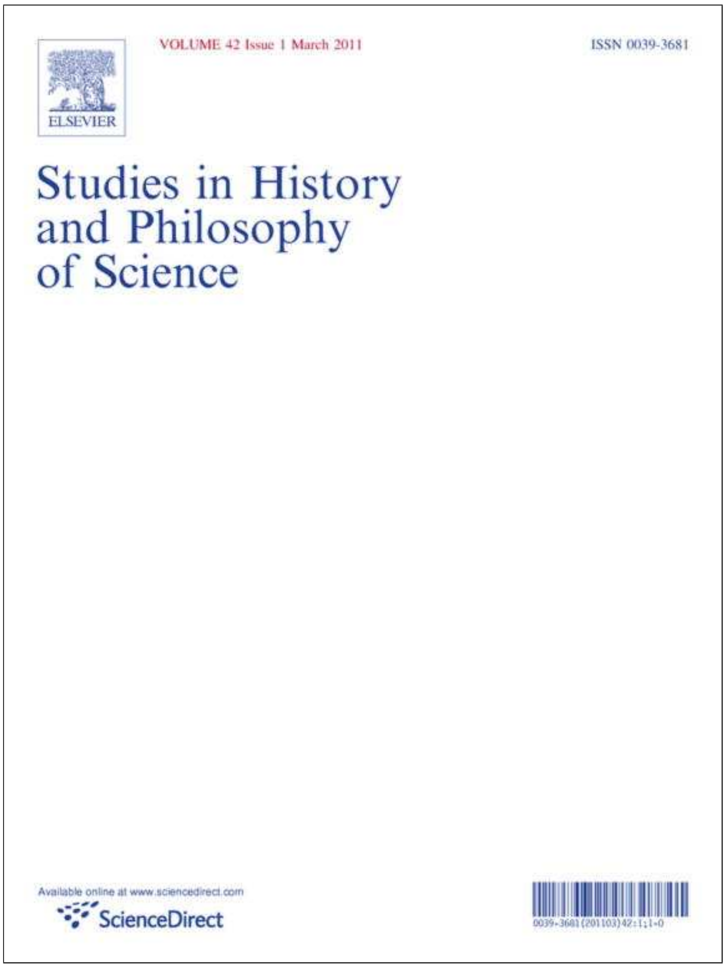
VOLUME 42 Issue 1 March 2011
ISSN 0039-3681
ELSEVIER
Studies in History and Philosophy of Science
Available online at www.sciencedirect.com
ScienceDirect

Studies in History and Philosophy of Science 42 (2011) 67–84

Contents lists available at ScienceDirect

Studies in History and Philosophy of Science

journal homepage: www.elsevier.com/locate/shpsa

The 'Landmark' and 'Groundwork' of stars: John Herschel, photography and the drawing of nebulae

Omar W. Nasim

ETH-Zurich (Swiss Federal Institute of Technology), Chair for Science Studies, Raemi-Strasse 36, Zurich, Switzerland

ARTICLE INFO

Article history:
Available online 26 January 2011

Keywords:
Ebenezer Porter Mason
Cartography
Draughtsmanship
Observation
Scientific Representation
Philosophy of Scientific Practice

ABSTRACT

This paper argues for continuity in purpose and specific results between some hand drawn nebulae, especially those 'descriptive maps' by John F. W. Herschel and E. P. Mason in the late 1830s, and the first photographs made of the nebulae in the 1880s. Using H. H. Turners' explication in 1904 of the three great advantages of astrophotography, the paper concludes that to some extent Herschel's and Mason's hand-drawings of the nebulae were meant to achieve the same kinds of results. This is surprising not only because such drawings were conceived and achieved over forty-years earlier, but also because the procedures used in the production of these pictorially and metrically rich images were those directly inspired by cartography, geodesy, and land-surveying. Such drawings provided the standard for what was depicted, expected and aimed at by way of successful representations of the nebulae; standards that seemed to have been used to judge the success of nebular photographs. Being conditions of expectation and possibility for later photography, these drawings were themselves made possible by such techniques of representation and measurement as isolines and triangulation, so fundamental to Imperial and 'Humboltian science.'

1. Introduction

It was over forty-years after the daguerreotype process was announced in Paris on January 7, 1839 that for the first time someone successfully photographed a nebula. This photograph was made by Henry Draper and was of the nebula in Orion (M42); an object, to be sure, represented by hand-drawings since Christiaan Huygens in 1659, and significant for first suggesting to Edmond Halley the possibility of the existence of a self-luminous material in the heavens. By the end of the 19th century celestial photographs of the nebulae captured the scientific and aesthetic imaginations of many. Though the wet collodion process was sensitive enough to have had captured the light of other faint celestial objects, such as individual stars, double stars, and star clusters, it was basically due to the faintness of the nebulae, and thus to the very long exposure times required, that earlier daguerreotype and wet collodion process could not successfully be applied to them.

The application of photography to stellar objects outside our solar system was unsatisfactorily begun using the daguerreotype process by William Bond in 1850, and later continued much more adequately with the wet collodion process by his son George Bond in 1857. This accomplishment by the Bonds was regarded in the next century as 'the greatest advance in astronomical photography' (Norman, 1938, p. 569).[1] By the mid 1860's Lewis Morris Rutherfurd succeeded in photographing the Pleiades star cluster, and built a measuring machine to take the position-angles and relative distance measurements of some visible stars in the cluster directly off the plate. Stellar photography was heralded as a major advance mainly because it revealed photography's power in being able to accurately preserve delicate and exceedingly minute relative distances and position-angles of the stars. But these 'great advances' in the 'new

E-mail address: omar.nasim@wiss.gess.ethz.ch

[1] Also see: de Vaucouleurs (1961), Lankford (1984).

0039-3681/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.shpsa.2010.11.019

method of observation' were not immediately recognized as such, and confidence in the ability of the plates to preserve metric properties had to be built over time and standards had to be recognized.[2]

These measured photographic plates were regarded in contrast to photographs of objects like the planets, the Sun, and the Moon which were far more prominent instances of astrophotography at the time. The latter sort of astrophotography, of the objects within our solar system, were of a form that frequently emphasized more of the descriptive, pictorial, and sensual details that dazzled as much as they informed. But as one champion of using photographic plates for accurate measurements was to later stress in relation to stellar photography, that in comparison to the pictorial 'the images of star-clusters possess no popular attractiveness. They are but black spots upon the albuminized surface of glass plates; and their value consists solely in the accuracy with which the relative positions of these several dots may be measured. But this is no slight value' (Gould, 1878, p. 15).

The invention of dry gelatin plates, also known as bromide or silver bromide, allowed celestial photographers to photograph by following faint sidereal objects, like nebulae and clusters, with long exposures times, with the help of a clock driven mechanism in tandem with large refractor or reflecting telescopes. One of the leading British celestial photographers at the time regarded 'the photographing of nebulae ... as being almost the only actually modern achievement of photography' (Common, 1888, p. 391). Apart from being able to reveal extremely faint details, some imperceptible to the eye even when assisted by powerful telescopes, the most important feature in the application of new photographic technologies to the nebulae was certainly the accurate preservation of the arrangements, relative positions of the stars *and* the visual, pictorial elements, such as bright nebulous patches, 'strata', 'knots', outline, nebulosity, etc. One may say that what made this a great achievement in the eyes of many was the fact that a photographed nebula presented astronomers with a well proportioned visual image preserving the object's form, copious detail, and metric properties, and was thereby regarded as a 'map' by some (e.g. Bond, 1890 [1857a], p. 302; Holden, 1886, p. 468).

Because star clusters and nebulae remained, even at the end of the century, 'hidden', mysterious and evasive, from the very outset of nebular research, especially with the work of Sir William Herschel in the latter part of the eighteenth century, one of the primary challenges was to trace changes that might indicate some directed motion or development in the nebulae and clusters. As Williams' son, one of the chief nebular observers of the next generation, John Herschel (1826, p. 487) succinctly put, 'the nature of nebulae, it is obvious, can never become more known to us than at present; except in two ways—either by the direct observation of changes in the form or physical condition of some one or more among them, or from the comparison of a great number, so as to establish a kind of scale or gradation from the most ambiguous to objects of whose nature there can be no doubt.'[3] This meant that ideally speaking, drawings of nebulae and clusters had to be qualitatively (descriptively), and quantitatively (numerically) accurate in their detail and structure. This demand, however, was rarely ever met because one was usually achieved at the expense of the other – sometimes due to associated difficulties with large reflecting telescopes (to see details with, but difficult to make refined measurements with) and smaller equatorial telescopes (used to make measurements with, but rarely to show nebulae in their detail), and because of the acknowledged problems in applying mathematical means to these nebulous objects.

Whatever the difficulties, however, the methods and results of hand drawing were meant to help detect apparent and proper motions of the parts of a nebula in a way that could help answer such 'natural philosophical' questions as, 'under what dynamical conditions do [nebulae and clusters] subsist? Is it conceivable that they can exist at all, and endure under the Newtonian law of gravitation without perpetual collisions?'[4] There were also such 'natural historical' problems as the possibility of a physical course of development from one sort of object (or class) to another—this was famously coined the 'Nebular Hypothesis.' The practical and theoretical tensions between the descriptive and numerical, or generally, the 'natural historical' and 'natural philosophical,' were often, throughout the nineteenth century, apparent in the drawings made—the trick was to attempt to include as much of both as possible.[5]

It is thus not surprising that at the Royal Astronomical Society's meeting of January 14th 1881, where the very first nebular photograph was presented and discussed, that it was immediately compared to the hand drawings of the nebula in Orion (M42) made by George Bond, John Herschel, William Lassell, Lord Rosse, Wilhelm Tempel, and other nebular observers. Arthur C. Ranyard, who presented and introduced Draper's photograph, concluded, 'The drawings differ very greatly amongst themselves, and they differ in type as well as in minor details. They do not appear to differ continuously in order of time, so that the drawings do not afford any proof that the form of the nebula is changing. Photographs will of course afford much more valuable evidence with respect to any such change in the future.' What might be surprising, however, was Andrew Common's initial reaction: 'I do not agree with Mr. Ranyard,' began Common, 'that we must look to photography to explain or prove any change in the form of the nebulae, because various kinds of plates give different results ... If you want to detect any change in the form of the nebulae you must entirely rely on the hand drawings.' What ensued thereafter was a detailed look at the drawings made of the nebula in Orion, some at the meeting declared Lord Rosse's drawing of the nebula as being superior to Father Angelo Secchi's, others disagreed.[6] The drawings of the nebulae, in other words, continued to play an important role in nebular research.[7]

2 Gould (1895), p. 435 recalls, 'most [astronomers] paid it no attention; others feared distortion of the relative positions of the stars as photographed, while others still distrusted the adequacy of the corrections to be applied; but the most serious criticism was based on the supposed liability of the film to contract or expand, thus introducing new sources of error.'

3 Also consider C. P. Smyth's statement that 'no vague expression or semblance of that which exists must be allowed to take the place of painstaking, accurate, and detailed delineation; for the passage of a celestial object from one state to another, which it is our prime object to ascertain, can only be established by the comparison of very exact and faithful representations' (Smyth, 2000 [1846], p. 73).

4 Herschel (1857c [1845]), p. 662.

5 For more on these issues and the interactions between natural philosophy and natural history in astronomy, see Schaffer (1980), Schaffer (1995).

6 Ranyard (1881), p. 82. For another direct reaction, which basically included a comparison of Bond's, Lord Rosse's and Secchi's drawings to the first photograph of M42, see: Knobel (1881).

7 Even for Ranyard this was also the case. See for instance Ranyard (1889), where he continues to compare photographs, reproduced using the half-tone process, to a drawing, specifically one made by William Lassell of M42. Good discussion of this in Mussell (2009), esp. pp. 361–66. And as Alex Soojung-Kim Pang (1997) reminds us, the intervention of the artist's hand continued to play an important part in the successful production and publication of astronomical photographs. The artist's hand and the photograph would often coincide, as when hands might contribute to a composite, or to corrections made on a photographic plate. For an excellent discussion on the issues surrounding the difficulties involved in the standardization of photography in mid to late 19th century, see Rothermel (1993), and for late century issues in astrophotography see Canales (2009), and Macdonald (2010). The latter, however, attributes differences among celestial photographers in procedures to psychology. For a treatment of the vast diversity of concerns of the new technologies of photography in Victorian England, see Tucker (2005), and more generally within an array of different epistemological contexts, see Daston & Galison (2007). For a treatment of the complexities of the relationship between science and photography see Wilder (2009, esp. ch. 1 and ch. 4).

It was no later than two years after the RAS meeting that Common made what was considered thereafter to be a better photograph of M42 (cf. Barnard, 1898, 353). In a 'Note' to his photograph of January 30, 1883, Common went on to compare it to some of the drawings made of M42, and now declared that it showed the shape and relative brightness of its parts 'in a better manner than the most careful hand drawings. To find if there is any change of form,' he continued, 'or relative brightness observable in a nebula with any degree of certainty, it will be necessary to compare photographs . . . Whilst a comparison of such a photograph as this now shown with any existing drawing can give no reliable evidence of any change having taken place, whatever the observable differences' (Common, 1883, pp. 255–56). So as photographic techniques quickly improved, it was also natural to view the results as marking a major shift in astronomical methods.

By the turn of the century, many would have therefore agreed with the eminent Oxford astronomer Herbert H. Turner's perceptive announcement given at a 1904 Address, that the invention of photography had brought about 'another great epoch' in astronomy that was of the same order as other past 'majestic' epochs in the history of astronomy, such as 'when Newton announced to the world the great Law of Gravitation, and that when Galileo first turned his telescope to the skies.' These epochs are normally considered to be breaks or discontinuities, with what came before, and according to Turner the epoch which heralded in astrophotography was just such a break from what occurred before, and this particularly for its three 'advantages': its *power* in bringing out light and details, some not immediately perceptible to the human eye; its ease and *facility*; and finally, its most important and valuable feature, according to Turner, the *accuracy* of its depiction, proportion, and metric.[8] At the time, no other celestial object instanced all these advantages of astrophotography better than the nebulae.[9]

In what follows, I intend to examine two sophisticated observational procedures of drawing the nebulae and clusters by hand that, I will argue, were in fact *continuous* with what were considered the most advantageous results of photography, namely, the power they displayed in capturing faint light and minute details, and the accuracy of their representation. According to Turner, these are primarily advantages in what *results* as finished products, rather than advantages in their production and procedure.[10] As to Turner's inclusion of facility and ease as an advantage, it specifically refers to the relative ease in the procedures of production.[11] Because all nebular projects, whether those of the hand or photograph, had their own unique procedures of production, and because there is absolutely no doubt that the procedures involved in photographing the nebulae were dramatically different from those involving images drawn by hand, I will leave facility out of the primary discussion and will only briefly return to it in the concluding section.

The chief nebular draughtsman I will instance as producing hand drawn results continuous with the advantageous results of celestial photography is Sir John Herschel, particularly his work in visually representing some of the nebulae observed from the Cape of Good Hope and published in 1847. I will use Herschel's Cape drawings as clear instances of an explicit attempt at an accurate visual depiction of pictorial and descriptive detail, *along with* the preservation of an object's light gradations, its numerical, geometric, and astrometric properties.[12] I will also briefly examine the work of the young American astronomer Ebenezer Porter Mason (1819-1840) for his attempt to accurately and numerically capture the fine gradations of light and relative brightness. These influential hand drawings are no different *in principle* from the photographs made of the nebulae, even though they are obviously different in degree from the latter.

While one might expect or be tempted to suppose that this continuity be simply accounted for by suggesting some sort of photographic comportment on the part of a draughtsman, what is extraordinary about the cases of Herschel and Mason is not only that their hand drawn 'descriptive maps' were continuous with the results of nebular photography, albeit in different and sometimes inferior ways, but that the drawings made of the nebulae were executed, within their respective 'procedures' of observation, *before* (in the case of Herschel) or just immediately after (in the case of Mason) the announcement of the French Daguerreotype and William Henry Fox Talbot's Photogenic Drawing at the very beginning of 1839.[13] Though his Cape Results were published almost ten years later, Herschel left for the Cape of Good Hope at the end of 1833 and returned to England in 1838, and it was between this period that he made the relevant drawings. Mason made the drawings he did for his final and only publication on the nebulae in the summer of 1839, before his early death in December of the following year.[14] One cannot, therefore, claim that these drawings made of the nebulae or clusters were prepared by astronomers who comported themselves as if they were human photographic cameras or some passive agents emulating photo-chemical emulsion processes of light and object reception—no such metaphor or exemplar even properly existed. Rather what makes the final images of the nebulae so distinctive are the procedures employed in their production. So what we will find when we delve into the respective internal procedures of observation, extraordinary in its own right, is that both Herschel and Mason borrowed techniques widely used in geodesy, cartography and land surveying in order to achieve the kind of results they did in their drawings of the nebulae; that is,

[8] Turner (1904), p. 393. Others, such as Holden, also referred to the application of silver bromide to the nebulae as a 'new epoch,' see: Holden (1882), p. 230, Barnard (1898), p. 353 also refers to the same as a 'new era.'

[9] It is certainly fascinating to note, and perhaps relevant, that in the same address to International Congress of Arts and Science in St. Louis, Turner begins by stressing the importance of Anthropology in light of photography. With regard to 'the few remaining native tribes and the monuments' scattered in face of the 'rapid spread of civilization,' Turner proclaims, 'No man of science . . . can be insensible to the vital importance of securing permanent records of these vestiges before they inevitably perish. No astronomer who is properly grateful for the endowment of his own science in time of need can fail to hope that the science of Anthropology may be equally fortunate at a most critical juncture' (Turner, 1904, p. 392). With regard to the power and accuracy of photography in Anthropology see the metrical and descriptive systems of the Victorian, John Lamprey, cf. Edwards (1992).

[10] Although it is true that the power of photography to capture light is significantly an aspect of process, if it did not hold and display that light on a plate it would be of little use. As for accuracy, Wilder's (2009, p. 31) conclusion that 'Measurement . . . often goes hand in hand with photographic observation,' is spot on, and raises the question whether the 'descriptive maps' examined in this paper may also be considered 'photographic observations'?

[11] It was common to take both the cases of the photographic plate and the engraved plate as exemplifying ease and leisure in examining and reading off information, see: Clerke (1888), p. 46, Holden (1886), p. 468.

[12] One must not forget that especially for such novel objects the demand for recording all details possible was essential, see: (Herschel, 1987 [1830], pp. 120–121, sec. 112).

[13] I am tempted to describe both Herschel's and Mason's drawings to be 'photograph-like' images; this is obviously anachronistic, but also uncanny. It was not until the 22nd of January, 1839 that Herschel had for the first time read in a letter about the French announcement of the daguerreotype made fifteen days earlier. The letter was written without any details of the technical processes involved, and it was not until the first day of the next month, when his friend William Henry Fox Talbot came over to visit him at Slough, that he witnessed the 'photogenic' productions of the latter, of which Talbot had informed Herschel about on 25 January 1839. Between this short time, Herschel had already invented his own photographic process, and even surprised Talbot with the perfect fixing agent for his photographic images, something Talbot had failed to accomplish Cf. Schaaf (1979, 1992, 1994).

[14] There is no indication that Mason was involved with any photo-chemical experiments or photography. Mason seems to have dabbled in some chemical experiments, but quickly gave up after one or two explosions in his dormitory room, (Olmsted, 1842, p. 123).

the kind of results that were continuous with later day photographs of nebulae and clusters. Such drawings provided the standard for what was depicted, expected and aimed at by way of successful representations of the nebulae—standards that seemed to have been used to judge the success of the photographs made of the nebulae over forty years later. These hand drawings were not some sort of fateful anticipation, however, of nebular photography, but provided the conditions of expectation and possibility for later photography. The fundamental idea, however, is that these drawings were themselves made possible by such techniques used in the procedures of observation and representation as isolines, triangulation and chains of triangles, extensively utilized in cartography and surveying, and so fundamental to the Imperial and 'Humboltian sciences' of the 19th century (Cannon, 1978; Dettelbach, 1996, esp., pp. 295–300; Musselman, 1998). We will find that expectations of stability, fixity, objectivity and existence are central to this transfer of cartographical and land surveying techniques to those in the production of nebular drawings—expectations, that is, which corresponded quite closely to some later day claims for astrophotography in general.[15] But before we delve into the 'descriptive maps' made by Herschel and Mason, it may be worthwhile in the next section to detail the different types and functions of nebulae illustrations, for not all functioned in the same way.

2. Nineteenth-Century Drawings of Nebulae

Right from the inception of modern nebular research at the beginning of the 18th century, drawings made of the nebulae played an essential part in not only recording what was seen, but also in visually and conceptually demonstrating or hinting at speculative and theoretical explanations for these mysterious object; in 'making-out' the features of a nebula; as proxies for these distant and hardly seen objects; and in the deliberate attempt to detect physical motion or a gradual development. Not all drawings were therefore alike in function, production and technique. Broadly speaking, pencil, wash, and/or ink sketches used as preliminary 'working images' within the observing books and notebooks of an astronomer, functioned quite differently from published engravings (Nasim, 2010). In fact, all nebular researchers had their own peculiar 'procedures' of observation. They often had, that is, their own ordered and distinct techniques in labeling, examining, arranging, describing, and drawing what they saw within a certain array of preliminary and preparatory notebooks. These procedures were meant to regulate and control for different sorts of errors by a governed selection process which would gradually narrow down to an object's visual properties, and contribute to a stabilized final image. In which notebook an observer drew, how he drew, with what he drew, and in what order, were all essential features of the procedures of observation involved.[16] These procedures, moreover, might have been inspired or suggested by other technical procedures external to nebular research, or even to astronomy. So for instance, the third Earl of Rosse loosely borrowed the techniques of bookkeeping for his procedures of nebular observation (Nasim, 2008, 2010).

Some of the fundamental dissimilarities, moreover, in the hundreds of drawings made of the nebulae from the time of William Herschel to the late nineteenth century were based on broader 'styles of reasoning' that informed the procedures of observation employed. Many of William Herschel's drawings of nebulae, for example, were essentially governed by the methods of natural history, where what interested him in particular was the determination of similar *general types* of a given class, rather than specific individual objects. His drawings distinctly reflect this interest (Fig. 1), and he goes on to say as much when he reminds the reader that 'the nebulous delineations in the figures are not intended to represent any of the individuals of the objects which are described otherwise than in the circumstances which are common to the nebulae of each assortment: the irregularity of a figure, for instance, must stand for every other irregularity; and the delineated size for every other size.'[17] Such general drawings, showing only the 'essential features' of a class, were consistent with William's concern to make a plausible case for a gradual shift from one nebular class-type into another. Classificatory, genetic, and morphological methods, consequently, played key roles in Herschel's procedures, drawings, and their arrangement.

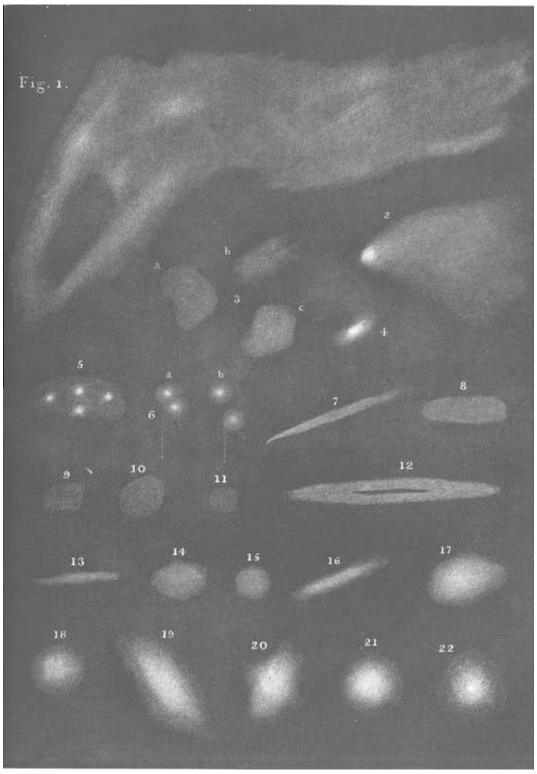

Fig. 1. William Herschel's General Representations of the Nebulae (W. Herschel, 1912 [1811], Plate II, vol. 2).

When contrasting William Herschel's drawings with those made by Lord Rosse nearly half a century later, one is immediately struck by the individuality of each nebula (Fig. 2). This is not surprising, considering that in contrast to Herschel's emphasis on classification and series, at least for the first decade of the Rosse project (1840-50) the question of resolution was at the forefront. That is, the question as to whether the nebulae are constituted merely of small and/or distant stars, or if there is really a non-particulate self-luminous nebulous material which made up these objects? Each of Rosse's drawings of individual nebulae details as much as they possibly can, but at the same time many lack an emphasis on exact measurement of its parts and the stars therein—in some

[15] In some ways, then, I wish to give new meaning and context to Cadava's statement, meant as an exegesis of Walter Benjamin, that 'the history of photography can be said to begin with an interpretation of the stars' (Cadava, 1997, p. 26).

[16] For more on notebooks, observing books, and other pre-published material linked to thinking, observing and creativity see: Hoffmann (2003), Rheinberger (2003); and Wittmann (2008).

[17] William Herschel (1912 [1811]), vol. 2, pp. 460-61. For a detailed and extensive examination of William Herschel's natural historical method, as applied to the nebulae and clusters, see: Schaffer (1980).

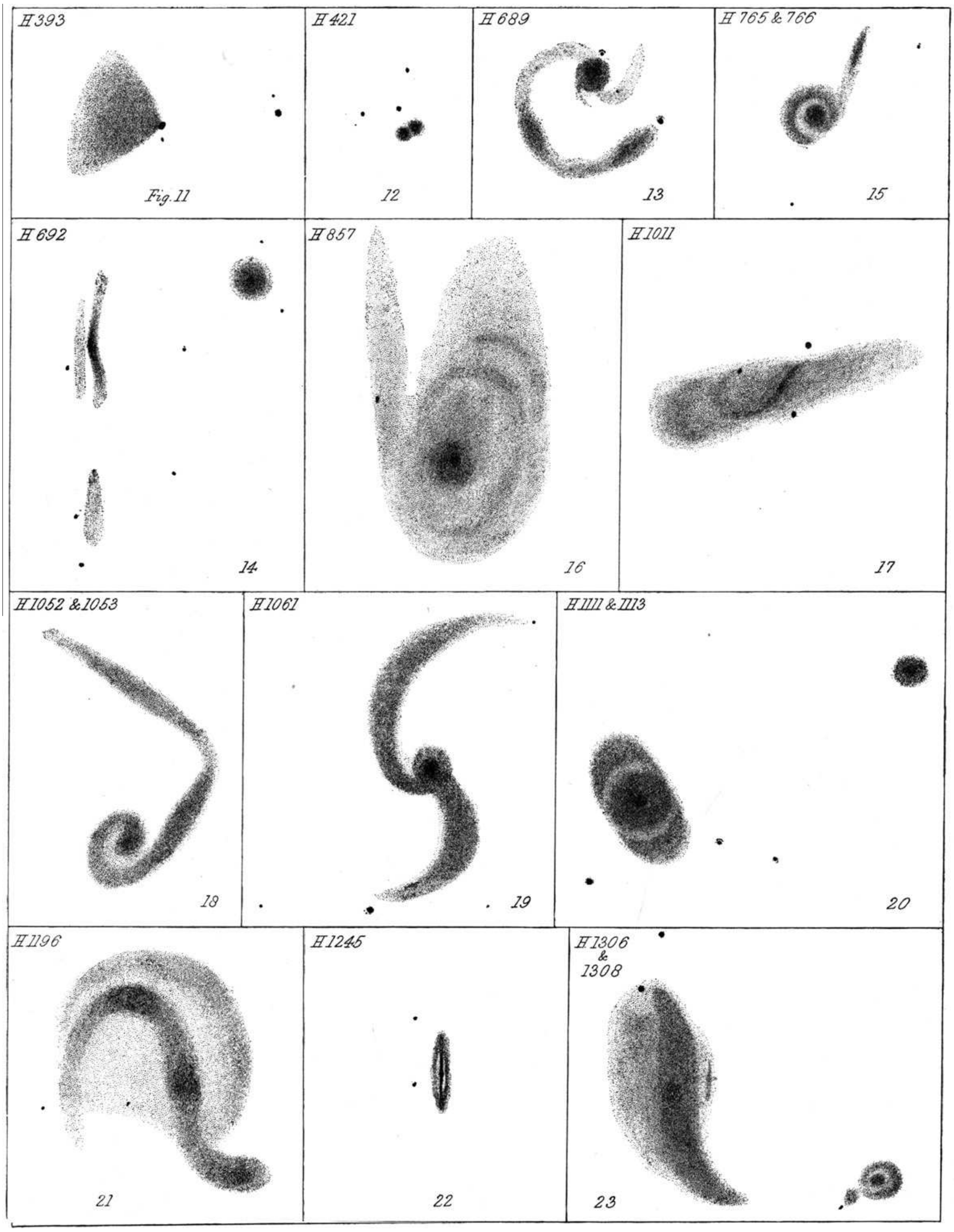

Fig. 2. Lord Rosse's Portraits of individual Nebulae, (Lord Rosse, 1861, Plate XXV).

cases Rosse even goes as far as to randomly sprinkle a few stars on the page to give a 'general effect'.[18] Many of Rosse's published engravings of the drawings were used as public proxies for the telescopic object—engravings that could be examined at leisure by those with or without the appropriate giant reflecting telescopes required. It was the examination of these recorded individual features of the nebulae that were supposed to act as 'ocular demonstrations' for some answer, either way, to the question of resolution. The question of general morphology, however, did arise later when 'the Rossian Configuration' (cf. Nasim, 2010, p. 379) or the spiral form was discovered and conceived by the Rosse project as a fundamental category or 'normal form' into which many nebulae, apparently of different shapes and sizes, could be reduced. However, even in this case, unlike the general types depicted by William Herschel, Rosse continued to illustrate *individual* and particular objects, but this time as 'characteristic types'. Following an apt label given by one of

[18] Rosse (1850), pp. 508–509; and Plate XXXVIII, Fig. 17.

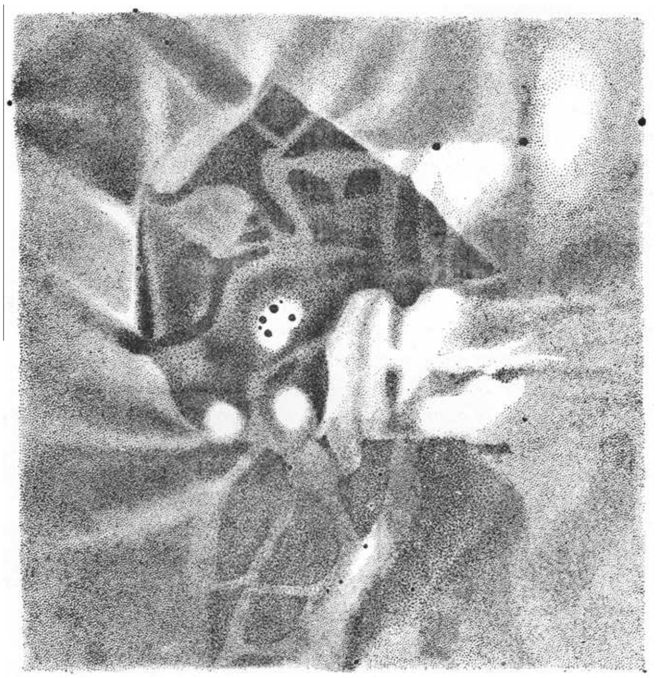

Fig. 3. The small 'Huygenian Region' of the nebula in Orion (M42); (Lord Oxmantown, 1868, Plate I).

Rosse's contemporaries, I will refer to these individual representations of the nebulae and clusters as '*portraits*.'[19] These portraits present specifically to the scientific gaze not only densely detailed and pictorial particulars of specific individual objects, but also provide general impressions, rather than precisely measured objects, that act as standards, proxies and aids to the observer and theoretician (cf. Nasim, 2009).

Rosse did point out, however, that sometimes when measurements were made, they were such as to be of 'the roughest approximations . . . the only measurements nebulosity admits of;'[20] or that they were mere 'eye-measurements.' When rough measurements were attempted, usually in order to give some proportion to the object drawn, they were either made using Rosse's three-foot reflector, or the giant six-foot, or both, or sometimes from measurements provided by other observers, such as Otto Struve. However, when we finally come to Rosse's extraordinary figures of a part of the nebula in Orion in 1868, we are confronted separately with both a schematic outline mapped onto a grid, and a portrait of the nebula—the former made as an outline based on the latter (Figs. 3 and 4).[21] But the two remain distinct and complete figures in themselves, and were never combined to form one image.

Many of John Herschel's early drawings of the nebulae may clearly be regarded as portraits that were used in a whole host of different ways. In some places, for instance in his 1833 catalogue, Herschel seems to have been interested in the classification of the nebulae, so that the objects he individually represents were used to provide token instances for each class.[22] Some of these drawings

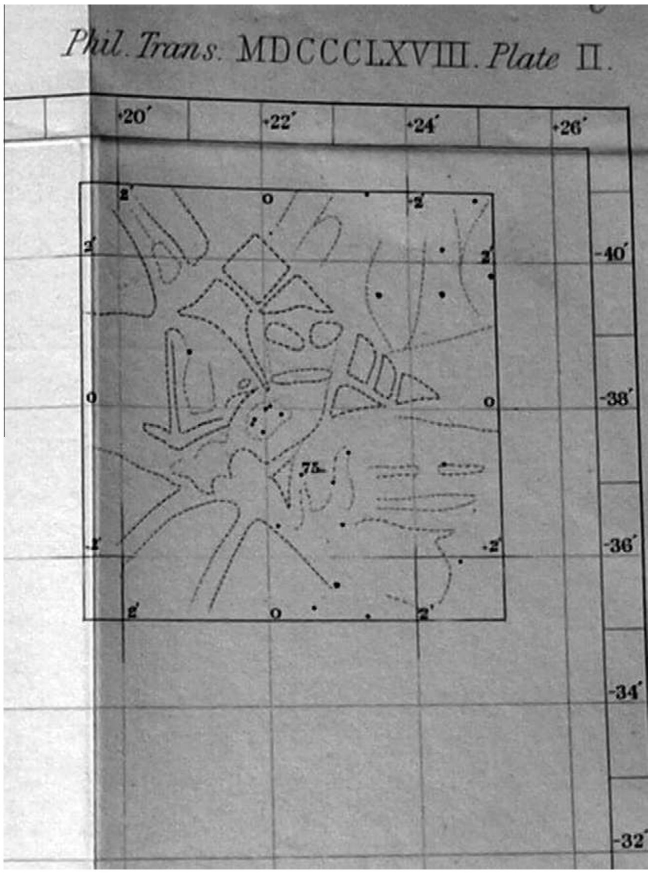

Fig. 4. Map of the 'Huygenian Region' of the nebulae in Orion (M42); (Lord Oxmantown, 1868, Plate II).

were also made by rough measurements and 'eye-drafts' of the nebulae. Herschel seems to have been interested in illustrating some nebulae mainly because of their strangeness, peculiarity, uniqueness, or beauty. At other times, following his father, John Herschel presents the reader with a whole series of figured nebulae arranged in a specific order of light density in order to visually demonstrate the possible action of physical condensation or other operations. He thereby *animates* specific physical operations, that take vast millennia to unfold.[23] Like Rosse, Herschel had also earlier published a separate schematic map meant to represent an outline of the nebula in Orion with its key regions labeled, as on a cartographical map, making it easier to reference and label (Fig. 5). The object it maps is also separately figured as a portrait (Fig. 6).[24] But as we shall see, what is distinctive about Herschel's Cape drawings is that a whole new kind of image is produced, one that takes into account *both* pictorial detail and numerical properties, at the same time and in the same image. But before this synthesis could properly occur in the procedures of observation, more confidence had to be gained in the application of mathematics to these faint and difficult celestial objects.

[19] Holland (1862 [1858]), p. 24. Later, at the end of the nineteenth century, Theodore Merz (2000 [1896-1914], vol. ii, p. 331) consistent with Holland, continued to refer to illustrations occurring within the context of the 'morphological methods' as 'portraitures.'

[20] Rosse (1850), p. 505.

[21] Also in Holden (1882, p. 200) Rosse's 1868 figure of the nebula in Orion is referred to as a 'map'. It ought to be noted, however, for the sake of clarity, that Oxmantown (1868) contains two very large fold out figures of the nebula in Orion in most of its entirety, one being a schematic map and another a descriptive map. Neither of these two have been figured in this paper, mostly due to logistics. But what have been figured here are the images of the small 'Huygenian region' of the nebula in Orion, one a portrait (Fig. 3) and another a schematic map (Fig. 4).

[22] Herschel (1833a), p. 361.

[23] A good example of such animated series of nebulae, with some objects even hypothetically postulated for the sake of continuity, is the work of the American mathematician and astronomer, Stephan Alexander, (cf. Nasim, 2009, pp. 405–407).

[24] For more on the dynamics of two related images and their productive interactions, see (Lynch, 1988).

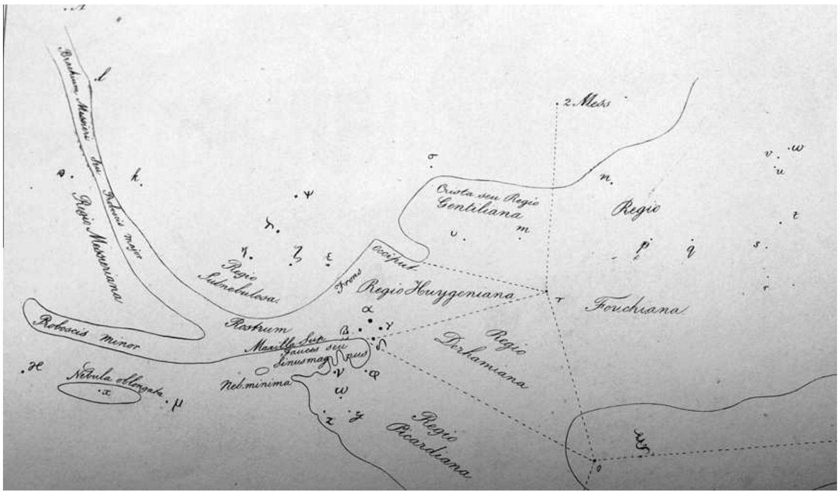

Fig. 5. John Herschel Cartographical Map of nebula in Orion (1826).

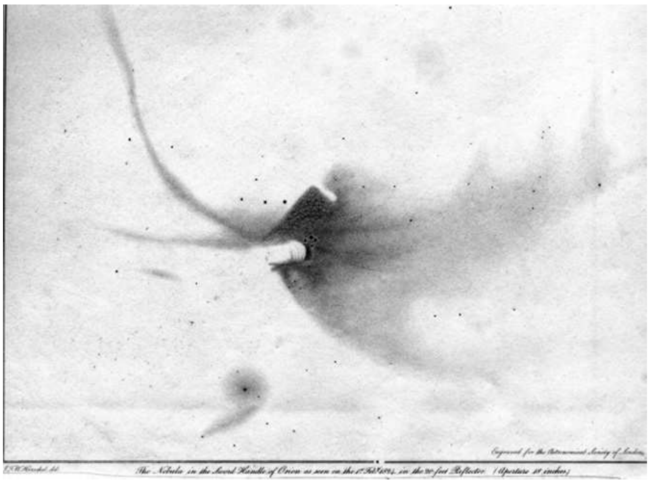

Fig. 6. John Herschel's 1826 Published Engraving of nebula in Orion.

Many at the time acknowledged the numerically resistant nature of the nebulae and clusters. In an early review of Rosse's project, for instance, both the descriptive and especially the numerical elements were described as impotent in the face of such vague objects to 'which nomenclature or arithmetic can hardly find an expression; and of which, even when represented to the eye by long lines of figures, the mind can form but a vague and indefinite conception.' George Airy, famous for implementing a strict numerical regime of observations at Greenwich, also proclaimed in 1836: 'Let it not be supposed that I am overrating the value of these drawings [of the nebulae and clusters]. The peculiarities which they represent cannot be described by words or by numerical expressions. It would be absurd to define the place of every point on a nebula, and the intensity of light there, by co-ordinates of any kind.'[25] But as Airy, of all people, was proclaiming such mathematical limits on nebular research, Herschel was busy in another Hemisphere attempting the absurd. And along with Mason, he was not alone in this.

It was the then recent research into the unusually difficult and delicate measurements of the binary stars and their orbits that gave John Herschel some hope and clarity in his task of applying mathematical and graphical methods to the nebulae. Alongside the likes of Wilhelm Struve and Johann Encke, who approached the challenges posed by binary stars by means of analysis and probability calculus, Herschel too made some significant headway in his research into the same, but by using graphical methods instead.[26]

It was not only the challenge of delicate measurements and the application of graphical methods that was at stake, however. By this time, unlike the nebulae, double stars had sufficiently been shown to have had proper motions, detected first by William Herschel, which when measured led to the extension of the law of gravitation to regions far beyond our own solar system. Now the same had to be done for the nebulae. This same sort of extension, from the case of double stars to nebulae, is explicitly at the forefront of both John Herschel's and Mason's work on the nebulae and in their image production. For instance take Herschel's remark about the determination of the mechanics of the nebulae, made in light of the his father's success with double stars, that 'all varieties of double stars as to distance, position, and relative brightness have their counterparts in nebulae; besides which, the varieties of form and gradation of light in the latter afford room for combinations peculiar to this class of objects.'[27] Mason begins his work on the nebulae by stating at the outset that 'the main object of this paper is to inquire how far that minute accuracy which has achieved such signal discoveries in the allied department of "the double stars," may be introduced into the observation of the nebulae, by modes of examination and description more peculiarly adapted to this end than such as can be employed in general reviews of the heavens' (Mason, 1841, pp. 165–66). It was therefore the success in the delicate and precise determinations of the orbits of some of the binary stars that inspired the application of geometric, numerical and graphical means to the nebulae. With this new confidence came new procedures, distinct from those used in the production of nebular portraits and schematic maps.

Finally, one way to bring out the tensions lurking in Mason's and Herschel's drawings of the nebulae, especially between the pictorial and descriptive, on the one hand, and the geometric, graphic, and metrical elements, on the other, it may be useful to employ some of Theordore Merz's (1840-1922) classic categories to conveniently catalogue the prevalent styles of reasoning in nineteenth century sciences. Two broad categories distinguish the

25 [Russell] (1845), p. 3; and Airy (1836), p. 173. This opinion is also expressed in Smyth (2000 [1846]).

26 See the important Hankins (2006), which ought to be read in conjunction with the present essay.

27 Quoted in Clerke (1895), p. 156.

different sciences of his century: the abstract sciences, centered on mathematical methods, such as 'Natural Philosophy,' and the descriptive ones, such as 'Natural History.' Respectively, indeed, in the one we have 'astronomical' and 'physical' methods, as opposed to the latter, wherein we rather have, among others, 'genetic, and 'morphological methods.'[28] The so-called 'astronomical view of nature' is best exemplified, according to Merz, by the purely mechanical considerations of motion and of course the attractive and repulsive forces, as discovered by Newton and analytically formulated by Laplace. The hallmark of this method, thus, is the abstraction into general relations or laws, mathematically expressed, 'which govern everything that is or can be real [which is opposed to] those sciences which study the actually existing forms as distinguished from the possible ones, the "here" and "there", the "where" and "how", of things and processes; which look upon real things not as examples of the general and universal, but as alone possessed of that mysterious something which distinguishes the real and actual from the possible and artificial. These sciences are truly descriptive sciences, in opposition to the abstract ones' (Merz, 2000 [1896-1914], vol. ii, p. 203).

The problem, however, and where Merz's categories seem to fall short, is in precisely how he understands scientific diagrams, models, and pictures—all are supposed to be abstractions.[29] This may not be a problem for understanding William Herschel's general drawings of the nebulae, but those drawings made of real, actual, and individual objects, as in the case of Rosse, Mason, and Herschel, present Merz's scheme with a counter-example. But even if Merz were to attempt to avoid this problem by replying that such abstractions are not restricted to the abstract sciences, but may have also been utilized by the descriptive sciences as well, he would still have a problem exactly because Mason's and Herschel's drawings of the nebulae endeavour to fall somewhere in between these categories; for they attempt to be *both* descriptive and quantitative, *both* individual and abstract, at the same time and in the same image, rather than in separated figures (e.g., a schematic map and a portrait, or as in 'split-screen' images (Lynch, 1988)).

By the late 1830's Herschel and Mason undertook to supply *descriptive maps*—illustrations that expressly attempted to properly preserve as much of the relative variations in light, the intricate placement of nebulosity, the precise relative positions and distances of the stars in or around the nebula, and as many other visually descriptive and pictorial details as possible—here the map and the portrait come together on one and the same image-surface. In fact, it is precisely for these reasons that Merz's categories must fail for some scientific photography as well, especially for those that are pictorially oriented. No one puts the dilemma involved in the representation of the abstract and descriptive, at the same time in the same place, and its possible solution better than Herschel when he says:

> But it is to the instructed only that the contemplation of nature affords its full enjoyment, in the development of her laws, and in the unveiling of those hidden powers which work beneath the surface of things ... we must educate our perceptions by practice and habit, till we learn to disregard specialties, whether of objects or laws, and see rather their relations and connexions, their place in a system, their fulfillment of a purpose ... And this we must endeavour to do without losing sight of the objects themselves, which come at length to stand in intellectual relations to these more spiritualized conceptions, as the notion of substance does to that of quality in some of our older metaphysical theories—as that substratum of being in which such conceptions inhere, and which serves to bind them together, give them a body, and coerce them from becoming altogether vague and imaginary (Herschel, 1857d [1848], pp. 271–72).

In fact, as we shall see in the next section, it is roughly the inverse that is practiced in Herschel's procedures—that is, he rather goes from relations and connexions, as a substratum which binds, to the individual body, as a concrete thing. Herschel's practice is closer to the metaphysics of twentieth century structural realism than the metaphysics of Locke— a practice, it ought to be noted, realized *without* the required logic of relations, a deficit that confines Herschel to the limited treatment of relations as qualities. But as we shall see, using layers of geometric construction, or what he also technically terms 'working skeletons', Herschel ties together 'spiritualized conceptions' to represented bodies, which are thereby bound or 'fixed' to a reality, exactly because they are bound to a representation susceptible to measurement, precise location and abundant detail. The procedures thereby direct the judgment of the eye and hand, control for error, and makes selection possible, especially in which details are shown, drawn, recorded and publically shared.[30]

3. The Descriptive Maps of the Nebulae

3.1. Herschel's Skeletons

John Herschel left England at the end of 1833 and arrived at the Cape of Good Hope in the beginning of 1834. The purpose of the trip was clear: to continue 'the Sweeps of the heavens' of the entire southern sky, for double stars, nebulae and clusters, which he had previously begun for the Northern Hemisphere, and which were also continuous with his father's sweeps begun much earlier in the latter part of the eighteenth century. With William's help, John had rebuilt his father's 20ft reflecting telescope in 1820, which was modeled on one that the elder Herschel had first constructed in 1782-83 for his sweeps of the northern skies. For the extensive and delicate measurements that were required, he also brought along his trusty 7ft equatorial telescope. With these two telescopes, he began at the Cape on March 5th 1834 with sweep number 429, in the sequence begun in the 1825, and ended with sweep number 810 on 22nd of January, 1838. The result of these sweeps was a catalogue of 1,708 nebulae and clusters, 1,268 of which had never been recorded before, and 2,103 pairs of double stars. This catalogue of sweeps and all the other results of the Cape observations and experiments were not published until nearly a decade later in 1847.[31]

Besides the highly engaged task of the sweeps, Herschel also wanted to take full advantage of the relatively favorable weather conditions in order to properly (re-) delineate and (re-) examine some of the more noteworthy nebulae, such as the nebula in Orion (M42) and M17. In fact, the sweeps and the pointed individual observations of the nebulae were two separate tasks, involving two separate procedures of observations.[32] Apart from all that physically and technically went into the sweeps at the telescopes,

[28] See discussion in Merz (2000 [1896-1914]), vol. ii, pp. 200–215.

[29] Cf. Merz, 2000 [1896-1914], vol. ii, pp. 200–201.

[30] This is not to say that photography allows for no selection whatsoever. A photographer in many cases may select the angle an object is taken from, choose what actually is photographed and how (focused in on or not), choose the chemicals and filters involved, etc. The point is merely that selections allowed by the procedures of drawing allow a different set of selections and choices, some which were explicitly used by the observers in particular ways in order to achieve particular results or to avoid others. For an interesting look at drawing and photography in natural history, see Wittmann (2008).

[31] For an account of Herschel's Cape journey and the adventure of its publication, see (Ruskin, 2004).

[32] For an excellent summary of the various actions required during the sweeps, see [Warner] (1992), esp. pp. 28–35.

the procedures of the sweeps also required Herschel to mark down the position, description, sweep number, date, object number, all in columned Ledgers, each column being a pre-set space for each kind of information. While a few scattered drawings of some nebulae and clusters were made during the sweeps, especially of those that caught Herschel's attention due to their peculiarity, because it was inadvisable to arrest the telescope in the midst of a sweep these had to be made swiftly within their pre-set columns meant for such contingencies. Many of the sketches in the 'Sweep Books' are therefore quite small, hasty and rough, but attempt to generally capture some peculiarity of shape or outline.

Unlike some of Herschel's earlier work, rather than presenting a scheme of classification or an animated series for different species, the Cape Results focused only on depicting individual objects. The more focused examination, or pointed observations, of the nebulae occurred on nights not dedicated to sweeping the heavens, or after the nightly sweep had been made, and occupied about a quarter of Herschel's time at the Cape. These examinations are arranged, as separate loose pieces of paper of varying sorts and sizes kept, in distinct folders or 'Monographs' that are dedicated to each nebula of interest. Whilst there are fifty-nine individual figures of nebulae and clusters figured in the Cape Results, there are eight Monographs corresponding to eight descriptive maps. What is immediately clear is that not all the figures of the nebulae and clusters found in the Cape Results are the result of the same procedure, nor have they the same function, type and value.[33] In fact, while many of the figures are portraits, the eight Monographs contain extensive work in preparation for descriptive maps of some significant nebulae (Fig. 7).

Like in many other nineteenth century nebular research projects, Herschel's notebooks and monographs contains a range of different kinds of 'working images', that act as tools for observation and as preparatory sketches for the final finished drawings meant for publication. Of chief interest among such working images are those he calls 'working skeletons,' which are to be found in the Monographs dedicated to the individual examination of each nebula, and to the production of its descriptive map (Fig. 8). What will be of relevance for our purposes in this section, more than the sweeps and the portraits of the nebulae and clusters found in the Cape Results, will be the procedures involved in the production of the descriptive maps for a select number of monographed nebulae. For it is exactly these descriptive maps that are the cumulative result of geometric and numerical nets cast on, behind and through individual nebula in order not only to make each an accurately proportioned and configured figure, from which one may 'read-off' star positions and nebulosity, but also help to make each robustly descriptive and pictorial.

Due to the extreme delicacy of taking measurements and of seeing the barely visible, faint and small stars involved in and around the nebulae, and because of the many possible sources of error inherent in such observations, Herschel stresses (1847, p. 11) that 'such figures in fact cannot be adequately described and figured in a single night.' This is no different from his earlier work (1833a, p. 360) on the nebulae, 'where several observations of one and the same object occur, their agreement or disagreement will enable every one to assign to them their proper degree of credit—to appreciate the amount of error, both accidental and inherent ...' By and large, it is by taking the visual mean of many observations that we are supposed to be assisted in avoiding or decreasing some of the errors involved, whether of the qualitative or quantitative sorts. However, what is different about the Cape observations and the resulting descriptive maps is that, as Herschel continues in the statement of 1847 above, '[such objects] require repeated examination and breaking up into triangles to be explored in detail.' In another place, he goes on to explain and lament, in the same breath, the difficulties involved in this procedure:

> To say that I have spent several months in the delineation of the nebula [around the star η Argus], the micrometrical measurements of the co-ordinates of the skeleton stars, the filling in, mapping down, and reading off of the skeletons when prepared, the subsequent reduction and digestion into a catalogue of stars so determined, and the execution, final revision, and correction of the drawings and engravings, would, I am sure, be no exaggeration. Frequently, while working at the telescope on these skeletons, a sensation of despair would arise of even being able to transfer to paper, with even tolerable correctness, their endless details. However, by breaking it up into parts, and executing each part separately, it has been accomplished, and I trust with such exactness as may afford a record capable of being appealed to in future whenever the question of internal changes of the form and situation of the nebulous branches shall be gone into (Herschel, 1847, p. 37).

This is a nice description of what went into the production of an image of just one nebula, and typical of the kind of work involved in each monographed object. Apart from all the taxing procedures, Herschel had also within the surrounding area of the nebula around the star η Argus (now known as Eta Carinae) geometrically determined the relative places of 1203 stars, and delicately included all the fine pictorial nuances and arrangements of the nebulosity, and their gradations of light—and all this thanks to the employment of 'working skeletons' in his procedures of observation.

The explicit purpose of such procedures of 'exactness' in the observations and figuring of the nebulae for Herschel was to assist and focus the eye and hand while 'filling-in' the nebula (with stars, light, and nebulosity), to manage possible errors in measuring such minute and faint stars, and finally, to 'preserve their configurations' and magnitude.[34] These interrelated aims were met using working-skeletons in the following manner. From micrometrical measurements taken for a few easy to find and conspicuous stars in or around a nebula or cluster, commonly taken using his 7ft equatorial refractor, Herschel determined each such star's respective mean Right Ascension (RA) and North Polar Distance (NPD). From out of these measured stars, with their relative position-angles and angular distances determined with a telescope, one was picked that was situated somewhere as strategically near the middle of the nebula as possible. This 'zero star' sits exactly at the 'zero point' of a grid, divided so that the x-axis plots the RA and the y-axis the NPD. With the grid in place, or at least a 'fiducial line' determined by a zero point, other directly measured stars are simply inserted into their places relative to one another, but especially in relation to the zero star. All these stars are referred to as Class 1 in the catalogues and form the basis for a network of triangles. Then angles of position taken with the 20ft-reflector, which are a little rougher than those made using the 7ft-refractor, are projected onto paper by a protractor in order to construct a network of triangles with some Class 1 stars helping to form the initial base of the one or two fundamental triangles. By simple trigonometry, then, one may further calculate Class 2 stars—stars, that is, whose positions in this co-ordinate system are determined by the network of triangles formed using Class 1 stars and their angles. Beginning with a known and directly determined base of a triangle and using established angles of position, the co-ordinates of a Class 2 star may be calculated, and the lines of this triangle may be further employed as a base for two other triangles used to calculate the co-ordinates of other Class 2 stars, and so on.

[33] Some, Hershel says, 'are eye-drafts' used to illustrate the strange and anomalous variety of structures, while others 'are rather intended as guides to the eye of any future observer' (Herschel, 1847, p. 19; p. 23).

[34] Herschel (1847), p. 10.

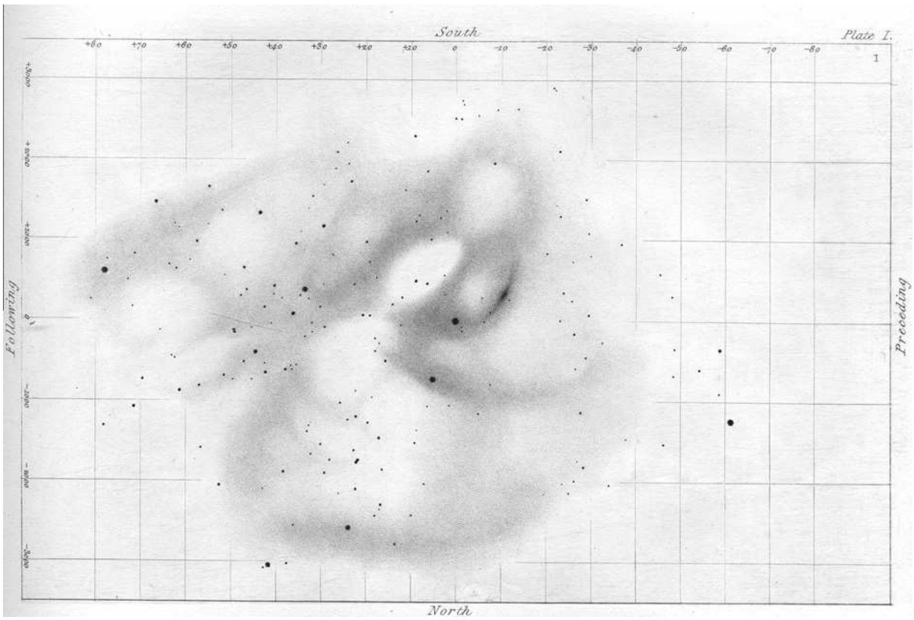

Fig. 7. A Descriptive Map of a nebula by John Herschel, Plate 1 of his *Cape Results* (1847, Plate I).

This may be continued for the entire surface area of a nebula and its surrounding regions. From such a skeleton the RA and NPD of each star may be simply 'read-off,' and in many cases Herschel went as far as to regard the mean position and distance of each Class 2 star to be 'a degree of exactness not inferior to what would have been afforded by direct measurements with the position micrometer.'[35]

Once the chain of triangles have been cast to some sufficient degree of robustness, stars much too faint (sometimes even to be sure of) or Class 3 stars are inserted within the triangles, and their mean measurements read-off in relation to the grid, the triangles in which they are enclosed, and the angles involved. This is a mere 'mental comparison,' says Herschel, and involves some controlled judgment on the part of the observer, because Class 3 stars are minute stars, which are 'laid down within each triangle by the sole judgment of the eye, [for] it is not possible to eliminate the errors of such judgment by any system of calculation.'[36] It is a similar set of judgments of the eye and mental comparisons that assist the manner whereby 'wisps', 'convolutions,' 'branches,' 'appendages,' 'strata,' and the cloudy nebulosity of the nebula, bright here and faint there, may be also inserted by pencil into the working skeleton. But there are also a few occasions in which a nebula is first drawn-in by the 'eye alone, unaided by any measurements', and then re-drawn and filled within the context of a working skeleton. For much more complex and populated nebulae, such as the one surrounding the star η Argus, the triangles are each even filled in more than once on different nights.[37] All in all, the use of working-skeletons, says Herschel, 'is the only mode in which correct monographs can be executed of nebulae of this kind, which consist of complicated windings and ill-defined members obliterated by the smallest illumination of the field of view [necessary for delicate micrometrical measurements].'[38]

Once all the stars are inserted, read-off, and reduced, a catalogue is made of them, and then begins the cumulative work towards a final publishable descriptive map of a nebula. It is from a series or collection of preliminary sketches and working skeletons made for one object (in some cases there are as many as eighteen made for one nebula) that a preliminary polished drawing is made, incorporating a faint grid constructed between two scaled brackets (Fig. 9). It is also not surprising to find that the final drawings made for transfer on to the copper-plate are of varying sizes, because the triangles and squares of the skeletons not only assist the eye and focus the hand in placing stars and nebulosity, and force the nebula to be traced in a distinctly well-proportioned and approximately isometric manner, but they also incorporate the possibility of either enlarging or reducing the size of the image—a method commonly used by painters (of frescoes, especially) and engravers.

It ought to be abundantly clear that the working skeletons not only include geometrically derived information, but that they are also graphical. In so far as they are the latter, one may correctly characterize the function of the working skeletons using a fundamental claim made for them in Herschel's work on double stars: working skeletons 'perform [in a manner] that which no system of calculation can possibly do, [that is] by bringing in the aid of the eye and hand to guide the judgment, in a case where judgment only, and not calculation, can be any avail' (Herschel, 1833b, p. 178). The geometrical scaffolding and the graphical method, as Herschel's practice so clearly exhibits, taken together are friendly to the various qualitative and quantitative details required in what Herschel regarded to be the full and proper scientific delineation of the nebulae and star clusters.

By the time the final engraved image of a monographed nebula is printed, it is stripped bare of all signs of a working skeleton, except for a faint grid, placed *behind* the nebulous mass, with lines fading away as they approach the body of the nebula (Fig. 10). All star numbers and triangles are omitted, and the magnitudes of the stars are indicated by different orderly sized dots.[39] Without

[35] Herschel (1847), p. 12.
[36] Herschel (1847), p. 40; p. 27.
[37] Herschel (1847), p. 40.
[38] Herschel (1847), pp. 12–13.
[39] 'In all these figures of nebulae,' says Herschel, 'I have held it unadvisable to disfigure the engraving with letters or numbers pointing out the stars. It is easy for any one who may wish to go into any minute comparison of them with the actual objects to take up the places of the stars on tracing paper, and then by affixing to them their proper references by the catalogue to form a skeleton chart adapted for his purposes' (Herschel, 1847, p. 15).

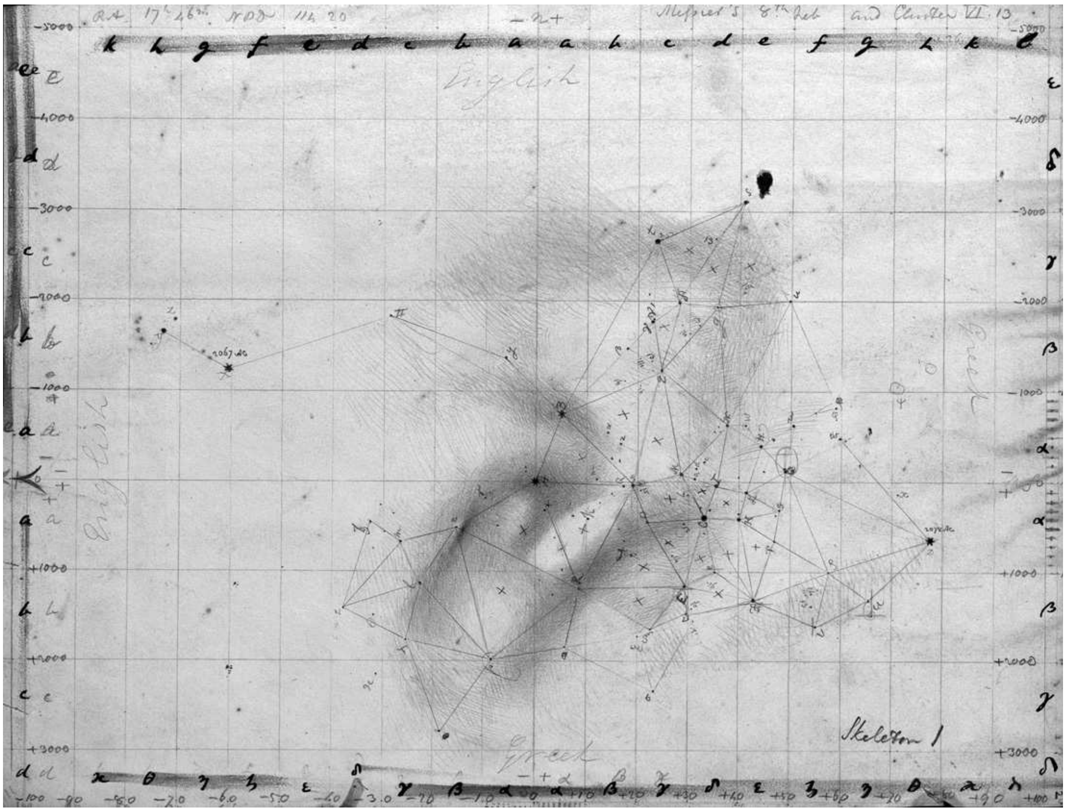

Fig. 8. A Working Skeleton by John Herschel, (M8) (Courtesy of the Royal Astronomical Society Archives; Monograph M8 JH 3/7 Skeleton 1, p.2).

any visual indication of the amount of work that went into each, the final printed images are prepared to look as immediate as possible, from which one may simply read-off the relative position of the stars, and thus instantly be presented with what ought to be a well-proportioned configuration of the different parts of a nebula, which are susceptible to further measurements. The figures of some of the most significant nebulae drawn by Herschel, visually present future astronomers with plentiful pictorial detail harmoniously coupled with a quantitatively preserved configuration, with both aspects residing in one and the same image-surface. The harmony, though, is never a perfect balance between the two aspects, sometimes one outdoing the other, but the point is that this harmony was indeed the ideal for Herschel, however approximately achieved. What is striking about Herschel's descriptive maps is that it was not until the 1880s that celestial photography was capable of producing images of the nebulae that functioned in principle in the same way that Herschel's descriptive maps did in the late 1830s. So the question to be asked is: if it was not photography, which scientific methods or techniques were the model for Herschel's procedures of observation and the production of descriptive maps?

The answer lies in the observation that such chains of triangles, as employed by Herschel in his working-skeletons, were already extensively used by cartographers, geographers, and land surveyors of the eighteenth century in order to create maps of nations and land masses that could be used to represent precise locations of any point (its longitude and latitude) on the globe (Figs. 11 and 12). Vast expanses of land, mountain ranges, river beds, valleys, etc, could all be covered in a system of triangles, and by using a directly measured base of one initial triangle a few kilometers long, with its two end-points or dots 'preserved with almost religious care, as monumental records of the highest importance,' one may triangulate a whole series of visible landmarks many kilometers apart, using only the angles measured with a theodolite (Herschel, 1834, p. 147). The network of triangles used in the working skeletons for figuring nebulae is thus clearly borrowed from the methods of the cartographer and surveyor.

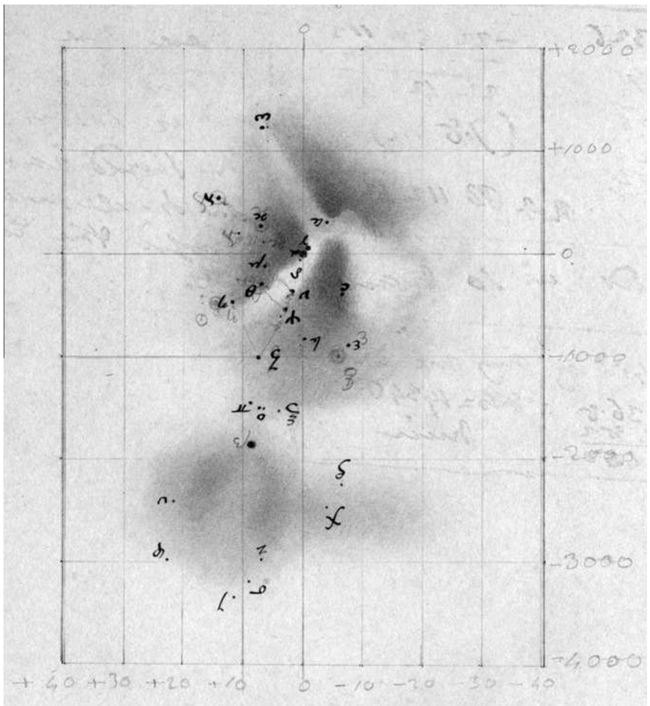

Fig. 9. John Herschel preliminary drawing of nebula, after working skeletons (Courtesy of the Royal Astronomical Society Archives; Monograph H. IV JH 3/4, p. 8).

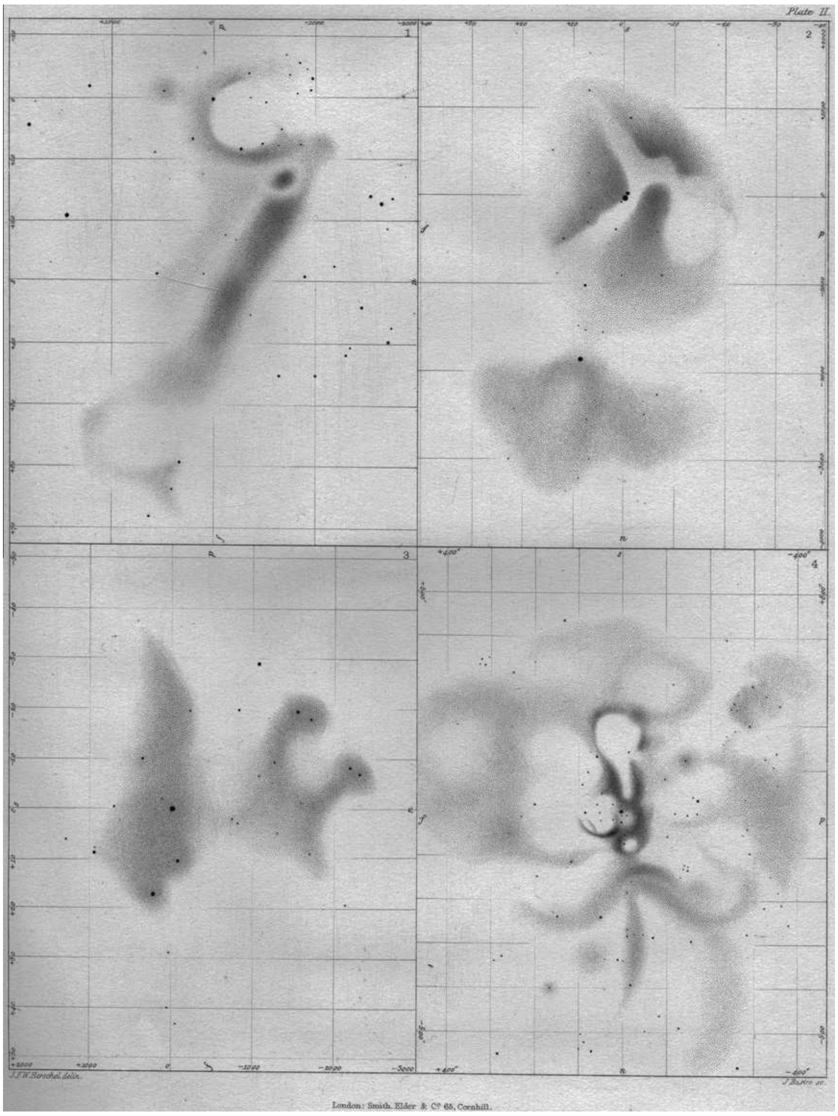

Fig. 10. Descriptive Maps by John Herschel (1847, Plate II).

Though some astronomers, such as Wilhelm Struve, were also famous for their extensive triangulation networks (Fig. 12) made in order to construct accurate maps and to calculate the geodesic arc of the earth, this was certainly not where the potent overlap between cartography, geography and astronomy ended.[40] For Herschel, these come together not by mere coincidence, convention, or convenience, but indeed on a *natural* basis—that is, in the context of the procedures of nebular observation the natural basis of this overlap are Class 1 stars, or as Herschel also refers to them, 'established authentic landmarks' (Herschel, 1847, p. 29). As early as 1827, at the presentation of the RAS gold medal for an important catalogue of the 'principle fixed stars,' John Herschel reminded his audience, in no less metaphysical or theological terms, of the importance for astronomy to have a good list of 'zero points' that may guide our ships, calibrate our instruments, and aid in our measurements of the heavens and their reductions.

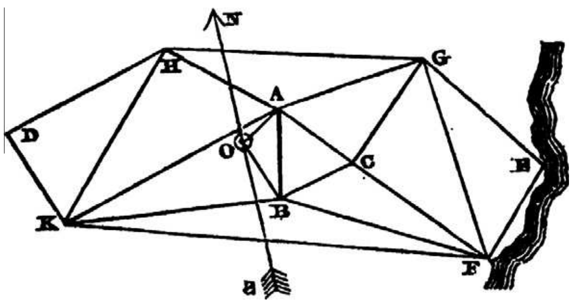

Fig. 11. A Figure from John Herschel's *Treatise on Astronomy* (1834) showing a Chain of Triangles for geodesic purposes.

> The stars are the land-marks of the universe; and amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in his work . . . Every well-determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor—a point of departure which can

[40] For instance see: Struve (1850). Gauss, Bessel, and Mason, to name a few, were all astronomers who did some work that would have involved the kind of triangulation networks employed in land-surveys, cartography, and geodesy.

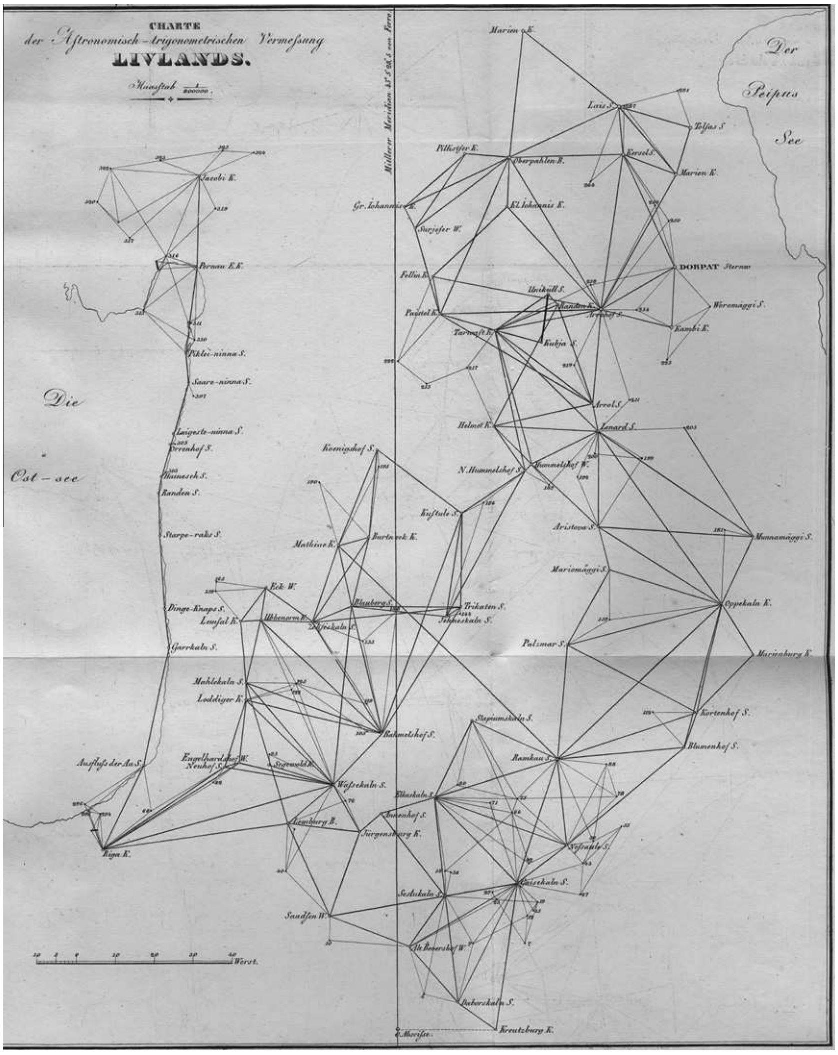

Fig. 12. Wilhelm Struve 1850 Plate I.

never deceive or fail him—the same for ever and in all places . . . (Herschel, 1857a [1827], p. 469).

What we have seen of Herschel's procedures thus far, therefore, taken in light of this jubilation, is in fact an instance of Herschel's actions and practice being guided by reference 'to what is immutable.' It is precisely by restricting ourselves closely to the determination of a 'spiritualized conception,' in this case the purely relational structures based on Class 1 stars in a skeleton, that our hands, eyes, and mind are guided in their actions of tracing, plotting, and detecting of stars, nebulosity, intensity or absence of light, shape, proportion, etc. But this is not all. For the end result—a system, or a body and its qualities—may thereby, recall, have its reality secured by 'that substratum of being in which such conceptions inhere, and which serves to bind them together, give them a body, and coerce them from becoming altogether vague and imaginary.'

It is not, however, so much the stars themselves as much as the fact that they may be located precisely in a *fixed* place and thereby susceptible to a public and 'objective' scrutiny that secures their reality. It was precisely such a scrutiny that led directly to questions of existence after Herschel made an extensive search for 629 nebulae and clusters that were previously registered by James Dunlop in 1828, another observer of the southern skies—but to Herschel's disappointment these were never to be found.[41] Stability, existence, and objectivity are thus connected to precise public locations, for as Herschel put it elsewhere, 'every *real existing material* body, must enjoy that indefeasible attribute of body, viz. *definite place*. Now place is defined by *direction* and *distance* from a fixed point. Every body therefore which does exist, exists at a certain definite distance from us and at no other, either more or less' (Herschel, 1857b [1841], p. 533). This same principle is expressed in John Herschel's reaction to those who doubted the reality of the aurora borealis, often associated with the same imponderable self-luminous material making up the nebulae: these 'luminous masses . . . have assuredly an optical *reality*—are *objects*, and capable of being seen in their true geometrical places by any number of spectators at once. It is impossible, in short, that a body of light, steady enough to be definitely referred by one observer to one given direction in space, and by another to another at the same instant, should not have an objective locality' (Herschels, 1857d [1848], pp. 324–5). These requirements do not necessitate that one observer be in constant visual contact with a well-determined body for its existence to be

[41] Herschel (1847), p. 4; When Dunlop won the French Academy's Lalande Medal for astronomy in 1835, John Herschel wrote in a letter: 'I wish the awarders would come here and look for some of his nebulae and double stars' (quoted in Evans et. al., 1969, p. 67, fn. 85). For more about Dunlop's poor condition at the Brisbane's Observatory, and the tragic results, see (Schaffer, 2010).

secured, but that it may be publically registered, as on a map or in a catalogue, and capable of being found when looked for by others (based on the map or catalogue). Thus by giving a well structured and ordered substratum to our undertakings we secure the existence and persistence of what results. This substratum may be formulated or assumed at the conceptual level, as it is in metaphysics, or within the *procedures* of scientific practice, as in the use of the working-skeletons. What is important for Herschel's working skeletons and what must be made clear is that, at least in the case of the physical and observational sciences, quantitatively 'well-determined' elements, and their relations, may provide further certainty and 'objectivity' as to the existence of some physical body, object, process or system, immersed within, fixed, and structured by such a registered substratum. The working skeletons therefore not only fix 'established authentic landmarks' (i.e. Class 1 stars) but these latter are used to further fix an ordered substratum of triangles into which other stars, relations, distances, pictorial detail, etc., all may be inserted and thus fixed in a controlled, guided, and disciplined manner. This rhetoric, therefore, suggests that 'objective locality' may be secured not only by direct visual measurement, but may also be publically 'read off' a record of some sort or another.

When stars finally come to 'register themselves' on photographic plates first in 1850, but more adequately in 1857 at the Harvard Observatory, they are 'unexpectedly' and 'quite surprisingly' recognized to be susceptible to delicate measurements allowing for their relative angles of position and distances to be *read-off* using an achromatic reading microscope, moved horizontally by means of a micrometer screw. George Bond's photographs of the star Alcor and the double star Mizar (ζ Ursae Majoris) are thus each measured off the plates, with special interest in the latter system for challenges posed by its being a double star. At first thirteen plates of Mizar are measured, then later eighty-six plates, and with the mean of these taken, the resulting reduced measurements are checked against and found nearly to agree with the measurements made by 'direct vision' for the same by Wilhelm Struve in his *Stellarum fixarum, imprimis compositarum positiones mediae* (St. Petersburg, 1852).[42] The great advantage for Bond, however, of taking measurements directly off the photographic plate of double stars and single stars, over those made by 'direct vision', is that the plates provide 'perfected fixedness of the images under the microscope [which] contributes to the exactness of the observations, presenting in this respect a singular contrast to this perpetual state of tremor and commotion of stars viewed directly through the telescope. Of these [fluctuating] positions the photographic image is an exact mean' (Bond, 1857c, p. 3). Compared to those stars found in catalogues and descriptive maps made by direct vision using a telescope, the stars on a photographic plate are landmarks not of a different order, but only of an increased level of 'fixedness.' But both, nevertheless, attempt to fix what is unstable, difficult and sensitive, i.e. the evasive telescopic object.

3.2. The 'Forgotten Astronomer' and his Isolines

Despite the fact that Herschel attempted to represent the magnitude of the stars involved in the nebulae or clusters by either trained 'eye-measurements' or by using a specially constructed device made for this purpose (his 'astrometer'), and that he expressly endeavored to capture the fine gradations of the light in and around the nebulae, some may object that Herschel's procedures do not emphasize a systematic concern for photometrics. Besides noticing that such an objection, if it has any real force to begin with, would still only point to some degree of difference between a nebular photograph and a descriptive map, I will instance the case of Ebenezer P. Mason, whose work in capturing the light of the nebulae is explicitly built into his procedures. I would like to therefore complete this section by briefly highlighting Mason's observational procedures, especially important for its uncanny resemblance to Herschel's methods of observation, and for his focused efforts to capture the gradual decrease or increase of light in various parts of a nebula. This he did at the tender age of nineteen while still at Yale College, using a telescope he had constructed with two other fellow students, which was also the largest of its kind at the time, on that side of the Atlantic.

In a paper read to the American Philosophical Society in 1839 and published after his death in 1841, Mason provides us with, *independent of Herschel*, another significant instance of descriptive maps of the nebulae continuous with later nebular photography (Fig. 13). Remarkably, the results, aims and some of the procedures of Mason's nebular research are almost identical to Herschel's. Like the latter's concern with a few pointed observations of the 'monographed' nebulae, Mason begins by emphasizing that his 'theory of observation,' 'consists not in an extensive review, but in confining attention to a few individuals; upon these exercising a long and minute scrutiny, during a succession of evenings; rendering even the slightest particulars of each nebula as precise as repeated observation and comparison, with varied precautions, can make them.'[43] Using 'landmarks', as Mason too refers to the stars whose relative position and angular distances have been directly and micrometrically measured and fixed, he lays in the details of only four nebula, two of which turn out to be one and continuous. This 'groundwork of stars' is first laid down and then extended using 'a kind of triangulation [which] was carried out by the eye to all the stars in the neighbourhood' and marked down on paper.[44] Once the stars are in place, 'the nebulae itself was drawn upon the map by the guidance of the stars already copied.' We have already seen a similar manner of tracing, one guided by the stars, in Herschel, but Mason is a bit more explicit about how the act of drawing what one sees is controlled and guided by such landmarks. The 'assistance' provided in tracing-in the nebulae comes directly from a well known 'expedient of artists, who divide any complicated engraving which they would copy, into a great number of squares, their intended sketch occupying a similar number.' It is thereby that the artist and the astronomer are limited in 'fixing the appearance of the future drawing.'[45]

But this well-known device for tracing an original, taken from the engraver and artist, is not all that guides and assists the work of Mason's hand and sight. He goes on to describe, 'a method that I hit upon for the exact representation of nebulae, which has essentially contributed to the accuracy of the accompanying delineations,' which is directly inspired by

> methods usually adopted for the representation of heights above the sea level on geographical maps, by drawing curves which represent horizontal sections of hill and valley at successive elevations above the level of the sea, that is, by lines of equal height; and it is the same in its principle. It is obvious, that if lines be imaged in the field of view winding around through all those portions of a nebula which have exactly equal brightness, these lines, transferred to our chart of stars, will give a faithful representation of the nebula and its minutiae, and of

[42] Cf. Bond (1857b, 1858).

[43] Mason, 1841, p. 166. Also see Olmsted (1842), p.26 for Mason's 'habit of individualities' in his drawing education.

[44] Mason (1841), p. 170. Mason had trained himself to bisect angles by the eye. His astronomical companion Hamilton L. Smith noted that 'I have often admired the neatness of his outlines drawings. It was his practice to make angles with his pen simply, estimate their quantity by the eye, and then to measure them with the protractor; and he scarcely ever failed to come extremely near the truth' (Olmsted, 1842, p. 228).

[45] Mason (1841), p. 170.

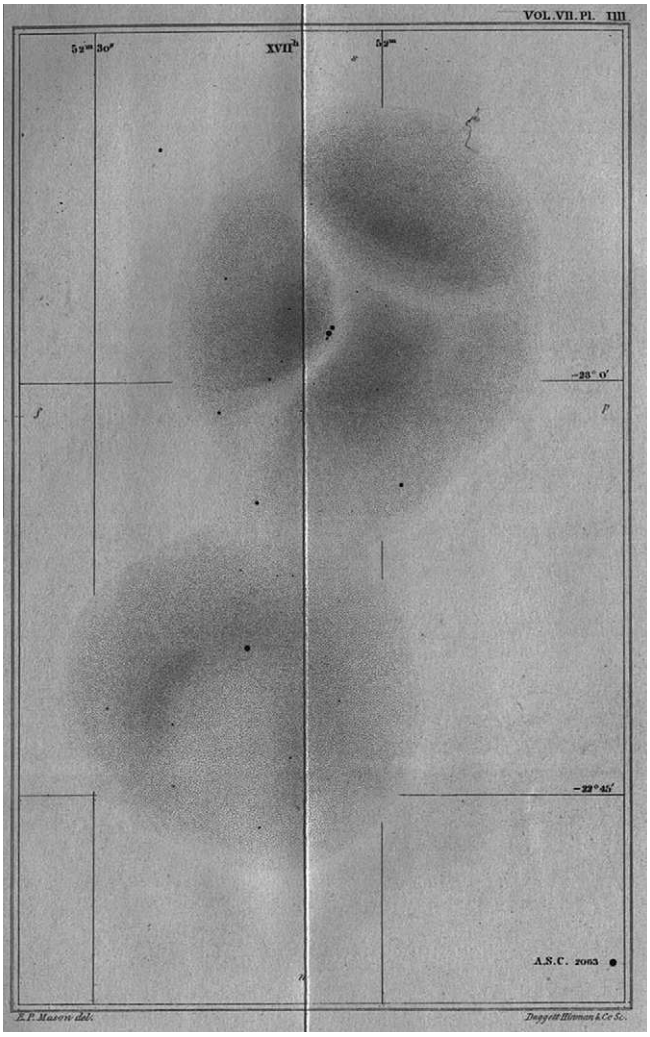

Fig. 13. E. Mason's (1841) Descriptive Map.

the suddenness as well as of the amount of transition from one degree of shade to another' (Mason, 1841, p. 172).

This 'method by lines of equal brightness'[46] is in fact nothing but *isolines* used in analogy with William Whewell's 'cotidal lines' in coastal surveys, or Alexander von Humboldt's enormously influential 1817 isotherms (lines representing, in a thematic map or isomap, equal temperature). This distinctive method of 'Humboldtian science' was 'commonplace' (Robinson, 1982, p. 56) by the first part of the nineteenth century, and by 'the 1840s there began a veritable isoline "craze", with atlases that described everything imaginable by means of isomaps' (Hankin, 2006, p. 624).[47]

By thus 'imagining' lines moving through and continuously along a nebula's regions of equal brightness, one transfers all such distinct lines onto a groundwork of stars already charted and fixed onto paper. Beginning with the brightest lines, marked '5', Mason gradually is able to continuously trace down to lower levels of light barely distinguishable by the human eye, numbered '1/2'. It is thereby, according to Mason, that one 'annihilates' such sources of error in drawing as are likely to arise from, for example, varying pressures of the pencil, inequalities of the paper, and even from the processes of engraving.[48] This isomap (Fig. 14) is separately drawn, and presented apart from its corresponding descriptive map. But what is essential to observe is that the isomap actively informs, assists, engages, and guides the detailed drawing-in of the light gradations of the nebula, with all its minutiae, onto paper already prepared with a 'groundwork of stars,' itself arranged by rough triangulations based on a few fundamental 'landmarks.' Therefore, unlike other nebular draughtsman, who published one set of figures for portraiture and another separately as a schematic map, Mason individually publishes an isomap in order not only to exhibit an ordered range of brightness in a nebula, but more importantly, to show at least one fundamental step that went into making proper observations, stabilizing the scientific object, and the final drawing of the nebula. Unlike Herschel, who visually 'conceals'[49] the work and procedures involved in the production of his immediate images, Mason uncovers for the reader a peak into at least one key aspect to his procedures—an isomap as a working image. It is therefore Fig. 13 that is the end result, with Fig. 14 being a step on its way in the procedures to this result. The former is thus another excellent example of a descriptive map continuous with later day nebular photography.

4. Conclusion

J. F. W. Herschel and E. P. Mason produced descriptive maps of the nebulae which turn out to be continuous, and not in principle different from, the photographs of nebulae produced much later in the nineteenth century. I have tried to show that this is precisely because the descriptive maps of the nebulae and clusters aimed at accuracy by way of astrometry and nebular configuration, and by being adapted to the delineation of the fine gradations of light in the stars, the surrounding nebulosity and other fine, sensitive and faint pictorial or visual details. This does not mean that the descriptive maps were equal in quality and precision with the photographs later made of the nebulae, but it does point to the fact that since they shared fundamental aims and results, however varyingly achieved and executed, they were continuous with, and not in principle different in kind from, nebular photography, as Turner might have thought. In fact, what these descriptive maps were meant to achieve, in practice and in theory, set the stage for what was expected of nebular photographs. But while what were set up as expectations and conditions by descriptive maps presaged the first successful photographs of the nebulae by over forty years, the overwhelming feature of these descriptive maps were their fundamental relation to cartographical and land surveying techniques, like the employment of isolines, triangulation, and chains of triangles. These techniques were well suited, on the one hand, to capturing metrical, graphical, geometrical, numerical information, and, on the other hand, the copious details, gradations of light, darkness, nebulosity, and all sorts of pictorial minutiae.

Such astronomical observations, as those instanced above with procedures resulting in descriptive maps, may be referred to as 'refined observations,'[50] to use Erna Fiorentini's (2007, p. 22) fitting

[46] Mason (1841), p. 174.

[47] There seems to have been only one other astronomer that used this method of isolines in drawing nebulae, these were never published. This was S. P. Langley (1834-1906), who was a part of an expedition for the United States Coast Survey, and who in 1879 made observations and drawings of the nebula in Orion in the same manner as Mason, cf. Holden (1882), pp. 105–106.

[48] When reviewing the life and work of Mason, Holden observed with regard to Mason's isomap that: 'In this way, and only in this way, can it [a drawing of a nebula] be made of 'minute accuracy', or 'numerical precision' be introduced into the artist's work. The methods of the topographical engineer can be thus applied to the delineation of the remotest celestial objects' (Holden, 1881, p. 592).

[49] Compare this to what John Herschel says about the differences between the technical arts in science and the 'empirical arts' (Herschel, 1987 [1830], pp. 71–72, sec. 65).

[50] Schaaf (1992, p. 30) refers to them as 'analytic observations'.

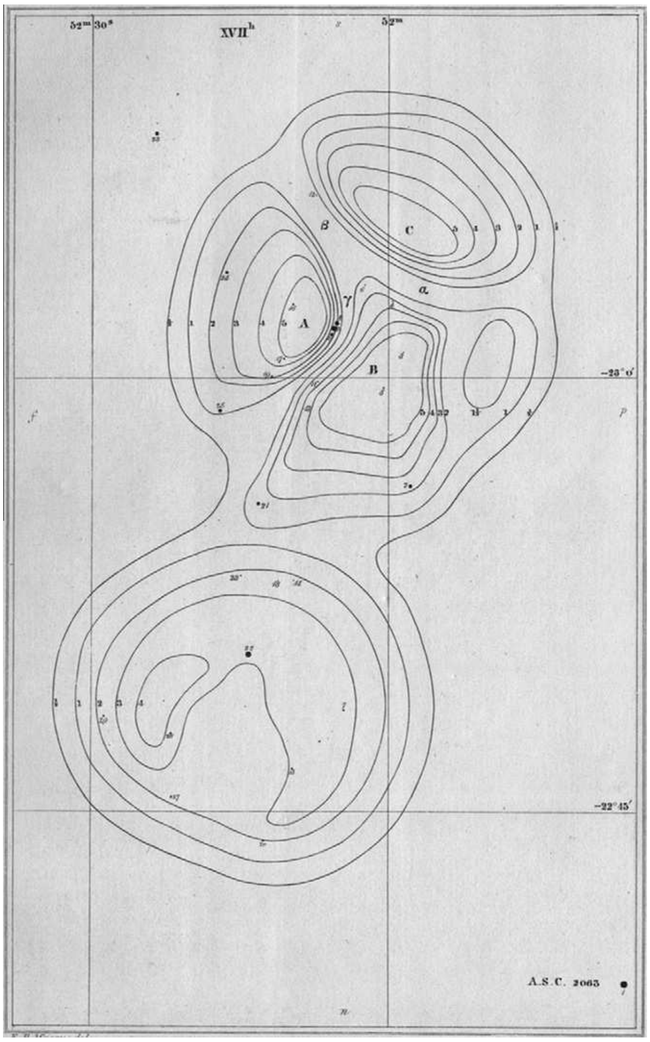

Fig. 14. E. Mason's (1841, Plate V) isomap of the nebula.

label for another instrument typically associated with the pre-history of photography, the camera lucida.[51] Refined observations are premised on the idea that 'sensory experience, attention and curiosity of the observer are expected to act in concert with elaborate instrumental equipment, in a process of mutual assistance, which is understood as the only way to attain the most accurate results.' It ought to be clear by now that observers such as Herschel[52] and Mason[53] also had their judgment, attention, curiosity, and a registration of detail and information guided by instruments of a more conceptual and methodical guise. Humboltian techniques aided the observer's eyes and hands in controlled, guided insertion and fixation of these latter aspects onto one image-surface, by which they also secured and fixed not only data but also an object's objectivity, existence, and stability. In fact, these were exactly the kinds of claims made later for pictorial photography in general, and might even suggest one proper context for the employment of the term 'fix' in the context of early photography.

Finally, a word about an exclusion in the foregoing discussion, namely, Turner's third advantage of astrophotography: its facility and ease. While it was common to flaunt the convenient mode of examining photographic plates during the day and at one's leisure, as one would with a copper-plate engraving of a nebula, I take Turner to mean the facility and ease involved in the *production* of the photographic images in contrast to what was inevitably integrated into the long procedures involved in the production of the drawings, not to mention the despair, fatigue, excitement, and the cold tremors of an overwhelmed observer's hand. It was precisely the exclusion of these latter aspects that were later celebrated, for instance, at the RAS meeting where Draper's photograph was first shown and discussed.[54] But as we have seen, to be sure, not only did different nebular draughtsman have their own unique procedures, internal to their own research projects and observing books, but even one and the same observer would have a variety of different procedures depending of course on the aim and the kind of visual image sought.

There were differences not only in how one made the images, but also how one used the images after they were produced. So, for example, descriptive maps were normally accompanied, on the one hand, by a catalogue of stars already determined, measured, and reduced, with all their relative places corresponding to those found in the structured, plotted, and graphed image. Photographic plates, on the other hand, had to be further prepared for measurement, in order to ascertain stars from dust specks and spots on the plate, peculiar machines and measuring devices had to be constructed, and whole new sources of error had to be confronted. It is not that I wish to deny how different by way of procedure photography and hand drawings each were, but I do wish to stress that perhaps it is exactly here, between these procedural differences rather than their associated relative facilities and difficulties, that we ought to focus our efforts in coming to understanding afresh their complex relationships.

Even with respect to end products, however, it should not be forgotten that *both* descriptive maps and photographs of the nebulae had to surmount major challenges in making reproductions transferable to some printable format for publication. In this connection it is of interest to note, therefore, that some of Herschel's very first experiments with photography were heavily involved with attempts to use new photochemical processes in order to make reproductions of engravings. At this early stage of photographic experiment, one of Herschel's specific challenges was to make a photographic reproduction of John Martin's (1789-1854)

[51] 'Strict adherence to proportion and perspective was all-important to Herschel; he would have recoiled in horror at the thought that man's truth could somehow exceed nature's. Contemporary reaction to the images of the camera lucida are important indicators of what photography itself was to face' (Schaaf, 1992, p. 30).

[52] No one used the camera lucida more than Herschel to make exquisite landscapes, cf. Schaaf (1992), pp. 27–28, and Schaaf (1994). But there is no evidence I could find that Herschel was using the device with the telescope in order to draw nebulae. There is a chance that Herschel might have used the camera lucida to duplicate drawings he made of the nebulae within his procedures. Charles Babbage (1836, p. 190) first discusses and recommends the possibility of using the camera lucida with a telescope.

[53] In Mason's Memoir there is extensive discussion about his excellent and prodigious drawing abilities, but no mention is once made about the use of a camera lucida; see Olmsted (1842), p. 12, p. 19, pp. 26–29, p. 93.

[54] Despite the martyrs of photography, some exclaimed against such 'evil influence [of] that old method of drawing', that 'if photography has done nothing more for astronomy than to prevent occurrences of this kind [of violent excitement and drawing from notes and memory] it would at least deserve lasting respect from a humane point of view' (Barnard, 1898, p. 345). One frequently mentioned martyr of photography was Father Stephan Joseph Perry (1833-1889) who famously 'with sickness of death upon him, this brave man, fearless in his duty, stood by his cameras, and carefully carried out his program [on 21 December 1889] during the eclipse, only to collapse at its close and die a few days later' (Barnard, 1898, p. 346). But notice that regardless of Perry's condition, Barnard does not attack the photographic production, as he would a drawing made under the same conditions. In Father Perry's Obituary, it reads, 'Not only religion and war, but also astronomy has its heroes' ([Knobel], 1890, p. 174). Also see Pang (2002) for a discussion on all that went into photographic expeditions, such as the solar expeditions, including the array of strenuous physical conditions. For more on the relationship between the human physiology and scientific observation see: Hoffmann (2006), esp., 229fn., and Canales (2001, 2009).

'fine' mezzotints, famous for their cloudy scenes of starry creation and apocalypse, and so appropriate to the cultural aura surrounding the nebulae in the nineteenth century.[55]

Permission

From the Royal Astronomical Society Archives for the use of Figs. 8 and 9.

Acknowledgements

I would like to thank Elizabeth Edwards and Wolfram Pichler for their penetrating comments on an earlier version. I am also indebted to both Christoph Hoffmann, Wolfgang Steinicke and Kelley Wilder for their time and detailed engagement with an earlier draft. The research could not have been possible without the financial support of the Fritz Thyssen Stiftung and the Max Planck Society, through my involvement with the associated project, *Knowledge in the Making*, and the scholarly support and assistance of my fine colleagues (both in Berlin and Florence). I must also thank Mr. Peter Hingley, Head Librarian of the Royal Astronomical Society, whose kind help in acquiring some of the material was crucial to this paper.

References

Airy, G. (1836). History of Nebulae and clusters of stars. *Monthly Notices of the Royal Astronomical Society, 3*, 167–174.

Babbage, C. (1836). On the application of a camera lucida to a telescope. *Monthly Notices of the Royal Astronomical Society, 3*, 190.

Barnard, E. E. (1898). The development of photography in astronomy (part 1). *Science, New Series, 8*, 341–353.

Bond, G. (1890). The future of stellar photography: Extract from a letter written in 1857 to Wm. Mitchell [1857a]. *Publications of the Astronomical Society of the Pacific, 2*, 300–302.

Bond, G. (1857b). Photographical experiments on the positions of stars. *Monthly Notices of the Royal Astronomical Society, 17*, 230–232.

Bond, G. (1857c). Stellar photography. *Astronomische Nachrichten, 1105*, 1–6.

Bond, G. (1858). On the relative precision of measures of double stars, taken photographically, and by direct vision. *Monthly Notices of the Royal Astronomical Society, 18*, 71–72.

Cadava, E. (1997). *Words of light: Theses on the photography of history*. Princeton: Princeton University Press.

Canales, J. (2001). Exit the frog, enter the human: Astronomy, physiology and experimental psychology in the nineteenth century. *British Journal for the History of Science, 34*, 173–197.

Canales, J. (2009). *A tenth of a second: A history*. Chicago: University of Chicago Press.

Cannon, S. F. (1978). *Science in culture: The early Victorian period*. New York: Dawson.

Clerke, A. (1888). Sidereal photography. *Edinburgh Review, 167*, 23–46.

Clerke, A. (1895). *The Herschels and modern astronomy*. New York: MacMillian & Co..

Common, A. A. (1883). Note on a photograph of the great nebula in Orion and some new stars near θ Orionis. *Monthly Notices of the Royal Astronomical Society, XLIII*, 255–257.

Common, A. A. (1888). Photographs of Nebulae. *The Observatory, 11*, 390–394.

Daston, L., & Galison, P. (2007). *Objectivity*. New York: Zone Books.

Dettelbach, M. (1996). Humboldtian science. In N. Jardine, J. A. Secord, & E. C. Spary (Eds.), *Cultures of natural history* (pp. 287–304). Cambridge: Cambridge University Press.

Edwards, E. (1992). Introduction. In E. Edwards (Ed.), *Anthropology and photography 1860–1920* (pp. 3–17). New Haven and London: Yale University Press.

Evans, D., Deeming, T. J., Evans, B. H., & Goldfarb, S. (Eds.). (1969). *Herschel at the Cape: Diaries and correspondence of sir John Herschel* (pp. 1834–1838). Austin and London: University of Texas Press.

Fiorentini, E. (2007). Practices of refined observation: the conciliation of experience and judgment in John Herschel's discourse and in his drawings. In E. Fiorentini (Ed.), *Observing nature – Representing experience: The osmotic dynamics of romanticism 1800–1850* (pp. 19–42). Berlin: Reimer.

Gould, B. (1878). Celestial photography. *The Observatory, 2*, 13–19.

Gould, B. (1895). *Memoir of Lewis Morris Rutherfurd (1816–1892)* (pp. 415–441). Biographical Memoirs, the National Academy.

Hankins, T. L. (2006). A 'Large and Graceful Sinuosity': John Herschel's graphical method. *Isis, 97*, 605–633.

Herschel, J. (1826). An account of the actual state of the great Nebula in Orion compared with those of former astronomers. *Memoirs of the Astronomical Society of London, 2*, 487–495.

Herschel, J. (1833a). Observations of Nebulae and clusters of stars, made at slough, with a twenty-feet reflector, between the years 1825 and 1833. *Philosophical Transactions of the Royal Society of London, 123*, 359–505.

Herschel, J. (1833b). On the investigation of the orbits of revolving double stars: Being a supplement to a paper entitled 'Micrometrical Measures of 364 Double Stars &c, &c'. *Memoirs of the Royal Astronomical Society, 5*, 171–222.

Herschel, J. (1834). *A treatise on astronomy*. London: Longman, Rees, Orme, Brown, Green, & Longman [New Edition].

Herschel, J. (1847). *Results of astronomical observations made during the years 1834, 5, 6, 7, 8, at the Cape of Good Hope: Being the completion of a telescopic survey of the whole surface of the visible heavens, commenced in 1825*. London: Smith, Elder and Co., Cornhill.

Herschel, J. (1857a). Address to the Royal Astronomical Society, April 11, 1827. *Essays from the Edinburgh and quarterly reviews with addresses and other pieces* (pp. 466–488). London: Longman, Brown, Green, Longmans, & Roberts.

Herschel, J. (1857b). Address to the Royal Astronomical Society, Feb. 12, 1841. *Essays from the Edinburgh and quarterly reviews with addresses and other pieces* (pp. 532–551). London: Longman, Brown, Green, Longmans, & Roberts.

Herschel, J. (1857c). Address to the British Association for the Advancement of Science, June 19, 1845. *Essays from the Edinburgh and quarterly reviews with addresses and other pieces* (pp. 634–684). London: Longman, Brown, Green, Longmans, & Roberts.

Herschel, J. (1857d). Kosmos, from the Edinburgh Review, Jan. 1848. *Essays from the Edinburgh and quarterly reviews with addresses and other pieces* (pp. 257–364). London: Longman, Brown, Green, Longmans, & Roberts.

Herschel, J. (1987). *A preliminary discourse on the study of natural philosophy*. Chicago: The University of Chicago Press (reprint of 1830 edition).

Herschel, W. (1912). Astronomical observations relating to the construction of the heavens, arranged for the purpose of a critical examination, the result of which appears to throw some light upon the organization of the celestial bodies,' [1811]. In J. L. E. Dreyer (Ed.), *The scientific papers of Sir William Herschel: Including early papers Hitherto unpublished* (pp. 459–497, Vol. 2) in two volumes. London: Royal Society and the Royal Astronomical Society.

Hoffmann, C. (2003). The pocket schedule: Note-taking as a research technique, Ernst Mach's ballistic-photographic experiments. In F. L. Holmes, J. Renn, & H. J. Rheinberger (Eds.), *Reworking the bench: Notebooks in the history of science* (pp. 183–202). London: Kluwer Academic Publishers.

Hoffmann, C. (2006). *Unter Beobachtung: Naturforschung in der Zeit der Sinnesapparate*. Göttingen: Wallstein Verlag.

Holden, E. S. (1881). A forgotten astronomer. *International Review, 10*, 585–593.

Holden, E. S. (1882). *Monograph of the central parts of the Nebula of Orion, Washington astronomical observations for 1878 – Appendix I*. Washington: Government Printing Office.

Holden, E. S. (1886). Photography the servant of astronomy. *Overland Monthly, 8*, 459–470.

Holland, S. H. (1862). Progress and Spirit of Physical Science [1858]. *Essays on scientific and other subjects contributed to the Edinburgh and quarterly reviews* (pp. 1–49). New Edition, London: Longman, Brown, Green, Longmans, & Roberts.

Knobel, E. B. (1881). Note on the comparative brightness of the nebulae of Orion. *Monthly Notices of the Royal Astronomical Society, 41*, 312–314.

Knobel, E. B. (1890). Obituary: List of fellows and associates deceased Perry, S. J. *Monthly Notices of the Royal Astronomical Society*, *50*, 168–175.

Lankford, J. (1984). The impact of photography on astronomy. In O. Gingerich (Ed.), *Astrophysics and twentieth-century astronomy to 1950: Part A* (pp. 16–39). Cambridge: Cambridge University Press.

Lynch, M. (1988). The externalized retina: Selection and mathematization in the visual documentation of objects in the life sciences. *Human Studies, 11*, 201–234.

Macdonald, L. T. (2010). Isaac Roberts, E.E. Barnard and the Nebulae. *Journal for the History of Astronomy*, *xli*, 239–259.

Mason, E. P. (1841). Observations on nebulae with a fourteen feet reflector, made by H.L. Smith and E.P. Mason, during the Year 1839. *Transactions of the American Philosophical Society*, New Series, *17*, 165–213.

Merz, T. J. (2000). *A History of European Thought in the Nineteenth Century*. Bristol: Thoemmes Press. (Reprinted from 1st edition Edinburgh: W. Blackwood, 1896-1914, in 4 volumes).

Musselman, E. G. (1998). Swords into Ploughshares: John Herschel's progressive view of astronomical and imperial governance. *British Journal for the History of Science, 31*, 419–435.

Mussell, J. (2009). Arthur Cowper Ranyard, Knowledge and the reproduction of astronomical photographs in the late nineteenth-century periodical press. *British Journal for the History of Science, 42*, 345–380.

Nasim, O. W. (2008). Beobachtungen mit der Hand: Astronomische Nebelskizzen im 19. Jahrhundert. In C. Hoffmann (Ed.), *Daten sichern: Schreiben und Zeichnen als Verfahren der Aufzeichnung* (pp. 21-46). Zurich and Berlin: Diaphanes Verlag. [An

[55] Letter from John Herschel to H. Fox Talbot, Feb. 10, 1839. *The Correspondence of William Henry Fox Talbot*, Online Project: Document number: 3801: http://foxtalbot.dmu.ac.uk/letters/transcriptDocnum.php?docnum=3801. (Accessed on April. 5, 2008; originally from the National Media Museum, Bradford, England, collection number: 1837-4831). Mezzotint plates were also limited to a very few presses, thereby limiting reproductions. With regard to John Martin, I am thinking of such prints as his 'Creation of Light' (1825) reproduced as a Plate in Book 7, line 339, bound at p. 203 in the book, *The Paradise Lost of John Milton (London: Charles Whittingham, 1846).*

English version was printed as: Observations, Descriptions, and Drawings of Nebulae: A Sketch. *Max Planck Institute for the History of Science Pre-Print Series,* (no. 345). Berlin, 2008].

Nasim, O. W. (2009). On seeing an image of a spiral nebula: From Whewell to Flammarion. *Nuncius: Journal of the History of Science, 24*, 393–414.

Nasim, O. W. (2010). Observation, Working Images, and Procedure: the 'Great Spiral' in Lord Rosse's Astronomical Record Books and Beyond. *British Journal for the History of Science, 43*, 353–389.

Norman, D. (1938). The development of astronomical photography. *Osiris, 5*, 560–594.

Olmsted, D. (1842). *Life and writings of Ebenezer Porter Mason*. New York: Dayton & Newman.

Oxmantown, L. [later the fourth Earl of Rosse] (1868). An account of the observations on the great nebula in Orion, made at Birr Castle, with the 3-feet and 6-feet telescopes, between 1848 and 1867, with a drawing of the nebula. *Philosophical Transactions of the Royal Society of London*, *158*, 57–73.

Pang, A. S.-K. (1997). 'Stars should henceforth register themselves': Astrophotography at the early lick observatory. *British Journal for the History of Science, 30*, 177–202.

Pang, A. S.-K. (2002). *Empire and the sun: Victorian solar eclipse expeditions*. Stanford: Stanford University Press.

Ranyard, A. (1881). Note on Dr. Henry Draper's photograph of the Nebula in Orion. *Science, 2*, 82–83.

Ranyard, A. (1889). The great Nebula in Orion. *Knowledge, 12*, 145–148.

Rheinberger, H.-J. (2003). Scrips and scribbles. *Modern Language Notes, 118*, 622–636.

Robinson, A. H. (1982). *Early thematic mapping in the history of cartography*. Chicago: University of Chicago Press.

Rosse, E. (1850). Observations on the Nebulae. *Philosophical Transactions of the Royal Society of London, 140*, 449–514.

Rosse, E. (1861). On the construction of specula of six-feet aperture; and a selection from the observations of nebulae made with them. *Philosophical Transactions of the Royal Society of London, 151*, 681–745.

Rothermel, H. (1993). Images of the Sun: Warren De la Rue, George Biddell Airy and Celestial Photography. *British Journal for the History of Science, 26*, 137–169.

Ruskin, S. (2004). *John Herschel's Cape voyage: Private science, public imagination and the ambitions of Empire*. Ashgate, Aldershot.

Russell, R. C. W. (1845). The monster telescopes, erected by the Earl of Rosse .... *The Dublin Review, 18*, 1–43.

Schaaf, L. (1979). Sir John Herschel's 1839 royal society paper on photography. *History of Photography, 3*, 47–60.

Schaaf, L. (1992). *Out of the shadows: Herschel, Talbot, and the invention of photography*. New Haven: Yale University Press.

Schaaf, L. (1994). John Herschel, photography and the camera lucida. In B. Warner (Ed.), *The John Herschel bicentennial symposium*. Cape Town: Royal Society of South Africa.

Schaffer, S. (1980). Herschel in Bedlam: Natural History and Stellar Astronomy. *British Journal for the History of Science, 13*, 211–239.

Schaffer, S. (1995). Where experiments end: tabletop experiments in Victorian astronomy. In J. Z. Buchwald (Ed.), *Scientific practice: theories and stories of doing physics* (pp. 257–299). Chicago University Press.

Schaffer, Simon. 2010. "Keeping the Books at Paramatta Observatory." In *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*. Edited by David Aubin, Charlotte Bigg, and H. Otto Sibum. Durhan and London: Duke University Press, 2010; pp. 118-147.

Smyth, C. P. (2000). On astronomical drawings. In P. Klaus Hentschel, Axel D. Wittmann (Eds), *The role of visual representations in astronomy: History and research practice* (pp. 66–78). Thun and Frankfurt am Main. (Originally published as (1846). On Astronomical Drawing. *Memoirs of the Royal Astronomical Society*, *15*, 71–82).

Struve, W. F. (1850). Resultate der in den Jahren 1816 bis 1819 Augefuehrten Astronomish-Trignometrischen Vermessung Livlands. *Mémoires de l'Académie Impériale des Sciences de Saint-Pétersbourg*, Sixiéme Serie, *4*, 1–86.

Tucker, J. (2005). *Nature exposed: Photography as eyewitness in Victorian science*. Baltimore: the Johns Hopkins University Press.

Turner, H. H. (1904). Some reflections suggested by the application of photography to astronomical research. *The Observatory, 27*, 391–399.

de Vaucouleurs, G. (1961). *Astronomical photography: From the Daguerreotype to the electron camera* (Translated R. Wright). London: Faber and Faber.

Warner, B. (1992). Sir John Herschel at the Cape of Good Hope. In B. Warner (Ed.), *The John Herschel bicentennial symposium* (pp. 19–55). Cape Town: Royal Society of South Africa.

Wilder, K. (2009). *Photography and science*. London: Reaktion Books.

Wittmann, B. (2008). Das Portraet der Spezies: Zeichnen im Naturkundemuseum. In Christoph Hoffmann (Ed.), *Daten sichern: Schreiben und Zeichnen als Verfahren der Aufzeichnung* (pp. 47–72). Zurich and Berlin: Diaphanes Verlag.