The Harmony of the Sphere

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Edited by

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To the memory of Gary Banham
(1965-2013)

TABLE OF CONTENTS

List of Images ix

Acknowledgements x

Abbreviations xi

Introduction xiii

Part I: KANT AND HERSCHEL ON THE UNIVERSE

WILLIAM HERSCHEL ON THE GALAXY AND THE NEBULAE 2
Michael Hoskin

THE EVOLUTION OF THE SPHERE: KANT'S CONCEPTION OF MATTER
AND THE EXPANDING UNIVERSE 17
Silvia De Bianchi

Part II: PHILOSOPHICAL FOUNDATIONS OF KANT'S COSMOLOGY

FROM KANT'S EARLY COSMOLOGY TO THE COSMOLOGICAL ANTINOMY.. 48
Brigitte Falkenburg

KANT, METAPHYSICS AND FORCES: HOW NEWTONIAN IS KANT'S
METAPHYSICAL FOUNDATIONS OF NATURAL SCIENCE?................................ 71
Jonathan Everett

KANT'S IMAGES AND IDEAS OF INFINITY 99
Gary Banham

Part III: KANT AND HERSCHEL IN CONTEXT

REFLECTIONS ON KANT AND HERSCHEL: THE INTERACTION OF THEORY
AND OBSERVATION? 122
Michael Rowan-Robinson

THEATRES, TOYS, AND TEACHING AIDS: ASTRONOMY LECTURING AND ORRERIES IN THE HERSCHELS' TIME 132
Hsiang-Fu Huang

Bibliography 156

Contributors 169

Index 171

List of Images

Figure 1: William Herschel (1738-1822)

Figure 2: Three-dimensional map of the galaxy distribution derived from the IRAS survey

Figure 3: A Philosopher giving that Lecture on the Orrery, in which a lamp is put in place of the Sun

Figure 4: The description and use of an orrery of a new construction (1771)

Figure 5: Proscenium of the English Opera House

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Silvia De Bianchi

ABBREVIATIONS

All references to Kant's works are in accordance with the *Akademie-Edition* Vol. 1-29 of *Kant's Gesammelte Schriften*, Berlin/Leipzig, 1902-. References to the *Critique of Pure Reason* follow the customary pagination of the first (A) and second (B) edition. Unless otherwise indicated, the English translations are from the *Cambridge Edition of the Works of Immanuel Kant* (New York: Cambridge University Press, 1992-). The following abbreviations are used throughout the book:

Ak	*Immanuel Kants Schriften*. Ausgabe der Königlich Preussischen (Deutschen) Akademie der Wissenschaften (Berlin: W. De Gruyter, 1902–)
Br	*Briefwechsel*, Ak 10, 11, 12 *Correspondence*
DS	*Von dem ersten Grunde des Unterschiedes der Gegenden im Raume* (1768), Ak 2 *Concerning the Ultimate Ground of the Differentiation of Directions in Space*
ID	*De mundi sensibilis atque intelligibilis forma et principiis* (1770), Ak 2 *On the Form and Principles of the Sensible and the Intelligible World*
KrV	*Kritik der reinen Vernunft* (1781, 1787). Cited by A/B pagination. *Critique of Pure Reason*
KpV	*Kritik der praktischen Vernunft* (1788), Ak 5. *Critique of Practical Reason*
KU	*Kritik der Urteilskraft* (1790), Ak 5. *Critique of the Power of Judgment*
LF	*Gedanken von der wahren Schätzung der lebendigen Kräfte und Beurtheilung der Beweise, deren sich Herr von Leibniz und andere Mechaniker in dieser Streitsache bedient haben, nebst einigen vorhergehenden Betrachtungen, welche die Kraft der Körper überhaupt betreffen* (1747), Ak 1. *Thoughts on the True Estimation of Living Forces*
MAN	*Metaphysische Anfangsgründe der Naturwissenschaft* (1786), Ak 4. *Metaphysical Foundations of Natural Science*
ND	*Principiorum primorum cognitionis metaphysicae nova dilucidatio* (1755), Ak 1. *A New Elucidation of the First Principles of Metaphysical Cognition*

P *Prolegomena zu einer jeden künftigen Metaphysik die als Wissenschaft wird auftreten können* (1783), Ak 4. *Prolegomena to Any Future Metaphysics*

PM *Metaphysicae cum geometria iunctae usus in philosophia naturali, cuius specimen I. continet monadologiam physicam* (1756), Ak 1. *The Employment in Natural Philosophy of Metaphysics Combined with Geometry, of which Sample I Contains the Physical Monadology*

RM *Reflexionen Kants über Metaphysik*, Ak 17. *Kant's Reflections on Metaphysics*

TH *Allgemeine Naturgeschichte und Theorie des Himmels oder Versuch von der Verfassung und dem mechanischen Ursprunge des ganzen Weltgebäudes, nach Newtonischen Grundsätzen abgehandelt* (1755), Ak 1. *Universal Natural History and Theory of the Heavens, or Essay on the Constitution and Mechanical Origin of the Entire Universe, Treated in Accordance with Newtonian Principles*

UD *Untersuchung über die Deutlichkeit der Grundsätze der natürlichen Theologie und der Moral* (1764), Ak 2. *Inquiry concerning the Distinctness of the Principles of Natural Theology and Morality [Prize Essay]*

VL *Logik. Ein Handbuch zu Vorlesungen* (1800), Ak 9. *Lectures on Logic*

OP *Opus postumum* (1796-1801), Ak 21, 22. *Opus postumum*

INTRODUCTION

SILVIA DE BIANCHI

The title “The Harmony of the Sphere” is an evocative one. In it, the reader will hear an echo of Kepler’s cosmological system. In fact, however, this title refers to the new model of the world defended by Kant and Herschel. In framing his model, Kant dismissed the idea of a finite static cosmos, and introduced an evolutionary perspective according to which the universe can be drawn as if it were an expanding sphere. Although novel, this is reminiscent of a longstanding cosmological tradition that the sphere is the appropriate figure to associate with the form of the universe as a whole. However, Kant’s hypothesis concerning the form of the universe appealed not only to metaphysical but also to mathematical and physical principles, such as the inverse square law. Kant rejected the Platonic argument that since the most perfect and regular figure in which all regular solids can be inscribed is a sphere, the universe must therefore have assumed that shape. Instead, he advanced the idea of a universe which is indefinitely expanding in space and time while destroying and creating new planets and stars. This claim was emblematic of the radical change that the application of Newtonian physics to large-scale bodies and new astronomical observations had produced in the eighteenth century.

Kant and Herschel applied important achievements of Newtonian optics and mechanics to the understanding of the universe; at the same time, they also gave an original twist to Newtonian cosmology by explicitly applying the forces of attraction and repulsion of matter—which they both saw as fundamental notions—to astronomical phenomena. The harmony of cosmic matter, arising out of chaos, was therefore dictated by the interplay of these forces of attraction and repulsion. Following on from Boscovich, for example, Herschel assumed that matter had a corpuscular nature and therefore particles would behave according to these forces. Kant, meanwhile, constructed an original theory of matter as endowed with attractive and repulsive forces and represented it as a *continuum*. On this view, matter can be indefinitely divided through an arbitrary act (*Handlung*) of division. Kant postulates that to the *continuum* of perception there corresponds the *continuum* of the matter which affects our senses. In order to think of matter as a *continuum*, Kant claimed that the cosmic aether, via its high degree of rarefaction, allows for the expansion of the universe. In the history of early modern science, the oscillating and vibrating aether was considered to be the element that allowed the propagation of sound. Kant's universe, which is filled with cosmic aether, is therefore an oscillating and resonant body.

The idea of the harmony of the sphere corresponding to physical laws inspires the title of the present work, and in so doing it also reminds us of Herschel's activity as a musician and composer. One aim of this book is to inspire further studies of Herschel's theory of matter and light. Another aim is to stimulate investigation into Kant's doctrine of the aether as applied to the universe and in its connection with the mechanics of the propagation of sound, and thereby to faithfully reconstruct his late cosmology (from 1790 onwards).

This volume not only highlights the significance of astronomy for Kant's philosophy, but also emphasises Kant's and Herschel's contributions to eighteenth- and nineteenth-century astronomy and cosmology. Notably, Kant's early writings up to 1755 focused on natural science and cosmology. Afterwards, without setting aside crucial questions of natural science, his research focused on its foundations, and thereby on genuinely metaphysical questions that opened the path to the construction of his transcendental philosophy. Interestingly, in the 1780s and 1790s Kant returned to cosmological questions and astronomical enquiries on the basis of his new philosophical system. His reading of Herschel's reports and astronomical observations certainly played an important role in the formulation of his late cosmology. Herschel himself was deeply engaged with questions concerning music and its mathematical foundations. This had led him to develop an interest in natural science, especially optics, in the 1760s. His major achievements, such as the discovery of Uranus, the hypothesis of the nature of Saturn's rings, and his studies on the nature of the sun, took place between the early 1780s and the mid-1790s. While performing his experimental studies on radiative heat, which led to the discovery of infrared radiation, Herschel was also speculating on metaphysics and Kant's transcendental philosophy.

The influence that these two figures had on each other is thus of great interest both for the history of science and for the history of philosophy. Although Kant and Herschel never met, they had the same research interests in cosmology and the theory of matter, and were attracted by the same texts in optics and experimental physics. But while Herschel's influence on Kant's mature writings on natural science is manifest, Kant's influence on Herschel's works is yet to be assessed.

Both thinkers assigned a crucial role to the forces of attraction and repulsion of matter, and addressed similar problems in their application of these concepts to the understanding of cosmic matter. Their common interests led them along similar research paths. They were also interested in the same late-1790s experiments: thus, Kant refers to Thompson's experiments on radiative heat and the general theory of heat, as well as to Leslie's counter-experiment on light aimed at showing Herschel's observations to be mistaken.

Current studies in the history of science can benefit from a deeper understanding of these figures and the role they played in Britain and on the continent in the early nineteenth century. Kant and Herschel were crucial figures for the circulation of knowledge between different disciplines. They gave significant contributions in discussing discoveries of their time, and in developing a consistent worldview which tied together scientific and anthropological elements. Both Kant and Herschel were exploring cosmological ideas that included human beings upon the stage but not as creatures of God; rather, humans appeared as scientists and observers of the skies, and were not alone in the universe. Concerning this central cosmological topic, Kant and Herschel held different views. In his *Universal Natural History and Theory of the Heavens* (1755), Kant supported the hypothesis that there could be living beings on other planets, provided certain boundary conditions were met that made such planets apt for life. However, he did not reaffirm this view in the 1790s. Herschel, meanwhile, held that the conditions for life could be met not only on other planets but also on stars similar to the Sun. What is most crucial here is that both authors associated the development of intelligence with features of the physical environment, and so believed that different forms of intelligence might emerge in different climates and given different surface conditions. In the *Opus postumum*, Kant set out a system of classification of the moving forces, and he included intelligence in this system without appealing to the existence of God or justifying it by reference to a theological order. This approach was the effect of a cosmology freed from direct divine intervention, and therefore a consequence of his development of transcendental philosophy. The contributors to this volume include professional historians of science, philosophers of science, and scientists, who offer different perspectives from which Kant's and Herschel's systems can be approached. The book is divided in three parts. The first is devoted to expound the main features of Herschel and Kant's cosmology. Michael Hoskin offers an overview of the connection between astronomical observations and speculations that were essential in constituting Herschel's view of the universe. Silvia De Bianchi explores the origin of Kant's "problem of the World" and reads Kant's *Antinomy of Pure Reason* within the history of astronomy in order to show both Kant's contribution to its development and the extent to which astronomical paradoxes informed his philosophy. The second part of the book is entitled *Philosophical Foundations of Kant's Cosmology*. In it, the reader will find three articles focused on expounding relevant philosophical problem underlying his cosmology. Brigitte Falkenburg shows how Kant developed his cosmology from 1755 to 1781 within the context of metaphysical debates on the notions of method advocated by Descartes, Wolff and Newton. Jonathan Everett discusses the main features of Kant's theory of matter and force and deals with the balancing argument. He suggests to understand the latter in terms of continuum mechanics rather than particle mechanics. Gary Banham presents the connection between Kant's notion of regulative idea and infinity in his 1755 cosmology and in the Critical period, in order to show a continuity of themes in Kant's works and the indispensability of regulative ideas for Kant's picture of experience and natural science. In the last and third part of the book, Michael Rowan-Robinson offers an overview of Herschel and Kant's relevance for the history of astronomy and cosmology, and relates their works to Laplace's system of the world. Hsiang-Fu Huang concludes the volume by showing the variety of forms taken by astronomical lecturing, and the evolution of orreries which were the most important visual aid prior to the invention of lantern slides and optical projection planetariums. Huang's contribution aims at giving the reader an insight of the Herschels' time and stimulates the research in similar topics that could assess the nature of astronomical lecturing that could have informed Kant's view. This volume, therefore, represents a contribution to studies which integrate the history and philosophy of science. It presents, for the first time, a comparative study of Kant and Herschel in order to highlight the historical and philosophical underpinnings of their worldviews—worldviews which would in turn have a crucial influence on the development of nineteenth and twentieth-century astronomy and cosmology.

PART I:

KANT AND HERSCHEL ON THE UNIVERSE

William Herschel on the Galaxy and the Nebulae

Michael Hoskin

William Herschel (1738–1822) was born in Hanover, Germany. His father was a bandsman in the regiment of Guards maintained by the Elector of Hanover, who was also King George II of Britain.[1] Herschel attended the Garrison School in the daytime, and his father taught him the violin and oboe in the evenings and at weekends. In Hanover, at the age of fourteen, children were confirmed in church, and left school to make their way in the world. And so, in 1753, Herschel joined the band of the Guards, alongside his father and his elder brother Jacob.

In July 1757, by which time Jacob had quit the army, the Hanoverians and their allies were defeated by the French at the Battle of Hastenbeck. In the aftermath Herschel's father ordered his two sons to take refuge in England, where they were to earn their living through music as best they could. After two years peace was restored and Jacob was able to return to Hanover, but William Herschel could not do so as he was formally a deserter from the army. Instead, from 1760, he made his living as an itinerant musician in the north of England.[2] There he had leisure to broaden his mind, and among the books he chose to study was *Harmonics* by Professor Robert Smith of Cambridge.

In 1766—by which time he had received his formal discharge from the army—Herschel was invited to Bath as organist to the Octagon Chapel then under construction. Bath was a spa centre favoured by the aristocracy, and the winter season was a period when a talented musician could earn a handsome income. By 1772 Herschel had bought Smith's other work, his two volumes of *Opticks*, which told the reader how to build telescopes and a little of what to see with them. This awakened his interest in astronomy. The same year he travelled to Hanover to rescue his younger sister Caroline from servitude in the family home, and to bring her to Bath in the

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[1] For biographies of Isaac Herschel, his wife and each of their ten children, see Hoskin (2007).
[2] Herschel's life-story is set out in Hoskin (2011).

hope that she might be able to sing as a principal in the Handel oratorios he regularly mounted. When the Bath season ended at Easter 1773, Caroline expected that her brother would find time to train her voice, but to her dismay she found that he had become obsessed with astronomy.[3] By March 1774 he felt able to open his first observing book, and the first objects he observed were Saturn and the Orion Nebula. He drew the Orion Nebula and noted that its current appearance was different from the sketch (made by Huygens in 1756) reproduced by Smith:

> "From this we may infer that there are undoubtedly changes among the fixt stars, and perhaps from a careful observation of this Spot something might be concluded concerning the Nature of it."[4]

In 1716 Edmond Halley had published a list of six of the milky patches in the sky known as nebulae,[5] and dozens more were now known to observers. Some astronomers thought that they were without exception star clusters so distant that existing telescopes were not able to "resolve" them into their component stars. Others (including Halley) thought that while distant star clusters would indeed appear nebulous, there were some nebulae that were formed of what Herschel was to term "a nebulous fluid", or "true nebulosity".

In his comments in his observing book, Herschel demonstrates the profound insight—unique to this novice amateur—that if a nebula changes shape perceptibly in only a matter of decades, then it cannot be a vast star system. In the years that followed, he encountered a number of nebulae and was struck by their variety of form, but the Orion Nebula was the one that he observed repeatedly and with care, for it was the only one for which he possessed a sketch from an earlier period. Herschel was no draughtsman and he had difficulty in committing to paper an accurate representation of the cloud of nebulosity, but he was able to make careful records of the alignments of the embedded stars. By 1782 he was convinced that the nebula had changed shape, and was therefore no distant star system but a nearby cloud of nebulosity (Hoskin, 2012, p. 36).

Herschel was by now a professional observer: Astronomer to King George III at Windsor Castle, no less. At Bath he had learned by practice (and the instructions in Smith) how to make reflecting telescopes, and in

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[3] Caroline Herschel tells her own story in *Caroline Herschel's Autobiographies*, see Hoskin (2003a).

[4] Royal Astronomical Society Herschel Archive (hereafter: RAS) W.2/1.1, f. 1.

[5] See Halley (1714-16). On the history of nebulae prior to Herschel, see Glyn Jones (1975).

1778 he had achieved for his reflector of 7-ft focal length a mirror of superlative quality; it was quite simply the best of its kind anywhere on Earth. With it he had embarked on a programme of examining each of the brighter stars in turn, to see whether or not it was a "double star", a pair of stars that at first sight appear as one. It was known that the stars lie at immense distances from us—Newton had made the working assumption that Sirius is physically similar to the Sun and appears fainter only because it is more remote, and he had shown that, if so, Sirius is about one million times further from us than the Sun.[6] As a result, the *apparent* movement of Sirius as we ourselves orbit the Sun each year—which is the most evident clue to the star's distance—is tiny, no more than the width of a coin at a distance of several miles, and nearly impossible to measure. But Galileo had popularised a way round the difficulty. If two stars happen by chance to lie in almost the same direction from us, so forming a double star, and if one star is near whereas the other is remote, then the remote star is in effect a quasi-fixed reference point supplied by a helpful Nature, and we need only measure changes in the observed position of the nearer star relative to this reference point. And tiny changes in this tiny angle may be possible to measure.[7]

There was a problem. As John Michell had argued in a paper published in *Philosophical Transactions* in 1767,[8] the number of double stars actually observed in the sky is so large that most of them cannot be chance alignments of the two stars with the Earth. The odds against this are simply overwhelming. Instead, most double stars must be formed of two stars that are companions in space, at the same distance from us and therefore of no use for the Galileian method. When Herschel's attention was drawn to Michell's paper, he was loathe to accept that his current programme of double stars was useless for the purpose he had in mind. But when he returned to some of his doubles two decades later, he found examples where the component stars had indeed moved in orbit around each other, just as Michell had predicted.[9] Of course the obvious assumption was that the force binding the two stars together was gravity, but proof that this was so—that the stars moved in Keplerian ellipses about

[6] Isaac Newton, Cambridge University Library Add. MS 3965, f. 279v: "Unde facile colligitur quod Sol distantia ejus a Terra 900000 vel numero rotundo 1000000 vicibus circiter augeretur".
[7] See Hoskin (2012, pp. 13–20). The method was not original with Galileo: Siebert (2005).
[8] See Michell (1767).
[9] See Herschel (1803; 1804).

their common centre of gravity—was not achieved until after Herschel's death in 1822.

Michell's study of the Pleiades had made it highly likely that these were stars similarly bound to each other by an attractive force, and the same argument would apply to all star clusters. Herschel's great insight would be that this was a process taking place *in time*: if in a scattered cluster (such as the Pleiades) the component stars were held together by gravity or a similar force, then as time went on this same gravity would bring the component stars ever closer together and so a more and more compact cluster would develop. In other words, a scattered cluster was young and a compact cluster old, and clusters went through a life-story. This was a cosmogony diametrically opposed to the clockwork universe of Newton. According to Newton, God the Clockmaker had established a universe that was stable and essentially unchanging. Indeed, if there was danger that a significant change was occurring, either on the small scale in the planetary system or on the large scale among the stars, Providence would have to intervene to restore the right order.[10]

Back in August 1779, knowing nothing of Michell's paper, Herschel had embarked on his quest for double stars, and on the very first night he had found that the Pole Star is a double; but it was weeks before any other English observer, amateur or professional, was able to confirm this. When confirmation was forthcoming, the President of the Royal Society, Sir Joseph Banks, wrote personally to Herschel to offer his congratulations.[11] Clearly an exceptional talent had appeared from nowhere.

On 13 March 1781 Herschel had been routinely examining stars one by one, when he came across a (supposed) star that his superb mirror showed was not in fact a star at all. It proved to be a planet, the one we know as Uranus, and the first to be discovered since the dawn of history. This gave Herschel's allies the leverage they needed to free him from endless hours spent teaching music and to devote himself instead to astronomy. In the course of 1782 Herschel named his planet the Georgian Star in honour of the King, and the King responded (as the customs of patronage required), by appointing Herschel his astronomer in residence at Windsor. He was to show the heavens to the royal family and their guests when requested, but otherwise he was free to devote himself to astronomy. After he had been a year in post, the King would encourage him to supplement his salary by making telescopes for sale, and in time Herschel became the unchallenged maker of reflectors, especially those of wide aperture, capable of

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[10] On Newton's universe, see Hoskin (1982), section B.2. See further below.

[11] On Herschel's negotiations with George III and his eventual appointment as Astronomer to the King, see Hoskin (2003b, pp. 48–56).

collecting enough light from faint nebulae to make them visible to the human eye.

In August 1782, on receiving the royal appointment, Herschel moved from Bath to Datchet, a couple of miles from Windsor Castle. His sister Caroline came with him, so ending her own career in music. Whereas Bath had been the most exciting cultural centre in the kingdom outside London, Datchet was a tiny village where nothing happened, and Caroline found that her life had lost its purpose. Herschel decided the answer was for her to become an astronomical observer in her own right.[12] He made her a little refractor convenient for "sweeping" large areas of sky in a short time, and he told her to go out and look for anything interesting—comets, double stars, nebulae, whatever. At first Caroline had no appetite for lonely observing on cold winter's nights, but then she began to come across nebulae, and these encounters were interesting enough to arouse both her and her brother's curiosity.

The first nebulae she encountered were, as it turned out, already known to astronomy. The leading French comet-hunter, Charles Messier, had found himself wasting time on milky patches that looked like comets but turned out to be nebulae, and so he had compiled a catalogue of nebulae. The second version of this catalogue, containing seventy objects, was published in 1780, and in December of the following year Herschel had been given a copy by his Bath ally Dr William Watson. Caroline's early nebulae were all to be found in Messier's list.

On 26 February 1783, however, Caroline found first one and then a second nebula and of each she was able to write, proudly, "Messier has it not", for it was not among the seventy. In fact, unknown to the Herschels, the former was in the final version of the Messier catalogue of 103 objects, which had been published in 1781; but the second was indeed unknown to astronomy.

Herschel was immensely impressed by the achievement of his novice sister armed with a telescope that was little more than a toy, and within a few days he himself "began to sweep the heavens for Nebulae and Clusters of Stars" (RAS W.4/14, f. 338). But he too was observing with a very modest instrument, and he soon realised that this was not appropriate, for nebulae (unlike comets) are permanent features of the night sky, and deserve to be examined carefully with the largest telescope available. He was then well advanced with the construction of a reflector of 20-ft focal length and 18-inches aperture, built into a stable, ladder-type mounting

[12] On Caroline Herschel's work in astronomy, see Hoskin (2005).

that allowed the observer to work in safety. He therefore suspended his sweeps until the 20-ft was commissioned, at the end of October 1783.

Herschel then embarked on what was to be a campaign of many years, systematically examining (almost) all of the sky visible from Windsor in the search for nebulae and clusters. Herschel was the first natural historian of the heavens, collecting specimens—first of double stars and then of nebulae—in vast numbers, classifying them, and drawing lessons from analysis of the classes. But the observing procedure he used for his first sweeps for nebulae was misconceived. He attempted to work alone, standing on the platform and dragging the tube first to one side and then across to the other. But this left him uncertain as to just what portion of sky had been "swept", and when he used artificial light to make notes of what he had seen, it was some while before his eyes were light-adjusted once more and he could resume observing.[13]

By the end of the year he had learned his lesson, and had developed a new and effective procedure for sweeping. The reflector was now kept facing exactly south (in the manner of a transit instrument), and Herschel was at the eyepiece, examining the sky as it slowly rotated before his eyes. Caroline was seated at a desk at a nearby window, and when a nebula came into the reflector's field of view, her brother would signal this by pulling a cord. Caroline would then open the window, and copy down her brother's shouted account of its appearance and its position relative to some star, which she would identify. In this way they were to accumulate nebulae that eventually made up two catalogues each of one thousand and a third of five hundred.

Believing as he did that some nebulae were star clusters disguised by distance while others were nearby objects formed of 'true nebulosity', Herschel wondered how he might distinguish the two. Some nebulae appeared to him as mottled, while others were milky in appearance, and he made the very plausible assumption that the mottled nebulae were star clusters on the verge of resolution into their component stars, while the milky nebulae were truly nebulous.[14]

In the spring of 1784 Herschel sent to the Royal Society his first paper on 'the construction of the heavens'.[15] Amongst much else, it offered Herschel's explanation of the ghostly, milky band we see around us in the sky and which we know as the Milky Way. Like some mid-century speculators, but probably independently, he proposed that the solar system is immersed as one star in a layer or "stratum" of stars; when we look

[13] See Hoskin (2003b, p. 69).
[14] See Hoskin (1979).
[15] See Herschel (1784); reprinted with notes in Hoskin (2012, pp. 99–112).

around us within the stratum, we see innumerable stars near and far and this generates the appearance of the Milky Way, but when we look outwards from the stratum we see only a few near (and therefore bright) stars before our gaze penetrates into empty space.

In this paper, but more completely in the paper he published the following year,[16] he shows how we might come to some knowledge of the shape of the stratum and our location in it. Clearly he must assume that his telescope can penetrate to the border of the stratum in every direction, for unless this is so his quest is hopeless. More interestingly, he assumes that the stratum, or Galaxy, was once composed of stars scattered at fairly regular intervals, and that the force of gravity (or whatever similar attractive force is at work among the stars) has not yet had time unduly to disturb the original near-uniformity of distribution. If this is so, then the number of stars visible in his field of view in any direction will be a clue to the (relative) distance to the border of the Galaxy in the given direction.

There was a limit to the amount of time he could spare from his sweeps, and so his star counts—the first example in history of the use of stellar statistics—were restricted to a great circle of the sky. In this way he gave a striking illustration of how his method should be applied, and a diagram presented the resulting cross-section of the Galaxy. It was a pioneering exercise. But in later life he came to abandon both of the assumptions on which it was based. When he built bigger telescopes he found that they brought additional stars into view, so that his first assumption was incorrect. And as he swept night after night for nebulae and star clusters, he came to recognise that high star counts were likely to be nothing more than the result of clustering.[17] He therefore had to abandon the cross-section that he had inferred from his star counts; but the methodology survived, to become a major tool in modern astronomy.

The stratum of our Galaxy was in Herschel's mind matched by other strata he saw around him in the universe. To us these are clusters of galaxies, but to him they were strata older than our Galaxy, in which gravity had already worked for long enough to produce fragmentation. Our Galaxy, he thought, might in time similarly fragment into perhaps three hundred star clusters.[18]

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[16] See Herschel (1785); Hoskin (2012, pp. 113–35).

[17] For example, "when we examine the milky way, or the closely compressed clusters of stars, […] this supposed equality of scattering must be given up" (Herschel, 1811, p. 270).

[18] See Hoskin (2012, p. 127).

Interestingly, for all his attempts at cosmogony, Herschel was never able to offer a suggestion as to how it was that near-uniform strata of stars had arisen in the first place. Three decades later, in 1814, he was to write:

> "We may also draw a very important additional conclusion from the gradual dissolution of the milky way; for the state into which the incessant action of the clustering power has brought it at present, is a kind of chronometer that may be used to measure the time of its past and future existence; and although we do not know the rate of going of this mysterious chronometer, it is nevertheless certain, that since the breaking up of the parts of the milky way affords a proof that it cannot last for ever, it equally bears witness that its past duration cannot be admitted to be infinite".[19]

Gravity became central in his thinking. The very existence of star clusters implied that gravity had been at work and the mutual attraction of the component stars had pulled them ever closer to one another—and this process would surely continue. In other words, the stars of a scattered cluster would go on attracting each other and so cause the cluster to be more and more condensed as time went on: a scattered cluster was young, at an early stage in its life cycle, whereas a condensed cluster was aged and perhaps not far from final dissolution.

Newton and his contemporaries had conceived of the universe as the work of God the Clockmaker, a piece of machinery in which there might be cyclic movements but no real change. According to Newton (1952, Query 20), the planets orbited round and round, and if a disturbance was threatened because of the mutual pulls of the planets, eventually Providence would intervene and restore the due order. Similarly, the system of the stars was highly regular, so that each star was pulled in all directions by forces that were (almost) equal and opposite; but if this right order came under threat in the long run, Providence would intervene.[20]

By contrast, Herschel taught that gravity is the agent of change, and under the action of gravity celestial bodies pass through a life cycle. By

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[19] See Herschel (1814), closing paragraph; Hoskin (2012, pp. 199–200).

[20] During Newton's early career, the stars were still apparently 'fixed' and motionless despite their being isolated bodies in space and subject to gravitational pulls from each other. Yet pulls result in motions, so how can all the stars be motionless? Newton addressed the problem only after the publication of *Principia* in 1687. His draft theorem, intended for a second edition from his own hand that never appeared, is transcribed from CUL Add. MS 3965 and analysed in Hoskin (1976, pp. 77–101), reprinted with additional material in Hoskin (1982), section B.2.

this profound transformation, Herschel opened the way to the modern universe, where stars, star systems, galaxies, even the cosmos itself, all have life cycles.

If we read Herschel's 1784 paper closely, we sense a tendency to see more and more of the nebulae as star clusters disguised by distance. Only the changes he believed he had himself observed in the Orion Nebula seem to hold him back from making this a universal proposition. But then it happened that not long after the paper had been sent to the Royal Society, Herschel came across first one nebula in which both mottled and milky nebulosities were present, and then a second (Hoskin 1979). How could this be, if mottled nebulosity was the sign of a distant star system and milky nebulosity evidence of a nearby cloud?

Second only to gravity in Herschel's current thinking were strata of stars, of which our Galaxy was the prime example. Suppose that a particular nebula was in reality another such stratum that happened to be seen by us edge-on? In that case the edge of the stratum nearest to us might well be composed of stars close to 'resolution' in Herschel's 20-ft and hence visible as mottled nebulosity, while the light of the more remote stars of the stratum would merge to give a more milky appearance. If so, the mottled/milky dichotomy resulted, not from the diverse physical nature of the objects under scrutiny, but from the differing distances of the stars from us.

Abandoning the 'changes' in the Orion Nebula as illusory, Herschel became convinced that all nebulae were simply star clusters disguised by distance, and this became the central doctrine of his 1785 paper on the construction of the heavens. A universe without nebulosity was a far simpler concept, and he has no difficulty in outlining the effects of gravity on various imagined distributions of stars that in origin are nearly, but not quite, uniform. He then points out that examples of the resulting configurations are actually to be found in his catalogues, and he infers that the real nebulae have indeed evolved from the action of gravity on what started out as near-uniform clusters of stars.

Now that he accepted the Orion Nebula as, not a nearby cloud of nebulosity, but a distant star system, so far away that it cannot be resolved into its component stars but yet spread across a surprisingly large region of the sky, he recognised it as what we would term a 'galaxy', a system that "may well outvie our milky-way in grandeur". And Herschel cites a handful more of nebulae of which the same is true, including the Andromeda Nebula. Herschel ends his 1785 paper with a discussion of 'planetary nebulae', "heavenly bodies, that from their singular appearance leave me almost in doubt where to class them". He had come across the first of these soon after arriving at Datchet (see RAS W.4/1.3, f. 231). We know it as the Saturn Nebula. It appeared to have the circular disk of a planet, but the pale light of a nebula, hence the name that Herschel gave it (and which we still use). Over the year he came across a handful more of these mysterious objects; they would puzzle him throughout his career, and visiting astronomers would be shown one and asked to give their opinion of it.

In 1785 he saw all nebulae, including planetaries, as star systems, and a planetary was therefore such a system in which the component stars were tightly packed. This suggested a system in which gravity had long been at work, nearing the end of its life story, and it seemed likely that the final stage would be what we know as ‘gravitational collapse’. He wondered if the star that flared up in 1572, ‘Tycho’s nova’, might have been a planetary nebula that had arrived at this final stage.

By 1789 the Herschel team had collected two thousand specimens of nebulae. A catalogue of the first thousand had been published in 1786, and now it was time for the second such catalogue.[21] This gave Herschel the opportunity for “a few introductory remarks on the construction of the heavens”, in which he sets out his vision of the development of a star system under gravity, from an initial near-uniform distribution to one “which approaches to the condition pointed out by a more equal compression, such as the nebulae I have called *Planetary* seem to present us with, [and which] may be looked upon as very aged, and drawing on towards a period of change, or dissolution”. In a sublime conclusion to the paper, Herschel presents his vision. Nebulae go through a life-cycle, and although our human lifespan is too short to allow us to watch any given nebula mature before our eyes, we can do the equivalent if we arrange examples of nebulae from his catalogues in order of their age:

> “This method of viewing the heavens seems to throw them into a new kind of light. They now are seen to resemble a luxuriant garden, which contains the greatest variety of productions, in different flourishing beds; and one advantage we may at least reap from it is, that we can, as it were, extend the range of our experience to an immense duration. Is it not almost the same thing, whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering, and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view?”. (Herschel 1789, p. 226)

[21] Herschel (1789). The “introductory remarks” are reprinted with discussion in Hoskin (2012, pp. 136–45).

But a surprise was in store. On 13 November 1790 Herschel was sweeping as usual, with Caroline at her desk at a nearby window, when there came into view

> "a most singular phaenomenon: a star of about the 8th magnitude, with a faint luminous atmosphere, of a circular form, and of about 3´ in diameter. The star is perfectly in the center, and the atmosphere is so diluted, faint, and equal throughout, that there can be no surmise of its consisting of stars; nor can there be any doubt of the evident connection between the atmosphere and the star".[22]

To modern astronomers this is the nebula catalogued as NGC 1514. It is a planetary nebula, that is, a star near the end of its cycle in which its outer layers have been expelled. In the Saturn Nebula and the other planetaries Herschel had come across, the central star had been too faint for him to see, and all he had glimpsed had been the outer shell. But NGC 1514 was near enough for him to see the central star. He regarded it therefore, not as a planetary nebula, but as a nebulous star—and one that was condensing under gravity out of a surrounding cloud of nebulosity. He had therefore been mistaken to deny the existence of 'true nebulosity', mistaken to equate nebulae with star clusters. In particular, the changes in the Orion Nebula that he had seen years earlier were not illusory but authentic after all.

Herschel's cosmogony of the later 1780s had begun with systems of widely scattered stars and had followed their development under gravity over time as the component stars pulled each other ever closer together, ending in all likelihood in the formation of a planetary nebula. Now it was evident that there was a pre-stellar—nebular—stage, in which stars condensed out of clouds of true nebulosity.

There was, one might say, little problem about revising the cosmogony to embrace the pre-stellar stage, but there were implications. Prominent nebulae such as the Orion Nebula and the Andromeda Nebula had been seen as galaxies fully comparable to our own Galaxy, because they were star systems that, though very distant, appeared as spread across the sky, and so in absolute terms must be vast. But now the stellar nature of these same objects was far from certain—they might be no more than nearby clouds of nebulosity. And at the same time it was becoming clear that the limits to our own Galaxy were unknown, for with each increase in telescopic power more and more of its stars came into view. Indeed, in some directions it might even be without limits. In short, the supposed

[22] Herschel (1791, p. 82); Hoskin (2012, p. 152).

galaxies were now seen as very possibly being mere clouds of nebulosity, while the Galaxy was of indefinite and even infinite extent. Herschel therefore could no longer maintain that he had identified galaxies comparable to our own. Second, the planetary nebulae reverted to being a mystery. There was no longer any compulsion to suppose they were star systems on the verge of gravitational collapse, so what were they? Herschel did not know. Third, in more practical terms, the great 40-ft reflector with mirrors 4-ft in diameter that he had built at immense labour with massive funding from the King had lost its primary purpose: to shed light on the question of whether or not all nebulae were star clusters. It was now certain that the answer was, No. The problem was, what to do with the white elephant. Herschel had pitched his initial application for funding unrealistically low, and the King had approved a second tranche only after a sensational face-to-face row with Herschel that left his astronomer shaken and outraged.[23] So much money and effort had been invested in the monster that it was essential that this monument to the King's munificent patronage of science should prove a success. This Herschel had achieved—temporarily—by announcing its discovery of two new satellites of Saturn within days of the reflector's completion; but this only made matters worse, because the scientific world now sat back and awaited further revelations on a weekly basis.[24] Herschel had to maintain it in some semblance of good order, if only to satisfy the royal guests sent from Windsor Castle to admire it, but the discovery of NGC 1514 answered once and for all the question the reflector had been built to address.

As a result Herschel lost enthusiasm for sweeping for nebulae. He had publicly committed himself to sweeping for nebulae across the entire sky visible from his base near Windsor, but he now had little incentive to carry out this promise. He had discovered over two thousand new nebulae and clusters, and what serious purpose would be served by adding to this collection? And so it took him until 1802 to assemble a third catalogue, this time of 500 nebulae,[25] after which he quietly abandoned the campaign.

The catalogue gave him another opportunity to pen some "remarks on the construction of the heavens", and what he says is notable for two reasons. First, two decades and more had passed since he had compiled his early catalogues of double stars, and it was time to revisit some of his doubles and see what if anything had happened to them in the meantime.

[23] Hoskin (2011, pp. 118–23).
[24] Hoskin (2011, pp. 123–27).
[25] Herschel (1802). The "remarks" are reprinted and discussed in (Hoskin, 2012, pp. 157–68).

He had earlier been resistant to Michell's argument that there were too many doubles in the sky for them all to be chance alignments, but by now gravity had come to play a central role in Herschel's thinking, and he announced with pleasure the discovery that the existence of binary stars was no longer merely probable but was an observational fact.

Secondly, it had been known since the seventeenth century that the speed of light, though immense, was finite: eclipses of moons of Jupiter were observed earlier than expected when the planet was near Earth and the light had less far to travel, later than expected when Jupiter was across on the other side of the Sun. It was a simple matter to establish that light from the Sun took some eight minutes to reach us, and to estimate that light from the nearest stars had been a few years on the journey. But no one before Herschel seems to have thought through the implications: that these objects must have existed however long ago, in order to send the light on its way. In itself, the conclusion was of minor interest. But Herschel estimated the time light had taken to reach him from the remotest objects accessible to his great reflector was to be measured in millions of years, and so these objects must have existed so long ago in order to be able to send the light on its journey—and this at a period when many thought the entire age of the universe since creation was only a few thousands of years:

> "A telescope with a power of penetrating into space, like my 40-feet one, has also, as it may be called, a power of penetrating into time past. To explain this, we must consider that, from the known velocity of light, it may be proved, that when we look at Sirius, the rays which enter the eye cannot have been less that 6 years and 4½ months coming from that star to the observer. Hence it follows, that when we see an object of the calculated distance at which one of these very remote nebulae may still be perceived, the rays of light which convey its image to the eye, must have been more than nineteen hundred and ten thousand, that is, almost two millions of years on their way; and that, consequently, so many years ago, this object must already have had an existence in the sidereal heavens, in order to send out those rays by which we now perceive it.[26]

Herschel shared this insight with the poet Thomas Campbell, who told a friend: "I really and unfeignedly felt at the moment as if I had been conversing with a supernatural intelligence."[27]

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[26] Herschel (1802, pp. 498–99) and Hoskin (2012, pp. 165–66).

[27] Lubbock (1933, p. 336), citing *Life and Letters of Th. Campbell*, ed. by W. Beattie, London, 1849.