate coordinates obtained from the ESO (B) catalogue (Lauberts, 1982), where coordinates are given for both B1950 and J2000. The offsets between the Dunlop position and the position given in the ESO (B) catalogue were calculated, in the sense ESO (B) minus Dunlop.

General trends become obvious when all objects are considered. Figure 6 plots the difference in Right Ascension against the difference in Declination. It shows that Dunlop's offsets in Right Ascension (0-30′) are generally worse than his offsets in Declination (0-20′) and that his positions are more likely to be negative in Right Ascension and positive in Declination.

There are a number of explanations for such large positional offsets including: misidentification of a reference star during one sweep of the Large Magellanic Cloud; copying errors from his hand-written notes to the printed catalogue; and in a few cases errors of 1° in reading or recording the South Polar Distance. Some examples of copying errors are given in Table 4.

Table 4: Some copy errors in Dunlop's published catalogue.

Dunlop Number	Position in Notes	Published Catalogue	Object ID
1	RA 04h 30m 00s	04h 13m 00s	60' offset
44	RA 01h 06m 02s	01h 06m 22s	N419
45	RA 01h 07m 15s	01h 07m 50s	
275	RA 14h 48m 10s	14h 18m 10s	
312	SPD 31° 58′	31° 38′	N5138
331	RA 04h 12m 30s	05h 12m 30s	N1553
357	RA 14h 50m	14h 15m	N5593
425	SPD 41° 12′	42° 12′	N6861
491	RA 09h 27m 16s	09h 07m 16s	
525	RA 18h 50m 30s	17h 50m 30s	
562	RA 03h 27m 39s	03h 37m 39s	N1365
628	RA 13h 28m 03s	13h 15m 03s	M 83

6 MAGNITUDE LIMITS

Like all early catalogues, Dunlop's catalogue does not include all objects that were bright enough to be visible to him. Nebulae and clusters are more difficult to see than stars of the same magnitude because they are larger and more diffuse. This means that the theoretical limiting magnitude calculated in Table 1 as 13.1 for stars does not apply for other types of objects.

Instead, to determine which objects he missed, a working magnitude limit was ascertained and a list of bright objects which were missed was compiled. To estimate the working magnitude limit, the magnitudes of identified objects were obtained from a modern catalogue specific to a particular type of object. Open clusters, globular clusters, nebulae and planetary nebulae were found to be unsuitable for finding the working magnitude limit of Dunlop's telescope. This is because open clusters vary greatly in size and detachment; there is a lack of globular clusters faint enough to test his magnitude limit; only a few diffuse nebulae have known magnitudes; and planetary nebulae are often very small and easily missed. Galaxies,

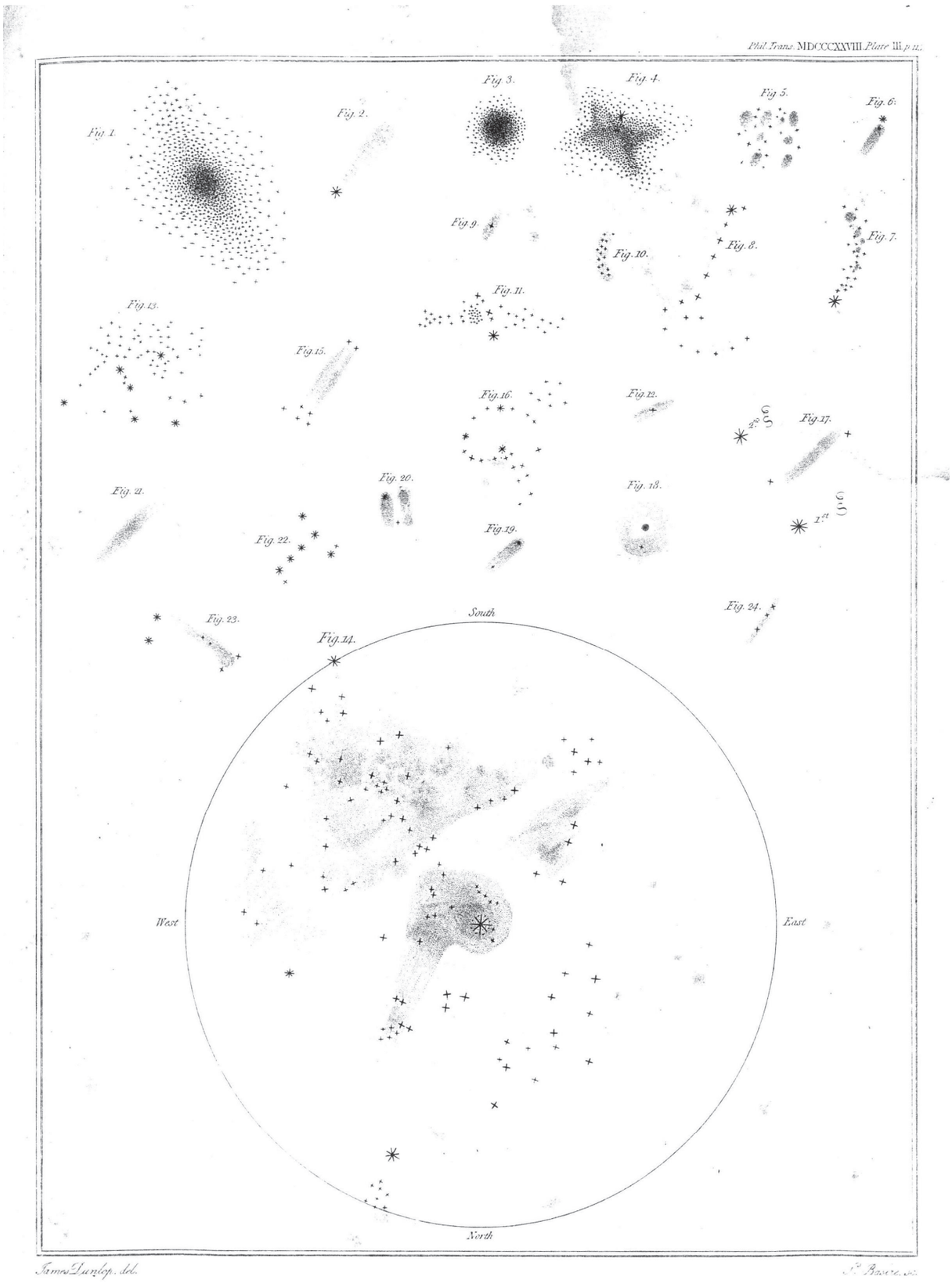

Figure 5: Dunlop's drawings of some of the objects he found.

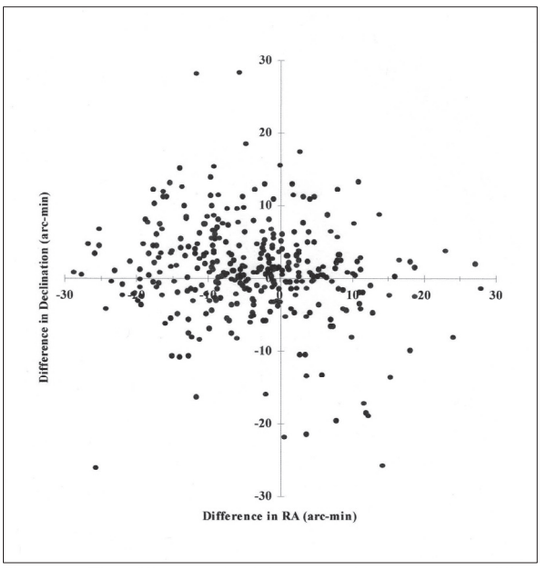

Figure 6: The difference in right ascension versus the difference in declination for identified objects in the Dunlop Catalogue (in the sense ESO – Dunlop).

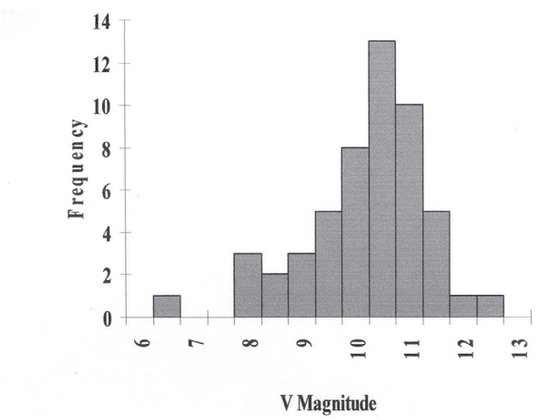

Figure 7: Histogram of the number of galaxies by half magnitude in the Dunlop catalogue.

however, do not have these limitations. Instead, the number of galaxies increases exponentially at fainter magnitudes. Dunlop's galaxies were compared with those in the LEDA galaxy catalogue (Paturel et al., 2003). 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 upon which values were given in the LEDA catalogue.

A number of different indicators were then used to determine Dunlop's working magnitude limit. These included comparisons using the following:

Table 5: Number of Dunlop objects brighter and fainter than magnitude 10.9 by type.

		Globular Clusters	Planetary Nebulae	Galaxies
Dunlop	Bright Objects Missed	5 (12%)	10 (71%)	46 (46%)
	Faint Objects Seen	0	2	14

- histograms of the number of Dunlop galaxies and LEDA galaxies, at half-magnitude increments (Figure 7)
- the log of the cumulative frequency of Dunlop galaxies with upper and lower Poisson limits
- the log of the cumulative frequency of Dunlop galaxies and LEDA galaxies (Figure 8)
- the log of the cumulative frequency of Dunlop galaxies and a line of 0.6 gradient (Figure 8), representing the increase in density that would occur in a homogeneous Universe with a homogenous mixture of galaxy types, and
- the magnitude at which Dunlop catalogued 50% and missed 50% of the LEDA galaxies.

Using the mean obtained from each method it was found that the working magnitude limit for the Dunlop catalogue was $m_v = 10.9$.

7 COMPLETENESS

With the working magnitude limit determined at 10.9, a list of bright objects missed by Dunlop was compiled. These objects could have been seen by Dunlop and included in his catalogue. A list of objects fainter than the working magnitude limit which were seen and catalogued by Dunlop was also compiled. The result of this analysis is summarised in Table 5.

Dunlop found most of the southern globular clusters, cataloguing 88% of those brighter than magnitude 10.9. None fainter than this was seen by him. Dunlop also catalogued 4 out of 14 (29%) planetary nebulae brighter than magnitude 10.9, and larger than 12″ according to the Strasbourg-ESO catalogue (Acker, et al., 1992).

Fifty-four percent of the galaxies brighter than 10.9 were seen by Dunlop and 46% were missed. The faintest galaxy in Dunlop's catalogue is NGC 1483, at magnitude 12.3, but it is unlikely that he actually saw this. Herschel (1847) wrote the following about this object:

> … very faint; pretty large; round; very gradually a little brighter in the middle; 80″ across. I feel convinced that this nebula is too faint to have been seen by Mr Dunlop. Put on the 9 inch aperture, could not discern the least trace of it. Mirror polished yesterday and in high beauty. Sky superb.

The second-faintest object in the Dunlop catalogue is the magnitude 11.4 galaxy IC 1633. His description for this (D437) is: "An extremely faint small nebula; round, with a very minute bright point in the centre." His position offset is only 5.5′ to the south-west. This galaxy has a bright core and Dunlop probably saw it.

Table 6 lists the four brightest globular clusters, planetary nebulae and galaxies missed by Dunlop. Suggested reasons for their omission are: NGC 1097 at declination +30°) was near his northern declination limit; NGC 5102 is near a bright star (magnitude 2.7); and it is just possible that the elliptical galaxies NGC 1399 and NGC 1549 were mistaken for stars because of dew on the optics of Dunlop's telescope.

The open cluster NGC 2516 is included in Dunlop's notes but does not appear in the printed catalogue. The galaxy NGC 253 is not in his catalogue because it is north of his declination limit. The planetary nebula NGC 5882 does not match Dunlop's description of D447. D567 is an asterism (see Table 7), not the

Table 6: The four brightest globular clusters, planetary nebulae and galaxies missed by Dunlop.

Globular Cluster		Planetary Nebula		Galaxy	
Name	Magnitude	Name	Magnitude	Name	Magnitude
NGC 6558	9.3	NGC 6302	9.7	NGC 1097	9.5
NGC 6528	9.6	IC 4406	10.2	NGC 1399	9.6
IC 4499	9.8	NGC 6153	10.6	NGC 5102	9.7
NGC 6453	10.1	NGC 3211	10.7	NGC 1549	9.8

planetary nebula NGC 6302, as suggested by Hartung (see Malin and Frew, 1995). The planetary nebulae NGC 3132 and NGC 3918 are in the Brisbane star catalogue (Richardson, 1835) but are not in Dunlop's catalogue of nebulae and clusters.

Analysis of Dunlop's catalogue shows that he produced a remarkably-complete catalogue in a very short time.

8 CONCLUDING REMARKS

Dunlop's catalogue contains most of the bright star clusters, nebulae and galaxies south of declination –30°, and therefore is the southern equivalent of Messier's famous northern catalogue, as suggested by Cozens and White in the June 2001 edition of *Sky and Telescope*. It unfortunately also contains a large number of entries which are probably faint double stars or asterisms, because Dunlop was unable to resolve them.

Omitting the double stars and asterisms gives rise to an impressive catalogue. We therefore believe that the Dunlop catalogue should be a useful resource for southern amateur astronomers viewing galaxies, nebulae and clusters. Table 2 lists 187 identified objects outside of the Magellanic Clouds. Objects in the Magellanic Clouds are not included as they require more detailed descriptions, which goes beyond the scope of this paper.

John Herschel failed to recover many of Dunlop's objects, but his criticisms did not take into account the limitations imposed by Dunlop's home-made equipment. Neither was the continued criticism of Dunlop by Forbes and others completely justified. James Dunlop was not a careless astronomer. He did his best with the resources he had at his disposal, and ended up producing a valuable catalogue. Yet he is virtually unknown today, a forgotten pioneer of the southern sky.

9 NOTES

1. As Saunders (2004: 208, Note 115) has pointed out, J. Service, who was one of Dunlop's biographers, was far from amused by these scurrilous attacks on his illustrious relative, quoting Henry Chamberlain Russell's views that:

   > There are a good many very stupid mistakes in Herschel's own Catalogue, he need not have been so hard on others. The effort in those days seems to have been to get through a fearful lot of work without too much regard for quality, but times have changed since then. (Service, 1890: 177).

   Russell could speak with some authority, for at that time he was Director of the Sydney Observatory and one of Australia's foremost astronomers (e.g. see Bhathal, 1991; Orchiston, 2002).
2. For details of the various instruments at the Parramatta Observatory see Lomb (2004).
3. In his biography of Dunlop, Jervis (1926: 44) incorrectly states that at this time Dunlop "... was officially appointed Astronomer Royal of New South Wales."
4. By way of comparison, Riekher (1957) gives the reflectivity of speculum at 555 nm as 60%, which produces a modern equivalent aperture of 15.8-cm for Dunlop's telescope. This is consistent with the values listed in Table 1

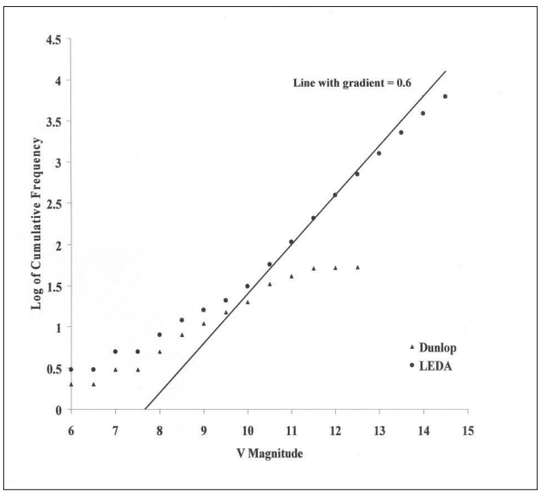

Figure 8: Distribution of log of the cumulative frequency as a function of V magnitude for the Dunlop and LEDA galaxies.

10 ACKNOWLEDGEMENTS

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Table 7: A sample of asterisms found by Dunlop.

Dunlop Number	Description	Constellation	Size (')	RA 2000	Dec 2000
509	stars in an F shape	Cen	29.0	12.400	-41.22
350	curve of stars	Lup	2.7	14.550	-55.10
315	5 stars	Nor	1.6	15.550	-58.67
316	arc of stars	Ara	4.0	16.733	-58.60
604	5 stars	Sco	2.5	16.883	-33.65
458	line of stars	Sco	8.0	17.726	-44.10
367	bunch of stars	Tel	2.2	18.994	-53.68
319	kite-shaped asterism	Tuc	2.0	22.321	-57.13
545	stars in a T shape	Gru	12.0	22.700	-38.10

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