Historical & Cultural Astronomy

Clifford J. Cunningham *Editor*

# The Scientific Legacy of William Herschel

Springer

# Historical & Cultural Astronomy

# Historical & Cultural Astronomy

More information about this series at http://www.springer.com/series/15156

Clifford J. Cunningham
Editor

# The Scientific Legacy of William Herschel

Springer

*Editor*
Clifford J. Cunningham
Austin, Texas, USA

ISSN 2509-310X ISSN 2509-3118 (electronic)
Historical & Cultural Astronomy
ISBN 978-3-319-32825-6 ISBN 978-3-319-32826-3 (eBook)
https://doi.org/10.1007/978-3-319-32826-3

Library of Congress Control Number: 2017952742

© Springer International Publishing Switzerland 2018
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

*Cover image*: Late 20th century bronze medal commemorating the Herschel family: John (left), William (centre) and Caroline (right). In possession of the author

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Foreword

Among the great scientists of the past, William Herschel (1738–1822) is exceptional in that for half his life he was a musician who hoped to be remembered for his symphonies and concertos. He was born in the capital city of the German "electorate" of Hanover, of which the elector was also the king of Britain. George II lived in London and administered his electorate from there, but he maintained a small army in Hanover, and Herschel's father was a humble bandsman in the Hanoverian Guards. On leaving the Garrison School at age fourteen, Herschel joined his father as a boy-bandsman.

In 1757, the Hanoverians were defeated in battle by the French, and Herschel (who as a boy was not under oath) deserted and fled to England in company with his older brother Jacob. The boys scratched a living from music in the London area, until in 1759 the French were expelled and Jacob was able to return home. Herschel however was a deserter, and in any case, he preferred life in England. In 1760, finding London "overstocked with musicians," he accepted a part-time post in the northern county of Yorkshire, and there he lived the stressful and demanding life of a jobbing musician.

Hoping to secure the more stable position of church organist, he began to teach himself the organ, and his dreams came true in 1766 when – probably by recommendation of a friend – he was offered the post of organist in the Octagon Chapel building in the fashionable spa resort of Bath in the west of England. Bath was second only to London in the opportunities it offered to enterprising musicians in the season, which lasted from the autumn to Easter.

Herschel's father had encouraged him to be intellectually curious, and it was probably in 1772 that he bought a copy of *Opticks* by the Cambridge professor Robert Smith. *Opticks* told the reader a lot about how to construct telescopes and a little of what to see with the finished instrument. It was that autumn that Herschel journeyed to Hanover to rescue his sister Caroline (1750–1848) from servitude to their illiterate mother. The pretext was that she might sing in the oratorios that he mounted from time to time, especially in Holy Week. It is a sign of his newfound interest in astronomy that, on the return journey through London, he took her to visit the shops of opticians.

Caroline accepted that, during the coming season, her brother would be too busy to spare time to coach her singing, but she hoped for better things after Easter. To her dismay, she found that her brother was obsessed with astronomy. In the years to come, she struggled to make a career as a singer, but the odds were stacked against her. Meanwhile, her brother experimented with the construction of reflecting telescopes, and in 1778, he made himself a 6-inch mirror for his 7-ft reflector that (though he did not know it) was the finest of its type on the planet. In 1779, he decided to use it systematically to familiarize himself with the brighter stars visible from Bath. And so it was that on 13 March 1781 he came to examine a (supposed) star in Taurus. With his superb mirror, he saw at a glance that it was not a star. Returning to the object 4 days later, he found that it had moved, and so was nearby, a member of the Solar System. Not knowing of speculations about undiscovered planets, he supposed it to be a comet.

By now Herschel had made contact with fellow enthusiasts in matters scientific, and he even had links with the Royal Society of London. This remarkable Bath musician-astronomer had acquired a circle of admirers, not least the president of the Royal Society Sir Joseph Banks – men who appreciated his talents and hoped to find some way for him to dedicate himself solely to astronomy. When the supposed comet proved to be a major planet (the one known to us as Uranus), they had their chance. King George III was a cultivated man and an amateur astronomer, and Banks suggested to him that Herschel might be the next astronomer at the king's observatory at Kew. This position was already promised, but after anxious thought, George decided to make Herschel his private astronomer, required to live near Windsor Castle and be available to the royal family from time to time but otherwise free to dedicate himself to astronomy. In this way, the king rewarded Herschel for naming his planet the Georgium Sidus.

Herschel simply took it for granted that his sister would abandon her career as a singer and quit fashionable Bath in order to live as his assistant astronomer in a tiny Berkshire village where nothing ever happened. He was right, and for some years, Caroline lived a busy and fulfilled life as the mistress of the Herschel household, an amanuensis to her brother astronomer, and even an observer in her own right.

Some astronomers in history have excelled as instrument-makers, some as observers, and some as theoreticians. Uniquely, Herschel excelled at all three. We have seen how the excellence of his telescope mirror was key to his discovery of a new planet. Months after becoming a professional astronomer, Herschel completed a reflector of 20-ft focal length and with 18-inch mirrors that in his hands (and later, refurbished, in the hands of his son John) became one of the great telescopes of history. The king, no doubt aware that he had driven a hard bargain in terms of salary, encouraged Herschel to supplement his income by making reflectors for sale and placing an order for five of 10-ft focal length. Herschel became the premier European maker of reflectors, and his clients included the King of Spain and the Empress of Russia. For his own use, with royal funding, he made a monster of 40-ft focal length and 4-ft mirrors weighing up to a ton, but this proved a cumbersome failure.

As an observer, Herschel had discovered his planet while searching among the brighter stars for those that were double, and this resulted in two long catalogs of doubles. When he became the king's astronomer, he soon focused on the problem of whether the milky patches known as nebulae were vast star systems disguised by distance or were nearby clouds of luminous fluid. He resolved to search the sky visible from Windsor for specimens of nebulae. In his "sweeps," he would be at the eyepiece of the 20-ft scanning the sky as it rotated overhead, while Caroline was at a desk at a nearby window ready to copy down his shouted observations. The next day, she would write up a fair copy, and she eventually assembled catalogs for publication that totaled 2500 specimens. Her accuracy almost defies belief, and her role though humble was crucial to the success of the team.

The Newtonian universe saw God as the great clockmaker whose mechanism functioned eternally without fundamental change. Herschel by contrast saw in star clusters evidence that gravity (or a similar attractive force) was at work among the stars, and if so, then in time a scattered cluster would mature by becoming more and more condensed. Illustrating his theory with specimens taken from his catalogs of nebulae, Herschel ushered in the evolving universe of modern astronomy.

For Herschel and his sister, the early Windsor years were immensely fulfilling: observations at night whenever the clouds and Moon allowed and days when Caroline would be writing at her desk and her brother supervising the workmen engaged to help with the construction of the 40-ft. Then, in 1788, calamity struck Caroline. Her 49-year-old brother married a rich widow who lived nearby. Caroline was no longer the mistress of the Herschel household but exiled to the adjacent cottage. However, there were compensations. Herschel was now in a position to pay Caroline for her work, but Caroline was tired of brotherly handouts and insisted that she receive a proper salary from the crown. The result was that she became the first professional female astronomer in history.

Not only that, but her newfound leisure – and her brother's diminishing enthusiasm for sweeping for nebulae – allowed her to spend hours searching for comets and so become an admired observer on her own account. Yet more important was the birth in 1792 of John Herschel. As an infant, John satisfied his aunt's maternal instincts; as an adult, he was to complete his father's work in astronomy and become one of the leading scientists of the age.

Perhaps because of unguarded comments by Herschel or his wife, in 1797, Caroline flounced out of the Herschel home and went to live with her brother's workman. She never again made an observation of note, and her activities as her brother's assistant were severely curtailed. Herschel for his part was in declining health, and in 1816, he prevailed upon John to abandon his career in Cambridge University and become his father's apprentice.

Herschel died in 1822. In her grief, Caroline impetuously took herself off to her native Hanover, where she soon found to her dismay that life had lost its purpose. She did however perform at her desk one last heroic deed, recasting the great catalogs of nebulae into a form that would allow John to reexamine the skies visible from Windsor. For this, she was awarded the Gold Medal of what is now the Royal Astronomical Society.

With the reexamination complete, in 1833, John published a consolidated catalog of his father's nebulae in a form suitable for use by observers. His father had never seen the skies too far south to be visible from Windsor, so John now took himself and his growing family to the Cape of Good Hope, where he spent the years 1834–1838 cataloging the southern skies. It was not until 1847 that John was at last able to bring his vast corpus of observations into print, but happily a copy of the book, and with it the completion of her brother's work, reached Caroline a few months before her death, in 1848 at the age of 97.

In recent years, a number of books have been written on the Herschels (the present writer must accept responsibility for eight of them), but these have naturally focused on the main themes of their lives, as outlined above. These themes are now well understood. Some of the essays in this volume pursue other questions to which William Herschel contributed, while others explore the cultural context in which the Herschels operated. The first essay in this volume, by Emily Winterburn, comes into the latter category. Dr. Winterburn's contributions to Herschel studies include a painstaking examination of unpublished materials in the British Library, notably the two huge volumes of autograph letters from Caroline in Hanoverian old age to her nephew John (letters that escaped the attention of Michael Crowe in his *Calendar* of John Herschel correspondence). In her essay, Dr. Winterburn explores in detail the educational pilgrimage of William Herschel, from his Hanoverian schooling to his early adult years in the north of England and then to the books he bought and read in Bath while on the brink of becoming a professional astronomer.

The second essay, by Woodruff T. Sullivan III, fills a gap in the existing literature that now appears remarkable. Dr. Sullivan is an astrobiologist, but he is known to historians of astronomy for his work in the history of radioastronomy. Recently he announced his intention of writing a full-length biography of William Herschel, and his present essay is a step toward this goal, namely, an exhaustive study of Herschel's work on comets. On Caroline's search for comets, we are well-informed, but her brother's work in this field has been neglected. Herschel, no orbit calculator but the possessor of uniquely powerful telescopes, explored the physical nature of comets, and Dr. Sullivan describes how this led him to speculate on the relations between comets and the nebulae that were his central interest.

Wolfgang Steinicke is an amateur observer and historian whose *Observing and Cataloguing Nebulae and Star Clusters* (Cambridge University Press, 2010) established him as the expert in the 2,500 nebulae of Herschel's catalogs. Everything he writes is distinguished by technical competence and attention to detail. In his essay, he studies the star "gages" that Herschel used in 1785 to propose the first map of the galaxy to which we belong. At this stage in his career, Herschel still thought the visible stars were reasonably uniform in their distribution in space (as indeed had Newton before him). If so, and provided his 20-ft reflector could reach to the border of the galaxy in all directions, then the number of stars visible in his reflector at any one time could be translated into the relative distance to the border in that direction. Herschel could not spare time to count stars across the entire heavenly sphere, but he did this around a great circle as an illustration of the technique and thus established the method of stellar statistics. He later found that his 40-ft could see stars invisible in the 20-ft, so that the 20-ft could not always see to the borders, and greater experience of star clusters led him to realize that higher "gages" were usually evidence of greater clustering rather than of greater distance. He therefore had to abandon his cross-section of the galaxy. But astronomers, like nature, abhor a vacuum, and Herschel's diagram continued to be reproduced.

Roger Ceragioli began adult life in classics but is now employed in the making of telescopes, and he brings to the history of telescope-making unique insights. Most of Herschel's telescopes were Newtonian reflectors, in which the light passes down the tube to the (parabolic) mirror at the bottom. This mirror reflects the light back up the tube, to a small, flat secondary mirror that reflects it sideways, so that the image can be examined by the observer looking through the eyepiece. I had always supposed that the challenge to the telescope-maker lay in shaping the curved main mirror, but Dr. Ceragioli shows that the precision of the shape of the flat secondary mirror was absolutely crucial.

In order to study nebulae and other distant and therefore faint objects, Herschel was forever calling for "more light," to be obtained by means of ever-larger primary mirrors. But his mirrors, both primary and secondary, were made of an alloy that of course reflected only a proportion of the light that reached them. With every reflection, light was lost. What if the telescope could be modified to require only one reflection rather than two? And so Herschel experimented with tilting the main mirror slightly so that the image came to a focus at the rim of the tube. There the observer would peer in with an eyepiece to examine the image directly, rather than after a second reflection. Of course the head of the observer would obstruct some of the incoming light, and so with modest reflectors, the modification would lose more light than it gained. But with large reflectors the observer's head proved to be a minor impediment and the slight loss of symmetry resulting from the tilting of the mirror an acceptable price to pay for the considerable gain in brightness. Dr. Ceragioli's technical analysis of the issues involved is a tour de force and the most important publication on Herschel as a telescope-maker ever to appear.

Michael Crowe has published extensively on the widespread belief (both before and after Herschel) in the existence of intelligent life elsewhere in the universe. The Creator had supposedly established intelligent life on our planet, and He had created not only other planets in our system but innumerable stars elsewhere, each no doubt with its own system of planets. Surely it was not beyond the power of the Creator to establish life on these other planets, and if He had the power, why would He refrain from exercising it? To borrow a tag from theology, *decuit, potuit, ergo fecit* (it was fitting, he could do it, therefore he did it).

Herschel's very first investigation in astronomy, in his Bath days, was to search the Moon (in vain) for structures built by the Lunarians, and when he referred to Lunarians in an early paper on lunar mountains submitted to the Royal Society, he was chided for unprofessional conduct. But if the Lunarians were keeping a low profile, the commitment of Herschel (and, later, his son) to universal intelligent life was to have decisive implications for his thinking in one of the most challenging problems in astronomy, namely, the structure of the Sun. Clearly sentient beings could not survive on the flaming surface visible to us. Herschel concluded that the Sun must be essentially a large planet, and the beings that populate the planet's surface are shielded from the outer shell of fire by an inner shell of clouds.

The second paper by Emily Winterburn discusses the eighteenth-century half of Caroline's scientifically distinguished but emotionally unfulfilled life. She contrasts her success with the fate of the majority of scientifically inclined females of her time.

Clifford J. Cunningham, the editor of this volume, is known as the authority on the early history of asteroids. In his paper, he assembles a mass of literary material, little of it familiar to Herschel specialists, that enables him to pioneer a study of the place of the (often controversial) Herschel in the poems published in his time and in the decades that followed.

Each of the articles in this fascinating volume adds significantly to our understanding of this great family.

Michael Hoskin
Churchill College
University of Cambridge
Cambridge, UK

# Preface

## Introduction

Clifford J. Cunningham

The subject of William Herschel (Fig. 1) has been an absorbing study of mine for many years. My first published article about him (in 1984) focused on his asteroid studies, and he was central to the subject matter in my Ph.D. thesis many years later at the University of Southern Queensland. My first thesis advisor was Brian Marsden, director of the Minor Planet Center. Whenever he needed sage advice about a matter concerning ancient history, he turned to the great Greek linguist John

**Fig. 1** William Herschel painted in the summer of 1819 by William Artaud. Herschel, 81, wears his insignia of the Royal Hanoverian Guelphic Order. The original portrait is in family possession, while this copy, which Caroline Herschel ordered for herself, is in the headquarters of the Royal Astronomical Society

Ramsey at the University of Chicago, and through this connection, he has assisted me many times through his knowledge of classical antiquity. When needing help on an astronomical project involving Latin astronomy, Ramsey suggested I contact Roger Ceragioli. In 2014 I first met Roger in person while in Tucson for an astronomy conference. He told me about his study of Herschel's front-view telescopes, and upon reading this important work, I realized at once it should be published. The idea for a book on Herschel had been on my mind for a while, although simmering on the back burner while working through the process of my doctoral studies. He is certainly worthy of such a book as, in the words of the Scottish novelist John Galt (1779–1839), he has gained "an immortal meed."[1] With Roger's agreement to have his work published as part of a wider survey of Herschel's scientific legacy, this endeavor was born.

Of course without the contributions of the world's leading experts on the Herschels – William, his sister Caroline, and his son John – it was still just a project. In 2015 I met Michael Crowe at the biennial history of astronomy workshop at the University of Notre Dame. When this great historian agreed to contribute a chapter, I knew the project had become a real book in progress. I am especially grateful that Woodruff T. Sullivan III, whom I met at an AAS Historical Astronomy Division conference in Seattle, also agreed to contribute, as he is writing what will surely be the definitive biography of William Herschel. To express the appropriate gratitude to the authors of each chapter would require the pen of Cicero, so here I merely express my heartfelt thanks to Crowe, Ceragioli, Sullivan, Wolfgang Steinicke, and Emily Winterburn. Wolfgang is now writing the definitive work on Herschel's observations, while Emily just completed writing a biography of Caroline. Every important book deserves the academic stamp of approval before it is sent into the world, and for this I thank Michael Hoskin, who showed me much kindness during my visit to Cambridge University a few years before this project began. No one has devoted more decades of study to William Herschel than Hoskin. The book you are reading now was made possible by the foresight of Maury Solomon of Springer, who has been very supportive during the production of this and my five-volume history of early asteroid studies. One major aspect of Herschel's work not included in this book is his asteroid research; for a thorough examination of his observations of and conclusions on the nature of Ceres, Pallas, Juno, and Vesta, I refer the reader to that five-volume series.[2] Thanks finally to Marion Dolan for her expertise which improved the text of this preface.

Among the themes that are encountered in this book that breaks new ground in several areas of Herschel scholarship are those of botanical/biological metaphors. We see this topic particularly in Sullivan's chapter, where he notes that Herschel couched the concept of a nebula producing a planetary body or a star as a process of

---

[1] Galt, G., *The Autobiography of John Galt*, Vol. 1. (Cochrane and M'Crone, London, 1833), 165.

[2] Historical Studies in Asteroid Research (Published by Springer): Discovery of the First Asteroid, Ceres (2016); Early Studies of Ceres, and the Discovery of Pallas (2016); Studies of Pallas in the Early Nineteenth Century (2016); Bode's Law and the Discovery of Juno (2017); Investigating the Origin of the Asteroids and Early Findings on Vesta (2017).

maturation (aging or development, in biological terms). In my own chapter, I quote Herschel as saying nebulae resemble a luxuriant garden in different flourishing beds. Another theme is the belief that most bodies of the Solar System are inhabited. This becomes the focus of an entire chapter by Crowe, but it also crops up in Sullivan's chapter and my chapter, which deals with a new aspect of Herschel studies – how his work influenced poets for a century after his discovery of Uranus. The chapter by Ceragioli approaches Herschel from a very different angle; Emily Winterburn (in one of her chapters) describes the most important work of Caroline Herschel, and Wolfgang Steinicke describes star gauges and the work of John Herschel. Here I will offer an unexpected intersection of the last four chapters just mentioned through the lens of poetry.

In the images evoked by Dante Gabriel Rossetti's poetry, Dometa Wiegand Brothers sees an active synergy with the astronomical work of the Herschels. Rossetti (1828–1882) was the central figure in the pre-Raphaelite movement in Victorian England. Although best known today for his extraordinary paintings, he was also a great poet, and it is here we find him in 1873 as the composer of the obscure sonnet "The Soul's Sphere," first published in 1881.[3]

Brothers, an assistant professor of British literature at Iowa State University, describes this poem as one that "creates a two-dimensional space that can imagine or recreate a three-dimensional reality."[4] The sonnet, which begins with explicit astronomical visions of a moon and dying star, asks what sense can be found in counting the infinite stars, "The soul's sphere of infinite images!"[5] Brothers says the poem's sphere "is that of the realm of images and reflections, like the light in the night sky."[6] Of course images and reflections are the soul of a telescope, none more so than the telescopes Herschel crafted to give him the scientific understanding that the universe might be infinite. Stellar cartography was a key element in pertinent studies of the cosmos, and while neither William nor Caroline prepared star charts of the Northern skies, Brothers traces the parallel metaphors:

> Caroline Herschel secured fame for herself as an astronomer in her own right in large part due to the work she did on revisions and updates to Flamsteed's catalog. From the 1780s on, attempts were made to catalog and provide star charts for the known skies in the Northern Hemisphere and continued with John Herschel's work sweeping the Southern Hemisphere… As John Herschel pointed out, "large tracts of the Milky Way exist so crowded as to defy the counting gages, not by reason of the smallness of the stars, but their number."[7]

Looking further into Rossetti's poetry, Brothers examines the so-called Willowwood sonnet cycle, "the centrally placed sonnets which form a bitter-sweet core to his *House of Life* sequence."[8] These famous sonnets were set to a cantata of

---

[3] Rossetti, D.G., *Ballads and Sonnets* (Ellis and White, London, 1881), 224.

[4] Brothers, D.W., *The Romantic Imagination and Astronomy* (Palgrave Macmillan, Basingstoke, 2015), 169.

[5] See footnote 3, pg. 224.

[6] See footnote 4, pg. 164.

[7] See footnote 4, pg. 164–165.

[8] Lancashire, I., 2003. The House of Life: The Sonnet. *Representative Poetry Online.* University of Toronto. https://tspace.library.utoronto.ca/html/1807/4350/poem1765.html

the same name in 1903 by the English composer Vaughan Williams, which I heartily recommend listening to. Rosetti certainly possessed a prerational commitment to the cosmological thought sparked earlier in the century by Herschel. Modern scholarship indicates he may have encountered the "House of Life" expression "from a projected painting of that title by his friend G. F. Watts – a panoramic and partially symbolic vision" of creation and the universe.[9] I incorporated a work by the English symbolist painter George Frederic Watts (1817–1904) in the fifth volume of my asteroid history series for Springer. Entitled "The Sower of the Systems," Watts' 1902 painting depicts a godlike figure creating the universe. While making his great cosmological studies, William Herschel must surely have experienced a sense of wonder and the sublime, concepts probed in their relation to science by Harvard professor Philip Fisher.[10] John Herschel surely received inspiration from the example set by his father when he stated that a natural philosopher "walks in the midst of wonders."[11]

Among the parallels with reflecting lenses discerned in the Willowwood cycle, Brothers mentions the bending over the pond by the speaker in the poem being akin to an astronomical observer gazing at an incline position to an off-center image (denoted in poem as Love, which is physically located beside and behind). As the "speaker inclines himself over the pond and gazes through the eye into the image (made of reflected light), his back is turned to the object. This process is much like that which Herschel perfected with his innovations to the reflecting telescope."[12] Brothers then quotes from the magisterial study of physical astronomy by the Scottish astronomer Robert Grant (1814–1892), which describes the front-view telescope design studied in depth by Ceragioli in this book:

> By giving a slight inclination to the speculum, so as to throw the image a little to one side of the tube, it was possible to view the latter directly with an eye glass. By this contrivance the light usually absorbed by the mirror was saved, and the illumination increased in a corresponding degree. In such a telescope it is obvious that the observer looks at the image with his back turned to the object.[13]

This quote serves as an introduction to a personal reflection by Ceragioli on his landmark study of front-view telescopes, which forms the centerpiece of this book, *The Scientific Legacy of William Herschel.* It is followed by a personal reflection from Crowe on his study of William and John Herschel.

---

[9] Banfield, S., *Sensibility and English Song: Critical Studies of the Early Twentieth Century* (Cambridge University Press, Cambridge, 1989), 78.

[10] Fisher, P., *Wonder, The Rainbow, and the Aesthetics of Rare Experiences* (Harvard, Cambridge, 1998).

[11] Herschel, J., *A Preliminary Discourse on the Study of Natural Philosophy* (Longman, Rees, Orme, Brown & Green, London, 1830), 15.

[12] See footnote 4, p. 171.

[13] Grant, R., *History of Physical Astronomy from the Earliest Ages to the Middle of the Nineteenth Century* (Baldwin, London, 1852), 54.

# Herschel and the Front-View Telescopes: A Personal Reflection

Roger Ceragioli

I began seriously thinking about William Herschel and his telescopes 10 years ago, in 2007 or 2008. I noticed in *Reflecting Telescope Optics*, vol. 1 (by Raymond Wilson, one of the preeminent authorities in the field) that he said Herschel's 40-ft telescope should have delivered arc-second (i.e., sharp) images. This startled me. You see, for many years, I had studied the design of telescope optics, both reading books and exercising my skill using ZEMAX™ optical design software (an industry-standard ray-tracing and optimization program). Since the nature of Herschel's "front-view" telescopes is very simple – being equivalent to Newtonians used so far off their optical axis that the flat secondary mirror is not needed and therefore ejected – it was easy to model the optical effects of a large front-view telescope. ZEMAX™ showed that the images must be very far from sharp. So Wilson's statement mystified me.

On the other hand, Michael Hoskin's 2003 article about the 40-ft telescope in the *Journal for the History of Astronomy* made quite clear from historical documents that the instrument had in fact proven unsuccessful in practice, never achieving anything of scientific significance despite the immense pains and expense that William Herschel lavished on its construction and maintenance. Resolving this stark difference between two eminent authorities was the initial impetus for my work.

Since childhood, I've been an avid amateur astronomer, and in adulthood, I've taken up telescope making. I built my first Newtonian in 1990. Over the succeeding 27 years, I've made many more, both for my own use and occasionally (like Herschel) for sale. Using these telescopes, I've had the thrill of seeing not only Herschel's two new moons of Saturn (Enceladus and Mimas) but also the two faint moons of Mars (Phobos and Deimos) that eluded Herschel, as well as the brightening of Comet Tempel 1 when the Deep Impact space probe shot it with an impactor in June 2005. I've known the thrill of observing with homemade instruments, experiencing the exultation of success when they worked, and (from time to time) the devastation of defeat when they failed!

Professionally, I've worked in the field of optics over the course of 20 years at the University of Arizona's Mirror Lab, where we built the largest single-piece mirrors in history and where I currently oversee fabrication processes for one of the 8.4-m-diameter mirrors of the Giant Magellan Telescope Project. Daily I have physical contact with giant telescope mirrors.

So understanding Herschel has a personal dimension for me. In this I also owe a debt of thanks to many people, including several people who contributed to this book, for example, to Michael Hoskin who unfailingly encouraged me and to Woody Sullivan who first alerted me to the epistolary battle between Thomas Romney Robinson and John Herschel in the 1840s, which closes out my chapter. Both men patiently read and commented on my work when it seemed simply an impossibly long article, unpublishable as it stood. But now it is published! And for this I have to thank Cliff Cunningham, a remarkable man whose vast energy and enthusiasm for ferreting out the details in the early history of the asteroids has led to his multi-volume work of that topic for Springer. It was Cliff who envisioned a way for my long work to see the light of day in integral form and who convinced Springer that a multi-author book about William Herschel was needed. To all these people, as well as to many others along the way, I say thank you!

But to return to the contradiction between Wilson and Hoskin, this soon vanished. I contacted Dr. Wilson, who initially defended his assertions. Some weeks or months later, after I pointed out that his own published equations indicated otherwise, he wrote me back a very gracious email conceding he made a units error in his calculations and indeed the images in the 40-ft telescope based on optical calculations could not have been good. He generously gave me permission to publish a statement to this effect, which I do now – not to embarrass him but simply to resolve that part of my narrative.

So based on both the historical evidence presented by Hoskin, and the ineluctable truth of optical calculations, it became clear: Herschel's 40-ft telescope must always have been a failure in terms of optical performance. It could not have been otherwise, and could never give adequately sharp images even at its lowest powers, because of its tilted primary mirror. It was simply too much too soon in the history of instruments. Herschel, like many an amateur telescope maker, had gotten carried away with himself and erected a "white elephant." But for reasons that Hoskin explained and I have amplified, William and Caroline Herschel and their close friends had to cover it up. It was imperative not to let George III (who paid for the beast and was irate at the price) know of the failure too clearly. The dirty laundry must not be aired! For me, recognition of the failure brought many questions in its train. If the 40-ft telescope had been a failure, well, the 20-ft one (built on the same lines as a front-view telescope) was known to have been a success. How could this be? Moreover, other astronomers such as Johann Hieronymus Schroeter (of whom more in a moment) used front-view telescopes with success. How could that be? And indeed, why did William Herschel decide in the first place to build a telescope with a tilted primary mirror, rather than continue with Newtonian telescopes, which lack the optical errors inherent in tilted-component systems?

My chapter tries to answer these questions in detail. And here I should say that I found the key in a brilliant paper published in 1983 by Rupert Hall and A. Mills. Without Mills' and Hall's unique study of flat secondary mirrors from the eighteenth and nineteenth centuries, my chapter would have been impossible or reduced to unsatisfying speculations. So I owe a big debt of gratitude to them too. Other thanks must ironically go to the much-maligned Johann Hieronymus Schroeter and his colleague Johann Schrader. Schroeter was a lawyer, civil administrator, and amateur astronomer, living near Bremen, Germany, in the time of Herschel. He specialized in the study of the planets. He wrote far too much for the good of his own reputation and never knew when to be silent. He was so much in love with every detail of his work that he couldn't bear to apply the scalpel, which make his books impossibly long to read. Many of Schroeter's scientific conclusions about the planets (though not all) were later shown to be false, so that his reputation long ago took a precipitous dive, even below his just deserts. It is true that his tedious tomes find few readers today. This is understandable, but perhaps a shame, since where he shines out is precisely in his painstakingly detailed description of things. For me the boon of his writings was in his description of telescopic images and difficulties of telescope alignment.

Schroeter had two young assistants to help at his observatory. The first was Karl Harding, who used Schroeter's Newtonians to find minor planet 3 Juno in 1804. Harding later went on to become an astronomer (under Gauss) at the Göttingen Observatory. The second assistant of Schroeter's was Friedrich Wilhelm Bessel. Bessel, it is clear, revered the memory of his mentor and rated one of Schroeter's large Newtonians as perfect, an irreplaceable masterpiece. And he said so in print. So it is clear that Schroeter's work in telescope making and his longwinded descriptions deserve attention. One of the ironies of my work is to show that though Schroeter may not have been a good astronomer, he was a great telescope maker: the "Herschel of Germany" as he was called in his day, whose fame, they said, would be imperishable. But ironically for Schroeter, his true fame came not in astronomy, as he wished, but in telescope making. Although Herschel found Schroeter an annoying prig, Schroeter went on writing detailed letters to him which survive in the Herschel Archive of papers preserved by the Royal Astronomical Society. In some ways, discovering Schroeter, his associates (Bessel in particular), and Schroeter's letters was the most unexpected aspect of my work. Schroeter and Schrader (with whom Schroeter built some of his greatest telescopes) deliver many useful, precise details about the telescopes of their age.

You see, William Herschel, as much as he was a great genius, had a strong propensity to cover up anything he considered "smelling of scandal," that is, not conducive to the betterment of his reputation and that of his family. There is thus a tendency for Herschel to be a smiling sphinx, keeping the most instructive details tightly clenched behind his lips. For this reason, we often have little useful information about the failures of his telescopes but only about their undoubted successes. And yet the failures have much to teach. Schroeter, on the other hand, was far less reticent to go on about the problems of telescopes. So Schroeter is in some ways the better friend of the historian. Still others who provided useful evidence were James South, the cantankerous double star observer, and Thomas Romney Robinson, the pugnacious director of the Armagh Observatory. Both men worked closely with Lord Rosse and provide invaluable evidence on the performance of his giant Newtonian telescopes. Rosse, as it turns out, showed South and Robinson in the 1840s how his smaller telescope (a 36″) worked in front-view mode. So Robinson and South got firsthand experience of the difference in performance of one and the same large telescope in both modes, as Newtonian and as front-view. Their descriptions are exceptionally illuminating.

It was through South in particular that I came in contact with the online, searchable archive of the *Times* of London, a rich source of historical information. South submitted a series of letters to the editor of the *Times*, which contain unique personal information about his contacts with William Herschel and vignettes of Herschel's life when very old. South alone of all these men had the enviable opportunity to look through both Herschel's acclaimed 20-ft front-view telescope and, two decades later, Rosse's 36″ and 72″ reflectors, three of the most important telescopes in history. South was not shy of saying exactly what he thought about these instruments in the *Times*. What he (and Robinson) say dovetails with the arguments and conclusions of my chapter.

Perhaps then it is this, the opportunity to live (as it were) vicariously in the worlds of the Herschels, of Schroeter and company, and of South, Robinson, and Rosse, some of the greatest telescope makers and observers in history, all of whom had rich and colorful lives, that was for me the most appealing aspect of my work. It was certainly this vicarious living that helped sustain me across the years of difficult work to produce my chapter. Many times I hesitated under the weight of integrating so much diverse information. I can only hope that patient readers of my long chapter will find it as rewarding to read as I did to write it and come away with a better appreciation for the famous persons involved.

## My Involvement with the Herschels

Michael J. Crowe

What follows is an abbreviated account of my involvement over more than four decades with William and John Herschel. In 1973, I had been on the faculty of the University of Notre Dame for 12 years, during which time I published one book, *A History of Vector Analysis* (1967), which led a friend to ask me on its date of publication, "who was Vector?" A more encouraging reaction came in 1992 when La Maison des Sciences de l'Homme in Paris awarded the book a $4000 prize. This contributed to the fact that, 50 years after its publication, the book remains in print.

For various reasons, I had decided by 1973 that the best use I could make of my doctoral training in history of science at the University of Wisconsin for my teaching and research at Notre Dame was to concentrate on the history of astronomy. In regard to research, I recognized that one area that as yet had received little attention from scholars but that stood a good chance of attracting an audience and a publisher. This was the history of ideas of extraterrestrial intelligent life. A curious feature of my interest in this topic was that it was, above all, its heavy involvement with astronomy and its linkage with values, including religion, that had attracted me. It was not a passion for science fiction or such shows as *Cosmos*. Thus I embarked on research that culminated in 1986 when Cambridge University Press published my *The Extraterrestrial Life Debate: 1750 to 1900* (700 pages). Because my undergraduate teaching was in a great books program that supported teaching mainline history of astronomy, I rarely mentioned extraterrestrials in my undergrad classes, which focused on such developments as the Copernican and Newtonian revolutions and the creation of stellar astronomy. These courses led to two books that were designed for use in classroom teaching of Copernican astronomy and stellar astronomy from Herschel to Hubble. The latter course and book led me to a careful study of the two Herschels, who also had figured prominently in my ET volume.

After the publication of my ET book in 1986, I sought a new area of research and was emboldened to attempt to fill the pressing need for a scholarly biography of John Herschel. With funding from the National Science Foundation and the hospitality of Cambridge University, which was the academic home of three prominent Herschel scholars, Michael Hoskin, Simon Schaffer, and James Bennett, I spent a year working on John Herschel materials. By year's end, I understood why no scholar had written a biography of him. The younger Herschel had contributed to almost every area of science and had left 15,000 letters scattered over the globe.

In the spring of my year at Cambridge, I was invited to give a talk on the Herschels, which led me to propose "The Herschels and Extraterrestrials," which was in effect a first draft of what may be my last scholarly paper – the essay in this volume. Because Cambridge had three scholars well known for their work on Herschel, I presented the talk with some fear and trembling. It turned out that only Jim Bennett was in town that day and was assigned to introduce my talk. He explained that both Michael Hoskin and Simon Schaffer were out of town, but he wryly predicted that Michael would assert that I had gone way too far and that Simon would suggest that I had not gone nearly far enough. As the academic year ended, I was hoping that I might edit 500 of the most important John Herschel letters. In 1989, I sought funding for this from the National Science Foundation. They contacted me offering a far larger grant provided that I would prepare a calendar of the John Herschel letters comparable to the well-known *Calendar of the Correspondence of Charles Darwin.* NSF had a sense of the magnitude of the effort this would require. They offered funding of nearly a quarter of a million dollars.

After I had agreed to this, I learned that this grant was one sixth of the external funding that Notre Dame's entire College of Arts and Letters (perhaps 300 faculty) received that year. This project involved assembling a team of 17 people, including undergraduates, graduate students, and some faculty who would contribute to this massive project. We located 14,847 letters in over a half dozen languages, and all of course were handwritten. We read and summarized each and assembled them into an 800-plus-page oversized publication: *Calendar of the Correspondence of Sir John Herschel* (Cambridge University Press, 1998). Various scholars have praised it. For example, Michael Hoskin in his *Annals of Science* review described it as a "splendid volume [that makes Herschel's correspondence] available with a convenience of which past researchers could only dream," and Brian Warner in *Observatory* stated that "The *Calendar* will be the starting point of all future Herschel scholarship." My special hope is that it will be of great help to the person who writes the first scholarly biography of the younger Herschel.

The Adler Planetarium and Astronomical Museum in Chicago has greatly contributed to Herschel research not only by putting this book online as a searchable database but also by accepting and cataloging all the materials (over 30 linear ft) involved in the creation of this *Calendar*. One too little known fact about our *Calendar* is that it almost certainly would not have been completed were it not for the fact that a University of Winnipeg historian of science, Professor David Dyck, donated two full years of his life to the project without receiving any salary for his contribution. By that time, I had decided that I was not the person to write the definitive biography. On the other hand, when the *New Oxford English Biography* staff asked me to write their new entry for John Herschel, I gladly complied.

One of my most important contributions to the history of Herschel research has been directing the doctoral theses of three scholars. The first was Marvin Bolt, whose massive *John Herschel's Natural Philosophy: On Knowledge of Nature and the Nature of Knowledge in Early-Nineteenth-Century Britain* (1998) illuminates many aspects of Herschel's career. Moreover, it was Marv who while vice president of the Adler Planetarium organized the online version of the Herschel *Calendar* and who also organized my donation of over 30 ft of Herschel research materials to the Adler. The second was Steven Ruskin's doctoral thesis, which is the basis of his excellent *John Herschel's Cape Voyage: Private Science, Public Imagination and the Ambitions of Empire*, published in 2004 by Ashgate. The third scholar who did a Herschel doctoral dissertation with me is Stephen Case, whose 2015 dissertation helped him prepare his forthcoming volume entitled *Making Stars Physical: John Herschel's Stellar Astronomy*.

Finally, it may be useful to mention two John Herschel projects in which I was involved but have realized I cannot at my age complete. The first concerns the approximately 220 letters John Herschel exchanged with his good friend William Whewell, two of the most brilliant Cambridge University figures of the nineteenth century. I have managed to get good-quality typed transcriptions of about 60 of these, some done by Isaac Todhunter in his two-volume biography of Whewell and others done by me. If a scholar could complete this volume and secure a publisher, the volume would be a greatly valued contribution. I am leaving these transcriptions in the hands of Professor Stephen Case of Olivet Nazarene University. The Adler Planetarium Library possesses photocopies of all the original letters.

The second not yet complete Herschel project was launched by Professor David Dyck with me playing a secondary role. Various Notre Dame graduates and undergraduates also participated. The goal of this project was to transcribe most of John Herschel's yearly calendars. It turns out that one of his offspring had transcribed most of these calendars, which John Herschel had written in his semi-legible handwriting. This is a project that does not as yet deserve publication. Nevertheless, if improved by someone with knowledge of Herschel's life, it would be a useful resource to place on the Internet. It would be of considerable help were a biographer to come forward.

# Contents

# About the Authors

**Roger Ceragioli** was trained as a classical scholar. He holds an A.B. degree in classical philology from the University of California, Berkeley (1984), and a Ph.D. from Harvard University (1992). His doctoral dissertation concerned ancient Greek and Roman astronomical folklore. For 5 years, he served as an assistant professor of classical studies at the University of Houston before changing career direction. Since 1998, he has worked at the University of Arizona's Steward Observatory Mirror Lab, learning the art and science of optics. He is now a master optician and has fabricated many hundreds of lenses and mirrors, small and large, for state-of-the-art professional telescopes. Some of the optics he has made have been in use on the Large Binocular Telescope (LBT), the MMT, and telescopes on Kitt Peak. He has worked on the primary/tertiary mirror of the Large Synoptic Survey Telescope (LSST), the primary mirror of the Daniel K. Inouye Solar Telescope, and the second, third, and fourth segments of the Giant Magellan Telescope (GMT), which when completed will be the largest telescope in history. At present, he holds the title of associate production manager, in charge of fabricating the fourth GMT segment. He is co-author (with Gregory Hallock Smith and Richard Berry) of the book *Telescopes, Eyepieces, and Astrographs: Design, Analysis, and Performance of Modern Astronomical Optics* (Willmann-Bell 2012). He has authored many articles on the history of telescopes. And he is currently at work on the first English-language translation and commentary of Kepler's seminal optical treatise *Dioptrice* (1610).

**Michael J. Crowe** is an emeritus professor at the University of Notre Dame, where he is the Rev. John J. Cavanaugh, C.S.C., professor in the program of liberal studies and graduate program in history and philosophy of science. Some of his publications relevant to his essay in this volume are *The Extraterrestrial Life Debate 1750–1900: The Idea of a Plurality of Worlds from Kant to Lowell* (Cambridge: Cambridge Univ. Press, 1986); *The Extraterrestrial Life Debate, Antiquity to 1915: A Source Book* (Notre Dame, IN: Univ. of Notre Dame Press, 2008); and *Calendar of the Correspondence of Sir John Herschel* (Cambridge, England: Cambridge Univ. Press, 1998). He is very appreciative of the opportunity that Dr. Cunningham extended to him to draw together into a single document researches that have extended for over 40 years.

**Clifford J. Cunningham** earned his Ph.D. (2014) in the history of astronomy at the University of Southern Queensland in Australia. His thesis dealt in large part with William Herschel's study of the asteroids. He is a USQ research fellow and is also a research associate with the National Astronomical Research Institute of Thailand. His undergraduate degrees in physics and classical studies were earned at the University of Waterloo in Canada. He has authored or edited 14 books on the history of astronomy, including seven volumes to date in *The Collected Correspondence of Baron Franz Xaver von Zach*, and a five-volume history of early asteroid research for Springer. In 2011, he discovered who created the word asteroid, and he has since advanced our understanding of astronomy in Milton's *Paradise Lost* and Ptolemy's *Almagest*. He is associate editor of the *Journal of Astronomical History and Heritage* and a contributor to the *Encyclopedia Britannica* and since 2001 has been the history of astronomy columnist for *Mercury* magazine. Asteroid (4276) was named Clifford in his honor in 1990 by the International Astronomical Union based on the recommendation of its bureau, the Harvard-Smithsonian Center for Astrophysics.

**Wolfgang Steinicke** studied physics and mathematics in Germany. He later specialized in general relativity and quantum mechanics. In his youth, he observed the sky with telescopes. Later his interest focused on Dreyer's *New General Catalogue,* which essentially rests upon observations by William and John Herschel. The research on non-stellar objects and their data and historical sources led to comprehensive catalogs, including a revision of the *NGC* and its supplements. In 2008, he received a Ph.D. at Hamburg University with a thesis on nineteenth-century deep-sky observations, published in 2010 by Cambridge University Press as *Observing and Cataloguing Nebulae and Star Clusters: From Herschel to Dreyer's New General Catalogue*. Steinicke is a fellow of the Royal Astronomical Society, the director of the History of Astronomy Section of the German *Vereinigung der Sternfreunde* (VdS), and a committee member of the British *Webb Deep-Sky Society* and works for international associations. He frequently organizes history of astronomy meetings and gives talks or courses on astrophysics all over the world. Steinicke is author of seven books (in German and English) and has published about 300 scientific articles.

**Woodruff T. Sullivan III** is professor emeritus in the Department of Astronomy and adjunct professor in the Department of History of the University of Washington (UW), Seattle. He has written *Cosmic Noise: A History of Early Radio Astronomy* (2009) and edited two earlier, related books. In 2012, he was awarded the LeRoy E. Doggett Prize for lifetime achievement in the history of astronomy by the Historical Astronomy Division of the American Astronomical Society. He is currently writing a biography of William Herschel. He is also the past director of the UW's graduate interdisciplinary astrobiology program. His research in astrobiology has centered on the search for extraterrestrial intelligence (SETI), for instance, as co-founder of the pioneering seti@home project. With John Baross, he was co-editor of the graduate textbook *Planets and Life: The Emerging Science of Astrobiology* (2007). Sundials are his passion.

**Emily Winterburn** currently lives in Leeds in England, writing books and training to be a teacher. Her biography of Caroline Herschel (*The Quiet Revolution of Caroline Herschel*) was published in late 2017. Prior to this, Emily studied physics at the University of Manchester before turning to the history of science (also at Manchester) as a postgraduate. In 1998, she began work as curator of astronomy at the Royal Observatory in Greenwich where she was responsible for a large collection of material relating to the Herschel family. At Greenwich, Emily began her thesis (with Imperial College, London) on education within the Herschel family and was awarded her Ph.D. in 2011. Since leaving Greenwich, she has worked at the History of Science Museum at the University of Leeds and written for both academic and popular audiences. Her book, *A Stargazer's Guide*, came out in 2008. She is a semi-regular contributor to *Sky at Night* magazine and won the Royal Society Essay Prize for a piece on William Herschel in 2014.

# Chapter 1

# Becoming an Astronomer: William Herschel's Journey Through an Eighteenth-Century Education

**Emily Winterburn**

William Herschel did not start out expecting to become an astronomer; it was not until he was in his mid-40s that he began to make waves in scientific circles. Until then, he had been trained to look upon music as his chief profession. It was only slowly, through decades of study in a culture that looked upon learning as a hobby as much as a means to a better life, that he began to consider astronomy, instrument making and natural philosophy as his main fields of expertise.

Very little has been written on this surprisingly long period in William Herschel's life.[1] His numerous scientific achievements have naturally meant that for a long time historians have tended to focus their attention on the period *after* he mastered instrument making and observing, and gained an understanding of current astronomical ideas and theories. Where the process of mastering these skills has been discussed, it has been only to allude to a couple of books, and his lack of formal schooling in this area and so to conclude that he was "self-taught," and remarkably efficient at doing so. However, William's education, when looked at in detail, offers some interesting insights not only into how William became the kind of astronomer that he did, but also in how we might better understand the resources available to others in the period interested in studying astronomy. In this chapter, I draw on recent work from the history of education, as well as work by historians' of science who have looked at the contributions of technicians, assistants and other peripheral characters in the story of science to develop a new narrative on William Herschel's formative years.

William Herschel's education was slow and methodical, as he gradually worked his way through various institutions and networks, and read books for a progressively more educated audience. By examining this journey, I will in this chapter place

---

[1] Exceptions include two articles by Michael Hoskin: "William Herschel's Yorkshire years", *Journal for the History of Astronomy*, **46**, 159–172 (2015), and "Vocations in conflict: William Herschel in Bath, 1766–1782", *History of Science*, **41**, 315–333 (2003).

E. Winterburn (✉)
Carnegie School of Education, Leeds Beckett University, Leeds, UK
e-mail: Ewinterburn1974@gmail.com

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_1

William's experience of education within its historical, cultural and educational context, and so see how those resources that he used so effectively might also have been available to others keen to dabble in science in this period.

The typical educational experience is an important one to understand. It is only by gaining such an understanding that we can appreciate what made William Herschel unique, and so begin to see why it was that his name is remembered when so many were forgotten. The typical experience highlighted by William's case can show us, too, why the eighteenth century scientific elite was so small. Today there are many more practitioners of science than there were in the eighteenth century. Partly this is down to simple population growth – the population of the UK today is around six times what it was in 1800 – but it is also relatable to other factors regarding available routes to becoming part of the scientific elite. William Herschel's story shows one of those routes, and the work that went into seeking it out.

## A Hanoverian Childhood

Religion and science are often thought of today as opposing forces, both trying to interpret the same phenomena but in different and sometimes contradictory ways. However, there are many stories from the history of science that show how much science owes to religion, and this is especially true of education. From Islamic Madrasas to English Sunday schools, religion, at least those that needed followers to be able to read important texts for themselves, has been a driving force behind many educational movements. In early eighteenth-century Europe, the Protestant reformation drove forward the introduction of universal education. This drive to educate – primarily so people could read and interpret the Bible for themselves – began in German states but soon spread across Europe. For the Herschel family this meant William and his brothers and sisters, unlike their mother, were able to go to school, and learn to read and write.

By William's generation, education was already well established in this family as a means of changing lives. Their grandfather had been a gardener, and trained his son, their father Isaac, to follow him into that profession. Isaac then used education – he learned music – to raise his status and change his opportunities. He became an army musician, for the Hanoverian Guards. This was a step up from being a gardener, but still a lowly profession compared to other musicians. He had higher ambitions for his children. According to William's sister Caroline, Isaac greatly desired to "see his children arrive at that eminence in this his favorite science [music], which he himself had not had the opportunity or time to attain".[2] William likewise concluded it was "my father's greatest attachment to music [which] determined him to endeavor to make all his sons complete Musicians."[3]

---

[2] Michael Hoskin, *Caroline Herschel's autobiographies* (Science History Publications Ltd., Cambridge, 2003), p. 19.

[3] 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 6.

Isaac's ambition for his children meant he taught music to all his surviving sons: Jacob, William, Alexander and Dietrich. William remembered being taught "to play on the violin as soon as I was able to hold a small one made on purpose for me." This teaching consisted of lessons from their father when Isaac was home followed by many hours of practice under the watchful eye of their mother Anna while he was away. He learned to combine lessons with long intense periods of repetitive practice. Aged 14 following an audition, William joined his father in the Hanoverian Guards.

Alongside their music practice William and his siblings went to the local Garrison school. These were schools set up by the Prussian military in the eighteenth century to teach the children of its personnel (in all ranks but the very top); elsewhere the state was establishing schools, though it would take many decades for there to be full attendance. At the Herschels' school the boys studied "basic literacy, arithmetic and religion."[4] Girls were taught there, too, and certainly learned literacy and religion; how much arithmetic they learned is unclear. Pupils would attend the Garrison school until the age of 14, with the older, more able pupils taking on some of the teaching of their younger cohorts. As an offshoot of this schooling, and towards the end of his time at the Garrison school, William and his brother Jacob started to learn French. These were private lessons, paid for either by their father or as William claims in some of his accounts, out of money he earned himself through music.[5] Although not directly relevant to his work as an army musician, these lessons still had practical value since French opera was popular within Court circles and so learning French made sense for an aspiring musician.

According to William's accounts, it was this French teacher who first introduced him to philosophy, or at least encouraged "the taste he found in his pupil for the study of philosophy, especially logic, ethics and metaphysics which were his own favorite pursuits."[6] These conversations on philosophical topics spilled over into their home life. In Caroline's autobiography, writing of a time when she was just 6 years old, she wrote that she remembered hearing: "the names of Leibnitz, Newton and Euler"[7] discussed in loud voices as she tried to get to sleep.

Instrument making too featured as part of the domestic life of this family. It offered a source of recreation, keeping the boys entertained at the end of a long day. Caroline mentioned instrument making several times in her description of family life. On one occasion she wrote of William's "self-constructed Globes &c &c."[8] Elsewhere she told of their brother Alexander who "often sat by us and amused himself with making all sorts of things on pasteboard, or contriving how to make a twelve-hour cuckoo clock go a week."[9] Although this might seem a particularly specialist form of

---

[4] 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 6.

[5] William Herschel to Charles Hutton, 1784, Harvard: MS Eng 1414 F(29); BL: microfilm M/541.

[6] Herschel, 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 7.

[7] Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 7.

[8] Caroline L. Herschel to John F. W. Herschel, 8 May 1827, BL: Eg.3761 f64.

[9] Mrs. J. Herschel (ed), *Memoir and Correspondence of Caroline Herschel* (London, 1876), p. 6.

recreation today, the autobiographical notes of some of William's contemporaries suggests it was not as unusual as it might seem. James Ferguson, James Watt, Alexander Cummings and David Rittenhouse all mention playing about at instrument making as children.[10] In each case, as with William, they used these skills in later life, but that only explains the inclusion of these anecdotes in later accounts of their lives. It is plausible the hobby was more widespread, but only remembered and commented upon in adulthood by those who made it their profession.

These early years in Hanover show the considerable groundwork that went into preparing William, albeit unintentionally, for the life he would later lead. His childhood education was primarily vocational: he was being trained to become a musician. In the process of learning music, he was taught what was involved in becoming very good at something. Yet it was also an education about education. He was taught to make use of educational opportunities as they arose – such as the chance to learn French and philosophy – and was then encouraged to see how these might weave their way into his professional life and so make him a more marketable musician. There were elements of this education that could be seen as autodidactic. He needed to put in hours of practice, and he was also encouraged to seek out teachers, but this behavior was not entirely independent or self-motivated. His mother watched over his practice, ensuring he put the hours in; his father and brother played some part in engaging a French teacher. Nonetheless, although he did not learn in total isolation, he was involved in the design and execution of his education.

## Music, Philosophy and Philomaths

In 1757 William and his older brother Jacob were sent to England by their family. The Seven Year War had begun, and the Hanoverian Guards were involved fighting on the side of the British against France and its allies. In 1757 the French occupied Hanover. There was every danger that Jacob and William would be killed if they remained, and so their parents did what they could to help them out of the country to safety. Isaac and the two boys had been to England the year before with the Hanoverian Guards, where they had made musical contacts; it seemed like the obvious choice.

London offered better prospects for jobbing musicians than Hanover, though the market was starting to become saturated. William stayed in England and managed to piece together a living. Jacob returned home as soon as he was offered a post in the Hanoverian Court Orchestra.[11] Jacob's training by his father had paid off; he had become a Court musician. William's success was slower to arrive.

---

[10] James Ferguson, Ebenezer Henderson (ed), *Life of James Ferguson, FRS: In a brief biographical account, and further extended memoir* (Cambridge University Press, 2010 reprint); Andrew Carnegie, *James Watt* (Forgotten Books, 2012 reprint). See also Dictionary of National Biography entries for Ferguson, Watt, Cummings and Rittenhouse.

[11] Michael Hoskin, *The Herschel Partnership: as viewed by Caroline* (Science History Publications Ltd., Cambridge, 2003), p. 17.

In mid-eighteenth century England there was a growing market for musicians as musical audiences expanded, and work was no longer confined (as it still was in Hanover) to Court circles. As Cyril Erlich has observed, this created a new breed of musician: a jobbing musician, no longer reliant on a patron at Court, and instead able to travel around, playing at concert venues, in country homes and giving private music lessons. It was a freedom of sorts, though as William soon discovered, it made for a very insecure way of earning a living. It was a profession dominated by foreigners, mainly Italian and German. English families who could afford music lessons tended to discourage their children from becoming performers.[12] As a musician, very much like a tradesman, William was reliant on winning over members of the upper and middle classes. His musical ability was only one aspect of that process, another equally important factor was his ability to socialize and learn the etiquette rules of polite society.

The rules of eighteenth-century English polite society were hard to define, but among these rules a strong emphasis was placed on the art of conversation. It was important to be well versed in a diverse range of topics, to a point where you might talk about them entertainingly without veering into pedantry. Natural philosophy was one of a number of polite topics of conversation. Handled well, it provided the opportunity to demonstrate a little learning, while at the same time was specifically non-vocational, and so not tied to professional expertise.[13] Lawrence Klein has shown how the tradesman Thomas Parsons studied polite topics to win over clients in his work as a maker and seller of luxury goods, and this study led him to engage in a program of self-education in natural philosophy.[14] In doing so, Parsons was able to converse with his clients on a slightly more equal footing than if he had confined himself purely to shop-talk. As a musician, William was in a similar position, serving polite society as an employee, mixing with clients, and trying to find ways of positioning himself in their company above that of servant as well as making himself stand out from other jobbing musicians. Like Parsons, there was a professional advantage to learning, and this helped motivate him to seek out a scientific education.

William's entry into this new world of polite society was gradual. He became an army musician and gradually came into contact with his new audience through performance and interaction with the social world of his band leader, Lord Darlington. There is however little explicit documentation showing how William learned the social and self-presentation skills needed to mix effortlessly with this group, his future musical clients. Ever mindful of his public image, William simply skimmed over this period in his later memorandum of his life. Caroline, luckily, was less circumspect in her accounts of her transition from domestic assistant to musician to astronomer. In her accounts, and indeed in William's accounts of her, they describe

---

[12] Cyril Ehrlich, *The Music Profession in Britain since the Eighteenth Century: A Social History* (Oxford University Press, 1985), pp. 31–32.

[13] Lawrence E. Klein, 'Politeness and the Interpretation of the British Eighteenth Century', *The Historical Journal*, **45**, 869–898 (2002); Alice Walters, 'Conversation Pieces: Science and Politeness in Eighteenth-Century England', *History of Science*, **35**, 121–154 (1997).

[14] Lawrence E. Klein, 'An Artisan in Polite Culture: Thomas Parsons, Stone Carver, of Bath, 1744–1813', *Huntington Library Quarterly*, **75**, 27–51 (2012).

her lessons not only in music but in self-presentation. She had a dance teacher to train her in how to hold herself, and was sent to London with a fashionable lady friend, to teach her how to socialize appropriately.[15] These additional lessons were designed to teach her how to perform, both on and off stage. Becoming a musician was not simply a question of learning how to play; it was also about performing a role. As a performer and jobbing musician, William, like his sister would have needed to master those skills.

After a few years in England as a jobbing musician first in London and then in the north of England with Lord Darlington, William decided he needed to find a permanent post, so when he saw a job advertised in Edinburgh in 1761 he went along to the audition. Although he writes that he did well in the audition, the work never materialized, as the former holder of the post decided to stay. Nonetheless, the trip to Edinburgh was a success in one very important respect. It helped to solidify his ambitions. He knew after this trip that he needed to find himself a permanent post, and also decided from this point on that he wanted to better understand contemporary philosophy. While in Edinburgh William had met the metaphysician David Hume and reported this event with enthusiasm in his *Memorandum*.[16] This was William's first real encounter with the world of philosophy, but after this he decided he wanted to know more.

Around this time, William had begun to read the philosopher John Locke's *Essay Concerning Human Understanding*[17]*:* "I applied myself to learn the English language" he wrote of a period sometime after arriving in England, "and soon was enabled to read Locke on the Human Understanding."[18] Locke's book – a surprisingly complicated one for a beginner – described the process of learning and emphasized that it came from practice and repetition. This description resonated with the way in which William had learned music. As a child, long hours of repetitive practice had been an essential component of his musical education. Following his meeting with Hume William began to extend his reading beyond Locke and look at other philosophical works.

In the early 1760s William referred to various books in letters to his brother Jacob. These included Leibniz's *Theodicée*, William King's *An Essay on the Origin of Evil*, and Robert Smith's *Harmonics, or the philosophy of musical sounds.*[19] In these letters he discussed the content of the books, and to what degree he agreed or disagreed with the arguments put forward. What he did not explain was where he got the books from or why he chose them. The options available to him, and others trying to acquire books in mid-eighteenth century Britain, were various. Some people bought books and accumulated vast libraries in their spacious country homes, but this was

---

[15] Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 55.

[16] 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 13.

[17] John Locke, *An Essay Concerning Human Understanding, in four volumes* (Glasgow, 1759).

[18] Herschel, 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, pp. 7–8.

[19] Robert Smith, *Harmonics, or the Philosophy of Musical Sounds* (Cambridge, 1749).

an expensive activity and the preserve of the wealthy and settled. For others – and William seems likely to have fitted into this second category – there were circulating libraries. Circulating libraries were organized by booksellers and agents, they provided catalogs and display shelves to help borrowers navigate their way around the collection, and they also offered their own expertise in recommending titles.[20] Given William's situation at the time, it would seem likely that he would have borrowed the majority of his books from circulating libraries, and indeed the absence of many of these titles in the family's later catalog of their library seems to bear this out.[21]

These books – Leibniz, King and Smith – were written to convince readers of a particular point of view; they were also all on topics already familiar to William, namely religion and music. After a few years of reading these sorts of philosophical works, William decided to try his hand at writing one of his own and in 1764 began to write his simply titled *Treatise on Music*.[22] Although never finished or published, this manuscript can be read as an attempt by William to emulate a certain style of writing, using his own expertise and his experience of teaching music. By looking only at what he published, his transformation from musician to astronomer can seem effortless and immediate; this *Treatise* however offers a more cautious picture. This was his first foray into a style of self-presentation that went beyond that purely of musician, and in it we can see him trying out a new style but then ultimately backing down.

What we are left with is a contents page, and the beginnings of a manuscript. Some seems to have been written directly to his music students. The manuscript contains for example a good deal of explanation regarding terminology and the rules of music and composition. At the same time, there is an attempt in certain passages to bring in some philosophy, and in particular to engage with the arguments presented in Smith's *Harmonics*. Smith's *Harmonics* is the only book cited in the manuscript. At one point he directs the reader to Smith where they might find "a mathematical Division and account of these intervals."[23] Later, more interestingly however, he mentions Smith again to show how it is that his ideas – grounded in his expertise in music – differ from Smith's, whose emphasis is on mathematics:

> But let us even suppose (which wants confirmation) that the degrees of pleasure arising from musical sounds answer'd perfectly the order of the simplicity of the ratios … [still we don't know] why those ratios were agreeable and so forth. … Music is a kind of natural philosophy where we reason best from Experience, and matters of fact are often the best and clearest arguments we can bring.[24]

---

[20] Edward H. Jacobs, 'Buying into Classes: The Practice of Book Selection in Eighteenth-Century Britain', *Eighteenth-Century Studies,* **33**, 1, 43–64 (1999).

[21] S. Ross and Isabella Herschel, *The catalogue of the Herschel Library: being a catalogue of the books owned by Sir William Herschel, Kt. and by his son Sir John F. W. Herschel, Bart.* (New York, 2001).

[22] Estimated date of authorship from reference in Lubbock, Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 16. William's treatise on music is described in Jamie Croy Kassler, *The Science of Music in Britain, 1714–1830: A catalogue of writings, lectures and inventions*, vol 1 (Garland Publishing, Inc., 1979), pp. 505–507.

[23] William Herschel, *Theory of Music*, Edinburgh: Ms. No. Dk.2.35, Book C, Chapter V, p. 9.

[24] William Herschel, *Theory of Music*, Edinburgh: Ms. No. Dk.2.35, Book C, Chapter V, p. 13.

Although not cited, this passage seems to draw heavily on Locke and his arguments regarding reasoning from experience. It is worth speculating on why it is that he cites Smith here but not Locke. Perhaps he was more confident in his understanding of Smith than Locke, or perhaps being new to treatise writing, he felt it appropriate only to cite the author to whom the treatise was a direct response.

William's correspondence with his brother over his *Treatise on Music* dates this work to around 1764. This gives us a sense of his gradual adoption of philosophy through the 1760s from his meeting with Hume and reading of Locke, through to reading Smith's *Harmonics* and writing his own treatise. In 1766 William then took his interest a step further, making friends and reading books and journals that suggest his interests were becoming more specialized, and that he was starting to get acquainted with a loosely connected group of like-minded enthusiasts, known to contemporaries as philomaths.

Philomaths was a term used in the eighteenth century by men and women who wanted to express their interest in a broad range of vaguely philosophical and mathematical topics, but who were not necessarily expert or in any position of intellectual authority. They were the readers and contributors to journals such as the *Ladies'* and *Gentleman's Diaries*. They read books, they attended lectures, they may even have owned a telescope and hunted for comets. Although some mathematical knowledge was common among the general population – through almanacs, such as *Poor Robin's Prophecies,* which often sat beside the Bible as the only reading matter many families would own – philomaths, and the journals they read, took this interest a step further.[25]

*The Ladies' Diary*, for example, which originated in 1704, had initially followed a similar format to the almanac, albeit with a more intellectually curious audience in mind, but it soon lost many of its almanac listings in favor of a focus on aiding mathematical discussion among its readers. *The Gentlemen's Diary,* which began some years later in 1741, modeled itself on this altered version of *The Ladies' Diary*. As Shelley Costa has pointed out, there were cost implications to the kind of intellectual dabbling carried out by philomaths, placing them in a particular social stratum. For Costa the typical reader was one with the time to ponder mathematical puzzles, and "also the luxury of using written correspondence as entertainment."[26] Paper was expensive, and free-time still a relatively rare commodity. Olaf Pedersen, in contrast, looking at *The Gentleman's Diary,* focused on their profession, concluding the readership was comprised mainly of school teachers and "leisured country gentlemen."[27]

One of the most comprehensive studies of philomath culture in the eighteenth century comes from Ruth and Peter Wallis. Their work shows the breadth of interests pursued by this informal, self-identifying group. As an indication of contemporary

---

[25] Benjamin Wardhaugh, *Poor Robin's Prophecies: A curious almanac, and the everyday mathematics of Georgian Britain* (Oxford University Press, 2012). NB Ladies' and Gentlemen's Diary both discussed as they compare to almanacs and came to serve different audiences, see pp. 132–141.

[26] Shelley Costa, 'The "Ladies' Diary": Gender, Mathematics, and Civil Society in Early-Eighteenth-Century England', *Osiris*, **17**, 49–73 (2002), p.56.

[27] Olaf Pedersen, 'The "Philomath" of 18th century England', *Centaurus*, **8**, 238–262 (1963), p. 250.

uses of the term, John Draper's print (Fig. 1.1) shows the types of subject considered to be philomathematical in the eighteenth century.[28]

This book was written by John Draper, a schoolmaster whose school in Whitehaven advertised itself as providing an education relevant to "trade and seamanship." This was a major reason for teaching mathematics and the use of mathematical instruments in the eighteenth century – it would help pupils find work in certain industries. (Image courtesy of the British Library Board.)

The Wallis' added still further to the vast set of interconnected subjects covered by Draper, suggesting the addition of both music and instrument making to the list. Philomaths were interested in mathematics in all its various forms and applications. They were interested in the practical sciences, too, though as Draper's diagram suggests, mainly concentrated on those that contained an element of quantitative measurement. William's journey through these different interests and specialties places him very definitely in the philomath tradition. The various descriptions of philomath culture given by Draper, the Wallis's, Peterson and Costa, give some broad characteristics, but offer little indication of how similar individual philomaths were to one another in their interests. Although many topics fell within this umbrella term, it does not follow that all philomaths were interested in all philomathematical subjects, or indeed treated all equally. William's example suggests philomaths could be, if they chose, rather selective. Drawing from his previous experience of learning and then mastering music and languages, William's approach to the world of philomaths was to pick and choose his subjects, learning from those around him how to move from one to another.

Having discussed some philosophy with his brother and tried his hand at his own treatise in the early 1760s, William became more explicit in 1766 in discussing who else was helping him to make connections within the philomathematical world. On January 1 he wrote:

> 1766, Jan 1. Wheatley. [in South Yorkshire].… This was the country seat of Sir Bryan Cook, where every fortnight I used to spend two or three days. Sir Bryan played the violin and some of his relations generally came from Doncaster to make up morning concerts… Feb. 19. Wheatley. Observation of Venus.[29]

Bryan Cook was a philomath. He was not a fellow of the Royal Society or a teacher or a bookseller, yet William's reference here suggests he had some interest in astronomy that he was keen to share, and that was, with their informal structures, enough to qualify him as a philomath.

Two weeks later he wrote of a "Mr. Grey, a philosophical Gentleman with whom I have corresponded. He was a brother of Sir Henry Grey of Northumberland and lived in Newcastle."[30] The Greys were a well-established aristocratic family (a later

---

[28] Peter and Ruth Wallis, *Mathematical Tradition in the North of England* (NEBMA, Durham, 1991).

[29] Lubbock, Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 35. NB Sir Bryan Cook here is plausibly Sir Bryan Cooke, 1717–1769, a baronet.

[30] Herschel 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 19.

**Fig. 1.1** Frontispiece to J. Draper, young students' pocket companion, or arithmetic, geometry, trigonometry, and mensuration, calculated for the improvement of youth at school (1772)

member of the family would have a tea named after him), but they were not well known within scientific or philosophical circles. Nonetheless William refers to him as "a philosophical Gentleman," suggesting this was a shared topic of conversation. Both Cook and Grey were men known to William through music, who, these references suggest, provided him with help in learning more philosophy.

Toward the end of 1766 William described an audition:

> I was a candidate for the place of organist, which by the interest of the Messrs Bates and many musical families I attended, I had great hopes to obtain. About this time I was an inhabitant of Halifax. My leisure time was employed in reading mathematical books such as the works of Emerson, Maclaurin, Hodgson, Dr. Smith's Harmonics, &c. This happened to be noticed by one of the Messrs Bates who told his brother: "Mr. Herschel reads Fluxions!"[31]

The books that he listed as having been seen reading were typical of the kinds of beginners' guides to fluxions popular with philomaths in the mid-eighteenth century.[32] Unlike the books he had been discussing with his brother, these were books of varying difficulty on a single topic. The books he had previously been reading were on such diverse topics as how to learn, harmonics, and religion. They were all books offering a philosophical view on subjects with which he was already familiar. This new reading list in contrast shows an attempt to master a new subject, one that was of central importance to the philomath community.

The authors and books specifically referenced in the above quote fall roughly into two categories. The authors William Emerson and James Hodgson were both schoolteachers, writing exclusively for a beginner/philomath audience. Maclaurin and Smith on the other hand were professors, writing as much for their university students as for the general public. Maclaurin's book on fluxions in particular – written, so he claimed in his introduction, because all existing literature on fluxions was inadequate – is a very complex book for a beginner. According to Niccolo Guicciardini, there was plenty of room for both approaches as the market for these books steadily grew in the eighteenth century, reaching its peak mid-century. William was not alone in taking up his new interest: as he read them, these books were at the height of their popularity.

The Bates brothers William referred to above were important figures in public music in Halifax in the eighteenth century. Joah Bates was a musician and civil servant, responsible for organizing public music events in the town and so an influential person to win over.[33] The brothers, William declared, knew and commented upon the fact that he "reads fluxions." This means William must have made this information public. He does not state how he did this, though it seems plausible to suggest he either took these books with him to the audition, or while there, talked extensively of their content. The Bates' surprise suggests this was a relatively unusual activity among musicians, but not so unusual that they were unfamiliar with the term 'fluxions.'

---

[31] Herschel 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 20.

[32] Niccolo Guicciardini, *The development of Newtonian calculus in Britain 1700–1800* (Cambridge University Press, 1989), p. 56 lists 12 frequently reprinted books on fluxions from 1736 to 1758. Maclaurin, Hodgson and Emerson are all on the list.

[33] Fiske and Johnstone, *Blackwell History of Music in Britain, Eighteenth Century* (Blackwell, Oxford, 1988), p. 246.

William was starting to use his intellectual interest in mathematics and philosophy to help him stand out in the competitive and overpopulated music market. He was also using his musical contacts to help him access an education through their associations with the philomaths world. This world offered many people the chance to gain a mathematical and philosophical education and so improve their prospects. Some, like Herschel and as we have seen, Thomas Parsons, used this education to give themselves the edge in their existing professional lives. For others, it offered the chance to change profession.

Although the term philomath is rarely used today the journals philomaths contributed to, such as the *Ladies' Diary* and the *Gentleman's Diary*, have often featured in the biographies of minor figures engaged in eighteenth century scientific life. Silk weaver and amateur astronomer James Six, "self-taught" mathematician John Dawson, and clergyman and man of science George Walker for example were known to be contributors. They all engaged in this world to help them learn and eventually contribute to science, mathematics and philosophy. William Wales meanwhile was able to use his associations with the philomath community, including contributions to the *Ladies' Diary*, to prepare him sufficiently to land a job as assistant at the Royal Observatory Greenwich.[34] All these men were aided in their ability to play a role in eighteenth century scientific and mathematical life by the education they gained through their engagement with the philomaths world.

William spent many years as a philomath while continuing to earn a living teaching and playing music. Fourteen years after his audition in Halifax, he was still involved with this culture, still reading and for the very first time contributing to the *Ladies' Diary*. In 1780 William made his first public attempt to test out his understanding of the mathematics he had been learning by sending in a solution to a problem in the *Ladies' Diary*.[35] Problems in the *Ladies' Diary* were always set to invite contributions. Everyone who sent in a correct answer would get their name published alongside each correct method.[36] Even after 14 years of part-time study, William's solution shows his reluctance to claim too much for his abilities. The problem he chose was one combining music and mathematics. It asked for the number of vibrations on a musical string to which a small weight has been attached, when length, tension and weight are all given.[37] In giving his answer, William timidly suggested it might "not be considered mathematically true" but was nonetheless practically true.[38]

---

[34] The role of philomath culture in the education of British mathematicians in the eighteenth century is referred to in Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Mathematical Physics* (University of Chicago Press, 2003) pp. 34–35.

[35] Herschel, 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 83.

[36] Niccolo Guicciardini, *The development of Newtonian calculus in Britain 1700–1800* (Cambridge University Press, 1989), pp. 115–117.

[37] From *Ladies' Diary* 1779 reproduced in John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. xxviii.

[38] William Herschel, 'The same [solution to...] by Mr. Wm. Herschel', *The Ladies' Diary*, 1780, pp. 46–47, p. 47 reprinted in John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. xxix.

William's first couple of decades in England offered him some excellent opportunities to continue his education, and he took them. This is a period that is often overlooked in traditional narratives of William's life, but its study shows how rich the educational landscape could be for those seeking out opportunities to learn. William's profession as a musician gave him access to a leisured class, people who had the time and money to pursue intellectual interests for no other reason but for the joy of learning. Through them, he saw in mathematics and philosophy a possible shared interest and used their knowledge to develop that interest. Over a period of 20 years, helped out by that informal network of schoolteachers, writers, lecturers and country ladies and gentlemen known as philomaths, he was able to gradually increase his understanding. Nevertheless, it took time to develop confidence in that knowledge, and to that end, even as late as 1780, he was still claiming expertise solely in music, and only a working knowledge of mathematics.

## Family Reunions and Telescope Building

In December 1766 William found a permanent and secure musical post as organist in a newly constructed chapel in the fashionable town of Bath. By the mid-eighteenth century Bath had become one of Britain's most popular spa towns among London society, and many would spend the whole winter "season" in Bath taking the waters, attending concerts and balls and going to music lessons. For a musician hoping to supplement his income serving this market, Bath made an excellent base. Once settled in his new home, William sent word back to Hanover and was soon joined by his younger brother Alexander, and for a brief time, their younger brother Dietrich, both of whom were also aspiring musicians. A few years later, William returned to Hanover, having arrived at a plan with Alexander, and brought their sister Caroline back to England with him.

It has been observed elsewhere that Caroline's arrival in Bath, and the duties she was able to take over, had an important role to play in freeing up William's time for instrument making.[39] Caroline, however, was not the only one of William's siblings to arrive and help make his instrument making project possible. Just as important was the arrival of their brother Alexander a few years before Caroline. Returning Alexander to this story gives a new way of understanding Caroline's contribution to this family business. Traditionally the story has focused only on William and Caroline, and as a result their contributions and respective talent have sometimes been viewed almost as though they were in competition with one another. So though some historians have been careful to place Caroline in a subservient role, assisting her more scientific brother, others have tried to raise her position in this perceived hierarchy and show her as a pioneer.[40] Adding Alexander to the story complicates

---

[39] Richard Holmes, *Age of Wonder* (Harper Press, London, 2008), p. 83.

[40] Michael Hoskin, *The Herschel Partnership: as viewed by Caroline* (Science History Publications Ltd., Cambridge, 2003), p. 4; Claire Brock, *The Comet Sweeper: Caroline Herschel's Astronomical Ambition* (Icon Books, London, 2007).

this binary approach, and instead highlights the diversity of roles and skills William had to draw upon to make his instrument making and observing ambitions a reality.

Workshops and within them a hierarchy of labor were an increasingly dominant feature of the scientific instrument trade in eighteenth century Britain. As Richard Sorrenson has observed, instrument makers often gave parts of the overall design of an instrument over to assistants, apprentices and subcontractors. Towards the end of the century this became more common as the heads of a number of predominantly London-based instrument making workshops became important names in the scientific world of the Royal Society, prized for their innovation and design skills, which took them away from the day-to-day practical (manual) work of the shop floor.[41]

This was the model to which William Herschel was working. Instrument making – or at least some aspects of it – was, for this brief period in history, a well-respected skill among Britain's scientific elite. The elements most prized were the ability to create an overall design, certain aspects of the practical work and the facility to draw together and make best use of the skills of others. Instrument making for William then offered a respectable and easily demonstrable way of engaging in the scientific world. In addition, there was another reason why William may have been attracted to instrument making, and that, as Anthony Turner has pointed out, was one of cost.[42] Shop-bought instruments were expensive. They were also difficult to get hold of outside of London. Instrument making therefore was as much a practical solution to that problem, as it was a means of gaining a reputation in the scientific world.

We know from James Spaight's study of Herschel's telescope making business the extent to which William subcontracted parts of his telescope making after he started making them for commercial sales in the 1780s. By then he had a cabinet maker and joiner to make the tubes and stands, an optician for the lenses, a smith to forge the metal for mirrors and other metal work. He also had his brother Alexander and an apprentice (termed their "brass man") to work on eyepieces and micrometers.[43] William was in charge of grinding and polishing the mirrors. In terms of the instrument making industry, this was the highest ranking task within the process, making him the official maker of the instrument despite the many contributions of others.[44] Even in this role, however, he seems to have had his helpers. Caroline referred at one point to having helped make mirror molds (out of manure and straw); elsewhere the siblings tell of an incident in which both William and Alexander were working together on a mirror when a mold broke, damaging the kitchen floor with molten metal.[45]

---

[41] Richard Sorrenson, *Perfect Mechanics: Instrument Makers at the Royal Society of London in the Eighteenth Century* (Docent Press, Boston, 2013).

[42] Anthony Turner, *Science and Music in eighteenth century Bath* (1977), p. 53.

[43] J. T. Spaight, '"For the good of astronomy": the manufacture, sale, and distant use of William Herschel's telescopes', *Journal for the History of Astronomy*, **35**, 1, 45–69 (2004).

[44] Gerard L'Estrange Turner, *James Short, F.R.S., and his contribution to the construction of reflecting telescopes* (Royal Society, 1969). See also Allan Chapman, *Dividing the Circle* (1995), pp. 139–145.

[45] Michael Hoskin, *Caroline Herschel's autobiographies* (Science History Publications Ltd., Cambridge, 2003), p. 63.

Alexander, William's younger/Caroline's older brother arrived in Bath in 1770, aged 24. Like all the Herschel brothers he was a trained musician, but he was also a keen amateur mechanic. As a child he had tried to make his own cuckoo clock. As an adult, a later family member discovered, he had grown ever more single-minded in this hobby. Among William's letters, gone through by this later family member, were found "some curious ones of his brother Alex all confined to the subject of mechanics."[46] Compounding this image still further, William's son John told the following anecdote about his uncle:

> He never moved away from his own home, except to pay a yearly visit to his brother's [i.e., William's] family and then invariably came accompanied by his turning lathe and other implements, and getting himself & them established the moment of his arrival, in the workshop (now H's observatory) scarcely left that apartment during the whole period of his stay.... He used to go away after his stated week of visitation had expired having scarcely seen his friends all the time, but declaring himself quite delighted with their society.[47]

All this reminiscence suggests Alexander was an avid, if unsociable, mechanic. Professionally he was a musician, but his spare time was happily filled carrying out just the kind of metalwork that William needed in order to make his own telescopes. He appears to have had no particular need for friends, but had a family who would indulge him. That William came to rely on his brother's talents is evident in the letters they exchanged after William moved to Slough in the 1780s and Alexander remained in Bath.[48]

Caroline arrived in Bath a couple of years after Alexander, in 1772, and immediately helped William take up instrument making by taking over the myriad tasks otherwise occupying his days. She took over supervising the household staff, and in time many of their duties, and as her English and musical skills improved, she began to copy musical scores and teach the choir for him, too.[49] For Caroline this was essentially a continuation of her work back in Hanover; she was there to carry out the many low-prestige tasks that needed to be done in such a way that her siblings would soon wonder how they could ever manage without her. For William it meant simply that he had more time to practice and perfect his instrument making.

In addition to the arrival of his two siblings, William was also helped to get started on telescope building by a local man who offered to sell him mirror making tools and give him a few starter lessons.[50] William was not especially generous in his account of this man's help, claiming that with these tools "I found no difficulty to do in a few days all what he could show me, his knowledge indeed being very confined."[51] Instead he suggested that books were of more help, turning to familiar

---

[46] Anecdotes of John F. W. Herschel as noted down by James Stewart, September 1833, JHS papers ARM.

[47] Anecdotes of John F. W. Herschel as noted down by James Stewart, September 1833, JHS papers ARM.

[48] William Herschel to Alexander Herschel, 10 March 1785, RAS: WH.1/9.2

[49] Richard Holmes, *Age of Wonder* (Harper Press, London, 2008), p. 83–86.

[50] John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. xxiv.

[51] John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. xxiv.

authors such as "the assistance of Dr. Smith's popular treatise."[52] He read three books by Emerson (whose book on fluxions had helped him before): *Trigonometry*[53]; *Optics*[54] and *Mechanics*.[55] He also read James Ferguson's *Astronomy*,[56] plausibly, as Anthony Turner has observed, because Ferguson was lecturing to large paying audiences in Bath at around this time.[57] In the 1740s William had mastered music, in the 1750s it was languages, in 1760s fluxions, now, in the 1770s it was the turn of instrument making.

William's debt to these authors is perhaps seen most clearly in the design of his infamous 7 ft. reflector telescope. As Michael Hoskin and Reginald Jones have discussed, Smith's book offered a step-by-step guide to building a reflector telescope very similar to William's.[58] Using Emerson's books, William was then able to amend and improve on this design.

However, William learned more from these books than simply how to build a telescope. He was also given an introduction to what to look for through his finished telescope.[59] Not only that, but Smith's book provided him with lessons in how to use his telescope, and more specifically, how to train his eye and brain to process what he could see.[60]

Besides its section on instrument making, on mathematics and on telescopic discoveries, Smith's *Opticks* also has a chapter "Concerning our ideas acquired by sight."[61] In this chapter, Smith told the story of William Cheselden, a famous

---

[52] Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 66.

[53] William Emerson, *The elements of trigonometry* (W. Innys, London, 1749) which he is quoted as having read in John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. xxiv.

[54] William Emerson, *The elements of optics* (London, 1768); Herschel, 'Memorandums from which an historical account of my life may be drawn', RAS: WH.7/8, p. 30.

[55] William Emerson and G. A. Smeaton, *The principles of mechanics* (W. Innys & J. Richardson, London, 1754).

[56] James Ferguson, *Astronomy explained upon Sir Isaac Newton's principles and made easy to those who have not studied mathematics* (London, 1756) which he is quoted as having read in John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. xxiv.

[57] Anthony Turner, *Science and Music in eighteenth century Bath* (1977), p. 53.

[58] Reginald Victor Jones, 'Through music to the stars: William Herschel, 1738–1822', *Notes Rec. R. Soc.*, **33**, 37–56 (1978), p. 42. Also Michael Hoskin, *William Herschel and the construction of the heavens* (Oldbourne, London, 1963), p. 20.

[59] Simon Schaffer, 'Herschel in Bedlam: natural history and stellar astronomy', *British Journal for the History of Science*, **13**, 45, 211–239 (1980), p. 222; Michael Hoskin, 'William Herschel's early investigations of nebulae: a reassessment', *Journal for the History of Astronomy*, **10**, 165–176 (1979), p. 167.

[60] William Herschel to Alexander Aubert, 28 January 1782 in Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 104.

[61] Robert Smith, *A Compleat System of Opticks,* (1738), pp. 42–43.

eighteenth-century surgeon, and his work on cataracts. Cheselden's work involved removing the cataracts by surgery and then teaching the patient to see, or to see again. In Smith's book, this story was told with specific reference to Locke's *Essay Concerning Human Understanding*. It was told as a means of explaining how sight is not just about the eye but about the brain and its interpretation of what is seen, and how with repetitive practice, the brain can learn to do this more efficiently. For William this had an obvious resonance. Locke had spelled out for him the process by which he had learned music; here was that process again, presenting him with a way of learning how to see better through his telescopes. As he explained to his friend and fellow astronomer Alexander Aubert, spelling out these connections:

> When you want to practice seeing (for believe me Sir, – to use a musical phrase – you must not expect to see at sight or a livre ouvert) apply a power something higher than what you can see well with, and go on encreasing [sic] it after you have used it some time.[62]

Smith and Locke had helped William to use his expertise and experience in music to understand how to become an instrument maker and astronomer. Through practice he became a better and better observer. His instrument-making skills improved too as he practised, experimenting with small but significant changes to the composition of the alloy he used for his mirrors and trying out different polishing techniques. In 1778 a paper was published in *The Philosophical Transactions of the Royal Society* by John Mudge, who was awarded the society's most prestigious prize, the Copley Medal. The paper described a new mirror-making technique devised by the author John Mudge, a physician and brother to the famous clockmaker Thomas. William was intrigued, and tried out this new method, only to find his own method was better.[63] This discovery gave him a new confidence in his abilities as an instrument maker.

Membership of the Royal Society at this time included a notable percentage of non-scientific men, rich gentlemen with no particular interest or talent for science but with the wealth to keep paying fees and so keep the society solvent. Among the scientific men, of whom there were also a reasonable number, were several highly talented instrument makers. For Mudge to have won the Copley Medal he would have needed to impress these makers; that William's telescope making techniques were better showed he had achieved a very high standard. William's solution to the *Ladies' Diary* question was couched in language to suggest his expertise lay in music, not mathematics or philosophy. After reading Mudge, William began to grow in confidence about his instrument making skills. While he was still careful not to claim too much for his mathematics, he now began presenting himself as much as an instrument maker as a musician.

---

[62] Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), pp. 104–5.

[63] Joachim Rienitz, 'William Herschel's mirror test and its consequences', *Bulletin of the Scientific Instrument Society*, **6**,(1985), p. 5 also in Reginald Victor Jones, 'Through music to the stars: William Herschel, 1738–1822', *Notes Rec. R. Soc.*, **33**, 37–56 (1978), p. 39.

## Bath Philosophical Society

Bath's fashionable status was newly won. According to Roy Porter as late as 1700 "no provincial town could hold a candle to London" and "outside London, culture merely glimmered with a few reflected beams; outside London, there seemed a wasteland of rusticity."[64] Between 1700 and 1800, however, several provincial towns grew exponentially, and their high culture facilities such as luxury accommodation, theatres, concert halls and pleasure gardens grew with equal speed. Bath itself went from having around 2,000 permanent resident to 34,000 by 1800. The country's infrastructure improved, too, so that Bath residents could connect with London through newspapers and better roads, quicker than ever before. As a winter destination for the London elite, Bath had the edge over other competing towns in part because of its waters, well-known since ancient times for their medicinal properties. A couple of well publicized royal visits added to the town's allure, but perhaps most important of all were the efforts of Beau Nash, whose work as master of ceremonies made Bath one of the liveliest resorts of the eighteenth century.[65]

Within the context of this burgeoning fashionable leisure industry, science played a relatively low-key role. For the most part, the town was a place of musical and theatrical diversions, alongside the therapeutic taking of the waters. Scientific entertainment was, however, becoming part of this world of polite leisure activities, so while they may not have dominated the cultural scene, Bath and Bristol were nonetheless part of the circuit for itinerant lecturers such as William Whiston and later James Ferguson, Benjamin Martin, James Arden, Henry Moyes and John Warltire.[66] Residing in Bath were a small number of individuals interested in furthering their scientific knowledge beyond what these lecturers and the often associated philomath authors could teach them, as William Herschel soon learned.

The Bath Philosophical Society was established in 1779, growing out of the Bath Agricultural Society, which had formed 2 years earlier. Both societies were established by the draper Edmund Rack, son of a weaver and keen social climber, but the Philosophical Society was created also with the help of Thomas Curtis, a governor of Bath General Hospital.[67] By the early 1800s there were many literary and philosophical societies in towns and cities across the country, but Bath was one of the first.

The society was designed to bring together interested individuals from a range of backgrounds, allowing them to discuss the latest philosophical ideas and report back on their own experiments and observations. It allowed the socially ambitious – people

---

[64] Roy Porter, 'William Herschel, Bath, and the Philosophical Society', in Garry Hunt (ed), *Uranus and the Outer Planets* (Cambridge: Cambridge University Press, 1982), pp. 23–34, p. 24.

[65] Anthony Turner, *Science and Music in eighteenth century Bath* (1977), p. 7.

[66] Roy Porter, 'William Herschel, Bath, and the Philosophical Society', in Garry Hunt (ed), *Uranus and the Outer Planets* (Cambridge: Cambridge University Press, 1982), pp. 23–34, p. 28; on science becoming part of polite society see Alice Walters, 'Conversation pieces: Science and politeness in eighteenth century England', *History of Science,* **35**, 121–154 (1997).

[67] Lawrence E. Klein, 'An Artisan in Polite Culture: Thomas Parsons, Stone Carver, of Bath, 1744–1813', *Huntington Library Quarterly*, **75**, 27–51 (2012); Rack's background also mentioned in Anthony Turner, *Science and Music in eighteenth century Bath* (1977), p. 82, p. 91.

such as Edmund Rack, William Herschel and the tradesman Thomas Parsons – to mix with people of a higher social standing than themselves.[68] It also gave them access to books and journals they might not otherwise be able to afford.[69] For those higher up the social scale, it provided a wider circle of philosophically minded individuals than they might find among their peers.

By the end of 1779 William, having tested his mirrors against those praised by the Royal Society, was confident in his telescope making abilities. He was also a consummate performer. With this in mind, he took his telescope into the street to observe the Moon:

> I brought my seven feet reflector into the street, and directed it to the object of my observations. Whilst I was looking into the telescope, a gentleman coming by the place where I was stationed stopped to look at the instrument. When I took my eye off the telescope he very politely asked if he might be permitted to look in, and this being immediately conceded, he expressed great satisfaction at the view. Next morning the gentleman, who proved to be Dr. Watson, jun. (now Sir William), called at my house to thank me for my civility in showing him the moon, and told me that there was a Literary Society then forming at Bath, and invited me to become a member of it, to which I readily consented.[70]

Dr. Watson was a member of the newly formed Bath Philosophical Society, referred to here as a "Literary Society." He was also a member of the Royal Society and a physician. His scientific interests, as was true of many in the Bath Philosophical Society, tended toward natural history rather than astronomy, but he could see William had enough in common with them to make a good member of this new group.

William picked up on this shared but not quite shared interest in scientific matters. In his enthusiasm to please his hosts, he chose to give his first paper not on mathematics, astronomy or instrument making but on their preferred area of interest: natural history.[71] This first paper described his observations over a series of days of a branch of coralline; giving particular attention to his apparatus and the microscope's magnifying power.[72] In his concluding remarks, he made a throwaway reference to Leibniz to show he was well read. This paper was William's way of introducing himself to the society, and grabbing their attention with a topic from their, rather than his, field of expertise. With their attention gained, he then proceeded to present himself as an expert on instrumentation, and well-informed in natural philosophy.

---

[68] Lawrence E. Klein, 'An Artisan in Polite Culture: Thomas Parsons, Stone Carver, of Bath, 1744–1813', *Huntington Library Quarterly*, **75**, 27–51 (2012).

[69] Máire Kennedy, 'Reading the Enlightenment in Eighteenth-century Ireland', *Eighteenth-century studies,* **45**, 3, 355–379 (2012).

[70] Constance Lubbock, *The Herschel Chronicle: The Life-Story of William Herschel and his Sister Caroline Herschel* (Cambridge, 1933), p. 73.

[71] William Herschel, 'Observations on the Growth and Measurement of Corallines', read to *Bath Philosophical Society*, 18 February 1780 reprinted in John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912), p. lxvi.

[72] He does not say who made the microscope.

William did not return to natural history after this first paper, at least not overtly. Instead he incorporated natural history into his astronomy. Most contemporary astronomers at this time were primarily interested in detailed measurements of objects within the Solar System. As Simon Schaffer has convincingly argued, William's time with the Bath Philosophical Society, surrounded by people interested in natural history, gave him a very different approach to astronomy to that of his contemporaries.[73] Like a natural historian, William looked at the sky with a view to surveying, collecting and classifying, and so produced his catalogs of nebulae, star clusters and double stars. This work helped him spot the unexpected (such as a new planet); it also gave him the raw data from which to theorize about the size of the universe and the evolution of nebulae.

William began to report to the society on observations made with his telescopes.[74] Two of these papers – one on a star in Collo Ceti, the other on Lunar Mountains – were later read to the Royal Society. His remaining papers to the Bath Philosophical Society were all kept and were eventually published in 1912 by John Louis Emil Dreyer. Through these papers, William can be seen gradually refining and improving his presentation of his ideas to conform to what was then expected in a scientific paper. To begin with, he would simply write out a description of what he had seen and done. Later, however, he learned how to incorporate more into his papers, so that he could use his observations to talk about ideas and talk about his telescopes and use his reading in a way that blended with the rest of the paper. By the time he came to discover the planet Uranus in 1781 he had perfected his paper writing skills, and understood the process of getting papers published by the Royal Society.

Through his involvement with the philomaths and later the Bath Philosophical Society, and through his reading and later writing, William had learned how to observe, make instruments, and write papers in such a way as to be taken seriously. So, when on the evening of Tuesday, March 13, 1781, he noticed an unexpected object in the constellation of Taurus, he knew what to do. No one at this point had ever discovered a planet (Mercury, Venus, Mars, Jupiter and Saturn are all visible to the naked eye and had been known since before written records began), so William assumed he had discovered a comet. Caroline was away that evening, dealing with the closure of their short-lived and unsuccessful millinery business, but he perhaps got her to have a look at it soon after. Four days later he checked again, and the following evening showed it to William Watson, who told him to write it up and arranged for that report to be sent, via Watson's father, to the Royal Society. By April

---

[73] Simon Schaffer, 'Herschel in Bedlam: natural history and stellar astronomy', *British Journal for the History of Science*, **13**, 45, 211–239 (1980).

[74] All reprinted in John Louis Emil Dreyer, *The Scientific Papers of Sir William Herschel* (Royal Society and the Royal Astronomical Society, London, 1912): 'Observations on the Mountains of the Moon'; 'Continuation of the Observations on the height of the lunar Mountains'; 'Astronomical Observations on the Periodical Star in Collo Ceti'; 'Communication of my letter to the Rev. Dr. Maskelyne, On the Measurement of the Lunar Mountains'; 'Observations on the Occultation of Gamma Virginis, made with a view to determine whether any Effect of a Lunar Atmosphere could be perceived'; 'On the periodical star Collo Ceti'; 'Account of a Comet'.

William's discovery was being talked about as a new planet.[75] William Herschel had become a world-renowned astronomer. (Fig. 1.2)

**Fig. 1.2** William Herschel, a portrait to accompany his interview in the *European Magazine*. This portrait accompanied an account given by William of his life leading up to his discovery of the planet Uranus. Around him you can see all the paraphernalia of astronomy an eighteenth-century reader would expect to see – a small telescope, a sextant, a globe – none of which he actually used for his discovery. Alongside these is a half unrolled scroll showing or hinting at a diagram showing the Solar System complete with his new planet (Courtesy of Wellcome Library London)

---

[75] Details of William's planet discovery can be found in Michael Hoskin, *Discovers of the Universe: William and Caroline Herschel* (Princeton: Princeton University Press, 2011), pp. 49–51.

## Conclusion

William Herschel's educational journey, from musician to astronomer, was at once both remarkable and entirely typical for his time. He was remarkable in his dedication, and his unrelenting focus, continuing to pursue subjects for years in order to truly master them. As a child musician, he was trained to see education as a process of gaining expertise in a single field. This was not a broad "liberal" education, as an upper or middle class English boy might have been given at this time. Instead, William was trained in music in order to make it his profession, and moreover, in order to excel in his profession. This gave him a different way of understanding education to many of his contemporaries. At the same time, the resources and opportunities to learn first mathematics and then instrument making and astronomy were the same as those available to anyone interested in those subjects in this period. Everyone effectively learned these subjects from the same books, journals, and traveling lecturers. A rare few found a gifted and well-connected mentor. Most, like William, had to build up their knowledge with guidance from a range of people, all with only slightly more knowledge than themselves.

Music was still considered connected and in some circumstances as a branch of philosophy and mathematics in the eighteenth century, and so that gave William his starting point. It was however his profession, and so in the interests of showing his employers he was more than simply a servant, he decided to develop his expertise in other areas of mathematics and natural philosophy. To do this he drew on philomath culture, talking to fellow enthusiasts, attending lectures, reading books and journals aimed at this audience, and later joining his local philosophical society and finally becoming a fellow of the Royal Society. Although few were as successful as William on this journey, many others who served the upper and middle classes – the traders and the tutors – would pursue these kinds of educational diversions and use them to either change professions or make themselves stand out in an often saturated market.

Scientific education in the eighteenth century did not, for the most part, take place in schools or universities. Some teachers may have provided a smattering of scientific learning, and mathematics teaching was fairly widespread, but for those wanting to understand and even participate in contemporary science, another kind of education was needed. This education came, as William Herschel discovered, through informal networks, each catering to a slightly different level. There were books, journals such as the *Ladies' Diary*, traveling lecturers, and booksellers able to help the literate beginner gain an understanding of the latest scientific theories and ideas. There were literary and philosophical societies for those with a slightly more in-depth knowledge and interest, keen to improve their understanding through experiment and discussion, and then, for a well-connected few, there was the Royal Society. By traveling through these different subsets of the eighteenth century scientific world, William was able not only to expand his mathematical, philosophical and scientific knowledge but also to learn at each stage the tacit knowledge of how to act and how to present ideas to each new audience.

To some degree William was self-taught. He sought out these various groups and used the skills he had learned in childhood to ensure he was able to master each new field of study. At the same time, however, William's story also shows the plethora of individuals and groups who helped make his journey possible. His parents taught him how to learn; his employers, booksellers and friends all showed him what to read, and the authors themselves helped in turn. He was aided, too, by his siblings and local craftsmen who helped make his instrument making ambitions a reality, while members of the Bath Philosophical Society, and their contacts at the Royal Society, patiently worked with him to improve each paper and make it ready for publication.

In this new interpretation of William Herschel's formative years, we see that what made Herschel unique and unusual was his focus and perseverance. The books he used, the friends he made, and the societies he joined were options available to many, but few would have invested almost a decade of their lives mastering fluxions and then another slogging away at perfecting their telescope-making skills, and all with no obvious end goal. He had advantages – his musical career taught him the benefits of practicing skills to perfection and gave him access to a set of people who could help him create a meaningful education. The Bath Society's interest in natural history helped him develop a new style of astronomy that set him apart from his contemporaries. He was lucky, too, in having such accommodating siblings, willing, once he was financially secure, to leave their home for his and so help him pursue his hobby. However, it was the combination of these environmental factors and good luck with his determination that created the astronomer we have come to see today as such a pivotal figure in the history of astronomy.

# Chapter 2
# William Herschel and Comets

### Woodruff T. Sullivan III

## Introduction

The bulk of what historians have written about William Herschel deals with his ideas on the structure of the Milky Way, as well as on the nature of the nebulae and stellar clusters that he cataloged. His study of Solar System bodies has been particularly neglected, excepting of course his remarkable 1781 discovery of Uranus that permanently changed him from a musician to an astronomer. Yet fully 40% of Herschel's publications in the *Philosophical Transactions of the Royal Society* (hereafter *Phil. Trans.*) were on Solar System topics. Is this corpus just a sideline, of little interest in understanding his grand schemes on the "Construction of the Heavens"? In this article we focus on only a fraction of Herschel's Solar System research, that on comets, and argue that in fact it was importantly connected with his picture of a larger "sidereal universe." Unlike his sister Caroline, William never discovered any *new* comets, but his acute observations of their structure with his superb telescopes, combined with his fertile mind, led to many new ideas.

Herschel was a remarkable natural philosopher in many ways. None of his contemporaries had his peculiar mix of talents. He was not much of a mathematician as were they, had never attended university, and didn't even start doing astronomy until about age 35. He designed and fabricated his own telescopes and within a short time produced instruments of optical precision that were unmatched (for many tasks) by those of men who had spent lifetimes making telescopes. He possessed tremendous energy and drive and cleverness. He enlisted and trained his devoted sister as full-time assistant, thereby increasing his output of observations and scientific papers by at least a factor of two or three from otherwise. And last, but hardly least, he thought about the cosmos in entirely new ways.

---

W.T. Sullivan III (✉)
Department of Astronomy, University of Washington, Seattle, WA, USA
e-mail: woody@astro.washington.edu

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_2

Why was Herschel interested in comets? First, throughout his career, he was fascinated with any type of *change* in the heavens – variable stars, planetary features, sunspots, variable nebulae. Comets exemplified change *par excellence*. Secondly, discovery and study brought fame, as one's name (or one's sister's name) often became attached to a new comet. Thirdly, comet orbits were very unlike those of planets, whose paths were close to circular and whose directions of rotation and orbital planes showed little variation. Comets not only had extremely non-circular orbits, but were often going "backwards" (retrograde), as well as moving at large angles to the orbital plane of the planets. Where did comets fit into the ever-growing census of Solar System objects? Fourthly, as he emphasized, and unlike most other comet observers, he wanted to focus on the "physical condition" of these strangers, not just their orbits (e. g., Herschel 1808:145). Finally, he was intrigued by their telescopic appearance, sometimes closely resembling many of the thousands of nebulae that he had cataloged and classified – could there be a connection? In fact, he developed a satisfying picture wherein these strange intruders into the inner Solar System were directly linked to the distant nebulae that he knew so well.

For millennia comets had been mysterious visitors to Earth's sky, always unannounced and usually portending doom and gloom (Olson 1985; Yeomans 1991; Schechner Genuth 1997). Their origins and great variety, especially the wondrous tails that always pointed away from the Sun, were puzzling. On the other hand, continually improving application of Newtonian theory throughout the eighteenth century meant that their orbits could be precisely calculated. A comet swooped into the inner Solar System, brightening as it passed closely by the Sun (and Earth), and then disappeared into far outer realms, predicted to return at best in hundreds of years, more often thousands, and sometimes never. The shortest period reliably known during Herschel's time was Halley's Comet, which famously had been demonstrated, upon its predicted return in 1759, to follow an elliptical orbit of period ~76 years.[1,2,3]

---

[1] The comet's return in 1759, just as Halley had predicted in 1705, was universally viewed as a triumph of Newtonian theory. At that time 20-year-old Herschel had just arrived in England and was scratching out a musician's living with his brother Jacob in London. We have no recollection from him of having seen the comet, even though in May it would have been a notable sight in the evening southern sky. We need to remember that, although London then had no light pollution, it did have heavy smoke; furthermore, Herschel was then a musician, not at all an astronomer.

[2] Comet Halley's following apparition in 1835–1836 was well after William Herschel's death; his sister Caroline, however, saw it at age 85 in October 1835 from Hanover, Germany, and even ~180 years ago she was hampered by light pollution. From her day book:

> Oct 14–15, 1835. I saw the Comet, weather hazy. Gas lights all around me in the Street where I was obliged to go, none of my windows allowing me a prospect of that part of the heavens where the comet was visible. I was however gratified by seeing an object which has for many years been an object of conversation.

Oct 17. Saw the Comet again, very Bright, at Mrs. Beckedorff's Country residence, but very near the horizon.

Caroline's day book is at the Harry Ransom Center, University of Texas (Austin) Herschel Archives (hereafter Texas), 36.12/p5.

In addition, William's son John made detailed observations of the comet from South Africa in January–May 1836.

[3] Edmond Halley also predicted that the Great Comet of 1661 would return in the winter of 1788–1789. Caroline and William searched for this, as did many others, but to no avail. While searching,

## Caroline Herschel's Observations of Comets

The eight comets traditionally associated with Caroline Herschel (1750–1848), discovered from 1786 to 1797 (Table 2.1), have been extensively investigated.[4,5] They are briefly discussed here for completeness and for comparison to William's observations, which are also included in the table. But it is important to emphasize that although "her" comets supplied a bit more material for William to study, we have absolutely no evidence that Caroline was ever interested in the types of questions and detailed observations undertaken by William. She focused instead on finding and tracking comets, as did virtually all comet observers of the age.

Using two relatively small, wide-field reflectors designed and built for her by William (her "comet sweepers"), Caroline often scanned the early evening or pre-dawn skies when weather and the needs of William's own observing allowed. Much later (1839, at age 89), when she finally gave one of her sweepers away, she wrote out detailed instructions for its use. They reveal how amazingly well she (and undoubtedly William, too) knew the sky. As you read these instructions (below), be aware that in the sky visible from southern England there are fully 350 fourth magnitude and brighter stars and another 100 Messier objects!

> *To Sweep For or To Seek Comets*
> [Caroline Herschel – Oct 1838]
>
> 1. *Look over with the naked eye every star of the 1st, 2nd, 3rd and 4th magnitude before you begin to observe with the telescope. In looking them over begin with the Sun as a Center and take every constellation round it at an equal* [angular] *distance that is visible.*
> 2. *Begin with the telescope in the same manner taking the Constellation*[s] *round the Sun as a Center and begin with those that set first.*
> 3. *If there has been an interruption of 3 or at most 4 days do not go on with the former series of observations but begin again at No. 1 as if no observation had been made at all.*
>
> *Requisites*
>
> 1. *The name of every star as far as the 1st, 2nd, 3rd and 4th magnitude must be known at sight.*
> 2. *Every Nebula in* [Messier's catalog] *must be known so well as to be found in the Sweeper in one minute.*[6]

---

however, Caroline discovered her second comet.

[4] Olson and Pasachoff 1998; Hughes 1999; Hoskin 2005 (the most complete study); Hoskin 2013; Hoskin 2014.

[5] The span of dates for Caroline's comet discoveries was driven by personal circumstances. As Hoskin has emphasized, seven of her eight discoveries took place between (a) William's marriage in May 1788, which meant that *his* observing time greatly shrunk and thus her labor as assistant was less needed, and (b) her moving to a separate apartment in late 1797, making sweeping for comets far less convenient.

[6] Bullard (1988:146, Hoskin 2005:382, 390).

**Table 2.1** Comets observed by William & Caroline Herschel

| Year | Name | CH # | CH & WH Obsns | Comments | Paper / Source |
|---|---|---|---|---|---|
| 1781 | [Georgium Sidus = Uranus] | | 13 Mar 1781+ | Identified as a new planet only after 6-12 months;<br>Paper entitled "Account of a comet" | WH (1781) |
| +++++ | +++++++++++++++++++++++ | +++ | +++++++++++++ | +++++++++++++++++++++++++++++++++++++ | +++++++ |
| 1781 II | C/1781 T1 Méchain | | 21–23 Nov | | WH (1802a:195) |
| 1783 | D/1783 W1 Pigott | | 29 Nov – 13 Dec | | WH (1802a:195) |
| 1786 II | C/1786 P1 C. Herschel | #1 | 1 Aug – 26 Oct | Discovered while WH in Germany, using new sweeper built by him for her | CH (1787),<br>WH (1787a) |
| 1787 | C/1787 G1 Méchain | | 19 Apr | | WH (1787b:232) |
| 1788 II | 35P/1788 Y1<br>C. Herschel – Rigollet | #2 | 21–22 Dec | 1939 – recovered and found to be periodic (155 yr) by Roger Rigollet | WH (1789)<br>(reports CH obsns) |
| 1790 I | C/1790 A1 C. Herschel | #3 | 7–10 Jan | Seen only twice by CH, but confirmed 12 days later by Charles Messier; Fig. 1 | RAS C.1/1.2/p56=i8 |
| 1790 II | 8P/1790 A2 Tuttle<br>(Méchain originally) | | 18 Jan | 1858 – identified as periodic (13.6 yr) by Horace Tuttle | WH (1802a:196) |
| 1790 III | C/1790 H1 C. Herschel | #4 | 17 Apr – 29 Jun | WH out of town | Letter to RS (unpub.)<br>RS L&P.IX.180 |
| 1792 I | C/1791 X1 C. Herschel | #5 | 15 Dec 1791 – 13 Jan 1792 | Confirmed by WH on discovery night with 7 ft & 20 ft telescopes | WH (1792)<br>(reports CH obsns) |
| 1792 II | C/1793 A1 Gregory | | 13 Jan – 7 Feb 1793 | naked eye | |
| 1793 I | C/1793 S2 Messier | #6 | 7–8 Oct | Observed 10 days after Messier's discovery | CH (1794) |
| 1795 VI | 2P/1795 V1 Encke<br>(C. Herschel originally) | #7 | 7–28 Nov | Naked eye<br>1818 – identified as periodic (3.3 yr) by Johann Encke | CH & WH (1796) |
| 1797 | C/1797 P1<br>Bouvard – C. Herschel | #8 | 14–28 Aug | Discovered (naked eye) by CH & Alexis Bouvard (and others) on the same evening; WH out of town; CH rides horse ~30 miles to Greenwich to report comet | RAS C.1/1.1&1.2/ pp91-6 |
| 1799 I | C/1799 P1 Méchain | | 8 Sep – 4 Oct | | WH (1802a:196) |

| | | | | | |
|---|---|---|---|---|---|
| 1806 I | 3D/1805 V1 Biela | | 8–9 Dec 1805 | WH: “I discovered a comet”–but 4 weeks after Jean Louis Pons; 1826 – identified as periodic (6.6 yr) by Wilhelm von Biela; Fig. 3 | RAS W.3/1.12/ p16=i10 (Dreyer 1912:cxi) |
| 1806 II | C/1806 V1 Pons | | 27 Jan – 1 Feb 1807 | CH learned of it via a German newspaper | WH (1807) |
| 1807 | C/1807 R1<br>Great Comet of 1807 | | 2 Oct 1807 – 21 Feb 1808 | Naked eye; 47-night observing campaign; Fig. 4 | WH (1808) |
| 1811 I | C/1811 F1<br>Great Comet of 1811 | | 2 Sep 1811 – 2 Jan 1812 | Naked eye; 33-night observing campaign; Figs. 5, 6, 7 | WH (1812a) |
| 1811 II | C/1811 W1 Pons | | 1–20 Jan 1812 | Naked eye | WH (1812b) |
| 1815 | 13P/1815 E1 Olbers | | 29–31 Mar | Learned of it via a newspaper;<br>1887 – identified as periodic | RAS C.1/1.3/ p110=i12 |
| 1819 II | C/1819 N1 Tralles<br>Great Comet of 1819 | | 3–22 Jul | Naked eye | RAS W.1/8.43/i137<br>RAS W.2/2.8/p22=i24 |
| +++++ | ++++++++++++++++++++++++ | +++ | ++++++++++++++ | ++++++++++++++++++++++++++++++++++++++ | +++++++ |
| 1823 | C/1823 Y1<br>Great Comet of 1823 | | 31 Jan 1824 | CH – in Hanover | RAS C.1/1.3/ p111=i12 |
| 1835 III | 1P/1835 P1 Halley | | 14–17 Oct | CH (age 85) – in Hanover | Texas 36.12/p5 |

*CH* Caroline Herschel; *WH* William Herschel

“Year” column contains the former convention (before 1995) for naming comets; “Name” column follows current convention

Start and end dates of “Obsns,” as well as “Paper / Sources,” refer only to CH and WH’s observations and papers; the span of observing dates is based on perusing various observing logs, in particular those in RAS C.1 and RAS W.3/1

CH’s 8 comets are numbered. Six still bear her name as discoverer; one had already been discovered; and one was named much later after Johann Encke, who first demonstrated it to be periodic

Primary sources: RAS Archives; Kronk (1999)

Her first comet in 1786 was greeted with joy by the Astronomer Royal, Nevil Maskelyne, in a letter to William:

> *I am happy in the expectation your sister gives me both of her discovering more comets and favoring me with immediate notice of them. I hope we shall by our united endeavors get this branch of astronomical business from the French, by seeing comets sooner and observing them later.*
>
> *Your continual attention to the heavens under their own canopy, without the glare of lights in a room, added to the superior excellence of your telescope, must give you great advantages in discovering and pursuing comets.*[7]

Caroline's persistence (e.g., she searched on and off for 3 years before finding her first), excellent eyesight, stamina, and intimate knowledge of the sky led altogether to the discovery of eight comets of which she had no prior knowledge. She gained fame as the lady comet hunter (Fig. 2.1). Most of her comets were sixth to eighth magnitude, except for the last one, a very bright third magnitude which she found in 1797 while making her routine naked-eye reconnaissance (see the instructions above) at the start of an observing session (Hughes 1999). After this particular discovery, a full night of observing, and only a short nap, she took no chances to lose her priority of discovery. At age 47 and less than 5 ft (152 cm) in height, she rode horseback 27 miles (44 km) to Greenwich, and exhaustedly reported the comet to Maskelyne in person![8]

Of Caroline's eight comets, only one had been discovered before (1793 I) and another was renamed for Johann Encke when much later he established it as a recurring comet with a period of 3.3 years. That leaves six comets with her name attached to this day. Once she had found a comet, she and William would pounce on it as much as weather and the comet's brightness allowed. Campaigns lasted for as long as 4 months (Table 2.1).

With regard to publication, only three of her comets were published under her own name (in brief reports), although note that she was the first woman to *ever* publish in *Phil. Trans.,* and no one would arrive in second place until Mary Somerville in 1826. Discovery details of two other of her comets were given in papers by William. For another (1790 III) she sent a letter to the Royal Society, but for some reason it was never published. Finally, results on two other comets were never reported. One was observed on only one night and the other for two weeks.

---

[7] Maskelyne:W. Herschel, 25 Oct 1786, Royal Astronomical Society (London) Herschel Archives (hereafter RAS) W.1/13.1/m30 = i891-2. (A notation such as "p22" refers to page 22 of the original Ms. (where numbered). Often more convenient is the "image number" indicated here by "i24", referring to PDF image number 24 on the set of three available DVD's containing the entire RAS Herschel Archives.) Maskelyne is referring here to the Herschels' technique of usually observing in complete darkness in the open air, resorting only rarely to dim light for jotting notes. The Greenwich refractors were apparently kept inside a partially lit room.

[8] C. Herschel:Joseph Banks, 17 Aug 1797, RAS C.1/3.8/i3.

**Fig. 2.1** "The Female Philosopher smelling out the Comet" by R. Hawkins(?) (1790). The cartoon does not mention Caroline Herschel, but it seems certain that it refers to her; by the end of 1790 she had discovered four comets and was becoming well known to the educated public. The woman says "What a Strong Sulpherous scent proseeds from this meteor" as she observes a comet with a baby emitting gas from its bottom. The term "meteor" had long referred to any sort of phenomenon taken to arise in Earth's atmosphere (e.g., lightning, shooting stars, and aurorae); until the seventeenth century this included comets (Pierpont Morgan Library/Art Resource, New York City. Used with permission)

## William Herschel's Observations of Comets

The late eighteenth century saw a rapid increase in seeking and observing comets. The French astronomer Charles Messier was the first to systematically scan the sky for a new comet night after night (he was called "the comet ferret"), and from 1760 to 1800 he and his compatriot André Méchain dominated the field. In the period 1781–1799, in which Caroline and William Herschel were most actively observing, there were 25 appearances of comets; of those Messier and Méchain discovered ten and Caroline was in third place with six (Hughes 1999:82). Of those 25 comets, the Herschels observed 14, as well as 7 more after 1799 (Table 2.1). Of the 22 papers published on comets during the period 1780–1822 in *Phil. Trans.*, fully 60% (13) were by either Caroline (3) or William (10).[9] During William's early observing days in Bath (when his fulltime "day job" was as a musician) there were three comets that came into the British skies that he might have seen, but none were entered into his observing log from 1774 until his first on Nov 22, 1781.[10] Of course Herschel was a relatively novice observer at that time and in any case not purposely looking for comets; nor was he tied into the network of astronomers who immediately notified each other of new comets.

At first it seems puzzling that William, despite his thousands of hours at the telescope, never managed to be first to find a comet, whereas Caroline discovered so many. There are two main reasons for this. The first is that William set up a division of labor whereby Caroline searched for comets only whenever she was not needed to assist William (indispensably) with his own varied observations. She also could observe when William was away on business or (after he married) on holiday; in fact three of her discoveries came when William was away. As in her instructions given in the previous section, she searched by methodically and quickly scanning the sky for a faint, fuzzy object near the just-set Sun in the evening twilight or the about-to-rise Sun in the morning. With a candidate in hand, she then tracked the object as long as possible to check whether it shifted its position with respect to the pattern of background stars; several hours of tracking were a minimum – night-to-night was much better. If it shifted, it was a comet; if not, it was a nebula located well outside the Solar System, also interesting but not the jackpot. Thus Caroline could search for 1–2 hours in the evening or morning twilight, when the sky was not absolutely dark, as William required to study his extremely faint objects.

Although comets can sometimes be found well away from the Sun (and Caroline searched for these, too, when she could), William was at a disadvantage to come upon a comet while sweeping for nebulae because his field of view (typically 15′)

---

[9] The listing of all *Phil. Trans.* papers on comets (and meteors) is given in Appendix 1 of Olson and Pasachoff (1998). The number of papers on comets peaks in the 1750–1800 period.

[10] In addition, we should not forget Herschel's most prominent "cometary" episode, early in his career. On the evening of 13 Mar 1781, he discovered a non-stellar object and tracked it for months, arguing in many publications and letters that it was a comet. Eventually others worked out a circular orbit and disagreed – the Solar System had acquired a new planet (Uranus) well outside Saturn. The discovery paper of 1781 is entitled "Account of a comet."

was much smaller than Caroline's (about 2°). Not only that, he had a far slower pace of sweeping than Caroline. With his telescope fixed on the meridian, he swept at $\leq 15°$ per hour, the rotation rate of Earth, whereas she zipped through the sky at ~10° *per minute*.[11] Furthermore, once William found a candidate nebula by sweeping, he typically did not check it again for weeks or months, far too long to confirm a new comet and announce it to the world. In fact roughly 70% of his cataloged nebulae ended up *never* being observed a second time – for these nothing was known about any possible non-sidereal motion. In one of his comet papers Herschel (1808:159) remarked that it would be a fascinating exercise ("were it not a task of many years labor") to re-check all of his cataloged nebulae and see if any of them were entirely "missing," i.e., had moved away from their position decades before.[12]

If he'd seen an obvious tail on any new object, he certainly would have stopped his routine and looked at it with other, smaller telescopes, but comets often don't exhibit tails, especially when first discovered. In fact, Herschel's classification scheme for his cataloged nebulae and star clusters (2,500 in all), based on their morphology to his skilled eye, even included the rubric "cometic nebulae" (Herschel 1786:469, 1811:306),[13] which resembled tail-less comets (although almost always *much* fainter) in having a faint halo surrounding a relatively bright center and "round figure" (in comets then and now called the head, or *coma*, from the Latin for "hair") (see Fig. 2.2). For example, Herschel noted that the Great Comet of 1807 would have fit nicely amidst descriptions of his cataloged nebulae when on Dec 16, 1807, he described it as a "very bright, large, irregular, round nebula, very gradually much brighter in the middle, with a faint nebulosity on the south preceding [southwest] side." (Herschel 1808:153–4) The sole discriminant between a nebula and comet was that the former's description and location remained stable, whereas the latter's changed dramatically as the weeks passed.

While sweeping the heavens Herschel did have a few puzzling cases where he suspected an encounter of the comet kind, but none panned out to a verifiable discovery:

> **5 Aug 1782**. Shortly after moving from Bath to Datchet (near Windsor Castle) he thought he'd found a new comet, but after several nights of study realized that it was No. 5 in Charles Messier's recent catalog of bright nebulae and star clusters [Dreyer 1912:xxxvii].[14]

---

[11] Hughes (1999:79–80) and Hoskin (2005:405), citing a letter in RAS Nathaniel Pigott, Maskelyne:Pigott, 6 Dec 1793.

[12] My rough estimate of ~70% of William's 2300 nebulae observed only once comes from a perusal of Herschel's published listings (excluding his clusters). For his Class III ("faint nebulae"), the fraction is much higher at ~90%. But despite this, Steinicke's (2010:32) exhaustive analysis of Herschel's catalogs concludes that only five of his nebulae cannot be found today at their reported positions. Might one of these five have been a comet? These results confirm that Herschel made a wise decision not to spend time checking all of his once-only nebulae to see if they might have been in fact comets.

[13] About 1% of Herschel's nebulae were classified "cometic."

[14] Herschel's confusion over whether some of his new nebulous objects might be comets shows how difficult it was to tell the two categories apart without multi-night observations. This in fact was precisely the reason that Messier had published his listing of nebulous objects; he wanted to

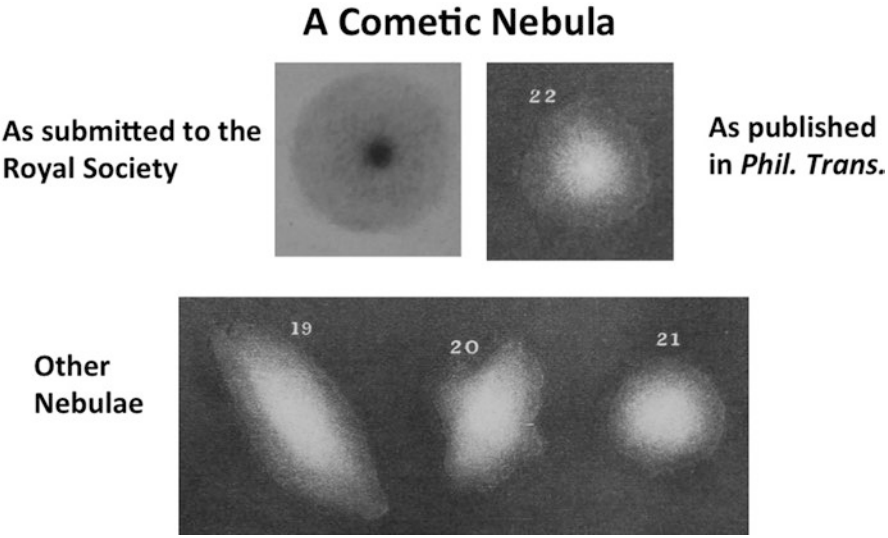


**Fig. 2.2** Drawings illustrating Herschel's class of "cometic nebulae." The top pair are different versions of the same drawing (of catalog number H I.4 first observed on 19 Dec, 1783), as submitted for publication and as finally appearing in *Phil. Trans.* Note the significant difference in appearance. The *bottom row* shows other types of nebulae for comparison (Numbered drawings from Herschel 1811; *top left* drawing from Royal Society PT.5.16. Used with permission)

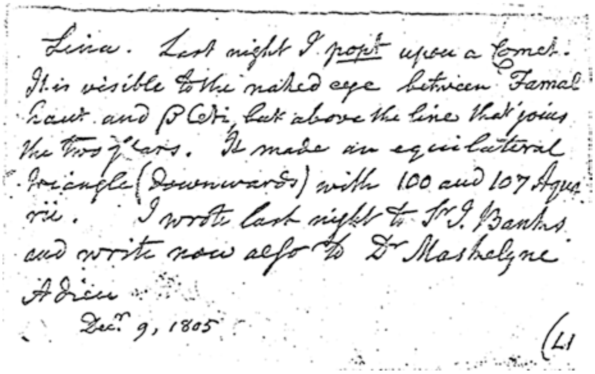
> **18 Dec 1783**. In his first catalog of 1,000 nebulae, he says that he saw a "cometic" nebula, but could never find it again (Herschel 1786:498; Dreyer 1912:294-5). Steinicke, however, says that Herschel must have made a mistake when checking, because Herschel's object can today be identified reliably with the galaxy NGC 1055.[15]
>
> **Jan 23, 1784**. He again "lost" a bright nebula, but many years later deduced that wrongly measured positions meant that he didn't recognize it as a Messier object (No. 49). (Herschel 1786, 498; Dreyer 1912: 294–5)
>
> **Dec 8, 1805**. He finally did "discover" a comet (Fig. 2.3) and promptly sent notice to the Royal Society, but, as with Caroline's sixth comet in 1793, it turned out that it had been already found, by Jean Louis Pons (Marseille) four weeks before (Dreyer 1912:cxi).

Herschel's first four papers on comets, from 1787 to 1796, were relatively brief reports on the comet *du jour*, providing mainly descriptions of how the comet's appearance had changed as it moved along its orbit. Sometimes he also provided rough sky coordinates, but these were awkwardly given and wanting in accuracy, for example: "about 42′ north of 22 Cygni, in a line continued from 21 (η) through 22

---

make life easier for comet hunters by establishing a reliable "nuisance list" of potentially misleading objects bright enough to be visible in small telescopes.

[15] W. Steinicke, Historical Catalogue of William Herschel Nebulae and Star Clusters. www.klima-luft.de/steinicke (accessed Nov 2016).



Lina. Last night I popt upon a Comet.
It is visible to the naked eye between Famal
haut and β Ceti, but above the line that joins
the two stars. It made an equilateral
triangle (downwards) with 100 and 107 Aqua
rii. I wrote last night to Sr J. Banks
and write now also to Dr Maskelyne
Adieu
Decr 9, 1805
(41

**Fig. 2.3** Note from William Herschel to his sister Caroline on 9 Dec 1805. "Lina. Last night I popt [popped] upon a Comet. It is visible to the naked eye between Fomalhaut and β Ceti, but above the line that joins the two stars. It made an equilateral triangle (downwards) with 100 and 107 Aquarii. I wrote last night to Sir J. Banks [President of the Royal Society] and write now also to Dr. Maskelyne [Astronomer Royal]. Adieu." (RAS W.1/8.23/i81)

nearly; it is not quite come to the line…" (Herschel and Herschel 1796:133) This kind of description was the best he could do because his expertise was *not* in properly measuring accurate right ascensions and declinations as with the carefully mounted and calibrated refractors that dominated his era, such as at Oxford University and Greenwich Observatory. Although the latter were superb for producing accurate positions of celestial objects, they were inferior to Herschel's reflectors in many other ways, such as in studying faint objects. Another striking difference was that Herschel's mathematical skills were severely limited compared to many of his colleagues, who were as much mathematicians as astronomers. This meant, for instance, that Herschel never in his career calculated an orbit based on measures of comet positions.[16]

With the new century, Herschel began to study comets more seriously, advancing detailed ideas in four more papers (1802–1812) on their origin, how they changed with time, their forms, etc. He may well have been inspired to think more about the Solar System by Giuseppe Piazzi's discovery in 1801 of the first asteroid (Ceres), taken to be a new planet between Mars and Jupiter and hailed as a first-class discovery not unlike Herschel's two decades earlier (Cunningham 2016a, b). Furthermore, two bright and long-lasting comets appeared in the skies, allowing detailed observations. Finally, his core project of sweeping the northern sky for faint nebulae and star clusters had come to a close, as at this time he published the final installment of his catalog of 2500 objects. (Herschel 1802b).

In a paper primarily addressing the nature of the new asteroids (a second one – Pallas – had just been found), Herschel (1802a) drew up a list of the properties of

---

[16] In the RAS Herschel archives is an undated document (no source given) in which Herschel lays out the many complicated steps to determine the parameters of a comet's orbit, given a few observed positions. But there is no extant evidence that he ever carried out such a calculation. (RAS W.3/39.2/pp48-52 = i28-32).

planets and comets, and wondered where asteroids might fit in. Arguing that they fit somewhere in between, he saw the need for a distinctive new name.[17] But he also pointed out that maybe an asteroid is nothing more than a comet far removed from the Sun.[18] In fact maybe "comets, asteroids, and even planets might possibly be the same sort of celestial bodies under different circumstances" (Herschel 1802a:231). Here he was characteristically thinking about changes of astronomical objects over long timespans, something he had repeatedly done from his earliest days of observation. Back in 1781, 8 months after he first sighted the "comet" whose nature was still being debated but which would be soon recognized as a new outer planet, he wrote to Joseph Banks at the Royal Society:

> [This] *may give room to suspect that a Body is now exposed to the attention of Philosophers, which may prove to be either a new Planet or perhaps a Star that may partake both of the nature of Comets and Planets; and be, as it were, a Link between the Cometary and Planetary Systems, uniting them together by that admirable connection already discovered in so many other parts of the creation....*[In the future we will] *obtain a still more extended view of the wonderful order that reigns throughout the whole Solar and Sidereal System.*[19]

## The Great Comets of 1807 and 1811

In the early nineteenth century, with Herschel in his 60s, two "Great Comets" excited both the public and astronomers. The first was the Great Comet of 1807 (Fig. 2.4). Its brightness and pathway through the sky allowed him to observe it for 47 nights over 5 months in the winter of 1807–1808. He was intensely interested in whether a distinct, small nucleus could be discerned at the center of the comet's bright head – the compact object presumed to exist by astronomers. In only two of sixteen of his previously observed comets had he seen a "very ill defined small central light" (Herschel 1807:266). But now this larger and brighter 1807 comet had allowed him to establish to his satisfaction the existence of a tiny nucleus, which he emphasized could only be achieved because of his superior telescopes:

> *The truth is that inferior telescopes, which cannot show the real nucleus, will give a certain magnitude [size] of the comet, which may be called its head....No telescope, but what has light and power in an eminent degree, will show it distinctly.* (Herschel 1808:146)

---

[17] Herschel's support for the term *asteroid*, which first appeared in print in Herschel (1802a:228), led to its eventual adoption by the astronomical community. The story of the naming is given in detail in Cunningham (2016a).

Searching for new asteroids himself, Herschel made a few sweeps within the ecliptic plane, but came up empty-handed.

[18] In 1785 Herschel had also considered the possibility that his nebulae of Class IV (coined "planetary nebulae") might actually be comets far from the sun. But he decided not, based on their large inferred brightness and size if at that distance compared to comets near the Earth and sun, when one would expect the opposite effect (Herschel 1785:265).

[19] Herschel:J. Banks, 19 Nov 1781, RAS W.1/7.

**Fig. 2.4** "John Bull making observations on the Comet" (Thomas Rowlandson etching, 1807). John Bull (Great Britain) observes the threatening Great Comet of 1807 (Napoleon) across the English Channel, with King George III as the Sun. "Aye..Aye..Master Comet – you may attempt your Periheliums – or your Devilheliums for what I care but take the word of an Old Man you'll never reach the Sun [Great Britain] depend upon it." (Bodleian Libraries, University of Oxford, Wikimedia Commons)

He went to great pains to measure its diameter despite his inability to employ his usual wire micrometer (used on double star separations, for instance) because high magnifications necessary to measure a small object did not work well when the object was also extended. Instead, he resorted to an unconventional technique. As a calibration, during the day before his night of observations, he viewed through his telescope three "globules" of sealing wax perched on top of a post measured to be precisely 2422 inches (~60 m) away. He was trying to fix in his head exactly how large a certain known angular size appeared in the eyepiece's field of view, so that in the night-time he could estimate *from memory* that the comet's nucleus was, say, 1.5 times his smallest globule (diameter 0.0290 inch, or 0.74 mm), which subtended an angle of 2.47″. For instance, using a magnifying power of 221 on one night with his reflector of 10 ft (3.0 m) focal distance, he measured a nucleus diameter of 2.5–2.6″. In this manner Herschel observed with several of his telescopes (including his 20-ft reflector), at various magnifications, and concluded that the nucleus diameter was less than 2.5″. In the end, however, he put more trust in views on a fine night through his 10-ft telescope when he could compare the nucleus's angular size with that of Jupiter's moon Ganymede, known to be ~1.5″. He finally settled on a figure of 1.0″; then knowing the distance to the comet, he calculated the “real diameter of the comet” as 538[20] miles (870 km) (Herschel 1808:156).

Herschel next used his observation that the small disk was always uniform and circular to infer that the comet was “self-luminous,” i.e., not shining by reflected light. (He optimistically felt his telescope and eye were able to discern object sizes and features as small as a few tenths of an arcsecond – see the following section.) He did this by working out the Earth-comet-Sun angle and therefore the expected phase and shape of the comet if it were a sphere shining solely by reflected light as does our Moon. Since he never observed the expected gibbous shape for the comet nucleus,[21] reflected light was not the answer. Final conclusion: the nucleus was planet-like with a “condensed or solid body,” but unlike a planet it was self-luminous (Herschel 1808:155).[22]

Herschel was less certain of the nature of the light seen in the coma and tail. He noted that many times he saw stars disappear behind the comet, but perhaps that was due to either blockage by reflecting “floating particles,” or to blending in the glow of self-luminous matter. But then he invoked Okham’s razor to argue against the supposed particles: “We ought certainly not to ascribe an effect to an hypothetical cause, when the existence of one [cause], quite sufficient to explain the phenomenon, is evident.” (Herschel 1808:158).[23]

In the end he favored a tail of “radiant matter,” perhaps like the aurora borealis.

The second Great Comet came in 1811 and took Europe by storm (Fig. 2.5). It was visible to telescopes for 17 months and to the naked eye for 9 months (a record not broken until Comet Hale-Bopp in 1997). Called “Napoleon’s Comet“(also see Fig. 2.4) because its bright head and long, branched tail were taken to have presaged his ill-fated invasion of Russia in 1812, Tolstoy even used it in the plot of *War and Peace*.[24] Starting in September 1811 Herschel observed this comet on 33 nights over 4 months of British weather, employing his naked-eye, a low-power “night glass,” and an arsenal of four large telescopes; this allowed him a variety of eyepieces (changing magnifications and fields of view) and ratio of focal distance to mirror diameter (f/d ratio, affecting sensitivity to brightness levels and visibility of struc-

---

[20] Significant figures apparently were a concept unknown to Herschel and his contemporaries.

[21] His calculated phases had the object’s illuminated diameter ~20–25% less in one direction than the other. His observations to look for this, as well as his uncertainties, are discussed in the following section”.

[22] Herschel also reported colors, but never used them in his interpretations. For example: “The colour of [the nucleus] was nearly white inclining to red, resembling the brilliancy of a coal in the fire when it is nearly as white as it can be, but not so white as Iron when it is in a welding heat.” (RAS W.3/1.12/p24 = i14).

[23] Newton, at the start of his Principia, had listed as one of the four “Rules of Reasoning in Natural Philosophy”: “To the same natural effects we must, as far as possible, assign the same causes.”

[24] Book 8, end of Chap. 22, where it is confusingly referred to as the “comet of 1812.” I have not been able to find any source reliably reporting that Napoleon *himself* viewed it as “his” comet, but certainly other persons did, portending good or bad depending on their nationality. In 1808 Napoleon was undoubtedly pleased when Messier pointed out that the Emperor’s birth coincided with the appearance of a bright comet in 1769 (Schechner Genuth 1987:54).

**Fig. 2.5** The Great Comet of 1811 "as seen at Daybreak the 15th October from Otterbourne Hill, near Winchester." Engraving by A. Pether, 1814 (Wellcome Library, London. Used with permission)

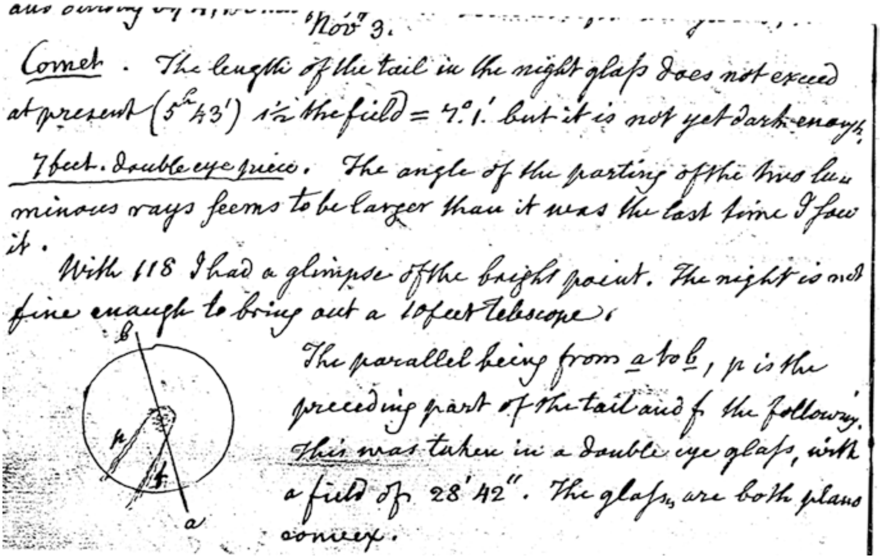
tures). He monitored how the structure of the comet's nucleus, coma and tail continually changed, and submitted a paper to *Phil. Trans.* even before the comet had left the skies. Although Herschel (1812a) devoted fully 18 pages to intricate descriptions, it is amazing that he offered readers not a single drawing of the comet.

His logbook too contains only *one* drawing (Fig. 2.6) to accompany ~2000 words of description! In order to aid discussion of the many aspects of the comet to which Herschel called attention, Fig. 2.7 attempts to fairly represent his words.[25]

Herschel's paper first presents his observations, followed by his interpretation, entitled "the *real* construction of the comet" (italics mine). In this he was paralleling his lifelong project of mapping out and deducing the *three-dimensional* shape of our stellar system, an endeavor he called "the construction of the heavens." Just as for the Great Comet of 1807, he was convinced that the combination of his skilled eye and his superior large telescopes (including the 20-ft (6.1-m) reflector) with high-power eyepieces (as much as 600×) could discern a tiny "planetary body" manifesting as an "extremely small bright round point, entirely distinct from the surrounding glare" (Herschel 1812a, p. 116). Employing the same globs of sealing wax as in 1807, he measured this planetary body to have a diameter of 0.775″, or 428 miles (690 km). He argued, along the same lines as for the 1807 comet, that he could

---

[25] If Herschel had published such a drawing as Fig. 2.7, in subsequent decades it would have become *the* standard to illustrate what a bright comet looks like; not until mid-nineteenth century did such detailed drawings finally appear. It is surprising that he did not seize this opportunity.



Nov^r 3.

Comet. The length of the tail in the night glaſs does not exceed at present (5^h 43′) 1½ the field = 7°.1.′ but it is not yet dark enough.

7 feet. double eye piece. The angle of the parting of the two luminous rays ſeems to be larger than it was the last time I ſaw it.

With 118 I had a glimpse of the bright point. The night is not fine enough to bring out a 10 feet telescope.

The parallel being from a to b, p is the preceding part of the tail and f the following. This was taken in a double eye glaſs, with a field of 28′ 42″. The glaſses are both plano convex.

**Fig. 2.6** William Herschel's observing log (in his hand) for 3 Nov 1811. This is his only drawing of the Great Comet of 1811. The circle defines the field of view of 29′ on his 7-ft telescope at magnifying power of 118. The labels and line indicate orientation of the comet on the sky. RAS W.2/2.8/p8v = i11

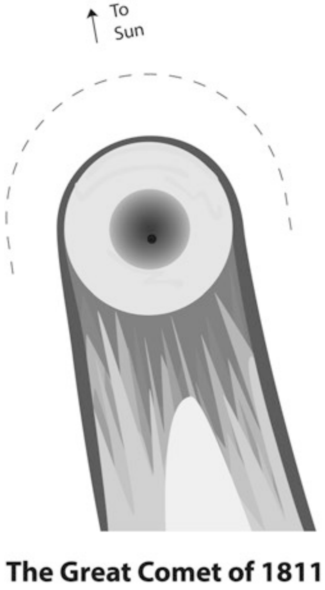


**Fig. 2.7** Author's drawing of the Great Comet of 1811, based on the detailed description by William Herschel (1812a). The drawing is a "negative," meaning that dark areas here were bright against the night sky, and light areas were dark. The small dot (slightly off-center) is the nucleus or central "planetary body." It is surrounded by the "head" of size 4′. The head is surrounded by an empty gap, which Herschel called the "transparent cometic atmosphere"; this gap is bounded by the thin bright "envelope," which wraps around the head and defines the outer edges of the tail. The "transparent cometic atmosphere" is presumed to extend indefinitely (and invisibly) outside the envelope (indicated in the drawing by the dashed circle). The tail extends far off the edge of the drawing (Drawing by Woodruff Sullivan)

discern that the object was truly round (i.e., showed no phase effect – see later) and therefore it shone by emitted rays rather than reflected. Around this bright central object was a circular region of uniform brightness which he called the "head," about 3–4′ in size, or 125,000 miles (205,000 km).

The head was the atmosphere of the central planetary body, just as the planets and the Sun (also considered to be a planet) had atmospheres; indeed, the structure of the comet's atmosphere bore strong resemblances to his two-decades-old model for the solar atmosphere (Herschel 1795:58–62).[26] Continuing outwards like nested Russian dolls, next was a dark "transparent cometic atmosphere," as large as 15′ or 500,000 miles (800,000 km) in diameter. He took it as transparent because one time the motion of the comet took it across three stars that suffered no diminution. It was also "elastic" because only a responsive gas would take on such a rounded form under the influence of gravity. This atmosphere was surrounded by a thin, bright "envelope" that was semi-circular on the sunward side and continued outwards on the anti-Sun side, defining the outer edge of the comet's tail. Herschel's greatest reported length for the tail was ~25°, which worked out to be far greater than the Earth-Sun distance. As the months passed, he saw the tail split in two, become curved and asymmetric, and change in width. He closely compared the nebulosity of the tail with that of the Milky Way and of the Orion Nebula, finding all of them to be "perfectly alike." He was struck by how all of the cometary components slowly disappeared as the comet moved away from the Sun, and concluded:

> *I had reason to suppose that all the still visible cometic phenomena of planetary body, head, atmosphere envelope, and tail, would soon be reduced to the semblance of a common globular nebula; not from the increase of the distance of the comet, which could only occasion an alteration in the apparent magnitude of the several parts, but by the actual physical changes which I observed in the construction of the comet.* (p. 127)

Here he directly compared the appearance of the weakened comet with one of the classifications of nebula that he had instituted, namely the "globular" type, which looked roundish and sometimes broke up into stars with a larger telescope.[27]

In the interpretive part of the paper, he argued that the planetary body, head and transparent cometic atmosphere were all actually spherical[28] because (1) gravity tends to make a spherical object (as Newton had shown), and (2) he had seen the comet at many different angles over the months, and "based on the doctrine of chances" their always-round appearance made a spherical volume very likely (p. 133). On the other hand, the tail material was in a hollow cone with a hemispherical cap toward the Sun – the tail's bright edges (the envelope) were simply a projection effect as one looked through a greater amount of luminous material. The light from

---

[26] Jean-André Deluc (1809), who visited Herschel several times, had earlier published identical ideas. Herschel (1812a:119) did cite Deluc (1809) for another aspect of comet structure, but not for this.

[27] Herschel (1785:218) had coined the term "globular cluster" much earlier.

[28] However, Herschel had also observed (p. 121) a slight sunward shift of the center of the comet's head and atmosphere relative to the planetary body (see Fig. 2.7). This he ascribed to a preferential heating and dilation of the atmosphere on the sun side.

the comet was “phosphoric” (self-emitting), a result of the Sun acting on the atmosphere, causing the cometic matter to expand and decompose. This seemed reasonable because it was well known that solar rays can produce all sorts of “light, heat and chemical effects.”

Herschel imagined that the planetary body’s initial transparent atmosphere extended well outside the visible envelope (Fig. 2.7). As the comet approached the Sun, vapors rose within the sunward side of the atmosphere and became rarefied and (for some unstated reason) finally came to a certain level where they remained suspended and formed the observed envelope. This envelope/layer was initially only on the sunward side, but:

> *If we suppose the attenuation and decomposition of this matter to be carried on till its particles are sufficiently minute to receive a slow motion from the impulse of the solar beams, then will they gradually recede from the hemisphere exposed to the sun, and ascend in a very moderately diverging direction towards the regions of the fixed stars* [away from the Sun]. (p. 138)

Herschel was essentially saying that pressure from sunlight on small particles caused their shining envelope/layer to wrap around to the anti-Sun side of the comet and eventually form the tail, which became more rarefied and fainter as it moved away from the planetary body. Finally, he suggested that the whole comet might be rotating just as planets do, which would explain various observed asymmetries in the envelope and tail if the planetary body or its atmosphere had inherent nonuniformities (pp. 139–40).

Herschel’s next step boldly linked the marvels of comets to the “immensity of the nebulous matter, which I have shown to exist in the heavens” (p. 140). Here he was of course referring to the thousands of nebulae, all well outside our Solar System, that he had discovered and categorized over his career. Might it not be that comets and his nebulae were different manifestations of the same object? Perhaps one was a younger version, and eventually morphed into the other? Or did they change back and forth, depending on where they were located? The Newtonian orbits calculated for almost every comet were very close to parabolas, meaning that they likely traveled in regions far outside the orbit of Uranus (or rather, the Georgium Sidus). Comets, then, might provide major clues to the nature of his nebulae. In fact in a previous paper about these nebulae published just 6 months before, Herschel had (as mentioned above) described a type of nebula called *cometic*:

> *Their great resemblance to telescopic comets, however, is very apt to suggest the idea, that possibly such small telescopic comets as often visit our neighbourhood may be composed of nebulous matter, or may in fact be such highly condensed nebulae.* (Herschel 1811:306)

Herschel devised a grand scheme (illustrated in Fig. 2.8) in which a comet far from the Sun was a small planetary body[29] surrounded by a very large tenuous atmosphere (the transparent cometic atmosphere). This stage was represented by one of

---

[29] Although Herschel had seen evidence for a nucleus in only 4 of 18 observed comets, he apparently felt that the visible nuclei of the much larger 1807 and 1811 comets inferred that *all* comets had central planetary bodies, but were often too small to discern.

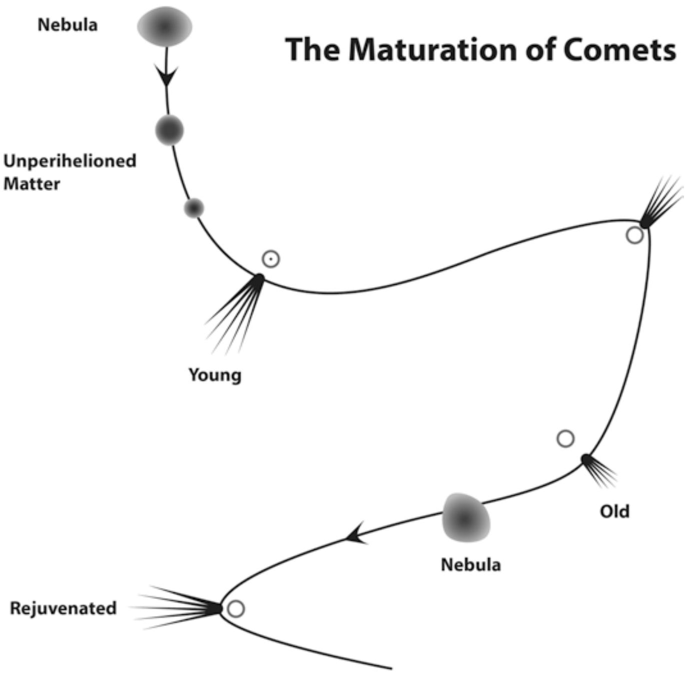


**Fig. 2.8** Author's schematic drawing of Herschel's (1812a) hypothesis on the "maturation" of a comet over its lifetime. Starting at the top, the comet's planetary body and its accompanying atmosphere form in a nebula collapsing due to gravity; this atmosphere of "unperihelioned matter" has not yet passed close by a star. The body then moves between the stars, by chance passing close enough to stars to have its atmosphere "perihelioned" (heated and swept away), its trajectory changed, and its tail formed. The apparent vitality (brightness, length of tail) or relative age of the comet depends on its recent history of stellar encounters. Also, by chance the comet may pass through another nebula (as shown), pick up more material and thus be rejuvenated for its next stellar encounter (Drawing by Woodruff Sullivan)

his highly concentrated nebulae moving through space and growing dense by the action of gravity.

Decades before, he had first presented the notion of a slow process of "maturation" (today astronomers would say *evolution*, biologists *ageing* or *development*) in which a nebula under the influence of gravity eventually produced a central planetary body or a star (Fig. 2.9). And now comets providentially allowed one to catch an object in this very act of transformation. As the planetary body and its large atmosphere approached the Sun and its intense rays, the atmosphere gave off vaporous material (plus possibly unspecified "elastic volatile substances" and "subtile fluids"), leading to a much smaller atmosphere – Herschel called a comet's passage through its perihelion "an act of consolidation."[30] The stripped comet then swung

---

[30] Herschel (1795:60–1) had earlier suggested that comets might well collide with our sun and thus restore its ever-decreasing mass due to emission of light particles. But in the present 1812 paper he did not mention this idea, nor specify the final resting place of the comet's stripped atmospheric material.

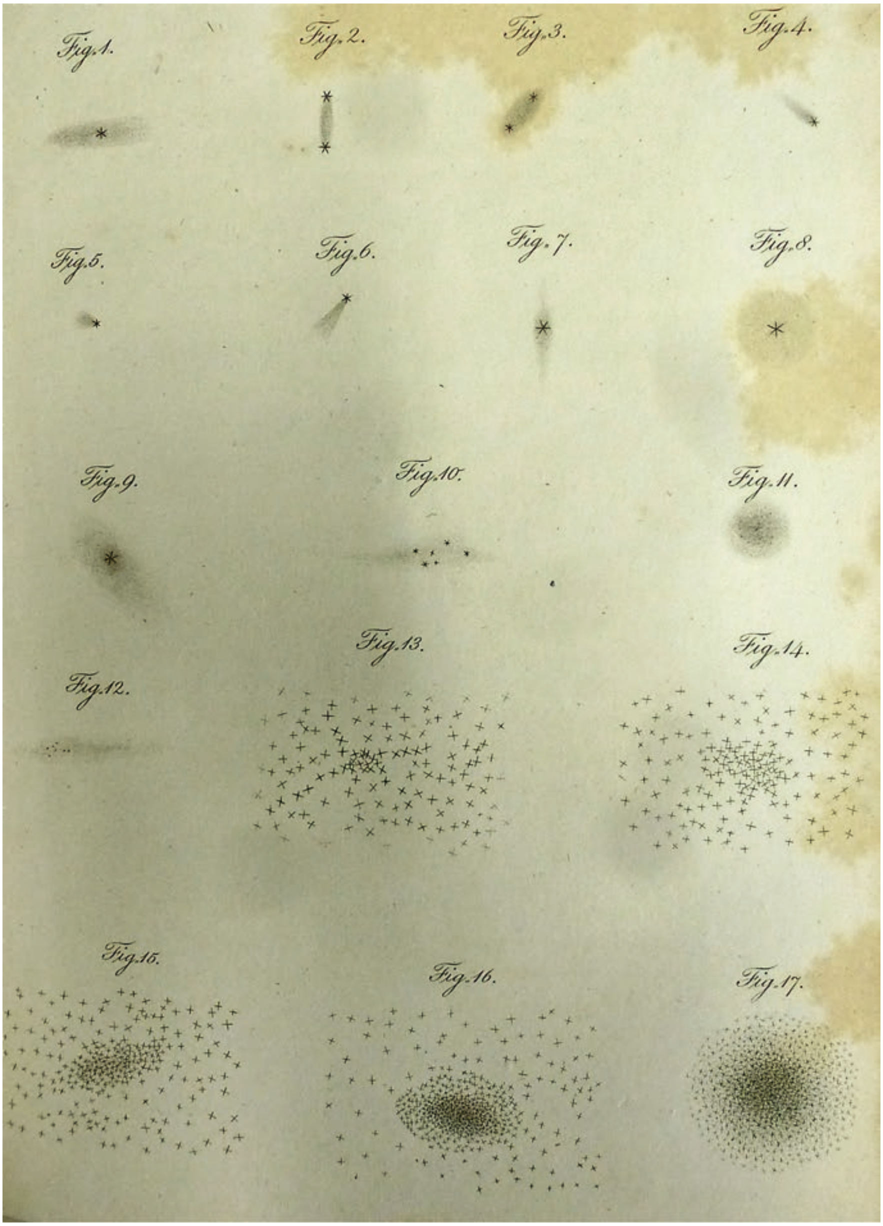


**Fig. 2.9** Herschel's scheme of maturation of nebulae and stellar clusters. In the illustrated sequence nebulosity contracts due to gravity and eventually forms clusters of stars. His Figs. 1 through 12 show varying amounts of nebulosity; later stages show only stars, ending with a "globular cluster" (his Fig. 17). Herschel (1814)

around the Sun and back out into the stellar and nebular world. Eventually, it would inevitably encounter either a nebula or a star.[31] If the former, it would be rejuvenated by picking up more nebulous material – Herschel delightfully called it *unperihelioned*[32] matter. If it encountered a star, it would be ablated even more.

It would also be possible that whenever more nebulous material was picked up that the central planetary body grew in size and mass along with its atmosphere. Thus the scheme neatly incorporated an idea of planet formation and subsequent "growing up to maturity," although there was no mention of how a comet's parabolic orbit could be transformed into the circular orbit of a planet. As shown earlier in Fig. 2.8, we can imagine the various stages of a planetary body's life: birth in a condensed nebula, careening through space, swinging by one star after another in the form of a rapidly changing comet, passing through "immense regions" with "extensive strata of nebulosity," and picking up unperihelioned matter. The denizens[33] of each planetary system on its circuit would suddenly and briefly see a comet of a form and brightness dependent on its recent history and how close it passed by the star.

When yet another comet (Pons) appeared even before the Great Comet of 1811 had faded away, Herschel (1812b) dutifully studied it for 3 weeks (Table 2.1) and developed these ideas further. He was struck by the profound differences between the structures of the two comets. The central planetary body of Comet Pons was much larger at ~2600 miles (4200 km) across, but there was no comet head and only the faintest of tails. Furthermore, the brightness of the planetary body was much less than for the Great Comet; for example, it could not bear 600× magnification. Altogether, it seemed that this faintness and the great size were pointing to an object that actually *was* a planet visible because of *reflected* sunlight. This then was a very consolidated comet, lacking atmosphere to be lit up by the Sun.

Herschel arranged the three recent comets in order of consolidation. Comet Pons was in an advanced state of consolidation, having lost whatever atmosphere it originally had and having not picked up a fresh supply of unperihelioned (nebular) material. The Great Comet of 1811 had a large atmosphere of nebulous material and therefore was bright and complex (full of "beautiful phenomena") and had a small planetary body. It must have either just come from being formed in a condensed nebula, or just passed through a nebula and picked up unperihelioned (nebular) material. Lastly, the Great Comet of 1807 was somewhere in between. He clearly liked this scheme, although with reservation: "[It] appears to me most likely to throw some light upon a subject which still remains involved in great obscurity" (Herschel 1812b:234).

---

[31] Herschel never provided estimates of how long it would take before an encounter occurred (but certainly he was thinking of a *very* long time), or what the odds were that such an encounter would even take place.

[32] The term *unperihelioned* does not appear in the *Oxford English Dictionary*, but many other Herschelian neologisms do: *planetary nebula, globular cluster, asteroid, binary system, star gauge, penetration* (power of a telescope), *invisible ray* (infrared radiation).

[33] Herschel believed that all planets, moons and stars were inhabited. However, the evidence for whether or not he extended the presence of intelligent life to comets (as did many) is ambiguous.

## Aspects of Herschel's Style of Science, as Illustrated by Comets

Herschel had always argued that speculating about the meaning of observations was necessary for science to make any progress. We have seen many examples of this as he interpreted the Great Comets of 1807 and 1811, and the role of comets in general. Exactly how to mix observations with rational analysis and imaginative leaps, however, required wisdom. As he stated a quarter century before these comets appeared in the sky:

> *If we would hope to make any progress in an investigation of this delicate nature, we ought to avoid two opposite extremes, of which I can hardly say which is the most dangerous. If we indulge a fanciful imagination and build worlds of our own, we must not wonder at our going wide from the path of truth and nature; but these will vanish like the Cartesian vortices, that soon gave way when better theories were offered. On the other hand, if we add observation to observation, without attempting to draw not only certain conclusions, but also conjectural views from them, we offend against the very end for which only observations ought to be made. I will endeavor to keep a proper medium; but if I should deviate from that, I could wish not to fall into the latter error.* (Herschel: 1785:213–4)

In the same vein Herschel's son John later recalled:

> *I remember it was a saying often in my Father's mouth 'Hypotheses fingo' in reference to Newton's 'Hypotheses non fingo' ['I frame no hypotheses'] and certainly it is this facility of framing hypotheses if accompanied with an equal facility of abandoning them which is the happiest structure of mind for theoretical speculation.*[34]

But what if the observations gleaned from long nights at the telescope were themselves dubious? Especially late in his career, when Herschel's standing among his contemporaries was so high and the superiority of his telescopes deemed so unimpeachable, it seems that he could publish just about any claim without serious objection. Notably, Herschel (1798) announced that the number of moons of the Georgium Sidus (Uranus) was not just the two he had found in 1787 but six. In a second case, he presented observations that Saturn's shape was not a compressed-at-the-poles spheroid, as he (and others) had earlier measured, but a significantly different squarish shape (Herschel 1805). These and other published claims turned out to be badly in error, often taking decades for others to sort out in the face of Herschel's authority.

In the case of the Great Comets of 1807 and 1811, he likewise made observational claims that, even taking his own words at face value, seemed on shaky ground. Despite this, based on these claims, Herschel built the sweeping picture of cosmic evolution described in the previous section. As an example, I will analyze one case in more detail, namely Herschel's argument that the central "planetary body" of a comet is round in shape. Showing this was very important for his entire logical edi-

---

[34] John Herschel:William Whewell, 20 Aug 1837, Royal Society HS 21.228. Cited by M. Bolt on p. 289 of John Herschel entry in *New Dictionary of Scientific Biography* (Vol. 3, 2007), ed. Noretta Koertge (New York: Charles Scribner's Sons).

fice of what a comet's parts were, and how and why they changed over time. Recall that he defined his key task as establishing which of two possibilities could be empirically established: (1) the bright central object *does* exhibit phases like our Moon, depending on the ever-changing geometry of the Earth-to-comet-to-Sun phase angle, or (2) it does not. If (1) were correct, the object shone because of reflecting incident sunlight, as does a planet. If (2) were correct, it had no phases and therefore was intrinsically shining, or "self-luminous."

If we read Herschel's papers carefully and dig into his archives at the Royal Astronomical Society, what do we find about how he proceeded to choose one of these options? As discussed earlier, he considered his most reliable data to come from the bright comets of 1807 and 1811, for each of which he wrote a long paper (Herschel 1808, 1812a). In October 1807 here are quotations from his observing logbook[35] (underlining mine) for the first comet[36]:

> *4 Oct. 7 feet [telescope] – [magnifying] Power 155.* [The nucleus] *is perfectly round. [p. 17]*
>
> *5 Oct.* [during daytime tests]: …<u>*contrary to my expectation*</u> [the comet nucleus] *was apparently round. [p. 18]*
>
> *18 Oct. 10 feet. The Nucleus is evidently round,* <u>*which if it were seen by light reflected from the sun, it would not be; this seems to prove that it shines by light of its own*</u>*. [p. 19]*
>
> *19 Oct.* [My new 10 feet mirror] *is uncommonly distinct and gives the diameter of small objects smaller than my former….The Nucleus is perfectly round and well defined….The night is uncommonly beautiful and the moon is not yet risen to take off from the brightness of the Comet. [p. 19]*

And from his published paper, appealing to his daytime experiments:

> *The same telescope, which could shew the spherical form of balls, which subtended only a few tenths of a second in diameter, would surely not have represented a cometary disk as circular, if it had been as deficient as are…the calculated appearances.* (Herschel 1808:157)

We here make three points: (1) Herschel is quite convinced that he could have detected a non-roundedness here. (2) He must also have known from long experience that looking at an object ~60 horizontal meters away yielded images much crisper and steadier than when looking upwards through the entire Earth's atmosphere above. (3) It is remarkable that Herschel intermixes in his *observational* log interpretations of what he is seeing – see the underlined phrases. Apparently he had

---

[35] To be more exact, William's logs are a "fair copy" (a neat copy, edited to varying degrees) made by Caroline of either William's original written notes or Caroline's notes as dictated to her by William with his eye to the telescope. Sometimes they are a Caroline copy of a copy of the originals. These copies even include reproductions by Caroline of William's sketches of star patterns, planetary features, sunspots, comets, etc. Once copied, the originals were sometimes unfortunately discarded, but the evidence of the archives is that Caroline was fastidious in her copying and made very few mistakes. It is much the same story for almost all of William's manuscripts submitted for publication – few drafts of any kind survive.

[36] These log book quotations for both comets are from RAS W.3/1.12, at cited page number.

earlier been criticized for this, for he defiantly argued that in fact when the object was in view was precisely the time to be thinking about how to understand it:

> *I must take notice of what will perhaps be censured in many of the observations; they may be said to be accompanied with surmises, suppositions, or hypotheses which should have been kept separate. In defense of this seeming impropriety, I must say, that the observations are of such a nature, that I found it impossible, at the very time of seeing the new objects that presented themselves to my view, to refrain from ideas that would obtrude themselves. It may even be said, that since observations are made with no other view than to draw such conclusions from them as may instruct us in the nature of the things we see, there cannot be a more proper time for entertaining surmises than when the object itself is in view.*
>
> *Now, since the suggestions that have been inserted were always such as arose at the moment of the observations, they are so blended with them, that they would lose much of their value as arguments, if they were given separately.* (Herschel 1801:269)

For the even brighter and larger (and therefore easier to study) Great Comet of 1811, again we quote from his logbook [underlining mine]:

> *18 Sep. Small 10 feet reflector. I examined the head of the comet with this instrument, as I know its distinctness to be so perfect that it will not admit of a possibility of deception. [p. 30]*
>
> *16 Oct. With a very excellent, new 10 feet mirror, power 120, I see the planetary disk in great perfection, and very steadily. It is in appearance a little larger than when I saw it last night, which however I ascribe to the goodness of the mirror. The planetary disk is of a pale ruddy colour, but it is so small that its round figure can hardly be perceived. [p. 33]*
>
> *17 Oct. With the new 10 feet mirror...power 120 shows the bright point extremely like the smallest [faintest] imaginable stars. The point is not otherwise than round, but the roundness cannot with certainty be perceived or ascertained with this power. [p. 34]*
>
> *18 Oct. [Regarding daytime experiments with wax globules placed at 2434.5 inches [~60 meters] from the same new 10 feet mirror and with the same magnifying power as used to observe the lucid point in the comet]:*
>
> *there was this evident difference that I could not a moment doubt of the roundness and well defined outline of the globule whereas the bright cometic point could not easily or at least but very doubtfully be ascertained to be round, and certainly no defined outline could be perceived. [p. 35]*

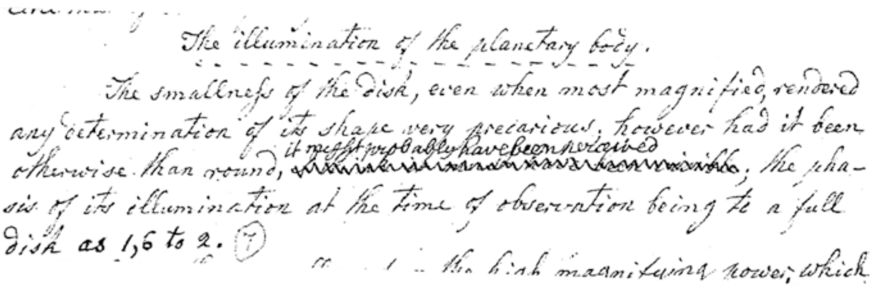
These 1811 comet results are considerably more mixed than in 1807, even though his telescope was "so perfect that it will not admit of a possibility of deception." What then does Herschel (1812a:119) publish as his conclusion, and with what degree of confidence? (underlining mine):

> *The smallness of the disk, even when most magnified, rendered any determination of its shape precarious; however had it been otherwise than round, it might probably have been perceived; the phasis [phase] of its illumination at the time of observation being to a full disk as 1,6 [1.6] to 2.*

In the fair copy of the paper, however, the underlined passage is a replacement for a heavily crossed-out original phrase (Fig. 2.10), which with some effort can reliably be made out to be "I think it must have been visible."[37] It appears that Herschel decided at the very end to be less certain than before, and yet he was still

---

[37] RAS W.3/37.1/p4.



The illumination of the planetary body.

The smallneſs of the disk, even when most magnified, rendered any determination of its shape very precarious, however had it been otherwise than round, it might probably have been perceived [illegible], the phasis of its illumination at the time of observation being to a full disk as 1,6 to 2. ⑦

[illegible] the high magnifying power; which

**Fig. 2.10** Revision by William Herschel to the manuscript (in Caroline Herschel's hand) submitted to the Royal Society; this text was finally published as Herschel (1812a:119). The revised text says "it might probably have been perceived"; the original crossed-out text said "I think it must have been visible." (RAS W.3/37.1/p4)

unwilling to say that, even with his best telescopes, he could not distinguish between the two cases: round or not.

What does a modern analysis indicate as to Herschel's ability to establish "roundedness"? In the Comet of 1807 paper Herschel (1807) supplied a drawing illustrating his calculated phases for the comet. These corresponded to a "gibbous comet" with about 77% of its circular disk lit, crudely equivalent to an oblong with relative dimensions of about 1.29 to 1 for its two axes. The geometry for the 1811 comet was even less favorable, with the predicted lit portion now 83% of the disk, which meant one was trying to distinguish between (1) a phase effect, indicated by slightly non-equal axes of ratio 1.25 to 1, each ~0.8″ in size and perhaps accompanied by a very small darkish region, and (2) no phase effect, indicated by equal axes. In his published article Herschel stated the 1.25 ratio (quotation above), but thought it unwise to show, as he had for the 1807 comet, an illustration of the predicted phase shape. Figure 2.11 shows what such a diagram might have looked like.[38] It would have been extremely difficult to visually establish with any certainty the "non-roundedness" or roundedness of the nucleus. Conspiring against one was its very small angular size, poor contrast with the surrounding comet head, and distortions from atmospheric scintillation causing rapid changes in intensity and position.[39]

In conclusion, Herschel often pushed himself to the very limits of what his instruments and his eye could reliably deliver. He made serious efforts to understand exactly where those limits were and how to handle them, but in the end often succumbed to his predilection to put forth what he himself called "conjectural views" for which the evidence was less than solid. These conjectures, as here, were almost always in the direction of shaping and/or backing his general principles of how the universe worked.

---

[38] Using Voyager planetarium software, I have verified Herschel's calculated phases and distances for these two comets.

[39] Today we know that each comet indeed does have a solid, icy body at its center, but its size is only ~10 km, meaning that Herschel had no chance of discerning it; only spacecraft passing close by comets have been able to see such nuclei. We do not know what apparent feature Herschel observed and measured.

**Fig. 2.11** How the central planetary body of the Great Comet of 1811 might have appeared to Herschel. The phase is for a disk 83% lit, such as Herschel was attempting to discern. The planetary body was of order 1″in diameter, surrounded by the bright comet's head of diameter ~240″(only the very central part of the head is shown) (Drawing by Woodruff Sullivan)

## Herschel's Cometary Concepts in Context

Herschel's concepts regarding comets were hardly wholly novel, although we find in his papers not a single citation of earlier authors.[40] We will start this brief review of earlier work with Newton, whose mathematical work on the nature of orbits heavily relied on comet observations.[41] He took comets to be hot, extremely dense, solid bodies with the mass of a planet and considered them to function "for the perpetual interchange of all things." This included colliding with the Sun (or stars) so as to replenish their brightness and sometimes cause great outbursts.

Subsequent Newtonians took this interchange to include both the bringing of life, or at least its raw materials (especially water and other vital, subtle "spirits"), as well as the destruction of Earth's life and perhaps even the entire planet (as proposed, for example, by Halley and later Pierre Louis Moreau de Maupertuis). Comets were blamed for the Deluge and predicted to cause the future Apocalypse. In 1749 the Comte de Buffon wrote in his magisterial *Histoire Naturelle* that comets had led to the formation of planets by drawing from the Sun filamentary material that eventually coagulated into planets. One popular author on whom Herschel cut his teeth while still a musician in Bath was James Ferguson. His *Astronomy Explained upon Sir Isaac Newton's Principles* was a standard text of the day (Herschel probably read the 4th edition of 1773). Ferguson faithfully followed

---

[40] Although during Herschel's era citations were far less frequent than today, my impression is that Herschel, even for his time, was below average in citing other's work.

[41] In this brief review I rely largely on Schaffer (1980), who was the first to analyze Herschel's ideas on comets vis-à-vis his cosmology, as well as Schechner Genuth (1997) and Heidarzadeh (2008).

Newtonian ideas, but went further by saying that comets and planets are probably all inhabited, not at all an unusual idea for the day (Crowe 1986).

Two of Herschel's contemporaries, astronomer/mathematicians Jérôme Lalande (a frequent correspondent with the Herschels and once a visitor) in France and Johann Lambert in Germany, prominently developed cometary cosmologies (Schaffer 1987). They saw comets as guarantors of Solar System stability as well as threats to the welfare of humans, and as signs of God's providence as well as a means to understand the geological history of Earth. In particular, Lambert (1761) argued for a non-changing Solar System in which comet-planet collisions did not happen despite his argument that several million comets resided in the known Solar System. These comets were not only inhabited by intelligent beings but moved from one star system to the next. In contrast, Lalande emphasized that comets could well collide with planets, that the Solar System and its orbits were continually changing, and that only a few hundred comets existed at this time.

By 1800 the field of cometography had no consensus on the basic properties of comets except for their orbits. After 40 years of study, in 1803 Lalande still considered the puzzles of comets the most important to solve in astronomy: "I dream of nothing but comets; I talk of nothing but comets; I recommend nothing to my correspondents but searching for comets, when I write to them that the only thing which astronomy lacks is the understanding of comets."[42]

Which of these predecessors influenced Herschel? If we examine the scheme described in his 1812 paper, we find that virtually all of its individual features had been proposed by others well before:

- Comets falling into the Sun to reverse its wasting away went back to Newton.
- A solid body sitting at the core of a comet was assumed by many, although no one before Herschel had claimed to see it, let alone measure its diameter.
- Observing phases of the central body was an old idea and one uncertain claim had even been made in 1744 (reported much later by Laplace).[43] Herschel was certainly the only person who authoritatively reported detecting such phases.
- Comets traveling between star systems was also not a new idea. It was part of Lambert's (1761) cosmology.[44] We don't know if Herschel first learned of this in Lambert's original book (in German), but we do know that he read an English translation of 1800 (even before it was published) because he left ten pages of detailed notes for us, criticizing it in the strongest language ("What an abuse of words is this kind of language"; "The author seems to be perfectly in the secrets of the Creator") (Hoskin 1978; Crowe 1986:68).[45] But although Herschel rejects most of Lambert's ideas, he did adopt one: namely that comets move from star to

---

[42] *Bibliographie Astronomique* (Paris), 850 (1803); cited by Schaffer (1987:67).

[43] Schechner Genuth (1997:209).

[44] The idea also shows up in the philosopher David Hume's work *Dialogues concerning Natural Religion* (1779); cited by Schechner Genuth (1997:213–4). As an aspiring 22-year-old musician, Herschel had dinner with Hume in Edinburgh in 1761.

[45] RAS W.7/2.1.

star. He would have also seen this suggestion in 1788 in a short publication by Henry Englefield that was designed to assist observers searching for the predicted return of the comet of 1661:

> *I cannot help therefore suspecting* [*that some comets exist*] *whose orbits may have been so far altered, as totally to quit the sun, and wander through the immeasurable voids of space, till they fall within the sphere of attraction of some other star (an hypothesis by no means improbable).*[46]

Comets transmuting into planets thus was not at all a new notion, but what *was* new with Herschel was the scheme of connecting his nebulae to comets, and laying out a transformational process in which a nebula spawned a small planetary body that wandered through space and happened upon stars, each time becoming a transient comet. Another feature of the scheme was the spent comet possibly growing in mass by passing through more nebulae, being rejuvenated as a comet, and eventually (no details given) becoming a proper planet.

Finally, Herschel's research is intimately tied to his French contemporary, Pierre-Simon Marquis de Laplace, giant of celestial mechanics. Herschel had extensive discussions with Laplace while visiting Paris in 1802. Over the period 1796–1824 Laplace published five editions of his authoritative *Exposition du Système du Monde*, designed to explain the cosmos without a single equation. Herschel's work on comets was not mentioned in *Exposition* until the fourth edition in 1813 (the first after Herschel's publication in 1812 of his scheme), when Laplace mentioned with approval the idea of comets forming by the condensation of distant nebulae, traveling between stars, and losing material whenever closely encountering a star (Schechner Genuth 1997:208–12; Heidarzadeh 2008:196–9).[47] For Laplace these alien comets removed a serious problem he had had explaining the peculiar orbits of comets as part of what came to be called his "nebula hypothesis" for the origin of the Solar System. This hypothesis dominated thinking throughout the nineteenth century. Laplace's proposal was similar to Herschel's gravitational mechanism for making a star and planets from collapsing nebular material, but Laplace supplied more details concerning conservation of angular momentum, planets forming from rings of material, etc.

## Herschel's Universe

Although this paper has described only William Herschel's observations and ideas on comets, his cometary work nicely leads us into his broader thinking. He did not segregate his research on our Solar System (Sun, planets, moons and comets) from

---

[46] Englefield, H. (1788). p. 9 in *Tables of the Apparent Places of the Comet of 1661, Whose Return is Expected in 1789*. London: P. Elmsly. Also see footnote 3.

[47] Laplace also argued that the mass of at least one comet was less than 1/5000 the Earth's mass, based on the fact that he could find no perturbations on the Earth's orbit (specifically the length of the year) arising from the close passage (0.015 AU) of the comet of 1770 (Heidarzadeh 2008:196–9). This of course made it unlikely that comets could turn into planets.

that on the sidereal universe beyond (nebulae of many kinds, binary stars, variable stars, star clusters) – they were all parts of the same novel cosmology. Simon Schaffer (1987:62) has called Herschel "the most radical cosmologist of the period."

Throughout his astronomical career one finds him guided by basic principles when trying to make sense of the phenomena he observed with his unmatched telescopes. His voluminous observations, of every possible target, including many types never before seen, were interpreted within an epistemological framework consistent with:

1. A *teleological, ordered and knowable universe* designed by a Creator such that everything in it had its purpose, and nothing was ever "useless."
2. A *unified universe* wherein all the parts fit together beautifully.
3. An *inhabited universe* fit throughout for intelligent creatures.

These principles, when combined with his decades of observation, led him to:

4. An *active, changing universe* in which all objects were continually forming, maturing, and dying.
5. A *universe vastly extended in time and space.*

In this paper we unfortunately do not have enough of Herschelian time and space to discuss these cosmological principles in any detail. But we have already seen many signs of Herschel's universe solely through the lens of his comet research (which comprises only 8 of his 73 lifetime articles in *Phil. Trans.*).

With regard to a purposeful universe made by a Creator, Herschel refers to comets as "tools, probably designed for some salutary purposes" in nature's "great laboratory," and required to save the Sun from wasting away as it continually loses particles of light:

> *Many of the operations of nature are carried out in her great laboratory, which we cannot comprehend; but now and then we see some of the tools with which she is at work....This throws a mystery over [the comets'] destination, which seems to place them in the allegorical view of tools, probably designed for some salutary purposes to be wrought by them; and, whether the restoration of what is lost to the sun by the emission of light...may not be one of these purposes, I shall not presume to determine….*
>
> [considering comet orbits in general] *it appears clearly that they may be directed to carry their salutary influence to any part of the heavens.* (Herschel 1795:60–1)

Regarding a cosmical unity and an ordered universe, recall his words in the letter of 1781 cited earlier:

> *….uniting* [the Cometary and Planetary System] *together by that admirable connection already discovered in so many other parts of the creation….the wonderful order that reigns throughout the whole Solar and Sidereal System.*[48]

To Herschel the concept of *planets* was central. A planet was a solid body with an atmosphere that fostered habitation by intelligent beings adapted to its conditions. The usual planets and moons (and later, asteroids) were of course included,

---

[48] Herschel:J. Banks, 19 Nov 1781, RAS W.1/7.

but also potentially comets (with their central "planetary body," perhaps still forming) and even stars, including the Sun. The Sun was evidently the grandest planet of our Solar System:

> *The sun, viewed in this light, appears to be nothing else than a very eminent, large, and lucid planet….Its similarity to the other globes of the Solar System with regard to its solidity, its atmosphere, and its diversified surface; the rotation upon its axis, and the fall of heavy bodies, leads us on to suppose that it is most probably also inhabited, like the rest of the planets, by beings whose organs are adapted to the peculiar circumstances of that vast globe.* (Herschel 1795:63)

> [My ideas on the sun given in 1795] *may be legitimately applied to the stars; whence it follows that stars, although surrounded by a luminous atmosphere, may be looked upon as so many opaque, habitable, planetary globes; differing, from what we know of our own planets, only in their size, and by their intrinsically luminous appearance.* (Herschel 1814:263)

He emphasized that this was not some wild speculation (as others had done in the past), but rather an eminently scientific conclusion, based on detailed observations and plausible deductions.[49] By analogy he further pointed out that:

> *We may have an idea of numberless globes that serve for the habitation of living creatures. But if these suns themselves are primary planets, we may see some thousands of them with our own eyes; and millions by the help of telescopes.* (Herschel 1795:68)

All stars thus have a teleological purpose, even if no planets of the usual kind can orbit them (say, in a crowded star cluster): "Many stars, unless we would make them mere useless brilliant points, may themselves be lucid planets." (Herschel 1795:71).

Herschel's unified and inhabited universe was also constantly undergoing change, and here Herschel appealed to processes of maturation (ageing) threading throughout space and time. We have seen his notion of comets, perhaps the most spectacular of all changeable phenomena in the firmament, as just one manifestation of a cyclic pathway that encompassed interstellar nebulae, stars and planets (Fig. 2.8). But based on his thousands of nebulae and star clusters, categorized into dozens of forms, Herschel also developed a second pathway for maturation. Gravity was the driving force for nebulosity to collapse and eventually turn into a star or star cluster, along the way taking on more and more concentrated forms (Fig. 2.9). For both of these pathways, change happened imperceptibly (except during the comet phase) over incalculable eons. Herschel was thus in accord with his contemporary, the Scottish geologist James Hutton, whom he read and visited. Hutton studied Earth's strata and extremely slow geological processes such as sedimentation and erosion, famously concluding in his *Theory of the Earth* (1788): "We find no vestige of a beginning – no prospect of an end."

---

[49] See Crowe (2011) for a full historical account of the notion of an inhabited sun, an idea that started long before Herschel and, abetted by his authority and arguments, lasted well past his time. Crowe (1986) exhaustively covers the larger question of extraterrestrial life during the eighteenth and nineteenth centuries. Sullivan (2013) examines aspects of Herschel's views on extraterrestrial life, in particular his use of analogy.

Herschel's universe likewise extended not only indefinitely in time both backwards and forwards, but seemingly also in boundless space, for he calculated the faintest star clusters visible with his 40-ft (12.2 m) reflector to be at the astounding distance of 2 million light-years (taking Sirius to be at ~5 light-years), yet felt confident from his experience that still fainter, and presumably farther, stars would be revealed by a larger mirror (Herschel 1800:83–4).

William Herschel's 21 comets observed over the period 1781–1819 thus surprisingly provide a gateway into many aspects of his life and science: his collaboration with Caroline, his style of observing, his rhetoric in argumentation, his elaborate scheme for the structure and lifetime history of a comet, and much of his overall cosmology.

**Acknowledgments** I give many thanks first to Michael Hoskin for his friendship and the insights and facts provided by his publications on the Herschels over the past half-century. In particular, his creation of purchasable DVD's containing the entire Herschel archives of the Royal Astronomical Society has been of immense use to me and many others. Michael Crowe has also been extremely helpful in my Herschel researches. For assistance with aspects of this paper I thank Peter Abrahams, Don Brownlee, and Don Yeomans. The excellent service of the Interlibrary Loan section of the University of Washington Libraries has been indispensable, as have many librarians and archivists, in particular at the Harry Ransom Center of the University of Texas, and the Royal Society in London.

## References

Bullard, M. 1988. My small Newtonian sweeper – Where is it now? *Notes & Records Royal Society London* 42: 139–148.

Crowe, M.J. 1986. *The extraterrestrial life debate 1750–1900*. New York: Cambridge University Press.

———. 2011. The surprising history of claims for life on the sun. *Journal of Astronomical History and Heritage* 14: 169–179.

Cunningham, C.J. 2016a. *Early investigations of Ceres and the discovery of Pallas*. New York: Springer.

———. 2016b. *Discovery of the first asteroid, Ceres*. New York: Springer.

Deluc, J.-A. 1809. "A letter on comets" [dated 1799]. *Nicholson's Journal of Natural Philosophy, Chemistry, and the Arts* 23: 206–213.

Dreyer, J.L.E. (Ed.) (1912; 2003 reprint). *The scientific papers of Sir William Herschel* (Vol. 1). 1912 (2003 reprint). Thoemmes Press: Bristol.

Ferguson, J. (1773). *Astronomy explained upon Sir Isaac Newton's principles*. 4th ed. London.

Heidarzadeh, T. 2008. *A history of physical theories of comets, from Aristotle to Whipple*. New York: Springer.

Herschel, C. 1787. An account of a new comet. Philosophical Transactions 77: 1–3.

Herschel, C. 1794. An account of the discovery of a comet. *Philosophical Transactions* 84: 1.

Herschel, C., and W. Herschel. 1796. Account of the discovery of a new comet. By Miss Caroline Herschel. *Philosophical Transactions* 86: 131–134. Two parts: pp. 131–2 by CH with title as given; pp. 133–4 by WH with title "Additional observations on the comet".

Herschel, W. 1781. Account of a comet. *Philosophical Transactions* 71: 492–501.

———. 1785. On the construction of the heavens. *Philosophical Transactions* 75: 213–266.

———. 1786. Catalogue of one thousand new nebulae and clusters of stars. *Philosophical Transactions* 76: 457–499.

Herschel, W. 1787a. Remarks on the new comet. Philosophical Transactions 77: 4–5.

———. 1787b. An account of three volcanos in the moon. Philosophical Transactions 77: 229–232.

———. 1789. Observations on a comet. *Philosophical Transactions* 79: 151–153.

———. 1792. Miscellaneous observations. *Philosophical Transactions* 82: 23–27.

Herschel, W. 1795. On the nature and construction of the sun and fixed stars. *Philosophical Transactions* 85: 46–72.

———. 1798. On the discovery of four additional satellites of the Georgium Sidus. The retrograde motion of its old satellites announced; and the cause of their disappearance at certain distances from the planet explained. *Philosophical Transactions* 88: 47–79.

———. 1800. On the power of penetrating into space by telescopes; with a comparative determination of the extent of that power in natural vision, and in telescopes of various sizes and constructions; illustrated by select observations. *Philosophical Transactions* 90: 49–85.

———. 1801. Observations tending to investigate the nature of the sun, in order to find the causes or symptoms of its variable emission of light and heat; with remarks on the use that may possibly be drawn from solar observations. *Philosophical Transactions* 91: 265–318.

———. 1802a. Observations on the two lately discovered celestial bodies. *Philosophical Transactions* 92: 213–232.

———. 1802b. Catalogue of 500 new nebulae, nebulous stars, planetary nebulae, and clusters of stars; with remarks on the construction of the heavens. *Philosophical Transactions* 92: 477–528.

———. 1805. Observations on the singular figure of the planet Saturn. *Philosophical Transactions* 95: 272–280.

———. 1807. Observations on the nature of the new celestial body discovered by Dr. Olbers, and of the comet which was expected to appear last January in its return from the sun. *Philosophical Transactions* 97: 260–266.

———. 1808. Observations of a comet, made with a view to investigate its magnitude and the nature of its illumination. To which is added, an account of a new irregularity lately perceived in the apparent figure of the planet Saturn. *Philosophical Transactions* 98: 145–163.

———. 1811. 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 new light upon the organization of the celestial bodies. *Philosophical Transactions* 101: 269–336.

———. 1812a. Observations of a comet, with remarks on the construction of its different parts. *Philosophical Transactions* 102: 115–143.

———. 1812b. Observations of a second comet, with remarks on its construction. *Philosophical Transactions* 102: 229–237.

———. 1814. Astronomical observations relating to the sidereal part of the heavens, and its connection with the nebulous part; arranged for the purpose of a critical examination. *Philosophical Transactions* 104: 248–284.

Hoskin, M. 1978. Lambert and Herschel. *Journal for the History of Astronomy* 9: 140–142.

———. 2005. Caroline Herschel as observer. *Journal for the History of Astronomy* 36: 373–406.

———. 2013. *Caroline Herschel: Priestess of the Heavens*. Sagamore Beach: Science History Publications.

———. 2014. Caroline Herschel's life of "mortifications and disappointments". *Journal for the History of Astronomy* 45: 442–466.

Hughes, D.W. 1999. Caroline Lucretia Herschel – Comet huntress. *Journal of the British Astronomical Association* 109: 78–85.

Kronk, G.W. 1999. *Cometography: A catalog of comets*. Cambridge: Cambridge University Press. 2 Volumes.

Lambert, J. 1761. *Cosmologische Briefe über die Einrichtung des Weltbaues*. Augsburg. Available in English as *Cosmological Letters on the Arrangement of the World-Edifice*, ed. and trans. S.L. Jaki (1976, New York: Science History Pubs.). Early translations: French trans. and condensation in 1770; English trans. of French in 1800; full French trans. in 1801.

Olson, R.J.M. 1985. *Fire and ice: A history of comets in art*. New York: Walker Publishing Co.

Olson, R.J.M., and J.M. Pasachoff. 1998. *Fire in the sky: comets and meteors, the decisive centuries, in British art and science*. Cambridge: Cambridge University Press.

Schaffer, S. 1980. "The great laboratories of the universe": William Herschel on matter theory and planetary life. *Journal for the History of Astronomy* 11: 81–111.

———. 1987. Authorized prophets: Comets and astronomers after 1759. In *Studies in eighteenth-century culture*, ed. J. Yolton and L.E. Brown, 17: 45–74. East Lansing: Colleagues Press.

Schechner Genuth, S. 1997. *Comets, popular culture, and the birth of modern cosmology*. Princeton: Princeton University Press.

Steinicke, W. 2010. *Observing and cataloguing nebulae and star clusters: From Herschel to Dreyer's New General Catalogue*. Cambridge: Cambridge University Press.

Sullivan, W.T. 2013. Extraterrestrial life as the great analogy, two centuries ago as well as in modern astrobiology. In *Astrobiology, history and society: Life beyond earth and the impact of discovery*, ed. D.A. Vakoch, 73–83. Heidelberg: Springer.

Yeomans, D.K. 1991. *Comets: A chronological history of observation, science, myth, and folklore*. New York: Wiley.

# Chapter 3
# William Herschel's 'Star Gages' and the Structure of the Milky Way

**Wolfgang Steinicke**

## Introduction

William Herschel's epochal observing campaign, using a self-made 18.7-in. reflector, lasted from 1783 to 1802. During his 'sweeps,' designed to find new nebulae and star clusters, he carried out a great number of star counts. In these so-called 'star gages'[1] Herschel counted the number of stars seen in the field of view. One major result was the star distribution for a considerable part of the sky, observable from the Windsor area. Of course, the stars appeared strongly concentrated towards the band of the Milky Way.

However, Herschel was not only interested in the two-dimensional view. Basing his investigation on the assumption of a uniform star distribution in space, he derived a relation between the number of stars in the field of view and their maximum distance, and this led him to an understanding of the boundary of the stellar system. Herschel thought it to be a finite, flattened 'stratum' of stars.

From the mass of star count data he selected a subset along a great circle on the sphere. This led him to a graphical representation, showing a section of the Milky Way. Herschel's figure, presented in 1785, became very popular – though it was sometimes misunderstood.

As a result of his later experiences as an observer, he came to reject the assumption of a constant star density. Herschel had found a large number of star clusters in the Milky Way, and there were moreover were many 'vacant fields,' such as the famous 'hole in Scorpius,' which he discovered in 1784. Thus the stratum later appeared to him to be an inhomogeneous mix of stars, clusters and voids, and he

---

[1] Herschel always used the incorrect word 'gage' instead of 'gauge.' Here we will go mainly with the correct term.

W. Steinicke (✉)
History of Astronomy Section of the German, Vereinigung der Sternfreunde,
Heppenheim, Germany
e-mail: Steinicke-zehnle@t-online.de

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_3

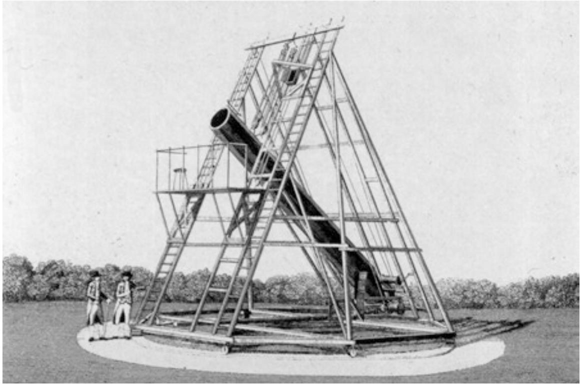


**Fig. 3.1** William Herschel's 20-ft reflector, equipped with a metal mirror of 18.7 in. diameter. It was his standard instrument for sweeping; then the tube was horizontally fixed in the south meridian (due to the shadow of the telescope, this could be the orientation seen here). The picture shows the instrument in 1794, the reflector being in the 'front-view' configuration (explained in the text)

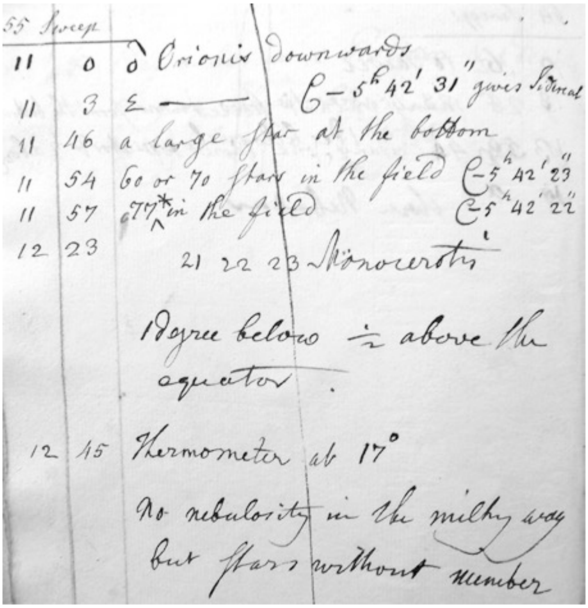
was forced to conclude that his famous figure did not show the boundary of the stratum. The new insights were discussed in several papers that he published after the sweep campaign.

Herschel's son John continued the star counts in the southern hemisphere, inspecting a large number of fields. Because of his extensive observations at the Cape of Good Hope, he became more and more critical of the idea of a stratum. He concluded that the stellar system was much more complex and that the Sun is located in a vacant region.

Many ideas of William and John Herschel about the structure and content of our galaxy became basic knowledge in the nineteenth century, published in the popular textbooks. This article covers the various steps of their theorizing in chronological order, and we discuss their methods, observations, data, ideas and publications.

## The First 'Star Gauges'

It was the cold clear night of December 19, 1783, at Datchet near Windsor Castle. William Herschel started to sweep the heavens at 11 pm. His self-made 18.7-in. reflector of 20 ft focal length, finished in October, was fixed in the meridian, looking south (Fig. 3.1). The tube was ready to oscillate up and down, while the sky passed by, due to Earth' rotation. The difference between the bottom and top position, the sweep breadth, was set to 1.5°. The observation on that December night started at the top. The telescope pointed to the belt of Orion at the celestial equator, about 36° above the horizon. Herschel stood on the platform at the focus looking through his standard eyepiece, offering a power of 157 and a field of view of 15.7′ diameter.



55 Sweep
11 0 δ Orionis downwards
11 3 ε ——— Є – 5h 42' 31" gives Sidereal
11 46 a large star at the bottom
11 54 60 or 70 stars in the field Є – 5h 42' 23"
11 57 77* in the field Є – 5h 42' 22"
12 23 21 22 23 Monocerotis

1 Degree below ÷ above the equator.

12 45 Thermometer at 17°

No nebulosity in the milky way but stars without number

**Fig. 3.2** Record of sweep 55, showing Herschel's first star gauges (at 11.54 pm and 11.57 pm) (Herschel Archive of the Royal Society, document MS/272)

The first object encountered in this sweep (the 55th since October 29) was the bright star δ Orionis at right ascension (RA) 5 h 20 min. About 50 min later, the western part of Monoceros culminated. The telescope was looking at the winter Milky Way and showed a great number of stars. Now, for the first time, Herschel counted the stars seen in the eyepiece. At a north polar distance (PD) of 91°, which equals −1° declination, he found '60 to 70 stars in the field' (Fig. 3.2). Three minutes later – during which time the sky had moved by three field diameters – another count was made at the same PD. He now registered 77 stars. As usual, Herschel shouted all the information to his sister Caroline, who wrote it down at her desk.[2] Only half an hour later sweep 55 was terminated, probably due to the low temperature; the thermometer showed about −8 °C. Herschel finally noted: 'no nebulosity in the milky way but stars without number.' This night marked the beginning of a campaign called 'star gauging' by him. It was to last until September 26, 1802 (sweep 1111).

The sweeps, each covering a certain rectangular sky area in RA and PD, were mainly designed to find new nebulae and star clusters. The harvest from Herschel's systematic survey of the northern sky, made between 1783 and 1802, was immense. He had seen some 2500 deep-sky-objects. Apart from the 103 known ones, cataloged by Messier in 1781, the overwhelming number were new.[3] However, Herschel

---

[2] Caroline's contribution is comprehensibly described in: Hoskin, M., *Caroline Herschel – Priestess of the New Heavens*, Science History Publications 2013.

[3] Except the double star M 40 in Ursa Major, Herschel has observed all 103 Messier-objects (the missing one was seen by Caroline).

was also interested in other object types entering the field of view: known stars (mainly from John Flamsteed's *British Catalogue*[4]), unknown stars to about 10th magnitude, double/multiple stars, stars with unusual color (e.g. 'garnet stars'[5]), and the planet Uranus. Besides observing individual objects, he also pursued another goal during his sweeps: star counts. Over 19 years, Herschel made about 17,700 individual observations of all types. No doubt, due to the amount of information that came to his attention in rapid succession, sweeping was stressful. For instance, on New Year's Eve night of 1785 (sweep 503) Herschel observed about 6.5 h, without any major breaks; the temperature was −7 °C. Caroline recorded 45 stars, 19 nebulae and clusters (16 were new) and 2 double stars. Of course, there was no time for star counts.

In the early sweeps – up to no. 189 on April 12, 1784 – Herschel counted a single field at a certain position (RA, PD). Often he counted areas of sky in different directions. Thus on January 18, 1784, in sweeps 80 and 81, he inspected again parts of the Orion/Monoceros region, and he found a maximum number of 110 stars in a single field. On the other hand, there were many sweeps without a count. From no. 55 to 189 only 12 sweeps contain a gauge. For gauges Herschel mainly selected Milky Way areas, characterized by a low number of nebulae.[6] Away from the Milky Way the situation was different. Here he was engaged in making new discoveries of individual objects, rather than determining star numbers.

How was a single-field gauge performed? At the equator the sky passes one field of view in a minute. If the tube is fixed both in azimuth (south meridian) and altitude (polar distance), stars continually leave the field at the western edge while new ones enter it at the eastern edge (Fig. 3.3). This makes it impossible to count 50 (or even 100) stars at once. To do this, the telescope must follow the motion of the heavens, i.e. the tube must be able to move westwards at a suitable speed. This he effected by means of a handle near the eyepiece. By turning it, Herschel could follow an object over three field diameters. Thus the view was kept for 3 min; time enough to count the stars. When this was completed, the tube was pushed back to the meridian position; a stopper ensured it could never get east of the meridian.

All gauges in sweeps 55–163 were taken in Milky Way regions. This changed for the next two gauges. Sweep 185 (March 27, 1784) covered parts of Hercules. Because of the many unknown stars to be registered, there was time for only one field: it showed just 24 stars. Bootes, visited in sweep 189 on April 12, 1784, brought many new nebulae. Only at the end of the sweep, after 2 h observing, did Herschel have the opportunity to count a field, finding only '5 or 6 stars.' He reacted and changed his tactic, using a new method the same night when making another sweep (190) in the Serpens/Hercules region, after some clouds had passed. It was 2 h after midnight when Herschel counted four fields, yielding 12, 6, 8 and 12 stars.

---

[4] Flamsteed, J., *Historia coelestis Britannica*, London 1725.

[5] Steinicke, W., William Herschel and the 'garnet' stars: μ Cephei and more, *Journal of Astronomical History and Heritage* 18, 199–217 (2015).

[6] Later the term 'zone of avoidance' was created.

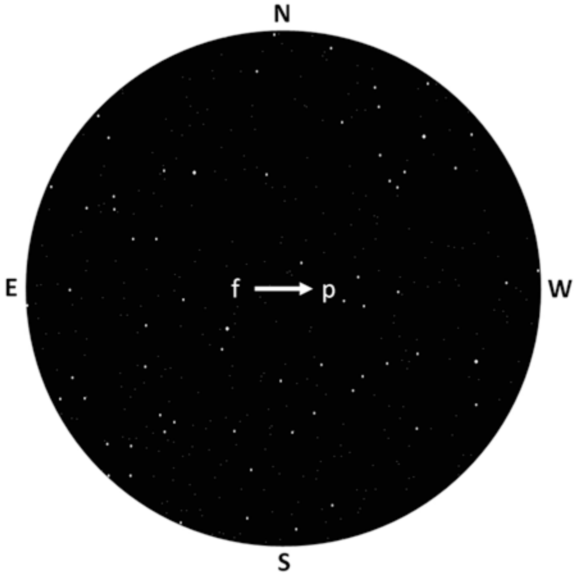


**Fig. 3.3** Herschel's field of view (diameter 15.7′) in the natural sky orientation (motion east to west). The western stars are preceding (*p*), the eastern following (*f*). For the Newtonian focus (two reflections) the field is rotated by 180°; in the 'front-view' design (one reflection) N and S are inverted

Now, the field positions were not independent but lay along the vertical sweep path, which had a breadth of 1° 46′. Altogether, the counts took about 8 min. Caroline's evaluation, made on the next day, gave an average number of 9.5 stars for the four fields. Herschel made three other multiple counts, each using six fields along the path; the average values were 6, 6.5 and 12. The position assigned to a multiple-field gauge was derived from the mean RA of the field centers and the mean PD between top and bottom of the sweep. Later 10 or even 13 fields were taken for one gauge. Of course, the result was the average value over the sweep breadth (1.8°–4.6°) and does not represent a star number in a specific direction. The statistical variation in multiple counts could be considerable (the highest number in a field could be ten times the lowest number).

## His Paper of 1784

In late April 1784 Herschel wrote his first paper on the subject.[7] It was read at the Royal Society on June 17. The title "Account of Some Observations tending to Investigate the Construction of the Heavens" implies that Herschel had an ambitious goal: revealing the form, structure and extent of the stellar system that is the home

---

[7] Herschel, W., Account of some Observations tending to investigate the Construction of the Heavens, *Philosophical Transactions* 74, 437–451 (1784).

of the Sun, stars, clusters and perhaps the nebulae.[8] He was influenced by the results of the star counts – an essential tool for the subject.

A key night was that of January 18, 1784, already mentioned above. Observing the Orion/Monoceros region, Herschel found in about 15 min 110, 60, 70, 90, 70 and 74 stars in single fields. He wrote: "I then tried to pick out the most vacant place that was to be found in the neighborhood, and counted 63 stars." He estimated "that a belt of 15° long and two broad, or the quantity which I have often seen pass through the field of my telescope in 1 h time, could not well contain less than 50,000 stars, that were large enough to be distinctly numbered." He estimated even twice that number when including faint suspected stars.

Herschel now explains his method of 'Gauging the Heavens, or the Star-Gauge', writing: "It consists in repeatedly taking the number of stars in ten fields of view of my reflector near each other, and by adding their sums, and cutting off one decimal on the right, a mean of the contents of the heavens, in all the parts which are thus gauged, is obtained." However, this method was by no means always applied, for the number of fields actually varied from 1 to 13.

Herschel's goal was the Milky Way. He had known about its appearance since 1773, for on May 10 of that year he acquired a later edition of an influential popular book on astronomy, first published in 1756 by James Ferguson. In the brief chapter "Of the fixed Stars" he read[9]: "There is a remarkable track round the heavens, called the *Milky Way*, from its peculiar whiteness, which is found, by means of the telescope, to be owing to a vast number of very small stars, that are situate in that part of the heavens. This track appears single in some parts, in others double." About 1774 Herschel purchased another important work: two large round charts of the northern and southern sky, called 'Harris' Star maps' by him.[10] They not only show the full circle of the Milky Way band but also a remarkable division, stretching from Cygnus to Scorpius (Fig. 3.4). Undoubtedly, Herschel had noticed this branching, later called the 'great rift,' with the naked eye on clear, dark summer nights. Moreover, his telescope had confirmed that the Milky Way is an accumulation of an immense number of faint stars, varying in density along the band.

The optical appearance of the Milky Way and its stellar content had led Herschel to the assumption that the Sun is located in a finite, flat, branching 'stratum' of stars. How this structure creates the observed divided ring of stars on the sphere is demonstrated by a figure published in his paper (Fig. 3.5). However, the collected observational data were not yet sufficient to determine the details of the stellar system, especially its spatial extent. Despite this, he discusses the effect on star counts, made from the interior position on the Sun.

---

[8] For a detailed study of Herschel's various papers on the 'Construction of the Heavens' see: Hoskin, M., *The Construction of the Heavens – William Herschel's Cosmology*, Cambridge University Press 2012.

[9] Ferguson, J., *Astronomy explained upon Sir Isaac Newton's Principles*, London 1756, p. 383–384.

[10] Steinicke, W., William Herschel, Flamsteed Numbers and Harris's Star Maps, *Journal for the History of Astronomy* 45, 287–303 (2014).

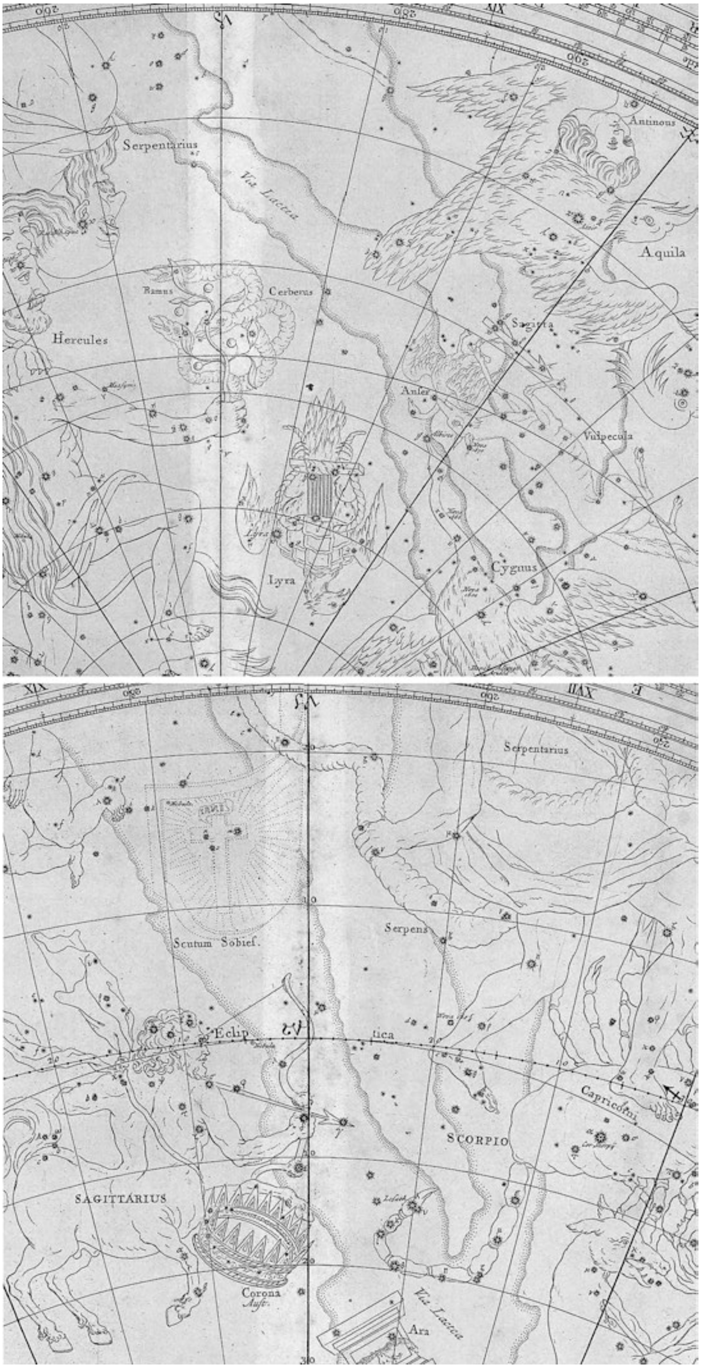


**Fig. 3.4** Parts of Harris' star maps, showing the division of the Milky Way ('great rift') from Cygnus to Scorpius (*top*: northern map; *bottom*: southern map)

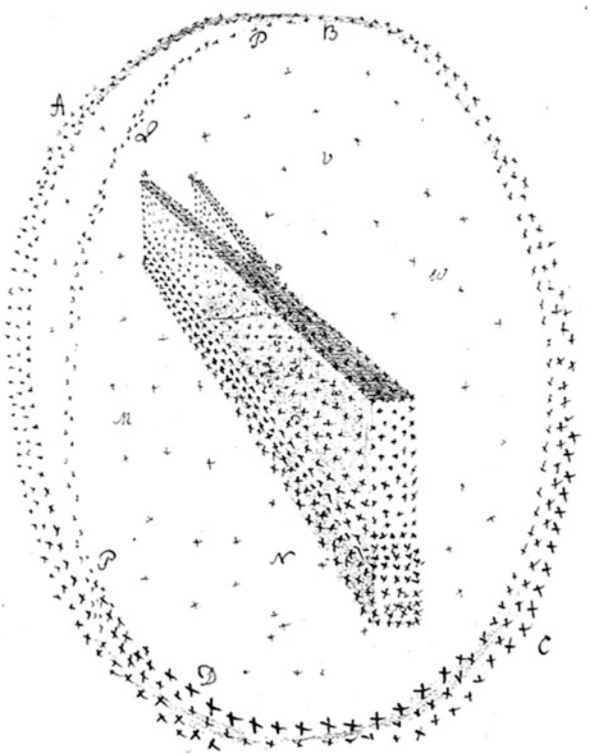
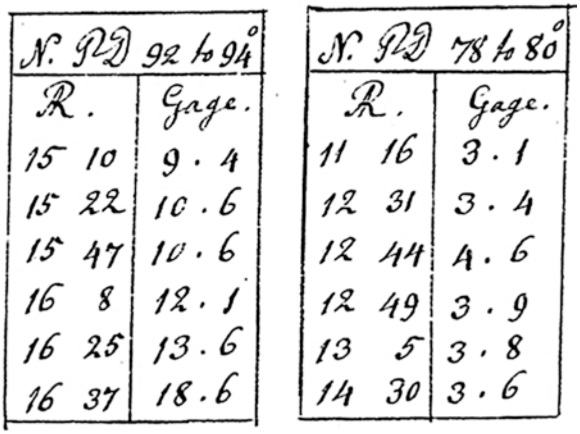


**Fig. 3.5** Herschel's figure of 1784 shows the branching 'stratum' of the Milky Way, creating the observed divided ring; shown here is the draft version from his manuscript (Herschel archive of the Royal Astronomical Society, document RAS W.4/23.1, p. 7)

For the paper, Herschel had selected gauges to illustrate the influence of the Milky Way ('Via Lactea') on the star numbers. He chose two areas with counts that he had made between April 13 and 24, 1784, in sweeps 191, 194, 195 and 206. Here 8–13 fields were averaged. Herschel created two tables with six gauges each (Fig. 3.6); the positions are for 1690. The table for PD 92–94° (below the celestial equator) shows gauges in Libra and Ophiuchus; that for PD 78–80° (above the celestial equator) gauges in Leo, Virgo and Bootes. Evidently, the numbers in the former region, nearer to the Milky Way, are about three times higher than in the latter. Table 3.1 gives the data relating to Herschel's collection.

Herschel knew that both the distance to the boundary of the stratum and the 'penetrating power' of the telescope can affect the counts. But only 58 star gauges were made for the 1784 paper. He wrote: "It would not be safe to enter into an application of these, and such other gauges as I have already taken, till they are sufficiently continued and carried all over the heavens." Without doubt, more observational data were needed – and Herschel was very keen to get them.



N. PD 92 to 94°

| R. | Gage. |
|---|---|
| 15 10 | 9 . 4 |
| 15 22 | 10 . 6 |
| 15 47 | 10 . 6 |
| 16 8 | 12 . 1 |
| 16 25 | 13 . 6 |
| 16 37 | 18 . 6 |

N. PD 78 to 80°

| R. | Gage. |
|---|---|
| 11 16 | 3 . 1 |
| 12 31 | 3 . 4 |
| 12 44 | 4 . 6 |
| 12 49 | 3 . 9 |
| 13 5 | 3 . 8 |
| 14 30 | 3 . 6 |

**Fig. 3.6** Herschel's gauges used for the 1784 paper. *Left* regions near the Milky Way. *Right* regions off the Milky Way

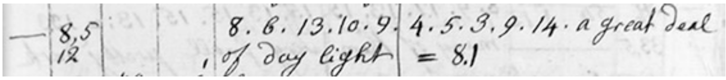
**Table 3.1** Data for Herschel's published table (using the same order)

| Sweep | Day | Const. | Gage | Fields | RA | PD | Lat. |
|---|---|---|---|---|---|---|---|
| 206 | 24 | Lib | 9.4 | 12 | 15 08 45 | 93 05 | 41.5 |
| 206 | 24 | Lib | 10.6 | 12 | 15 21 00 | 93 05 | 39.2 |
| 206 | 24 | Oph | 10.6 | 12 | 15 46 30 | 93 05 | 34.4 |
| 206 | 24 | Oph | 12.1 | 12 | 16 08 11 | 93 09 | 30.0 |
| 206 | 24 | Oph | 13.6 | 12 | 16 24 11 | 93 09 | 26.8 |
| 206 | 24 | Oph | 18.6 | 12 | 16 35 48 | 93 15 | 24.3 |
| 191 | 13 | Leo | 3.1 | 8 | 11 16 52 | 81 38 | 62.3 |
| 194 | 15 | Vir | 3.4 | 11 | 12 30 40 | 79 03 | 72.1 |
| 191 | 13 | Vir | 4.6 | 13 | 12 46 51 | 81 40 | 69.4 |
| 194 | 15 | Vir | 3.9 | 13 | 12 48 19 | 79 04 | 71.9 |
| 194 | 15 | Vir | 3.8 | 12 | 13 01 19 | 79 04 | 71.2 |
| 195 | 15 | Boo | 3.6 | 13 | 14 30 08 | 80 38 | 57.0 |

The second column gives the day in April 1784; the last column lists the galactic latitude (°). The 6 gages, made in sweep 206, are closer to the Milky Way and show higher numbers

## His Paper of 1785

The star counts continued on May 9, 1784, with sweep 210, now mainly using ten fields for a gauge (Fig. 3.7). However, on June 16(sweep 228) Herschel observed a single field in the Scutum Star Cloud, counting no fewer than 358 stars (Fig. 3.8). Five minutes later, he made another gauge. Again, the field appeared enormously rich, and he decided to count only half of the field. This 'half gauge' brought 94 stars, to get 188 for the whole field. From that point on, Herschel used 1/2, 1/3 or even 1/4 of a field in crowded regions.



— 8,5 12 | 8. 6. 13. 10. 9. 4. 5. 3. 9. 14. a great deal of day light = 8.1

**Fig. 3.7** Sweep 210 with first 10-field gauge; the average value is 8.1 (Royal Society MS/274)

**Fig. 3.8** Herschel's field (*circle*) in the dense Scutum Star Cloud, showing 358 stars; 2.3° northeast is the bright open cluster M11, located at the edge of the cloud

The peak value was reached in sweep 254 (August 23, 1784), located in the central summer Milky Way at the border of Sagitta and Aquila. The sky was 'immensely rich,' showing 147 stars in a quarter field, thus 588 in total. The same number appeared 2 min later at a different position. Herschel noted: "All the time the whole breadth of the sweep equally rich with the last gauge." As already done for the 1784 paper, he extrapolated the star number in this field (588) to a rectangular sky area, now measuring 1 h in RA and 2° in PD. He not only estimated the total amount but also presented a calculation, considering the number of fields inside this area at the sweep's mean PD (73°) and the ratio of the circular field to the square area ($\pi/4 = 0.7854$). Herschel correctly gets 343,636 stars.[11] He swept in this branch of the Milky Way for about 15 min. With respect to the breadth of 2° 26′ he noted that "in all probability in this last quarter of an hour not less than 125,000 stars have passed my view."

Sweeps 281–285, made from October 5 to 7, 1784, were exceptional: the telescope was turned to the east.[12] Here the sky motion is not horizontal but skewing

---

[11] RAS W.2/3.2.

[12] The eastern sweeps are not listed in Caroline's records (RAS W.2/3), but in the *Journal No. 10 A*

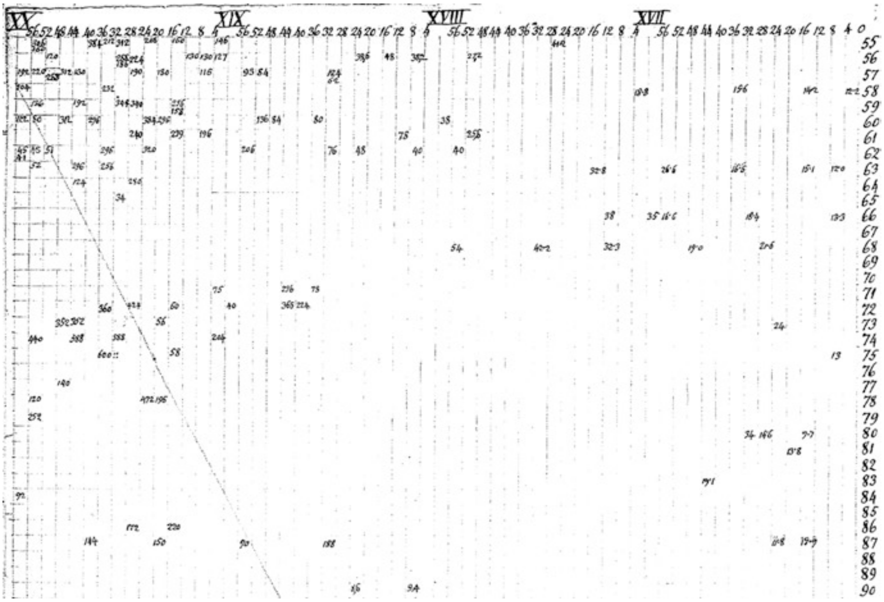


**Fig. 3.9** Part of Caroline's 'Register of Gauges,' ranging from right ascension 16–20 h and polar distance 55–90°; the numbers represent the star counts. (The line on the *left* is explained in the text)

upwards, which makes it difficult to determine positions from sweeping. Nevertheless, 7 nebulae were discovered and 14 gauges performed; 12 were made from single fields, one from a half field and one over 10 fields. With polar distances between 45 and 50° the counts in Andromeda and Perseus were the most northern so far. This trial would remain the only one in which Herschel swept off the meridian.

January 10, 1785, marks another critical date. Herschel had finished sweep 357 and had taken 689 gauges, ten times more than for the 1784 paper. However, due to hazy or damp conditions, six gauges were rejected, leaving 683 for further study. Just 16 % of them were derived from fractions of a field, 35 % from single fields, 8 % from combinations of 2 to 9 fields, 38 % from combining 10 fields and 2 % from combinations of 11 to 13 fields. Thus the 10-field-method, building an average over the full sweep breadth, was standard.

For Herschel the collected data were likely to represent the star distribution in the 'stratum,' though from latitude 53.5° about 30 % of the Milky Way was unobservable. Caroline had continuously plotted the recorded star numbers on a chart called 'Register of Gauges' (Fig. 3.9).[13] The positions lie between PD 55° and 122°, i.e. at declinations from +35 to −32°. The southernmost gauge was made on July 13, 1784 in sweep 237; the single field in Sagittarius lies 1° northeast of the bright globular cluster M70. It culminated only 5° above the horizon, a real challenge for

---

(RAS W.2/1.10). There was a test observation on 29 September; the target was the Andromeda Nebula (M 31).

[13] RAS W.2/8.5.

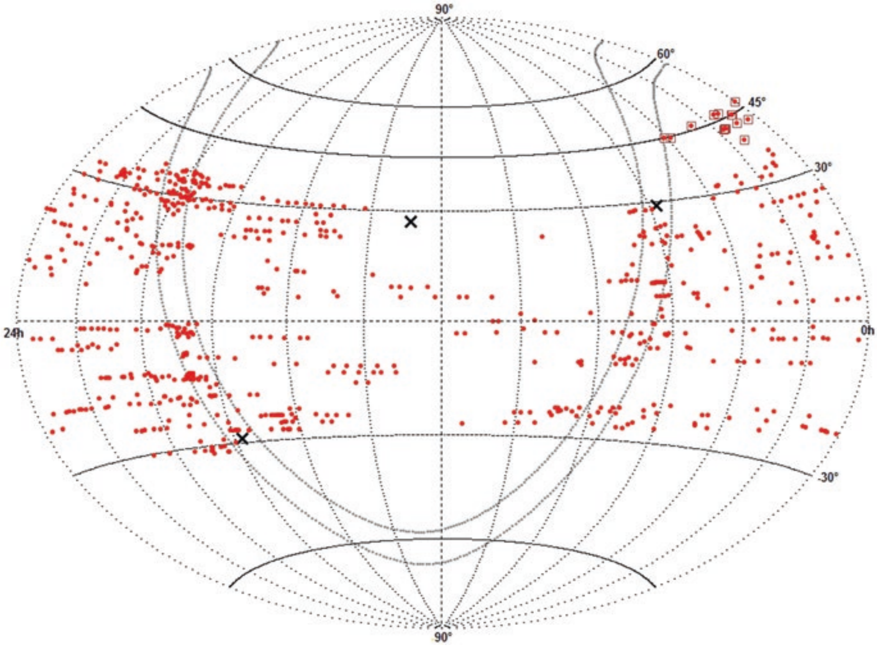


**Fig. 3.10** Distribution of the 683 gauges, used for the 1785 paper. An equal-area Mollweide projection is used. The highlighted points at upper right refer to the gauges, made in the eastern sweeps of October 1784. The celestial band is the Milky Way; the two crosses inside mark the galactic center in Sagittarius (*lower left*) and the anti-center in Auriga (*upper right*); the central cross is the northern galactic pole in Coma Berenices

counting stars (resulting number: 12). The 14 gauges from the eastern sweep (PD 45–50°) were not plotted by Caroline.

What is so special about January 10, 1785? Herschel had decided to publish the (reliable) 683 gauges, made up to this date. The resulting paper "On the Construction of the Heavens" was read at the Royal Society on February 3.[14] Curiously, the text is signed "Datchet near Windsor, January 1, 1785," too early a date, for Herschel's manuscript contains 22 gauges made on January 10.[15] Figure 3.10 shows a distribution of the 683 gauges on the sphere. Beside the northern regions there were still large blank areas. The region in Coma Berenices, Leo and Virgo near the north galactic pole (at 13 h, +30°) shows only a few gauges. This is easily explained. Here many nebulae were found, which belong to the Virgo Cluster, which Herschel saw

---

[14] Herschel, W., On the Construction of the Heavens, *Philosophical Transactions* 75, 213–266 (1785). The publication shows two added notes below the text, mentioning observations of nebulae made on 1 and 7 February.

[15] RAS W.2/24.1.

as the remnant of what he termed the "stratum of Coma Berenices."[16] The sweeps in which the objects were discovered had left no time for counting stars.

The paper of 1785 was revolutionary and goes beyond that published a year before. Here Herschel initiated a field of astronomy later known as 'stellar statistics.' The text starts with a 'theoretical view' concerning the evolution of a system of stars distributed with near uniformity. He was familiar with Newton's theory of gravitational attraction.[17] Herschel defines five 'forms': structures representing the possible results when stars of different sizes interact gravitationally. Forms I and II relate to the globular and irregular cluster, respectively. Form III is a 'stratum of stars,' built by 'long extended, regular, or crooked rows, hooks or branches.' Form IV is a more complex form with stars and clusters, while Form V describes 'vacant' regions (discussed below).

For Herschel the gauge data provide the necessary observational facts to confirm his ideas. This is presented in the chapter "Results of Observations," giving a Table of Star Gauges (Fig. 3.11). It lists the 683 star counts, sorted by right ascension (RA). The positions of the (averaged) field centers refer to the 'time of Flamsteed's Catalog' (1690). The table also gives the (calculated) number of stars, the number of contributing fields (or parts) and a column with remarks.

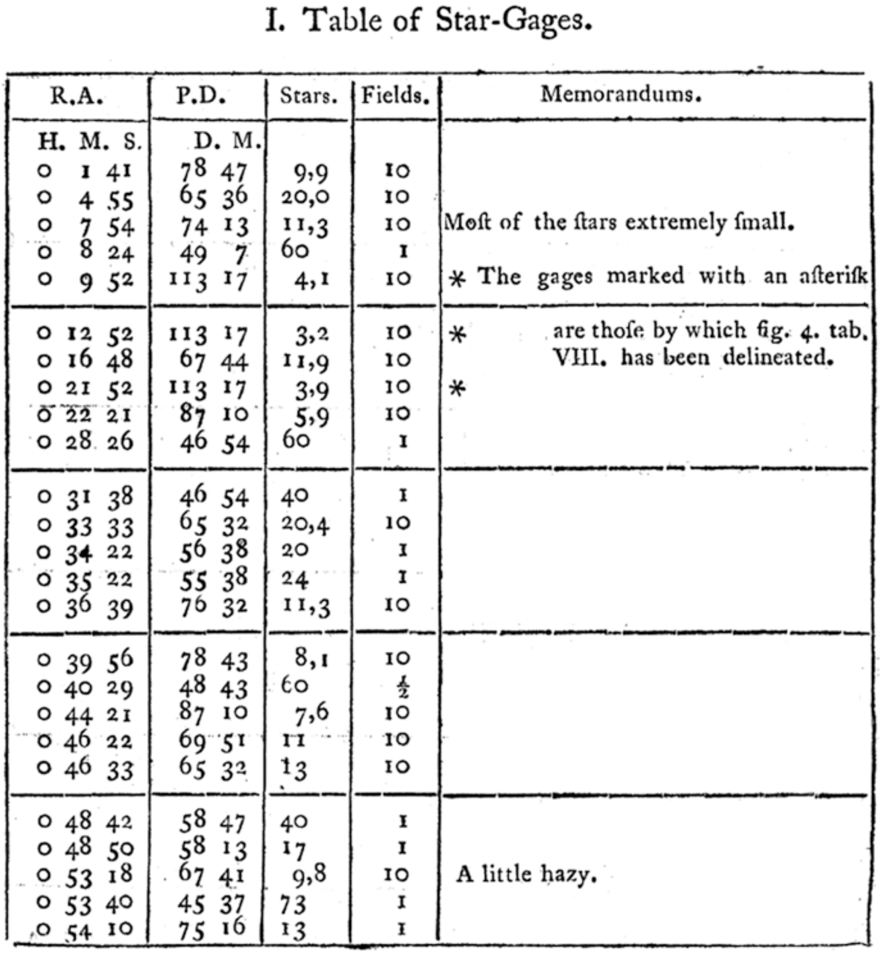
The data analysis is contained in the section 'Problem.' Of course, the counts show the star distribution on the heavenly sphere. However, Herschel elaborates the idea that they could be used for something greater: the star distribution in space! This would reveal the form, structure and extension of the stellar system as a whole – an ambitious task. Clearly, the crucial question is distance.

Herschel's thesis: "The stars being supposed to be nearly equally scattered, and their number, in a field of view of a known diameter, being given, to determine the length of the visual ray." The basic assumption is that the stars are uniformly distributed in space ('equally scattered'), i.e. there is a constant volume containing just one star and a unit distance to its nearest neighbor. Herschel knew that this claim is valid only on large scales: "It may seem inaccurate that we should found an argument on the stars being equally scattered, when in all probability there may not be two of them in the heavens, whose mutual distance shall be equal to that of any other two given stars; but it should be considered, that when we take all the stars collectively there will be a mean distance which may be assumed as the general one." Consequently, he rejected all gauges in which "the stars happened either to be uncommonly crowded or deficient in number, so as very suddenly to pass over from one extreme to the other." The latter was called a 'border-gauge' (examples are found in sweep 243 of July 22, 1784). Another rejected case was the 'distance-gauge,' defined in sweep 252 (August 18, 1784): "By way of seeing how the stars were mixed I imagined them to be divided into four magnitudes and called them LL = very large; L = large; S = small; SS = very small this I did with a view to the distance of the stars and intended it for a Distance-Gauge."

---

[16] See Fig. 3.8 (made by the author) in Hoskin, M. (ref. 8), p. 52.

[17] He probably had purchased an English translation of Newton's *Principia* by Andrew Motte, published 1729 (private communication M. Hoskin).



I. Table of Star-Gages.

| R.A. | | | P.D. | | Stars. | Fields. | Memorandums. |
|---|---|---|---|---|---|---|---|
| H. | M. | S. | D. | M. | | | |
| 0 | 1 | 41 | 78 | 47 | 9,9 | 10 | |
| 0 | 4 | 55 | 65 | 36 | 20,0 | 10 | |
| 0 | 7 | 54 | 74 | 13 | 11,3 | 10 | Moſt of the ſtars extremely ſmall. |
| 0 | 8 | 24 | 49 | 7 | 60 | 1 | |
| 0 | 9 | 52 | 113 | 17 | 4,1 | 10 | * The gages marked with an aſteriſk |
| 0 | 12 | 52 | 113 | 17 | 3,2 | 10 | * are thoſe by which fig. 4. tab. |
| 0 | 16 | 48 | 67 | 44 | 11,9 | 10 | VIII. has been delineated. |
| 0 | 21 | 52 | 113 | 17 | 3,9 | 10 | * |
| 0 | 22 | 21 | 87 | 10 | 5,9 | 10 | |
| 0 | 28 | 26 | 46 | 54 | 60 | 1 | |
| 0 | 31 | 38 | 46 | 54 | 40 | 1 | |
| 0 | 33 | 33 | 65 | 32 | 20,4 | 10 | |
| 0 | 34 | 22 | 56 | 38 | 20 | 1 | |
| 0 | 35 | 22 | 55 | 38 | 24 | 1 | |
| 0 | 36 | 39 | 76 | 32 | 11,3 | 10 | |
| 0 | 39 | 56 | 78 | 43 | 8,1 | 10 | |
| 0 | 40 | 29 | 48 | 43 | 60 | ½ | |
| 0 | 44 | 21 | 87 | 10 | 7,6 | 10 | |
| 0 | 46 | 22 | 69 | 51 | 11 | 10 | |
| 0 | 46 | 33 | 65 | 32 | 13 | 10 | |
| 0 | 48 | 42 | 58 | 47 | 40 | 1 | |
| 0 | 48 | 50 | 58 | 13 | 17 | 1 | |
| 0 | 53 | 18 | 67 | 41 | 9,8 | 10 | A little hazy. |
| 0 | 53 | 40 | 45 | 37 | 73 | 1 | |
| 0 | 54 | 10 | 75 | 16 | 13 | 1 | |

**Fig. 3.11** First rows of Herschel's 'Table of Star-Gauges,' published in 1785

Herschel further assumed that the stellar system has a boundary and that his telescope could detect all the stars within it. Because the stars within the boundary are thought to be uniformly distributed, Herschel concludes that the distance is proportional to the number of stars in the field of view. He derives a simple formula, which will be explained below in modern terms (Fig. 3.12).

The parameters of the cone are:

d = distance to the boundary of the stellar system in the viewing direction ('visual ray')
r = radius of the cone at the boundary
α = cone angle (2α = field of view = 15.7′ for the standard eyepiece).

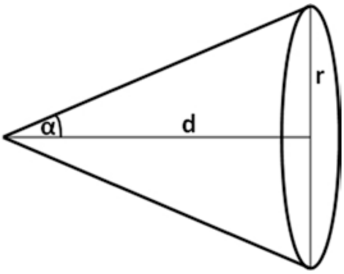


**Fig. 3.12** The observer at the telescope views a cone in space (see text)

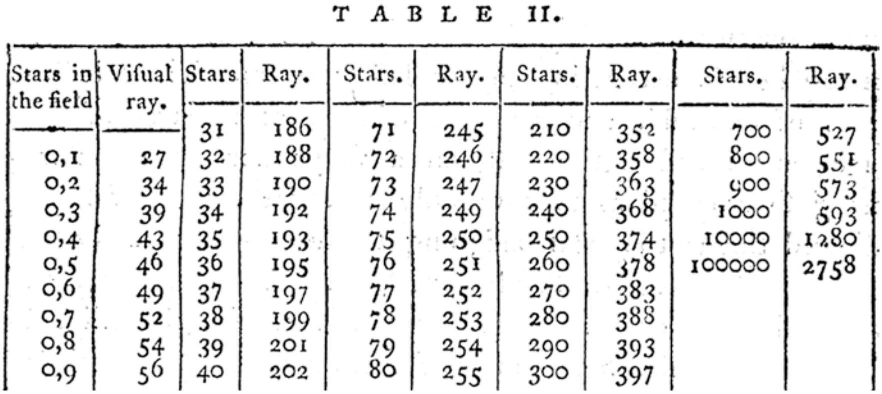


TABLE II.

| Stars in the field | Vifual ray. | Stars | Ray. | Stars. | Ray. | Stars. | Ray. | Stars. | Ray. |
|---|---|---|---|---|---|---|---|---|---|
| | | 31 | 186 | 71 | 245 | 210 | 352 | 700 | 527 |
| 0,1 | 27 | 32 | 188 | 72 | 246 | 220 | 358 | 800 | 551 |
| 0,2 | 34 | 33 | 190 | 73 | 247 | 230 | 363 | 900 | 573 |
| 0,3 | 39 | 34 | 192 | 74 | 249 | 240 | 368 | 1000 | 593 |
| 0,4 | 43 | 35 | 193 | 75 | 250 | 250 | 374 | 10000 | 1280 |
| 0,5 | 46 | 36 | 195 | 76 | 251 | 260 | 378 | 100000 | 2758 |
| 0,6 | 49 | 37 | 197 | 77 | 252 | 270 | 383 | | |
| 0,7 | 52 | 38 | 199 | 78 | 253 | 280 | 388 | | |
| 0,8 | 54 | 39 | 201 | 79 | 254 | 290 | 393 | | |
| 0,9 | 56 | 40 | 202 | 80 | 255 | 300 | 397 | | |

**Fig. 3.13** Part of Herschel's table showing the calculated values for the 'visual ray' (measured in units of the distance to Sirius)

From r and d we get the volume of the cone: $\mathrm{V} = \frac{1}{3}\pi r^2 \mathrm{d}$.

Using the trigonometric relation r = d tan $\alpha$ one can eliminate r to get: $\mathrm{V} = \frac{1}{3}\pi d^3 \tan^2 \alpha$.

Let N be the counted number of stars in the field of view, spread over the entire cone. If the star density is constant in space, the volume V is proportional to N. One now defines a unit volume $V_0$, containing 1 star (its radius is the distance to the next star). Thus we have N stars in the volume $V = N \cdot V_0$ and we get $N = V/V_0$, or simply N = V if V is measured in unit volumes.

Solving the last equation, one finally gets (with V = N): $\mathrm{d} = \sqrt[3]{\frac{3\mathrm{N}}{\pi \tan^2 \alpha}}$.

The quantity d is the distance to the star at the boundary in units of the distance between two neighboring stars. Herschel chose for this unit the distance between the Sun and the brightest star, Sirius, thought to be the nearest to us. We see by the formula that for a fixed field of view (fixed α), d depends only on the counted number of stars. The function d (N) is sometimes called 'Herschel's ray-function.' In his paper Herschel gives a tabular representation of its values (Fig. 3.13); Fig. 3.14 shows a plot of the function. Note that for the calculation it is not assumed that all

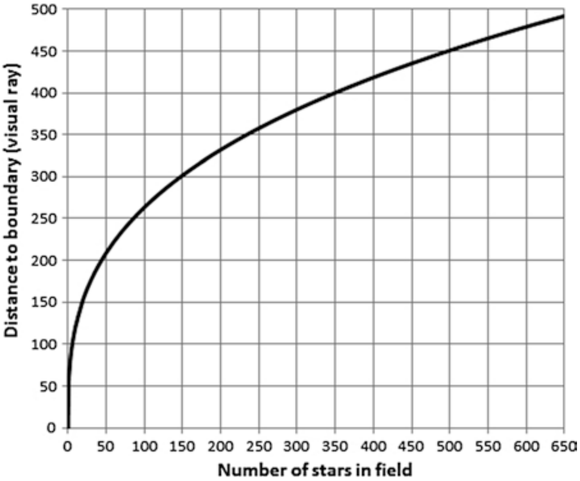


**Fig. 3.14** Plot of Herschel's ray-function d (N)

stars in the system have the same luminosity! (In the literature, this is sometimes asserted in connection with Herschel's star counts.)

By the star gauges we have – based on Herschel's assumptions – we can calculate distance value (d) for each observed field on the sphere. Thus, we can get a three-dimensional view of the stellar system. Because it was impractical for Herschel to create a graphical representation for the full dataset, he chose a simple subset. It forms a great circle on the sphere between the northern and southern PD limits. The result is a section of the stellar system. Though it would have been ideal to take the great circle formed by the band of the Milky Way, this could not be realized because the part north of about 30° declination was not yet swept and that south of −30° is invisible.

Using Caroline's gauge register, Herschel defined a suitable circle (part of it is seen as a line in Fig. 3.9 earlier). He wrote: "I have taken one which passes through the poles of our system, and is at rectangles [right angles] to the conjunction of the branches which I have called its length. The name of the poles seemed to me not improperly to those which are 90° distant from a circle passing along the milky way, and the north pole is here assumed to be situated in R.A. 186° and P.D. 58°." Herschel's section "makes an angle of 35 degrees with our equator, crossing it in 124½ and 304½ degrees." Caroline has also plotted parts of the section on the 'Register of nebulae,' actually the chart showing the sweep areas (Fig. 3.15).[18] The data came from 127 gauges, marked by an asterisk in Herschel's table (Fig. 3.11). The distribution of the sample on the sphere is shown in Fig. 3.16. Due to the lack of data, the deviation is considerable in some parts. However, Herschel wanted to 'fill' the circle as much as possible.

---

[18] RAS W.2/8.5.

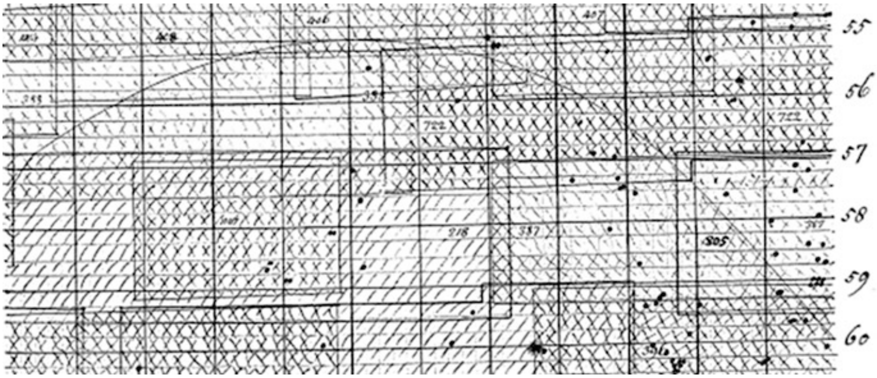


**Fig. 3.15** Caroline's sweep map, showing the section from AR 12 to 16 h and PD 55° to 60°

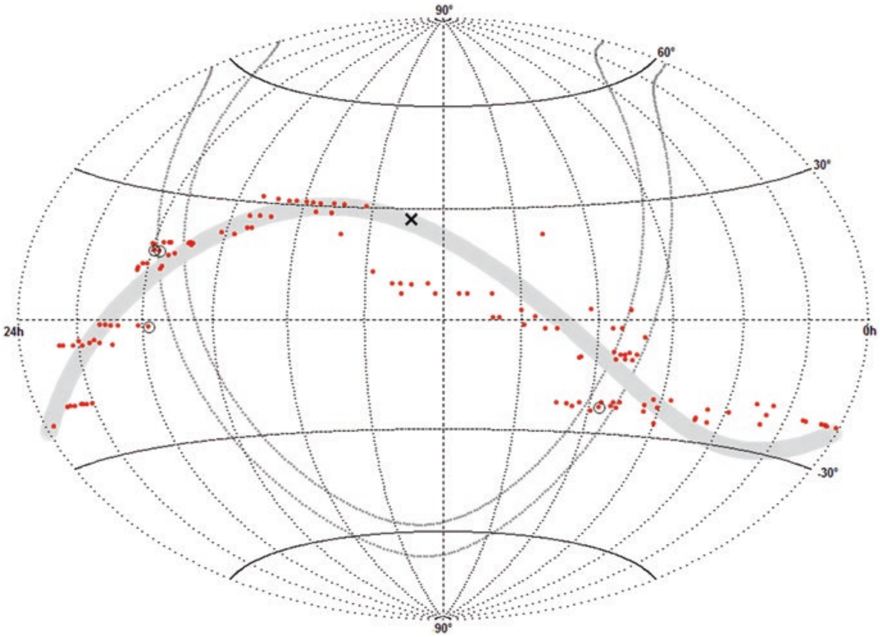


**Fig. 3.16** Herschel's section data on the sphere (The small circles are explained in the text)

After defining a longitude along the great circle, Herschel transformed the gauge positions (RA, PD) to this coordinate. The latitude (orthogonal distance from the section line) was ignored and set to zero. This naturally leads to a planar plot of the distances in polar coordinates. To show the result of the calculations, Herschel drew a graphical representation: the famous and often copied 'Fig. 3.4'.

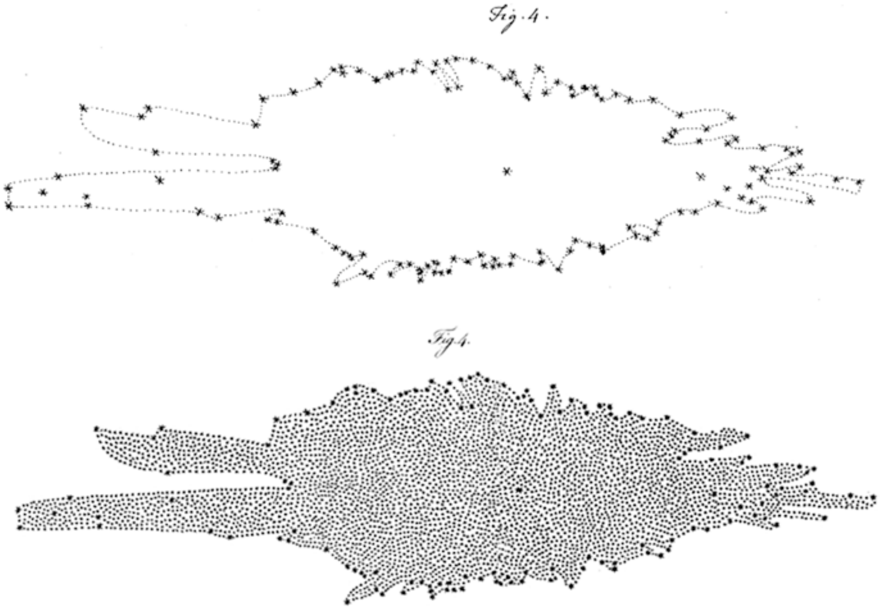


**Fig. 3.17** Herschel's plot, showing a section of the stellar system. The central point marks the Sun. *Top:* draft version. *Bottom:* published version

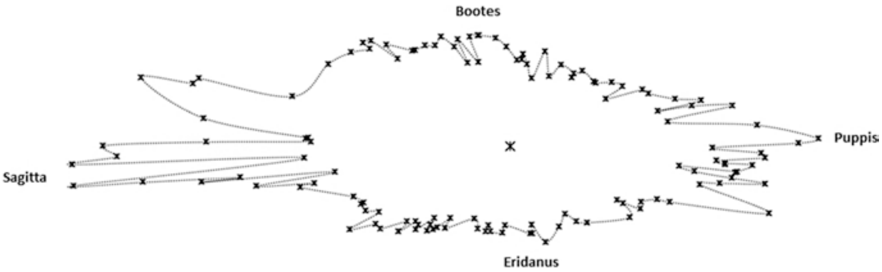


**Fig. 3.18** A modern reproduction of Herschel's Milky Way section shows slight differences

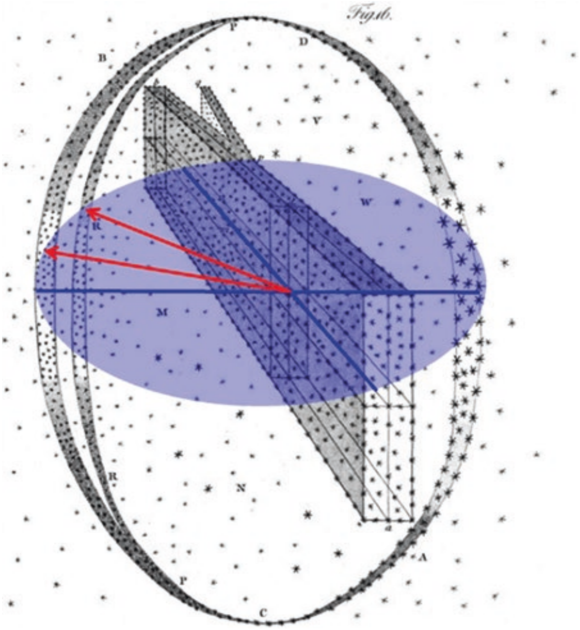
Figure 3.17 shows both the draft version, included in his manuscript,[19] and the published one, filled with stars.

Using the star count data and the d (N)-function, it is easy to reproduce Herschel's figure (Fig. 3.18). However, there are some differences. The double peak at the left lies at the intersection with the Milky Way above the equator in Sagitta (588 stars counted); the right peak is at the intersection below the equator in Puppis (204 stars). Both are marked by circles in Fig. 3.16. Herschel ignored the cut seen

---

[19] RAS W.4/24.1.

**Fig. 3.19** Location of Herschel's section (*blue*) relative to the block-shaped stratum. (Here the published version is presented, clearly showing the Sun's position; see Fig. 3.5.) The division, seen in the section, is related to the two red rays



between the Sagitta peaks (also marked). This gauge (62.2 stars) was taken in Aquila, below the section. The effect is due to the projection on the section plane. Herschel was aware of this and smoothed the boundary by interpolation. Interesting are the minimum (56 stars) above the Sagitta peaks and the following second maximum (368 stars). This marks the 'great rift' in the Milky Way where a branch goes off the main band from Sagitta in the direction of Ophiuchus. We now know that the decrease in the star numbers is due to massive dark clouds, absorbing the light in the line of sight.

What is the relation between Herschel's section and his representation of the 'stratum' in the 1784 paper (Fig. 3.5)? The section refers to a plane perpendicular to the block-shaped stratum, as shown in Fig. 3.19. A more realistic picture is presented in Fig. 3.20 – the orientation of Herschel's section of the galaxy. By rotating the plane around its vertical axis one gets different sections – for instance, one passing through Perseus/Scorpius (90° rotation). Clearly, Herschel had chosen an angle so that one intersection with the Milky Way lies in Sagitta (between Cygnus and Aquila), where the maximum star number (588) was registered.

The extent of the section is measured in units of the (unknown) distance to Sirius. The rays to the borders are (compare Fig. 3.18): Sagitta 497, Puppis 349, Bootes 122, Eridanus 108. Thus we get a horizontal extent of 846 units and a vertical extent of 230 units.

If we allow a modern point of view, Herschel's plot covers only a small neighborhood of the Sun. Assuming a limiting magnitude of about 14 for the stars, counted

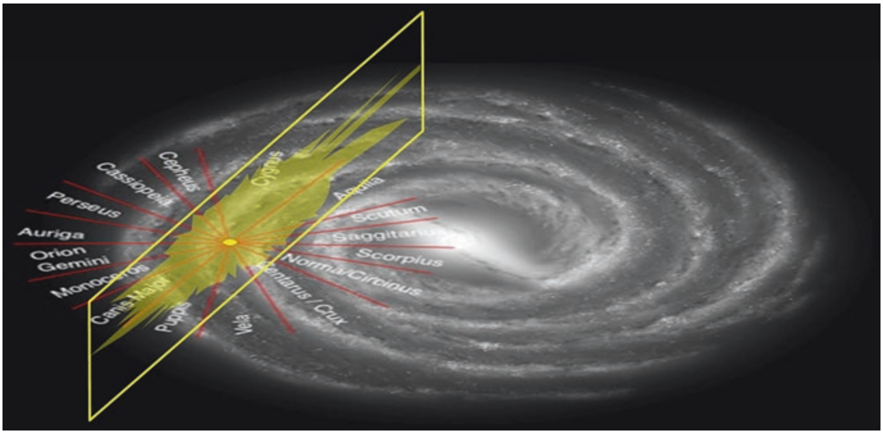


**Fig. 3.20** Orientation of Herschel's section in the Milky Way (the size of the rectangle is not important)

in the standard eyepiece, he could see Sun-like stars to about 2000 light-years. This is one tenth of the actual distance to the nearest edge of the Milky Way in the chosen orientation.

Anyway, the confined view inside a flattened stellar system – the 'stratum of stars' – is fairly correct: "We inhabit the planet of a star belonging to a compound nebula of the third form" containing "many millions of stars." It is important to stress that Herschel's 'Fig. 3.4' does not show our galaxy![20] As already explained, it only represents a section in a plane perpendicular to it.

## Further Gauges and His Paper of 1802

After sending the manuscript of the 1785 paper to the Royal Society in early January, Herschel continued the star counts on the 27th (sweep 358). Two 10-field-counts were made in Eridanus giving low numbers (7.4, 9.8); haziness forced the termination of the sweep after half an hour.

Except the few eastern sweeps of October 1784, all were made south of +35° declination (PD 55°). To get the coordinates (RA, PD) of a new object or field center, the position of a reference star must be known. The relative distance was calculated from the sweep data.[21] The reference stars were taken from Flamsteed's *British*

---

[20] This wrong interpretation often appears in the literature; this point is discussed in the last chapter. However, it may be interesting to create a section in the Milky Way plane, based on the star count data. The author has produced such a planar view of the galactic 'boundary'. Due to the observational limits of Herschel's method, it does not show any significant structure.

[21] Caroline recorded the sidereal time and the elevation of the tube for each observation (e.g. object and reference star).

*Catalogue*, giving positions for 1690. However, the arrangement of the catalog data was not suitable for sweeping. Flamsteed had ordered the stars by constellation and within by right ascension. Because a sweep covers a certain PD interval, Herschel needed the stars listed in PD zones of 1° breadth and ordered by RA within. This was Caroline's task. For the sweeps up to March 1785, her table includes the Flamsteed stars from PD 45° down to 124°, though the upper 10° were still not swept. She prepared a new table including the stars up to the pole (PD = 0°–44°). It was first used in sweep 389 on March 17, 1785, which searched Ursa Minor (PD = 16°). The night brought one 5-field- and two 10-field-counts with low values (11.6, 10.1, 15.5).

Another methodical improvement was tested in sweep 600 (September 22, 1786): the focus was changed from Newtonian to the 'front-view.' Herschel removed the secondary mirror, tilted the main one (by 1.35°) and installed the eyepiece at the front of the tube, now looking directly onto the mirror.[22] He now could see somewhat fainter stars and observing was easier, especially at high elevations. The regular front-view observations started with sweep 609 on October 13. A gauge was made in sweep 600 (Cygnus), the next in sweep 612 (Pegasus).

Herschel published nothing about gauges until 1795. Meanwhile the number of star counts had markedly decreased. The new paper[23] mainly discusses the Sun, but at the end, four remarkable star counts are mentioned. They were made on August 22, 1792, in sweep 1024, covering an area reaching from Aquila over Sagitta to Delphinus. Herschel was impressed by the great number of stars. For instance, he first counted 150 stars in a quarter field, giving 600 for the whole – and this density remained over 16 min of sweeping. He calculated the total number of stars to be 133,095. In the same manner he determined 36,601 stars over the next 6 min, followed by 74,889 over 15 min and 14,419 over 4 min. Thus, 258,981 stars were passing in 41 min. This result (and the formula used) was worthy to be published in the paper.

In autumn 1802, the sweeping campaign ended. The last star counts were made in sweep 1111 on September 26 (two single fields in Draco). Four days later Herschel started the final sweep (1112).[24] From the first gauge in sweep 55 (December 19, 1783) to the last one, we have 1091 star counts, made in 265 sweeps (Fig. 3.21). One can divide the gauges into two periods. The first relates to the 683 gauges, listed in the 1785 paper (plus 6 rejected); the second relates to the 402 made later. Altogether, Herschel actually counted more than 88,000 stars in 5567 fields. It should be noted that a gauge is defined as a star count giving a number greater than 0. Fields with zero result are called 'vacant' by Herschel (they are treated below).

---

[22] A slight distortion at the field edge, due to the tilted main mirror, was not problematic. See the article by Roger Ceragioli (Herschel's Front View Telescopes) in this book.

[23] Herschel. W., On the Nature and Construction of the Sun and the fixed Stars, *Philosophical Transactions* 85, 1795, 46–72.

[24] A sweep, numbered 1113, was made on 31 May 1813 in Bootes; it lasted only 25 min (Royal Society RS/278).

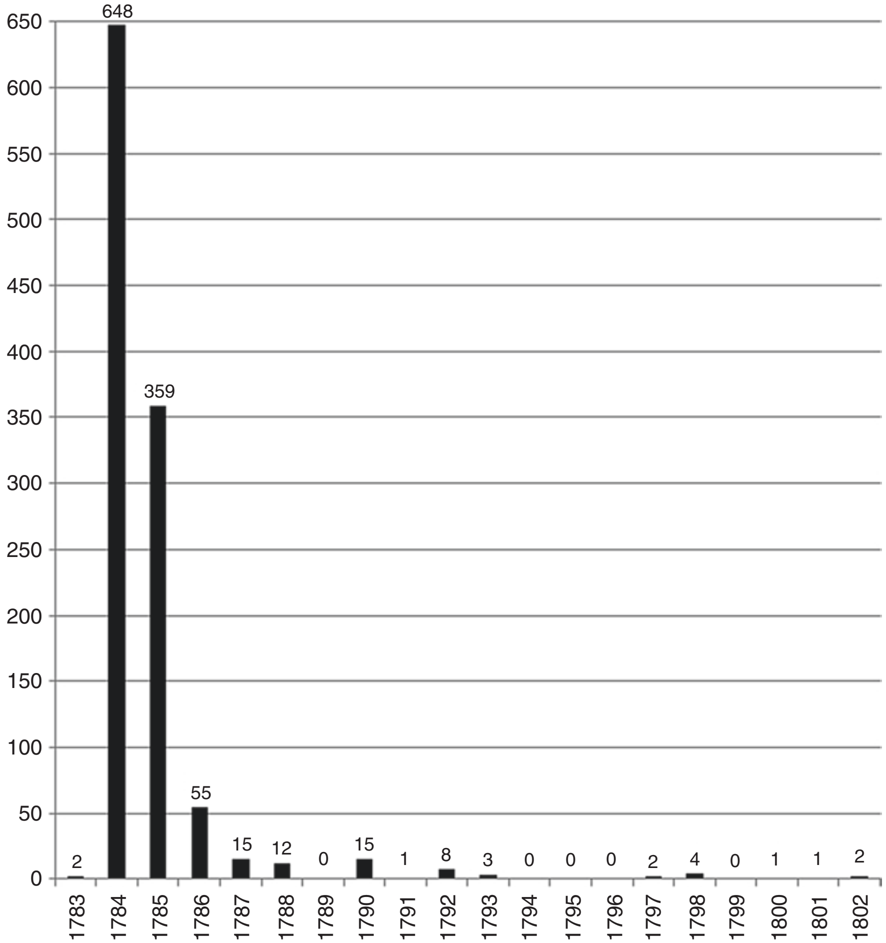


**Fig. 3.21** Annual number of gauges made from December 1783 to September 1802. After 1785, Herschel's interest in star counts dropped significantly

Herschel did not publish the gauges taken after the 1785 paper on the construction of the heavens. This was done 100 years later by Edward Holden, director of the Washburn Observatory at the University of Wisconsin. Volume II of the observatory publications contains two tables.[25] The first lists the 683 gauges of Herschel's 1785 paper and the second 405 unpublished gauges (based on sweeps 358–1111). Holden's tables contain altogether 1088 gauges, i.e. slightly less than actually

---

[25] Holden, E. S., *Publications of the Washburn Observatory*, Vol. II, 1884. The star count data are given in two chapters: X. The Star-gauges of Sir William Herschel, reduced to 1860.0. First Series, (Nos. 1–683), p. 113–140. XI. The Star-gauges of Sir William Herschel, reduced to 1860.0. Second Series, p. 141–173.

registered by Caroline in the sweep records (1091). The positions are reduced to 1860. What was his source for the second table? He writes that Lieut. Col. John Herschel (son of John Herschel) "kindly undertook the search for the unpublished gauges, and I owe to him and to Miss Rose Herschel [daughter of John Herschel] a complete copy of the *ms* [manuscript] by Miss Caroline Herschel, in which these are given, and also a list in which they are arranged in order of R.A." Holden quotes a handwritten note of Caroline: "The following gauges begin with the 358 sweep. As far as 357 sweep, they are printed in the paper on the Construction of the Heavens and their places have been given in Flamsteed's time and polar distance. But these gauges are calculated for the time when the observations were made, though as far as the 438 sweep, the places are down in the journals in Flamsteed's time and P.D. But every gauge is calculated twice, and after having been brought to the time of observation carried into this book."

Up to sweep 439 Caroline determined positions for 1690, based on Flamsteed's star catalog. But in sweep 440 on September 24, 1785, this changed. Now positions were "calculated for the time when the observations were made." This actually means for the year 1785, i.e. a precession for 95 years was applied for the reference stars. Because Flamsteed had already calculated a precession for 72 years for each star in the *British Catalogue* (this is the time for 1° precession of the equinox), Caroline simply applied the factor 95/72 = 1.319444 to get the new values. The day of September 24 was not ambiguous: it saw the successful installation of a 'PD machine' by which the polar distance could be read directly at the observation. Hitherto a number on a scale (0…100) showed the elevation of the tube from which the PD was calculated. The installed device was more accurate and Herschel took the opportunity to change to a new equinox. Later Caroline precessed all positions once again, now to the standard equinox 1800.[26]

It is interesting that J. L. E. Dreyer (author of the famous *New General Catalogue*[27]) copied Holden's second table in an appendix to the *Scientific Papers* (1910), titled "Star-Gauges from the 358th to the 1111th Sweep."[28] He added the observation date and a few remarks. Dreyer wrote: "The table is here printed from Caroline Herschel's MS." Caroline mentions in her 'temporary index' of 1802 that when observations "which belong to Planets, Double Stars, Nebulae, Comets and Star gauges are looked for, their respective books and parcels must be consulted" Fig. 3.22.[29]

---

[26] Caroline's final version of the sweep records (RAS W.2/3) gives positions for 1800.

[27] Steinicke, W., *Observing and Cataloguing Nebulae and Star Clusters – from Herschel to Dreyer's New General Catalogue*, Cambridge University Press 2010.

[28] Dreyer, J. L. E., *The Scientific Papers of Sir William Herschel*, Vol. II, London 1912, p. 699–711.

[29] RAS C.3/1.1. Unfortunately, both the archives of the Royal Astronomical Society (RAS) and the Royal Society (RS) do not have Caroline's manuscript. A search in the Herschel family papers, archived at the Harry Ransom Center (University of Texas at Austin), brought a negative result too. Therefore the author had extracted the gauge data directly from Caroline's sweep records (RAS W.2/3).

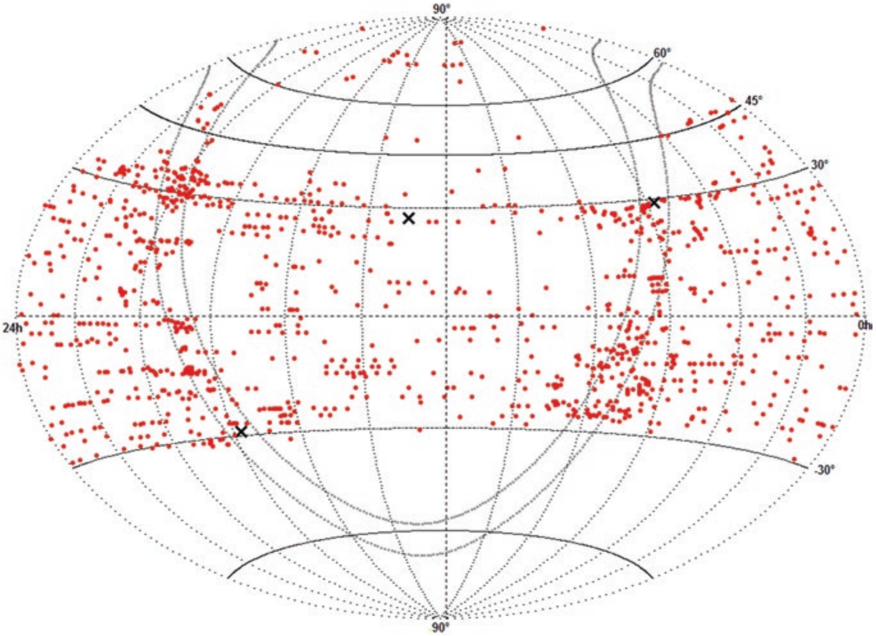


**Fig. 3.22** Shows the distribution of Herschel's 1091 star gauges on the sphere. Most of them lie between −30° and +30° declination. There is a certain crowding in the Cygnus Milky Way at right ascension 20 h and declination +30°; about 40 gauges were taken here. Among them is that with the highest number of stars in a field: 612 (sweep 1027, 15 September 1792). For other notable gauges, see Table 3.2 (most of them are discussed in the text)

## The Death of Herschel's Section

After finishing the epochal sweep campaign in late September 1802, Herschel had time for an astronomical resume. He published five papers in the *Philosophical Transactions* treating (among other themes) the structure of the Milky Way, based on his observations of stars, double stars, clusters and nebulae; the last appeared in 1818. The data analysis had changed some of his early opinions, especially concerning the stellar system.

In 1802 Herschel published his third and final catalog of nebulae and star clusters.[30] The relevant parts on the Milky Way are contained in the section "Enumeration of the parts that enter into the construction of the heavens." A major point treats star clusters. Herschel had discovered 197 objects of different concentration and struc-

---

[30] Herschel, W., Catalogue of 500 new Nebulae, nebulous Stars, planetary Nebulae, and Clusters of Stars; with Remarks on the Construction of the Heavens, *Philosophical Transactions* 92, 477–528 (1802).

**Table 3.2** Notable gages; the sweep number relates to the gage were a new situation appeared first

| Sweep | Date | Fields | Gage | Const. | Remarks |
|---|---|---|---|---|---|
| 55 | 19 Dec. 1783 | 1 | 60–70 | Mon | First gage (Datchet) |
| 185 | 27 Mar. 1784 | 1 | 24 | Her | First gage off the Milky Way |
| 190 | 12 Apr. 1784 | 4 | 9.5 | Ser | First multiple star count |
| 191 | 13. Apr. 1784 | 13 | 4.6 | Vir | Maximum number of fields (first appearance) |
| 206 | 24 Apr. 1784 | 12 | 18.6 | Oph | 58 gages made for the 1784 paper |
| 210 | 9 May 1784 | 10 | 8.1 | Vir | First 10-field count |
| 222 | 21 May 1784 | 10 | 0.5 | Sco | Minimum gage ('hole in Scorpius' near M 80) |
| 228 | 16 Jun. 1784 | 0.5 | 422 | Sct | First ½ field counted |
| 232 | 24 Jun. 1784 | 1 | 84 | Sgr | Gage near galactic centre |
| 237 | 13 Jul. 1784 | 1 | 12 | Sgr | Most southern gage (-32°) |
| 238 | 15 Jul. 1784 | 10 | 11.1 | Aqr | Maximum number of gages in a sweep (38) |
| 254 | 23 Aug. 1784 | 0.25 | 588 | Sge | Maximum gage so far |
| 282 | 5 Oct. 1784 | 10 | 28.1 | And | First eastern gage (of 14 until 7 Oct.) |
| 357 | 10 Jan. 1785 | 10 | 11.1 | Hya | 683 gages made for the 1785 paper |
| 358 | 27 Jan. 1785 | 10 | 7.4 | Eri | First 'unpublished' gage |
| 360 | 29 Jan. 1785 | 0.5 | 245 | Aur | Gage near galactic anti-centre |
| 389 | 16 Mar. 1785 | 5 | 11.6 | UMi | First gage north of PD 45° (new star table) |
| 393 | 6 Apr. 1785 | 10 | 5.3 | Com | Gage near the north galactic pole |
| 418 | 1 Aug. 1785 | 5 | 26.2 | Sgr | First gage at Clay Hall |
| 445 | 28 Sep. 1785 | 10 | 5.6 | Aqr | Positions changed from equinox 1690 to 1785 |
| 523 | 15 Feb. 1786 | 5 | 18.6 | Dra | Thousandth gage |
| 558 | 20 Apr. 1786 | 10 | 6.8 | Vir | First gage at Slough |
| 600 | 22 Sep. 1786 | 0.25 | 220 | Cyg | First gage in front-view mode |
| 1027 | 15 Sep. 1792 | 0.25 | 612 | Cyg | Maximum gage |
| 1056 | 5 Oct. 1793 | 0.5 | 80 | Aql | Last gage before 1795 paper |
| 1111 | 26 Sep. 1802 | 1 | 25 | Dra | Last gage (1091); most northern gage (+80°) |

ture, collected in his classes VI, VII and VIII.[31] Of these, 86 % lie in the band of the Milky Way (galactic latitude between +15 and −15°); only 14 % are outside. Figure 3.23 shows the 172 Milky Way clusters. Because there were so many objects in such a narrow region, Herschel was led to doubt his assumption of equally scattered stars. We see this already in sweep 765 (October 14, 1787) made in Lacerta: "It is very evident in this part of the heavens, that there is some distance between us

---

[31] VI = very compressed and rich clusters of stars, VII = pretty much compressed clusters of large and small stars, VIII = coarsely scattered clusters of stars. Herschel's eight objects classes should not be confused with his five forms of stellar systems described in the 1785 paper (ref. 14).

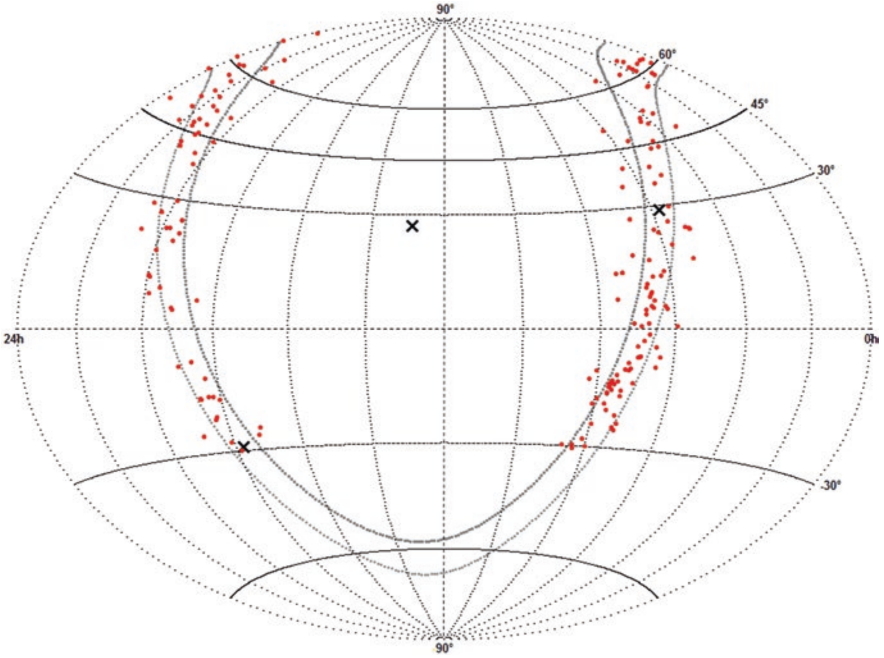


**Fig. 3.23** There are172 clusters in Herschel's classes VI–VIII, located in the Milky Way (galactic latitude between −15 and +15°)

and the milky-way not equally scattered over with stars." There are other sweeps, where both gauges are taken and clusters discovered. For instance, in sweep 934 (March 4, 1790) Herschel found 4 open clusters[32] and took 10 gauges in the central Milky Way of Canis Major and Puppis, getting star numbers between 129 and 286.

Obviously, the 'stratum' was a mix of stars (including double and multiple stars) and clusters – and thus far from being uniform. The observational facts undermined the major assumption, used by Herschel in the 1785 paper to determine the boundary of the stellar system: the constancy of the spatial star density, if only on a large-scale view. He wrote: "On a very slight examination it will appear that this immense starry aggregation is by no means uniform. The stars of which it is composed are very unequally scattered, and show evident marks of clustering together into many separate allotments."

Moreover, the rare observations with his largest reflector, the 40 ft, erected in 1789, had shown another assumption to be untenable: that his 18.7-in. reflector, used for sweeping, could show all the stars up to the boundary of the stellar system and there was nothing beyond. With the 48-in. reflector Herschel could see many more stars – and thus 'penetrate' much deeper into space.[33]

---

[32] These are NGC 2358 (VIII 45), NGC 2432 (VI 38), NGC 2479 (VII 58) and NGC 2509 (VIII 1).

[33] There were only a few sweeps made with the 40-ft reflector in the early years; the field of view was 9.5′, which is significantly smaller than that of the 20-ft. No gages were performed in the sweeps.

In his paper of 1811 Herschel wrote[34]: "I must freely confess that by continuing my sweeps of the heavens my opinion of the arrangement of the stars […] has undergone a gradual change; and indeed when the novelty of the subject is considered, we cannot be surprised that many things formerly taken for granted, should on examination prove to be different from what they were generally, but incautiously, supposed to be. For instance, an equal scattering of the stars may be admitted in certain calculations; but when we examine the milky way, or the closely compressed clusters of stars, of which my catalogs have recorded so many instances, this supposed equality of scattering must be given up."

In the next paper, published 1814, the structure and content of the Milky Way were discussed again.[35] Herschel confirms that it is not a mere stratum of individual stars but a mix of stars and clusters of various forms (e.g., aggregations of stars, irregular clusters, globular clusters). He explicitly mentions 157 objects, writing: "The milky way is generally represented in astronomical maps as an irregular zone of brightness encircling the heavens, and my star gauges have proved its whitish tinge to arise from accumulated stars, too faint to be distinguished by the eye. The great difficulty of giving a true picture of it is a sufficient excuse for those who have traced it on a globe, or through the different constellations of an *Atlas Coelestis*, as if it were a uniform succession of brightness. It is, however, evident that, if ever it consisted of equally scattered stars, it does so no longer."

Three years later, Herschel wrote in the 1817 publication[36]: "In addition to 863 [683] gages already published [1785], above 400 more have been taken in various parts of the heavens, but with regard to these gages, which on a supposition of an equality of scattering were looked upon as gages of distances, I have now to remark that, although a greater number of stars in the field of view is generally an indication of their greater distance from us, these gages, in fact, relate more immediately to the scattering of stars, of which they give us a valuable information, such as will prove the different richness of the various regions of the heavens." And later we read: "By these observations it appears that the utmost stretch of the space-penetrating power of the 20 ft telescope could not fathom the Profundity of the milky way." Herschel writes that the 40-ft reflector "would then probably leave us again in the same uncertainty as the 20 ft telescope."[37] Examples from 11 sweeps, made between 1784 and 1792, are given.

---

[34] Herschel, W., Astronomical Observations relating to the Construction of the Heavens, arranged for the Purpose of a critical Examination, the Result of which appears throw some new Light upon the Organization of the celestial Bodies, *Philosophical Transactions* 101, 269–336 (1811), p. 269–270.

[35] Herschel, W., Astronomical Observations relating to the sidereal part of the Heavens, and its Connection with the nebulous part; arranged for the purpose of a critical Examination, *Philosophical Transactions* 104, 248–284 (1814), p. 282.

[36] Herschel, W., Astronomical observations and experiments tending to investigate the local arrangement of the celestial bodies in space, and to determine the extent and conditions of the Milky Way, *Philosophical Transactions* 107, 302–331 (1817), p. 325.

[37] Herschel, W. (ref. 36), p. 327.

In Herschel's last paper,[38] published in 1818, he states that "The milky way, at the profundity beyond which the gaging powers of our instrument cannot reach, is not an ambiguous object." The term 'ambiguous' is explained in the text: "When the nature or construction of a celestial object is called ambiguous, this expression may be looked upon as referring either to the eye of the observer, or to the telescope by which it has been examined." Based on examples from four sweeps, made between 1786 and 1790, Herschel concludes: "Celestial objects can only be said to remain ambiguous, when the telescope that have been directed to them leave it undetermined whether they are composed of stars or of nebulous matter." Herschel eventually wrote[39]: "when our gages will no longer resolve the milky way into stars, it is not because its nature is ambiguous, but because it is fathomless." This sounds like a capitulation – and it means the end of his famous Milky Way section, plotted in 1785.

Though the star gauges eventually turned out to be useless to reveal the extent of the Milky Way, the method itself was not. Herschel opened the field of 'stellar statistics.' His son John took things further during his survey of the southern sky, where the Milky Way looks much more impressive. This led to a modification of the 'stratum.' But still another point became significant: Herschel's detection of 'vacant places.' i.e. fields with no stars.

## William Herschel's 'Vacant Places'

In sweep 54 of December 19, 1783 – the same night the first star gauge (sweep 55) was taken – Herschel noticed "many vacant places" in southern Taurus (Fig. 3.24); and in sweep 78 (January 17, 1784) he even found "the longest vacant space I ever have seen" in the northern part of the constellation (Fig. 3.25). The same description appears 11 days later in sweep 131 (Virgo). However, no coordinates are given for these fields.

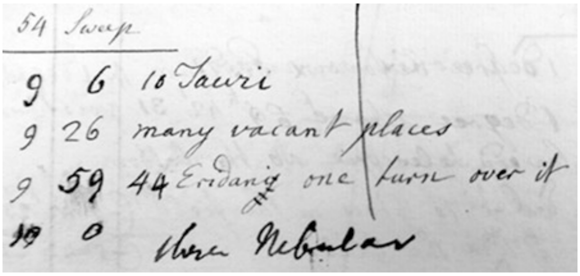
Then, after another 12 sweeps in which more or less blank fields were detected, the situation changed and he calculated coordinates. In sweep 189 on 12 April 1784, a gauge was taken in Bootes, showing 'about 5 or 6 stars generally in the field'. Then seven sweep paths, spread over about 1 h of time, showed 'many fields without stars'. He determined the average position of this void in Bootes.

Sweep 222 on May 21 brought a remarkable observation at the border of Scorpius and Ophiuchus. After a 10-field-gauge was taken (17.1) the globular cluster M80 came into view and was described. It was already after midnight. Then, in another ten-field gauge, the number dropped to 0.5 and remained low in subsequent counts:

---

[38] Herschel, W., Astronomical observations and experiments, selected for the purpose of ascertaining the relative distances of clusters of stars, and of investigating how far the power of our telescopes may be expected to reach into space, when directed to ambiguous celestial objects, *Philosophical Transactions* 108, 429–470 (1818).

[39] Herschel W. (ref. 38), p. 463.



54 Sweep

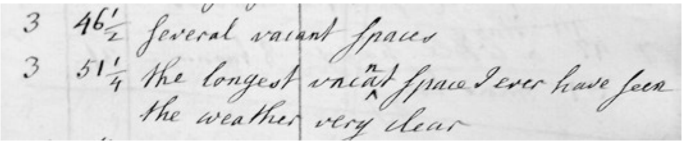
9 6 10 Tauri

9 26 many vacant places

9 59 44 Eridani one turn over it

10 0 three Nebulae

**Fig. 3.24** Sweep 54: Herschel's first 'vacant places' (Royal Society MS/272)



3 46½ ſeveral vacant ſpaces

3 51¼ the longest vacant ſpace I ever have ſeen

the weather very clear

**Fig. 3.25** 'Vacant spaces' in sweep 78

0.7, 1.1, 1.4, 1.8 (Fig. 3.26). The sky was "in all appearance perfectly clear" (the region was only 13° above the horizon). After 13 min the numbers gradually increased (4.7, 13.5, 20.3). Herschel later commented concerning this remarkable observation: "So that by the Gages it seems as if there were a Perforation or Hole in the body of the Scorpion.'[40] Figure 3.27 shows the area.

Herschel was so impressed by the case that he included the chapter "An opening in the heavens" in his paper of 1785.[41] He wrote:

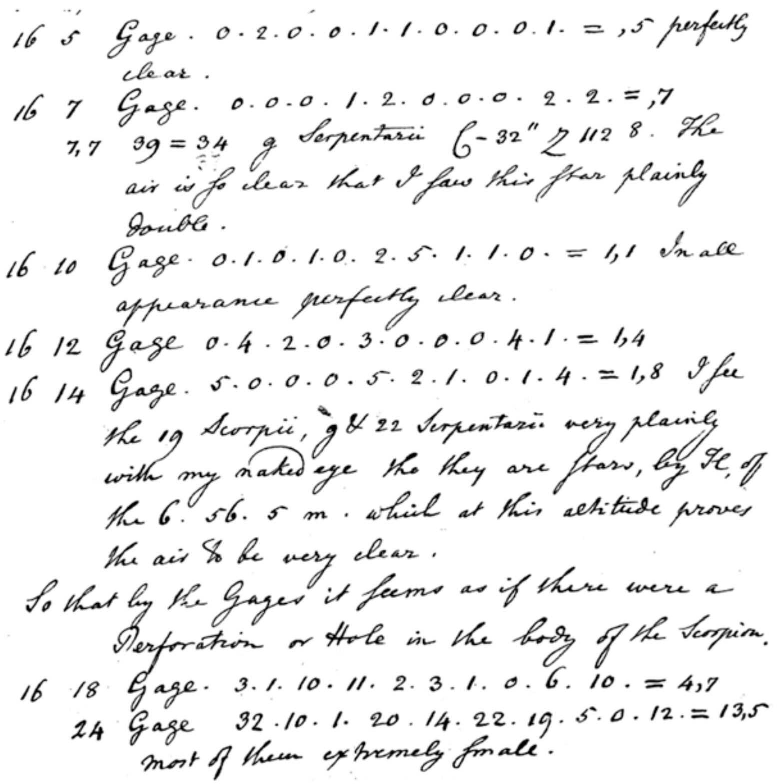
> Some parts of our system indeed seem already to have sustained greater ravages of time than others, if this way of expressing myself may be allowed; for instance, in the body of the Scorpion is an opening, or hole, which is probably owing to this cause. I found it while I was gaging in the parallel from 112 to 114 degrees of north polar distance. As I approached the milky way, the gauges had been gradually running up from 9,7 to 17,1; when, all of a sudden, they fell down to nothing, a very few pretty large stars excepted, which made them shew 0,5, 0,7, 1,1, 1,4, 1,8; after which they again rose to 4,7, 13,5, 20,3, and soon after to 41,1. This opening is at least 4 degrees broad, but its height I have not yet determined. It is remarkable, that the 80th Nebuleuse sans étoiles of the Connaissance des Temps [M80], which is one of the richest and most compressed clusters of small stars I remember to have seen, is situated just on the western border of it, and would almost authorize a suspicion that the stars, of which it is composed, were collected from the place, and had left the vacancy.

Herschel gives a diameter for the 'hole' of at least 4°, but by the star chart it is not more than 2° (Fig. 3.27 above). Due to the sweeping method, he could not survey greater areas (the breadth of the sweep 222 was 2°). Therefore, his value is a mere extrapolation. However, it is extraordinary that Herschel did not notice the reflection nebulae around ρ Ophiuchi (IC 4604) and a fainter star about 1° south (IC

---

[40] RAS W.4/1.7, p. 623.

[41] Herschel W. (ref. 14), p. 256–257.



16 5 Gage . 0 . 2 . 0 . 0 . 1 . 1 . 0 . 0 . 0 . 1 . = ,5 perfectly
clear .
16 7 Gage . 0 . 0 . 0 . 1 . 2 . 0 . 0 . 0 . 2 . 2 . = ,7
7,7 39 = 34 g Serpentarii 6 - 32″ ζ 112 8 . The
air is ſo clear that I ſaw this ſtar plainly
double .
16 10 Gage . 0 . 1 . 0 . 1 . 0 . 2 . 5 . 1 . 1 . 0 . = 1,1 In all
appearance perfectly clear .
16 12 Gage 0 . 4 . 2 . 0 . 3 . 0 . 0 . 0 . 4 . 1 . = 1,4
16 14 Gage . 5 . 0 . 0 . 0 . 5 . 2 . 1 . 0 . 1 . 4 . = 1,8 I ſee
the 19 Scorpii, g & 22 Serpentarii very plainly
with my naked eye tho they are ſtars, by Fl, of
the 6. 56. 5 m . which at this altitude proves
the air to be very clear .
So that by the Gages it ſeems as if there were a
Perforation or Hole in the body of the Scorpion.
16 18 Gage . 3 . 1 . 10 . 11 . 2 . 3 . 1 . 0 . 6 . 10 . = 4,7
24 Gage 32 . 10 . 1 . 20 . 14 . 22 . 19 . 5 . 0 . 12 . = 13,5
most of them extremely ſmall .

**Fig. 3.26** Sweep 222 of May 21, 1784. Herschel's detection of a "hole in the body of the Scorpion."The naked-eye star 'g Serpentarii' is now called ρ Ophiuchi

4603), though he crossed the area. In other places, he was very sensible about 'extended diffuse nebulosity.'[42]

In 1833 the story of the 'hole' was continued by Caroline, now living in Hanover. In a letter of August 1 to her nephew John, who was preparing the astronomical expedition to the Cape of Good Hope, she wrote: "As soon as your instrument is erected I wish you would see if there is not something remarkable in the lower part of the Scorpion to be found, for I remember your father returned several nights and years to the same spot, but could not satisfy himself about the uncommon appearance of that part of the heavens. It was something more than a total absence of stars (I believe)."[43] John Herschel investigated the region and replied on June 6, 1834: "I have not been unmindful of your hint about Scorpio. I am now rummaging the recesses of that constellation and find it full of beautiful globular clusters. A few

---

[42] See his table of 52 cases: Herschel, W. (ref. 34), p. 275–276.

[43] Lubbock, C. A., *The Herschel chronicle*, Cambridge 1933, p. 373

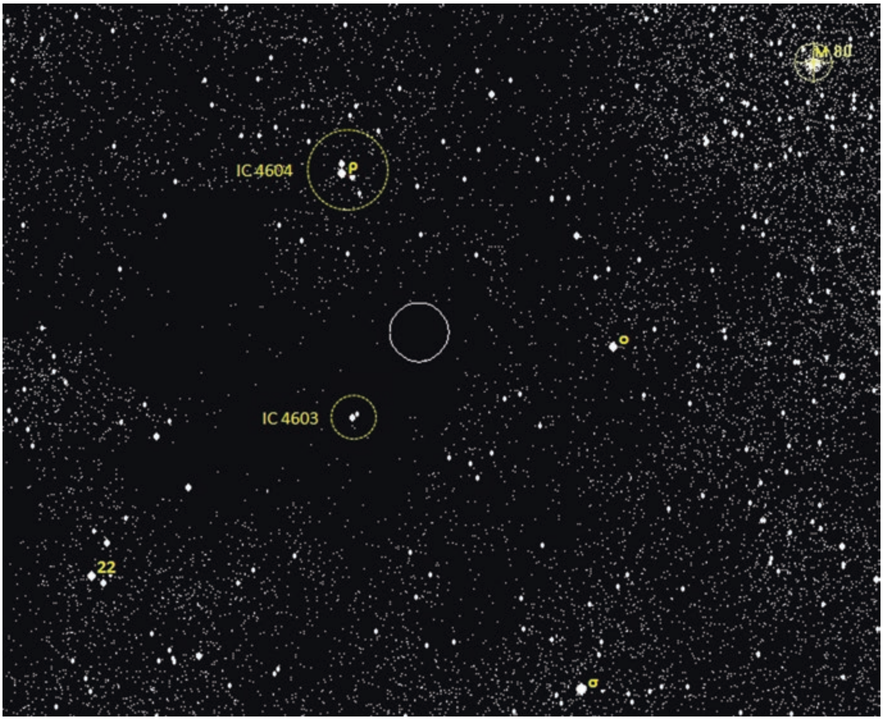


**Fig. 3.27** Herschel's 'hole' in Scorpius (at the border to Ophiuchus), located about 1.7° southwest of the globular cluster M80. The circle shows the central field (of 10) on the sweep path. The four bright stars around are σ Scorpii, o Scorpii, ρ Ophiuchi and 22 Ophiuchi. Herschel missed the reflection nebulae IC 4603 and IC 4604 (ρ Ophiuchi Nebula); their sizes are given by the dotted circles. Both objects were visually discovered in 1885 by Edward E. Barnard with a 5-in. refractor!

evenings ago I lighted on a strange nebula which here is a figure!"[44] Caroline, not satisfied with this reply, wrote on September 11: "I thank you for the promise of future accounts of uncommon objects. It is not clusters of stars I want you to discover in the Scorpion (or thereabout), for that does not answer my expectation, remembering having once heard your father, after a long, awful silence, exclaim: '*Hier ist wahrhaftig ein Loch im Himmel!*' [Here is truly a hole in the sky!], and, as I said before, stopping afterwards at the same spot but leaving it unsatisfied."

This statement led to some doubts about the identity of Herschel's hole in the sky. Though not knowing the sweep records, some astronomers – first of all the director of Vatican Observatory, Johann Georg Hagen – claimed that the conspicuous dark nebula Barnard 86 near the globular cluster NGC 6520 in Sagittarius is intended. However, this object is about 25° southeast of M80. Though Herschel had

---

[44] See also: Evans, D. S., *Herschel at the Cape*, Austin 1969, p. 72.

discovered NGC 6520 in sweep 224 on May 24, 1784 (three days after finding the hole), he never observed the dark spot 10′ northeast.[45]

In his paper Herschel mentions a second case about 4° south of the hole in Scorpius: "the fourth cluster of stars of the *Connaissance des Temps* [M 4]; which is also on the western border of another vacancy, and has moreover a small, miniature cluster, or easily resolvable nebula of about 2.5 min in diameter, north following it, at not very great distance [NGC 6144]." The observation was made in sweep 223 (May 22, 1784). North of bright globular cluster M4, located 1.3′ west of Antares, the star numbers dropped down to low 10-field-values (1.6, 2.0). The region of the hole near M80 was revisited in sweep 566 on May 26, 1786.[46] Herschel found seven vacant places. Later, in sweep 741 (May 19, 1787), a region 5° northeast of M80 brought 20 more.

Caroline lists 53 vacant places in her 'temporary index,' made on 12 August, 1802.[47] Later Dreyer checked the sweep records, starting at sweep 383. He lists 77 cases in the *Scientific Papers*.[48] The original documents cite 199 vacant places, found in 77 sweeps. In line with Caroline's procedure, this includes gauges with a star number up to 5. About half the places (98) lie in or near the band of the Milky Way. We now know that the low star numbers in such regions are due to absorbing interstellar matter (dust), i.e., there are no holes in the sky.

However, the vacant fields outside the Milky Way are real, at least regarding stars brighter than 14th magnitude. In some directions, e.g., towards the north galactic pole in Coma Berenices, there are not many stars beyond the brighter ones. Of course, Herschel could not distinguish between the two categories. However, the existence of vacant places was an additional argument against the uniform scattering of stars.

Another point about the gauges with low star numbers is interesting. Often they were taken from 10 fields along the sweep path. This means that no nebula or cluster was seen here (such a discovery always stopped gauging). This remarkable coincidence was never discussed by Herschel. But he treated the rare reverse case: a meeting of cluster and void. The theoretical background is found in the paper of 1785. In the chapter "Formation of nebulae" the Form V is defined. Herschel wrote: "there will be formed great cavities or vacancies by the retreat of the stars towards the various centers which attract them; so that upon the whole there is evidently a field of the greatest variety for the mutual and combined attractions of heavenly bodies to exert themselves in."[49] The prime example is the hole near the globular cluster M80 in Scorpius. Herschel believes that the gravitational forces of the massive cluster have attracted the stars in its neighborhood, leaving an empty space: "the stars, of which it is composed, were collected from the place, and had left the vacancy." He may have thought about a 'circular hole' around the center of gravity, but there were no observations to prove it.

---

[45] The full story will be told by the author in another paper.

[46] 'My sister swept by way of practise to myself of booking for her.'

[47] RAS C.3/1.1, p. 40.

[48] Dreyer, J. L. E. (ref. 28), p. 712–713.

[49] Herschel, W. (ref. 14), p. 216.

## John Herschel's Star Counts and the Fate of His Father's Stratum

John Herschel never used his father's 'Fig. 3.4' of the Milky Way section in one of his publications. Due to his own observations, made at Slough and later at the Cape, he agreed with William's critical remarks about the conditions (uniformity, boundary) leading to the section. John Herschel even rejected the term 'stratum.'[50] In 1835 he wrote that "the Milky Way is not a mere stratum, but an annulus; or at least, that our [solar] system is placed within one of the poorer and almost vacant parts of its general mass."[51]

Nevertheless, in his important textbooks *Treatise on Astronomy* (1833) and *Outlines of Astronomy* (1849) he presents a figure showing a bifurcated stratum containing the stars and clusters (Fig. 3.28).[52] It was copied in many textbooks (Fig. 3.29). For John Herschel the famous nebula M51 in Canes Venatici was a model of the Milky Way (Fig. 3.30).[53] He had often observed the object at Slough. On April 26, 1830, he made a drawing showing a bifurcated ring (M51 was even

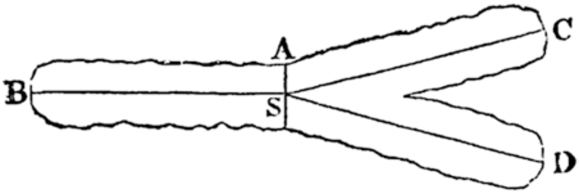


**Fig. 3.28** John Herschel's figure of the Milky Way, showing a bifurcated stratum

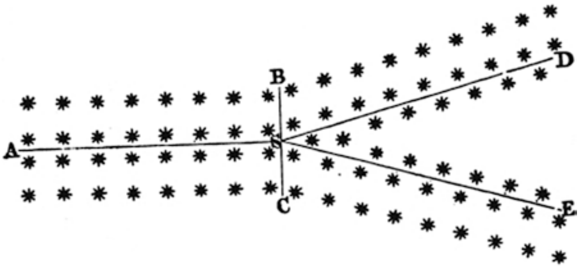


**Fig. 3.29** John Hind's version of John Herschel's graphic of the divided stratum appeared in 1853 (Hind, J. R., *The illustrated London astronomy*, London 1853, p. 92)

---

[50] Hoskin, M., John Herschel's Cosmology, *Journal for the History of Astronomy* 18, 1–34 (1987).

[51] Hoskin, M. (ref. 50), p. 18.

[52] Herschel, J., *Treatise on Astronomy*, London 1833, p. 376; Herschel, J., *Outlines of Astronomy*, London 1849, p. 527.

[53] Steinicke W., Birr Castle Observations of Non-stellar Objects and the Development of Nebular Theories, in: Mollan, C., *William Parsons, third Earl of Rosse – Astronomy and Aristocracy in Nineteenth Century Ireland*, Manchester University Press 2014, p. 210–270.

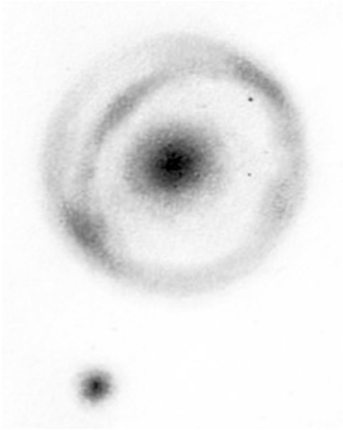


**Fig. 3.30** The bright 'ring nebula' M51 in Canes Venatici was seen by John Herschel as a model of the Milky Way (The spiral structure of M 51 was discovered by William Parsons (Lord Rosse) in April 1845 (ref. 59))

called a 'ring nebula').[54] This looks very similar to William Herschel's figure showing the divided band of the Milky Way (Fig. 3.5). However, the central condensation of M51 appears more like a globular cluster; there is no equivalent in the Milky Way.[55]

John Herschel made no star counts at Slough. He was absorbed by the huge task of revisiting the objects of his father's to prove their identity and get better positions. While observing from 1825 to 1832 (sweeps 1 to 428) he had time neither for counts nor for any deeper theoretical analyses. There are only a few remarks about unusual star densities. This changed in South Africa. Here John Herschel made systematic 'star gages' of the southern sky.[56] Following his father, they were performed in the regular sweeps. John Herschel made 382 sweeps (first = no. 429 on March 5, 1834, last = no. 810 on January 23, 1838). The 268 sweeps contain star counts, starting in no. 516 (December 1, 1834) and ending in no. 783 (April 1, 1837). About 2600 gauges were made.

The results of the Cape observations were published in 1847. Chapter 4 of the impressive work is headed "Of the distribution of stars and of the constitution of the Galaxy in the southern hemisphere." It contains a Synoptic Table of Southern Star-Gauges.[57] John Herschel arranged 68,948 stars (from 2299 fields) in galactic coordinates, quantifying the expected concentration towards the band of the Milky Way. Moreover, he separated the stars by magnitude. A special focus was on vacant places: the Cape observations include a list of 49 areas.[58]

---

[54] Herschel, J., Observations of nebulae and clusters of stars, made at Slough, with a 20-ft reflector, between the years 1825 and 1833, *Philosophical Transactions* 123, 359–509 (1833), Fig. 3.25.

[55] More details in: Hoskin, M. (ref. 50), p. 9–14.

[56] Now using the correct word.

[57] Herschel, J., *Astronomical Observations*, London 1847, p. 375–379.

[58] Herschel, J. (ref. 57), p. 381–382.

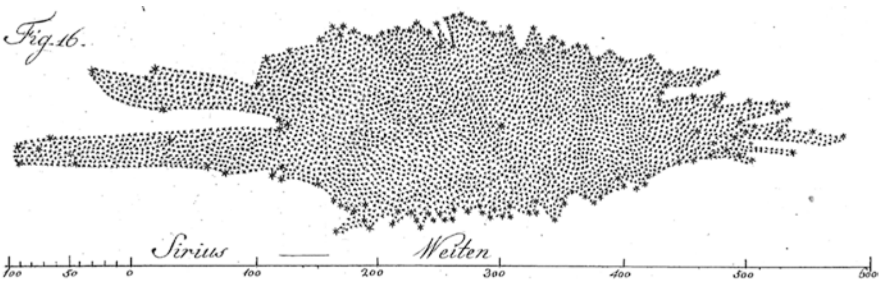


**Fig. 3.31** Copy of Herschel's figure in a German translation of the 1785 paper. Fischer, E. G., Ueber die Anordnung des Weltgebäudes. Ein freyer Auszug aus Hrn. Herschels Schriften über die Materie; in: Bode, J. E., Astronomisches Jahrbuch für 1794, Berlin 1791, p. 213–226, Fig. 3.16. The scale shows the distance in units of distance to Sirius ('Sirius-Weiten'); the horizontal extent is 600 (the '0' point at *left* is strange)

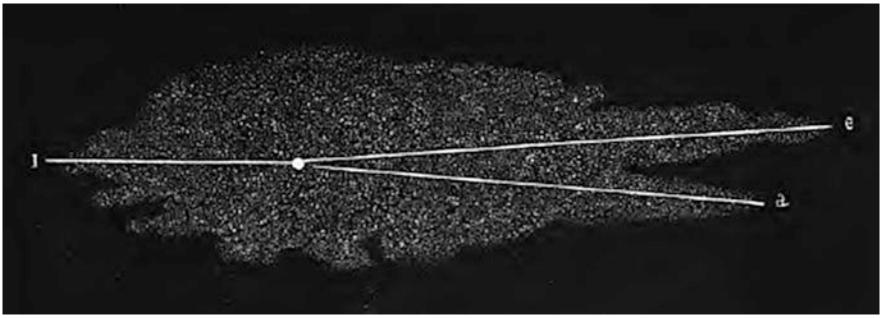


**Fig. 3.32** Ormsby Mitchel's 'reversed' version of Herschel's section appeared in 1851 (Mitchel, O. M., *The Orbs of Heaven*, London 1851, p. 186)

John Herschel concluded from his star counts that the brighter (nearer) stars show a uniform distribution, while the fainter (distant) stars are strongly concentrated towards the Milky Way. Moreover, the region around the Sun is almost vacant, clearly separated from the Milky Way. John Herschel's Galaxy is much more complex than a mere stratum of regular thickness and homogenous formation.[59]

However, the new views did not diminish the popularity of William Herschel's Milky Way section (Fig. 3.17). His famous Fig. 3.4 appeared in various versions in later publications (Figs. 3.31, 3.32, and 3.33). But sometimes it is wrongly interpreted; either as a plane view of the Milky Way,[60] or as a derivative of Herschel's 1784 representation of the Milky Way. William Herschel's figure actually shows a section of the Milky Way, perpendicular to its plane and oriented in a certain direc-

---

[59] Hoskin (ref. 50), p. 22.

[60] This wrong interpretation can be seen on several websites too.

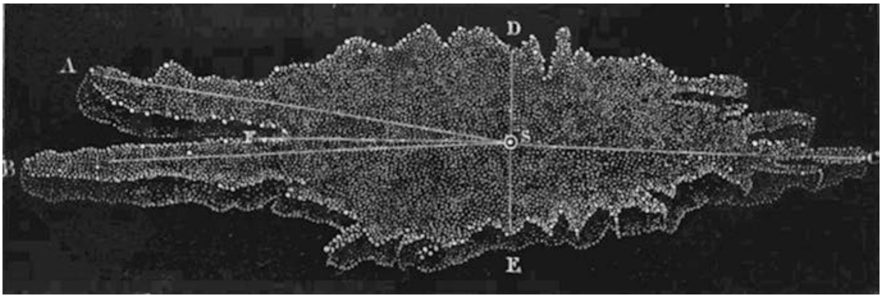


**Fig. 3.33** This 'thick' version of Herschel's section was published by George Chambers in 1890 (Chambers, G. F., *A Handbook of Descriptive and Practical Astronomy*, Vol. III: The Starry Heavens, Oxford 1890, p. 110)

tion. It is an independent view and does not replace the figure of 1784 (Fig. 3.19). Often the crucial word 'section' is missing in the literature. In some modern textbooks Herschel's Fig. 3.4 is compared with later (plane) views of the Milky Way by Jacobus Kapteyn, Harlow Shapley or John Plaskett, demonstrating the changing knowledge about its size (larger system) and the position of the Sun (off the center).

## Summary

When exploring the heavens, William Herschel entered new land. Equipped with the best telescopes of the time and open to revolutionary ideas, he became the leading astronomer in the late eighteenth and early nineteenth centuries. There was no competition. Recognizing his privileged position, Herschel wasted no time in using the full capacity of his resources. He was not only the master of observational astronomy but learned all that was needed about mechanics, optics, physics and applied mathematics, and, if necessary, he created new methods. This he did for one great task: to reveal the 'construction of the heavens' – the theme of his life.

Herschel first investigated the building blocks: astronomical objects, in all their variety. The essential tool to get the necessary data was sweeping: a systematic method to survey the sky. Herschel became a natural historian of the heavens, compiling the largest catalogs of nebulae, star clusters and double stars. The basic collection was soon condensed into classes and forms to determine the physical nature and evolution of the objects.

The sweeps included extensive star counts (gauges). With these elements, Herschel created the field of stellar statistics to determine the distribution of stars in the stellar system surrounding the Sun. He thought it to be a branched stratum of stars. From the star count data he finally derived a spatial view of the Milky Way for a particular section. Concerning stellar astronomy, Herschel was the first to prove theoretical views by quantitative observations. His astronomy was influential, which sometimes led to the view among the contemporaries that there was nothing left to discover in the sky. However, there was an exception: Herschel's son John.

John Herschel was the only person able to do comparable work. Equipped with a large telescope in the style of his father he entered a new land: the southern sky. John discovered a large number of objects, which fitted into the known classes. However, he did not rest on a pure compilation. He took the opportunity to combine the northern and southern data to draw a picture of the whole sky. It is natural that some of William Herschel's ideas were modified or even rejected by the extended view enjoyed by his son. But this in no way diminished the achievement of this exceptional, multi-talented man.

# Chapter 4
# William Herschel and the "Front-View" Telescopes

**Roger Ceragioli**

## Abbreviations

| | |
|---|---|
| AJ | Astronomical journal |
| AJJ | Bode, J.E., ed., *Astronomisches Jahrbuch für das Jahr XXXX*, (Berlin) |
| AN | *Astronomische Nachrichten* |
| Anon | Anonymous |
| ApJ | Astrophysical journal |
| ATM | A.G. Ingalls, ed., Amateur telescope making, (New York, 1935–1953; reorganized and reprinted by Willmann-Bell, 1998), i–iii |
| JBAA | Journal of the British Astronomical Association |
| JFI | Journal of the Franklin Institute |
| JHA | Journal for the history of astronomy |
| MC | *Monatliche Correspondenz zur Beförderung der Erd- und Himmels-Kunde, herausgegeben von* Fr. von Zach |
| MmRAS | Memoirs of the Royal Astronomical Society |
| MNRAS | Monthly notices of the Royal Astronomical Society |
| NRRS | Notes and records of the Royal Society of London |
| Obs | The observatory |
| PA | Popular astronomy |
| PT | Philosophical transactions of the Royal Society of London |
| TCPS | Transactions of the Cambridge Philosophical Society |
| TOS | Transactions of the Optical Society |
| TSP | J.L.E. Dreyer, The scientific papers of Sir William Herschel, (London, 1912), i–ii |

---

R. Ceragioli (✉)
Richard F. Caris Mirror Lab, University of Arizona, Tucson, AZ, USA
e-mail: lensbender@msn.com

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_4

## Introduction

In September 1786, William Herschel (1738–1822) renewed an experiment he had tried several times earlier. He removed the elliptical flat mirror ("diagonal") from his 18.7-in. f/12.8 Newtonian reflecting telescope ("20-feet reflector"), tipped its concave primary mirror slightly to the side, and viewed the images directly with an eyepiece held along the inner wall of his telescope tube. He wrote a memorandum in his observing log: "…the light is incomparably more brilliant, and I thought sometimes that the stars were, if not better, at least full as well defined as in the Newtonian way…".[1] After briefly reverting back to Newtonian configuration, he permanently adopted the new arrangement, calling it "front-view" (Fig. 4.1).[2]

Herschel was soon rewarded by finding two new satellites of the *Georgium sidus* – Uranus – the planet which he had unexpectedly discovered almost 6 years earlier in March 1781 and dedicated to the glory of his monarch and future patron, George III (1738–1820) of Britain. Herschel credited the discovery of the new moons to the adoption of the front-view configuration, and he was so pleased that he employed it for nearly all of his subsequent large instruments, most famously for his 40-ft reflector, a 48-in. diameter f/10 behemoth that remained the largest telescope in the world for nearly 60 years.[3]

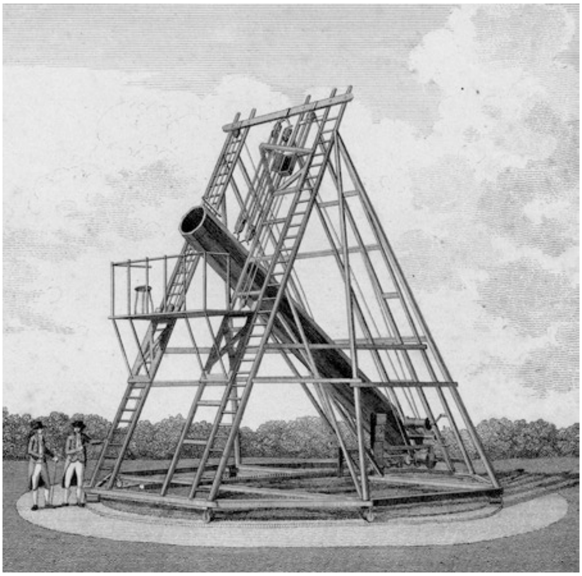


**Fig. 4.1** William Herschel's "20-feet reflector" seen in its front-view configuration, with the eyepiece located inside the mouth of the tube along the lower left panel of the octagonal wooden tube. The image dates to 1794 (Reproduced by permission of the Royal Astronomical Society)

---

[1] RAS MS Herschel W.2/3.6, sweep 600 (memorandum). *Cf.* also Bennett, J.A., "'On the power of penetrating into space': the telescopes of William Herschel," *JHA*, vii (1976), 75–108, p. 85.

[2] Herschel, W., "Catalogue of one thousand new nebulae and clusters of stars," *PT*, lxxvi (1786), 457–499, p. 499 [*TSP*, i, 260–303, p. 294].

[3] Herschel, W., "An account of the discovery of two satellites revolving round the Georgian planet," *PT*, lxxvii (1787), 125–129, p. 125 [*TSP*, i, 312–314, p. 312]; and *idem*, "Description of a forty-feet reflecting telescope," *PT*, lxxxv (1795), 347–409, p. 382 [*TSP*, i, 485–527, p. 509].

In spite of Herschel's obvious success with front-view instruments, modern optical theory shows that they were far from perfect. A single tilted concave mirror gives rise to image errors ("aberrations"), which must have been plainly visible to Herschel – indeed glaringly so in the case of his 40-ft. Despite some extravagant claims to the contrary, historians have come to recognize that Herschel's largest telescope was in its essentials a failure, sterile of scientific results.[4] The reasons why it failed, however, have not been fully explored in the historical literature.

Even apart from that failure (which Herschel sought to obscure in his lifetime[5]), the inherent limitations of his smaller front-view telescopes have also not been fully detailed in past accounts. Perhaps the awe in which the great astronomer and telescope-builder is rightly held has made it seem impossible that his instruments could have had serious deficiencies. Yet to understand the brief lifespan of the front-view form, why Herschel adopted it in the first place, how he learned to use it with success, and why his successors dropped it and returned to Newtonians, we must consider the front-view's limitations. That is one goal of the present chapter.

Intertwined is a problem affecting Herschel's Newtonian reflectors – or rather, *all* Newtonians constructed before the late nineteenth century. This concerns the flat secondary mirrors that redirect the converging light cone arriving from the concave Newtonian primary laterally out the side of the telescope tube. Such "diagonals" pose a major problem for telescope makers even today. They must be rigorously flat and smooth to within some dozens of nanometers (millionths of a millimeter); otherwise their use at a 45° oblique incidence produces "astigmatism," an optical aberration that greatly reduces image sharpness. Far from inconsequential bits of glass (or metal), diagonal mirrors are the Achilles' heel of the Newtonian reflector.[6]

Yet it was not until after Herschel's death in 1822 that an even modestly successful test for optical flatness came into use, while the modern tests were not introduced

---

[4] For extravagant claims, *cf. e.g.*: Pearson, W., *An introduction to practical astronomy*, ii, (London, 1829), p. 76, where it is said that powers as high as 6652× were used; also, Brewster, D., *A treatise on optics*, (London, 1831), p. 356, where the high power is given as 6450×. The best modern accounts of the 40-ft are: Hoskin, M., "Herschel's 40 ft. reflector: funding and functions," *JHA*, xxxiv (2003), 1–32; and *idem*, *Discoverers of the universe, William and Caroline Herschel*, (Princeton, 2011), pp. 114–128 and 171–178.

[5] By restricting use of the instrument to a few trusted persons, and devising public rationales to explain his own lack of use. *Cf. e.g.*: Pearson, W., "Telescope," in A. Rees (ed.), *The cyclopædia; or, universal dictionary of arts, sciences, and literature*," xxxv, (London, 1819), 61, column two of the article: "…this is probably the reason why few persons have been in a situation to form an estimate of the merits of this transcendent instrument"; Hoskin, M., [*op. cit.* ref. 4, (2011)], p. 176: "…almost nobody was ever allowed actually to look through the telescope…."; and Dreyer, J.L.E., *TSP*, i, pp. liii–liv: "…Herschel is supposed not to have allowed anyone else (except Prof. Vince) to use this telescope," and "…all the same it is likely enough that the instrument did not generally perform well." Herschel's expressed reasons for not using the instrument are enumerated at, *e.g.*: Herschel, W., "A series of observations of the satellites of the Georgian planet, *etc.*," *PT*, cv (1815), 293–362, pp. 295–296 [*TSP*, ii, pp. 543–544]. More will be said about his reasons later in the present work.

[6] Texereau, J., *How to make a telescope*, 2nd English ed., (Willmann-Bell, 1984), pp. 107–108 and 116.

until the end of the nineteenth century. In Herschel's lifetime, there was no effective means of ascertaining the inherent surface quality of flat mirrors. Nor was aberration theory sufficiently developed to forewarn telescope makers about the need for extraordinary optical quality precisely here – or the consequence of failure.

At the same time, it is undeniable that many of Herschel's smaller Newtonians gave excellent images, even by modern standards. Did he perhaps possess a "trade secret" for making true flat surfaces, lost to subsequent generations? The documentary record he left behind relative to telescope making indicates no. Thus, another goal of the present study is to investigate how Herschel's smaller Newtonians were able to function at all as precision imagers. Modern tests of his surviving flat mirrors indicate that they were far from adequately flat by modern optical standards (Fig. 4.2).

The purpose of the present work, therefore, is to explore from a theoretical and practical perspective the telescope optics of William Herschel, especially as embodied in his front-view reflectors. This is feasible not only because modern optical theory tells us a great deal about the limits of Herschel's instruments but also because all three Herschels (William, Caroline, and John) left behind a vast paper trail of published and unpublished articles, logbooks, notebooks, and private letters. Alone the four volumes of William Herschel's *Experiments on the construction of specula* in the Royal Astronomical Society's Herschel archive contain a vast trove of practical information about his telescope-making. In addition, modern tests of surviving Herschel mirrors directly reveal their limits.

By paying attention to optical theory as well as to Herschel's practical usages, we can gain much insight into why some of his instruments performed splendidly, whereas others were only partly successful, and why his monster 40-ft failed and *had to fail* as a productive telescope. We can also gain insight into the strategies Herschel developed to maximize the utility of his instruments. William Herschel was, after all, an instrumental genius. His genius consisted not only in transcending the limits of his time but even more in extracting every gram of performance where he could not overcome the limitations, as with his front-view telescopes (Fig. 4.3).

In turn the insights gained from studying Herschel's optics will provide fresh perspectives on the work of Herschel's contemporaries in Germany, Johann Hieronymus Schroeter (1745–1816) and Johann Gottlieb Friedrich Schrader (1763-*ca*. 1830), as well as his successor in England, his own son John Frederick William Herschel (1792–1871). These men built and successfully used large front-view telescopes as well as Newtonians.

In order to organize the mass of information needed to understand the optics of William Herschel's telescopes, the present work is divided into nine parts. The first comprises this brief introduction. In the second, we give a short overview of the development of reflecting telescopes from their origins up to Herschel's day; in the third, we discuss material and engineering limitations of telescope mirrors in the eighteenth and nineteenth centuries; in the fourth and fifth, we review the optical aberrations that affect reflecting telescopes and consider the state of aberration theory in Herschel's time and its subsequent development in the nineteenth century; in the sixth, we turn to Herschel's methods of optical fabrication and testing; in the

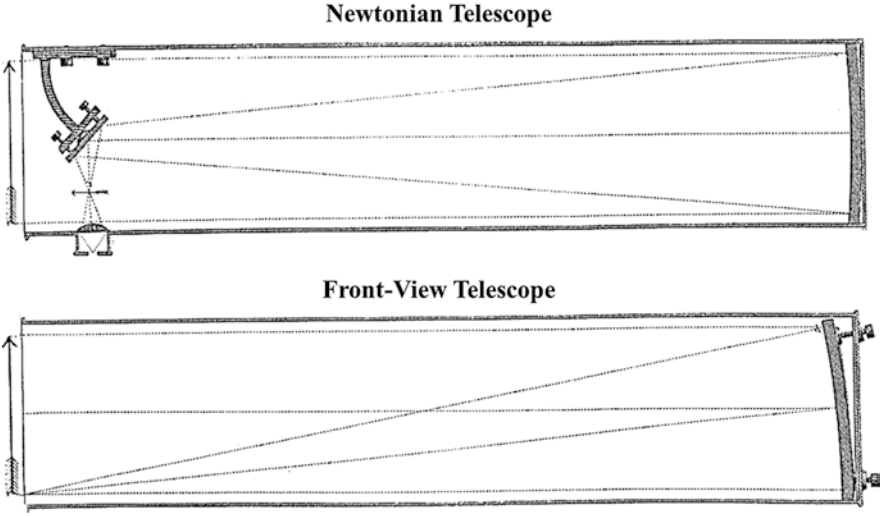


**Fig. 4.2** Schematic illustration of a Newtonian telescope (*top*) with untilted concave primary mirror (*right*) and flat elliptical secondary mirror (*left*), compared to a front-view (*bottom*) with tilted primary mirror and no flat (Illustrations derived from Rees’ *Cyclopaedia*, London, 1819, “Astronomical instruments,” plate XXVII, Figs. 4 and 5)

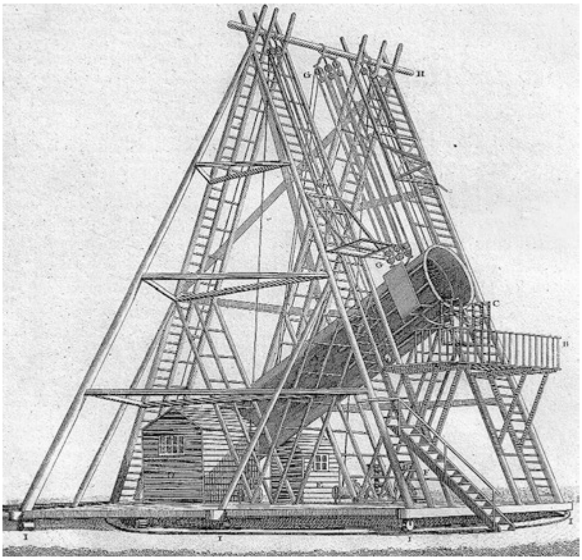


**Fig. 4.3** William Herschel’s 40-ft front-view telescope, which contained a 48-in. diameter mirror. Herschel dated its completion to August 1789, when he announced the discovery of two new moons of Saturn

seventh and eighth sections, we consider his strategies for using Newtonian and front-view instruments. And finally, in the ninth section, we consider the historical controversy over whether Herschel’s 40-ft front-view was to be regarded as a successful instrument or not, from Herschel’s own day up to the middle nineteenth century. There will also be much to say about Schroeter, Schrader, and John Herschel's use of his father's refurbished 20-ft reflector in the 1820s and 1830s. Finally, no discussion could be complete without touching on the work of Lord Rosse (1800–1867) and William Lassell (1799–1880) in the nineteenth century. These men were the first to succeed in constructing large Newtonians that gave critical definition.

## Reflecting Telescopes

### *Origins to Herschel*

Recent research has shown that the idea of using mirrors to achieve telescopic vision already existed in sixteenth century, that is, even before the first effective refracting telescope made its appearance in Holland in 1608. In addition, we know that Galileo Galilei (1564–1642) and his associates, such as Bonaventura Cavalieri (1598–1647), considered replacing the convex lenses of refractors with concave mirrors in the early seventeenth century; and many years later in 1652, the Italian Jesuit Niccolò Zucchi (1586–1670) claimed to have succeeded in employing a concave mirror and eyepiece as a telescope already in 1616.[7] The basic theory of one- and two-mirror reflecting telescopes was explored by Cavalieri and Marin Mersenne (1588–1648) between 1632 and 1651. They understood that the mirror surfaces needed to be shaped as conic sections to correct "spherical aberration," the most important imaging error in any telescope, about which more will be said below.[8]

Yet a big problem stood in the way of dependably making reflecting telescopes in the seventeenth century: mirror surfaces have to be finished about four times more accurately than lens surfaces in order to achieve equal freedom from aberration. The crude technology of optical fabrication then in use did not allow this, especially since effective mirrors could not be made from glass, there being no means by which to obtain a useful thin-film reflective mirror coating before about 1850. Instead, astronomical mirrors had to be made by grinding and polishing bulk metal, principally speculum metal, a brittle and difficult-to-work mixture of copper and tin.[9]

---

[7] Reeves, E., *Galileo's glassworks, the telescope and the mirror*, (Harvard, 2008); Ariotti, P.E., "Bonaventura Cavalieri, Marin Mersenne, and the reflecting telescope," *Isis*, lxvi (1975), 302–321; Zucchi, N., *Optica philosophia*, i, (Lugduni, 1652), p. 126 [quoted in Pezenas, E., *Cours complet d'optique, traduit de l'anglois de Robert Smith, etc.*, ii, (Avignon & Paris, 1767), pp. 420–421]; and Danjon, A. & A. Couder, *Lunettes et télescopes*, (Paris, 1935; reprint, Paris 1979), pp. 604–609.

[8] Cavalieri, B., *Lo specchio ustorio*, (Bologna, 1632), pp. 29ff. (conjugate properties of conics); 103ff. (confocal paraboloidal mirrors); and p. 126 (catoptric and catadioptric afocal telescopes); and Mersenne, M., *Harmonie universelle contenant la théorie et la pratique de la musique*, (Paris, 1636), pp. 61–62; and *idem*, *L'optique et la catoptrique*, (Paris, 1651), pp. 102–103 and 127. Mersenne was aware of Cavalieri's earlier work.

[9] Willach, R., "The development of the reflecting telescope in the 18th century from John Hadley to James Short," *Storia della scienza e della tecnica, atti della "Fondazione Giorgio Ronchi,"* lxii (2007), 255–288.

Thus, in 1663, when James Gregory (1638–1675) re-invented the two-mirror reflecting telescope now named for him, the prototype mirrors made by Richard Reeve, a well-regarded commercial optician in London, were not of high enough quality.[10] The practical development of reflecting telescopes began several years later with Isaac Newton (1643–1727). Newton pioneered new methods of fabrication that allowed accurate small spherical reflecting surfaces to be made. He was thus able to produce for demonstration purposes several small speculum-metal reflecting telescopes of his preferred construction, the Newtonian, consisting of a concave primary mirror and a small elliptical flat mirror tilted at 45° so as to divert the converging ray bundle out the side of the telescope tube, where it could be received by an eyepiece and viewed by an observer (see Fig. 4.2). But even Newton produced only small speculum mirrors of about 2 in. (50 mm) diameter. And these were avowedly not of the paraboloidal surface figure that theory demanded.[11]

It was not until the 1720s – half a century later – first through the efforts of John Hadley (1682–1744), and then Francis Hauksbee the younger, Claude-Siméon Passemant (1702–1769), and finally above all, James Short (1710–1768), that useful metal mirrors of 4–12 in. (100–300 mm) diameter could be made. Their efforts not only involved improved methods of optical fabrication, but even more, improved methods of casting and forming speculum metal for usable mirror blanks. Although Hadley initially built a successful Newtonian reflector that evoked wonder, he later turned to Gregorian telescopes, and this is what most of his successors assiduously cultivated until the time of William Herschel.[12] Gregorians are useful as terrestrial telescopes (giving erect images) and avoid the problems inherent in making flat diagonal mirrors.

## *Materials and Engineering*

As we have noted, in the eighteenth and first half of the nineteenth centuries effective astronomical mirrors (except for special applications, such as solar observing) could only be formed from polished bulk metal. Speculum was widely in use because it could be cast largely free of pores, was silvery in appearance, very hard,

---

[10] Simpson, A.D.C, "James Gregory and the reflecting telescope," *JHA*, xxiii (1992), 77–92, p. 88; *idem*, "The beginnings of commercial manufacture of the reflecting telescope in London," *JHA*, xl (2009), 421–466; and Court, T.H. & M. von Rohr, "A history of the development of the telescope from about 1675 to 1830 based on documents in the Court collection," *TOS*, xxx (1929), 207–260, p. 218.

[11] Newton, I., *Opticks*, book i, (London, 1704), pp. 75–80; Simpson, A.D.C., [*op. cit.* ref. 10, (2009)], pp. 423–427; Court, T.H. & M. von Rohr, (*op. cit.* ref. 10), pp. 218–219; and Hall, A.R. & A.D.C. Simpson, "An account of the Royal Society's Newton telescope," *NRRS*, l (1996), 1–11.

[12] Simpson, A.D.C., [*op. cit.* ref. 10, (2009)], pp. 427–451; Court, T.H. & M. von Rohr, (*op. cit.* ref. 10), pp. 219–227; and Passemant, C.-S., *Construction d'un télescope de réflexion*, (Paris, 1738). This last item is Passemant's complete treatise on the making of reflecting telescopes, a book that he describes on its title page as "useful to artisans who would like to essay this novel art…[*utile aux Artistes qui voudront s'appliquer à cet Art nouveau*]."

and took a good polish. In addition, it was resistant to tarnish when cast in the best proportional ratio of copper to tin.[13]

Unfortunately, being a mixture of heavy metals it is very dense compared to glass (about 3.4 times denser), making it deform easily under its own weight (called "self-weight deflection" or "own-weight deformation"), which results in damaging "flexure" when the precise optical figure is lost. A flexured mirror shows stars not as round points but as enlarged, distorted blurs, the extent and nature of the distortion depending on the type and magnitude of the flexural bending. Flexure is still very much a problem today with glass mirrors, and much effort is given to engineering and building systems of load support to minimize flexure. The first scientifically engineered support systems ("whiffle-trees" and "astatic levers") for astronomical mirrors date to about 1840, that is to say, about two decades *after* the death of William Herschel. This must be borne in mind to understand some of the engineering problems that Herschel encountered when he attempted to construct his enormous telescopes.[14]

Another important problem with speculum is that it is brittle, and prone to cracking from differential contraction in cooling, either when cast as a molten liquid into a mirror-blank mold or during thermal equilibration in the telescope at night in times of intense cold. Stresses experienced during grinding may also crack speculum. For this reason mirror-makers such as William Herschel resorted to less-than-optimum proportions of copper to tin, in order to make the speculum less brittle. This succeeded in preserving the mirror blanks, but also made the speculum far more easily tarnished in the presence of atmospheric moisture, such as dew and ice at night.[15] In addition, the debased speculum inclined to a reddish-brown appearance

---

[13] Willach, R., (*op. cit.* ref. 9), pp. 265–273; Mudge, J., "Directions for making the best composition for the metals of reflecting telescopes; together with a description of the process for grinding, polishing, and giving the great speculum the true parabolic curve," *PT*, lxvii (1777), 296–349; Edwards, J., "Directions for making the best composition for the metals of reflecting telescopes, *etc.*," *The nautical almanac and astronomical ephemeris, for the year 1787*, (London, 1783), appendix, pp. 3–22; *idem*, "An account of several compositions of metals and semi-metals, on which trials were made to find out the most proper mixture for the specula of reflecting telescopes," *ibid.*, pp. 23–48; Oxmantown, Lord, "An account of experiments on the reflecting telescope," *PT*, cxxx (1840), 503–527, pp. 503–506; and Herschel, J.F.W., *The telescope*, (Edinburgh, 1861), pp. 123–130.

[14] For modern methods of supporting large mirrors, *cf.* Lemaitre, G.R., *Astronomical optics and elasticity theory*, (Berlin, 2009), pp. 16–21 and 413–415; Wilson, R.N., *Reflecting telescope optics*, ii, 2nd ed., (Springer, 2001), pp. 242–273; and Kärcher, H.J., "Die Kunst, Linsen und Spiegel zu halten," *Sterne und Weltraum*, (3/2012), 52–63. For a historical perspective, *cf.* Herschel, J.F.W., (*op. cit.* ref. 13), pp. 91–97. On the density of speculum, *cf.* Texereau, J., (*op. cit.* ref. 6), p. 25; on the origin of whiffle-trees, *cf.* Oxmantown, Lord, (*op. cit.* ref. 13), p. 524 and Rosse, Earl of, "On the construction of specula of six-feet aperture, *etc.*," *PT*, cli (1861), 681–745, pp. 689–691 and plate xxiv, fig. 10; and on the origin of astatic levers, *cf.* Lassell, W., "Description of an observatory erected at Starfield, near Liverpool," *MmRAS*, xii (1842), 265–272, p. 269. And for the earliest surviving whiffle-tree, *cf.* Fig. 4.33 below.

[15] For cracking, *cf.* Herschel, J.F.W., (*op. cit.* ref. 13), pp. 126–130; for dew and ice accumulating on a mirror, *cf. e.g.*, Herschel, W., "Astronomical observations relating to the sidereal part of the heavens, and its connection with the nebulous part; arranged for the purpose of a critical examina-

from the increased copper content. For his second 48-in. mirror, Herschel was compelled to add so much copper that, years later, Sir James South (about whom we will learn more later in this chapter) described it as looking "nearly the color of mahogany" and being "the prey of tarnish."[16]

Another undesirable feature of speculum metal is its comparatively low reflectivity, typically about 60% in the visual spectrum. Thus, a two-mirror telescope (Newtonian, Cassegrainian, or Gregorian) made with speculum mirrors transmits only about 36% of incident light, losing two-thirds of the light to absorption and scatter by the metal. The final "through-put" of light compares very unfavorably with a modern reflecting telescope. Modern aluminized glass mirrors can reflect as much as 90–95% of incident light, and the through-put of two-mirror telescopes is the square of this, or about 80–90%.[17]

A final significant problem with speculum that greatly complicated its usage is its large coefficient of thermal expansion ("CTE"), coupled with a high thermal conductivity. The net effect is a large and rapid expansion and contraction of the metallic mass during temperature changes. This, along with great stiffness after solidification, is what makes speculum prone to cracking. But more fundamentally it makes the metal hard to figure accurately – that is, hard to give the precise geometrical shape through polishing needed for an astronomical mirror. We shall

---

tion," *PT*, civ (1814), 248–284, p. 275, footnote * [*TSP*, ii, p. 536]; for water vapour causing damage, *cf. e.g.*, RAS MS Herschel W.2/2.5, Review No. 5, f. 57v [*TSP*, ii, p. 600]: "1799, Dec. 28, 40 feet telescope…my mirror has been injured by condensed vapours"; also, RAS MS Herschel W.5/9.1 (instructions for the Russian 20 ft telescope), p. 10: "Then if we should lift up the [mirror] cover after an observation at night, some drops of dew or crumbling of hoar frost might fall on the open mirror, and such accidents would soon destroy it." Herschel always took care to emphasize the need to keep mirrors dry. *Cf.* also, Schrader, J.G.F., "Beschreibung des Mechanismus eines unweit Kiel errichteten sechs und zwanzigfüßigen Teleskops," *Schleswig-Holsteinische Provinzialberichte*, viii (1794), 1–19, p. 13: "If the composition of the speculum metal is not of the best type, [mirrors] very soon lose some of their polish and shine by frequent fogging, or in common parlance, they tarnish. [*Ist die Komposition des Spiegelmetalles nicht von der besten Art, so verlieren [die Spiegel] durch das häufige Beschlagen sehr bald von ihrer Politur and Glanze, oder in der gemeinen Sprache zu reden, sie laufen an.*]"

[16] South, J., "Sir W. Herschel's Forty Feet Reflector," *Times of London*¸ 6-Oct-1838 (letter to the editor), p. 5.

[17] For reflectivity of speculum and silver, *cf.* Herschel, J.F.W., (*op. cit.* ref. 13), pp. 87–88; for modern aluminum coatings, *cf.* Bass, M. et al., *Handbook of optics*, iv, 3rd edition, (New York, 2010), 7.106–109. William Herschel occasionally constructed other forms of telescopes, such as the Gregorian reflector, since this design gives upright images and can be used in the daytime to look about the countryside. The configuration of this two-mirror system (as well as its cousin, the Cassegrain reflector) can easily be found by consulting books and the internet. Since the present chapter concerns Herschel's astronomical work and centers on the telescopes he constructed as research tools to further that work, I do not wish to lengthen an already long chapter by discussing extraneous forms of instruments which at most formed occasional sidelights to Herschel's predominate work.

discuss later the necessary figuring accuracies, as well as Herschel's methods of optical figuring and testing.[18]

Less significant problems with speculum are its tendency to form pores during casting, which creates holes of various sizes in the finished mirror surface. These in turn lead to polishing defects nowadays called "crow's feet," but which Herschel called "burs." Easily visible to the naked eye, "burs" around pores scatter light in the focused image and reduce the image's contrast. In addition, crystallizations in the metal lead to further polishing problems. The inherent difficulty of controlling solidification of the metallic mass during the casting process can lead to internal inhomogeneities and stresses in the finished blank, which annealing cannot remove. Residual mechanical stresses in the solid mirror blanks can contribute to figure variation and even cracking of the speculum during temperature changes.[19]

It was therefore a revolutionary improvement in nineteenth-century astronomical optics when glass replaced speculum; and a second revolution occurred in twentieth-century optics when zero-expansion vitreous ceramics replaced the classical soda-lime glasses. The vitreous ceramics go under trade names such as Cer-Vit™, Zerodur™, Astro-Sitall™, ULE™, *etc.*[20] Since polishing and figuring liberate heat *via* friction, mirrors expand and contract locally and globally as the optician rubs them. The amount is minute, but the figuring tolerances are also minute. That the physical shape of a mirror continually varies due to heat flow during the fabrication

---

[18] For the CTE and conductivity (also called "diffusivity") of speculum and various glasses, *cf.* Texereau, J., (*op. cit.* ref. 6), p. 25; and in general Lemaitre, G.R., (*op. cit.* ref. 14), pp. 416–423. During hand working Herschel typically attached a wooden polishing handle on the backs of his mirrors: "Polishing without a handle is properly speaking to polish in an artificial temperature, and must be liable to all the inconveniencies of it; it is therefore advisable to use a handle on account of preserving a more equal temperature in the mirror," RAS MS Herschel W.5/14.1, section 4.2, f. 13r. Such a handle is sometimes called a "spivvy" among modern opticians; *cf.* Gregory, J., "A quest for the perfect refractor," *Sky and telescope*, lxiii (1987), 662–667, p. 665. With glass optics, spivvies are not necessary; *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 35–53. To avoid difficulties arising from temperature changes in speculum during fabrication, Lord Rosse introduced the practice of partially submerging his mirrors in a tank of water to act as a heat stabilizer: "…in working large specula, the [fabrication] uncertainty was so great, that it gave rise to difficulties which I found it impossible to combat, and therefore I resorted to the simple expedient of making the speculum revolve in water, kept at a uniform temperature of 55° [F]: all change also in the figure of the speculum, from variation of temperature during the process, was thus at the same time prevented." *Cf.* Oxmantown, Lord, (*op. cit.* ref. 13), p. 520.

[19] For pores and crystallizations, *cf.* Willach, R., (*op. cit.* ref. 9). Also *cf.* RAS MS Herschel W.5/14.1, section 31.7, f. 136r: "Burs are extremely troublesome, it is therefore necessary to prevent them, or if they happen to be contracted to get rid of them as soon as possible. Holes in the face of a mirror are very apt to contract burs about them, which become very troublesome in polishing"; and f. 137r: "Very coarse crystallizations are bad faults in the face of a mirror, and show themselves often in polishing. I surmise that when they are not to be seen they still may render a mirror less distinct. Some are so bad that it is best to throw the mirror aside." For an instructive account of casting and fabricating a speculum metal mirror blank, *cf.* Bailey, E.F., "I tried to follow Herschel," *The sky*, iii (Sept. 1939), 6–7.

[20] Lemaitre, G.R., (*op. cit.* ref. 14), pp. 418–419.

process creates the effect of a moving target for the optician, who has not only to aim at the correct final figure but also to guess how the figure is actively varying as he or she attempts to coax the surface toward the final goal. The larger the coefficient of expansion and thermal conductivity, the more the target actively moves during figuring, and the greater the headache becomes for the optician, since the figuring tolerances are so tight.[21] If stresses are present in the substrate, the balance of tensions can change unpredictably as material is rubbed away. This further increases the figuring difficulty.

Collectively, these materials properties mean that for an astronomer such as Herschel, who frequently observed in the open air with falling temperatures at sites subject to dew, fog, and ice, and who did not generally use speculum of optimum composition, reflecting telescopes were inevitably cantankerous, impermanent instruments, necessitating frequent interventions.[22] Making and using such instruments to advantage meant “humoring their moods and whims,” so to speak. Herschel struggled so hard for so many years to master the difficulties of speculum-metal reflecting telescopes that he once wrote to his friend Alexander Aubert (1730–1805): “It would be hard, if they had not proved kind to me at last.”[23] But equally, once viable silver-on-glass reflecting telescopes became available after 1850, speculum lost its preeminence. The triumph of the modern aluminized reflecting telescope depends absolutely on glass – a far more favorable substrate to work than metal – and on thin-film vacuum deposition to provide a highly reflective, durable, and long-lasting mirror surface.

---

[21] As we noted previously, on the order of a few dozen *nanometers*. In optical testing it is easy to see how heat from the hand can distort an optical surface: *cf.* also the comments of Grubb, H., “Telescopic objectives and mirrors: their preparation and testing,” *Nature*, xxxiv (1886), 85–92, p. 90, col. 1. Grubb’s article is filled with highly useful information about optical fabrication and testing. The finest optical figuring was done (and even today sometimes still is) using the tips of the optician’s fingers or thumbs charged with polishing compound: “…Mr. [Alvan G.] Clark took up an old castaway disk [of glass] and gave it less than a dozen sharp rubs with the smooth, soft thick of his thumb. ‘There,’ said he, ‘if this had been a perfect lens, that would have changed its shape enough to ruin it.’ I wanted to accuse the man of playing upon me, but his earnestness forbade.” In Hawkins, W.B., “The Clarks,” *Popular Astronomy*, xxxiv (1926), 379–382, p. 382.

[22] RAS MS Herschel W.5/14.1, section 1.4, f. 6r: “A…very desirable quality is that a reflecting metal should not be very liable to tarnish when exposed to air. I cannot however put this quality in competition with the reflection of light; but will readily allow that the perishable nature of mirrors ought to be an additional inducement for us to bring the art of making and repolishing them to perfection.” Herschel wished to make polishing a predictable process, which he called “giving figure,” consisting of manipulating the motions of his polishing machines and pitch laps by definite rules, making the frequent repolishing less onerous. For an overview, *cf.* Herschel, J.F.W., (*op. cit.* ref. 13), pp. 140–151.

[23] RAS MS Herschel W.1/1.1, p. 22: quoted in Lubbock, C.A., *The Herschel chronicle*, (Cambridge, 1933), p. 103. At the end of his life Herschel pronounced to James South about mirrors: “I have done much for them – they have done much for me – they are, however, in their infancy, as you will live to see,” in South, J., (*op. cit.* ref. 16).

## Optical Aberrations: Origins and Appearances

Next let us examine the aberrations seen in telescopes. These arise in the first place from geometrical errors in the convergence of light rays passing through optical systems; but the resulting image appearances are also modified by diffraction and the interference of light.[24]

The three most important optical aberrations are: spherical aberration, coma, and astigmatism. We start with spherical aberration, which if present affects images everywhere in the telescopic field of view. Coma and astigmatism can only appear in images formed away from the optical axis ("off-axis") – in other words, in the exterior telescopic field – in an otherwise well-made and centered instrument.

Spherical aberration results from the inability of a single lens or mirror with spherical surfaces to focus light from an infinitely distant source to a point. Rays impinging near the periphery of a converging lens or mirror focus at a shorter longitudinal distance than rays impinging near the optical axis. This is shown graphically in Fig. 4.4.

The resulting convergence error is called "undercorrected" spherical aberration. This can be remedied by using pairs of lenses suitably shaped, or by means of aspheric optical surfaces. It can even be reversed, yielding marginal rays that focus long and "paraxial" rays (*i.e.*, those lying very close to the optical axis) focusing short. This situation is called "overcorrected" spherical aberration. In the case of a single concave mirror (such as that used in a Newtonian telescope), a spherical surface produces undercorrection, a paraboloidal surface produces a "stigmatic" (*i.e.*, perfect) focus with all rays converging to a single point, and a hyperboloidal surface produces overcorrection.

The geometrical ray errors shown in the longitudinal cross-section of Fig. 4.4 can also be viewed head-on in transverse section by means of a so-called "spot diagram," which shows graphically how the light rays coalesce to form an image at various focus positions. Figure 4.5 shows the corresponding spot diagrams.

The dots in the stippling represent individual light rays in the image at the selected focus positions along the optical axis. The five image spots shown in Fig. 4.5 correspond to the numbered longitudinal positions given in Fig. 4.4. As can easily be seen, in no case are all the light rays concentrated to a point. Even position three shows an obvious physical extension. Thus, in the presence of spherical aberration images cannot be sharp.

For small amounts of spherical aberration, when diffraction and the interference of light are taken into account as they would be in an actual telescope, the images shown in Fig. 4.5 become modified and appear as below in Fig. 4.6.

---

[24] For discussions of geometrical aberrations and image spot diagrams, *cf.* Smith, W., *Modern optical engineering*, 3rd ed., (SPIE-McGraw Hill, 2000), pp. 61–89; and Smith, G.H., *Practical computer-aided lens design*, (Willmann-Bell, Richmond, 1998), pp. 55–97. For introductory texts, *cf.* Rutten, H.G.J. & M.A.M van Venrooij, *Telescope optics, a comprehensive manual for amateur astronomers*, (Willmann-Bell, 1999), pp. 21–44; and Smith, G.H., R. Ceragioli, and R. Berry, *Telescopes, eyepieces, and astrographs*, (Willmann-Bell, 2012), pp. 64–74.

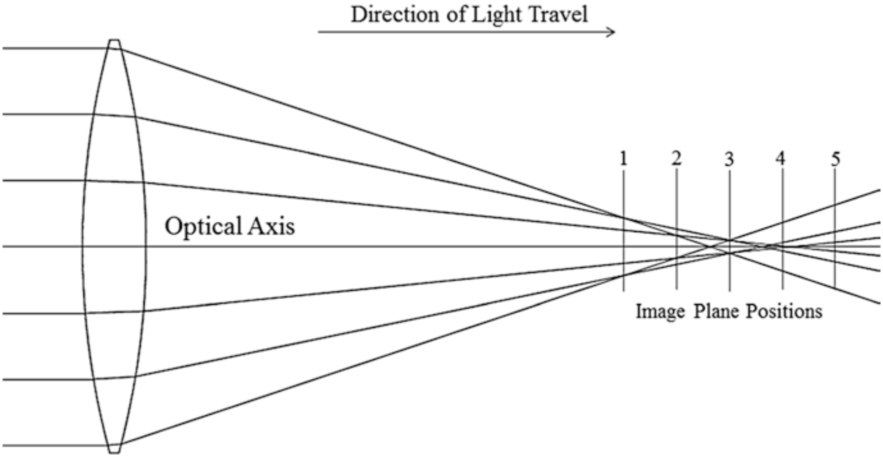


**Fig. 4.4** Undercorrected spherical aberration. As the entrance height of parallel incoming light rays (*on left*) increases, their intersection lengths along the optical axis decrease. Five image plane positions are marked on the *right* of the figure. The concentration of light at these positions is shown in Fig. 4.5

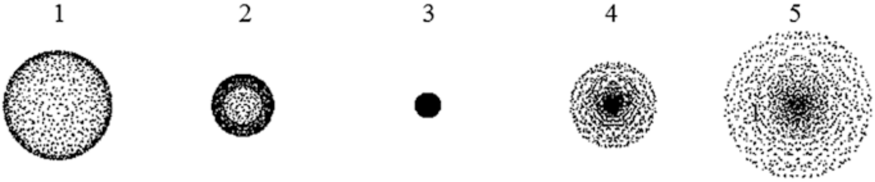


**Fig. 4.5** Geometrical optics "spot diagrams" for undercorrected spherical aberration at five focus positions along the optical axis. The *numbers* correspond to the image plane positions shown in Fig. 4.4

These images show how a star would appear in a real telescope under optimum conditions, that is, at high power in the absence of atmospheric seeing disturbances. The form of the images is a bull's-eye pattern, consisting of circular diffraction rings caused by the passage of light through the circular aperture of the telescope. The bull's-eye pattern is also known as a point spread function, or PSF, after the mathematical function that determines the pattern.[25] None of the PSFs in Fig. 4.6 is well-formed, indicating once again that the telescopic image will not be sharp.

For comparison, in Figs. 4.7 and 4.8 we show how the geometrical spots and PSFs would appear without spherical aberration, that is, how they would be seen in a reflecting telescope fitted out with a perfect paraboloidal primary mirror. In the spot diagram (Fig. 4.7), the ray convergence at best focus (position 3) produces a

---

[25] On point-spread functions, *cf.* Smith, W., (*op. cit.* ref. 24), pp. 361–362 and 385–391. For physical optics aberrations in general, *cf.* Suiter, H.R., *Star testing astronomical telescopes*, 2nd edition, (Willmann-Bell, Richmond, 2008).

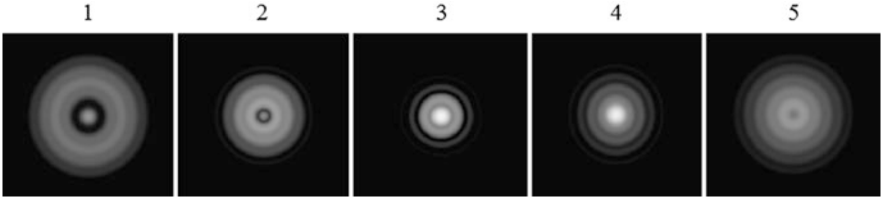


**Fig. 4.6** Physical optics images (PSFs) corresponding to Fig. 4.5 geometrical spot diagrams, taking into account the effects of diffraction and the interference of light, and assuming only a small amount of spherical aberration

**Fig. 4.7** Image spot diagrams for corrected spherical aberration, showing a perfect distribution of light rays, inside, at, and outside best focus

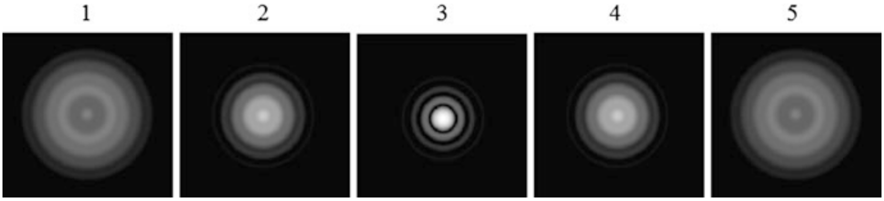


**Fig. 4.8** Physical optics PSFs for a perfectly corrected telescope, seen at high power. Position 3 illustrates the image formed at best focus

barely discernible single point. And the spots on either side of best focus (1 and 5; 2 and 4), taken at equal distances inside and outside of focus, appear identical to one another.

The corresponding physical optics PSFs appear in Fig. 4.8. The PSF seen at position 3 is now perfectly formed, illustrating the best possible type of real telescopic image visible at high power under perfect conditions.

Since William Herschel's best Newtonian telescopes definitely produced images close to this ideal, it is important to examine the PSF at position 3 in greater detail. Figure 4.9a shows this at a larger scale with reversed coloration. The PSF viewed head-on consists of a bright central disk, called the "Airy disk" after George B. Airy (1801–1892), the Astronomer Royal who first derived the equation describing the PSF. Airy will figure prominently later in the paper in connection with the discovery of astigmatism. Surrounding the Airy disk is a set of dark and light rings that result from diffraction and the interference of light. Most of the light energy (84%) from a star forming a perfect PSF is concentrated inside the Airy disk; the rest (16%) is spread among the bright rings.[26] Figure 4.9b shows the same PSF as a three-dimensional intensity profile seen in perspective. The Airy disk is represented as an "intensity mountain" at the center of the figure, looking rather like a Gaussian bell-curve. Surrounding it are low-profile diffraction rings, whose troughs and crests form a decaying sinusoidal pattern in cross-section. What is important to note in Fig. 4.9b is how high the "peak of the mountain" is relative to the low-intensity rings. A well-formed bright star image in an excellent telescope at high power on a very good night with minimal air turbulence will appear as an intensely bright disk, of finite and perceptible size, surrounded by a sequence of faint rings. William Herschel was well aware that the best possible real image in a telescope was not a mathematical point, but a "spurious disk." This is what he saw in his finest telescopes, although he did not did not know the cause of such disks.[27]

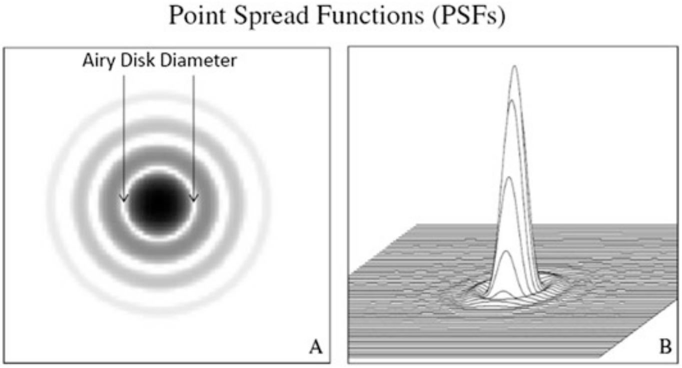


**Fig. 4.9** (**a**, **b**) Perfect PSFs. On *left* we see the so-called "Airy diffraction pattern," consisting of a bright disk of finite size, the "Airy disk," surrounded by a set of much fainter circular light and dark rings (in reversed coloration from reality). On *right* we see the same pattern represented as a three-dimensional intensity profile

---

[26] For Airy's original paper, *cf.* Airy, G.B., "On the Diffraction of an Object-Glass with Circular Aperture," *TCPS*, v (1835), 284–291. On the distribution of light in a perfect Airy pattern, *cf.* Smith, W., (*op. cit.* ref. 24), p. 160.

[27] Because the modern wave theory of light, on which the formation of the Airy pattern rests, was not yet established. *Cf.* below, section "Herschel's manufacture and testing of telescope mirrors." *Cf.* also Herschel, J.F.W., *Treatises on physical astronomy, light and sound, contributed to the Encyclopaedia Metropolitana*, (*ca.* 1827), p. 491. That Herschel's best instruments showed stars as small disks with little or no asymmetry evoked wonder in the 1780s. Therefore, it was long remembered in the Herschel family how in 1786 William Herschel attended a dinner party and was seated next to Henry Cavendish (1731–1810), the famous chemist and physicist, a man who spoke but little: "Some time passed without his uttering a word, then he suddenly turned to his neighbour and said: 'I am told you see the stars round, Dr. Herschel.' 'Round as a button,' was the reply. A long silence ensued till, towards the end of the dinner, Cavendish again opened his lips to say in a doubtful voice: 'Round as a button?' 'Exactly, round as a button,' repeated Herschel, and so the conversation ended." Quoted in Lubbock, C.A., (*op. cit.* ref. 23), p. 102.

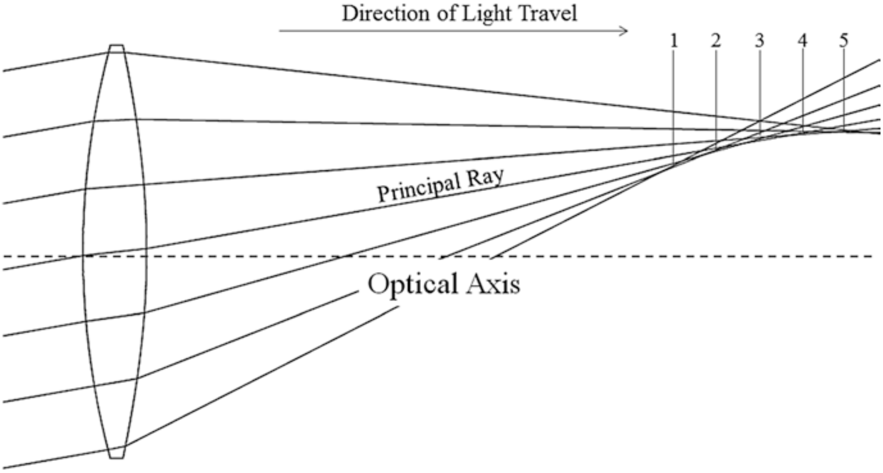


**Fig. 4.10** Coma occurs because light rays arriving at a lens or mirror from an off-axis object point do not all focus together, as shown here. Star images appear as small "comets," consisting of bright "head" and fading "tail," or side flare

**Fig. 4.11** Comatic image flares. These geometrical optics spot diagrams show the faulty ray convergence of an off-axis image point affected by coma. The *numbers* appearing above the spots correspond to the image plane positions shown in Fig. 4.10. In no case, not even at the best focus (position 3), are the light rays well concentrated

Aberrations distort the perfect "Airy pattern." Figure 4.6 shows one type of distortion, caused by undercorrected spherical aberration. Two other aberrations of great importance for understanding telescopes are coma and astigmatism. Coma occurs because different annular zones of a lens or mirror focus light to different off-axis image heights, as shown in Fig. 4.10. The resulting errors give images of stars in the shape of small comets, consisting of a bright concentrated "head" and a gradually fading "tail" or side-flare, as seen in Fig. 4.11.

In the past, this error was sometimes called "spherical aberration off-the-axis." Since, however, the flaring can appear in addition to spherical aberration proper, modern usage restricts the term spherical aberration to a variation of *longitudinal* focus distance with annular zone height, and defines coma as the variation of *transverse* focus distance (*i.e.*, off-axis image position) with annular zone height. Spherical aberration causes a uniform circular blurring of the image, whether on-

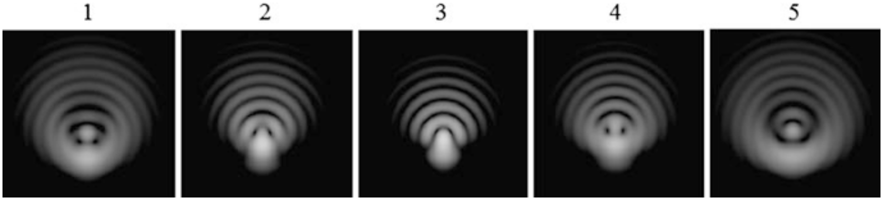


**Fig. 4.12** Physical optics PSFs for an off-axis image affected by coma. At best focus (position 3) we can clearly see the distortion of the Airy disk and the eccentric side flaring of the diffraction arcs. The *numbers* above each PSF correspond to the image plane positions shown in Fig. 4.10

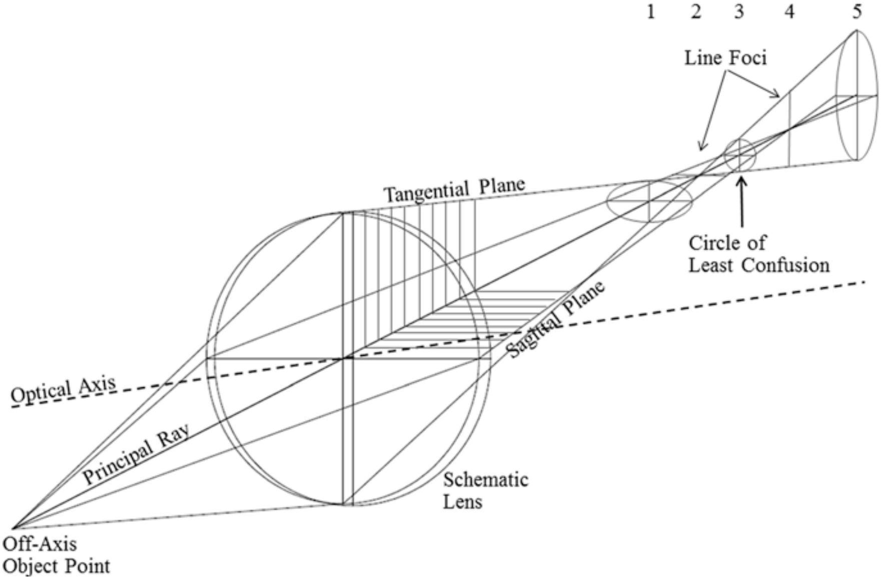


**Fig. 4.13** Astigmatism occurs in a lens or mirror because its optical surfaces appear foreshortened to rays arriving from an off-axis object point. The foreshortening seems greatest in the tangential plane, so that the lens or mirror surface appears more curved in that plane than in the sagittal plane (Images take the form of ellipses, lines, or a small circle called the “circle of least confusion,” as shown at the right of the figure)

axis or off-axis; coma causes an eccentric flaring of off-axis images. If the amount of coma is not too large, then when modified by diffraction and interference, the image PSFs can appear as in Fig. 4.12.

Coma is the main off-axis image aberration seen in Newtonian telescopes under typical conditions of usage. Secondarily, one sees astigmatism. The origin of astigmatism is more difficult to explain than coma, since it requires a three-dimensional visualization. Figure 4.13 tries to illustrate this. A schematic lens appears at center-left of the figure, and is rotated out of the plane of the paper. Five rays emanating from an off-axis object point arrive at top, bottom, left, and right extremes of the lens, as well as at center. The ray passing from the object through the center of the lens and extending to the image is called the "principal ray." For the off-axis ray bundle it is analogous to the optical axis of the on-axis ray bundle, defining the center of the off-axis bundle and passing through the center of the off-axis object and image.

The top and bottom rays belonging to the off-axis bundle define a plane called the "tangential plane." This cuts the image in a vertical slice. Perpendicular to the tangential plane is the "sagittal plane," which cuts the image horizontally, as shown in Fig. 4.13. To understand the origin of astigmatism the key idea is this: *astigmatism of the image arises when the convergence point for rays lying in the tangential plane (i.e., the tangential focus) does not coincide with the convergence point for rays lying in the sagittal plane (i.e., the sagittal focus)*. Instead, for the schematic lens illustrated in Fig. 4.13, the tangential focus (position 2) lies closer to the lens than the sagittal focus (position 4).

The net effect on the geometrical image is to create two *foci* in the form of lines: the first line, for rays in the tangential plane, stretches out in a direction tangential to the field edge; and the second line, for rays in the sagittal plane, stretches radially away from field center. The size of these lines depends on the magnitude of the astigmatism. Between the line *foci*, as well as outside the focal region delimited by the line *foci,* the image takes on an elliptical shape of varying eccentricity, the major axis of the ellipse pointing vertically or horizontally, as shown in Fig. 4.13. The best image (position 3) forms a circle, called the circle of least confusion. It is the smallest image in the presence of astigmatism.

Astigmatism arises because to the off-axis object point, the optical surfaces of the lens or mirror appear foreshortened in the tangential plane, so that those surfaces seem to have a cylindrical component overlying their base sphericity. That is to say, the radius of curvature in the tangential plane appears to be shorter than in the sagittal plane. Thus, a foreshortened mirror or lens surface appears to be a section of a three-dimensional solid, called a *toroid*. The most commonly encountered toroids in daily life are potato chips, donuts, and eyeglass lenses with surface correction for astigmatism. Indeed, it was George Airy who first conceived of utilizing toroids in eyeglasses in 1827, in order to correct his own faulty vision, as we will discuss further below. Toroids also have a quite surprising connection to William Herschel and other makers of Newtonian telescopes before the mid-nineteenth century. It seems that their elliptical flat mirrors were by-and-large toroidal, to a degree that should have been disastrous to sharp image formation. That it was not so will perhaps form the most surprising conclusion of the present work, as discussed later.

Figure 4.14 shows the geometrical optics image shapes due to pure astigmatism, produced at the numbered focus positions shown in Fig. 4.13. Position 2 shows the tangential line focus; position 3 the circle of least confusion; and position 4 the sagittal line focus.

Actual star images, when the total magnitude of astigmatism is small compared to a perfect PSF, will appear as in Fig. 4.15, taking diffraction from the circular telescope aperture and the interference of light into account. As can be seen, an actual astigmatic image in a telescope then takes on a cross-like appearance, seen best at image position 3, which is located at the circle of least geometrical confu-

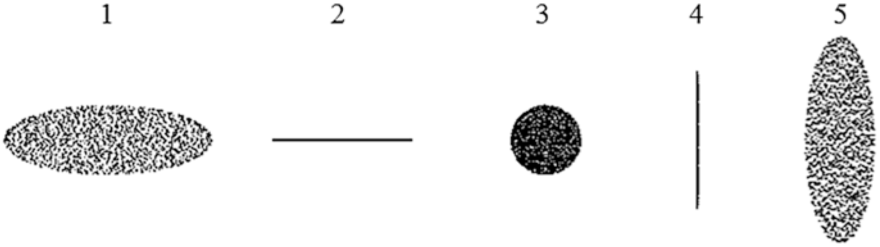


**Fig. 4.14** Geometrical-optics spot diagrams for pure astigmatism. Positions 1 and 5 show the ray convergence inside and outside of focus, giving ellipses with major axes perpendicular to one another. Positions 2 and 4 are the line foci (tangential and sagittal respectively). Position 3 shows the circle of least confusion

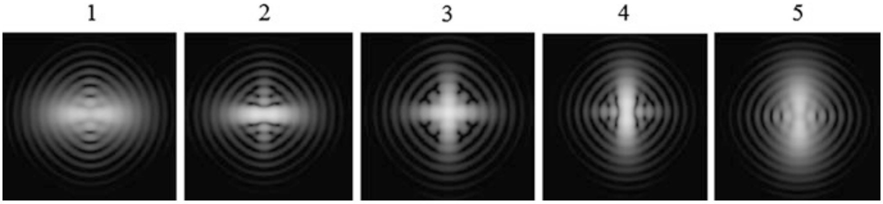


**Fig. 4.15** Physical optics PSFs for astigmatism. These show the actual appearance of a telescopic star seen at high power in the presence of a small amount of astigmatism under excellent observing conditions with no air turbulence. The *numbers* correspond to the image positions shown in Fig. 4.13

sion. Under excellent observing conditions this cross pattern will be surrounded by squarish diffraction rings.

Newtonian reflectors exhibit a mixture of coma and astigmatism in their off-axis images. These aberrations are inherent in the system. Their magnitude varies with the focal ratio of the primary mirror and off-axis image height (*i.e.*, field angle), as will be discussed in more detail later. For now suffice it to say that a front-view telescope is equivalent to a Newtonian used far off-axis.

## Development of Aberration Theory

The theory of the imaging errors (aberration theory) developed slowly over centuries. Already in antiquity through the work of the Greek geometers, it was understood that spherical concave mirrors could not concentrate the rays of the Sun to a perfect focus. Instead paraboloidal mirrors were necessary to focus parallel (collimated) incoming light rays to a point along the axis of the mirror. This understanding resulted not just from the geometrical study of conic sections but also from the formulation of the law of reflection. The imaging error that arises from the imperfect ray convergence of a spherical mirror is spherical aberration, as discussed previously.[28] It is the fundamental aberration of all reflecting telescopes, since it affects image sharpness everywhere in the telescopic field of view.

It also affects refracting telescopes. Refraction, too, was studied in antiquity, but it was not until the early seventeenth century through the work of Willebrord Snel van Roijen (1580–1626) and René Descartes (1596–1650) that an equivalent law of refraction was published (Snell's law) in explicit form. Even before this, however, scholars such as Francesco Maurolico (1494–1575), Giovanni Battista della Porta (1535–1615), and Johannes Kepler (1571–1630) were aware that spherical refracting surfaces give rise to imperfect ray convergence, although they could not investigate the error precisely without a mathematical law.[29] Aberration theory has always progressed in tandem with the development of physics and mathematics.

Once Snell's law was formulated, giving a precise rule for refraction, Descartes in the 1630s began to investigate the relationship between surface shape ("figure") in a lens and spherical aberration. He concluded that, as in the case of mirrors, lenses, too, could be freed from spherical aberration by use of conic surface figures. Depending on the overall shape of the lens (*e.g.*, planoconvex or biconvex), hyperboloidal or ellipsoidal surfaces would be needed. Descartes' analysis depended on his development of analytical geometry.[30]

For systems of mirrors, we noted previously the work of Bonaventura Cavalieri and Marin Mersenne. In 1632 Cavalieri demonstrated the "conjugate" properties of conic mirrors, both concave and convex.[31] This refers to the ability to receive rays arriving from a perfect object point and to reflect them to a perfect image point. A paraboloidal telescope mirror, for example, receives rays from point sources (stars) lying at essentially infinite distances, and reflects them to theoretically perfect image points (*foci*) lying at one-half the distance to the mirror's center of curvature. An ellipsoidal mirror receives rays emanating from one of its geometrical *foci* and reflects them to a perfect point located at the other geometrical focus. Based on his understanding of conjugate properties, Cavalieri suggested systems of mirrors equivalent to what we now call Cassegrain and Gregorian telescopes in afocal form (*i.e.*, beam compressors). He also suggested a system consisting of a concave mirror,

---

[28] Toomer, G.J., *Diocles on burning mirrors*, (Berlin, 1976), pp. 15–16. Diocles (third-second century BCE), demonstrated that a concave mirror must be paraboloidal to concentrate the light of the sun to a perfect focus.

[29] Della Porta, G.B., *De refractione*, (Neapolis, 1593), pp. 35–64 (Book 2); Kepler, J., *Dioptrice*, (Augusta Vindelicorum, 1611), pp. 21–22 (*Propositio LIX*). *Cf.* also Riekher, R., *Fernrohre und ihre Meister*, 2nd ed., (Berlin, 1990), p. 31; and Smith, A.M., *From sight to light, the passage from ancient to modern optics*, (Chicago, 2015), pp. 322ff.

[30] Descartes, R., *La dioptrique*, *discourses 8–9*, and *La géométrie*, *livre 2*, in Adam, C. & P. Tannery, *Oeuvres de Descartes*, *Discours de la méthode & essais*, vi (Paris, 1902), pp. 165–211 and 428–441. Already Kepler had suggested the use of a hyperboloid (*op. cit.* ref. 29).

[31] Apollonius of Perga (third-second century BCE), in his treatise on conic sections had demonstrated the conjugate properties of the *foci* in ellipses and hyperbolas, although without direct reference to mirrors. *Cf.* Heath, T.L., *Apollonius of Perga, treatise on conic sections*, (Cambridge, 1961), pp. 112–118.

a plane mirror, and eyepiece, which may have been equivalent to a Newtonian telescope; his description is too obscure to be certain.

Mersenne developed Cavalieri's two-mirror results further by making the mirrors coaxial (Cavalieri had mainly been concerned with tilted mirrors), and suggested not only afocal forms, but focal ones, too. These were equivalent to Cassegrain and Gregorian telescopes.[32] Since, however, prior to the eighteenth century there was little hope of producing actual mirrors with surfaces sufficiently smooth and accurately figured, Cavalieri's and Mersenne's theoretical developments received little attention.

Thus, when James Gregory, Isaac Newton, and Laurent Cassegrain (*ca.* 1629–1693) made their own proposals for reflecting telescopes late in the seventeenth century, they did it independently of their predecessors. Newton, in particular, turned to the reflecting telescope because of his understanding that white light consists of many colors (*i.e.*, is polychromatic), each color differently "refrangible" – that is, with a different index of refraction. Thus, all lenses refracting white light (no matter what their surface figures) will form images of differing colors at differing distances, giving rise to "chromatic" aberration. And this, Newton demonstrated numerically, is for more damaging to image sharpness than spherical aberration.[33]

Thus by the beginning of the eighteenth century, two forms of image aberration were known and understood theoretically, chromatic aberration, which affects only lenses, and spherical aberration, which affects both lenses and mirrors. These collectively are called "on-axis aberrations" since they degrade image sharpness at the center of the telescopic field of view, or, in other words, on-axis. They also degrade image sharpness in the off-axis, exterior field.

Newton had believed – or generally professed to believe – that chromatic aberration was incurable, so that the only way to improve telescopes was by means of reflection. During the eighteenth century after Newton's death, skepticism to his view mounted since the human eye seemed to provide a counter-example of a refractive system corrected for chromatic aberration. Gradually, through the work of many people such as Giovanni Rizetti (?-1751), Leonhard Euler (1707–1783), Samuel Klingenstierna (1698–1765), and finally John Dollond (1707–1761), it was realized that chromatic aberration in a lens systems could be corrected by the use of "achromatic lenses," that is, systems of two or more lenses consisting of different glass types (so-called crowns and flints). Klingenstierna, Euler, and a host of other theoreticians such Alexis-Claude Clairaut (1713–1765), Jean le Rond d'Alembert (1717–1783), and Roger Boscovich (1711–1787) composed long and learned articles and treatises, proposing not only how to correct chromatic aberration but also

---

[32] Ariotti, P.E., (*op. cit.* ref. 7), and *cf.* ref. 8 above. *Cf.* also, Baranne, A. and R. Launay, "Cassegrain: un célèbre inconnu de l'astronomie instrumentale," *Journal of optics*, xxviii (1997), 158–172.

[33] Newton, I., (*op. cit.* ref. 11), book i, pp. 59–74.

spherical aberration in doublet and triplet lenses.[34] John Dollond, his son Peter (1731–1820), and a great many other opticians began producing achromatic telescope objectives in large volume from 1758.

By the end of the eighteenth century enormous strides had been made in improving systems of lenses for precision imaging, contrary to Newton's ideas, so much so that with equal strides in industrial production of precision optical glass during the early nineteenth century, the ensuing decades of that century became the era of giant refracting lenses in astronomy.

However, equally important were small lenses, not only for eyeglasses but also for microscopes and later for photographic cameras. In particular photography played a decisive role in the development of aberration theory, since camera lenses have to form sharp images not only at field center but far off-axis too.

The four classic off-axis imaging aberrations are: (1) coma; (2) astigmatism; (3) Petzval curvature; and (4) rectilinear distortion. In correctly manufactured, so-called "centered" systems of optics (that is, systems in which the lenses and mirrors are placed perpendicularly along a single axis passing through their centers), these aberrations can only appear away from field center: hence the designation "off-axis." For the present paper, the last two aberrations have no significance, and we shall not discuss them further. But coma and astigmatism are of central importance, since front-view telescopes are equivalent to Newtonian reflectors used very far off-axis. Newtonians are uncorrected for off-axis coma and astigmatism. Just how obtrusive these aberrations become in particular Newtonian or front-view instruments depends on the details of construction. We will discuss these details later. For now let us consider the discovery and theoretical comprehension of coma and astigmatism.

We will start with astigmatism, which was recognized first. In Figs. 4.14 and 4.15 of the present work, we showed the geometrical and physical optics manifestations of astigmatism. Historically, the geometrical effects were recognized first, in the form of line *foci*. Isaac Barrow (1630–1677) in the 1670s noticed theoretically that under certain limited conditions, an image could break up into two separated line *foci*. This was treated as an optical curiosity until Thomas Young (1773–1829) at the beginning of the nineteenth century recognized that these lines have a practical upshot, in the function of the human eye.[35] In 1801, as part of a seminal study, Young illustrated forms of images seen when a bundle of rays passes obliquely through a spherical refracting surface, such as the cornea of the eye.[36] George Airy

---

[34] The best overall account of these developments is given by Boegehold, H., "Zur Vor- und Frühgeschichte der achromatischen Fernrohrobjektive," *Forschungen zur Geschichte der Optik*, iii (1943), 81–114. *Cf.* also, Rudd, M.E. et al., "New light on an old question: who invented the achromatic telescope?," *Journal of the Antique Telescope Society*, xix (2000), 3–12; and Riekher, R., (*op. cit.* ref. 29), pp. 102–118.

[35] For a succinct history with much documentation on the recognition of astigmatism, *cf.* von Rohr, M. (ed.), *Geometrical investigation of the formation of images in optical instruments*, (London, 1920), pp. 201–209. This is the English translation of von Rohr's German treatise, *Die Bilderzeugung in optischen Instrumenten vom Standpunkte der geometrischen Optik*, (Berlin, 1904), pp. 199–205.

[36] Young, T., "On the mechanism of the eye," *PT*, xci (1801), 23–88, p. 30 and Fig. 28.

in the 1820s investigated the optics of his own eyes when he recognized that his left eye formed such a "totally useless image" of nearby objects that he did not actually employ it in reading but had unconsciously been utilizing just the images formed by his right eye. His investigation led him to the discovery that by applying a cylindrical eyeglass lens to his left eye he could restore its utility. He published an important article on this practical discovery in 1827.

Twenty two years later in 1849 he conducted a second enquiry, having found that the defect in his left eye had in the meantime changed. This led to a second article in which Airy noted that William Whewell (1794–1866) – prolific coiner of scientific terms in the nineteenth century – had devised the name "astigmatism" for the cylindrical eye defect. Although for many years astigmatism was used mainly in ophthalmic optics to describe corneal irregularities, eventually it became the *terminus technicus* for the geometrical imaging error that in its pure form leads to the phenomenon of two separated line *foci*.[37]

In 1830, Airy also considered the optics of telescope eyepieces. In these, bundles of rays pass eccentrically through two or more glass lenses faced with spherical surfaces. Airy developed the first theory of off-axis aberrations in eyepieces and described eyepiece astigmatism (not yet so named) as follows:

> *If a brilliant point, as a star, be viewed* [off-axis], *with one position of the eye-piece, it appears a bright line in the direction of a radius of the field, and with another position it appears a bright line in a direction perpendicular to the former: with other positions it appears an ellipse, or a circle.*

Airy also provided an illustration analogous to Fig. 4.14. In addition, he discussed field curvature and rectilinear distortion. Following Airy, Henry Coddington (1798–1845) developed his classic treatment of the same subjects in his general treatise, *A system of optics*. Coddington, like Airy, mathematically considered the refraction and reflection of infinitesimally wide bundles of light rays passing obliquely through an optical surface.[38]

Later in the century other scientists and mathematicians greatly extended the theory of astigmatism and explored its correction in optical instruments.[39] Of particular interest is the work of Richard Potter, a professor of astronomy at University College, London. In his 1851 textbook, *An elementary treatise on optics*, Potter reviewed the mathematical work of Coddington and presented the illustration shown

---

[37] Airy, G.B., "On a peculiar defect in the eye, and a mode of correcting it," *TCPS*, ii (1827), 267–271; *idem*, "On a change in the state of an eye affected with a mal-formation," *TCPS*, viii (1849), 361–362; *idem*, "Substance of the lecture delivered by the Astronomer Royal on the large reflecting telescopes of the Earl of Rosse and Mr. Lassell, at the last November Meeting," *MNRAS*, ix (1849), 110–122, p. 119; Green, J., "On the detection and measurement of astigmatism," *The American journal of the medical sciences*, liii (1866), 117–127; von Rohr, M., "Der Astigmatismus in sprachlicher und sachlicher Hinsicht," *Die Naturwissenschaften*, xx (1932), 848–850; and Levene, J.R., "Sir George Biddell Airy, F.R.S. (1801–1892) and the discovery and correction of astigmatism," *NRRS*, xxi (1966), 180–199.

[38] Airy, G.B., "On the spherical aberration of the eye-pieces of telescopes," *TCPS*, iii (1830), 1–63, p. 2 and Fig. 6; and Coddington, H., *A system of optics*, i, (Cambridge, 1829), pp. 20–35 (esp. 26–28) and 66–72.

[39] For bibliography, *cf.* von Rohr, M., (*op. cit.* ref. 35).

in Fig. 4.16, to demonstrate the geometrical imaging of an infinitesimally wide bundle of rays passing obliquely through a lens.

The diagram clearly shows the geometrical optics ellipticity of a star image affected by pure astigmatism as the focus point is shifted along the axis from inside focus (left) to outside (right). Focus-point 4 (center of series) represents the enlarged circle of least confusion, and points 2 and 6 are meant to illustrate the two perpendicular line *foci,* as Potter states in his text.[40]

Mention of Potter's treatise is opportune because of his pioneering study of coma, the aberration to which we turn next. We showed in Figs. 4.11 and 4.12 how coma transforms round star-images into little "comets," consisting of a bright head and gradually fading tail or side flare. It was Clairaut and d'Alembert in the early 1760s who had first drawn attention to the aberration theoretically in their work on refractors. But because in a typical astronomical refractor with its slow focal ratio and narrow field of view coma is usually invisible, little attention was paid to the matter.[41] Indeed in 1821, John Herschel dismissed coma as an aberration that no one ever actually saw in a refractor.[42] Neither he nor anyone else understood as yet that it was quite visible and damaging in his father's front-view telescopes. It was the principal image aberration in them.

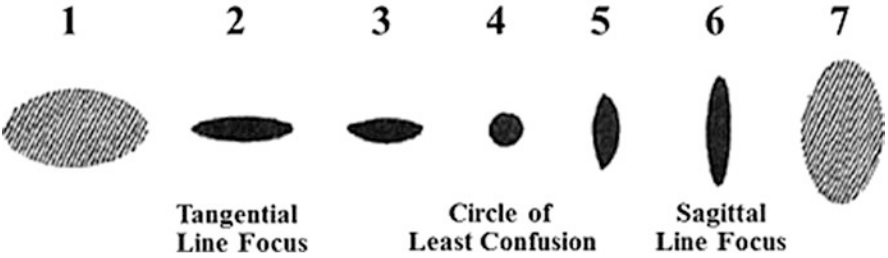


**Fig. 4.16** The illustration of image astigmatism as it varies through focus (Taken from Richard Potter's 1851 book, *An elementary treatise on optics*. Positions 2 and 6 represent the line *foci*)

---

[40] Potter, R., *An elementary treatise on optics*, ii (London, 1851), p. 113.

[41] *Cf.* Boegehold, H., "Die Leistungen von Clairaut und d'Alembert für die Theorie des Fernrohrobjektivs und die französischen Wettbewerbsversuch gegen England in den letzten Jahrzehnten des 18. Jahrhunderts," *Zeitschrift für Instrumentenkunde*, lv (1935), 97–111, p. 98 and 102; and also Church, J.A., "Clairaut's Forgotten Legacy," *Sky and telescope*, lxvi (1983), 259–261.

[42] Herschel, J.F.W., "On the aberrations of compound lenses and object-glasses," *PT*, cxi (1821), 222–267, pp. 226–227. This is true as long as the objective lens is made properly square ("collimated") to the axis of the telescope tube. If it is not square, and if the lens has not been corrected for coma in design (most nineteenth century telescope objectives were not so corrected), then the aberration would be glaringly apparent in the middle of the field of view. Hence most refractor makers and users must have been familiar with coma empirically. Still, because it could be eradicated on axis by aligning the objective lens and simultaneously made vanishingly small off-axis over the limited visual field, coma elicited no great interest or theoretical study until the mid-to-late nineteenth century. See further below in the present chapter for more details.

Some years later, in 1830, Joseph Jackson Lister (1786–1869), the great microscopist, again called attention to image flares, this time in the fields of compound microscopes of high numerical aperture that were just then coming into use. Lister said that in some of his objectives: "…the image of any bright point that was at some distance from the center of the field had a faint light or coma stretching outwards from it; with others the coma was as much inwards."[43] Lister's description shows that he was referring to what modern optical designers call coma, but the wording of his sentence ("a…coma stretching outwards") indicates that as yet coma was not a technical term for the image aberration, but merely a useful description of an empirically observed phenomenon. Being the Latin word for "a head of hair" (derived from ancient Greek *κόμη*), coma had long been used to refer metaphorically to the nebulous head and tail of a *cometa*, that is, a comet. Lister's usage is descriptive, because no one had as yet begun a serious mathematical study of off-axis imaging aberrations in general.

However, it was not long in coming. William Rowan Hamilton (1805–1865), the great mathematician, was the first person to begin this work, about 1830.[44] A more practical formulation only came later, in the mid-1850s with the work of Ludwig von Seidel (1821–1896), who precisely characterized the five so-called "third order" monochromatic or "Seidel aberrations," known today: spherical aberration, coma, astigmatism, Petzval curvature, and rectilinear distortion. Seidel's work had been spurred both by developments in astronomical refracting telescopes and also the advent of photography in 1839. To record human portraits with the original, very slow Daguerreotype photographic process, or with the somewhat faster collodion wet-plate process, photographers required large, fast camera lenses. Focal ratios of f/15–f/20, suitable for astronomical telescopes and the *camera lucida* of pictorial artists, were impossible for photographic portraiture. So already in 1840, Joseph Max Petzval (1807–1891), a professor of mathematics at the University of Vienna, developed mathematical methods thought to anticipate Seidel's, which he used to devise a camera lens with the revolutionary speed of f/3.6. Petzval never published his methods, and so lost credit for them. But the intrinsic field curvature of lenses and mirrors, the so-called "Petzval curvature," is named in his honor. This he clearly

---

[43] Lister, J.J., "On some properties in achromatic object-glasses applicable to the improvement of the microscope," *PT*, cxx (1830), 187–200, p. 193.

[44] Hamilton, W.R., "On some results of the view of a characteristic function in optics," *Report of the third meeting of the British Association for the Advancement of Science*, (London, 1834), 360–370; and Rayleigh, Lord, "Hamilton's principle and the five aberrations of von Seidel," *The London, Edinburgh, and Dublin philosophical magazine and journal of science*, xv (1908), 677–687.

described and illustrated graphically in the late 1850s.[45] Seidel, on the other hand, published a full mathematical treatment of imaging errors at about the same time.[46]

Despite these advances in optical theory and practical photographic optics, the name coma itself did not achieve widespread use until decades later. It only became canonical for the second Seidel aberration in the early twentieth century. Seidel himself seemingly never used the term.

As an empirical description for image flare, coma was next taken up by Richard Potter in his 1851 treatise already mentioned. The second volume of Potter's treatise contains, as Potter believed, the first published geometrical investigation of off-axis aberrations in lenses and mirrors for non-infinitesimal cones of light (his work antedated that of Seidel). Previously as we noted, both Airy and Coddington had investigated obliquely incident infinitesimal cones and so characterized astigmatism. Potter was well aware of their work but also wished to investigate theoretically the empirical observations of Lister.[47]

He found the cause of Lister's flares when he investigated extended bundles of rays falling obliquely on lenses or mirrors. Potter thus not only gained insight into how comatic flares arise but also their numerical magnitude, so that when he came to the subject of optical instruments and in particular the front-view telescopes of William Herschel, he was the first person in a position to understand quantitatively the size of the expected image flares.

Equally important, he investigated the effect on axial-image quality of replacing Herschel's presumed paraboloidal primary mirrors in his Newtonian telescopes with spherical mirrors. Potter derived an expression for the minimum diameter of an axial image in the presence of uncorrected spherical aberration in a Newtonian. He realized that in fact Herschel's Newtonians never needed to be parabolized to achieve the sharp images that his best instruments were known to deliver. Hence, when Potter analyzed Herschel's front-view telescopes he assumed that these, too, contained only spherical mirrors. The resulting images, Potter stated, could never be sharp because of the oblique aberrations. But the deleterious effects could be mini-

---

[45] Kingslake, R., *A history of the photographic lens*, (Academic Press, 1989), pp. 1–8; Wilson, R.N., *Reflecting telescope optics*, i, 2nd ed., (Springer, 2007), p. 63; and Petzval, J., "Fortsetzung des Berichtes über optische Untersuchungen," *Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften*, xxiv (Wein, 1857), 92–105, pp. 95ff.

[46] von Seidel, L., "Zur Theorie der Fernrohr-Objective," *AN*, xxxv (1853), 301–316; *idem*, "Zur Dioptrik," *AN*, xxxvii (1854), 105–120; and *idem*, "Zur Dioptrik," *AN*, xliii (1856), 289–304, 305–320, and 321–332. Seidel worked closely with Carl August von Steinheil and his son Hugo Adolph on camera optics (among other things), and developed refined methods of trigonometrical "ray tracing" for them: *cf.* Franz, H. & E. Reutinger, *Steinheil, Münchner Optik mit Tradition*, (*ca.* 2001, Stuttgart), pp. 66–67 & 94–95; and Seidel, L., "Trigonometrische Formeln für den allgemeinsten Fall der Brechung des Lichtes an centrirten sphärischen Flächen," *Sitzungsberichte der königl. bayer. Akademie der Wissenschaften zu München*, ii (1866), 263–283.

[47] Potter, R., (*op. cit.* ref. 40), pp. iv–vi; 28–42; and 108–116. *Cf.* also the important comments of H.D. Taylor in Taylor, H.D., *A system of applied optics*, (London, 1906), pp. 3–4.

mized by maintaining a high focal ratio such as f/15 or f/20.[48] Unfortunately, Herschel's actual focal ratios ran to considerably faster speeds, even down to f/10 in his largest instrument. This had an unfortunate consequence.

Both Airy and Coddington had illustrated with figures the effects of astigmatism on oblique bundles of light imaged by lenses or mirrors. Potter's equivalent illustration has been introduced as Fig. 4.16 above. Another illustration from Potter (Fig. 4.17) shows the combined effects of astigmatism and coma. Both aberrations normally appear conjointly in the off-axis images of lenses or mirrors, unless specifically corrected. Thus Potter's added illustration gives a more realistic picture of actual imaging errors, such as those seen in front-view telescopes.

Far from best focus (extreme left and right illustrations in the series) image ellipticity results from astigmatism. The weaker coma component of the combined image blur manifests itself in the intermediate images of the figure as a downward-pointing eccentric flare. The combined error takes on various shapes as the focus is shifted from inside (left) to outside (right) of best focus. We will see a similar variation in image shapes when we examine the theoretical imaging properties of front-view telescopes later in this work (Fig. 4.35). The most important feature to notice now is that no focus position delivers an image that is small, round, and "star-like": there is merely a choice of evils among the smaller images. That is the situation in a front-view telescope.

Concerning position 5 in Fig. 4.17, Potter says: "…[this] would generally be considered the best focus, the light being strongly concentrated at the head of the figure, although there is a lengthened coma; but an image of an object formed by such *foci* is necessarily very indistinct."[49] Potter is correct. The indistinctness, however, can be minimized in a telescope by utilizing low magnifications. This is precisely the reason why front-view telescopes with their tilted optics and uncompensated aberrations can work at all, because much light is still concentrated by the instrument into a relatively compact lozenge-shaped head.

In spite of Potter's work and Seidel's later masterful mathematical synthesis of imaging aberrations, astronomers in the nineteenth century remained largely ignorant of coma and astigmatism. Their very slow optically-centered achromatic refractors, and occasional Newtonian reflectors showed insignificant traces of both aberrations. Since during most of the nineteenth century astronomy was principally a science of positional measurements, little heed in general was given to off-axis imagery in telescopes.

---

[48] Potter, R., (*op. cit.* ref. 40), pp. 18–23 and 28–33. On p. 22 Potter found that for a spherical mirror in a 7-ft Herschel Newtonian: "the diameter of the least circle of aberration [on-axis] subtends… an angle of 5/8 of *one second* of a degree; and this would not prevent the telescope separating the images of many difficult double stars, which are considered most effectual test-objects for telescopes [Potter's emphasis]." Also *cf.* Potter, R. *An elementary treatise on optics*, i (London, 1851), 129–130, where speaking about front-view telescopes, he says: "The image being formed by pencils reflected obliquely by the mirror, is never distinct." But Potter notes the value of the front-view for viewing faint objects.

[49] Potter, R., (*op. cit.* ref. 40), p. 113.

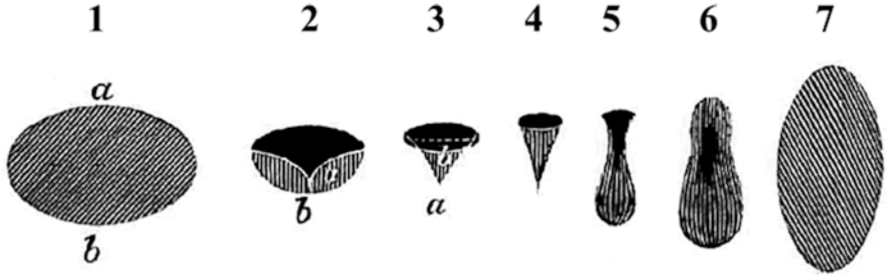


**Fig. 4.17** A second illustration taken from Richard Potter's textbook, now showing astigmatism mixed with coma in the off-axis image created by a lens. The figure shows how the resultant image varies through focus. A similar mixture of coma and astigmatism affected the images seen in Herschel's front-view telescopes

That began to change in the early 1880s. The advent of gelatin bromide dry photographic plates, which were far more sensitive to light than their wet-plate predecessors, suddenly made it possible to record more information photographically than the human eye could perceive through a given telescope. Astronomers were not slow to exploit the possibilities. In the mid-1880s they formed an international collaboration to map the entire heavens photographically, called the "*Carte du ciel*" project. This required large, relatively fast refracting telescopes with wide and well-corrected fields of view. Thirteen-inch f/10 refractors were employed and had to be specially manufactured for worldwide distribution to participating observatories.[50]

Beyond mapping, astronomers realized that they could now form permanent images of "deep-sky" objects, such as nebulae and galaxies. To form these images rapidly they needed large, fast telescopes. Silver-on-glass reflectors with their inherent freedom from chromatic aberration and relative cheapness became the instruments of choice, first for amateur astro-photographers such as Isaac Roberts (1829–1904) and Andrew Ainslie Common (1841–1903), and later for professionals too. By 1900, photographic reflectors comparable in aperture to the largest achromats ever built were in use, with speeds down to f/4. Even faster mirrors were under construction or soon would be, such as the 16-in. f/2.25 mirror completed in 1906 by the optician Bernhard Schmidt (1879–1935) – who became famous 30-years later for inventing the "Schmidt camera" – on behalf of Hermann Carl

---

[50] On the general development of astrophotography at the time, *cf.* Gill, D., "Observations of the Great Comet, 1882. II.," *Annals of the Royal Observatory, Cape of Good Hope*, ii.1 (1885); *idem*, "The applications of photography in astronomy," *Obs*, x (1887), 267–272 and 283–294; *Anon.*, "Direct photography of the heavens," *The astronomical register*, xxiv (1886), 245–248; Barnard, E.E., "On some celestial photographs made with a large portrait lens at the Lick Observatory," *MNRAS*, l (1890), 310–314; and *idem* "The development of photography in astronomy i–ii," *Science*, viii (1898), 341–353 and 386–395. For the *Carte du Ciel* project, *cf.* Chinnici, I., *La carte du ciel*, (Paris & Palermo, 1999), pp. 3–10; Grubb, H., "The construction of telescope object-glasses for the international photographic survey of the heavens," *The scientific transactions of the Royal Dublin Society*, iv (1891), 475–480; and Taylor, H.D., "Telescope objectives for photographic purposes," *MNRAS*, liii (1893), 359–368.

Vogel (1841–1907), the director of the Royal Astrophysical Observatory at Potsdam, Germany.[51]

Before this in the 1890s, Common’s 36-in. reflector (sold to Edward Crossley, and later donated to the Lick Observatory) came into photographic use, first by James M. Schaeberle (1853–1924) at Lick and then more successfully by James Keeler (1857–1900), who took spectacular deep-sky images with it in the late 1890s. Schaeberle himself later ground and polished his own mirrors, including a 13-in. f/1.5.[52]

As a result of these instrumental developments astronomers were suddenly confronted with off-axis aberrations, especially coma. In Newtonian reflectors (the form favored at the time for deep-sky photography) for a given object angle, coma increases in size as the square of the focal ratio. This means that while in an f/8 reflector coma may still be relatively unobtrusive, in an f/4 Newtonian the flare is 4 times larger, and in an f/2 Newtonian it is 16 times larger. Suddenly coma became all-too obvious. And on astrometric plates (such as those of the *Carte du ciel*) any coma whatever was unacceptable since the side flare made it impossible to decide where the image center lay.

There was consternation among astronomers of the day, who seemed to have found a new and startling phenomenon in their telescopes. Professional journals brimmed with articles describing and analyzing the image deformation. James Schaeberle himself wrote a number prominent papers, and for a time it was even suggested that the error should be called the “Schaeberlian aberration.”[53]

---

[51] Vogel, H.C., “Über Spiegelteleskope mit relativ kurzer Brennweite,” *Sitzungsberichte der königlich preussischen Akademie der Wissenschaften*, (Jahrgang 1906), 332–350; and the English translation in Vogel, H.C., “On reflecting telescopes of relatively short focus,” *ApJ*, xxiii (1906), 370–389.

[52] Schaeberle, J.M., “On the photographic efficiency of a 13-inch reflector of 20-inches focus,” *AJ*, xxiii (1903), 109–113.

[53] For contemporary discussions of off-axis aberrations in reflectors (*i.e.* coma), *cf.* Poor, C.L., “The aberration of parabolic mirrors,” *AJ*, xviii (1897), 98–99; Schaeberle, J.M., “On the fundamental optical imperfection of the parabolic reflecting telescope,” *AN*, cxliv (1897), 377–380; *idem*, “On a fundamental optical defect in the images formed by a parabolic reflector,” *AJ*, xviii (1897) 35–38; Crockett, C.W., “The parabolic mirror,” *ApJ*, vii (1898), 362–366; Plummer, H.C., “On the star-image formed by a parabolic mirror,” *AJ*, xix (1898), 21–23; Poor, C.L., “The aberration of parabolic mirrors,” *ApJ*, vii (1898), 114–123; Schaeberle, J.M., “General theory of the aberration in the focal plane of a parabolic reflector,” *AJ*, xix (1898), 17–21; *idem*, “On the definition and intensity of a star’s image in the field of view of a parabolic reflecting telescope,” *PA*, vi (1898), 33–38; *idem*, “On the aberration of parabolic mirrors,” *PA*, vi (1898), 38–40; Wadsworth, F.L.O., “On the ‘worthlessness’ of methods of geometrical optics in dealing with the problems relating to the definition and the delineating and resolving power of telescopes,” *PA*, v (1898), 528–536; Reese, S.C., “Field of the reflecting telescope,” *ApJ*, xii (1900), 219–227; Plummer, H.C., “On the images formed by a parabolic mirror,” *MNRAS*, lxii (1902), 352–369 and lxiii, 16–26. For references to “Schaeberlian aberration,” *cf. e.g.*, *Anon.*, “New form of achromatic telescope – Airy’s Gregorian,” *English mechanic and world of science*, mdccclxv (1900), 428–429, p. 429, column i, *infra*; and Musson, W.B., “New forms of telescopes and other optical instruments,” *Obs*, xxiii (1900), 350–352, p. 352.

More optically knowledgeable telescope users soon pointed out that the image flare was not in fact new, but resulted from the well-known phenomenon sometimes called a coma. Gradually both the name and optical appearance became familiar to astronomers. Then in 1905, the astrophysicist Karl Schwarzschild (1873–1916) published a lengthy paper in three parts that further developed the work of Seidel and applied it for the first time specifically to reflecting telescopes. This gave the first complete analytical theory of the on- and off-axis aberrations of one- and two-mirror reflecting telescopes; Schwarzschild specifically characterized and discussed coma, the word now becoming standard to name the second Seidel aberration, which creates the side flare seen in Newtonian images. On the basis of his theory, Schwarzschild broke new ground by showing how to design a two-mirror reflecting "astrograph," free of coma. This became known as the Schwarzschild camera.[54]

Independently, without knowledge of Schwarzschild's papers, Henri Chrétien (1879–1956), the great French optical designer, working with instrumentalist George Ritchey (1869–1945) at the then-new Mt. Wilson observatory, began to develop an alternative coma-free reflector. Eventually in 1922 Chrétien published his complete theory for what later became known as the "Ritchey-Chrétien" reflecting telescope.[55] Ritchey-Chrétiens became the most important, indeed the *fundamental* form of reflecting telescope built worldwide for the largest professional observatories in the last decades of the twentieth century.

By now in the present discussion, one point should have become sufficiently clear: even up to the time of his death in 1822, William Herschel could have no clear theoretical grasp of the optical consequences of tilting the mirrors of his front-view telescopes. Richard Potter in 1851 was the first person to be in a position to understand and calculate the resulting coma-plus-astigmatism blur, and not until Karl Schwarzschild's publication in 1905 were astronomers in general possessed of a complete theory (to the optical "3rd order") for the imaging aberrations of reflecting telescopes. Only then could the aberrations be calculated at will. Instead, as Herschel's private writings show, he tended to attribute asymmetries in the images of his telescopes to what he called the "lateral faults" of his mirrors, that is, to asymmetric figuring errors. We shall say more on this topic later in the present study.

---

[54] Schwarzschild, K., "Untersuchungen zur geometrischen Optik I-III," *Astronomische Mitteilungen der königlichen Sternwarte zu Göttingen*, ix (1905), i, 3–31; ii, 3–28; and iii, 3–54. For complete modern treatments of image aberrations in reflecting telescopes, *cf.* Schroeder, D.J., *Astronomical optics*, 2nd ed., (London & San Diego, 2000); and Wilson, R.N., (*op. cit.* ref. 45). For an expert overview of Schwarzschild's work, *cf.* also: Wilson, R.N., "Karl Schwarzschild and Telescope Optics," *Reviews in Modern Astronomy*, vii (1994), 1–29.

[55] Chrétien, H., "Le télescope de Newton et le télescope aplanétique," *Revue d'optique*, i (1922), 13–22 and 49–64.

## Herschel’s Manufacture and Testing of Telescope Mirrors

There is no real mystery surrounding William Herschel’s methods of manufacturing and testing of his telescope mirrors. Hundreds of pages of his detailed, methodical notes exist in the Royal Astronomical Society’s Herschel Archive. These are preserved in four fair-copy volumes which makes them no more difficult to read in general than a printed book. The bound volumes span the years 1773–1818. They detail over two thousand *Experiments on the construction of specula* – that is, circumstantial accounts of grinding and polishing sessions that took place over 45 years on all manner and sizes of mirrors, including all of Herschel’s most famous mirrors.[56] Out of these experimental notebooks, in later years Herschel extracted what he considered the most important results and synthesized them into a systematic manual for the fabrication of reflecting telescope mirrors. Each section and subsection of the *Results of experiments on the construction of specula* gives detailed references back to the original notebooks to justify its assertions.[57] Collectively, the information goes vastly beyond anything written before Herschel’s day, and was not superseded in detail until the twentieth century. Alas, it has never been published in any form, so that its influence among later opticians and telescope makers has been essentially nil.

One telescope maker who did profit from this documentation was John Herschel. In order to fulfill a vow to his father, John gave up a potential career in mathematics or law to become an astronomer whose mission it was to complete his father’s visual survey of the entire heavens by “sweeping it” with his father’s refurbished 20-ft front-view reflector. Therefore, during the last years of William Herschel’s life, John became his apprentice not only in visual astronomy but also in telescope making. John learned to use all the methods, tools, and machines that his father had developed.[58] At his father’s behest, John even made detailed drawings of the tools and machines since he was endowed with the draftsman’s talent that his father lacked. The drawings are highly valuable to historians of optical technique.

Once his apprenticeship was completed and after his father’s death, John reswept the entire northern sky from England and then journeyed with his family to South Africa, where he spent 4 years sweeping the southern sky that his father never saw. Having discharged his vow in 1838, John took down his telescope, transported it back to England, and consigned it to storage. He completed and published the

---

[56] RAS MS Herschel W.5/12.1-4. Two thousand one hundred sixty-one experiments are enumerated in the four volumes.

[57] *Results* is found in two redactions, RAS MS Herschel W.5/13.1 and W.5/14.1. The second redaction was reviewed by John Herschel who pronounced it the “most perfect copy.” John also executed a large series of drawings of his father’s grinding and polishing machines to accompany the second redaction. This is preserved as RAS MS Herschel W.5/14.2.

[58] Hoskin, M., [*op. cit.* ref. 4, (2011)], pp. 158–207.

results of his southern astronomical work in 1847.[59] We shall have some occasion to examine these results later in the present paper. For now we can say that although John Herschel gave up his career as an observational astronomer in 1838, he never lost interest in telescopes and their continued development. He assiduously followed the labors of others and offered full assistance from his own experience when asked. In 1861 he published a short and up-to-date book on telescopes. Tucked into the book is a detailed discussion of his father's methods of fabricating and testing concave mirrors.[60] On the basis of John's own publications as well as the abundant information in the RAS Herschel archive, we can confidently summarize the Herschels' methods of making mirrors.

The basic process involved melting copper and tin (without further addition) to make the speculum metal, casting the mixture into a mold to form the mirror blank, and annealing it. The cooled blank was then edged round, and its rear surface ground to a regular face. Next, the front surface was ground concave with wet, loose abrasives (emery, a natural form of aluminum oxide, was used) on a grinding tool, as the optician from time to time tested the surface curvature, correcting it as needed. Testing and correction were accomplished by means of what Herschel termed "gages." These consisted of thin metal plates (like modern brass shim stock) on which precise circular arcs were scribed and cut. The radius of such arcs was intended to equal that which the optician wished on his mirror. Gages (also known more correctly as gauges) were cut in pairs, one convex and the other concave, and then gently ground together to make them more regular in curve. In part, they served the function of a modern optician's "spherometer." This is because the screw micrometer did not come into use until after about 1810. Gauges are still widely used in machinist's work today, and the Herschels' mirror gauges find their descendants in modern radius gauges. They are (and were) used by holding them on edge against the ground mirror surface and carefully checking to see whether the gauges' arcs contacted the mirror surfaces evenly all over, or if they showed signs of non-contact near their center or outer edges. If areas of non-contact were detected, then suitable changes in grinding procedure would alter the curvature of the mirror surface and correct it.

Once the mirror was ground smooth with very fine-grit abrasives, the Herschels formed a channeled pitch lap, polished the speculum to a high luster, and then tested its figure and repolished as needed. Anyone familiar with the modern production of astronomical mirrors can see that the essential steps are exactly the same as those commonly used today, aside from the employment of speculum metal instead of glass for the mirror blank, the consequent lack of a silver or aluminum mirror coating, and the use of a spherometer in place of a metal radius

---

[59] Herschel, J.F.W., *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, etc.*, (London, 1847).

[60] Herschel, J.F.W., (*op. cit.* ref. 13), pp. 126–151.

gauge. In essence the Herschels made mirrors in just the same way as other people since the time of Newton.[61]

Some details differ. At the end of loose-abrasive grinding, the Herschels did not use a bed of hones (fixed abrasives) as other opticians did before and after them to prepare the speculum for polishing. Refined jewelers rouge (ferric oxide), which William Herschel called by the old name of “colcothar of vitriol,” was their preferred polishing compound in place of “putty” (tin oxide) powder. And the Herschels ground and polished all their mirrors, even the 48 in., face down (“mirror on top” in the language of opticians) on their grinding and polishing laps, which were therefore made a bit larger in diameter than the mirrors so as to control the mirrors’ radii of curvature. Most laps had a circular outline, but some were purposely made oval with a significantly larger major than minor axis.[62]

Apart from these differences, what mainly separated William Herschel from his predecessors in mirror-making was his use of machinery. Initially, in the early 1770s, Herschel began by making small mirrors in the 4–6 in. range. These he worked by hand as his predecessors had done, and he continued this practice for many years. By the 1780s, however, when he reached his 48-in. mirrors, the larger of which weighed above one ton, he soon found that the gang of 20 men who were needed (pushing and pulling in tandem by means of poles attached to the mirror, while singing) to move it on its polishing lap could not manipulate the mirror with sufficient smoothness to achieve a usable figure. So reluctantly Herschel began to develop machines (still human powered) to provide smooth motive force. Eventually he dispensed with nearly all handwork and developed machines, large and small, with which he could polish all his mirrors, even his diminutive elliptical diagonal mirrors (see Fig. 4.20a, b below).

Herschel’s successors in the nineteenth century – Lord Rosse, James Nasmyth (1808–1890), William Lassell, and Thomas (1800–1878) and Howard Grubb (1844–1931) – extended and greatly improved the use of machines (by adding steam engines, for example) so that to a modern eye Herschel’s equipment looks rickety and clumsy, with ropes and hand-cranks for power and spindly toothed gears. Nevertheless, Herschel’s development of grinding and polishing machines for mirrors in itself was great step forward, and allowed him to attempt very large mirrors for the first time. Much in Herschel’s *Experiments* and *results of experiments on the construction of specula* has to do with the details of his mirror making *via* machine:

---

[61] For modern methods, *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 17–59. Newton introduced the use of pure pitch to form the polishing lap, which has been essential to the production of precision optics even up to today: Newton, I., (*op. cit.* ref. 11), pp. 76–77; and most recently, Williamson, R., *Field guide to optical fabrication*, (SPIE Press, 2011), p. 39. Other opticians used paper, cloth, and pitch-impregnated silk laps: Smith, R., *A compleat system of opticks*, (Cambridge, 1738), book 3, pp. 296–297 and 307–309. But James Short, and John Mudge recommended pure pitch, which is what Herschel nearly always used, as shown in RAS MS Herschel W.5/12.1-4 and W.5/14.1, sections vi–vii. *Cf.* also, Short, J., “A method of working the object glasses of refracting telescopes truly spherical,” *PT*, lix (1769), 507–511, pp. 509–510; and Mudge, J., (*op. cit.* ref. 13), pp. 317–327 and 344–345. Mudge severely criticized other types of polishing laps as described by Smith.

[62] RAS MS Herschel W.5/14.1, section viii.

thus, not only do the volumes discuss such things as ratios of tin to copper for speculum, correct methods of channeling pitch laps, and the best mixture of pitch and tar for polishing, but also stroke lengths and offsets, turntable and stroker speeds, lap overhang, *etc*. These details will be of interest to the historians of optical technique, but need not detain us now.[63]

Instead, of more importance is the matter of mirror testing. For his concave mirrors, Herschel principally used the test-method that had been published by John Mudge (1721–1793). He divided his mirror into annular zones using aperture masks. Typically the zones were three in number: (1) an outer *annulus* some inches in breadth; (2) a similar middle *annulus*; and (3) a central circular zone. As test objects Herschel would observe, *e.g.*, a star at night, or if more convenient a page of print by day, or a watch dial, or a finely printed card set at a great distance. During Herschel's years at Slough near Windsor, he would sometimes observe the windows, flag, or other architectural details of Windsor Castle.[64]

To conduct his test, Herschel would block up the entire aperture of his telescope except for the single zone that he wished to examine. Then he would focus the telescope as sharply as possible using light from just that zone. He would carefully measure the eyepiece position in hundredths of an inch. Next – without in any way shifting his apparatus – he would expose a different zone of the mirror. After refocusing, he would measure the difference (if any) in eyepiece position from the first zone. Finally, he would repeat the procedure for a third test zone. If no eyepiece shift occurred during the entire examination, and individually by zone and collectively with the whole aperture exposed the image looked completely sharp at low and high power without any anomalies, Herschel pronounced the mirror perfectly parabolized, since the test objects were effectively at infinity. If focus differences were found, or image anomalies were seen, then the mirror needed further work. The test is spelled out in William Herschel's notebooks and also in John Herschel's 1861 book, *The telescope*.[65]

From a modern standpoint, the test would be judged crude. Its spatial resolution of possible surface errors on a mirror is limited to three broad zones. Moreover, it cannot detect the surface errors directly, but only their effects *via* focus shift. Nevertheless, it represented a step forward from the simple "star test" or "point source test" used earlier by John Hadley, which could not discriminate zonal errors

---

[63] On Herschel's machines in general, *cf.* Herschel, W., "On polishing specula by a machine," in *TSP*, i, pp. cviii-cix; and Herschel, J.F.W., (*op. cit.* ref. 13), 142–151. For the intricate details, *cf.* RAS MS Herschel W.5/14.1, section iv. For polishing elliptical diagonals, *cf.* RAS MS Herschel W.5/14.1, sections iv, f. 25r and xxxiv, article 1. RAS MS Herschel W.5/14.2, Figs. 4.22, 4.23 and 4.28 illustrate the bracket used to hold an elliptical diagonal, as well as an entire small polishing machine for a diagonal, with a diagonal mirror atop a pitch lap. An earlier hand-lapping procedure of Herschel's for finishing diagonals is discussed in Edwards, J., (*op. cit.* ref. 13), p. 43. This corresponds to Herschel's letter to him, dated 2-May-1782, in RAS MS Herschel W.1/1.1, p. 53.

[64] RAS MS Herschel W.5/12.3, Exp. 366 (25-ft mirror): "Upon the flag of Windsor castle it shows all the threads of the canvas."

[65] Mudge, J., (*op. cit.* ref. 13), pp. 335–338 and Fig. 3; RAS MS Herschel W.5/14.1, section xxxii, articles 2–3; and Herschel, J.F.W., (*op. cit.* ref. 13), pp. 154–156.

quantitatively at all. And given that nearly all of William Herschel’s mirrors were optically slow, with focal ratios in excess of f/10, and therefore in principle very close to spherical even if correctly parabolized, the zonal test was not hopelessly inadequate for his needs. Herschel’s successors also used it, and a form of zonal test is still used by amateur mirror makers in conjunction with Léon Foucault’s (1819–1868) “knife-edge test,” the first sensitive mirror test introduced in 1858–1859 and still practiced today. John Herschel gave an early English-language description of the “Foucault test” in his 1861 book, based on Foucault’s recent publication of the method. John’s description makes clear that the knife-edge test was completely novel to him at that time. Certainly his father had not used it.[66] Of course, the ultimate test of a telescope was (and is) how well it focuses individual stars, bringing them to a point (or showing the Airy disk and diffraction rings at high power), without side flares.[67]

Modern methods of mirror testing involve the use of optical interference and lasers. Laser interferometers coupled with digital camera sensors and high-speed image processing software allow modern opticians to assess surface-height errors on mirrors directly in high resolution. But even before the advent of lasers, modern electronics, and computers, in the nineteenth century optical interference began to play a role in mirror testing, for example in the making of flat mirrors, to which we turn next.[68]

As difficult as concave mirrors are to make, flat mirrors are considerably more difficult. This is because flats must not only be smooth and without zonal irregularities; they must also be *truly flat* to within a fraction of a wavelength of light. A typical depth-of-curve (“sagitta”) tolerance for an elliptical diagonal mirror is a maximum of about one-fifth of a wavelength of light across the minor-axis – in other words about ±0.0001 mm.[69] Concave primary mirrors for Newtonian tele-

---

[66] Herschel, J.F.W., (*op. cit.* ref. 13), pp. 173–178. For modern discussions of the Foucault knife-edge test, *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 65–87; and Lecleire, K. & J.-M., *A manual for amateur telescope makers*, (Willmann-Bell, 2003), pp. 109–119.

[67] RAS MS Herschel W.5/14.1, section xxxii, article 2, f. 146r: “Astronomical observations alone are the criterion of the perfection of a mirror.”

[68] Goodwin, E.P. & J.C. Wyant, *Field Guide to Interferometric Optical Testing*, (SPIE Press, 2006).

[69] On the difficulty of making optical flats, *cf. e.g.*, Grubb, H., (*op. cit.* ref. 21), pp. 90–91; Kitchiner, W., *Economy of the eyes – part ii: of telescopes*, (London, 1825), pp. 104–105, 114, and 235–236; and Potter, R., “On various improvements in the casting, working, *etc.* of specula for reflecting telescopes, with sundry hints for amateur opticians,” *The Edinburgh journal of science*, iv, (1831), 13–27, p. 20: “It is acknowledged to be the most difficult part of the art of the working optician to produce a lens or speculum with a good plane surface; and those amateurs who undertake the Newtonian telescope for astronomical purposes, – if they find their instrument when finished will not show difficult astronomical objects well, may satisfy themselves that it is a hundred to one the greatest fault lies in the small oval speculum not being truly plane; and this may be told from the figure of the planets, *etc*. appearing oblong in place of round….” Even Newton discovered the difficulty: “I should tell you also, that the little plain piece of metall, next the eye-glass, is not truly figured…I hope, that by correcting its figure, (in which I find more difficulty than one would expect)…,” in Newton, I., “Mr. Newton’s letter to the publisher of March 26, 1672, *etc.*,” *PT*, vii (1672), p. 4032. On diagonal flat tolerances, *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 107–108; and Suiter, H.R., (*op. cit.* ref. 25), pp. 365–366.

scopes often have depth-of-curvature tolerances of ±0.0100 mm or even more, that is, on the order of 100 times greater.

The reason why Newtonian elliptical flats have such tight tolerances is that they are used at a 45° obliquity to deviate the converging cone of rays proceeding from the primary mirror out the side of the telescope tube at 90° from the original direction of the rays. In this situation, general errors of curvature on flats appear foreshortened in the plane of deviation. The foreshortening manifests itself as astigmatism in the image. We have seen above in Fig. 4.15 what astigmatism can do to the PSF of a star image. Even a small amount of astigmatism quickly degrades high-resolution telescopic performance, blurring the images of planets and ruining the resolution of close double stars. Equivalent radius-of-curvature errors in concave mirrors pass completely unnoticed.[70]

For this reason the Newtonian telescope, far from being simple to implement, is in fact harder to execute well than either the Gregorian or Cassegrainian system, where small general curvature and aspheric errors of the two mirrors may cancel out one another.[71] Elliptical flat mirrors are absolutely not innocuous bits of optics, easily disposed of, but in fact the Achilles' heel of the Newtonian system. Most modern amateur telescope makers do not attempt to make their own diagonals, but buy them ready made from commercial vendors, even if they zealously insist on making every other component of their instruments.[72]

Given the very tight tolerance on surface flatness, the modern method of testing Newtonian diagonals (made of glass) is by interference of light against a master glass flat. Illuminated in monochromatic light, the glass pair exhibits dark and light interference fringes at their thin air-film interface. The fringes appear in strong contrast, and directly reveal surface height differences between the master and the optic-under-fabrication. Using this method, the optician has a clear guide to the figuring steps needed to render the diagonal sufficiently flat. This method of interference testing has been in use for making glass diagonals since at least the 1880s, and possibly much earlier by Joseph Fraunhofer (1787–1826) for testing convex

---

[70] Suiter, H.R., (*op. cit.* ref. 25), pp. 282–283. Even Herschel was aware of this. In RAS MS Herschel W.5/14.1, section xxxiv, article 1, f. 158v, he says: "A plain mirror must be perfect in figure from the grinding, which is not so necessary with object mirrors; a few tenths of an inch more or less focal length is of no consequence, but the least deviation from a plain will be concave or convex."

[71] This cancellation was understood in the eighteenth and nineteenth centuries: Mudge, J., (*op. cit.* ref. 13), pp. 340–341; Kitchiner, W., (*op. cit.* ref. 69), pp. 92–94; and Pearson, W., (*op. cit.* ref. 5), p. 9 of article, column 1 (quoting George Dollond): "Mr. Short, the celebrated maker of reflecting telescopes, used to proceed by first making his large metal as nearly correct or parabolical as he could, and then, from a number of small metals, to select, by trial, that which corrected the large one in the best manner."

[72] Texereau, J., (*op. cit.* ref. 6), p. 108: "Errors [in flatness of Newtonian secondaries] of fully a wave are common. We had occasion once even to see a convexity of nine fringes [4½ waves] in a beautiful 12-inch telescope!" Lecleire, K. & J.-M., (*op. cit.* ref. 66), p. 125: "A complete plan for making a Newtonian secondary diagonal mirror is detailed below. However, *this step is not essential in the construction of the…telescope*. Although purchasing a finished mirror may seem to go against the spirit of this project, beginners are advised to buy their secondary mirror [authors' emphasis]."

spherical lens surfaces against concave master “testplates.”[73] Unfortunately, the method was completely unknown to Herschel and his contemporaries.

Why the method was unknown is important, since it has a bearing on Herschel’s astronomical and instrument-making practices. Although colored interference fringes in white light had been observed since the mid-seventeenth century and were extensively discussed in Isaac Newton’s 1704 book *Opticks*, Newton’s “corpuscular theory” that light consists of tiny particles acted on by attractive and repulsive forces precluded a correct understanding of how the fringes arise. Instead, on the basis of corpuscular theory Newton had advanced a hypothesis of “fits of easy reflection and easy transmission” to explain the production of colored fringes in thin films. The hypothesis depended on the light corpuscles having an inherent periodic variation, during part of which they could pass easily in transmission through a transparent medium, while at other times they would be easily reflected from the medium’s surface.

The “easy fits” hypothesis suffered some attack in the eighteenth century, and William Herschel himself wrote three controversial papers attempting to explain colored fringes by other means. But not until the mid-nineteenth century was Newton’s underlying corpuscular theory definitively replaced by the modern wave theory of light, and later by the theory of electromagnetism. Only in the twentieth century was it recognized that light inherently combines both wave and particle phenomena, as described in quantum theory.

The modern wave theory of light traces its origins to Thomas Young and his famous double-slit experiment of 1801. Later in 1819, Augustin-Jean Fresnel (1788–1827) improved Young’s theory, and it was gradually confirmed through the work of Siméon-Denis Poisson (1781–1840), François Arago (1786–1853), Armand-Hippolyte Fizeau (1819–1896), and Léon Foucault. According to this wave theory, the fringe pattern seen in thin films such as the air-film existing between glass surfaces placed in near contact arises from the interference of wave trains reflected from the two slightly separated glass surfaces. Viewed in monochromatic light, the fringe pattern varies regularly from bright to dark to bright, *etc*., depending on whether the wave-trains interfere constructively or destructively. The origin of colored fringes stems from the particular wavelength of polychromatic white light that is in constructive interference at a particular position in the air-film, when viewed in white light. This in turn depends on the thickness of the air gap between the glass surfaces. Suffice it to say that according to the wave theory of light, the fringe pattern can be used to diagnose surface height differences between the two glasses; if one of them has a known shape such as truly flat, the errors of the other

---

[73] For an early account of interference testing of glass flat mirrors, *cf.* Brashear, J.A., “Critical Methods of Detecting Errors in Plane Surfaces,” *Scientific American supplement*, xix, no. 484, (11-April-1885), 7724–7726. For Fraunhofer’s possible use of testplates (*Probegläser*), *cf.* Riekher, R., (*op. cit.* ref. 29), pp. 154–155. For modern methods, *cf.* Selby, H.H., “Flats,” in *ATM*, ii, pp. 535–554 (with many pictures of interference fringes); Texereau, J., (*op. cit.* ref. 6), pp. 111–115; and Lecleire, K. & J.-M., (*op. cit.* ref. 66), pp. 131–133.

from flatness can be diagnosed directly in absolute terms. This is the theoretical basis behind the use of test plates or glass master flats in fabricating optics.[74]

Unfortunately, the wave theory and theory of test plates were not available to William Herschel. In any case, so long as reflecting telescopes depended on speculum metal, test plating against a transparent glass master surface would have been difficult since fringe visibility depends on contrast, which is greatly reduced unless the reference (master) and test surfaces have nearly the same reflectivity. Obviously polished metal reflects far more light than polished uncoated glass.[75]

Therefore, Herschel and his immediate successors such as Lord Rosse and William Lassell had to employ other methods to test flat mirrors, and these were much less sensitive to surface errors than interference testing. William Herschel's test method is clearly described in his *Results of experiments on the construction of specula*. The method consisted in naked-eye comparison of angular sizes: two strips of paper, card, or brass shim – one an object, the other a reference standard – were cut. The object strip was exactly twice the length of the reference strip. The reference was held against the flat mirror under test, and both mirror and reference strip together were set at a given distance – Herschel specifies between 6 and 10 ft – from the observer. The object strip was held close to the observer's eye. Finally, the observer examined the object at its reflection in the flat mirror, and compared the angular size of the reflection to the reference strip. The arrangement is illustrated in Fig. 4.18. Clearly, if the mirror is indeed flat, the angular size of the reflected object should be just exactly as large as the reference strip. This is guaranteed by geometry. If, on the other hand, the reflected object appears larger than the reference, then the mirror cannot be flat but must be concave; if the reflected object appears smaller than the reference, the flat must be convex.[76]

It is a clever test and certainly an improvement over what preceded, which could only have been to test flats against a metal gauge such as the knife blade of a machin-

---

[74] For an overview of Newtonian corpuscular theory and the subsequent wave theory of light, *cf.* Darrigol, O., *A history of optics from Greek antiquity to the nineteenth century*, (Oxford, 2012), pp. 98–108 and 166ff. Newton's own discussion of his theory of "fits" is in Newton, I., (*op. cit.* ref. 11), book ii, parts iii–iv, pp. 78–112. For Herschel's papers, *cf.* Herschel, W., "Experiments for investigating the cause of colored concentric rings, discovered by Sir Isaac Newton, between two object-glasses laid upon one another," *PT*, xcvii (1807), 180–233 [*TSP*, ii, pp. 368–398]; *idem*, "Continuation of experiments for investigating the cause of colored concentric rings, and other appearances of a similar nature," *PT*, xcix (1809), 259–302 [*TSP*, ii, pp. 414–440]; and *idem*, "Supplement to the first and second part of the paper of experiments, for investigating the cause of colored concentric rings between object glasses, and other appearances of a similar nature," *PT*, c (1810), 149–177 [*TSP*, ii, pp. 441–458]. *Cf.* also Dreyer's comments on the controversy surrounding publication of Herschel's papers: *TSP*, i, pp. lvi-lviii; and Hoskin's comments: Hoskin, M., [*op. cit.* ref. 4, (2011)], p. 154.

[75] *Cf.* Mills, A.A. and R. Hall, "The production of a plane surface as illustrated by specula from some early Newtonian telescopes," *NRRS*, xxxvii (1983), 147–166, p. 153. This highly important paper will be discussed below.

[76] RAS MS Herschel W.5/14.1, section xxxiv, article ii. RAS MS Herschel W.5/12.1, Experiment 426, pp. 135–136 (dated 20-Aug-1790), gives a more detailed account and illustrates some brass testing hardware.

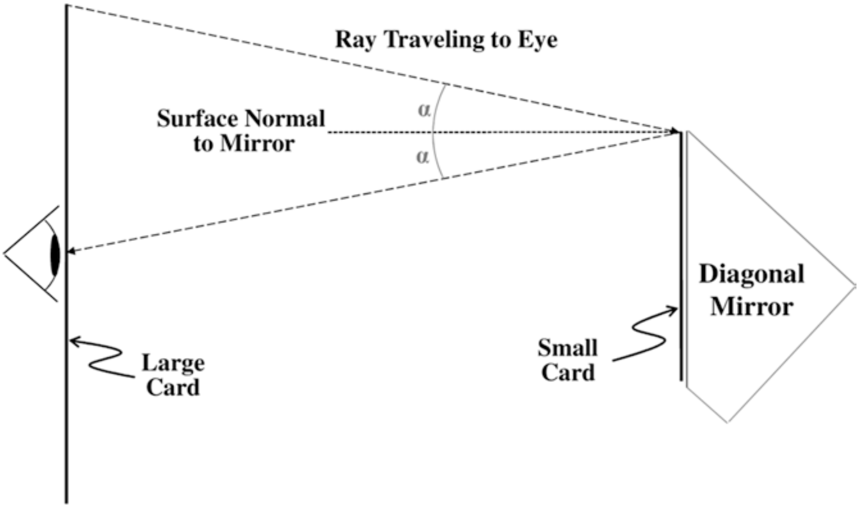


**Fig. 4.18** Schematic illustration of William Herschel's naked-eye test for elliptical diagonal mirrors. A large card (*left*) is held close to the eye (*extreme left*) and viewed by reflection in the diagonal mirror (*extreme right*). The reflection is compared in length to a second small card (*right*), which is exactly one-half as long as the large card and held against the diagonal. If the diagonal is truly flat, the geometry of the test guarantees that the reflected image of the large card will appear exactly as long as the small card

ist's square, or sets of three reference flats produced by the well-known method of grinding them in pairs against one another.[77] But unfortunately, the uncertainty in cutting Herschel's two strips of card – one exactly twice as long as the other – as well as the human eye's limited angular acuity in comparing edges, parallax from rotating the eye in its socket between the left and right edges of the paper strips under comparison, and finally the fact that the eye ought to coincide exactly with the large card (but cannot) for the geometrical construction to be correct – all this makes it inconceivable that the test could reach the extreme accuracy needed for a flat mirror inclined at 45° so as to avoid astigmatism in the image of a telescope. Indeed, as we shall see later, out of a group of elliptical diagonal mirrors dating from the eighteenth and nineteenth centuries, including almost a dozen by Herschel, which have been successfully tested *via* interference methods in recent decades, none can be considered flat by modern standards. Most are highly defective, including all of Herschel's.

---

[77] Herschel mentions both these methods, *e.g.*, at RAS MS Herschel W.5/12.1, experiment 295, #2, p. 75 (May-June 1787): "These [brass] tools were turned flat by a straight gage and afterwards ground with emery, two and two alternately till all the three fitted each other completely." For a modern discussion, *cf.* Lecleire, K. & J.-M., (*op. cit.* ref. 66), pp. 129–131. As to Herschel's two-card method, illustrated in Fig. 4.17, it is possible to show geomtrically that (if we assume a reasonable value for the angular accuity of the eye, namely 2 arcmin), by using this two-card method Herschel could reliably arrive at curvatures on his diagonals which are comparable to those found below in Figs. 4.22, 4.23, 4.24, and 4.25. Flatter than this the method could not guarantee.

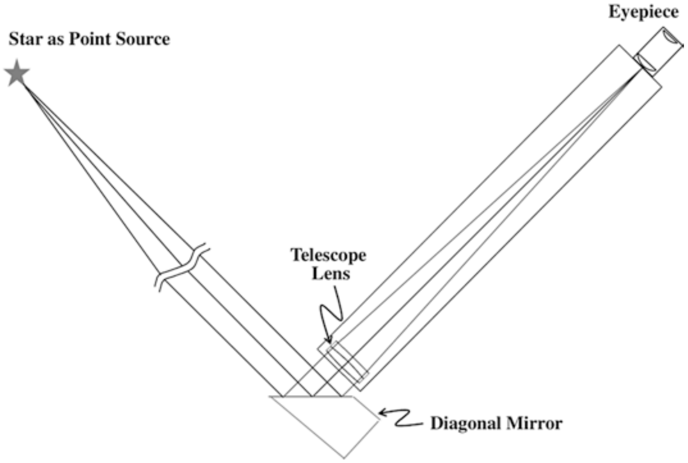


**Fig. 4.19** Improved method of testing a flat mirror *via* 90° reflection of a point source at infinity (*star*) viewed at high magnification in a well-corrected telescope. The method was used by Lord Rosse and William Lassell in the mid-nineteenth century

A further step forward in testing came in the late 1820s, after Herschel's death, through work attributed to Lord Rosse. He published an optically acute testing method, as shown schematically in Fig. 4.19. This involves a comparison under magnification: an observer carefully focuses a well-corrected telescope on a point source at infinity, such as a star. Then without shifting focus, using the same telescope the observer examines the same star as reflected at 90° in the flat mirror being tested. If the star image remains sharply in-focus, then the mirror is flat; if the star goes out of focus, then the mirror is curved and must be corrected. Although this test is still not sufficiently acute to make an impeccable flat reliably, it is far better than Herschel's naked-eye test, and it was successfully used by many telescope makers in the nineteenth century before the superior interference test came into use.[78]

For the sake of completeness we should also note another test for flat mirrors which is fully adequate to produce excellent results. This is called the "Ritchey-Common test." It can be used with or without an interferometer, and was first described in 1888 by Andrew Ainslie Common. Unfortunately, without a laser interferometer the method requires Foucault's knife-edge test to work. And as we have seen, the knife-edge test was unknown to William Herschel. The method could, however, easily have been used on speculum mirrors.[79]

---

[78] That Lord Rosse devised this method of testing is claimed by Brashear, J.A., (*op. cit.* ref. 73), p. 7724. Rosse did publish details of the method in 1840 in Oxmantown, Lord, (*op. cit.* ref. 13), p. 524, but spoke of the method as "the usual way," as if it were nothing new. It was discussed earlier in 1829 without attribution by Pearson, W., (*op. cit.* ref. 4), pp. 69–70. A modern discussion of the method can be found in Suiter, H.R., (*op. cit.* ref. 25), pp. 287–288.

[79] For a modern discussion of the method, *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 115–118. For Common's discussion *cf.* Common, A.A., "Note on Testing Polished Flat Surfaces," *MNRAS*, xlviii (1888), 105–106.

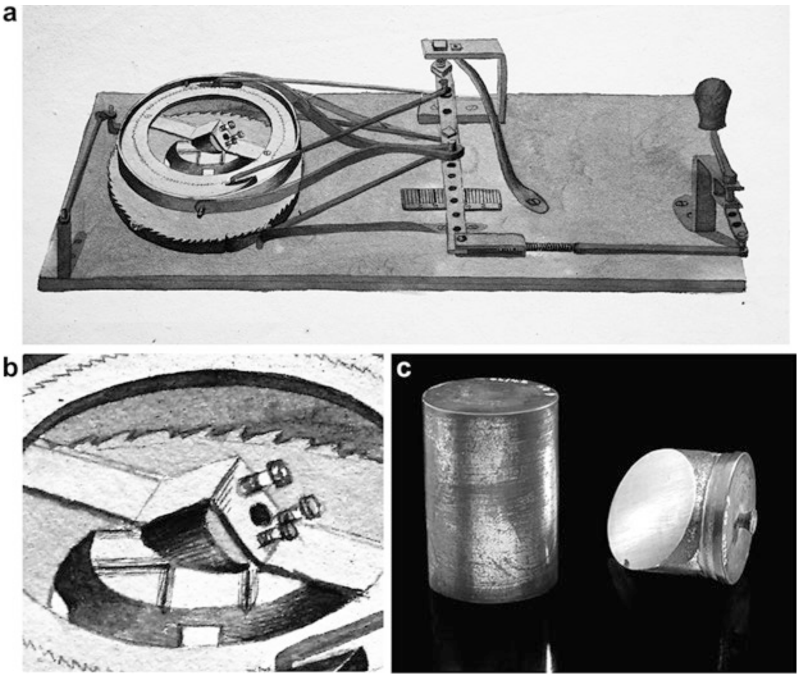


**Fig. 4.20** (**a**) Herschel’s polishing machine for small elliptical diagonal mirrors. The machine was actuated by the crank seen on *extreme right* in this drawing, executed by John Herschel under his father’s supervision about 1820 (Image courtesy fo the Royal Astronomical Society). (**b**) Close-up view showing the ratchet ring and angular bracket to which the inverted diagonal mirror was screwed by means of three clearly visible screws. The mirror sits on top of a channeled pitch lap, which is larger in diameter than the major axis of the elliptical diagonal. (**c**) A typical Newtonian secondary mirror (*right*) from William Herschel, and its brass protective case (*left*). The secondary body was made in the form of a right-angle cylinder and soldered onto a circular brass plate into which a screw is threaded (*extreme right*) (Image reproduced by permission of the London Science Museum/Science and Society Picture Library)

Turning now to Herschel’s mature method of producing elliptical flat mirrors, two details are essential to understand in the context of the present work. First, as mentioned before, Herschel always polished with his mirrors face-down on the pitch lap. Second, in the case of his diagonals, the lap was always larger then the major axis of the mirror. This can be seen graphically in one of John Herschel’s “machine drawings,” which he executed under his father’s supervision around 1820. The drawing in question is shown, first in full, as Fig. 4.20a, and then in part as a close-up of the diagonal mirror resting on the lap in Fig. 4.20b. There the diagonal mirror is held in an angular bracket, which is screwed to the polishing machine’s ratchet ring.[80]

---

[80] Herschel’s production methods are specified at RAS MS Herschel W.5/14.1, section xxxiv, article 1–4.

Figure 4.20c presents a modern image of a surviving Herschel secondary (on right of figure), fashioned from a cylinder of speculum metal, the mirror's face being sawed, ground, and polished to form a plane cutting the cylinder axis at 45°. A flat brass plate was soldered to the rear, and into the plate a mounting screw was threaded. The hollow brass casing (on left of the figure) slips over the cylinder and encloses the mirror surface for protection when not in use.[81]

It is obvious from Fig. 4.20b that the channeled surface of the pitch lap is far larger in diameter than the major axis of the mirror. This has an important consequence, well known to modern opticians.

Since pitch is a visco-elastic substance, although from moment to moment it behaves as a brittle solid, over time it gradually relaxes and deforms while interacting with the optic under fabrication. It responds not only to pressure from the weight of the optic but to heat liberated through friction as the optic rubs against it, which warms the pitch. The advantage of this gradual lap-subsidence is that it guarantees an excellent fit between the pitch and optical surface at any moment.[82]

The disadvantage is that as lapping progresses, in Herschel's arrangement since the mirror principally rubs the lap over the lap's central area, there is a strong tendency for the lap to become concave in shape and for the optic to become correspondingly convex. John's drawing in Fig. 4.20b perhaps exaggerates the mismatch in size between the lap and mirror in order clearly to illustrate the process. His father's written instructions, found in the *Results of experiments on the construction of specula* specify that in general the lap should be only about 5–7% larger than the major axis of the mirror. Even so the mirror will still inevitably rub the middle of the lap more than its edge. But on the other hand, at the end of each polishing stroke the mirror will overhang the lap; pressure from the unsupported metal of the mirror will tend to compress the edge of the lap more than its center. When properly balanced the net result of these tendencies will keep the lap approximately flat.[83]

Unfortunately, however, another factor creates an upset to this balance. Since the flat is elliptical in contour, it presents more metal for lapping along its major axis than along its minor axis, if the elliptical face of the diagonal cuts the cylinder wall of the metal at 45°. Because of this, the wear pattern during lapping will tend to make the flat become toroidal in shape, rather than purely flat or purely spherical. The optical face of the diagonal will therefore tend to lose its rotational symmetry – that is, it will develop two *different* curvatures aligned with the major

---

[81] *Cf.* RAS MS Herschel W.1/1, pp. 53–54 for Herschel's description of his Newtonian secondaries.

[82] Williamson, R., (*op. cit.* ref. 61), p. 39; Karrow, H.H., *Fabrication methods for precision optics*, (Wiley-Interscience, 1993), pp. 206–209.

[83] RAS MS Herschel W.5/14.1, section xxxiv, article 1, f. 158r: "The diameter of a polisher for a plain mirror of an elliptical form must not exceed much the transverse of the ellipsis…A polisher of 1,05 $L$ is of a sufficient size…A plain mirror having $L = 5{,}6$ came out of a fine figure with a polisher 6 inches or 1,07 $L$ in diameter…A polisher of 2 inch diameter for an elliptical plain mirror 1,6 inch the transverse axis or 1,25 $L$ is large but with proper management will do extremely well." Here $L$ is the "transverse" or major axis of the ellipse. William Herschel did sometimes employ elliptical polishers; perhaps that is what is depicted in Fig. 4.20.

and minor axes of the ellipse. This tendency can be avoided by means of special polishing arrangements, not used by the Herschels. Let us briefly consider these arrangements.

Opticians nowadays typically use one of three different methods for making elliptical diagonal mirrors. The first method consists of beginning from a round disk of glass, which is ground and polished sufficiently flat, and then cut or edged to the final elliptical shape on a vertical milling machine or lathe. Performing the grinding and polishing on a circular disk and testing *via* interference methods prevent the formation of a toroidal surface on the glass. Another method is to cast or mill the elliptical shape of the secondary mirror first, and then temporarily to bond the glass ellipse to a large round holder using a special adhesive called "blocking pitch," while also surrounding the ellipse with either a circular ring of glass (containing an interior elliptical orifice fitted to the secondary mirror) or carefully shaped small pieces of flat glass. The entire assemblage is a called "a block" or "a blocking," and the extra glass is called "a surround." The purpose of a surround is to generate a synthetic circle of glass so as to simulate a full disk during the grinding and polishing, which leads to even stock removal in all directions. Once the elliptical secondary is complete, it is freed from the blocking and cleaned for use (Fig. 4.21).[84]

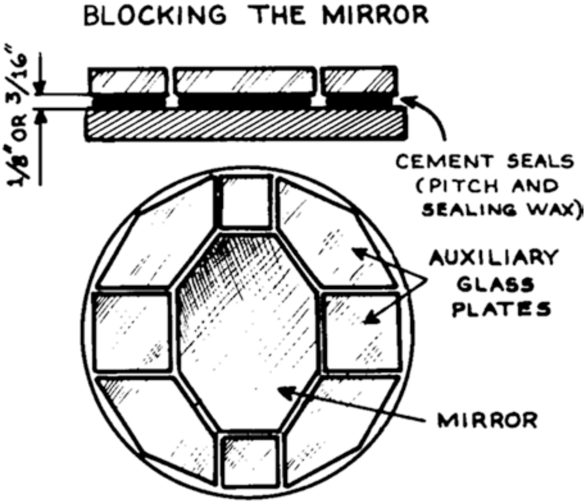


**Fig. 4.21** A meticulously formed pitch blocking designed to restore approximate circular symmetry to the work piece, facilitating uniform stock removal in all directions during grinding and polishing. By this means the oblong octagonal mirror avoids developing an asymmetric figure (Illustration from *How to make a telescope*, Second Edition, by Jean Texereau and translated by Allen Strickler. Used with permission. Copyright © 1984 by Willmann-Bell, Inc.)

---

[84] For milling and blocking methods, *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 118–122; Lecleire, K. & J.-M., (*op. cit.* ref. 66), pp. 127–129; and Williamson, R., (*op. cit.* ref. 61), pp. 17–18. For "surrounds" with elliptical orifices, *cf.* Potter, R., (*op. cit.* ref. 69), pp. 20–21; and Hindle, J., "How to make a diagonal for a Newtonian," in *ATM*, i, pp. 164–165.

The third method in use is the best of all and highly suitable for mass production. Most glass elliptical diagonals today are finished by this method. In essence, a very large ring of flat pitch is formed on a machine turntable. The ring is kept flat using a large disk of glass or granite, called a “conditioner” or a “bruiser,” which rides on the ring. The much smaller diagonal mirrors are figured by being captured in special small round fixtures that effectively float on the very slowly turning ring of pitch. In this situation, the diagonals must eventually go flat if the ring is itself sufficiently flat. This type of lapping machine is called an “annular polishing” or “continuous polishing machine.”[85]

Because William Herschel (and his contemporaries) did not use these types of methods and had no means to directly examine the surface profiles of their elliptical diagonal mirrors, the expected result of Herschel’s polishing procedures would in general be to form somewhat convex and toroidal surfaces, with the flatter curvature aligned to the major axis of the metal since this direction would experience less total contact with the polisher (and hence less material removal) than the minor axis direction. And indeed, in a specially conducted modern interferometric examination of eighteenth- and nineteenth-century speculum diagonals, this is exactly what has been found. The sole interferometric examination of which the author is aware was performed by A. A. Mills and R. Hall in 1983.[86] They examined 17 historic flat mirrors produced by such famous makers as James Short, William Herschel, Lord Rosse, William Lassell, and James Nasmyth. Of these, 11 came from Herschel. It would be very desirable for a much larger sampling of surviving flats to be analyzed interferometrically using even more modern methods. But so far this has not been done. Possibly the seeming unimportance of small secondary mirrors compared to the more physically imposing primary mirrors of Newtonians has made the analysis of the secondaries seem unimportant. It is hoped that the present study will convince researchers that the contrary is true: secondaries deserve just as much attention as historic primaries, because they are just as critical to the good functioning of a telescope.

Five of Mills’ and Hall’s interferograms and radial surface profiles are reproduced below in Figs. 4.22–4.26. The interferograms show the fringe patterns generated by joining the speculum diagonals to a modern glass master flat, coated with a thin metallic film to improve fringe contrast. The first diagonal comes from James Short; the second, third, and fourth come from William Herschel; and for compari-

---

[85] For continuous polishing machines, *cf.* Williamson, R., (*op. cit.* ref. 61), p. 45; Karrow, H.H., (*op. cit.* ref. 82), pp. 451–463.

[86] Mills, A.A. and R. Hall, (*op. cit.* ref. 75). Recently, the author using a polishing machine at the University of Arizona experimented on a small glass elliptical flat mirror of commercial grade. Polishing this on top of a circular flat pitch lap proportioned to match or slightly exceed in diameter the major axis of the elliptical flat mirror, in a matter of 5–6 h of machine time and using a stroke pattern like that which Herschel would have used, the author was able to convert the originally straight interference fringes (see below in text) provided by the commercial diagonal, to elliptical fringes. That is, the author found it easy and natural to convert a flat surface on the elliptical mirror to a toroid, similar to the surfaces shown below in Figs. 4.22, 4.23, 4.24, and 4.25 of this paper from Herschel and Short.

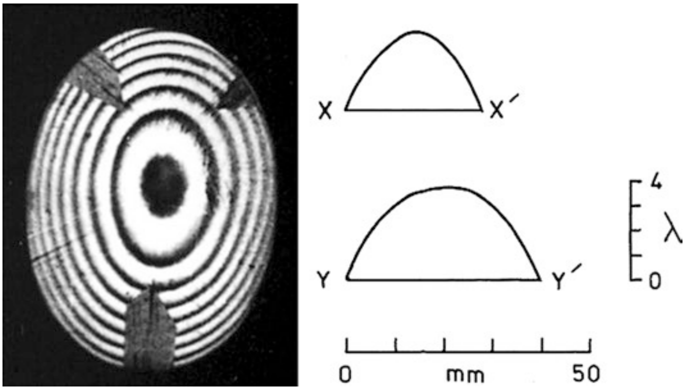


**Fig. 4.22** An elliptical diagonal mirror by James Short, tested *via* interference against a modern master flat mirror. Minor axis dimension is 28.3 mm. The *dark* and *light* interference rings can be used to measure directly the deviations of the diagonal from planarity. Their ellipticity means that the optical surface is significantly toroidal, although the toroid is well aligned to the major and minor axes of speculum surface. The *dark pointed shadows* result from strips of thin paper, acting as shims and meant to keep the surfaces from direct contact with one another (Image reproduced by permission of the Royal Society of London)

son a fifth flat comes from James Nasmyth and was made in the mid-nineteenth century. The difference between Nasmyth's mirror and the four preceding is dramatic: Nasmyth's comes far closer to the ideal of a modern flat.

Before turning to Short's and Herschel's flats in detail, we should say a word about how to interpret the reproduced interferograms. Although optical shop experience is much the best teacher of this, basic information can be gleaned from books, and the reader is referred to a selection of these in the footnotes of this chapter.[87]

In general, we should say that straight fringes, evenly spaced apart, indicate perfect conformity of the optic under test and its master surface. If that surface is flat, then the optic under test will also be flat. Nasmyth's diagonal comes closest to this ideal among the mirrors tested by Mills and Hall, although a modern flat produced by the methods outlined above can come still much closer and even appear perfect *via* this form of interference testing.

In cases when the optic under test does not conform exactly to the master, it may depart by a uniform difference in radius of curvature. Then circular fringes will become visible if the radius difference is sufficiently large. If the two surfaces are carefully leveled such that they have no tilt with respect to each other, a bull's-eye pattern of fringes will become visible centered on the optic and master; if on the other hand, the center of the bull's-eye is displaced to the side, then the optic is tilted with respect to the master.

---

[87] Texereau, J., (*op. cit.* ref. 6), pp. 111–115; Lecleire, K. & J.-M., (*op. cit.* ref. 66), pp. 73–76 and 131–133; Williamson, R., (*op. cit.* ref. 61), pp. 86–90; and Selby, H.H, (*op. cit.* ref. 73), pp. 535–555. For a thorough treatment, *cf.* Karrow, H.H., (*op. cit.* ref. 82), chapter 6.1.

Another possibility is that the fringes may be elliptical rather than circular. That would indicate that the optic under test does not have a single radius of curvature – it is not a spherical surface. Instead it has varying radii that reach a maximum along the major axis of the elliptical fringes, and a minimum along their minor axis: the optical surface is a toroid. Still another possibility is that the fringes may have irregular twists, or even kinks, indicating an irregular surface. Most of these possibilities are seen in the interferograms presented here.

If the bull's-eye pattern can be centered on the optic by pressing appropriately on the glass master (in upper position) such that a black fringe is made to appear at the center of the rings, as in Figs. 4.22, 4.24, and 4.25, then the optician can count radially outward from this black central fringe the numbers of succeeding black fringes to the edge of the optic. For example in Fig. 4.25, we have five successive black fringes to the right of the central fringe, as well as a white fringe at the very edge, giving a grand total of 5.5 fringes; on the left we also have 5.5 fringes. The master is therefore untilted in the horizontal direction with respect to the optic under test. And since each new black fringe occurs where the gap between the master and optic widens by one-half wavelength of light, if we know the wavelength used in this monochromatic test, we can directly compute the relative maximum gap between the flat and the optic in the horizontal direction, along the elliptical diagonal's minor axis. So, for example, in Fig. 4.25 we have a maximum relative gap of 5.5 fringes, or 2.75 waves. Since Mills and Hall specify their light source as the green emission line of mercury, with a wavelength of 0.546 microns, we now know that the relative gap (sagitta) along the minor axis of the diagonal is $(2.75) \times (0.546)$ μm, or 1.50 μm.[88]

From this information we can compute the radius of curvature of the diagonal mirror along its minor axis, when we also know the minor axis dimension of the speculum surface, which in the present case is 1.15 in., or 29.2 mm.[89] The formula for the computation can be found in the relevant literature.[90] The resultant radius of curvature is 71,000 mm or about 233 ft. For nearly any use besides a Newtonian telescope this would make an excellent flat. Equally, along the major axis we have 9 fringes vertically upward in the illustration, and 8 fringes vertically downward, for an average of 8.5 fringes, or 2.32 μm of sagitta. Assuming a major axis dimension of $\sqrt{2} \times 29.2$ mm or 41.3 mm, the radius of curvature along the major axis is 91,900 mm or about 302 ft. Since the radii of curvature differ significantly and the fringes are smooth, we have a uniform toroidal surface.

Looking now comprehensively at all the diagonal mirrors shown in Figs. 4.22, 4.23, 4.24, and 4.25, we can see that these eighteenth-century mirrors are toroidal

---

[88] Mills, A.A. and R. Hall, (*op. cit.* ref. 75), p. 152.

[89] The catalog numbers of Herschel diagonals (*e.g.* A-13, *etc.*), refer to designations established by W.H. Steavenson in his 1924 paper: "Catalogue of instruments made and (or) used by Sir William Herschel, as preserved at Slough and examined there in 1924, May and June," *TOS*, xxvi (1924), 221–238, p. 232. Diagonal A-13 is said to have a minor-axis of 1.15 in., which corresponds to the dimension of diagonals for Herschel's 7-ft Newtonians: RAS MS Herschel W.5/14.1, section i, article 1, f. 4v.

[90] Karrow, H.H., (*op. cit.* ref. 82), p. 674, equation 6.38.

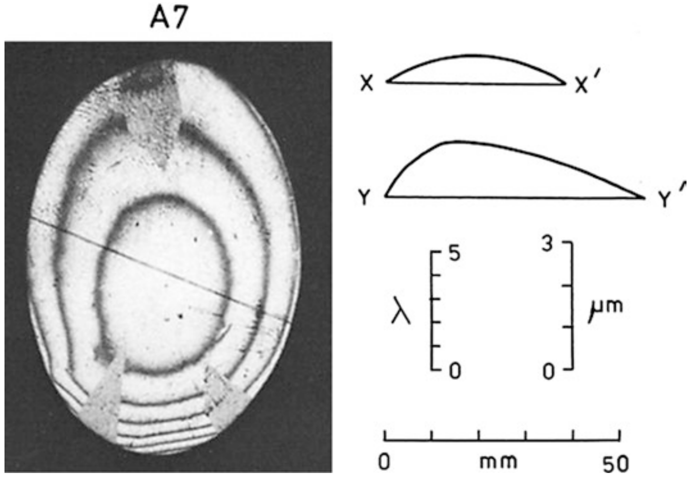


**Fig. 4.23** An elliptical diagonal mirror by William Herschel. Minor axis dimension is 37.8 mm. This is one of Herschel’s flatter diagonals in the collection, being only a few fringes out of planarity over the majority of its surface. The toroid is well aligned with the major and minor axis of the speculum surface, but a large scratch and irregular fringe shapes mar the workmanship (Image reproduced by permission of the Royal Society of London)

and convex in shape, as expected, since their makers had no adequate way to test for surface planarity during fabrication. James Short’s mirror has a minor axis radius of curvature equal to about 61,100 mm and a major axis radius of about 109,000 mm.

The three mirrors illustrated here from Herschel are among the best of the 11 Herschel diagonals shown by Mills and Hall in respect to regularity of surface and absence of severe zonal errors. Diagonal A-7 is the flattest overall of the lot, showing only about 2.5 fringes of convexity. Unfortunately, it has a severe turned-down edge at its lower perimeter, causing the fringes to bunch up there. But for a star viewed along the optical axis of the telescope (at the center of the field of view), the cone of rays intercepted by the diagonal mirror would likely occupy no more than the inner two-thirds of the optical surface. Thus, the rolled-off edge would have no effect on that star’s image, since over this portion of the flat we find a convexity of about 1.5 fringes both in the minor and major axis directions, yielding radii of curvature equal to 194,000 mm and 388,000 mm, respectively.[91]

---

[91] A simple calculation for the minimum minor-axis size of any given Newtonian telescope is presented by Texereau, J., (*op. cit.* ref. 6), pp. 109–111. Using Texereau’s equation 18, the minimum minor-axis size for a diagonal mirror that just fully intercepts the axial ray bundle arriving from the primary mirror is *Dl/f*, or in other words *l*/(focal ratio). In RAS MS Herschel W.5/14.1, section i, article 1, f. 4v, Herschel states that the minor-axis (“conjugate diameter”) size used in his 10-ft telescopes is 1.5 in. or 38.1 mm. This equals the minor-axis dimension of diagonal A-7. Hence, we may assume that A-7 was intended for a 10-ft Newtonian. On f. 4r, Herschel says that the clear optical diameter of his 10-ft mirrors was 8.8 in. (although he made 1 of 9.82 in.). Assuming the latter, and a distance from the focus to the minor-axis equal to 1/2 the mirror diameter plus 4 in. (this equals Texereau’s variable *l*), then the minor-axis dimension of the axial ray bundle for a 10-ft

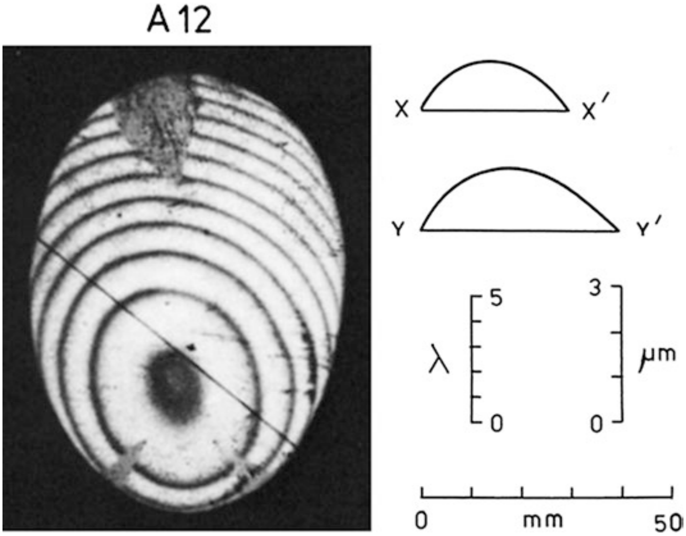


**Fig. 4.24** Another elliptical diagonal mirror by William Herschel. Minor axis dimension is 29.2 mm. This surface, too, is obviously toroidal and more regular in shape than the last mirror, although the toroid is not as well aligned with the major and minor axes of the speculum surface, but rotated in the counterclockwise direction (Image reproduced by permission of the Royal Society of London)

Diagonal A-12 is more difficult to analyze, since the bull's-eye is not centered. However, counting and averaging fringes suggests 3.75 fringes and 6.5 fringes of sagitta along the minor and major axes, yielding radii of 104,000 mm and 120,000 mm. Diagonal A-13 was discussed previously. Most of the other Herschel diagonals analyzed by Mills and Hall have zonal irregularities, making them inferior in quality to the three discussed here. All are convex toroids. None shows a significantly better surface profile. And a second diagonal from James Short, though flatter than the one in Fig. 4.22, is still a convex toroid and significantly irregular in shape. Hence, without exception all the 13 diagonals that Mills and Hall were able to analyze from the eighteenth century had convex toroidal profiles overall. None compares even remotely in flatness to Nasmyth's diagonal shown in Fig. 4.26.

Below, we will discuss the upshot of using a convex toroidal diagonal mirror in a Newtonian telescope, rather than an actual optical flat as would now universally

---

Herschel Newtonian, employing a 9.82-in. diameter mirror, would be [(9.82/2)+4]/(120/9.82)=0.73 in. This is about 1/2 of the actual minor-axis dimension of A-7's speculum surface. Accordingly, the ray bundle would entirely miss the turned-down edge of this diagonal, and the image of an on-axis star or planet would not be degraded. In fact, as we will show later, it would seem perfect and so too therefore would the diagonal: off-axis stars could not be magnified enough to show the effects of the turned edge in Herschel's narrow field-of-view singlet eyepieces. Such stars would fall outside the field of his high-power eyepieces.

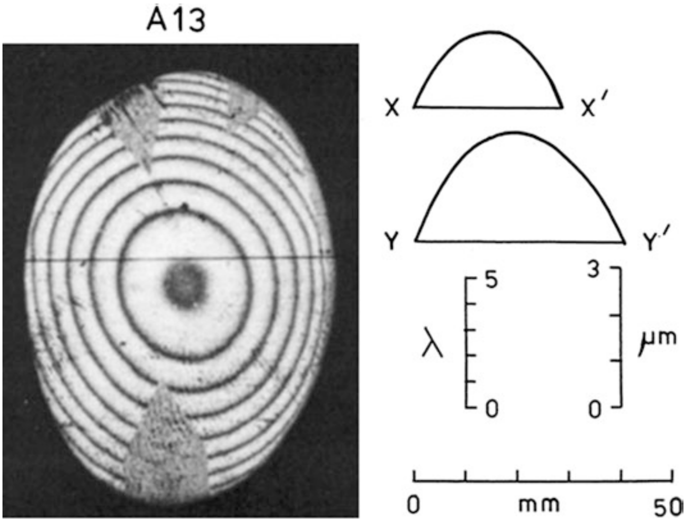


**Fig. 4.25** A third elliptical diagonal mirror by William Herschel. The minor axis dimension is 29.2 mm. The optical surface is also slightly toroidal, but very regular (Image reproduced by permission of the Royal Society of London)

be done. But first we should also consider the modern tests of William Herschel’s surviving primary mirrors, of which there have been a great many.[92]

In general it can be said on the basis of the published evidence that the surviving primary mirrors of Herschel’s that were intended for Newtonian telescopes (he also made some Gregorian optics) are relatively smooth optically, with only weak zonal errors, and are typically either approximately spherical, somewhat undercorrected with respect to the theoretical paraboloid, or mildly hyperbolic. These are all small mirrors for 7-ft and 10-ft telescopes. All of the surviving 20-ft mirrors were later refigured by John Herschel at the Cape of Good Hope in the 1830s. Of these, one

---

[92] Davies, C.D.P., “Herschel’s 18¾-inch speculum (‘the 20 ft.’),” *MNRAS*, lxxxiv (1923), 23–26 (Davies knife-edge tested one of the mirrors John Herschel used at the Cape); Steavenson, W.H., (*op. cit.* ref. 89), pp. 224–231 (Steavenson examined 13 Herschel mirrors, testing many of them *via* knife-edge; and one *via* a star-test); *idem*, “The Herschel instruments at Slough,” *Obs*, xlvii (1924), 262–267 and 303–308 (for further discussion by Steavenson); *idem*, “A peep into Herschel’s workshop,” *TOS*, xxvi (1924), 210–220 (still more discussion); *idem*, “Herschel’s first 40-ft speculum,” *Obs.*¸ l (1927), 114–118 (Steavenson’s report on finding the thinner of Herschel’s two 40-ft mirrors); Ainslie, M.A., “Note on the performance of two specula by Sir William Herschel,” *JBAA*, xlii (1931), 65–68 (Ainslie reports on testing two 7-ft mirrors *via* knife-edge and star-test); Hysom, E.J., “Tests of the shape of mirrors by Herschel,” *JHA*, xxvii (1996), 349–352 (Hysom knife-edge tested three mirrors by Herschel, using a Dall null-lens: a 10-ft mirror, a 7-ft, and a 7-in. diameter mirror for a Gregorian telescope); and Leue, H-J., “Johann Gottlieb Schrader und der Lilienthaler Fernrohrbau,” in Dick, W. and J. Hamel (eds), *Astronomie von Olbers bis Schwarzschild, Acta historica astronomiae*, xiv, (Harri Deutsch, 2002) 37–50, pp. 44–46. Leue gives Ronchi tests of the 10-ft Goettingen mirror by Herschel from 1786, and the 7-ft and 10-ft mirrors now in the Mathematisch-Physicalischer Salon, Dresden.

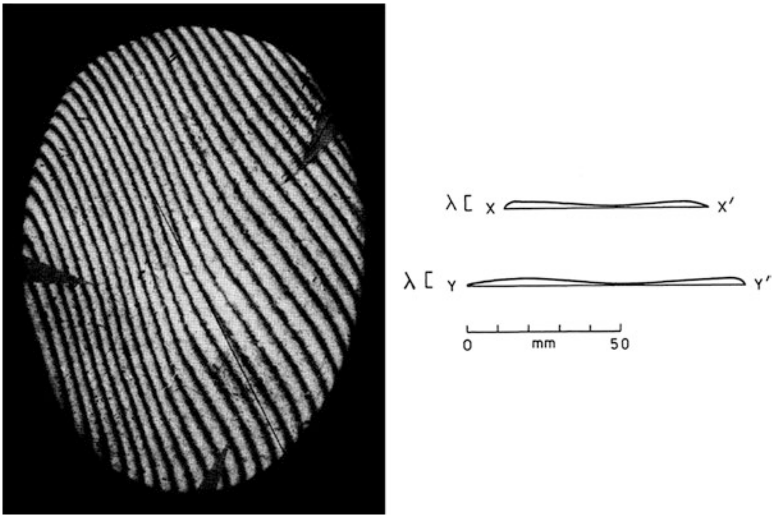


**Fig. 4.26** A large elliptical diagonal mirror by James Nasmyth, measuring about 66.5 mm along the minor axis. Planarity is far better than in the preceding mirrors. Nasmyth probably figured this mirror, guided by the refractor test illustrated above in Fig. 4.19 (Image reproduced by permission of the Royal Society of London)

has been tested. William H. Steavenson (1894–1975) did that in 1924 with a knife-edge tester.[93] He discovered after repeated measures that it was strongly hyperbolic and so could only give reasonable images at low power, although as Steavenson noted it did have a very smooth figure. Neither of the surviving 40-ft mirrors of William Herschel's has been tested. One is very thin, and even Herschel recognized that it flexed severely in use, making it of small value astronomically; the thicker one is unfortunately very pitted and tarnished from being exposed to the air in the telescope tube for many years after Herschel last polished it.

As to the smaller Newtonian mirrors, since in general they are all of a very slow focal ratio (typically about f/12), in fact any kind of smooth figure ranging from an oblate spheroid of conic constant of about $K = 2$ to a hyperboloid of conic constant of about $K = -4$ would form an acceptable image ($K = -1$ for a paraboloid).[94] As Richard Potter long ago realized, any figure close to spherical would form a sharp image in Herschel's ordinary 7-ft and 10-ft telescopes. Thus, nearly all the mirrors described in the literature cited in footnote 92 of this chapter would work admirably in practice. Herschel's zonal testing procedure derived from Mudge would easily reveal the focus errors of smooth conic aspheres significant enough to cause problems for him: at $K = 2$, the marginal rays of a typical 10-ft telescope mirror will

---

[93] On Steavenson, *cf.* Dewhirst, D.W., "William Herbert Steavenson," *Quarterly journal of the Royal Astronomical Society*, xviii (1977), 147–154.

[94] Acceptable means diffraction-limited. For the meaning of the conic constant, *cf.* Schroeder, D.J., (*op. cit.* ref. 54), pp. 41–42.

focus nearly six hundreths of an inch shorter than the central (paraxial) rays. Herschel was used to measuring focus differences of a hundredth of an inch using his zonal test masks.[95]

It is unlikely, therefore, that William Herschel improved Newtonians and made them a viable option for research telescopes by being a wizard at producing excellent paraboloidal primary mirrors. The published evidence from modern tests points strongly away from this idea. If Herschel succeeded in producing better Newtonians, it is likely that this stems from improvements to his secondary mirrors, and from his consistent use of pitch polishers to achieve smooth surfaces with low-light scatter. Even John Hadley had used cloth polishers soaked in pitch. But these cannot produce metal surfaces nearly as fine as pure pitch polishers.[96] Since there is nothing remarkable or particularly interesting about the optical quality of Herschel's Newtonian primary mirrors, as revealed in the modern testing literature, there seems little point in analyzing them further or illustrating them here. For brevity's sake, the information provided in the literature of footnote 92 appears sufficient.

## Usage and Performance of Eighteenth-Century Newtonian Telescopes

More revealing is to consider Herschel's (and his contemporaries') usages of Newtonian and front-view telescopes. First we consider Newtonians, and as a part of that, the effect of employing convex toroidal secondary mirrors in place of true flats.

We begin by saying that early in his career, Herschel employed Newtonians for almost all of his observations, especially once he become a serious astronomical observer in the late 1770s. But after his success in finding the two largest satellites of Uranus (Oberon and Titania) in early 1787 by means of a front-view telescope, it is not hard to see from his observational records that in the main, Herschel reserved Newtonians for high-resolution observing, that is say, for viewing and measuring close double stars and for examining the details of planetary surfaces and atmospheres. His front-view telescopes he mainly reserved for what in modern terms is called "deep-sky observing," that is, low-power visual searches for faint nebulae, star clusters, and galaxies – what modern amateur astronomers whimsically term from their visual appearance "faint fuzzies."

---

[95] RAS MS Herschel W.5/14.1, section xxxii, article 2, ff. 145v-146r. On folio 146r Herschel recognizes that some difference in zonal *foci* is acceptable, but recommends striving for zero difference: "A 20 feet mirror [*i.e.* 12-inch f/20] with a difference of 0,05 inches more the inside than the two outside foci will show extremely well; but we ought to make them exactly alike."

[96] *Cf.* ref. 61. Herschel reported results from using many other types of polishers besides pitch, but found them all defective. He found that cloth polishers produced what he called a "scabrous" polish, which appears to mean what opticians now call a "lemon peel" finish – a well-known result from polishing with cloth. RAS MS Herschel W.5/14.1, section vi, article 12, f. 50r-50v; and section xxxi, article 12, f. 140r.

This does not mean, however, that Herschel never employed Newtonians for deep-sky objects at low power, or front-view telescopes at high power for planets and double stars. On the contrary, like any resourceful scientist, Herschel did whatever he hoped would prove useful to secure valid observations. Nevertheless, as his published papers and private records show, in the main he employed his Newtonians for high-power, high-resolution views, and his front-views as what are sometimes now informally termed "light buckets," that is, instruments meant to collect as much light as possible to form useful low-power images – even if at high power they lacked sharpness. Exploring the ramifications of these assertions is the subject of the present section of this chapter.

## *Primary Mirrors*

That Herschel's Newtonians could in fact provide substantially diffraction-limited views can be shown in several ways. First we have some testimony from later users of Herschel optics to this effect. For example, W. H. Steavenson, who in 1924 surveyed and cataloged all the surviving Herschel optics in the possession of Herschel's descendants at Slough (UK), performed a star-test on the one complete 7-ft instrument in their collection. He reported that after gently dusting and removing tarnish from the primary and secondary mirrors of this instrument, its definition was excellent: "Arcturus showed a sharply-defined round disc, with diffraction rings…The moon was very well shown…The central craterlet in Plato was clearly seen as such." He considered the definition of the reflector to be approximately equivalent to a modern 6-in. refractor, though its image was naturally much less bright.[97] Steavenson's report is all the more interesting since it shows that even with the presumably original speculum-metal secondary mirror, a good Herschel primary could still form an excellent star image on-axis by modern standards (Fig. 4.27).

In 1931, Capt. Maurice A. Ainslie (1869–1951) – a well regarded British amateur astronomer of the day – star-tested two speculum primary mirrors considered by Steavenson to be "almost certainly the work of Sir William Herschel."[98] Both mirrors were 6.3 in. in aperture and designed for a 7-ft Newtonian. Ainslie employed a modern framework telescope tube, which was oversized, having been intended for a modern 10-in. mirror; he also used a modern glass right-angle prism in place of an elliptical diagonal. This he reported to be of "a very perfect" quality, having been lent to him by "Mr. Hargreaves" – probably Frederick J. Hargreaves (1891–1970), another well-known British amateur astronomer and optician. Ainslie reported that "the image of a fourth magnitude star with a power of about 350 was exquisite; I have hardly ever seen a better image, even with a good refractor of the same aperture.

---

[97] Steavenson, W.H., (*op. cit.* ref. 89), pp. 230–231.

[98] On Ainslie, *cf.* Mobberley, M.P., "Captain M. A. Ainslie, (1869–1951): his observations and telescopes," *JBAA*, cxx, 1, (2010).

**Fig. 4.27** A 7-ft Newtonian telescope by William Herschel, showing the typical lightweight, elegant wooden stand of Herschel's smaller instruments (Image reproduced by permission of the London Science Museum/Science and Society Picture Library)

The star disc was round, free from stray light, and the ring around it was even, and quite circular."[99]

Ainslie's report should cause no surprise since the Herschel optics he tested were just the primary mirrors; and as we said earlier, the aspheric tolerances on these (to obtain diffraction-limited images on-axis) because of the very slow focal ratios that William Herschel employed – about f/13.65 in the present case – are generous indeed: $K = -1 \pm 3$! John Herschel himself seems to have understood this implicitly when he stated in 1861: "And here we may once for all remark that *that* is a good form which gives a good image; and that the geometrical distinctions between the parabola, sphere, and hyperbola become mere theoretical abstractions in the figuring and polishing of specula, there being no practical mode of ascertaining, by any

---

[99] Ainslie, M.A., (*op. cit.* ref. 92), pp. 65–66. *Cf.* also *TSP*, i, p. li, footnote †: "A 10-foot Newtonian of 9-inch diameter, giving excellent images, is now in the possession of H[erschel]'s great-grandson, Mr. J.A. Hardcastle."

system of measurements on a scale, *what* form the surface has, apart from its optical effect on the rays of light [author's emphasis]."[100]

Several further observations by Ainslie also deserve notice. On first trying the speculum mirrors he discovered how flexure-sensitive they were: "I mounted the Herschel specula…and at once found that [they] were much more liable to distortion by their own weight than a glass mirror of the same or even smaller, weight would be; this was easily overcome by an even cloth backing, and the star images became perfectly symmetrical."[101] What Ainslie probably means by "an even cloth backing" is a support bed consisting of cloth such as felt, with even texture and no stitching, to act like a set of tiny springs, millions of them, pressing very evenly over the rear speculum face in support. As we will see in a moment, John Herschel also found this effective. His father, however, seems not to have used it.

Ainslie's second observation is even more interesting: "The mirrors were also tried as 'Herschelian,' or 'front-view,' the prism being displaced laterally so as to be just clear of the incident beam. This, however, caused considerable deterioration of the image, the astigmatism being very much in evidence, in spite of the large ratio of focal length to aperture."[102] At 350× in such a 6-in. reflector with the primary tilted enough (about 1.25°) to allow use of a 90° total reflection prism without vignetting the incoming ray bundle, the geometrical aberration would completely overwhelm the Airy disk and diffraction rings. We shall show the effect in detail for larger mirrors a bit later. But it is important to keep this in mind, since sometimes in the literature on Herschel the aberration is passed off as of little account. In fact, compared to the excellent axial images that one of Herschel's optically centered Newtonians could produce, the aberration seen in a front-view telescope would be large and plainly apparent, as other observers and theoreticians, too, have noticed.[103]

---

[100] *Cf.* Herschel, J.F.W., (*op. cit.* ref. 13), pp. 81–82. This must be kept in mind when we read in his father's letters, for example, the proud claim to control all forms of conic aspheres: "The mirrors of my telescopes are perfectly parabolical, and have no aberration from sphericity.... Any figure of the conic sections can be given to them, intirely [*sic*] by mechanical contrivances, and chance has no share in the operation.... The method of making and giving figure to mirrors has been established by a long series of experiments, and is recorded in several volumes, reduced to a systematic order." By "mechanical contrivances" William Herschel means his polishing machines. *Cf.* RAS MS Herschel W.1/1.1, p. 293, letter to Capt. Krusenstern, dated 12-Oct-1814.

[101] Ainslie, M.A., (*op. cit.* ref. 92), p. 65.

[102] Ainslie, M.A., (*op. cit.* ref. 92), pp. 65–66. For "astigmatism" Ainslie really means "coma and astigmatism."

[103] Ainslie, M.A., (*op. cit.* ref. 92), p. 66. For theoreticians, *cf.* R. Potter (ref. 40) cited above. Also, Coddington, H., *A system of optics* ii, (Cambridge, 1830), pp. 34–35, who politely says that in Herschel's 40-ft "the circle of least confusion in the image must have been 0.015 of an inch [381 microns], giving rise to a degree of indistinctness which would hardly be tolerated in a refracting telescope." The theoretical Airy disk for Herschel's 40-ft at f/10 was only 13.4 μm in diameter, or nearly 30× smaller in linear extent. For observers beside Ainslie, *cf. e.g.* Lord Rosse in Oxmantown, Lord, *(op. cit.* ref. 13), p. 524 (speaking of his 36-in. reflector): "I use it as a Newtonian, as I find that…the saving of light by the Herschellian [*sic*] construction is not at all an equivalent for the sacrifice of defining power"; and Gill, D., "Telescope," *Encyclopædia Britannica*, 9th ed., (London, 1894), 135–154, p. 145: "In consequence of the tilting of the mirror aberration is created, and this increases rapidly with increased tilting. The construction is thus limited to telescopes in which the

Ainslie also examined Uranus: "…the most interesting object to observe with these mirrors…was Uranus. I have several times seen it stated, that the fact that Herschel recognized at once that it was not a star that he was looking at shows that his eyesight must have been exceptional. But to me it was quite obvious at the first glance that I was not looking at an ordinary star, and even with the power used (180), I feel quite sure that no observer of even small experience could have taken the planet for a star." He concluded: "I think we may say, then, that at least two of Herschel's smaller specula are fully up to modern standards, and would bear comparison with the best work of any modern artist."[104] This is undoubtedly a correct assessment, bearing in mind that Herschel's best Newtonians were all of such a slow focal ratio that any smooth figure from a weak oblate spheroid to a weak hyperboloid would all perform well in his telescopes.

That was one key to Herschel's success in the realm of high-resolution telescopes: by using good speculum, pure pitch polishers, *and keeping the focal ratio high* (normally in excess of f/12), he was both able to apply the polishing lessons of Short and Mudge from Gregorians to Newtonians (and so produce smoother surfaces than could be done with Hadley's pitch-soaked cloth polishers), and at the same time far more easily achieve excellent image sharpness than could be done with the fast mirrors typically employed in Gregorians (f/4–f/6). Herschel could thereby produce larger telescopes of low-light scatter and good figure, affording him apertures well in excess of the largest refractors of his day. This in turn made it relatively easy for him to recognize Uranus as an object with a planetary disk, rather than a concentrated core like a true star. But of course, at the same time this also required a usable elliptical diagonal mirror.

## *Secondary Mirrors*

So we turn at last to consideration of Herschel's diagonals, specifically to the question of how they were usable at all, if indeed they were as convex as modern tests show. We noted earlier that a tilted spherical surface used as a secondary mirror in a Newtonian telescope would by virtue of its curvature introduce astigmatism into the image of a star. This results from foreshortening in the plane of the tilt. Figure 4.28 shows the effect greatly exaggerated in cross section. In A an untilted convex spherical secondary mirror has been inserted in front of a paraboloidal Newtonian

---

proportion of aperture to focal length is not too great." Even John Herschel admitted the problem in 1861: "Among [the front-view's] disadvantages, it must be considered that the aberration of the mirror is much increased by the oblique incidence of the…rays," and suggested that "from the facility with which glass prisms of sufficient purity and silver mirrors on glass can now be obtained, it seems probable that the Newtonian will supersede all other forms." *Cf.* Herschel, J.F.W., (*op. cit.* ref. 13), pp. 81–82.

[104] Ainslie, M.A., (*op. cit.* ref. 92), pp. 66–67.

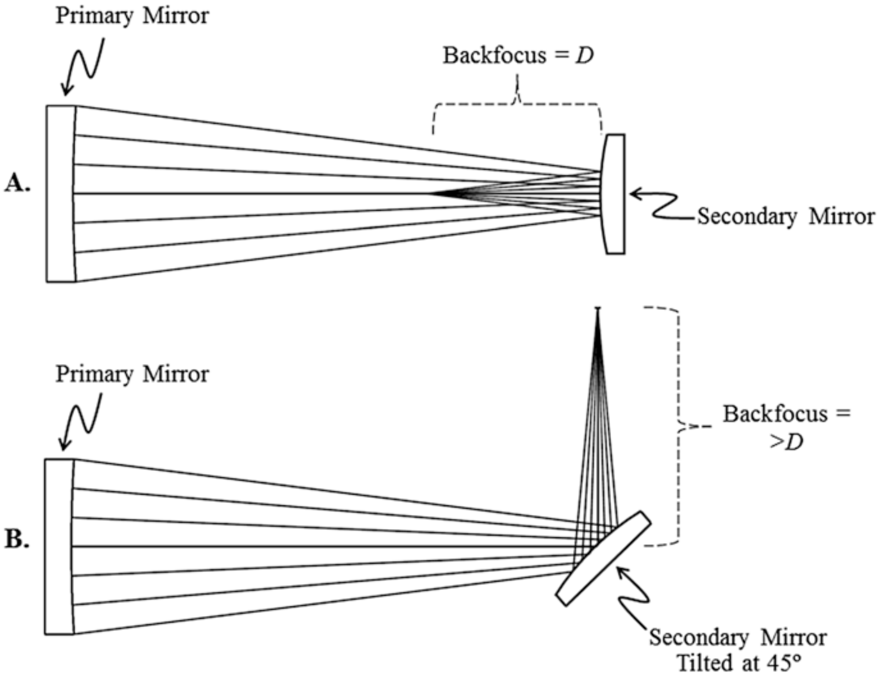


**Fig. 4.28** The effect of tilting a convex secondary mirror. In A and B the same paraboloidal primary and convex spherical secondary are combined. With foreshortening in B because of the 45° tilt, the backfocus in the plane of the tilt (*tangential plane*) lengthens *versus* the untilted secondary. The curvature of the secondary and backfocus change have been exaggerated for clarity. At the same time, the backfocus does not change in the perpendicular plane (*sagittal plane*). Thus we have astigmatism because of the secondary mirror tilt

primary. This reflects the ray bundle arriving from the primary backward by distance *D*, termed the "backfocus."

If the same secondary is now tilted at 45°, as in Fig. 4.28b, the backfocus increases *within the plane of the figure* (the tangential plane) to a distance greater than *D*, because the surface of the tilted secondary mirror – and hence its radius of curvature – seem compressed *via* foreshortening to the oncoming ray cone from the primary mirror. In the perpendicular ray plane (sagittal plane), on the other hand, *the backfocus will not lengthen*, since to the converging ray cone, the secondary's mirror surface (and its radius of curvature) seems unchanged. The existence of two separate foci, one in the tangential plane and another in the sagittal, means that the image will be astigmatic.

We can conveniently show this effect by examining the image produced using a secondary mirror with one wave of spherical curvature across the minor axis – similar to the curvature seen in Fig. 4.23 – *minus the toroidal component*. The mirror in Fig. 4.23 was intended for use in one of Herschel's 10-ft Newtonians, containing a mirror of about 8.8 in. clear aperture. Figure 4.29a shows the result, in the form of

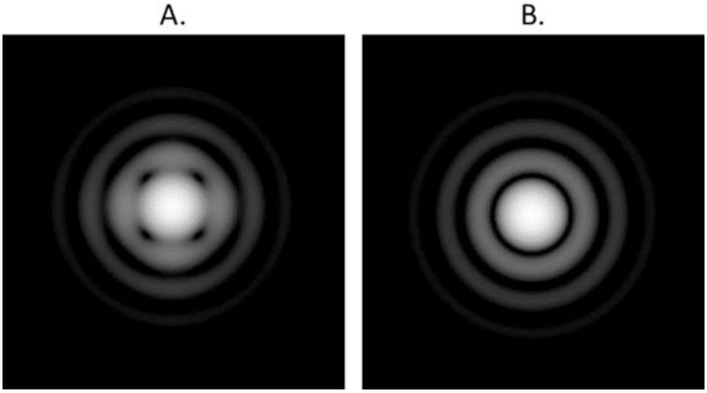


**Fig. 4.29** Point spread function (PSF) graphics for a model 10-ft Herschel Newtonian. In (**a**) (*left*) the secondary mirror has a *spherical* figure with 1 wave of sagitta over its 38 mm minor axis. In (**b**) (*right*) the secondary has a toroidal figure with 1 wave of sagitta over both its major as well as its minor axis

a PSF diagram. Compare it to Fig. 4.8 showing the PSF for a perfect image. It is obvious at a glance that the Airy disk is no longer distinctly visible but has been replaced by a squarish cross pattern plus surrounding rings. This means that if an otherwise perfect 10-ft Newtonian were used with this spherical secondary mirror, the resultant astigmatism would degrade the visibility of close double stars. In addition, since the image is no longer diffraction-limited (the Strehl ratio is now 75%), low contrast details on planetary surfaces and atmospheres, such as Jupiter's cloud bands, would be washed out.[105] The type of crisp views that W. H. Steavenson noted could not occur.

With a smooth toroidal component included, as in the secondary of Fig. 4.25 where the sagitta both along the minor and major axes of the elliptical surface is approximately identical (excluding the turned-down edge), which leads to a major axis radius of curvature that is double that of the minor axis, we now get an astonishing transformation of the image. The right-hand PSF, Fig. 4.29b, appears to show a perfect Airy disk and diffraction-ring pattern, as if the elliptical diagonal were truly flat. Seeing this in his star images and having no accurate surface profile test, William Herschel would surely feel he had found a method of making perfect flats. The Strehl ratio in the PSF is now 100%, *i.e.*, perfect, using a toroidal mirror that would be rejected as a disaster in a modern production facility!

How so poor a flat can work so well is not difficult to understand. Consider again Fig. 4.28. In A we show a spherical secondary mirror in an untilted position. A fan of rays confined to the tangential plane (*i.e.*, the plane of the figure) and converging toward the secondary will see the same curvature on the secondary as an identical

---

[105] For the criterion of "Strehl ratio" as a metric of image sharpness, *cf.* Smith, W., (*op. cit.* ref. 24), p. 356–360; and Suiter, R. (*op. cit.* ref. 25), pp. 7–10 and 399–400.

fan confined to the sagittal plane (*i.e.*, the plane perpendicular to the figure). Thus both fans when encountering the secondary will be reflected to the same backfocus position.

If on the other hand we replace the spherical secondary with a toroid having twice the radius of curvature in its tangential section as in its sagittal, the ray fan confined within the tangential plane will focus to a longer backfocus position than the ray fan in the sagittal plane. If we then tilt the secondary in the tangential plane to make an angle of 45° with the optical axis, then while the sagittal ray fan will detect no change, the tangential ray fan will see a secondary with the same sagitta but compressed in linear extent to $\sqrt{2}/2$ (*i.e.*, 70.7%) of its former length. And since in the case of nearly flat surfaces, radius of curvature is related to sagitta by the simple formula $R = r^2/2s$, where $R$ is the radius of curvature, $r$ is the physical radius of the optic, and $s$ is the sagitta, it is easy to see that with a constant sagitta, the radius of curvature varies as the square of the physical radius of the optic. In other words, if the sagitta stays constant but the physical radius of the optic decreases to $\sqrt{2}/2$ of its former size, then the new radius of curvature is $[\sqrt{2}/2]^2$ or 1/2 of its former value. Thus the tangential ray fan now seems to see a mirror that is twice as fast as formerly. The mirror appears to have the *same* radius of curvature in the tangential as the sagittal planes. So astigmatism vanishes!

This means that with careful use of Herschel's method for fabricating secondaries, as outlined above, and a dose of good fortune one could make a functional secondary mirror that is decidedly *not* flat. An irreducible condition for success is that the radius of curvature in the tangential section (along the major axis) of the elliptical diagonal's surface must be *twice* as great as in the sagittal section (along the minor axis) – which is equivalent to saying that the sagittae in the two sections must be identical to one another, so that in an interference test, the ring system will be exactly concentric to the outline of the elliptical secondary. This assumes that the "center of the bull's eye" is brought to the center of the secondary during interference testing (as seen very nearly in Fig. 4.25), and that the elliptical diagonal has been made for use at a 45° tilt angle.

In this way, despite the obvious errors in William Herschel's secondary mirror surfaces when compared to their modern equivalents, tested by modern methods, Herschel's secondaries (at least the best of them) could indeed produce better than diffraction-limited optical images. And it was not just Herschel who could achieve this. A close inspection of James Short's highly convex and toroidal secondary (shown in Fig. 4.22) indicates that he, too, could realize good results. The tangential radius of curvature on Short's secondary is about 109,000 mm and the sagittal is about 61,100. The ratio of these numbers is 1.78:1 rather than the optimum 2:1. Nevertheless, if we substitute this mirror for the flatter Herschel mirror just discussed we obtain a PSF nearly as good, with a Strehl ratio of 95%. This is still practically perfect.

So it was possible for other master craftsmen besides Herschel to make functional Newtonian secondary mirrors in the eighteenth century. Probably John Hadley succeeded in just this same way with his famous Newtonian of *ca.* 1720. Nevertheless, the process was not easy as we know from many contemporary sources including Herschel, who in 1782 wrote to Rev. John Edwards (*ca*. 1748–1784): "Nothing can be more difficult than to make a perfect plane spec[ulum]. I have bestowed much pains upon it and made many experiments and after all am not arrived to such a perfection as to be intirely [sic] satisfied."[106] Herschel made this statement before he devised his method of testing for flatness *via* the two cards as explained earlier. He seems to have established the card test by the summer of 1790.[107]

Despite possessing this improved test, Herschel certainly had no method for evaluating toroidal optical surfaces, and he could have no precise understanding of them or even a name for their optical product – astigmatism – as we previously showed. Because aberration theory was largely undeveloped in the eighteenth century and the physical wave theory of light was not established, Herschel did not possess a precise vocabulary to describe the forms of the images that he saw. For example, he often described the "spurious disc" of a star (the Airy disk) seen in a good telescope. But he never mentioned, it seems, the spurious diffraction rings that should accompany that disk. Perhaps he assumed these rings were "adventitious rays" that should not be present in a perfect instrument. Equally, he seemingly never described the squarish cross patterns that must have been visible in his Newtonians when they were equipped with insufficiently accurate diagonal mirrors. At most he understood that such a mirror might affect the apparent diameter of a planet, for example, Mars:

> *To obviate any doubts concerning a fallacy that might arise from the…irregular shape of the small speculum, I need only refer…to the experiments of the 7th and 9th of October, 1783: for should the short diameter* [*i.e.*, minor axis] *of my small plane speculum have occasioned a compressing of the polar diameter of Mars when exposed to it, half a turn of the telescope must bring the other diameter of that speculum into the same situation, and a contrary effect would have followed.*[108]

Actually, an insufficiently flat or inaccurately toroidal secondary mirror would in the first instance cause image *blurring* – a planet would not focus sharply. Secondarily as the observer racked through focus, the planetary disk would be stretched in the tangential or sagittal optical plane by astigmatism.[109]

Nevertheless, it is clear now from the evidence and explanations provided that the reason why Herschel's Newtonian telescopes worked – or those of other makers, such as Hadley, Short, or Johann Hieronymus Schroeter and Johann Schrader (about whom more in a moment) – was probably that their secondary mirrors combined a weak convex surface curvature with a toroid in such a way that when tilted at 45°, the aberrations contributed from the various sources of error canceled sufficiently

---

[106] RAS MS Herschel W.1/1.1, p. 53.

[107] RAS MS Herschel W.5/12.1, Experiment 426, pp. 135–136.

[108] Herschel, W., "On the remarkable appearances at the polar regions of the planet Mars, the inclination of its axis, the position of its poles, and its spheroidal figure; with a few hints relating to its real diameter and atmosphere," *PT*, lxxiv, (1784), 233–273, p. 270 [*TSP*, i, p. 155]. *Cf.* also Potter in ref. 69 above.

[109] *Cf.* also Potter, R., (*op. cit.* ref. 69), p. 20.

well to make the resultant image resemble the theoretically correct PSF. Unfortunately, their methods of fabrication were "hit or miss," so that if the convexity and toroidal shape did not match sufficiently, the resultant images would show astigmatism.

The images might show other aberrations as well, depending on the precise irregularities, curvature, and tilt angle of the secondary mirror. It is noteworthy that all the instruments produced by Herschel, Schroeter, and Schrader that were intended for high-resolution diffraction-limited imaging contained very high focal ratio mirrors in excess of f/12, extending as high as f/17 in the case of Schroeter's 13-ft Newtonian, which contained a 9.5-in. diameter mirror, or f/20 in the case of Herschel's "small" 20-ft Newtonian, containing a 12-in. mirror. Other Schroeter instruments, such as his 15-ft Newtonian with its 12-in. mirror or his 25-ft Newtonian (later changed to a front-view) with its 20-in. mirror were built at f/15. And only after Herschel had devised his improved test for secondary mirrors did he succeed in 1811 in producing an excellent 13.75-in. diameter 14-ft f/12.2 Newtonian.[110] These very slow focal ratios not only offered generous figuring tolerances on the speculum primary mirrors but restricted the minor axis dimensions of secondary mirrors to small values on the order of 25–30 mm. We can see from the secondaries of Short and Herschel that eighteenth-century technology was able to provide small secondaries with figures that, although not actually flat, at any rate were sufficiently good to make diffraction-limited long focal ratio Newtonians.

Trouble arose if the maker attempted to fabricate larger Newtonian secondaries. Larger optical surfaces, not surprisingly, are harder to make in general than small ones. A larger secondary would be needed either for a larger-diameter telescope or for a faster, smaller system. For a given backfocus (the optical distance from the secondary to the focus, needed to throw the image clear of the tube for examination by an eyepiece), the minimum minor axis dimension that completely intercepts the converging cone of rays from the primary mirror is given by the formula $ma = bfl/f\#$, where $ma$ is the minor axis dimension, $bfl$ is the backfocus or clearance from the secondary mirror (located on the axis of the tube) to the focal position outside the tube, and $f\#$ is the focal ratio of the primary mirror. Thus, an 8-in. f/15 Newtonian giving a backfocus distance of 7 in. requires a secondary mirror with a minimum minor axis dimension of 7/15, or 0.467 in.; while the same diameter mirror constructed at f/4 requires a diagonal mirror with minor-axis of 7/4, or 1.75 in. Since the back focus distance is often irreducible, a faster focal ratio inevitably means a bigger secondary mirror. The one large Herschel secondary that Mills and Hall tested, with a major axis of 114 mm, was so convex that they were unable to assess the curvature of its surface accurately.[111] Larger secondaries only became feasible

---

[110] For Schroeter's equipment, *cf.* Gerdes, D., *Die Lilienthaler Sternwarte 1781 bis 1818*, (Lilienthal, 1991), pp. 226–234 and *passim*. For Herschel's 12-in."small" 20-ft, *cf.* Bennett, J.A., (*op. cit.* ref. 1), pp. 79–83; and for the Glasgow 14-ft Newtonian, *cf.* Warner, B., "The William Herschel 14-foot telescope," *Monthly notes of the Astronomical Society of South Africa*, xlvi (1987), 158–163.

[111] Mills, A.A. & R. Hall, (*op. cit.* ref. 75), p. 157.

with the advent of superior testing methods from the time of Lord Rosse, as previously discussed, who pioneered high-performance Newtonians as fast as f/9.

In addition, several of the smaller Herschel secondaries, such as that seen in Fig. 4.23, A-7, show a surface along the major axis that is uneven. We spoke previously of a "turned-down edge" in characterizing the lower periphery of mirror A-7. But a closer examination of the fringe pattern and the Y-Y′ radial profile given on the right side of Fig. 4.23 shows that the surface curve rises abruptly on one side of the mirror (bottom of image), quickly reaches a peak far from its mechanical center, and then slowly declines on the other side. A uniform toroid with a turned-down edge would have its peak at the center of the graph and fall evenly toward its edges, with a final abrupt turn down. Instead, what we have in mirror A-7 is a surface rapidly rising to a sudden peak displaced from its mechanical center and then gradually declining. This means that the radius of curvature on the rapidly rising side of the peak is shorter than on the slowly declining side. This is a hallmark of coma figured into the glass surface. Such a surface if used from edge to edge in reflected light from the primary mirror would produce a comatic image *on the optical axis* of the primary mirror.

## *Stress and Mirror Support*

Compounding all this trouble is that speculum metal, being so much denser than glass and not amorphous in its structure, is very liable to flexure from uneven support and from annealing irregularities. The latter can lead to internal stresses, manifesting themselves as astigmatism (for example) in the optical surface. Since metal or glass once cooled has a fixed internal structure and stress pattern, this type of deformation would be permanent. Thermal cycling (cooling) at night might exacerbate the problem. Even for his far smaller mirrors, James Short was well known for rotating his primary and secondary mirrors with respect to one another to find the relative "clocking" angle at which the two performed best when used in tandem. Short marked the primaries for his Gregorian telescopes with a line on their sidewalls to indicate how they were to be oriented in the telescope tube for best performance.[112] Herschel, too, sometimes "clocked" his primaries. He was aware that they might develop different focal lengths at right-angles to one another.

---

[112] *Cf.* Turner, G.L'E., "James Short, F.R.S., and his contribution to the construction of reflecting telescopes," *NRRS*, xxiv (1969), 91–108, plate 10, which presents a broadsheet from Short giving directions for the use of his Gregorians. About two-third of the way to the bottom of the sheet, we read: "There is a black Stroke on the Back of the great Mettal, and Care must be taken, that this Stroke always points upwards from the Hole." *Cf.* also Mudge, J., (*op. cit.* ref. 13), pp. 339–340.

This constituted one type of surface asymmetry, which Herschel with his limited terminology called a "lateral fault."[113]

In regard to the specifics of mirror support in Herschel's telescopes, previous makers of reflecting telescopes such as James Short supported their primaries on a bed of small springs, in an attempt to absorb the load of the mirror's mass evenly across its back. Herschel rejected this, as did the Rev. John Edwards, a contemporary telescope maker. Nevil Maskelyne (1732–1811), the Astronomer Royal, published Edwards' critique of springs in 1783 and added his own remarks against them.[114]

Instead, for both his Newtonians and at least for his largest front-view, Herschel adopted a different mode of support. This is well documented for small Herschel mirrors in museum collections, and from a detailed description produced by Schroeter: Herschel enclosed these mirrors in a cell (his term was a "case"), something like a conventional lens cell. The cell was open at the front but closed at the back by a base plate. A ring extending around the sidewall and terminating in a front flange, whose inner diameter was smaller than the mirror's outer diameter, served as a retainer.[115]

In recent years, the author was privileged to examine a 10-ft Herschel mirror housed in the collections of the London Science Museum. This belonged to a telescope made in 1812 for the Radcliffe Observatory at Oxford.[116] Museum staff facilitated the examination, and the author wishes to thank the museum and especially Ms. Rebecca Storr for their support and assistance. During the examination, it became clear that the mirror was slightly loose inside its cell, as Herschel recom-

---

[113] For rotational adjustment of primaries, *cf. e.g.* Herschel, W., "On the discovery of four additional satellites of the *Georgium sidus*," *PT*, lxxxviii (1798), 47–79, p. 68 [*TSP*, ii, p. 14] and RAS MS Herschel W.1/1, p. 54. For the term "lateral faults," *cf.* RAS MS Herschel W.5/14.1, section xxx, article 2, f. 131v: "When a mirror has lateral faults, they may be detected by limitting [*sic*] diaphragms of proper shapes… A limiting aperture of one quadrant open, the other three being excluded, is the best way to find whether a mirror has lateral faults, for if it has any the foci of the four quadrants separately taken will differ… The corner of a card, or a fine cross drawn upon it being viewed by a mirror that has lateral faults will discover them; when the perpendicular is in focus, the horizontal will be out; and vice versa." This last test – examining the focus differences of two sharp edges or lines at right angles – is an imaging test for astigmatism. It is reasonable to conclude, therefore, that Herschel understood the concept of a toroidal mirror surface, but did not possess the terminology to name it or its imaging consequences.

[114] Edwards, J., "An account of the cause and cure of the tremors particularly affecting reflecting telescopes more than refracting ones," *The nautical almanac and astronomical ephemeris for the year 1787*, (London, 1783), pp. 51–54; and Maskelyne, N., "Remarks on the tremors peculiarly affecting reflecting telescopes more than refracting ones," *ibid.*, pp. 57–60.

[115] On "cases," *cf.* RAS MS Herschel W.5/14.1, section iv, article 13. For Schroeter's description, *cf.* Schröter, J.H., "Darstellung des Herschelschen siebenfüβigen Teleskops mit praktischen Bemerkungen," *Beiträge zu den neuesten astronomischen Entdeckungen*, (Berlin, 1788), 154–209, pp. 175–177; reproduced in Gerdes, D., (*op. cit.* ref. 110), pp. 71–74.

[116] RAS MS Herschel W.1/3.1-6; and Spaight, J.T., "'For the good of astronomy': the manufacture, sale, and distant use of William Herschel's telescopes," *JHA*, xxxv (2004), 45–69, p. 60.

mended.[117] A gentle shaking of the cell made its slippage clear. Slight looseness prevents optical flexure of the mirror due to compressional stresses, which would ensue if the mirror were held solidly. Avoidance of rigid restraint is a well-known necessity in the mounting of precision optical components.[118]

In addition, the Science Museum staff opened the cell to allow examination of its interior. Figure 4.30 shows the results. Image A displays the exposed mirror (retaining ring at upper left of image) resting on its base plate; image B shows the mirror

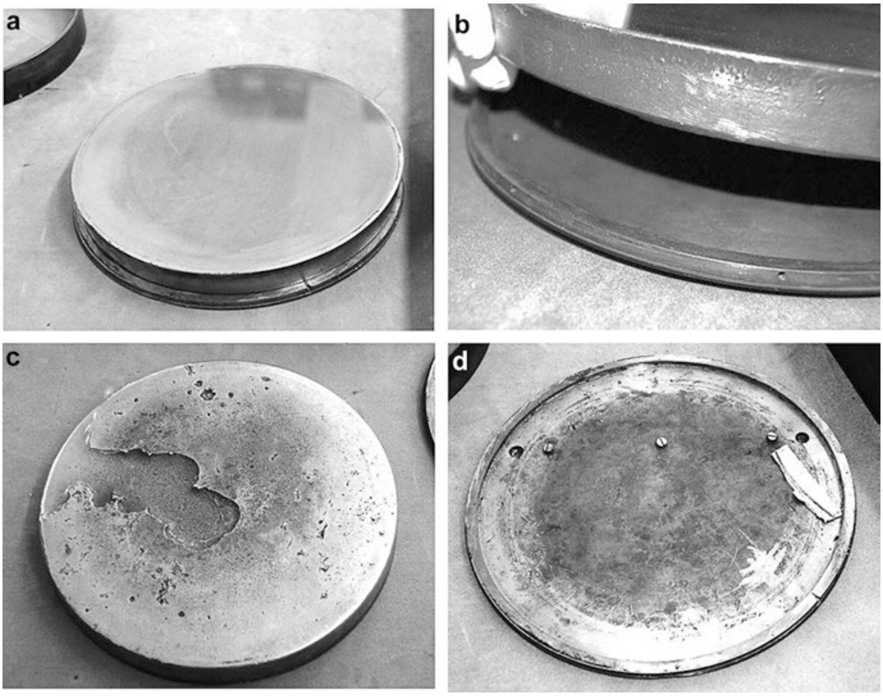


**Fig. 4.30** A 10-ft Newtonian speculum made by William Herschel in 1812. In (**a**) the mirror sits on its support rim, the retaining ring of the "case" having been removed already (*upper left* of image). In (**b**), the mirror is lifted off its support rim exposing the inside of its base plate. In (**c**), the rear surface of the mirror is shown, including a large void in the casting. In (**d**), the inside of the base plate is exposed (Images reproduced with permission of the London Science Museum/Science and Society Picture Archive)

---

[117] RAS MS Herschel W.5/14.1, section xxxix, article 1, f. 170r: "In the box that holds the mirror should be no pasteboard, or other thing to prevent a considerable shake which it ought to have."

[118] Texereau, J., (*op. cit.* ref. 6). pp. 123–128: "It is *essential* that the mounting impose no restraint whatever on the mirror disk [author's emphasis]"; otherwise there may ensue: "severe image deterioration, caused by the resulting serious mechanical strain," which in extreme cases may lead to "the hazard of fracture."

being lifted off its base, exposing a peripheral support rim; image C displays the rear surface of the mirror blank, showing large pits and an extensive void in the casting (called a "sink" by Herschel); and image D shows the fully exposed base plate. The peripheral rim extends above the plate: the rim is the sole support surface for the mirror. Three flathead screws located in a row across the base plate are recessed and do not touch the rear surface of the mirror when it rests on its peripheral rim.

It is clear from Fig. 4.30 that the technology used to support this mirror is of the same sort used to support lenses in their housings even today. This is not unreasonable for a small, nearly spherical mirror and is sometimes still recommended. An improvement would be to rest the mirror on three small tabs projecting above the support rim, located at 120-degree intervals, in order to give definite uniformly spaced contact points. What function the oblong slip of folded paper (seen in image D and presently located under the mirror in the recessed base) may have had is uncertain.[119]

It was also immediately clear to the author on lifting the mirror during his examination that it weighs considerably more than an equivalent glass mirror would, and was certainly more in need of careful support than an equal-diameter glass disk would be to avoid flexure in use. We already noted that Capt. M. A. Ainslie in 1931 found even smaller Herschel mirrors sensitive to flexure and recommended supporting them on "an even cloth backing." It is unclear how William Herschel supported his 18-in. mirrors for the 20-ft telescope. John Herschel, however, discussed the support system he used in the refurbished 20-ft. John discovered that:

> *A speculum (I speak from experience) of the dimensions and thickness used in my sweeps, is* totally spoiled *by supporting it on three metallic points at the circumference, when directed to the zenith. The image of every considerable star becomes triangular, throwing out long flaring caustics at the angles. On one occasion, I supported a mirror simply against a flat board, at about 45° elevation from the horizon. In this state its performance was tolerably good; but on stretching a thin packthread vertically down the middle of the board, so as to bring the weight to rest on this as on one axis, the images of stars were elongated, in a horizontal direction, to a preposterous extent, and all distinct vision utterly destroyed by the division of the mirror into two lobes, each retaining something of its parabolic figure, separated by a vertical band, in a state of distortion, and of no figure at all* [emphasis, in Roman type, added].[120]

He therefore recommended supporting the 130-lb mirror blanks for his 20-ft on several thicknesses of woolen blanket:

> *And here, perhaps, I may be allowed a digression on a point of the utmost importance in the use of reflecting specula, viz., the mode of supporting the metal in its case. This, in my own practice, is provided for as follows: – between the back of the case and the mirror are interposed six or eight thicknesses of coarse woollen baize, or blanketing, of even texture, and quite free from knots, stitched together at the edges to prevent any hard substance from getting between them. On this bed the metal is laid flat, and being shaken into a concentric situation, as respects the rim of the case, two supports formed of strips of similar woollen stuff, many times doubled, occupying about 30° each of the circumference of the case, are*

---

[119] On the use of three peripheral contact points, *cf.* Texereau, J., (*op. cit.* ref. 6), pp. 123–126; and Riekher, R., (*op. cit.* ref. 29), pp. 156–157.

[120] Herschel, J.F.W., (*op. cit.* ref. 59), p. xi–xii.

> *introduced, so as to leave an arc of about 40° unoccupied, opposite the point which is intended to be placed lowermost in the tube. The case being then raised into an inclined position…and slightly shaken, the mirror takes its own free bearing on these supports, which by their elasticity obviate the possibility of any lateral compression which might go to the extent of seriously disfiguring the metallic surface,* were the whole vertical pressure of the mirror confined to a hard point near the bottom … [emphasis added].[121]

Elsewhere in respect to utilizing a load-distributing system of support and good mirror alignment, John noted:

> *[I]t is not among the least advantages afforded by this [support] system that it permits a mirror to be used in the only mode which can give full scope to its optical capacity and do full justice to the care bestowed on its figure and polish.* Indeed I am persuaded that very much of the difficulty complained of in figuring large reflectors has arisen from mistaking the distorsion produced by flexure arising from unequal support for imperfection of workmanship [emphasis added].”[122]

Although it is uncertain how William Herschel supported his 20-ft mirrors, it is known that for the two 48-in. mirrors in his 40-ft telescope, just as for his smaller Newtonians, Herschel used a “case.” This is shown both in the detailed paper he published in 1795, describing the mechanism of the 40-ft reflector, and in one of the “machine drawings” that John Herschel drew for his father to depict the equipment discussed in the *Results of experiments on the construction of specula*. The latter is reproduced below as Fig. 4.31.[123]

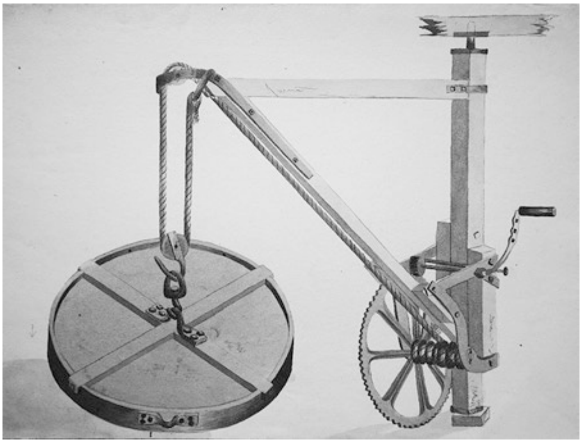


**Fig. 4.31** Drawing by John Herschel depicting the hoist used to raise and lower the 48-in. mirror on and off the polishing lap for William Herschel’s 40-ft telescope. On lower left is shown the rear of the mirror in its cell. Two iron cross bars straddle the mirror to reinforce the case and to provide a lift point (Image courtesy of the Royal Astronomical Society)

---

[121] Herschel, J.F.W., (*op. cit.* ref. 59), p. x. Edwards had already counselled likewise for much smaller mirrors in 1783: Edwards, J., (*op. cit.* ref. 114), pp. 53–54.

[122] Quoted by B. Warner from the unpublished ms. notes of John Herschel to his volume of Cape results, in Warner, B., “Sir John Herschel’s description of his 20-ft reflector,” *Vistas in astronomy*, xxii (1979), 75–107, p. 96.

[123] RAS MS Herschel W.5/14.2, Figure 55, discussed in RAS MS Herschel W.5/14.1, section iv, article 15, f. 38r. For an illustration of the front of the cell (with protecting cover in place) and a detailed description, *cf.* Herschel, W., [*op. cit.* ref. 3 (1795)], pp. 403–407 and Figs. 46 and 47 [*TSP*, i, p. 524–526].

This figure shows one of the 48-in. mirrors hanging face down from the lifting hoist used to set it on and take it off its polishing lap. What is important is that the machine drawing clearly shows the exterior iron containment cell surrounding the mirror itself, as well as the rear flange and a pair of iron bars straddling the back of the mirror, used to reinforce the case, as well as for the purposes of lifting the mirror. A central lifting bracket is bolted onto the bars. A hook then connects the bracket to the pulley of the hoist.

The thicker of the two mirrors and some of its hardware still exist.[124] It is shown in Fig. 4.32, which clearly displays the peripheral containment cell and rear supporting ring, as well as the cross bars. William Herschel indicates in his 1795 paper that the thicker mirror blank was intentionally cast meniscus to make it of uniform thickness from center to edge. The image in Fig. 4.32 indeed seems to show a convex surface, and moreover that the cross bars appear to be arched so as to follow the surface. Whether they perfectly match the surface curvature is unclear. Nor is it clear whether the mirror in use would actually rest on them as load supports.[125]

Although such a mirror cell no doubt seemed reasonable – or even unavoidable – to William Herschel in view of his prior experiences, it is certain to give a modern telescope designer pause. As discussed earlier, modern engineers spend much time

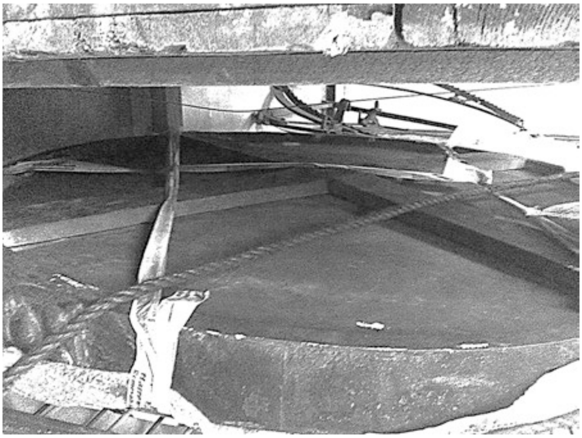


**Fig. 4.32** The thicker of the two surviving 48-in. diameter mirrors that William Herschel ground and polished for his 40-ft telescope. Shown above is the rear surface of the mirror revealing the simple support system

---

[124] This mirror is said by Herschel to be about 3.5-in. thick and to have weighed 2118 lb as cast. The thinner mirror also survives and is housed at the London Science Museum. For a good description of it, *cf.* Steavenson, W.H., "Herschel's first 40-foot speculum," *Obs*, 1 (1927), 114–118. According to Steavenson it is 1.9 in. thick at the periphery, was intended to be meniscus, but has a central depression of about 0.9 in. Herschel recognized that the blank was too thin ever to keep a stable figure and so he cast the second, thicker one.

[125] *Cf.* also the comments of J.L.E. Dreyer about the 40-ft in the introduction to the 1912 edition of William Herschel's scientific papers, in *TSP*, i, p. liv: "[A]ll the same it is likely enough that the instrument did not generally perform well. The speculum was supported in an iron ring, resting there at its lowest point and confined there by an iron cross over its back. It would seem that a speculum weighing a ton and supported in this simple manner *must* have been subject to considerable flexure and cannot as a rule have done justice to the skill of its maker."

designing load-equalizing systems of mirror support with many contact points, since even glass mirrors in the 1-m class easily flex enough to ruin good image quality. One of the decisive steps forward in the development of large reflecting telescopes came when Thomas Grubb, a professional engineer, invented a system of "equilibrated levers" (*i.e.*, "whiffle-tree") for mirror-support, which in more developed versions are used extensively today for large and small telescope mirrors. Grubb's invention is linked to a 15-in. Cassegrain telescope that he built in 1834 for Thomas Romney Robinson (1792–1882), director of the Armagh Observatory in Ireland and a well-known physicist and astronomer who played an important role in the advancement of large reflecting telescopes in the middle of the nineteenth century. Robinson was a close associate of Grubb, Lord Rosse, and James South (1785–1867). Both Robinson and South will appear further below in the present study (Fig. 4.33).[126]

The absence of any engineered system of load-support for Herschel's 48-in. mirrors, designed to minimize self-weight deflection, combined with the large mass of the speculum (over one ton for the thicker 48-in. mirror), by themselves guaranteed that the 40-ft telescope could never reliably achieve diffraction-limited images. In any position other than nearly zenith pointing a large fraction of the mirror's mass would be loaded against the lower edge of the cell. Flexure of the optical surface

**Fig. 4.33** Thomas Grubb's "whiffle-tree" mirror support for the 15-in. Armagh Cassegrain reflector (1835). Each white pad acts as a contact point. The points are spaced and mounted to three articulating triangles in order to provide uniform load support and so as to minimize flexure of the metal mirror (Image reproduced with permission of the Armagh Observatory)

---

[126] For Grubb, Romney, Rosse, and South, *cf.* Glass, I.S., *Victorian Telescope Makers*, (Bristol, 1997), especially pp. 17–22. For the origin of the whiffle-tree, *cf.* ref. 14 above, and also Robinson, T.R. & T. Grubb, "Description of the Great Melbourne Telescope," *PT*, clix (1869), 127–161, p. 145.

would be inevitable. Perhaps John Herschel's remark quoted above, that "the difficulty complained of in figuring large reflectors has arisen from mistaking the distortion produced by flexure arising from unequal support for imperfection of workmanship," is an oblique reference to his father's complaints about his difficulties with the 40-ft telescope. It is well known that William Herschel in later years advised against trying to refurbish the by-then dilapidated 40-ft. And despite John's extensive scientific education and personal connections, which might have uncovered the engineering problems (as well as the optical ones discussed below) of the 40-ft and proceeded to rectify them, he accepted this advice. As it was, Aunt Caroline – and probably William, too, during his lifetime – did what they could to deflect John's attention from the instrument's deficiencies using a variety of excuses.[127]

For small mirrors, however, such as those that William Herschel used in his Newtonian telescopes, a simple system of three peripheral contact points might work and is still sometimes recommended for amateur telescopes today.[128] It is certainly better than a support bed of small springs, which cannot provide stable tip-and-tilt control under varying loads, and therefore accurate alignment ("collimation") for critical definition. In any case, it is clear from the statements of Steavenson and Ainslie, as well as from Herschel's own observing record, that his best 7- and 10-ft Newtonians could and did give sharp, high-resolution images. Herschel's discovery of many difficult, close double stars, some of very unequal brightness and others of under 1 arcsecond separation gives indisputable proof of image sharpness.[129]

On the other hand, the various sources of optical imprecision – mirror flexure, figuring errors, convex toroidal secondaries, or secondaries of irregular figure – are probably enough in the aggregate to explain the repeated complaints found in the historical literature about the difficulties of obtaining sharp images from Newtonian optics made even by master opticians such as James Short and William Herschel himself.

---

[127] Hoskin, M., [*op. cit.* ref. 4, (2011)], p. 172. *Cf.* also, South, J., (*op. cit.* ref. 16): "[L]et me quote the words as they escaped from Sir W. Herschel's lips to me, nearly 20 years ago: – 'I shall never more do anything to this instrument myself; it must be remade – the metals are spoiled, and to make new ones will be in fact remaking the instrument; and should John, after my death, attempt it, you will, I trust, do your utmost to dissuade him.'" South's letter to the *Times* came in response to a call from an anonymous "Lover of Science" to obtain a government subvention or to establish a private subscription to re-erect the 40-ft (now that Sir John Herschel had returned home from the Cape of Good Hope). South counter-suggested a new mirror, for which he sent a check of £20 to the *Times*. John Herschel then put a stop to proceedings, writing 4 days later: "With reference to such a project, and before it goes further, I may be allowed to say that I have often and maturely considered the question of re-erecting, improving, or entirely remodelling that instrument, and have very deliberately come to the conclusion (on grounds perfectly satisfactory to myself) to take no step of the kind": Herschel, J.F.W., "Herschel's Telescope," *The Times of London*, 10-Oct-1838 (letter to the editor), p. 5.

[128] Ref. 118.

[129] Examples of very close doubles include ζ Cnc, η CrB, δ Cyg, ω Leo, ξ Sco. *Cf. TSP*, ii, pp. 662–667.

## *Mirror Collimation*

The procedures for mirror alignment articulated by Herschel for his Newtonian telescopes are to be found in many surviving documents.[130] These envision a simple naked-eye mechanical process of observing through the instrument with its eyepiece removed and a small sighting tube with narrow eyehole inserted into the focuser, a procedure still recommended today for amateur astronomers. Once the primary and secondary mirrors are tipped and tilted enough to render the entering parallel light cone, converging light cone, and the shadow of the secondary mirror on the primary concentric, then according to Herschel's instructions a Newtonian was properly and sufficiently aligned. He specifies no further instructions.

This is undoubtedly because with an f/12 or slower Newtonian, only a relatively large misalignment of the mirrors will make a visible difference to the final image sharpness. For example, even if a 200-mm f/12 primary mirror is tilted 0.4° out of coincidence with the mechanical axis of a Newtonian telescope tube – displacing the axial image by over 33 mm from the center of the eyepiece – the image seen at the center of the field of view will still be diffraction-limited. But the mechanical collimation as defined by Herschel's sighting tube procedure will be visibly very wrong. This suggests another advantage to the use of slow optical systems for Newtonian telescopes: they exhibit very relaxed collimation tolerances compared to the typical f/3 to f/4.5 systems in use by amateur astronomers today. Modern sets of instructions for collimation normally begin with a naked-eye mechanical alignment procedure (often involving a laser pointer) and end with a star test under high magnification.[131]

Herschel's procedure should work easily for a slow Newtonian, *if* the optics are made correctly and not subject to damaging flexure. But not all optics are made well, and neither were all of Herschel's, as we have previously seen. And so for example, Nevil Maskelyne complained in print in 1783 about his 6-ft Newtonian made by James Short:

> *I removed the great Speculum from the Position it ought to hold perpendicular to the Axis of the Tube, when the Telescope is said to be rightly adjusted, to one a little inclined to the same; and found a certain Inclination, of about 2½°…which caused the Telescope to shew the Object, a printed Paper, incomparably better than before; insomuch that I could read many of the Words, which before I could make nothing at all of. It is plain therefore that this Telescope shews best with a certain oblique Pencil of Rays. Probably it will be found that this Circumstance is by no means peculiar to this Telescope.*[132]

That Maskelyne found his images better and clearer with a large mirror tilt is extraordinary, since in a modern Newtonian telescope with an axisymmetric pri-

---

[130] *E.g.*, RAS MS Herschel W.1/3.6; W.5/6; W.5/8, f. 8v-10r; & W.5/14.1, section xxxix, article 2, ff. 170v-171r. In addition, the Whipple Museum of the History of Science at the University of Cambridge (UK) has a set of instructions relating to a 7-feet telescope. Other sets also exist.

[131] Texereau, J., (*op. cit.* ref. 6), pp. 297–300; Lecleire, K. & J.-M., (*op. cit.* ref. 66), pp. 261–263; and Suiter, H.R., (*op. cit.* ref. 25), pp. 111–129.

[132] Maskelyne, N., (*op. cit.* ref. 114), p. 59.

mary and correct, flat secondary, such a significant mechanical decentration causes gross coma and astigmatism. Maskelyne also found that removing the springs supporting his primary mirror immediately ended the continual image tremors that reflecting telescopes had long suffered from; indeed, it was Maskelyne who had originally induced the Rev. John Edwards to investigate the source of image tremors in reflectors, and the latter after some experiments discovered that it was the spring-support causing them.

Johann Schroeter also reported difficulties in collimating his reflectors. Schroeter owned two optics sets made by William Herschel. The first was from 1783 consisting of a 4.5-in. primary and flat secondary, which he fitted into a pre-existing 4-ft telescope (from an unknown maker) that he had acquired from Johann Elert Bode (1747–1826) in Berlin; and the second was made in 1785 and consisted of a 6.5-in. primary and flat secondary, which Schroeter fitted into an optical tube assembly of a 7-ft telescope that he had built in Germany exactly on the pattern of Herschel's reflectors (*cf.* Fig. 4.27 above), based on measurements and a drawing provided by Herschel. Schroeter described this instrument in detail as part of his first major astronomical publication, the *Beiträge zu den neuesten astronomischen Entdeckungen* [*Contributions to the newest astronomical discoveries*], a book of over 300 pages published in 1788 under the aegis of Bode. The fourth essay in the collection is entitled *Darstellung des Herschelschen siebenfüßigen Teleskops mit praktischen Bemerkungen* [*Representation of the 7-ft Herschel telescope with practical remarks*].[133]

Although in general Schroeter was delighted with his two Herschel optics sets, and used the larger one to collect a massive number of observations that formed the basis of his largest book, the *Selenotopographische Fragmente* [*Selenotopographical fragments*], a detailed study of the Moon's visible surface concentrating on selected areas (therefore called "fragments" by Schroeter), nevertheless already in October 1784, he began to complain: "My 4-foot reflector has just one fault, that it causes 1st and 2nd magnitude stars to appear unclear in too much false light, hanging on them like a small torch." He hoped Herschel could suggest a remedy, "since otherwise the instrument is so splendidly sharp and good."[134]

---

[133] For the 4.5-in. in general, *cf.* RAS MS Herschel W.1/13.1, S.12-S.15, a set of letters from Schroeter to Herschel. The last of these letters, dated 14-Jan-1784 announces the arrival of the mirror-set. For the 6.5-in. in general, *cf.* RAS MS Herschel W.1/1.1, p. 136, a letter from Herschel to Schroeter, dated 20-July-1785; and RAS MS Herschel W.1/13.1, S.16-S.27, a large set of letters from Schroeter to Herschel. A memorandum from Herschel preserved with letter S.24, says: "Sent to Mr. Schroeter in a Box…Drawing of the stand & parallelogram with an accurate description & measures of its size." For the *Darstellung*, *cf.* ref. 115, where Schroeter reproduced Herschel's drawing as Fig. 1. For an overview of Schroeter's life and writings, *cf.* Voigt, H.-H., "Johann Hieronymus Schroeter – Lilienthal – Astronomische Gesellschaft," *Sterne und Weltraum*, xxxix (2000), 1040–1047. For detailed accounts, *cf.* Gerdes, D., (*op. cit.* ref. 110); and Schumacher, H.A., "Die Lilienthaler Sternwarte," *Abhandlungen herausgegeben vom naturwissenschaftlichen Vereine zu Bremen*, xi, (1890), 39–170.

[134] Schroeter, J.H., *Selenotopographische Fragmente zur genauern Kenntniss der Mondfläche, etc.*, (Göttingen, 1791). For the quotations of Schroeter, *cf.* RAS MS Herschel W.1/13.1, S.17(3), bottom: "*Mein 4. füssiger Reflector hat den einzigen Fehler, daß er die Sterne der 1. und 2ten Grösse*

Likewise with the 7-ft reflector, Schroeter complained in December 1786: "I see double stars of the 2nd class very clear and extremely sharp…yet it still has the inconvenience that with bright stars – for example α Lyrae, Castor, Rigel (the main component) – it does not show them round and it throws out too many false rays, which is indisputably a fault of centration…." Schroeter then requested a set of printed instructions for collimation: "Should there exist a publication or booklet in England about the centration of Newtonian telescopes, I would be extraordinarily obliged to Your Excellence, if you would deign to send over such, cost what it will." Herschel replied, saying: "There is nothing in print about the adjustment of speculums, but as soon as I have time I will consider that subject exactly and acquaint you with the result."[135] At present, he noted, he was "rather hurried" with work on his 40-ft reflector.

It is not clear whether Herschel ever found the time to inform Schroeter of his methods. But as we noted previously, they were not complex, and probably would not have satisfied Schroeter, who was a trained lawyer and senior provincial administrator (*Oberamtmann*) with a penchant for exactitude and prolixity of expression in his books and letters. He luxuriated in details and *minutiae*. In any case, Schroeter was a determined learner. By August 1791 he had advanced so far that he sent a lengthy letter to Bode, which was later printed in the Bode's widely read *Astronomisches Jahrbuch*, under the title "Remark on the centration of telescope mirrors."[136] It contains Schroeter's theory of how Herschel's front-view telescopes operate, and his discovery that he could improve the imagery of his 7-ft Newtonian by purposely decentering its mirrors. The letter begins with the comment: "It were to be wished that Dr. Herschel acquainted us more exactly with the improved para-

---

*in zu vielem, wie eine kleine Fackel daranhängenden falschen Lichte, undeutlich erscheinen läßt… da das Instrument sonst so herrlich scharf und gut ist….*" For "*undeutlich*" Schroeter has written "*erndeutlich*" probably in anticipation of the following word "*erscheinen*."

[135] For Schroeter's comments and request, *cf.* RAS MS Herschel W.1/13.1, S.28, f. 4v-5r: "*Die Doppelsterne der 2$^{\text{ten}}$ Classe sehe ich sehr deutlich und äusserst scharf…; allein es hat noch den Umstand, daß es bey hellen Sternen z[um] E[xempel] α Lyrae Castor Rigel den Hauptstern nicht rund zeiget und zu viele falsche Stralen wirft, welches wol unstreitig ein Fehler des Concentrirens ist…Sollte in England vom Concentriren der Neut. Telescope eine Abhandlung oder Werkgen vorhanden seyn; so würden Ew. Wohlgeb. mich äusserst verpflichten, wenn Sie mir solches, es koste was es wolle, zu übersenden geneigten.*" For Herschel's reply, *cf.* RAS MS Herschel W.1/1.1, p. 157.

[136] For the *Astronomisches Jahrbuch*, *cf.* Schwemin, F., *Der Berliner Astronom: Leben und Werk von Johann Elert Bode 1747–1826*, in Dick, W.R. and J. Hammel (eds), *Acta historica astronomiae*, xxx (2006), pp. 21–24 and 27–28. This yearbook (begun by Bode in 1774 and continued by him until 1826) combined an ephemeris, a section of essays by various authors, and news notes. It was a predecessor of the more widely known (and still current) *Astronomische Nachrichten.* The French astronomer, Joseph-Jerôme de Lalande (1732–1807), later said of Bode's yearbook and its commencement: "*C'est depuis ce temps-là que les astronomes sont obligés d'apprendre l'allemand; car on ne peut se passer de ce recueil* [It is from that time that astronomers have been obliged to learn German; for one cannot do without this collection]." *Cf.* De Lalande, J.-J., *Bibliographie astronomique*, (Paris, 1803), p. 539. Already as an appendix to his letter of December 1786, Schroeter had sent Herschel an 8-point description of an early attempt at precise opto-mechanical alignment: RAS MS Herschel W.1/13.1, S.28, f. 7–8.

bolic figure that he gives to the large mirrors of his telescopes, and withal the method of how he collimates them."[137]

Schroeter developed in his letter the remarkable notion that Herschel's front-view telescopes formed an improvement over Newtonians not so much because they gave brighter images by utilizing only one reflection, but rather because they shaded the outer portion of one side of their primary mirror through occlusion of defective light rays by the telescope tube. In other words, the tube wall selectively vignetted the entrance pupil, so that: "Probably Mr. Herschel in this way gained not at all more light, rather he gained less but better, and more clarity."[138]

In fact this theory is false, as Schroeter later discovered in correspondence with Herschel.[139] Nevertheless, he came to the notion after discovering that his own 7-ft Newtonian with optics by Herschel could give improved images by tilting the primary mirror between 1° and 2° out of coincidence with the tube axis, even though this vignetted light from one side (presumably the defective side) of his 6.5-in. primary mirror. Schroeter cites as analogous the case of Nevil Maskelyne's Newtonian, noted above, and then states: "…some time ago when [William Herschel] invited me to visit and observe with him, he desired me to bring the object-mirror along so that he might improve it since he was now able to give his mirrors a markedly better figure."[140] Although Herschel's letter signifying this desire apparently does not survive (Schroeter's papers were nearly all destroyed in the French burning of Lilienthal in April 1813), the implication of Schroeter's published statement is that Herschel acknowledged that the 6.5-in. mirror he sold to Schroeter was of a lesser quality than he could achieve in later years, after his introduction of machine polishing.

---

[137] Schroeter, J.H., "Bermerkung über das Concentriren der telescopischen Spiegel," in *AJJ 1795*, (Berlin 1792), 138–142, p. 138 [Gerdes, D., (*op. cit.* ref. 110), 106–109, p. 106]: "*Es wäre zu wünschen, daß uns Herr D. Herschel mit der verbesserten parabolischen Figur, welche er den großen Spiegeln seiner Telescope giebt, und dabei auch mit der Art, wie er seine Telescope concentriret, genauer bekannt machte*."

[138] Schroeter, J.H., (*op. cit.* ref. 137), p. 139 [Gerdes, D., (*op. cit.* ref. 110), p. 106]: "*Wahrscheinlich gewann Herr Herschel dadurch wohl eben nicht mehr, sondern eher weniger, aber besseres Licht und mehr Deutlichkeit*."

[139] RAS MS Herschel W.1/1.1, p. 198, a letter from Herschel to Schroeter dated 4-Jan-1794: "The eye glass, in the front-view must be 2 inches more than the semidiameter of the Speculum from the center of the tube, and inclined so as to be directed to the center of the Speculum; which latter, of course must be inclined in such a manner as to throw *a full pencil of rays* into the eye glass [emphasis added]."

[140] Schroeter, J.H., (*op. cit.* ref. 137), p. 142 [Gerdes, D., (*op. cit.* ref. 110), p. 109]: "…*als er mich vor einiger Zeit einlud, ihn zu besuchen und mit ihm zu beobachten, verlangte er, daß ich den Objectivspiegel mitbringen möchte, um ihn zu verbessern, weil er jetzt den Spiegeln eine merklich bessere Figure zu geben wisse.*" Privately Schroeter told the physicist and philosopher Georg Christoph Lichtenberg in Göttingen: "In addition, I have markedly improved the 7-feet reflector by giving the large mirror an inclination of 1° 50′ to the axis of the telescope *[Auch habe ich den 7f. Refl. dadurch merklich verbessert, daß ich dem grossen Spiegel eine inclination von 1° 50′ gegen die Axe des Telescops gegeben habe*]." *Cf.* Joost, U. & A. Schöne (eds), *Georg Christoph Lichtenberg Briefwechsel*, Band III (1785–1792), p. 973.

So perhaps Schroeter's primary mirror had a slightly defective figure. Possibly it was a bit astigmatic, and this astigmatism interacted in a complex way with the residual errors of the secondary mirror so that Schroeter could detect aberration on very bright stars, where the PSF would be fully visible.

## *Schroeter's Newtonian Telescopes*

Be that as it may, Schroeter also complained about his own mirrors. For about 10 months in 1792–1793, Johann Gottlieb Friedrich Schrader, a professor of physics and mathematics at the University of Kiel (then part of Denmark), visited Schroeter in Lilienthal, having obtained a sabbatical from the king for the purpose of learning to cast speculum metal, to form mirror blanks, to grind and polish them, and to build complete reflecting telescopes.[141] In the end, Schrader and Schroeter were so successful that they built instruments rivaling, perhaps in some cases even surpassing, those of Herschel. While Schrader was in Lilienthal, together they built two complete 7-ft Newtonians (with 6.5-in. mirrors) and one 13-ft Newtonian (with a 9.5-in. mirror), as well as cast blanks for a 25-ft Newtonian (later reworked into a 27-ft front-view with *ca.* 20-in. mirrors) and 26-ft Newtonian (with a 14-in. mirror), employing a copper-tin alloy into which they melted about 2.5% arsenic by weight. The mixture was adapted from Rev. John Edwards, and produced an especially lustrous, silvery metal that was not as subject to cracking as the optimum ratio of copper to tin.[142] Schrader also trained a former gardener of Schroeter's named Harm

---

[141] For information on Schrader, *cf.* Leue, H.-J., (*op. cit.* ref. 92). Schroeter wrote about Schrader's activity in a letter to William Herschel, dated 16-Sept-1792, RAS MS Herschel W.1/13.1, S.37, f. 1v-2r: "*Desto interessanter ist es aber für mich, daß H. Schrader, Prof. der Physik und Chemie in Kiel, ein junger, thätiger und geschickter Mann, der sich zu gleichen Zweck mit könig[lichem] Urlaube von Ostern bis gegen Weihnachten bey mir aufhält, wirklich zwey ganz vortreffliche 7, einen 12 und einen 13füssigen Spiegel unter meiner Mitwirkung zu Stande gebracht hat, die sammtlich eine so genaue vortreffliche Figur haben, daß sie unter völliger Oeffnung von 6 ½, 9 and 9 ½ eng. Zollen und sehr starken Vergrösserungen ein sehr lichtvolles und deutliches Bild geben. Für mich habe ich einen 7 und den 13füssigen gewählt.* [All the more interesting is it for me that Mr. Schrader, prof. of physics and chemistry in Kiel, a young, active, and skilled man, who is staying with me on a royal sabbatical for the same purpose from Easter until about Christmas, has really completed two quite excellent 7-, a 12-, and a 13-feet mirror with my collaboration, which collectively have such a precise, excellent figure, that at their full apertures of 6½, 9, and 9½ English inches and under very strong magnifications, present a very bright and clear image. For myself I have selected one 7-feet and the 13-feet.]"

[142] For the telescopes, *cf.* the extracts from Schroeter's and Schrader's writings reprinted in Gerdes, D., (*op. cit.* ref. 110), p. 114–123, 126–131, and 137–204; and letters which passed between Schrader and Georg Christoph Lichtenberg in Joost, U. & A. Schöne, (*op. cit.* ref. 140), Band III (1785–1792), pp. 1138–1139 and 1174; and Band IV (1793–1799), pp. 61–62 and 69. For Edwards' account of his speculum mixture containing arsenic, *cf.* ref. 13. Edwards revived the practice of adding arsenic, on the recommendation of Newton. Herschel avoided arsenic, wisely it seems since Edwards died from the fumes in 1784: Croarken, M., "Mary Edwards: computing for a living in 18th-century England," *IEEE Annals of the History of Computing*, xxv (2003), Oct-Dec,

Gefken to do the same work, and Gefken later completed a 15-ft Newtonian for Schroeter. For a time Schrader, Schroeter, and Gefken also competed with Herschel for commercial customers, offering complete reflectors at substantially lower prices.[143]

The famous astronomer Friedrich Wilhelm Bessel (1784–1846) held his first astronomical post with Schroeter from 1806 to 1810. He was afterwards promoted by the king of Prussia to the Königsberg Observatory in East Prussia. In 1807, Bessel reported to Baron Franz Xaver von Zach (1754–1832) as follows about Schroeter's largest Newtonians:

> *Gefken, the optician, was quite delighted to hear that he lives on in your kind remembrance. The excellence of his mirrors seems now to have reached the highest point, and Mr. Justice-Counselor Schröter's new 15-foot reflector gives a very telling proof of it. You know the excellent goodness of his 13-foot telescope, and yet it is certain that its performance cannot be compared to the 15-foot. The extraordinary sharpness of this beautiful reflector, combined with its great light-grasp, makes it extremely valuable, and one can consider it as a true jewel of the instrumental stock here.*[144]

---

9–15, p. 11. *Cf.* also, Schrader, J.G.F., (*op. cit.* ref. 15), p. 13; and especially, Schroeter, J.H., *Aphroditographische Fragmente zur genauern Kenntniss des Planeten Venus; sammt beygefügter Beschreibung des Lilienthalischen 27 füßigen Telescops, etc.* [*Aphroditographical fragments toward a more precise understanding of the planet Venus, together with an appended description of the Lilienthal 27-feet telescope, etc.*], (Helmstedt, 1796), 201–250, p. 203: "*Beyde [Spiegel] sind von gewöhnlicher Edwardischer, besonders aber das neuere größere von vorzüglich schöner, überaus dichter weisglänzender Composition, deren Metall mit ungefähr 5 Pfund Arsenik abgedampft ist.* [Both mirrors (especially the newer larger one) are of typical Edwards composition: extremely beautiful, exceedingly compact, and white-gleaming. The metal has been volatilized with about 5 pounds of arsenic.]" This statement by Schroeter has been misunderstood in recent times to mean that the mirrors were "vapor-deposited" with arsenic when completed. But the technical term for vapor deposition in German is "aufdampfen" and not "abdampfen." Schroeter most probably refers to the well-known volatilisation of arsenic when added to a copper-tin melt during formation of speculum. *Cf.* Willach, R., (*op. cit.* ref. 9), p. 266: "The use of arsenic also had a very old tradition. Already in early times it was well known that a small amount of arsenic mixed with the molten copper gave the alloy a white shine, making it look like silver. That technique was sometimes used to produce fake silver coins. However, the method was very dangerous because the vapor is extremely toxic and since arsenic does not melt, at a temperature of 615°C it vaporizes." C.-S. Passemant in his treatise on making reflecting telescopes from 1738 confirms this: "…as for the arsenic, its weight is to be accounted as nothing, since the greatest part of it goes off as vapors… […*pour l'arsenic, son poids n'est à compter pour rien, la plus grande partie s'en allant en fumée*…]." *Cf.* Passemant, C.-S., (*op. cit.* ref. 12), p. 25.

[143] von Zach, F.X., "*Auszug aus einem astronomischen Tagebuche, geführt auf einer Reise nach Celle, Bremen und Lilienthal im September 1800*," *MC*, iii (1801), 476–491, p. 489–491 [Gerdes, D., (*op. cit.* ref. 110), p. 38]; Bessel, F.W., "*Auszug aus einem Schreiben des Herrn Bessel*," in F.X. von Zach (ed), *MC*, xv (1807), 373–376, pp. 375–376; and de Lalande, J., *Histoire abrégée de l'astronomie, depuis 1781 jusqu'à 1802*, (Paris, 1803), pp. 837–838.

[144] Bessel, F.W., (*op. cit.* ref. 143): "*Der Opticus Gefken freute sich sehr, zu hören, daß er noch in Ihrem gütigen Andenken fortlebt. Die Vortrefflichkeit seiner Spiegel scheint jetzt den höchsten Punct erreicht zu haben, wovon der neue 15füßige Reflector des Hrn. Justizraths Schröter einen sehr redenden Beweis gibt. Sie kennen die vorzügliche Güte des hiesigen 13füßigen Telescops, und dennoch ist es gewiß, daß sich seine Wirkung gar nicht gegen die des 15füßigen vergleichen läßt. Die außerordentliche Deutlichkeit dieses schönen Reflectors, verbunden mit seiner großen*

Nine years later in a private letter to Carl Friedrich Gauss (1777–1855), dated Feb. 14, 1816, from Königsberg, Bessel expressed himself in similar terms, candidly comparing the 15-ft to Schroeter's other instruments. Since Bessel was always devoted to astrometry, and thus concerned with obtaining the sharpest possible images for his positional measurements, his complete words deserve to be quoted:

> *I do not delay answering your letter just received, since you await a report from me concerning the great telescope* [*i.e.*, the 27-foot front-view] *at Lilienthal. And I must confess that I am not very familiar with this instrument, since for the observations that chiefly exercised me at Lilienthal it could afford little utility. Nevertheless, I do not believe that its performance is as outstanding as should be expected from the size of the instrument. Light-grasp it has, of course, in great measure. But it never seemed to me to possess great sharpness. During my time, the 15-foot reflector and the 10-foot Dollond were outstanding instruments in the collection: both leave everything else I have otherwise seen of the type far behind. Especially the reflector is excellent – or at least it used to be. The 7-foot Herschel telescope too is a good instrument. You yourself know the 13-foot. The rest always seemed to me to be of lesser worth, although Schroeter often held a different opinion. I don't insist on my own point of view, since Schroeter has far more practice and experience in the use of large telescopes than I do. Nevertheless, I think that there could indeed arise cases where one might like to collect the light of 3 or 4 square feet of surface area, even at the cost of image-sharpness; for these cases, the telescope would be desired, so that it could indeed be missed, if you were not to have it set up. Above all, I think that your observatory should be the final word in Germany in all astronomical cases. To favor this point of view, it would please me if you were to set up the telescope.*[145]

The passage requires some commentary. In 1799, George III (in his capacity as Elector of Hanover) had purchased on a leasing agreement the entire stock of Schroeter's instruments then in existence, with the intention of transferring them

---

*Lichtstärke, machen ihn äußerst schätzbar, und man kann ihn als eine wahre Zierde des hiesigen Instrumenten-Vorraths ansehen.*" For an assessment of Bessel's life, *cf.* Herschel, J.F.W., *A brief notice of the life, researches, and discoveries of Friedrich Wilhelm Bessel*, (London, 1847).

[145] Bessel to Gauss, cited in *Anon.*, *Briefwechsel zwischen Gauss und Bessel*, (Leipzig, 1880), pp. 232–233: "*Ich zögere nicht, Ihren eben empfangenen Brief zu beantworten, da Sie eine Nachricht wegen des grossen Teleskops in Lilienthal von mir erwarten. Auch ich muss gestehen, dieses Instrument wenig zu kennen, da es für die Beobachtungen, die mich in Lilienthal vorzüglich beschäftigten, wenig Nutzen gewähren konnte. Indessen glaube ich nicht, dass seine Wirkung so sehr ausgezeichnet ist, als von der Grösse des Instruments erwartet werden sollte. Lichstärke besitzt es allerdings in einem hohen Maasse; allein grosse Deutlichkeit schien es mir nie zu haben. – Vorzügliche Instrumente der dortigen Sammlung waren zu meiner Zeit der 15füssige Reflector und der 10füssige Dollond; beide lassen alles, was ich sonst wohl von der Art gesehen habe, weit hinter sich zurück; namentlich ist der Reflector vortrefflich, oder er war es wenigstens. Auch das 7füssige Herschel'sche Teleskop ist ein gutes Instrument; das 13füssige kennen Sie Selbst. Die übrigen schienen mir immer von geringerm Werthe zu sein, obgleich Schröter oft anderer Meinung war; ich bestehe auf der meinigen auch nicht, da Schröter in dem Gebrauche der grossen Teleskope weit mehr Uebung und Erfahrung besitzt als ich. Indessen glaube ich, dass doch wohl Fälle vorkommen können, wo man das Licht, selbst auf Kosten der Deutlichkeit, gern von einer Oberfläche von 3 bis 4 Quadratfuss gesammelt haben möchte; für diese würde also das Teleskop erwünscht sein, so dass es doch wohl vermisst werden könnte, wenn Sie es nicht aufstellen liessen. Ueberhaupt glaube ich, dass Ihre Sternwarte in allen astronomischen Fällen in Deutschland die letzte Instanz werden muss; dieser Ansicht zu Gefallen würde es mich freuen, wenn Sie das Teleskop aufstellen liessen.*"

ultimately to Göttingen University, an institution founded by his grandfather, George II.[146] Schroeter was an upper-level civil magistrate (*Oberamtmann*) and later a justice-counselor (*Justizrath*) of the Hanoverian court in northwestern Germany. Göttingen, officially the *Regia Georgia Augusta Universitas*, was a favored institution of the Georgian kings, and in exchange for his equipment Schroeter obtained 1200 lb sterling. This was a substantial sum of money, equivalent to 6 years of William Herschel's salary as Royal Astronomer. Schroeter retained use of his equipment according to the terms of the lease until his death. In the event, after the burning of Lilienthal in April 1813 and the partial destruction of his equipment, Schroeter, who was by then growing old and had never been a physically strong man, let the surviving instruments go in 1815. They were brought to Göttingen by Karl Ludwig Harding (1765–1834), who had served Schroeter as his first paid assistant (1799–1805) and who was later promoted to astronomer at Göttingen after his discovery of minor planet 3 Juno at Lilienthal in 1804.[147] Harding thereafter worked under Gauss as director. Bessel was hired to replace Harding as Schroeter's second paid assistant. He took charge of positional measurements, while Schroeter attempted to investigate the physical constitution of Solar System bodies.[148] Schroeter finally died in August 1816, a few weeks after being knighted by the Prince Regent (later George

---

[146] Dieter Gerdes has published the original text of the leasing-agreement in (*op. cit.* ref. 110), pp. 213–217.

[147] Extensive documents relating to the transference survive in Göttingen University Library.

[148] *Cf. e.g.*, Bessel, F.W., *Untersuchungen über die scheinbare und wahre Bahn des im Jahre 1807 erscheinenen grossen Kometen* [*Researches on the apparent and true path of the great comet that appeared in the year 1807*], (Königsberg, 1810), p. 3: "*Die Lilienthaler Sternwarte war zum würdigen Empfange des Kometen vorzüglich gut ausgerüstet; denn sie enthielt, ausser den bekannten grossen und schönen Teleskopen, die recht geeignet waren, uns Aufschlüsse über die räthselhafte physische Beschaffenheit dieses Himmelskörpers zu verschaffen, einige kleinere Instrumente, die sich vorzüglich zu den Ortsbestimmungen des Kometen schickten. Die Beobachtungen zerfielen also in zwei Branchen, die wir, mein verehrter Freund der Herr Justizrath Schröter und ich, unter einander theilten. Der getroffenen Abrede zufolge, beschäftigten den Herrn S. ausschliesslich die physischen Beobachtungen, deren merkwürdigen Resultate er öffentlich bekannt zu machen jetzt im Begriff ist. Über diese schweige ich also ganz; säume aber nicht länger, das was die Ortsbestimmungen des Kometen angeht, mitzutheilen.* [The Lilienthal Observatory was exceedingly well fitted out for the worthy reception of the comet. For it contained, aside from the well-known great and beautiful telescopes which were quite appropriate to provide information about the enigmatic physical nature of this celestial body, several smaller instruments which were excellently fitted to positional determinations of the comet. Thus, the observations sundered themselves into two branches, which we – my honored friend, the Justice-Counselor Schröter, and I – divided between ourselves. According to the agreement struck, Mr. Schröter busied himself exclusively with physical observations, whose remarkable results he is now on the verge of publishing. Hence, I pass over these in complete silence, but will not put off any longer communicating what pertains to the comet's positional determinations.]" Schroeter's companion book discussing the comet as a physical object was published as, Schroeter, J.H., *Beobachtungen des grossen Cometen von 1807 in physischer Hinsicht* [*Observations of the Great Comet of 1807 from a physical standpoint*], (Göttingen, 1811).

IV) into the Royal Guelphic Order, the same order into which William Herschel had been knighted a few months earlier.[149]

The transference of the equipment to Göttingen led Gauss in January 1816 to query his friend Bessel for his opinion “quite sincerely *sub rosa*” on Schroeter’s 27-ft front-view. Gauss was concerned about the cost of re-erecting it, since it was a large instrument. He had only looked through it once, in 1803, he explained, and found the performance far beneath his expectation. Gauss, too, was interested mainly in astrometry and so was not looking for a “light-bucket.” Bessel’s reply is what has been quoted above. From this it is clear that Bessel wished to see the 27-ft re-erected; he considered Schroeter his “honored friend,” and not merely his former boss.

The 10-ft Dollond that Bessel mentions was a 3.9-in. f/30 achromat built by Peter Dollond, which Schroeter had acquired in Copenhagen. Schroeter had it mounted equatorially, which allowed him to locate and observe planets high in the sky during daylight hours. Bessel used the 10-ft Dollond for making positional measurements. It is clear from his statements that Bessel considered this refractor as well as the 15-ft Newtonian (containing a 12-in. f/15 mirror) as giving the *ne plus ultra* of image sharpness. Elsewhere, in an article on Saturn and its moon Titan, Bessel expanded on the idea, giving several additional interesting details:

> *The telescope that I used for my measurements of the 4th satellite’s distances is a 15-foot Gefken reflector of outstanding goodness. It possesses a very good machinery, and can be moved so quickly and easily that it is not very difficult to hold a star relatively still for a time in the field of view. The reflector is equipped with two mirrors, the first of which although initially very perfect, began in the early part of 1806 to alter its figure somewhat and to show images that were not always completely sharp. Mr. Justice-Counselor Schroeter, when he investigated the cause, discovered it in the insufficient thickness of the metal, which had occasioned a flexure. Immediately he contracted with the optician Gefken to fabricate a new mirror, which on July 9, 1806, took the place of the old. This can be considered the master-work of its maker. The 15-foot telescope henceforth combined the* most perfect *sharpness with extraordinary light-grasp. Hardly ever again might its equal exist in the world* [author’s emphasis].[150]

---

[149] Gerdes, D., (*op. cit.* ref. 110), p. 18; Bode, J.E., *AJJ 1819*, (Berlin, 1816), p. 258; and on “Sir” William Herschel’s knighthood, *cf.* now, Hanham, A., and M. Hoskin, “The Herschel knighthoods: facts and fiction,” *JHA*, xliv (2013), 149–164.

[150] Bessel, F.W., “Untersuchungen über den Planeten Saturn, seinen Ring und seinen 4ten Trabanten,” *Königsberger Archiv für Naturwissenschaft und Mathematik*, i (1812), 114–172, pp. 122–123: “*Das Teleskop, welches ich zu meinen Messungen der Abstände des 4ten Trabanten benutzte, ist ein 15fussiger Gefkenscher Reflector von vorzüglicher Güte; der eine sehr gute Maschinerie besitzt, und sich so schnell und leicht bewegen lässt, dass es nicht sehr schwierig ist, einen Stern einige Zeit im Sehefelde relativ ruhend zu erhalten. Zu dem Reflector gehören zwei Spiegel, deren erster, obgleich er anfangs sehr vollkommen war, im Frühjahr 1806 anfing, seine Figur etwas zu verändern, und die Bilder nicht immer vollkommen deutlich zu zeigen. Herr Justizrath Schroeter, der der Ursache davon nachspürte, entdeckte sie in der nicht hinlänglichen Dicke des Metalls, die eine Biegung verursacht hatte; und gleich trug er dem Optikus Gefken die Verfertigung eines neuen Spiegels auf, der am 9 July 1806 den Platz des alten einnahm, und der als das Meisterstück seines Verfertigers angesehen werden kann. Mit ausserordentlicher Lichtstärke vereinigte das 15fussige Teleskop von nun an die* vollkommenste *Deutlichkeit; schwerlich möchte mehr als einmal seines Gleichen in der Welt existiren.*”

The alteration of the figure in Gefken's original mirror for the 15-ft telescope might refer to stress in the metal, which could have been imperfectly annealed rather than simply being too thin. Be that as it may, it is clear that Schoeter possessed some excellent telescopes, including one Newtonian of the highest optical quality.[151] Hence, Schroeter's complaints about the difficulties of collimation – more of which will be presented in a moment – cannot be ascribed to his ignorance of how telescopes should perform in practice or how to align them. Moreover, as we shall see, Prof. Schrader agreed with his complaints. And yet these very slow mirror systems (up to f/22) ought to have been trivial to align since their centration tolerances were in principle very loose.

After Schrader returned to Kiel in 1793 he incorporated his own 14-in. mirror into a 26-ft Newtonian telescope. Schroeter incorporated his large mirrors (near twins of about 20 in. diameter) into a 25-ft Newtonian. Later, he had Gefken rework them and converted the Newtonian into a 27-ft front-view. In 1796, Schroeter – as an appendix to his book on the planet Venus, the *Aphroditographische Fragmente* – described the resultant telescope. In Section 27 of his detailed description, Schroeter discusses the optical arrangements. He prefaces his discussion with the comment:

> *This invention* [*i.e.* the front-view] *of Dr. Herschel's has – to my knowledge – been nowhere described as yet in sufficient detail, and just this fact has in the past for me as for others caused a somewhat erroneous conception. But now that I have gotten a better theoretical and practical acquaintance with it, I have come to value it so highly that in the case of this large reflector for a long time I have used it alone, having completely removed the secondary mirror, and resolved never to use it again in the telescope. Just as valuable seems to me the present opportunity to communicate what I know about this useful construction, and all*

---

[151] Some disparaging comments in the published literature about Schroeter's telescopes (even his Newtonians) are certainly referable to observers who were not familiar with the difficulties that plague large telescopes, especially reflectors. For example, Wilhelm Olbers visited his friend Schroeter in May 1806 and observed through the 15-ft Newtonian. Olbers had long suspected that Schroeter's anomalously large measurements of the diameters of the minor planets Ceres, Vesta, and Juno were due to problems with his reflecting telescopes (Olbers' own instruments consisted of small refractors). And sure enough, Olbers found aberration blurs around double stars in the 15-ft which he reported confidentially to Gauss were larger than 4 arcseconds, seeming to confirm his suspicions. His letter to Gauss survives and has been published and cited to the detriment Schroeter. Yet Bessel's discussion of this telescope makes clear that he and Schroeter were aware of the problem with the mirror and that Gefken was fabricating a replacement. Seemingly Olbers was not aware of this. But when next he returned to Lilienthal in October 1806 for another visit, Olbers discovered a very different mirror, and reported to Gauss: "There is now in Lilienthal a 15-feet telescope that surpasses everything else I have witnessed there….Never before in such a manner could I discern the separation of double stars there. [*In Lilienthal giebt es jetzt ein 15 füssiges Teleskop, das noch alle übertrifft, die ich dort gesehen habe….So habe ich dort noch nie die Zwischenräume der Doppelsterne unterscheiden können.*]" *Cf.* Oestmann, G., "Astronomischer Dilettant oder verkanntes Genie? Zum Bild Johann Hieronymus Schroeters in der Wissenschaftsgeschichte," in Dick, W. and J. Hamel (eds), *Astronomie von Olbers bis Schwarzschild, Acta historica astronomiae*, xiv, (Harri Deutsch, 2002), 9–24, p. 12; and Schilling, C., *Wilhelm Olbers, sein Leben und seine Werke*, Band 2.1, (Berlin, 1900), pp. 300 and 312.

> *the more so in the best interests of science, because it can beneficially be applied to smaller telescopes as well.*[152]

Herschel had in fact, a year earlier, in 1795, at length described the imposing edifice of his 40-ft front-view in a long article that appeared in the *Philosophical transactions*.[153] This was 6 years after he declared the instrument complete.[154] Although his article is richly illustrated, the optical arrangements per se are not described in much detail. Principally Herschel focuses on the mechanics, which were certainly awe-inspiring. The 40-ft was the first telescope ever built whose tube was large enough for people to walk through (some such as Caroline Herschel (1750–1848) and the novelist Fanny Burney (1752–1840) walking upright), and a famous story recounted decades later by Caroline in a letter told how during its construction George III conducted the Archbishop of Canterbury, John Moore (1730–1805), through the tube, saying "Come, my Lord Bishop, I will show you the way to Heaven!"[155] Nevertheless unlike Schroeter, William Herschel did not make a habit of publishing detailed descriptions of his instruments. The one exception is his article on the 40-ft.

The reason for this exception is uncertain. Perhaps it was the enormous cost of the instrument (£4000 in two grants from the crown) combined with the slender scientific output. This led to whispers about the instrument (see below).[156] But in addition Schroeter, whose activities and publications were well known to the Herschels, had been busily issuing letters, notices, and articles drawing attention to the successful completion of his own instruments in the late 1780s and early 1790s.[157] It will be well to list these. (1) In 1784 and 1786 Schroeter sent letters to Bode (later published in the *Astronomisches Jahrbuch*) discussing the completion of

---

[152] Schroeter, J.H., (*op. cit.* ref. 142), p. 224: "*Diese Erfindung des Herrn D. Herschel ist meines Wissens noch nirgends umständlich genug beschreiben, und eben das hat vorher bey mir, so wie bey andern, eine etwas irrige Vorstellung veranlasset. Jetzt aber, da ich sie theoretisch und practisch näher kennen gelernt, ist sie mir so schätzbar geworden, dass ich sie bey diesem grossen Reflector seit geraumer Zeit ganz allein angewandt, den Fangspiegel ganz weggeschaffet, und mir vorgenommen habe, diesen nie wieder dabey mit anzuwenden. Eben so schätzbar scheint mir aber auch die jetzige Gelegenheit, das, was mir von dieser nützlichen Einrichtung bekannt ist, um so mehr zum Besten der Wissenschaft hier mitzutheilen, weil sie auch bey kleinern Telescopen mit Vortheil angewandt werden kann.*" The front-view arrangement was used very successfully on small instruments, containing 3.9 to 10-in. mirrors, by the early American telescope maker, Amasa Holcomb. For tests of Holcomb's telescopes, *cf.* Hamilton, W., "Report on Amasa Holcomb's reflecting telescopes," *JFI*, xiv (1834), 169–172; xv (1835), 11–13; and xviii (1836), 109–110 and 312; & Mason, E.P., *Introduction to practical astronomy*, (New York, 1841), pp. 5–20.

[153] Herschel, W., [*op. cit.* ref. 3 (1795)].

[154] Herschel, W., [*op. cit.* ref. 3 (1795)], p. 350 [*TSP*, i, p. 487].

[155] Herschel, Mrs. J., *Memoir and correspondence of Caroline Herschel*, 2nd ed., (London, 1879), p. 309.

[156] Already in October 1787, Georg Christoph Lichtenberg wrote to Schroeter wondering if some misfortune had not befallen the instrument, since no one heard any news about it: Joost & Schöne, (*op. cit.* ref. 140), Band III, p. 453.

[157] Sometime around 1797, Caroline Herschel compiled a *ca.* 22-page manuscript catalog of notable articles and papers published in Bode's *Astronomisches Jahrbuch*¸ in which on a separate sheet of paper inserted near the end, she gave a sequential listing of 38 items from Schroeter, including all those concerned with his telescopes. *Cf.* RAS MS Herschel C.3/6.

his 4-ft and 7-ft Newtonians; (2) In 1788, he published a lengthy description with illustrations of the 7-ft Newtonian. (3) In 1792, he published notices of his work with Schrader in the *Astronomisches Jahrbuch*, as well as his letter concerning the collimation of telescope mirrors. (4) In 1793, Schroeter published a description of his 13-ft Newtonian, which appeared in Latin in the *Memoirs of the Royal Society of Sciences* at Göttingen. (5) Also in 1793, he published in Bode's *Jahrbuch* further notices of his work with Schrader, and a German description of his 13-ft Newtonian. (6) In 1794, he published an article in the *Jahrbuch* on his 25-ft Newtonian, which was then the largest Newtonian telescope in the world. And finally, (7), in 1796, Schroeter published a lengthy illustrated description of his 27-ft front view as an appendix to his book on Venus. Johann Schrader, in the meantime, also in 1794, published a lengthy description of his own 26-ft Newtonian, which he erected near Kiel.[158] All or nearly all of these publications make repeated mention of William Herschel in laudatory terms. Although none of the publications matches Herschel's own from 1795 in sumptuousness (including a beautiful engraving of the telescope and elegant dedication to George III), it is perhaps not unreasonable to think that they helped to create some pressure on Herschel to speak publicly about his own vast, royally expensive telescope, which had evoked widespread awe during its construction in the late 1780s, as well as hopes for magnificent discoveries to follow. Indeed, Herschel fueled the excitement by hastily announcing – even before the instrument was actually complete – the discovery of two new satellites of Saturn (Enceladus and Mimas, which Herschel termed "the sixth" and "the seventh"). But after the initial fanfare, he fell largely silent, announcing no further discoveries of note. And he remained silent in print until 1795.[159]

---

[158] Schroeter, J.H., *AJJ 1787*, (Berlin, 1784), 253–254; *idem, AJJ 1789*, (Berlin, 1786), 153–154; *idem,* (*op. cit.* ref. 115); *idem, AJJ 1795*, (Berlin, 1792), 108–110; *idem,* (*op. cit.* ref. 137); "*Descriptio telescopii xiii pedum, et observationum eius ope in Saturno et Luna institutarum*," *Commentationes societatis regiae scientiarum Gottingensis*, xi (1793), 32–37; *idem, AJJ 1796*, (Berlin, 1793), 158–160 and 226–234; *idem, AJJ 1797*, (Berlin, 1794), 184–203; *idem,* (*op. cit.* ref. 142); and Schrader, J.G.F., (*op. cit.* ref. 15). Most of these sources are reproduced in Gerdes, D., (*op. cit.* ref. 110), pp. 46–204.

[159] For the circumstances surrounding the building of the 40-ft, the discovery of Saturn's additional moons, and the excitement and expectations of the time, *cf.* Hoskin, M., [*op. cit.* ref. 4, (2011)], pp. 118–127. In Germany, as well as France and England, there was excitement, but here tinged with pride for a native son made good. Georg Christoph Lichtenberg (who was hunchbacked) declared in June 1787, that as soon as he heard that the 40-ft was finished, he would "gird his loins" and make the journey from Göttingen to Slough, because he could not die peacefully, living at that time and not seeing such a thing!: Joost & Schöne, (*op. cit.* ref. 140), Band III, p. 368. Schroeter repeatedly wrote to Herschel enquiring for news and stating that he would join Lichtenberg in the journey: "We Germans are extremely fervent in our wish for news about it…[*Aeußerst sehnlich wünschen wir Deutschen davon Nachricht zu erhalten*….": RAS MS Herschel W.1/13.1, S.28, f. 5v. And he swooned to think of the sights to follow: "What delights and new discoveries will this astonishing tool not vouchsafe to you? Could I but once enjoy the good fortune to be present at your observations! [*Welche Wonne und neue Entdeckungen wird Ihnen nicht dieses bewunderungswürdige Werkzeug gewähren? Könnte ich doch nur ein einzigesmal das Glück geniessen, Ihren Beobachungen beyzuwohnen!*]": RAS MS Herschel W.1/13.1, S.32, f. 2r.

Schroeter had connections at court, through his friend and former colleague, George August Best (1755–1823). Best was British, lived in London, and served as Chamber Secretary for the Electorate of Hanover. He had gone to Germany, the land of his fathers, and had studied law at Göttingen like Schroeter. Together they served the Chamber in Hanover itself during the 1770s. It was there that Schroeter, through his love of music, had come into contact with Jacob (1734–1792) and Dietrich Herschel (1755–1827), William's brothers, who were members of the court orchestra. Later George Best became a privy councilor to George III and a member of the Royal Society. It was through his agency that several of Schroeter's papers, translated from German into English, were published in the *Philosophical transactions*; it was also through Best's agency that the court of George III made the leasing agreement with Schroeter for his instruments in 1799. Finally, Best served as intermediary between Herschel and Schroeter, conveying money to Herschel for the various purchases that Schroeter made from him in the 1780s, and delivering the letters and essays from Schroeter that still survive in the RAS Herschel archive. Best's services as intermediary continued until at least 1804. Schroeter mentions him by name in his letters to Herschel nearly two dozen times.[160]

Schroeter even attempted to cultivate a direct connection to George III by dedicating his most important book, the *Selenotopographische Fragmente* (published at Göttingen in 1791) to him as king and lord. George III's youngest surviving son, Prince Adolphus Frederick (1774–1850), 1st Duke of Cambridge, personally visited Schroeter in September 1800 at Lilienthal. In view of these connections and Schroeter's many publications mentioning William Herschel over and over again, Herschel could hardly ignore him, even if he was not altogether enamored with the loquacious *Oberamtmann* and his theories about Solar System bodies.[161]

Whatever hesitations Herschel felt toward Schroeter, at the end of the eighteenth century in Germany they were celebrated together, von Zach going so far as to pronounce that: "Herschel's and Schroeter's names will glitter like Castor and Pollux,

---

[160] For George August Best, *cf.* Jefcoate, G., "Wilhelm Philipp Best," in *Oxford Dictionary of National Biography*, www.oxforddnb.com/index/101039065/Wilhelm-Best, (Oxford, 2004–13).

[161] Herschel's annoyance is evident, *e.g.*, in his paper of 1793, entitled: Observations on the planet Venus," *PT*, lxxxiii, 201–219 [*TSP*, i, 441–451], where he attacked Schroeter's observations of Venus and suggestions of possible high mountains, and insinuated that Schroeter might have appropriated his own invention of the lamp-micrometer. In a folder of loose notes preserved in the RAS archive, Herschel wrote: "This machine is an immediate application of my lamp & disk micrometers & projection on a wall." *Cf.* RAS MS Herschel W.7/14.1, f. 38v. In addition, Herschel later wrote to his friend Prof. Patrick Wilson in a letter, dated 21-Feb-1796: "I must in the next place have turned to a tedious treatise on the solar spots written but lately by Mr. Schroeter, which must infallibly have brought on a controversy, as that Gentleman has sufficiently shewn in his last paper on Venus a disposition to take hold of every opportunity to defend his erroneous as well as his good communications." On the other hand, Herschel told Joseph Planta in 1793 that he counted himself among among Schroeter's friends "very sincerely": RAS MS Herschel W.1/1.1, p. 193. And in 1798 he supported Schroeter's election to the Royal Society as a foreign fellow (Royal Society Archive item GB 117, EC/1798/05).

as long as stars twinkle in the firmament…."[162] And certainly Schroeter did possess some excellent telescopes, so that his ideas about optics merit attention. We have noticed his dissatisfaction with the mirrors he had received from Herschel. No matter how painstaking his efforts, he could not achieve fully round and compact images during collimation. But he also complained more generally about Newtonians, and about collimating his own telescopes, for example, his 13-ft Newtonian:

> *During* [centering] *above all a double reflection of the light rays, which happens through use of a secondary mirror, is very irksome. The experience of many years has persuaded me that theory certainly suffices for a provisional centering, but in no wise for a* positively exact one. *Usually, if one wishes to dispose of a glimmer and faint traces of a double image, which often remains even with the best figured pair of mirrors, and if one wishes to obtain perfect sharpness and clarity, one must in the end resort to a multiplicity of trials that often demand a lot of time and patience, but through which the remaining imprecision in the placement of both mirrors and eyepiece (theoretically too small to detect) is completely removed. Naturally, this difficulty increases as a reflector and its quantity of light grow. The latter must be centered on the axis of the eyepiece; the slightest imprecision in the placement of the mirrors renders the image unclear and the reflector unusable. How great the trial and tribulation may become especially in the case of a 27-foot reflector which has to remain exposed in the open air to dampness and dryness, warmth and cold and occasionally also to stiff winds, will best be judged by the practical expert. Already in the case of my 13-foot, whose mirrors had been imperceptibly jarred in their first trials upon the sky, I had to spend several weeks experimenting in order again to be rid of a slight sideways gleam or double image which made the reflector useless at high powers for which it was otherwise very suitable. How onerous, therefore, can cases like these not become especially for such a large instrument which is exposed to the free air, where despite every solidity and durability of construction such an imperceptible dislocation can arise much more easily?* [author's emphasis][163]

---

[162] "*Herschel's und Schröter's Namen werden wie Castor und Pollux am Himmel glänzen, so lange Sterne am Firmamente funkeln….*" *Cf.* von Zach, F.X., "Joh. Hieron. Schröter, als Astronom," *Allgemeine geographische Ephemeriden*, iii (1799), 549–550, p. 550 [Gerdes, D. (*op. cit.* ref. 110), p. 24].

[163] Schroeter, J.H., (*op. cit.* ref. 142), p. 225–226: "*Bey [dem Concentriren] ist überhaupt eine doppelte Reflexion der Lichtstrahlen, welche bey dem Gebrauche eines Fangspiegels Statt findet, sehr lästig, und mehrjährige Erfahrung hat mich überzeuget, daß die Theorie zwar für ein beyläufiges, keinesweges aber für ein pünktlich genaues Concentriren hinreiche. Gewöhnlich muss man zuletzt, wenn man einen bey der besten Figur beyder Spiegel oft übrig bleibenden geringen Schimmer und entfernte Spuren eines doppelten Bildes wegbringen, und die vollkommene Schärfe und Deutlichkeit erhalten will, zu mannichfachen, oft sehr viel Zeit und Geduld erfordernden Experimenten seine Zuflucht nehmen, wordurch die noch übrige, theoretisch unentdeckbare geringe Ungenauigkeit in der Lage beyder Spiegel und des Augenglases vollends gehoben wird. Natürlich nimmt aber diese Schwierigkeit zu, je größer ein Reflector und die Lichtmenge ist, welche auf die Axe des Augenglases concentrirt werden muss, wo die geringste Ungenauigkeit in der Lage der Spiegel das Bild undeutlich und den Reflector unbrauchbar macht. Wie gross also diese Schwierigkeit und Beschwerlichkeit vollends bey einem 27füßigen Reflector werden könne, welcher der Feuchtigkeit und Trockniss, Wärme und Kälte und dabey zwischendurch heftigen Winden in völlig freyer Luft ausgesetzt bleiben muss, wird der practische Kenner am richtigsten beurtheilen. Schon bey meinem 13füßigen, dessen Spiegel sich bey dem ersten Versuche auf den Himmel unmerklich verrückt hatten, mußte ich verschiedene Wochen mit Experimenten zubringen, einen geringen Nebenschimmer oder doppeltes Bild wieder weg zu schaffen, welches den Reflector bey starken ihm sonst sehr angemeßen*

Elsewhere in his writings, too, Schroeter makes a point of mentioning centration of the mirrors in his telescopes, as if it were the arduous "finishing touch" to the building of any reflector. With fast modern Newtonians, this can often be the case, since their centering tolerances are rigorous. But the loose tolerances of a very slow f/15 or f/20 Newtonian should make collimation almost trivial. And so it seems to have been with Herschel's later Newtonians, since as previously noted, his surviving sets of collimation instructions, provided to customers, make no mention at all of the star testing that Schroeter routinely performed and to which he alludes in the passage above. Instead, Herschel gave a set of very simple directions for rough mechanical centering. Apparently this is all he found necessary, and it accords with what modern optical theory suggests about a correctly made slow Newtonian.

Very likely Schroeter was not using Herschel's more advanced method of testing flats, employing the double-card technique discussed earlier and illustrated in Fig. 4.18. Herschel kept that method a secret. Primitive as the test is by modern standards, seemingly it was enough to render Herschel's small secondary mirrors usable when their remaining convexity was combined with the inevitable toroid generated by the polishing technique. Schroeter probably had worse flats in general that required a long, touchy collimation process of aligning primary mirror to secondary so as to compensate and minimize the combined aberrations of the mirror pairs arising from their individually sub-optimal figures.

As a result, when Schroeter's primary mirrors became larger than 12 in. in diameter, he (like Herschel) found it best to dispense with the secondary mirrors altogether, and tilt the primaries into the front-view configuration:

> *Against every mischief of this sort the removal of the secondary mirror and its attendant second reflection serves as a preventive (at least in large measure) to such an extent that I am able…to center* [the front-view] *reflector* in a few minutes *as well as I could not achieve perhaps in as many days when using the secondary mirror… But the most important factor is that by means of the added reflection of the secondary mirror some light is always dispersed and lost – all the more so, the less precise its figure and its placement are with respect to the objective-mirror. How difficult it is to give a* perfectly *plane surface to the secondary mirror in the Newtonian construction, and to set its inclination while maintaining the parallelism with absolute precision at 45°, is well enough known in practice.* [author's emphasis][164]

---

*Vergrößerungen unbrauchbar machte. Wie lästig können also nicht dergleichen Fälle vollends bey einem so großen, der freyen Luft ausgesetzten Instrumente werden, wo bey aller Festigkeit und Dauer der Einrichtung eine so unmerkliche Verrükung viel leichter vorkommen kann*?"

[164] Schroeter, J.H., (*op. cit.* ref. 142), p. 226–227: "*Allem dergleichen Unheile wird aber durch Wegnehmung des Fangspiegels und der damit verbundenen zweyfachen Reflexion, wenigstens größentheils und so sehr vorgebeugt, daß ich…in etlichen Minuten eben so gut zu concentriren vermögend bin, als ich es unter Anwendung des Fangspiegels vielleicht in eben so viel Tagen nicht seyn würde…Der wichtigste Umstand ist aber, daß durch die zweyte Reflexion des Fangspiegels immer einiges und desto mehr Licht zerstreuet wird und verlohren geht, je weniger seine Figur und seine Lage gegen den Objectivspiegel genau ist. Wie schwer es aber sey, dem Fangspiegel nach der Neutonischen Einrichtung eine vollkommen plane Fläche zu geben, und ihn unter Beybehaltung des Parallelismi pünctlich genau auf 45° zu incliniren, ist practisch bekannt genug.*"

In all of this Professor Schrader agreed. He published a detailed description in 1794 of his own 26-ft Newtonian telescope, which he had erected just outside Kiel. In justifying his choices, Schrader noted:

> *To conclude this brief essay, I want to subjoin several more remarks. Everyone with practical knowledge of the construction of reflecting telescopes knows well what a painstaking and patience-exhausting labor it is to center the mirrors properly. Let a man execute this labor ever so precisely according to all the practical rules, yet he will find that in the end there must still be a small displacement of the mirror to give sufficient sharpness with increasing magnification. To ascertain this small displacement, he often searches many weeks or indeed months in vain, until a lucky accident puts it in his hands. Often too a less than perfect mirror figure causes the most correct positioning not to yield the greatest sharpness. In these circumstances, a slight gleam is continually found which impedes the most perfect clarity, especially in the case of large mirrors and high magnifications. Probably this is caused by light-rays that the mirror cannot unite to a point because of its imperfection (even though this imperfection may often be very slight). Unhappily one takes refuge – especially if he is convinced that the mirror's figure is very close to a parabola – in so-called aperture stops, which necessarily rob the mirror of light… In this case it is often manifest that a slightly tilted positioning of the objective-mirror yields all desirable sharpness. It seems to me as if the incorrectly reflected light rays were thereby, so to speak, cut off and impeded from entering the eye. Nevertheless, one is often just as wrong in wishing to ascribe this situation to an erroneous figure alone, since other practical rules exist to convince oneself of the mirror's good figure. So it must be the case, as can be explained from the principles of higher optics, that a very small error in the placement both of the primary and secondary mirrors relative to one another in itself diminishes the sharpness. Herschel, therefore, deserves hearty thanks for greatly easing the burdensome labor of centration by getting rid of the secondary mirror and inclining the primary laterally….*[165]

---

[165] Schrader, J.G.F., (*op. cit.* ref. 15), pp. 16–17: "*Zum Beschlus dieses kleinen Aufsazes will ich noch ein Paar Bemerkungen hinzufügen. Jeder, der mit praktischen Kentnissen in der Konstruktion der reflektirenden Fernröhre versehen ist, wird wol wissen, welche mühsame und Geduld ermüdende Arbeit das gehörige Centriren der Spiegel sei. Man verrichte diese Arbeit nach allen praktischen Regeln noch so genau, so findet man, daß es zulezt noch auf eine Kleinigkeit in der Stellung ankomme, in die der Spiegel versezt werden mus, um bei zunehmenden Vergrösserungen stets hinlängliche Schärfe zu zeigen. Diese Kleinigkeit in Veränderung der Lage zu finden, sucht man oft viele Wochen ja Monate lang vergebens, bis sie ein glükliches Gerathewohl an die Hand giebt. Oftmals ist auch eine nicht völlig vollkommene Figur des Spiegels Ursache, daß die richtigste Stellung nicht gerade die grösste Schärfe gewährt. Man findet unter diesen Umständen stets einen schwachen Schimmer, der die vollkommenste Deutlichkeit, zumal bei Spiegeln von grossem Durchmesser und bei starken Vergrösserungen hindert. Wahrscheinlich verursachen dies diejenigen Lichtstrahlen, die der Spiegel wegen seiner wiewol öfters nur sehr geringen Unvollkommenheit nicht in einem Punkte vereinigen kan. Ungerne nimt man, zumal wenn man überzeugt ist, daß die Figur des Spiegels der Parabel sehr nahe gekommen sei, zu den sogenanten Blendungen seine Zuflucht, die nothwendig dem Spiegel Licht rauben…Hier zeigt es sich oft, daß eine etwas wenig schiefe Stellung des Objektivspiegels alle erwünschte Schärfe gewährt. Es scheint mir, als wenn dadurch die unrichtig zurükgeworfenen Lichtstralen gleichsam abgeschnitten und verhindert würden ins Auge zu kommen. Allein man irrt sich oft eben so sehr, wenn man diesen Umstand einer Unrichtigkeit der Figur allein zuschreiben wollte. Denn man hat auch andere praktische Regeln, durch welche man sich von der guten Figur des Spiegels überzeugen kan; und daher mus, wie sich auch schon aus den Grundsäzen der höheren Optik erläutern lässt, die kleinste unrichtige Stellung beider, des Objektiv- und Okularspiegels, gegen einander schon allein eine Verminderung der Schärfe bewirken. Herschel verdient daher vielen Dank, daß er die mühsame Arbeit des Centrirens durch Weglassung des Okular- oder Fangspiegels und durch eine seitwärts gerichtete Neigung des*

Since it is clear from this discussion that Schroeter and Schrader were well aware of what good telescopic images should look like, and that (on the authority of Wilhelm Bessel) Schroeter's larger Newtonians achieved this, we must take seriously their complaints about the difficulties of collimating large, *very slow* Newtonians. The most probable explanation of their difficulties is just what they themselves both pointed to: figuring imperfections of the mirrors and in particular the difficulty of making flat mirrors. This is just exactly what this chapter has attempted to demonstrate, in part by illustrating the imperfections of surviving eighteenth-century flat mirrors, even from Herschel himself. The various surface imperfections, the use of dense speculum metal for mirrors, the absence of precise testing methods, the lack of engineered systems of mirror support – all this led to the impossibility of constructing large, effective Newtonian telescopes in the eighteenth century, as well as the need to maintain very slow focal ratios in smaller Newtonians intended for high-resolution imaging, and the adoption of the front-view configuration for large telescopes intended for low-power usage as "light-buckets."[166] It was the work of the nineteenth century to overcome these limitations, by developing, first of all, the whiffle-tree and astatic-lever systems of mirror support; second, Foucault's knife-edge and the Ritchey-Common test; third, the earliest interference testing for flat mirrors; and fourth, silver-on-glass front-surface mirrors. These developments led to drastic improvements in mirror figures, and ultimately to the triumph of modern reflecting telescopes as the sole instrument of choice for professional astronomers. Already the work of Lord Rosse in the 1830s and 1840s achieved enough improvement that he abandoned the front-view arrangement for his enormous reflectors. He returned to the standard Newtonian. This is evident in Rosse's discussion of his 36-in. f/9 reflector in 1840:

> *I use it as a Newtonian, as I find that, with its large aperture and short focus, the saving of light by the Herschellian construction is not at all an equivalent for the sacrifice of defining power, at least that is the result of my present experience; the indistinctness, however, from the obliquity of the speculum, does not appear to me to be so great as I should have expected, considering the size of the circle of least confusion; for this I cannot account.*[167]

---

*Objektivspiegels sehr erleichtert hat….*" This essay was noticed in England and a synopsis published in translation: Schrader, J.G.F., "Description of the mechanism of a reflecting telescope twenty-fix feet in length, constructed near Kiel in Holstein," *Philosophical Magazine*, i (1798), 113–118.

[166] William Kitchiner, the Regency telescope connoisseur, stated: "The Proportion fixed by those Experienced Makers of Reflectors Messrs. Tulley, is one Inch of Aperture to one foot of Focal length. They have assured me that they cannot make them shorter, without the Instrument being much less perfect." *Cf.* Kitchiner, W., (*op. cit.* ref. 69), p. 76. For Charles Tulley and his sons, *cf.* King, H., *The history of the telescope*, (London, 1955), pp. 192–196. *Cf.* also, the Rev. William Pearson's account of Herschel's 40-ft (written in consultation with Herschel): "It was not to be expected that a speculum of such large dimensions could have a perfect figure imparted to its surface, nor that the curve, whatever it might be, would remain identically the same in changes of temperature; therefore we are not surprised when we are told, that the magnifying powers used with the telescope seldom exceeded 200, *the quantity of light collected by so large a surface being the principal aim of the maker* [emphasis added]," in Pearson, W., (*op. cit.* ref. 4), pp. 74–75.

[167] Oxmantown, Lord, *(op. cit.* ref. 13), p. 524.

As we saw earlier, already in 1829 Henry Coddington published his classic analysis of astigmatism and realized that the aberrations of Herschel's 40-ft front-view must have been enormous, in view of the mirror tilt. He predicted that the circle of least confusion would be about 380 μm across – 30 times larger than the Airy disk. Yet despite this magnitude (which does not take into account coma, an aberration unknown to Coddington), Herschel was able to make at least some observations with the 40-ft; and for his part, Lord Rosse found the tilt-induced aberrations of his 36-in. f/9 reflector less enormous than he had suspected they would be. We shall examine this issue in greater detail later.

## *Herschel's 24-in. f/5 Newtonian*

First let us consider one last issue regarding Herschel's usage of Newtonian telescopes. This concerns an unusual instrument that he built late in life, namely a 24-in. f/5 Newtonian, which he called his "large 10-feet telescope."[168] Such an aperture and focal ratio is common among amateur astronomers nowadays, and good specimens would be expected to perform well both at low power on deep-sky objects, and also at high power – when atmospheric seeing permits – on the moon, the planets, and double stars. But Herschel wrote of his instrument: "This telescope was made in the year 1799, with an intention to obtain a high power of penetrating into space with an instrument that should be very manageable; and that it has answered this end, will appear from the observations that have been made with it. Some of them may be found in the *Philosophical transactions* for the year 1814."[169]

Herschel further reported that the magnifications used were 71, 108, 171, and 220 times. By the phrase "power of penetrating into space," Herschel meant the light-grasp of a telescope allowing it to reveal fainter, more distant objects and to resolve closer objects consisting of stars.[170] It is clear from his statements that he considered the large 10-ft another "light-bucket," rather than a precision imager, like his smaller Newtonians. Indeed, the published observations he refers to concern the visual detection of stars in globular clusters, for which high magnification was not needed, but rather light-grasp.

After using the large 10-ft for over a decade, Herschel – now nearing 80 years of age – sold it to Lucien Bonaparte (1775–1840), the younger brother of the French emperor. Bonaparte took possession in 1816. Prior to this, Bonaparte had initiated

---

[168] On the large 10-ft Newtonian, *cf.* Bennett, J.A., (*op. cit.* ref. 1), pp. 95–97; and Hoskin, M., [*op. cit.* ref. 4, (2011)], pp. 173–174. In his polishing log, Herschel also referred to it as his large "X feet." *Cf.* RAS MS Herschel W.5/12.4, Exps 403–462.

[169] Referring to Herschel, W., "Astronomical observations relating to the sidereal part of the heavens, *etc*.," *PT*, civ (1814), 248–284, pp. 276–277 [*TSP*, ii, pp. 520–541, pp. 536–537]. The words quoted appear in RAS MS Herschel W.5/8, f. 8r.

[170] *Cf.* Herschel, W., "On the power of penetrating into space by telescopes, *etc*.," *PT*, xc (1800), 49–85 [*TSP*, ii, pp. 31–52].

negotiations with Herschel in 1814, and in reply to his early queries, Herschel wrote him a letter, dated Sept. 16, 1814, in which he stated:

> *A higher magnifying power than 220 is not given with the large 10 feet telescope, because it is intended for a high space penetrating power….*
>
> *I have not used high magnifying powers with instruments intended for the purpose of penetrating into space. Most of my observations with the 20 feet telescope were made with 157. Occasionally I have used 240 and 300. The large 10 feet telescope, when directed to celestial objects that require space penetrating power, will show with a magnifying power of 220 what my small 10 feet telescope cannot show with a power of 600.*
>
> *…when both instruments* [viz. the 20-feet and the large 10-feet] *are charged with equal magnifying powers the long focus of the 20 feet mirror will certainly have the advantage of a greater distinctness of vision.*[171]

So again we see that Herschel did not consider his large instruments – and certainly not this Newtonian – to be precision imagers. They were intended to collect a great deal of light for observation at comparatively low power, as Bessel had suggested to Gauss in regard to Schroeter's 27-ft front-view. And to be quite clear, Herschel explicitly tells Lucien Bonaparte that his 20-ft front-view can be expected to deliver *sharper images* than the large 10-ft Newtonian. This is an extraordinary admission, since as we shall discover in the next section, the theoretical aberrations of a front-view telescope are vastly larger than those given by any correctly made Newtonian of moderate focal ratio. A modern 24-in. f/5 Newtonian of good construction should handily outperform Herschel's front-view in image quality at field center, if both are used under good seeing and thermal conditions.

## Usage and Performance of Eighteenth-Century Front-View Telescopes

Since large Newtonian telescopes for high-resolution imaging could not be made before the time of Lord Rosse, and even smaller instruments of high quality were often very fussy in their adjustments despite focal ratios above f/12, telescope makers such as Herschel and Schroeter explored the alternative of ejecting the cantankerous Newtonian diagonal and tilting the primary mirror in order to obtain large apertures of improved image sharpness. In any case the low reflectivity of speculum metal meant that the diagonals robbed the instruments of light, with no compensatory gain.

---

[171] RAS MS Herschel W.1/4.4, f. 1v-2r. *Cf.* also, Maurer, A., "Lucien Bonaparte and his Herschel telescopes," *Journal of the Antique Telescope Society*, xxxiii (2011), 3–5.

## *Comparison Testing of Newtonians with Front-Views*

The difference between this situation and what came after the developments of Rosse and Thomas Grubb cannot be more strikingly illustrated than by a quotation of a letter sent to *The Times* of London by Sir James South. This was printed on April 16, 1845, and concerned principally Rosse's "Leviathan" reflector, his 72-in. f/9 Newtonian, the largest telescope ever constructed before the twentieth century. Sir James was one of the most skilled visual observers of double stars in the early part of the nineteenth century. Already in 1821 he owned a 3.75-in. refractor with an objective by Dollond, and a 5-in. with an objective by Tulley. These were large refractors at the time. By the end of the decade, however, through the work of Pierre-Louis Guinand (1748–1824), Joseph Fraunhofer, and the Munich Institute, much larger refractors were being built. In 1829, South acquired an 11.75-in. refractor with an objective by Robert-Aglaé Cauchoix (1776–1845), the great French optician, which he mounted at his private observatory. Although the mounting (by Troughton and Simms) was not to South's liking and led to a row which become legendary in British astronomical circles, there was no dispute about the excellence of the objective, nor about South's skill as an observer. He was awarded the Royal Society's Copley Medal for his double-star work.[172]

South certainly understood what a good telescopic star image should look like, namely a bright Airy disk and faint circular diffraction rings of a well-formed PSF, such as we showed previously in Figs. 4.8 and 4.9. Thus, his description of the images produced by Lord Rosse's 72-in. Newtonian, and the contrast between those and what South had seen in William Herschel's 20-ft reflector is decisive:

> *The night of the 5th of March* [1845] *was, I think, the finest I ever saw in Ireland. Many nebulae were observed by Lord Rosse, Dr.* [Thomas Romney] *Robinson, and myself. Most of them were, for the first time since their creation, seen by us as groups or clusters of stars….Never…in my life did I see such glorious sidereal pictures as this instrument afforded us….*
>
> *Although…the power of this telescope in resolving nebulae into stars hitherto considered irresolvable was extremely gratifying, still it was in my mind little more than I had anticipated; for experience has long since told me that a telescope may show nebulae, even those resolvable by it, very well, whilst, when directed to a bright star, with a very moderate magnifying power, its imperfections will be actually offensive. During Sir W. Herschel's lifetime, with the 20-feet reflector at Slough I saw, amongst others 3 Messier, 5 Messier, 13 Messier, 92 Messier, the annular nebula of Lyra* [M57], *and the great nebula of Andromeda* [M31]. *No telescope of its size probably ever showed them better;* yet on the same night the

---

[172] On South and his telescopes, *cf.* Hoskin, M., "Astronomers at war: South *v*. Sheepshanks," *JHA*, xx (1989), 175–212; and Herschel, J.F.W. & J. South, "Observations of the apparent distances and positions of 380 double and triple stars, *etc*.,…Also a description of a five-feet equatorial instrument employed in the observations," *PT*, cxiv (1824), 1–412, pp. 11–12. John Herschel used the Cauchoix objective to discover the sixth star of the Trapezium, $\theta$ Orionis: c*f. Anon.*, "Report of the Council of the Society to the tenth annual general meeting, held this day," *MNRAS*, i (1831), 151–156, p. 153, footnote *.

> same instrument, when directed to Alpha Lyrae [Vega] (a star of the first magnitude), broke down under a power of about 300 [emphasis added].
>
> *Perfection of figure, then, of a telescope must be tested, not by nebulae, but by its performance on a star of the first magnitude. If it will, under high power, show the star round and free from optical appendages, we may safely enough take it for granted it will not only show nebulae well, but any other celestial object as it ought. When about to buy my large object glass at Paris, in 1829, I directed it to Aldebaran, viewed it in the telescope, certainly not one minute, and paid for it the next, without any one of the astronomers of Paris then present, and by my side, imagining I had even had the telescope on a star, much less that I had purchased it in consequence.* Regulus on the 12th being near the meridian, I placed [Rosse's 72-inch] telescope on it, and with the entire aperture and a magnifying power of 800 I saw, with inexpressible delight, the star free from wings, tails, or optical appendages; not indeed like a planetary disk, as in my large achromatic, but as a round image resembling voltaic light between charcoal points; and so little aberrations had this brilliant image that I could have measured its distance from, and position with, any of the stars in the field with a spider's line micrometer, and a power of 1000, without the slightest difficulty; *for not only was the large star round, but the telescope, although in the open air and the wind blowing rather fresh, was as steady as a rock*…[emphasis added].
>
> *Thus, then, the difficulty of constructing a Newtonian telescope of dimensions never before contemplated is completely overcome….*[173]

Since South was born in 1785, he could only have visited Herschel late in the latter's career.[174] Thus, the 20-ft reflector was likely to have had a figure as good as Herschel could ever have produced. Clearly, it was no match for Rosse's giant Newtonian in definition. Of course, by 1840 Rosse was in possession of the far better optical test for making flat diagonal mirrors, which we illustrated in Fig. 4.19 above.

South also noted in his letter to *The Times* that during his stay at Rosse's estate of Birr Castle (Parsonstown, Ireland), in February and March 1845, Rosse arranged for him to observe with his 36-in. f/9 reflector, both in Newtonian and front-view configuration, in order to compare image brightness experimentally on one and the same telescope. Just as Rosse had noted 5 years earlier in his 1840 *Philosophical transactions* article, so, too, now South found the image considerably brighter in front-view mode, but visibly very defective compared to what he had seen in Newtonian mode.

South was joined on the visit by his friend, Thomas Romney Robinson, an eloquent speaker, writer, Irish patriot, and powerful promoter of reflecting telescopes. Robinson gave his own report of the visit to the Royal Irish Academy in Dublin. This was reproduced in the *Proceedings* of the academy as a third person narration. Robinson told them:

---

[173] South, J., "The Earl of Rosse's Leviathan telescope," *The Times of London*, 16-Apr-1845 (letter to the editor), 8–9, p. 8. Paraphrased in *American journal of science and arts*, xlix (1845), 221–227. Partially reprinted as *idem*, "*Auszug aus einem Berichte über Lord Rosse's großes Telescop, etc.*, *AN*, xxiii (1846), col. 113–118.

[174] He is known to have visited in 1820 and 1821 and to have looked through the 20-ft. *Cf.* Hoskin, M., [*op. cit.* ref. 4 (2011)], pp. 183–185.

> *Enormous as is the illuminating power* [of the 72-inch], *it might be increased one-third by using it with the front view, supposing it can be properly figured for this oblique action. Without that,* [Robinson] *fears that in an instrument where the aperture is so large compared with the focal length, the definition would be imperfect. He verified this by an experiment with the* [36-inch], *and found that though the light was increased quite as much as he expected, yet the perfection of the image was utterly destroyed for large stars.* There was no exact focus, but merely two places where the sections of the cone of rays were smallest. One, the least exceptionable, shewed a flare in the direction of the slope [of the mirror] like a comet's tail: at the other this disappeared, but the star became a sort of curved rectangle with rays from its corners. *In the Newtonian form this speculum a few nights before had defined ζ Orionis very well with 500; but now γ Leonis could not be seen double with any power*…[emphasis added]*"*.[175]

The two stars mentioned, ζ Orionis and γ Leonis, are double stars, the first consisting of a bright (mag. 1.9) central and a fainter (mag. 3.7) companion star of about 2.5 arcsec separation in 1840, and the second consisting of two stars of more equal brightness (mags 2.4 and 3.6) and a separation of about 2.8 arcsec in 1840. The latter double can easily be split in a small telescope, and its duplicity was discovered by William Herschel in 1782; the former double is harder to discern, and Herschel never found it.[176] So again it is clear that the front-view configuration introduced significant aberrations into the image.

More important, however, is that Robinson provided a detailed description of the aberration seen in front-view mode. He noted that a condensed round star image was no longer seen, but at best there was a choice of two defective images: one (the better of the two) which showed the star as possessing a tail, like that of a comet, extending along the slope of the mirror (*i.e.*, in the tangential optical plane); and the second, which showed the star as a "curved rectangle with rays from its corners." All hope of fine definition was destroyed by this aberration. And although neither Robinson, South, Rosse, nor William Herschel possessed the optical terminology to describe precisely what he saw – aberration theory being only in its infancy – nevertheless we can today easily illustrate the effects, using modern optical ray tracing and analysis computer software. We shall do that in a moment. But first, let us consider again the illustration that Richard Potter published in 1851, reproduced above as Fig. 4.17 and here again as Fig. 4.34.

Potter's illustration was derived from empirical observation of a point source imaged by a lens off-axis. The aberrations are nevertheless similar to those of a concave mirror when tilted, as in a front-view telescope. Potter's focus position 5 corresponds to Robinson's "least exceptionable" star image. This is the sagittal focus for the front-view mirror, which leaves a radial flare – "like a comet's tail" – extending in the tangential optical plane, that is, the plane defined by the mirror's tilt. Potter's position 2 corresponds to the tangential focus of the front-view mirror.

---

[175] Robinson, T.R., "On Lord Rosse's telescope," *Proceedings of the Royal Irish Academy*, iii (1847), 114–133, pp. 131–132.

[176] *Cf.* Herschel, J.F.W., "A synopsis of all Sir William Herschel's micrometrical measurements and estimated positions, *etc*.," *MmRAS*, xxxv (1867), 21–136, pp. 34 (γ Leonis) and 64 (a second companion much further from ζ Orionis); and Dawes, W.R., *"Catalogue of micrometrical measurements of double stars*," *ibid.*, 137–449, pp. 327–328 and 347–348.

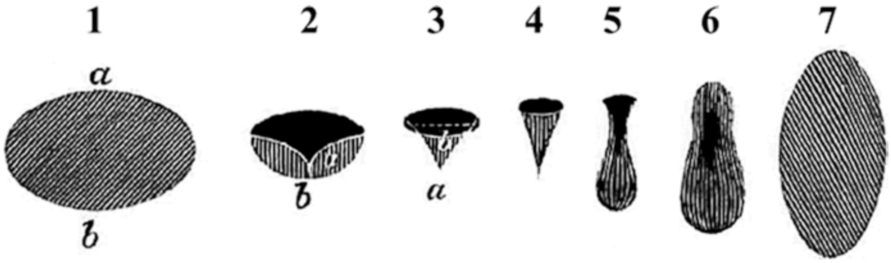


**Fig. 4.34** Richard Potter's textbook illustration showing astigmatism mixed with coma in the off-axis image created by a lens. The figure shows how the resultant image varies through focus. A similar pattern of aberration is seen in front-view telescopes

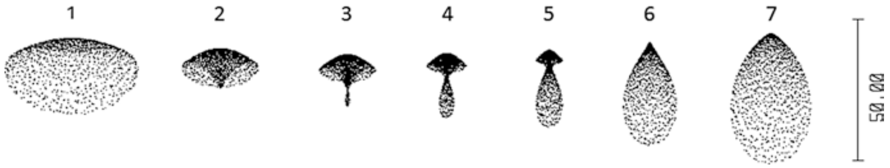


**Fig. 4.35** A modern rendering analogous to Richard Potter's illustration seen in Figs. 4.17 and 4.34. The scale at right is in arcminutes of apparent angle. Position 5 (sagittal focus) gives the tightest image of a *star* – apart from the eccentric flare. Stipple density suggests the brightness gradient of the image

The aberrations seen in his illustration are the classical ones, namely coma and astigmatism, as described earlier. Astigmatism causes the overall ellipticity of the image as seen most easily in the blurs on the extreme left and extreme right of the illustration; coma causes the radial flare seen most clearly in the middle blurs. In the leftmost image blur (position 1), Potter has labeled the upper margin of the ellipse along its minor axis "*a*" and the lower margin "*b*." In the succeeding blurs (positions 2 and 3), Potter shows how the image is essentially folded back onto itself (by the action of the comatic flare), such that in position 3 what had been the upper margin of the blur, namely "*a*," is now folded and stretched so as to be below "*b*."

Using modern ray-tracing software we can show the same sequence of blurs a bit more realistically, in Fig. 4.35.

The numbers in the sequence of Fig. 4.35 correspond to Potter's. Note that the hatch-marked areas in Potter's image blurs and the diffuse stippling in the modern rendering of Fig. 4.35 indicate areas fainter than those shown in black. Hence it is easy to see that (for example in focus position 5) the radial flare is a fainter area than the lozenge-shaped head. This means that the full blur will only be visible for a bright star. Fainter stars will exhibit just the lozenge area, or even just the tip of it in the case of very dim stars. The scale on the extreme right of the figure is in arcminutes of apparent angle as seen by the eye through an eyepiece. It has been calculated to show the approximate apparent size of the image blurs as seen in William

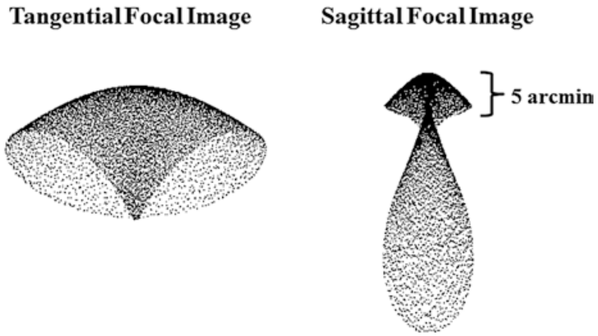


**Fig. 4.36** Theoretical tangential (*left*) and sagittal (*right*) focal images for Herschel's 20-ft front-view, at the sweeping power of 157×, calculated using modern computer ray-tracing software (ZEMAX™), and assuming a mirror tilt angle of 1.35°. A blur subtending 5 arcmin will appear very small in an eyepiece, although not dimensionless

Herschel's 20-ft telescope at a magnification of 157×, the power used in his sweeps. Herschel referred to this power in his letter of Sept. 16, 1814, to Lucien Bonaparte, quoted above. To understand how this compares to pinpoint star images, consider Fig. 4.36.

This figure shows the blurs for positions 2 and 5 (tangential and sagittal *foci*) of Fig. 4.35, much enlarged. Near the head of the sagittal blur is a scale showing the extent of 5 arcmin of apparent angle. In modern eyepiece design an apparent image blur subtending 5 arcmin at the observer's eye would be considered the maximum acceptable for a relatively sharp image. A truly sharp apparent image requires a blur no larger than 2 arcmin, a dimension that William Herschel himself was just able to detect under daylight conditions when examining pinheads in one of his Newtonians to distinguish from a mathematical point.[177] Hence it is clear from Fig. 4.36 that, in the first place, the tangential focus gives a grossly enlarged image that could never be mistaken for a dimensionless point. It is roughly the size of the full Moon when seen with the naked eye. This is the form of focus that Thomas Romney Robinson referred to as "a sort of curved rectangle with rays from its corners." If we ignore the faint stippling on the underside of this blur, which represents light that would only be seen for very bright stars, then his description is a plausible one. In the second place, at the sagittal focus, a bright star will be much sharper though still giving an obviously non-stellar image, in particular by showing a side flare. This is the feature that Robinson referred to as being "like a comet's tail." It results from the optical coma induced by the tilted front-view mirror, imaging stars obliquely far from the optical axis.

---

[177] Herschel, W., "Experiments for ascertaining how far telescopes will enable us to determine very small angles, and to distinguish the real from the spurious diameters of celestial and terrestrial objects, *etc.*," *PT*, xcv (1805) 31–64, pp. 31–32 [*TSP*, ii, 297–316, pp. 297–298]. John Herschel assigned as a limit "…for the generality of eyes, an angle of about 2½ or 3 minutes…." *Cf.* Herschel, J.F.W., (*op. cit.* ref. 13), p. 84.

Figure 4.36 is intended to illustrate the aberrations seen in Herschel’s 20-ft f/13 front-view, the tilt angle adopted for the mirror amounts to 1.35°, which deviates starlight to a focal position 2 in. outside the incoming bundle of parallel rays. This is the clearance distance that Herschel advised Johann Schroeter to adopt. To achieve it, Schroeter’s own 27-ft front-view, operating at about f/16, required a smaller mirror tilt of only about 1.06°. Herschel’s 40-ft telescope operating at f/10 required a mirror tilt of about 1.5°; for that telescope Herschel adopted a smaller clearance distance of 1 in.[178] Now, for a given mirror, coma varies directly with field angle, and astigmatism varies as to the square; so it is clear that the 40-ft suffered from increased aberrations on this score alone. In addition, however, the reduction of the focal ratio from f/13 (used in the 20-ft) to f/10 (used in the 40-ft) aggravated the situation. We shall examine the results in more detail below.[179]

For the time being, we should say that in Fig. 4.36, although a very bright star may exhibit the entire sagittal blur including the disturbing cometary tail (which is likely what caused James South’s disgust when viewing Vega in Herschel’s 20-ft), fainter stars will only show the lozenge-shaped head. This is obviously much smaller, and closer to the 5 arcmin limit for a relatively sharp star image. Very faint stars – and these were the intended quarry of the front-view system – may exhibit just the tip of the lozenge, which is so small at 157× that it would indeed appear point-like. It is probably for this reason that in Herschel’s *Experiments on the construction of specula*, when he praises a good front-view mirror he says that it “brought the small stars to a point.”[180] And John Herschel early in his career noted:

> *The inconvenience of this* [viz. the front-view system] *is a little distortion of the image, caused by the obliquity of the rays; but as such telescopes are only used of a great size,* and for the purpose of viewing very faint celestial objects, in which the light diffused by aberration is insensible, *little or no inconvenience is found to arise from this cause. Such is the construction of the telescopes used by Sir William Herschel in his sweeps of the heavens.* [emphasis added][181]

On the other hand, a brilliant star like Vega examined at 300× would certainly give an abominable image with much of the comatic flare visible, as shown in Fig. 4.36. No wonder then that South spoke of the image in the 20-ft as “breaking down” in this situation. Even the far smaller errors which Schroeter’s 27-ft front-view presumably exhibited were enough to offend the fastidious eye of Bessel and Gauss. The imaging errors of William Herschel’s telescopes even led to a quip from

---

[178] Herschel’s advice to Schroeter is contained in his letter of 4-Jan-1794. *Cf.* ref. 139 (above). For the clearance distance of the 40-ft, *cf.* Herschel, W., [*op. cit.* ref. 3 (1795)], p. 383 [*TSP*, i, p. 510].

[179] *Cf.* Section 7.4, and Wilson, R.N., (*op. cit.* ref. 45), pp. 89–90.

[180] *E.g.*, RAS MS Herschel W.5/12.1, Exp. 357; W.5/12.2, Exp. 145; W.5/12.3, Exp. 355; and W.2/1.13, f. 31r (“25 ft. reflector”). This contrasts with his Newtonians. For example, on 21-July-1801 Herschel wrote of the 7-ft Newtonian that he was constructing for the King of Spain (RAS MS Herschel W.5/12.3, Exp. 590): “…the stars of the *first magnitude* were brought to points [emphasis added].” *Cf.* also, W.5/12.3, Exp. 109 (another 7-ft Newtonian): “It gives a fine well determined point for a star of the 1st magnitude.”

[181] Herschel, J.F.W., (*op. cit.* ref. 27), pp. 403–404. John says here “a little distortion.” Later in his career he seems to have changed his mind, calling the “distortion” *much increased*. *Cf.* ref. 103.

Richard Proctor (1837–1888), the nineteenth-century astronomy popularizer, that: “It used to be remarked of the great four-foot mirror of Sir William Herschel, that it ‘bunched a star into a cocked hat….’”[182]

Despite the aberration, observers found the front-view advantageous in making stars appear brighter. Herschel credited the discovery of Titania and Oberon, the two largest moons of Uranus, to his adoption of the front-view arrangement, as we noted at the beginning of this chapter. Rosse and Robinson, too, noted the increased brightness, but felt it was hardly worth the degraded image quality. South, for his part, gave the most interesting testimony in his 1845 letter to *The Times*:

> *That we might have a practical proof of the advantages of the light of the* [front-view] *construction, the 3 feet Newtonian of 27 feet focus which stands in the demesne by the side of the* [72-inch] *Leviathan was temporarily fitted up as a* [front-view]. *Stars of the first magnitude were seen, not well defined as in the Newtonian form of the instrument, but the superiority of the* [front-view], *where a large quantity of light was required, was most decided….The dumb-bell nebula, 27 of Messier, was resolved into clusters of stars in a manner never before seen with it. The annular nebula of Lyra* [M57], *brilliant beyond what it had ever yet appeared, was surrounded by stars too bright to escape immediate notice, although neither the dumb-bell nebula nor the annular nebula had more than 15 degrees of altitude when I placed the telescope on them.*
>
> *On the 15th of March, when the moon was seven days and a-half old, I never saw her unilluminated disk so beautifully nor her mountains so temptingly measurable….*
>
> *Seeing, then, that the change from the Newtonian to the* [front-view] *construction will be attended with such an accession of light, Lord Rosse, having determined geometrically the form of the curve requisite to produce with it a definition of objects equal to that which each of the telescopes at present gives, is devising mechanical means for producing it….*[183]

Thus, South found the front-view useful not only on deep-sky objects but even for examining the Moon. More than that, he revealed Lord Rosse’s proposed plan to refigure his primary mirrors such that the definition lost through mirror tilt would be compensated by figuring. This means that Rosse hoped to produce what in modern terminology is called an “off-axis parabola.” This type of surface can most easily be understood as a subsection of a larger axially symmetric complete paraboloidal mirror, the subsection being cut such that the axis of symmetry (“optical axis” or “parent vertex”) of the paraboloidal surface no longer coincides with the physical axis of the sub-mirror. Rosse hoped to displace the optical axis to the periphery of his mirrors – or rather, even off the mirrors entirely and into free space. This would mean that the mirrors could be used without Newtonian diagonals, and also without the tilt-induced aberrations of the front-view configuration.

The resultant mirror surfaces would completely lack rotational symmetry. Such mirrors are formidable to make, whether by hand or by machine. Currently a series of off-axis parabolas – each 8.4 m in diameter – are under construction for the Giant

---

[182] Proctor, R.A., “The Rosse telescope set to new work,” *Fraser’s magazine for town and country*, lxxx (1869), 754–760, p. 755.

[183] South, J., (*op. cit.* ref. 173), p. 8.

Magellan Telescope project, and the present author is part of the team producing these mirrors.[184] Of course, the technology needed to make large off-axis parabolas successfully lay well beyond the capabilities of Lord Rosse and his times. So despite South’s optimism, they never happened at Birr Castle, not least because until 1849 Rosse was called away to parliamentary duties related to the Great Potato Famine in Ireland.

It has been conjectured that William Herschel might have made off-axis parabolas for his front-view mirrors. Already in 1829, Henry Coddington tentatively suggested this as a possibility.[185] Anyone, like Coddington, who understands the size of the expected aberrations in a large front-view telescope, will likely feel immense surprise, if not downright incredulity, that Herschel could have used such instruments productively. Below in Fig. 4.37 we shall consider just how large the aberrations theoretically are.

Despite conjectures about eighteenth-century off-axis parabolas, there is no evidence that William Herschel attempted such vastly difficult optics. Nothing can be found in either the four-volume *Experiments on the construction of specula* nor in the synoptical *Results* to support this notion. Moreover John Herschel, who carefully described his father’s mirror-making practices in 1861, gives no hint that off-axis parabolas were attempted. Indeed, he suggests just the opposite when he says: “It is evident, too, that in grinding and figuring such a reflector [viz. a front-view], it is needless to insist on a parabolic form in preference to a good spherical one, *unless it were possible to work the surface to a portion of a paraboloid, having its vertex at the circumference of the mirror.* [emphasis added]”[186] The proviso clause is couched as a contrafactual. Had William Herschel been assiduously perfecting off-axis parabolas, he would certainly have recorded this stupendous achievement in his private notebooks and taught the invaluable technique to his son. John, however, in 1861 noted of the front-view system: “Among its disadvantages, it must be considered that *the aberration of the mirror is much increased by the oblique incidence of the…rays.* [emphasis added]”[187] Since the whole purpose of figuring off-axis parabolas is to avoid the aberration occasioned by tilting a paraboloidal mirror and so to obtain *sharp* images, it is plain that John (and by implication his father) did not employ them in their front-view telescopes.

## *Magnitude of Aberrations in Front-View Mode*

Let us at last consider the expected magnitude of the image aberrations seen through front-view reflectors. Fig. 4.37 presents spot diagrams for four historical systems: Johann Schroeter’s 27-ft (containing a mirror of about 20 in. diameter with focal

---

[184] http://www.gmto.org/

[185] Coddington, H., (op. cit. ref. 103), p. 34, note †.

[186] Herschel, J.F.W., (*op. cit.* ref. 13), p. 81.

[187] *Cf.* ref. 103.

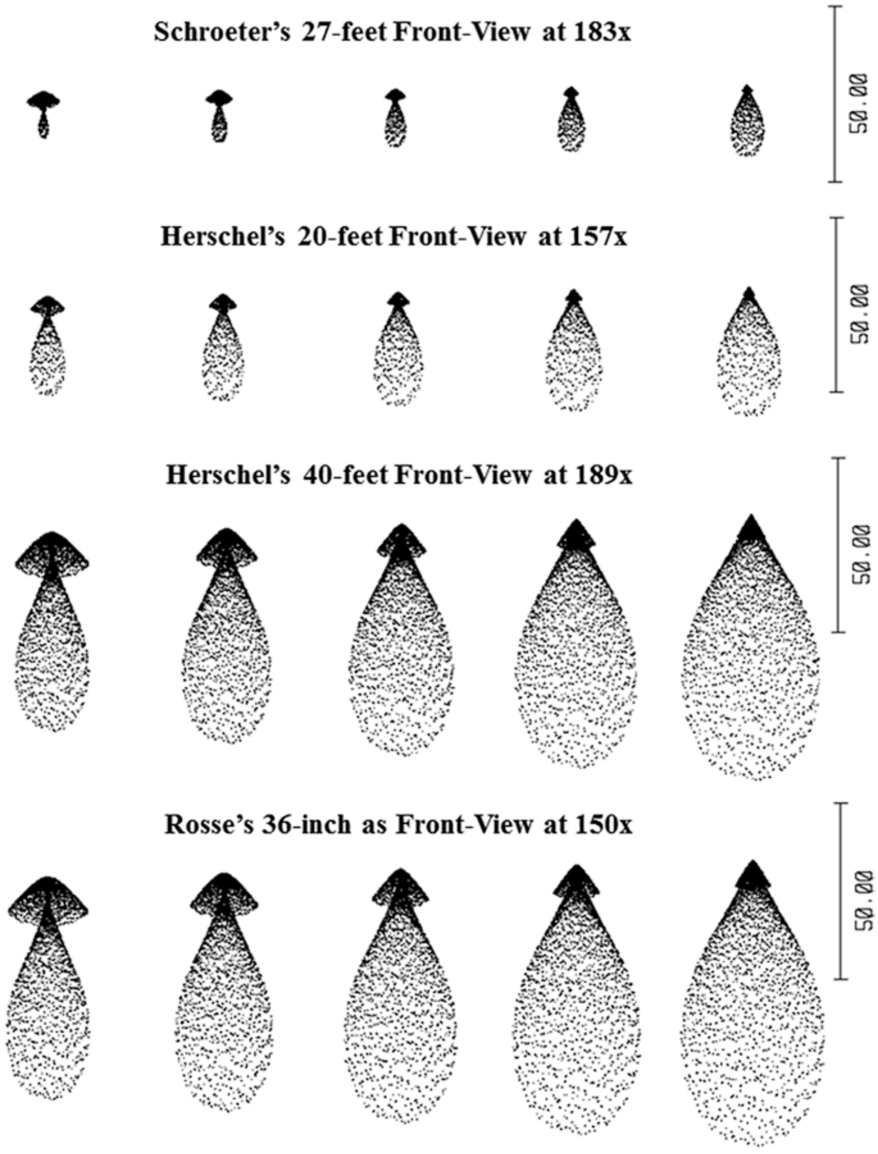


**Fig. 4.37** Through-focus spot diagrams for various historical front-view telescopes. The apparent angular extent of each spot sequence depends on magnification, chosen here to approximate the lowest-power affording full use of the aperture in question, or according to the observer's known preference. In each given horizontal sequence one spot differs from the next by 1/4 diopter of focus shift

ratio of about f/16); William Herschel's 20-ft (containing a mirror of about 18.7 in. with a focal ratio of about f/13); William Herschel's 40-ft (containing a mirror of 48 in. diameter with focal ratio of f/10); and lastly Lord Rosse's 36-in. f/9 mirror configured for front-view usage. Scale bars at the right side of the figure are in arcminutes. The mirrors in all cases are assumed to be perfectly paraboloidal.

The image blurs are magnified by 157× in the case of Herschel's 20-ft, and 189× in the case of the 40-ft. The first was Herschel's preferred sweeping power, while the second is a low power attested to in his observation logbook. The 183× is the magnification Schroeter cited in his published description of his 27-ft front-view.[188] South does not record what magnification he and Robinson used. The 150× has been adopted as a reasonable standard of comparison. All telescopes used visually have a lowest useful magnification defined by the ratio of the entrance pupil of the telescope (the primary mirror in the present cases) to the exit pupil of the eyepiece. Since normally the observer wishes to transfer all the light entering the telescope through the anatomical pupil of his or her eye, maximum iris dilation of the observer's eye defines the largest exit pupil allowed. William Herschel took this quantity as about 0.2 in., or about 5 mm.[189] Although the maximum pupil size for a young observer may reach 8 mm, as people age this normally declines, so that by age 50 (William Herschel turned 50 in the fall of 1788 during the period when he built his 40-ft reflector) the maximum iris dilation may be no more than 5 mm.

For the four systems of Fig. 4.37, we can calculate the exit pupils as about 2.8 mm for Schroeter at 183×; 3 mm for Herschel's 20-ft at 157×; 6.45 mm for the 40-ft at 189×; and 6.1 mm for Rosse's 36-in. at 150×. Hence, while Schroeter's 27-ft and Herschel's 20-ft could be used at still lower magnifications, thereby shrinking the angular size of their blur spots proportionally and making them less conspicuous, the 40-ft and the Rosse 36-in. could not be so used without also vignetting the entrance pupil. In other words, if for example in order to make the blur spot one-half as large and therefore sharper in appearance, Herschel had lowered the magnification of the 40-ft to 94.5×, he would also effectively halve the entrance pupil of his telescope to 24 in., thereby rejecting about 75% of the incoming light, which would be absorbed by the iris of his eye. This is the dilemma of using a large telescope for visual observation: more light is concentrated into the image, but the minimum magnification must be raised to accommodate the anatomy of the human eye. And this makes the image look more blurred.

It is clear, therefore, from Fig. 4.37 that in principle Schroeter's 27-ft at f/16 gave the smallest and sharpest images, followed by William Herschel's 20-ft at f/12.8. John Herschel found in the latter case that despite the enlarged blurs, for faint stars "the light diffused by aberration is insensible." Decreasing the focal ratio below f/12, on the other hand, as with the 40-ft at f/10 and Rosse's 36-in. at f/9 in front-view configuration, quickly leads to distended images with gross comatic flares. Nevertheless for dim stars such as the field stars associated with the Ring Nebula

---

[188] For 157× *cf.* Herschel, W., (*op. cit.* ref. 2), p. 457 [*TSP*, i, p. 260]; for 189× *cf.* RAS MS Herschel W.2/4, f. 1v; and for 183× *cf.* the text below at footnote 194.

[189] Herschel, W., (*op. cit.* ref. 170), pp. 53 and 66 [*TSP*, ii, pp. 33 and 41].

(M57) and the Dumbbell Nebula (M27), the flares become too faint to be seen, and only the "head of the comet" remains visible.

By refocusing, this head area can be diminished in size, as we find in the image blurs on the right side of Fig. 4.37. Alas, the cost of this maneuver is to divert still more light into the expanded comatic blur, which ultimately deprives the front-view of its only rationale for existence. Yet even in the case of Lord Rosse's 36-in., according to James South, "the superiority of the [front-view], where a large quantity of light was required, was most decided." Since the aberration blur in that case by calculation was comparable to what must have been seen in Herschel's 40-ft reflector, it is reasonable to conclude that despite the enormous blurs, in practice deep-sky images were still somehow usable. At the same time it is obvious that they cannot have appeared very sharp, and must have been a disappointment to Herschel compared to the relative sharpness of the 20-ft.

Herschel had publicly announced the adoption of the front-view configuration for the smaller instrument in 1786 with the upbeat statement that:

> [The front-view] *consists in looking with the eye glass, placed a little out of the axis, directly in at the front, without the interposition of a small speculum; and has the capital advantage of giving us almost double the light of the former constructions. In the year 1776 I tried it for the first time with a 10 feet reflector, and in 1784 again with a 20 feet one;* but the success not immediately answering my expectations, it was too hastily laid aside. *By a more careful repetition of the same experiment I find now that several other considerable advantages, added to the brilliant light before mentioned, make it so valuable a construction that* a judicious observer may avail himself of it at least in all cases where light is more particularly wanted."[190] [emphasis added]

Privately in a memorandum to himself he added: "…the light is incomparably more brilliant, and *I thought sometimes that the stars were, if not better, at least full as well defined as in the Newtonian way*...[emphasis added]"[191] It seems clear from the tentative character of the praise, that although very pleased with the brighter images, Herschel was not so impressed by their sharpness: they were defined about as well as in Newtonian configuration. Thankfully they were not defined worse. In the previous section of this paper we discussed at length why large Newtonians of good definition could not be built before the age of Lord Rosse. The front-view was only an improvement over contemporary large Newtonians because those gave both unsharp and none-too-bright images. The front-view addressed the latter problem.

So a "judicious observer" might find uses for this tilted-mirror configuration, at least for seeing faint objects – or in other words, at low-to-moderate power on the "deep-sky." It was with this perspective in mind, probably, that William Herschel turned to the construction of his 40-ft front-view, and reported to his correspondent, Count Hans Moritz von Brühl (1736–1809), ambassador of the Electorate of Saxony to the court of St. James and member of the Royal Society (who in turn relayed the information to Bode's *Astronomisches Jahrbuch*): "Mr. Herschel will soon complete his 40-foot telescope.... One should think that so marked a bending of the rays

---

[190] Herschel, W., (*op. cit.* ref. 2).

[191] RAS MS Herschel W.2/3.6, sweep 600 (memorandum).

[*viz.* from the mirror tilt] must present an unclear image. Yet Mr. Herschel assures us that thereby the clarity receives no notable injury and much light is saved."[192]

Indeed, in front-view instruments of long focal ratio, such as Schroeter's 20-in. f/16 system, the image in practice does seem to have been *better* than what could be seen in Newtonian configuration, and moreover the trial and tribulation of collimating the Newtonian was abolished. Prof. Schrader stated publicly in 1794 concerning the invention of the front-view:

> *Herschel, therefore, deserves hearty thanks for greatly easing the burdensome labor of centration by getting rid of the secondary mirror and inclining the primary laterally, even if this is applicable only in the case of large telescopes because the shadow of the observer's head would take too much light from smaller mirrors.*[193]

And Schroeter, writing in more detail in 1796, stated:

> *This invention of Dr. Herschel's has – to my knowledge – been nowhere described as yet in sufficient detail, and just this fact has in the past for me as for others caused a somewhat erroneous conception. But now that I have gotten a better theoretical and practical acquaintance with it, I have come to value it so highly that in the case of this large reflector for a long time I have used it alone, having completely removed the secondary mirror, and resolved never to use it again in the telescope. Just as valuable seems to me the present opportunity to communicate what I know about this useful construction*…[A lengthy, minute description of Schroeter's implementation follows.]
>
> *In particular, however, the advantage of this simple construction becomes clear…through* a relatively greater intensity of light and sharpness. *As was previously noted, the rays which collectively proceed through the aperture of the tube, falling on every part of the equally large mirror, are concentrated in a perfectly round full light bundle on the ocular, so that no light is ever lost; whereas in the case of Gregorians, Newtonians, and Cassegrainians light is abstracted by striking the interposed small central secondary mirror. The important factor, however, is that by means of the added reflection on the secondary mirror some light is always dispersed and all the more so, the less precise its figure and its placement are in respect to the objective-mirror. How difficult it is to give a* perfectly *plane surface to the secondary mirror of the Newtonian construction, and to set its inclination with absolute precision at 45 degrees while maintaining parallelism,*[194] *is well enough known in practice.* [author's emphasis] *So in the Herschelian front-view, where this disadvantage is absent, the light is much brighter and whiter,* and the image appears notably sharper than when a sec-

---

[192] Brühl, H.M von, "Astronomische Beobachtungen und Nachrichten aus England," in J.E. Bode (ed), *AJJ 1790*, (Berlin 1787), p. 175: "*Herr Herschel wird bald mit seinem 40schuhigen Fernrohr zu stande kommen….Man sollte vermuthen, daß eine so merkliche Beugung der Stralen ein undeutliches Bild darstellen müsse. Allein Herr Herschel versichert, daß damit der Deutlichkeit kein merklicher Eintrag geschehe und dabey viel Licht erspart werde.*" For Brühl, *cf.* Brosche, P., *Der Astronom der Herzogin, Acta historica astronomiae 12*, 2nd ed., (Harri Deutsch, 2008), pp. 35–37.

[193] Schrader, J.G.F., (*op. cit.* ref. 15), p. 17: "*Herschel verdient daher vielen Dank, daß er die mühsame Arbeit des Centrirens durch Weglassung des Okular- oder Fangspiegels und durch eine seitwärts gerichtete Neigung des Objektivspiegels sehr erleichtert hat; wiewol dieses nur bei grossen Teleskopen anwendbar ist, weil der Schatten von dem Kopfe des Beobachters den kleinen Spiegeln zu viel Licht nehmen würde.*"

[194] Probably Schroeter refers here to the axis of the cylinder forming the body of the secondary mirror (*cf.* Fig. 4.20c). This axis should be made parallel and coincident to the optical axis of the Newtonian primary mirror.

> ondary mirror intervenes [emphasis added], *so that Dr. Herschel estimates the light to be almost doubled. It is definitely the case that I likewise find the light much brighter than with a secondary mirror, and at a magnification of 183x…find the image* far and away brighter *than at only 136x in my 13-foot reflector.* [author's emphasis][195]

Schroeter's observations are informative, if typically verbose. He emphasizes once again the difficulties of making good Newtonian flat secondaries and the problem of aligning them to the primaries. He reiterates the improved image brightness resulting from removal of the secondaries. In addition, he now states that in his front-view, "the image appears notably *sharper* than when a secondary mirror intervenes." This is an extraordinary statement, completely at variance with the expectations of optical theory – if the Newtonian mirrors were made correctly. Schroeter's statement only makes sense in the context of defective optics. And since Schroeter continued in the use of the same primary mirrors for his front-view, expelling just his diagonal mirror, the conclusion is forced upon us that the diagonal was bad. Just how bad is suggested by Fig. 4.37: bad enough to make the Newtonian images even more bloated than the obviously distended images produced in front-view mode.

Although in his private memorandum of 1786, Herschel had merely stated of the front-view that its image was "if not better, at least full as well defined as in the Newtonian way," several years later in his observing journal he acknowledged that a front-view image could be *decisively* better. On November 13, 1793, Herschel recorded in his observing journal:

> *20 feet reflector, with the Newtonian construction….I suppose the small plain speculum to have a good figure; but have not tried it otherwise than by the polishing method. (See Vol. 2$^{d}$ experiment 426, on the construction of telescopes.) However the telescope with 157 is not*

---

[195] Schroeter, J.H., (*op. cit.* ref. 142), pp. 224–227: "*Diese Erfindung des Herrn D. Herschel ist meines Wissens noch nirgends umständlich genug beschrieben, und eben das hat vorher bey mir, so wie bey andern, eine etwas irrige Vorstellung veranlasset. Jetzt aber, da ich sie theoretisch und practisch näher kennen gelernt, ist sie mir so schätzbar geworden, daß ich sie bey diesem grossen Reflector seit geraumer Zeit ganz allein angewandt, den Fangspiegel ganz weggeschaffet, und mir vorgenommen habe, diesen nie wieder dabey mit anzuwenden. Eben so schätzbar scheint mir aber auch die jetzige Gelegenheit, das, was mir von dieser nützlichen Einrichtung bekannt ist,…zum Besten der Wissenschaft hier mitzutheilen….*

*Vornehmlich wird aber der Nutzen dieser einfachen Einrichtung…durch eine* verhältlich grössere Lichtstärke und Schärfe *einleuchtend. Wie oben bemerkt ist, werden die sämmtlichen, durch die Oeffnung des Rohrs auf alle Theile des gleich grossen Objectivspiegels fallenden Lichtstrahlen in einen vollkommen runden vollen Lichtbüschel des Augenglases concentrirt, so daß nicht einmahl das Licht verlohren geht, welches sonst nach der Gregorianischen, Neutonischen und Cassegrainischen Einrichtung, bey dem Einfallen durch den mitten befindlichen kleinen Fangspiegel benommen wird. Der wichtige Umstand ist aber, daß durch die zweyte Reflexion des Fangspiegels immer einiges und desto mehr Licht zerstreuet wird und verlohren geht, je weniger seine Figure und seine Lage gegen den Objectivspiegel genau ist. Wie schwer es aber sey, dem Fangspiegel nach der Neutonischen Einrichtung eine* vollkommen *plane Fläche zu geben, und ihn unter Beybehaltung des Parallelismi pünctlich genau auf 45° zu incliniren ist practisch bekannt genug. Daher ist das licht mit einem Herschelischen Front view, bey dem dieser Nachtheil wegfällt, viel stärker und weiser, und das Bild erscheinet merklich schärfer, als bey Dazwischenkunft eines Fangspiegels, so daß Herr D. Herschel das Licht beynahe doppelt so stark schätzet. Gewiß ist es, daß ich es ebenfalls weit stärker, als mit einem Fangspiegel, und unter* 183 maliger *Vergrösserung… das Bild* ganz ungleich lichtvoller, *als unter nur* 136 maliger *Vergrösserung des 13 füssigen Reflectors finde.*" The first paragraph of this quotation was previously cited in endnote 152 above.

> *nearly so distinct in this construction, as it is when I use it with a single reflection. As for the power of…300 which I used Nov.ʳ 5th it is totally defective. By the 7 feet reflector it appears that the evening is very fine. 20 feet Reflector, my own construction; extremely distinct.*[196]

Herschel's reference to trying the small "plain" speculum "by the polishing method" seems to refer to testing for planarity by means of his two-card method illustrated earlier in Fig. 4.18, and as discussed in experiment 426 of volume 1 of his *Experiments on the construction of specula*.[197] If so, then the quotation shows Herschel acknowledging explicitly that a diagonal mirror for his 20-ft reflector after passing his most advanced method of metrology still gave a "totally defective" image at 300× compared to the use of the same telescope according to "my own construction" – that is, the Herschelian front-view. Even at half the magnification (157×, the sweeping power), the image in Newtonian mode was "not nearly so distinct." Yet, through his 7-ft Newtonian on the same night, Herschel found that "the evening is very fine," and the image in the 20-ft *via* front-view mode is "extremely distinct."[198]

We saw in Figs. 4.22, 4.23, 4.24, and 4.25 examples of surface errors on elliptical diagonal mirrors made by the best opticians of the eighteenth century. Unless these errors existed in a smooth balance, the resulting aberration when the diagonals were used at 45° obliquity was astigmatism. If the surface errors were not smooth, but irregular, then coma and other aberrations might occur, as well as astigmatism. Nevertheless, if the magnitude of the surface errors was small enough, and if the primary mirror had its own errors, then by a painstaking process of adjusting tip-and-tilt and rotational angle of the primary to the secondary, it *might* be possible to play off the errors one against another until something like an Airy disk and rings resulted. But it is obvious that the process could be messy, and the aberrations could quickly exceed the simpler aberrations resulting from the tilt of the primary mirror alone in the front-view, which at least reliably gave a bright concentration of light in the "head of the comet," good for viewing faint stars.

Experienced observers, however, could see the difference from a sharply focusing smaller Newtonian. So even Schroeter's 27-ft front-view with its modest aberration blurs proved no match for his 15- and 13-ft Newtonians with their 12-in. and 9.5-in. diameter mirrors. We have Bessel's testimony for this, and also for the 13-ft a description by Baron Franz Xaver von Zach, publisher and director of the Seeberg Observatory near Gotha, Germany.[199] Zach visited Schroeter at Lilienthal in September 1800 at the time of the royal visit from Prince Adolphus Frederick. The meeting included other notables, such as the astronomers Wilhelm Olbers (1758–1840) and Karl Harding, as well as Ferdinand Adolph von Ende (1760–1817), judge in the Upper Court of Appeals [*Appellationsrath*] in Celle – an administrative center of the Hanoverian Electorate. Ende was an amateur astronomer and correspondent

---

[196] RAS MS Herschel W.2/1.12, f. 92r.

[197] Not "Vol. 2ᵈ" as he mistakenly states in his observing journal.

[198] Herschel's observing records show that he often changed telescopes and even mirrors within his telescopes on one and the same night, in hurried activity.

[199] For Zach, *cf.* Brosche, P., (*op. cit.* ref. 192).

of William Herschel's. The meeting ended in the formation of the famous "celestial police," organized by von Zach and headed by Schroeter to conduct a coordinated search for the presumed "missing planet" between Mars and Jupiter, as postulated by the famous Titius-Bode law of planetary distances.[200] Ultimately Harding discovered the third such "missing planet," the minor planet Juno, at Lilienthal in 1804 using Schroeter's telescopes. In 1800, the visiting dignitaries were given a tour of Schroeter's observatory and extensive collection of instruments.

Zach later published a detailed description both of the buildings and the telescopes, including the 13-ft Newtonian with optics by Schrader and the 27-ft with mirror by Gefken. The description appeared in one of von Zach's journals, the *Monthly correspondence* [*Monatliche Correspondenz*]. His remarks about observing with these two telescopes are worth quoting *in extenso* since they give a vivid testimony to the nature of Schroeter's instruments:

> *Some clear hours over the course of several nights afforded us the pleasure, in company with the Senior-Counselor von Ende and Dr. Olbers, to experience the performance of the Lilienthal Observatory's excellent visual instruments. We were fortunate enough to undertake an extensive examination of the heavens, and to receive under our consideration some of the most delicate celestial objects, close double stars, planetary nebulae, star clusters, etc., as well as the planets then visible, especially Mars, through all the gradations of these splendid telescopes. It was truly a joy for me and an indescribable delight to be able with my own eyes to verify the magnificent performance of these instruments. Charmed with admiration, we lingered over the most remarkable celestial objects, then hastened from one telescope to another in order to test and compare them. Yet candidly I must admit that each time I returned with the greatest delight to the 13-foot reflector – not excepting the 27-foot – and in all honesty I set forth my public confession that never yet have my eyes beheld the heavens with a better, clearer, and sharper instrument. The planets Jupiter and Mars shown forth to me, through this excellent telescope, in such etched clarity as if (to use the common expression) I could reach out and grasp them. The splendid sight left an indelible impression.*
>
> *With the 27-foot reflector in front-view mode without the secondary mirror we had a magnificent view of the Milky Way. We let this grand object of nature pass under our gaze hours-long, delighting and feasting our eyes on the sublime scene with attentive listening to the informative lectures of our hospitable guide, who had prepared for us such an ample and enjoyable entertainment….*
>
> *The eyepiece field was studded thickly with stars at every turn; one compact group from a hurrying host of worlds passing by gave way incessantly to another even more compact. And just when the stars seemed less numerous, a closer examination revealed the glimmer of the finest, faintest points of light in the background, like sand on the seashore….*
>
> *Such experiences and perceptions were bound to give rise to the warmest wish and eagerest desire in me for an excellent reflector of such light-grasp as the above mentioned 13-foot, manufactured in Lilienthal – indeed, an optical device perfect in its kind and not easily surpassed. On my return home, His Highness the Serene Duke of Gotha immediately con-*

---

[200] Clerke, A.M., *A popular history of astronomy in the 19th century*, 4th ed., (London, 1902), pp. 71–72 and Brosche, P., (*op. cit.* ref. 192), pp. 133–140. For the term "celestial police [*Himmels-Polizey*]," *cf.* von Zach, F.X., "Über einen zwischen Mars und Jupiter längst vermutheten, nun wahrscheinlich entdeckten neuen Hauptplaneten unseres Sonnen-Systems," *MC*, iii (1801), 592–623, p. 603.

> *sented to my prayer and proposal to acquire a 13- to 15-foot reflector of this type for the truly princely observatory at Seeberg, and Oberamtmann Schroeter had the kindness to see the primary mirror for the same forthwith begun under his direction and supervision.*[201]

Zach's enthusiasm is obvious. Yet despite his enchantment in viewing the deep-sky through the 27-ft front-view with its large mirror, he still preferred the sharper images found in the smaller 13-ft Newtonian, so much so that on returning home he instantly importuned his employer to buy one! However, not everyone in Germany preferred Newtonians, or even Schroeter's manufacture. Count Friedrich von Hahn (1742–1805) of Remplin, Mecklenburg, preferred the competition, and so elected to buy a 20-ft front-view (with a 12-in. diameter mirror) from William Herschel. Von Hahn used it to discover the faint central star of the Ring Nebula (M57) in Lyra, a very challenging object to see, and something that had escaped Herschel's scrutiny.[202]

---

[201] von Zach, F.X., (*op. cit.* ref. 143), pp. 487–489 [Gerdes, D., (*op. cit.* ref. 110), pp. 34–36]: "*Einige heitere Stunden in ein Paar Nächten gewährten uns das Vergnügen, in Gesellschaft des O. A. R. v. Ende und Dr. Olbers, die Wirkungen der vortrefflichen Sehewerkzeuge der Lilienthaler Sternwarte zu erfahren. Wir waren so glücklich, mit denselben manche Musterung am Himmel vorzunehmen, und einige der zärtesten himmlischen Gegenstände, feine Doppelsterne, planetarische Nebelflecke, Sternringe u.s.w. so wie auch die damahls sichtbaren Planeten, vorzüglich den Mars, durch alle Abstufungen dieser herrlichen Instrumente in Betrachtung zu nehmen. Es war wahre Wonne für mich, und ein unbeschreibliches Vergnügen, mich mit eignen Augen von der prachtvollen Wirkung dieser Gesichtswerkzeuge überzeugen zu können. Mit Entzücken und Bewunderung verweilten wir bey Betrachtung der merkwürdigsten himmlischen Gegenstände, und von einem Fenrohre eilten wir zu dem anderen, um sie zu vergleichen und zu prüfen. Aber offenherzig muß ich hier gestehen, daß ich jederzeit am liebsten zu dem 13 füßigen Reflector (den 27 füßigen nicht ausgenommen) zurückkehrte, und aufrichtig lege ich hier das öffentliche Geständnis ab, daß meine Augen den Himmel noch nie mit einem bessern, deutlichern und bestimmtern Werkzeuge beschaut haben. Besonders blickten mir die Planeten Jupiter und Mars, mit diesem vortrefflichen Teleskope besehen, mit einer solchen Schärfe und Deutlichkeit, wie man zu sagen pflegt, bis zum Greifen ins Gesicht, und hinterließen einen unauslöschlichen Eindruck dieses herrlichen Anblicks.*

*Mit dem 27 füßigen Reflector hatten wir, ohne Fangspiegel, mit bloßer front-view, einen prachtvollen Blick auf die Milchstraße. Wir ließen diesen großen Naturgegenstand Stunden lang die Musterung passiren, ergötzten und weideten uns mit stiller Betrachtung dieser erhabenen Naturscenen, und mit aufmerksamer Anhörung der lehrreichen Bemerkungen unsers gastfreundlichen Führers, der uns ein so großes, genußreiches Vergnügen bereitete....*

*Dicht mit Sternen war das Feld des Oculars auf jeden Blick übersäet; eine gedrungene Gruppe eines vorübereilenden Heeres von Welten machte unaufhörlich einer viel gedrungeren Platz. Selbst da, wo die Sterne weniger zahlreich schienen, blinkten bey näherer Betrachtung noch die feinsten matten Lichtpünktchen, wie Sand am Meer, aus dem Hintergrunde hervor….*

*Solche Erfahrungen und Empfindungen mußten natürlich den heißesten Wunsch und das sehnlichste Verlangen nach einem so lichtstarken vortrefflichen Reflector in mir erregen, wie oben angeführter 13 füßiger, in Lilienthal verfertigter; gewiß ein in seiner Art vollkommenes, und nicht leicht zu übertreffendes optisches Werkzeug. Nach meiner Zurückkunft bewilligten Sr. Durchlaucht der Herzog von Gotha, auf meine Bitte und Vorschlag, sogleich die Anschaffung eines solchen 13 bis 15 füßigen Reflectors für die wahrhaft fürstliche Seeberger Sternwarte, und der O. A. S. hatte die Güte, den großen Spiegel zu demselben unter seiner Leitung und Aufsicht sogleich in Arbeit nehmen zu lassen.*"

[202] Steinicke, W., *Observing and cataloguing nebulae and star clusters*, (Cambridge, 2010), p. 43. On von Hahn's 20-ft telescope, *cf.* also Bode, J.E., "Verzeichniß der vorzüglichsten in dem astronomischen Salon des Herrn Erblandmarschal von Hahn zu Remplin befindlichen Instrumente," *AJJ 1797*, (1794), 240–244, pp. 242–243.

## *Seeing, Resolution, and Stray Light*

Another reason why smaller instruments tended to provide sharper images has to do with seeing effects, which we have so far neglected to mention. Wavefront distortions and their resultant image aberrations arise from temperature gradients in the air, both at high altitudes ("atmospheric seeing") and even inside telescope tubes ("tube seeing"). It lies beyond the scope of the present work to discuss in detail the ramifications of turbulence on telescopic images – a highly complex subject – but nevertheless a few comments are in order.[203] Reflecting telescopes usually suffer more severely from seeing effects (especially tube seeing and ambient, "local" seeing around telescopes) than do refractors. And large telescopes with their increased apertures are more exposed to the ill-effects than small ones. Herschel and Schroeter were aware of this, probably more so than many of their contemporaries, who tended to use only small refractors for their observations. Herschel and Schroeter were the first astronomers to possess telescopes in the half-meter class. Even in the mid-nineteenth century, after a general increase in the size of professional telescopes, the transient effects of seeing on reflectors were still used to disparage them, so that in another quip from Richard Proctor about Lord Rosse's Leviathan: "…a distinguish[ed] foreign astronomer was once invited to look at the planet [Saturn] by its aid, and his account of what he saw was thus worded: 'They showed me something and they told me it was Saturn, and I believed them.'"[204] Proctor insists that large reflectors are unable to give sharp views – contrary to the express testimony of South and Robinson.

Another user of a large nineteenth-century reflector – an instrument frequently maligned – was Robert L. J. Ellery (1827–1908), the director of the Melbourne Observatory in Australia. From 1869 onward he was in possession of the best-mounted Cassegrainian reflector built up to that day, namely the 48-in. Great Melbourne Telescope, with optics and mounting by Thomas and Howard Grubb. Ellery had a clearer picture of how seeing affects large reflecting telescopes, when he wrote in 1885:

> *As in all instruments of large aperture, atmospheric condition is all important in the use of this one, and only those who have had experience in observing with such instruments can form an idea of how limited are the hours per year, even in a climate like that of this part of Australia, in which such large apertures show the full extent of their powers. On the average of ordinary fine nights, the performance of this telescope on a planet or a double star is disappointing – except perhaps in occasional glimpses – to one accustomed to observe with smaller apertures; but on* really good nights *it is quite different, and such occasions show the most delicate markings on Saturn, clear separation of discrete points in some of the resolvable nebulae, and a separation of close double stars, indicating an optical perfection which under other conditions was not apparent.* [author's emphasis][205]

---

[203] For general discussions of seeing and its effects on telescopes, *cf.* Texereau (*op. cit.* ref. 6), pp. 307–326; Suiter, H.R., (*op. cit.* ref. 25), pp. 139–154; and MacRobert, A.M., "Beating the Seeing," *Sky and Telescope*, lxxxix, (April 1995), 40–43.

[204] Proctor, R.A., (*op. cit.* ref. 182), p. 755.

[205] Ellery, R.L.J., *Observations of the southern nebulae made with the Great Melbourne Telescope from 1869 to 1885, part i.*, (Melbourne, 1885), p. 4.

Schroeter, too, was familiar with atmospheric difficulties in relation to his 27-ft front-view:

> *Finally, as far as the power of this reflector is concerned, it is quite fully correct as Dr. Herschel asserts, that too large an aperture in a 20-foot (or greater) reflector can be disadvantageous to the greatest possible clarity, and this much more often and more completely than a small aperture in a moderate telescope. Not only must a much greater quantity of light be concentrated very exactly, but the column of air and vapor through which the rays must penetrate to the telescope and its mirror is significantly larger in diameter. In addition, temperature equalization of such a great mirror and of the air inside its tube with the air outside must often occur far more slowly, so that, of course, during unfavorable weather, especially when the atmosphere is turbulent, so-called "flickering" and "shaking" of the image must very greatly increase. Yet no practiced observer will ever enjoy using such a large reflector in unfavorable air, making more observations on the changes of the atmosphere than on the heavens….The truth is and certainly remains that a fully appropriate use of so large a telescopic body with the best imaginable mechanical construction is nevertheless a much more tedious, limited one, and above all one subject to greater inconveniences. Still, under quite favorable weather conditions, a much greater light-intensity and sharpness will afford the observer much greater (though rarer) advantages. At any rate, I am convinced that the performance of this reflector yields complete satisfaction to my expectations, so that after repeated comparisons with an otherwise excellent 13-foot, it gives more than twice as great a quantity of light, and compared with the latter, it is as much more powerful as the 13-foot is compared to a 7-foot.*[206]

Schroeter here alludes to a footnote in William Herschel’s 1794 paper on the rotation of Saturn, where Herschel comments: “In the course of these observations, I made 10 new object specula, and 14 small plain ones, for my 7-ft reflector; having already found, that with this instrument I had light sufficient to see the belts of Saturn completely well; and that, here, the maximum distinctness might be much

---

[206] Schroeter, J.H., (*op. cit.* ref. 142), p. 228 [Gerdes, D., (*op. cit. ref.* 110), p. 183]: “*So viel schließlich die Kraft dieses Reflectors betrifft, hat es zwar seine völlige Richtigkeit, daß, wie sich auch Herr D. Herschel äußert, eine zu große Oeffnung eines 20- und mehrfüßigen Reflectors der größten möglichen Deutlichkeit weit öfterer und weit mehr nachtheilig werden könne, als eine kleine eines mittelmäßigen Telescops; weil nicht nur eine ungleich größere Menge von Lichtstrahlen sehr genau concentriret werden müssen, sondern auch die Luft- und Dunstsäule, durch welche sie bis zum Telescope und Spiegel dringen, in ihrem Durchmesser beträchtlich größer ist, und eine gleiche Temperatur eines so großen Spiegels und der innern Luft des Rohrs mit der äußern oft weit langsamer zu erhalten ist; als wodurch natürlich bey ungünstiger Witterung, besonders dann, wann die Atmosphäre in Gährung ist, das sogennate Flimmern oder Beben des Bildes sehr vermehret werden muß. Allein kein geübter Beobachter wird auch wohl je Lust haben, einen so großen Reflector bey ungünstiger Luft zu brauchen, um damit mehr Beobachtungen über die Modification der Atmosphäre, als über den Himmel zu machen….Wahrheit ist und bleibt es freylich, daß ein völlig zweckmäßiger Gebrauch eines so grossen telescopischen Körpers bey der besten denkbaren mechanischen Einrichtung dennoch weit langsamer, eingeschränkter und überhaupt größern Unbequemlichkeiten unterworfen sey; allein dagegen wird auch bey recht günstiger Witterung eine weit größere Lichtstärke und Schärfe dem Beobachter desto größere, wenn gleich seltenere Vortheile gewähren. Wenigstens halte ich mich überzeuget, daß die Wirkung dieses Reflectors meiner Erwartung völlige Genüge leiste, daß er nach wiederholter Vergleichung mit einem sonst so herrlichen 13füßigen, mehr als zweymal so viel Lichtstärke habe, und gegen diesen gewiß reichlich eben so viel kraftvoller sey, als es der 13füßige gegen einen 7füßigen ist.*”

easier obtained, than where large apertures are concerned."[207] Herschel also commented in his letter to Lucien Bonaparte: "…my smallest telescopes will generally bear the highest magnifying power."[208]

Although it is true even today that large telescopes tend to suffer more visibly from the effects of seeing and thermal disturbances than small telescopes, the use of the front-view arrangement also guaranteed a blurring through geometrical aberrations. And the larger the instrument, and the faster its mirror, the worse the aberrations became, as Fig. 4.37 vividly demonstrates. That figure gives the *apparent angular size* of a bright star at the specified magnification. The true angular size as projected onto the sky is also easily calculated. If we take into consideration the blur spots in the center row of Fig. 4.37 (which are the most compact in size and shape overall), there are two components to consider in the blurs: (1) the bright triangular head areas; (2) the comatic side flares.

For Schroeter's 27-ft front-view, the head area would subtend about 1.75 arcsec on the sky and the flare would subtend about 5.5 arcsec. This is still reasonably small and compact, roughly equivalent to the resolution of a 6-in. telescope – apart from the comatic flare. For Herschel's 20-ft front-view, the head would subtend about 2.5 arcsec and the side flare about 12 arcsec, giving for the head area a resolution roughly equivalent to a 4-in. telescope. These are not terrible numbers, particularly for fainter stars where the tail would not register on the eye. And with the 20-ft front-view, Herschel was well satisfied since its mirrors in their best condition could "bring the small stars to a point" at 157×. However, it is clear that such an instrument would be unsuitable in general for double-star or planetary observation, and so it is easy therefore to comprehend why Herschel preferred his 7- and 10-ft Newtonians for high-resolution work, as his catalogs of double stars and records of planetary observations show. While as for the refined astrometric eyes of a Gauss, even the modest aberrations of such instruments were "far beneath his expectations."[209]

Larger front-views were another matter. In Herschel's 40-ft, the triangular head would have subtended about 4 arcsec on the sky and the comatic flare about 19 arcsec; while in Rosse's 36-in. used as a front-view the respective numbers would be about 6 arcsec and 28 arcsec! So these large instruments would have been roughly equivalent to a 2.5- and 2-in. refractor in resolution, capable of separating doubles only down to about 2 and 3 arcsec, respectively. We know from Robinson's testimony, previously cited, that the Rosse instrument in front-view configuration could

---

[207] Herschel, W., "On the rotation of the planet Saturn upon its axis," *PT*, lxxxiv (1794), 48–66, p. 50, footnote * [*TSP*, i, 458–469, p. 459, footnote ‡]. *Cf.* also Herschel, W., (*op. cit.* ref. 170), p. 80–81 [*TSP*, ii, 49].

[208] RAS MS Herschel W.1/4.4, f. 2r.

[209] *Cf.* Herschel, W., (*op. cit.* ref. 207), p. 51, footnote [*TSP*, i, p. 460, footnote *]; and for Gauss, *cf. Anon.*, (*op. cit.* ref. 145), p. 232. Note that the numbers given here for the absolute angular blur sizes of the aberrations (derived from ray-tracing in ZEMAX™ optical design software) differ substantially from the equivalent numbers found in Wilson, R.N., (*op. cit.* ref. 45), p. 19. In emails with the author during 2008–2009, Wilson acknowledged his numbers to be in error. They are many times too small.

not resolve γ Leonis, which in 1840 had a separation of about 2.8 arcsec. This accords with our calculation of the size of the triangular head in the aberration blur.

As light-gatherers these instruments performed much better, however. Yet here, too, there is a paradoxical difficulty most evident in the case of Rosse's 36-in. The express rationale for utilizing a front-view was to "save light," and so to achieve a higher instrumental "energy through-put" by ejecting the Newtonian secondary mirror with its low-reflectivity speculum surface. And since according to both Herschel's and Schroeter's express testimony, image sharpness actually *improved* in their 20- and 27-ft telescopes on ejecting the secondary mirrors, not only was there a light saving (in itself producing a higher energy concentration in the image) from the absence of the second reflection, but the energy concentration was enhanced by the more compact images. Thus from every direction there came an advantage: stars would indeed look brighter according to this explanation.

Herschel's 40-ft front-view with its 48-in. mirror, on the score of surface area alone, also produced a brightening compared to his 20-ft front-view. In principle the increased light would have amounted to $(48/18.75)^2$, or about 6.5×. Partially counterbalancing this, however, was the need to increase the copper content of the 48-in. blanks which reduced their reflectivity through rapid tarnishing. More serious, the greatly increased image aberrations from the tilting of the mirror diffused the image and lowered its energy concentration. Nevertheless, it is not hard to believe that the monster instrument did produce a notably brighter image than its little brother, the 20-ft.

With Rosse's 36-in. Newtonian, on the other hand, we enter new territory. Both South and Robinson attested to its brighter images in front-view mode. Yet it is clear on the basis of the blur spots seen in Fig. 4.37 that the enormous side flare of the 36-in. in front-view mode must have sapped a great deal of the energy. Indeed, an "encircled energy" calculation (*i.e.*, the amount of light in an image concentrated within a specified diameter, *cf.* note 210) suggests that at most only about 55% of the light reaching focus in the instrument was concentrated into the triangular head of the blur. Moreover, the expanded head was at least 2× larger than the corresponding Newtonian image if, as Robinson stated, the 36-in. was capable of resolving ζ Orionis in Newtonian mode. So stars seen in front-view mode should *not* have appeared brighter but dimmer and more diffuse than in Newtonian mode. There might be a 60% light saving by ejecting the secondary mirror, but 45% of the total light through-put would be wasted on the side flare alone, and furthermore, the core of the image would be at least twice as large in front-view mode, diminishing the energy concentration. And so we arrive at a paradox. South and Robinson seem to attest to the impossible: the 36-in. should not have presented obviously brighter stars as a front-view than as a Newtonian.

A way out of this paradox is offered by the concept of "stray light" in optical systems. Most telescopes are inherently subject to stray light – light that does not contribute to the focused image but arrives unwanted in the form of "veiling glare." Glare effectively covers the scene of interest, reducing its contrast against the background as seen in the telescope. How this occurs is easiest to understand in respect to a Cassegrainian telescope, in which the observer looks in the direction of the sky to find the object of interest. Light from the night sky itself (which is never completely dark when viewed from Earth) can easily pass obliquely by the side of the secondary mirror, and descend through the central hole in the Cassegrainian primary mirror, and so on to the image plane. To screen out such light, modern Cassegrainian telescopes typically employ a set of baffle tubes (one attached to the hole in the primay mirror, the other skirting the secondary mirror) in order to erect a mechanical barrier to the transmission of light directly from the sky. To an observer looking through the focuser tube of the baffled telescope, nothing is visible *except* the telescope mirrors. All other light is completely blocked out.[210]

It may seem self-evident that a system of internal baffles is *essential* to a Cassegrainian (or Gregorian) telescope, but in the nineteenth century it did not seem so. The Great Melbourne Telescope, for example, lacked internal baffles, instead utilizing an "eye-hole" (mechanical stop) on each of its eyepieces to define the exit pupil (Ramsden disk) and screen out unwanted light.[211] But this was a nuisance to the observer, since the eye should occupy the exit pupil but cannot, being blocked by the metal cap containing the eye-hole on the end of the eyepiece. William Herschel, therefore, enlarged and repositioned his eye-holes for use on his Newtonians, and advised a friend that he could dispense with them altogether for use at night in a Cassegrain or Gregorian telescope – which would thus be totally unbaffled. So although nowadays it is considered obvious that telescopes must rigorously screen out stray light, this was not always so.[212] Herschel himself accepted the lack of baffling to avoid other problems.

Not just Cassegrainians or Gregorians are subject to veiling glare. Newtonians suffer from it, too, even if less obviously so. Observers looking through Newtonian

---

[210] For "encircled energy," *cf.* Smith, G.H., (*op. cit.* ref. 24), p. 160. For stray light and baffling, *cf.* Rutten and van Venrooij, (*op. cit.* ref. 24), pp. 227–234.

[211] For an illustration of an unbaffled Gregorian-*cum*-eyepiece containing an eye-hole, *cf.* Pearson, W., (*op. cit.* ref. 4), plate xxvii, Fig. 2. For the eye-hole of a Newtonian-*cum*-eyepiece, *cf.* Fig. 4.2 of the present work.

[212] *Cf.* Coddington, H., (*op. cit.* ref. 103), p. 40, footnote *: "In applying [an] eye-piece to Gregory's telescope, it is found necessary to put a cap over the eye-glass, with an aperture just sufficient to let the effective pencils pass out to the eye, this being the only means of avoiding the unpleasant effect of *stray light* coming through the eye-piece without having been properly reflected at the mirrors." On the eye-holes (or "eyestops") of the Great Melbourne Telescope, *cf.* Robinson, T.R. & T. Grubb, (*op. cit.* ref. 126), p. 134; and *idem et al.*, *Correspondence concerning the Great Melbourne Telescope*, iii, (London, 1871), p. 58. For Herschel's enlarging and repositioning of eye-holes, *cf.*, "A series of observations of the satellites of the Georgian planet, *etc.*," *PT*, cv (1815), 293–362, p. 297 [*TSP*, ii, 542–574, p. 544]: "The hole through which [light rays] pass in coming to the eye, should be much larger than the diameter of the optic pencils, and considerably nearer the glass than their focus; for the eye ought on no account to come into contact with the eye piece…." For Herschel's advice to his friend, Alexander Aubert about Cassegrainian or Gregorian telescopes, *cf.* RAS MS Herschel W.1/1, pp. 27–28: "The lenses will need no guard or cap to screen the eye from light as they are to be used in the night time…." Edwards and Maskelyne also inveighed against eye-holes: *cf.* Edwards, J., (*op. cit.* ref. 114), pp. 52–53; and Maskelyne, N., (*op. cit.* ref. 114), pp. 58 and 60, and Maskelyne noted – already in 1783 – that Herschel did not use them.

reflectors do not direct their gaze in the direction of the sky but laterally across the telescope tube toward its side-wall – if there is a solid side-wall and not a mere framework tube. In the path of their vision lies the body of the Newtonian secondary mirror itself and its supporting structure (spider), both of which are never completely dark but scatter unwanted light. In addition, the interior side-wall of the telescope tube (even when painted black) is also never completely dark. All of these sources produce some stray light and, therefore, veiling glare in Newtonians. However, far worse can occur if the telescope maker positions the focuser and eyepiece too close to the front opening of the telescope tube – or if there is no solid tube. Then it is possible (and often occurs in practice) that from the position of the eyepiece the surrounding countryside or even the sky itself is seen *directly*. This occasions a flood of stray light.[213]

Unfortunately, surviving specimens and depictions of William Herschel's Newtonians show that he positioned his focusers quite close to the upper opening of his telescope tubes (*cf.*, *e.g.*, Fig. 4.27). Similarly, engravings of Lord Rosse's 72-in. depict the same thing. Hence it may be that all these instruments suffered to some extent from stray light and veiling glare.[214]

The front-view system, however, is inherently free from this type of stray light. There is no secondary mirror and no supporting structure to scatter rays, and the observer looks down the long darkened tube at the telescope mirror. Herschel's and Rosse's instruments were closed at the bottom. Hence, they were inherently free of such stray light. And as for light scattered by the pores and crystallizations in speculum metal itself (which act like so many particles of dust), this is also greatly diminished by reducing to one the number of mirrors used in the instrument.

Front-view telescopes belong to the class of instruments called "tilted component telescopes," or "TCTs" for short. These are reflecting telescopes with tilted optics, intentionally free of obscurations in the path of the light rays used for observation. The front-view is the most basic member of this class, capable of elaboration by means of lenses and further mirrors, as we shall discuss later in this work, to ameliorate or eliminate aberrations. For now we should say that users of all kinds of TCTs frequently note how dark the telescopic fields of view are, in comparison to those of other reflecting telescopes, and how much improved the contrast is.

So the doctrine of stray light suggests another reason why front-view reflectors were attractive to eighteenth and early nineteenth-century users – a reason that they themselves may not have recognized. The increased image brightness they attributed to the ejection of the speculum secondary mirror alone probably, in fact, was partly due not to an actual increase in energy concentration in the image but to an increase in image *contrast* through the suppression of stray light, scattered light, and veiling glare. The most obvious case of this would be Rosse's 36-in. used in front-

---

[213] For a framework tube, *cf.* William Lassell's 48-in. Newtonian used on Malta in the 1860s, as shown in King, H., (*op. cit.* ref. 166), p. 221.

[214] *Cf.* King, H., (*op. cit.* ref. 166), pp. 125 and 208; Rosse, Earl of, (*op. cit.* ref. 14), plate xxiv, Figs 5 and 7.

view mode. We noted previously how much of the energy recovered by ejecting its speculum secondary was then wasted on the enormous comatic image plumes. Nevertheless, South and Robinson perceived the telescopic images as brighter than in Newtonian mode. "Brighter" may in reality have meant "more contrasty" rather than truly brighter. The sky background as seen in the front-view looked darker. It is easy to comprehend how front-view telescopes could be very "contrasty" instruments, with very little veiling glare compared to Newtonians – or much worse, to Cassegrainians and Gregorians with no mechanical baffles.

## *Improving Performance by Diaphragms: Spanish 25-Ft and Restored 20-Ft*

South, Robinson, and Rosse in the 1840s projected improving front-view reflectors by converting their mirrors to off-axis parabolas. Their words to this effect have been previously quoted. They understood that in this way they could overcome the gross image blurs of standard front-view telescopes and recover the excellent sharpness of Rosse's large Newtonians. Hence, they also understood that those blurs resulted from geometrical aberrations occasioned by tilting the primary mirrors – or equivalently, to using them off-axis. Rosse had expressly stated in 1840 about the 36-in.:

> *I use it as a Newtonian, as I find that, with its large aperture and short focus, the saving of light by the Herschellian construction is not at all an equivalent for the sacrifice of defining power, at least that is the result of my present experience; the indistinctness, however, from the obliquity of the speculum, does not appear to me to be so great as I should have expected, considering the size of the circle of least confusion; for this I cannot account.*[215]

How Rosse determined the "circle of least confusion" he does not say. Perhaps he did it using the methods of computation introduced by Henry Coddington in his treatise of 1829–1830, *A system of optics*, which we previously discussed. Be that as it may, Rosse knew that the aberrations in front-view mode did not arise from "lateral faults" of his mirrors. For the mirrors acted perfectly in Newtonian mode, seated on their uniform support-bed of "equilibrated levers" invented by Thomas Grubb. Hence, too, Coddington's suggestion that: "It may be possible, by giving to a mirror a form different from that of revolution, to give accurate convergence to an oblique pencil," could now be taken seriously by Rosse, who according to South, "having determined geometrically the form of the curve requisite…is devising mechanical means for producing it." Robinson was even more sanguine, saying:

> *Lord Rosse does not apprehend any insurmountable difficulty in applying his method to give the form necessary for aplanatic oblique reflection: more than one plan for this has occurred to him; and Dr. R*[obinson] *believes it is his purpose, as soon as the* [72-inch] *has its machinery completed to try them on one of the* [36-inch] *specula, and, if successful, to alter the great one.*[216]

---

[215] Oxmantown, Lord, *(op. cit.* ref. 13), p. 524.

[216] Robinson, T.R, (*op. cit.* ref. 175), p. 132.

Alas, as we noted, in the end Lord Rosse was unable to build any giant off-axis parabolas so as to improve the action of front-view telescopes.

A more straightforward way to reduce their aberrations was simply to "stop them down," that is to say, reduce their apertures by placing a mechanical stop at the front opening of the telescope tube. William Herschel routinely stopped down his mirrors during optical testing, using the aperture diaphragms advised by John Mudge. Herschel had become aware of Mudge's article almost immediately after its publication, first mentioning Mudge under the date of April 26, 1778, in his *Experiments on the construction of specula.* Ten days later on May 6, Herschel was busy measuring zonal *foci* with diaphragms.[217] These diaphragms, or stops, took many forms for Herschel over the years as the *Experiments* show, and some were designed to discover and locate asymmetric portions of mirror surfaces, the parts that gave rise to the "lateral faults" of images.[218] Since the finest mirror testing occurred on the heavens: "[a]stronomical observations alone [being] the criterion of the perfection of a mirror," Herschel became accustomed to using stops during his astronomical observations. Inevitably, he noticed that they produced sharper views – even if the reduction in light-gathering defeated the purpose of making larger mirrors.[219]

Prof. Schrader, too, noticed that the use of aperture stops improved the action of defective mirrors: "Unhappily one takes refuge – especially if he is convinced that the mirror's figure is very close to a parabola – in so-called aperture stops [*Blendungen*], which necessarily rob the mirror of light…." And so it is not surprising that Johann Schroeter's initial explanation for the improved performance of Herschel's large front-view telescopes was that the upper end of the tube wall must itself be acting as a stop to vignette the aperture: "Probably Mr. Herschel in this way gained not at all more light, rather he gained less but better, and more clarity."[220]

On occasion Herschel even stopped down the 40-ft telescope. For example, in December 1804 Herschel wrote to his friend, Prof. Patrick Wilson (1743–1811) formerly a professor at Glasgow University, that he was investigating possible differences in the velocity of light according to color by way of further research on "the rays that occasion heat," that is, infrared light that Herschel had discovered experimentally several years earlier. For this purpose Herschel examined the sun *via* projection, using the 40-ft front-view – not at full aperture, but rather stopped down: "I had prepared to view the sun only with 9 inches, but when I opened the mirror it was immediately covered with ex[h]alations….This made me change my plan and give 24 inches of aperture; this being the next I happened to have ready." A 24-in. diaphragm was one of Herschel's zonal testing masks, which he mentions in the

---

[217] RAS MS Herschel W.5/12.1, pp. 7–8.

[218] RAS MS Herschel W.5/12.1, pp. 22–23 and 30.

[219] For the *dictum*, *cf.* ref. 67. For an early use of a stop, *cf.* RAS MS Herschel W.5/12.1, p. 100, exp. 336.2 (20-Jan-1789): "I tried the [20-ft] speculum in the evening on Jupiter and with 12 inch [*sic*] open saw that planet better than ever I have seen it before." Note that the outer 3-inch *annulus* of this mirror was at the time known to have a defective figure. Thus, when stopped down it gave a splendid image – even better, it seems, than his smaller Newtonians.

[220] For Schrader *cf.* ref. 165; for Schroeter ref. 138.

*Experiments* in connection with polishing tests of the thicker of the two 40-ft mirrors.[221]

By the end of his life, William Herschel might even have had a standard set of nesting diaphragms for use on the 20-ft front-view. Certainly when John Herschel refurbished that instrument under his father's guidance around 1820, in a notebook of "20-feet Memoranda", John recorded a table of "Diameters of Apertures in Tin to fit into Each Other." Eight such apertures are recorded ranging in size from 1 in. to about 15.5 in., the next larger size being the "whole mirror" at 18.5 in.[222] As a physicist and mathematician, John was fascinated by the effects of aperture stops – not only circular stops but triangular and of other shapes as well – on the diffraction pattern of a star. He experimented with stops and recorded the results in his earliest logbook of astronomical observations. He made good use of these results in the late 1820s, when he contributed a long, learned memoir to the *Encyclopaedia metropolitana*, which was also separately printed as *Treatises on physical astronomy, light and sound*. The plates in the treatise show many of the effects he had studied through the telescope.[223]

In the course of his experiments, John found that a stop with an opening in the shape of an equilateral triangle gave to a star a drastically altered diffraction pattern from a circular aperture, completely suppressing the circular diffraction rings around the Airy disk, and replacing them with six long and brilliant spikes radiating outward from the star. John recognized that this alteration could help in the discovery and measurement of close double stars, improving the visibility of a faint companion star in the immediate vicinity of a much brighter primary, if the apices of the triangular stop could be oriented such that the companion star fell between the bright spikes. This device (later later changed to an hexagonal aperture in order to increase light through-put) has been in use among modern double-star observers.[224]

John had planned to discuss his use of aperture stops during observations with the refurbished 20-ft front-view, and indeed to illustrate in a drawing some of these stops in his 1847 book presenting the results of his years of observing at the Cape of Good Hope. Economic exigencies, it seems, in the production of the book forced him to jettison this material (already composed), along with other detailed drawings

---

[221] For the letter to Wilson, *cf.* RAS MS Herschel W.1/1, pp. 255–256. For the 24-inch testing diaphragm, *cf.* RAS MS Herschel W.5/2.1, p. 124, exp. 392.

[222] RAS MS Herschel J.1/9, p. 8. RAS MS Herschel W.4/31.2 contains a large set of diaphragms labelled "10 feet gaging powers."

[223] For John's observation logbook showing his interest in diffraction patterns, *cf.* RAS MS Herschel J.1/9, f. 15r-26v, dated from April 1822 to October 1823. For his discussions and illustrations in the *Treatises on physical astronomy, light and sound*, *cf.* Herschel, J.F.W., (*op. cit.* ref. 27), pp. 491–493 and plates 9–10.

[224] An hexagonal aperture was mentioned in 1867 by Dawes, W.R., (*op. cit.* ref. 176), p. 155. In recent times, it has been recommended by Sidgwick, J.B., *Amateur astronomer's handbook*, 4th ed., (London, 1979), p. 464; and Jones, K.G. (ed.), *Webb Society deep-sky observer's handbook*, vol. 1, (New Jersey, 1979), pp. 18 and 22. The present author routinely uses one on his 8-in. and 11-in. refractors.

of the 20-ft and a textual description of the construction and use of the telescope. Fortunately, these rejected materials have survived and are now conserved at the University of Texas at Austin’s Harry Ransom Humanities Research Center, among a much larger collection of John Herschel’s papers, bought at auction by the university in 1958. The South African astronomer Brian Warner published an account of the rejected materials in 1979.[225] The drawings consist of 7 sheets; the text consists of 27 pages of manuscript. Most of this material (aside from some calculations and a few stricken comments by Herschel) Warner transcribed and published.[226]

One of the drawings, executed in pencil, illustrates a perspective view of the 20-ft in its refurbished guise. It is reproduced here as Fig. 4.38. A close-up is annexed as Fig. 4.39. The first of these figures displays a view of the entire instrument. An attentive examination of the observing platform perched before the front opening of the telescope tube shows that hanging from its front railing are two circular objects, one (at center) displaying an equilateral triangle inside the circle, and the second (on left) showing a series of (more or less) concentric rings. These depictions were drawn free-hand, apparently as an afterthought, while most of the drawing exhibits crisp pencil lines from the use of a straightedge.

The accompanying text (quoted from Warner) is as follows:

> *The diaphragms. The performance of telescopes on different nights and under different atmospheric circumstances is so unequal that it is indispensable to have constantly ready at hand and to be familiar with the application of every means of bringing on distinctness of vision, even at the sacrifice of some portion of the light afforded by a large aperture; when, for example it is required either to separate a close double star – to perform some careful micrometrical measurement, or to examine with attention and minuteness any particular object for which perfect definition is required and whose light is powerful enough to bear some sacrifice. It has been my practice therefore to have constantly within reach (suspended on the outside of the gallery railing, as seen in the perspective view) a set of circular diaphragms, ring within ring, fitting into one another and finally into the aperture of the tube, by which the aperture might be contracted successively to 15, 12, 9 and even to 6 inches as occasion might require. Besides these were also provided two other diaphragms in the form of equilateral triangles of 9 in and 6 in respectively, in their sides. Such a form of aperture, area for area, is much more effective in the division of double stars than a circular form since it reduces their spurious discs to a smaller apparent diameter without destroying their circular shape, and gives them a neatness and insulation by converting their whole system of interferential appendages into six hair-breadth rays…which is extremely advantageous in such observations: though of course fatal to distinct vision if*

---

[225] *Cf.* Warner, B., (*op. cit.* ref. 122).

[226] One stricken comment of interest in the present context states: “My principal object being the discovery of new nebulae and the determination with greater precision of the places of known ones; when objects of that nature were to be expected, little leisure was allowed for a minute examination of stars, especially on new ground. But in regions which had been once or twice well swept, or where nebulae were comparatively thinly scattered or altogether absent, stars down to the 6th or 7th magnitudes were seldom finally dismissed from the field of view till they had undergone the application of one or more of the diaphragms whether circular or triangular (almost universally the latter) with or without increased magnifying power according to the state of the air. To have executed a review with the 20-feet reflector expressly for the detection of close double stars would have required some additional years.” *Cf.* Herschel, J.F.W., “Description of the 20-feet reflector [with figures],” Box W0106 -W0195, Folder WO147, p. 29.

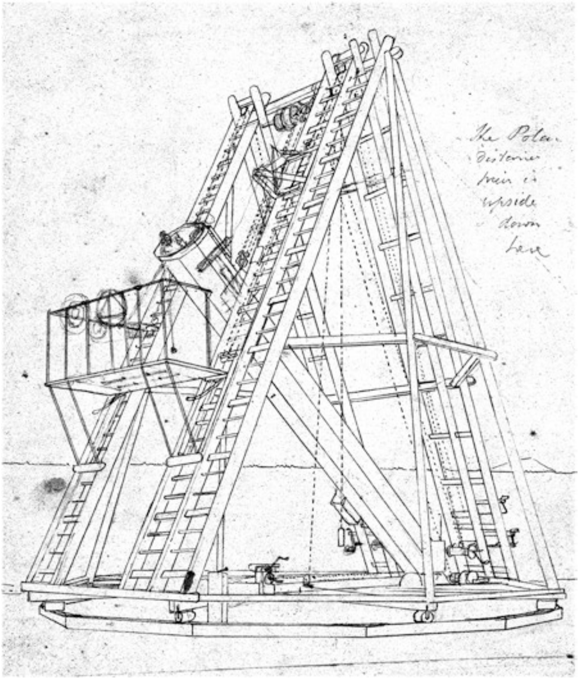


**Fig. 4.38** Pencil drawing by John Herschel, depicting a perspective view of his father's refurbished 20-ft front-view reflector (*cf.* Fig. 4.1 earlier for its earlier incarnation), as John used it at the Cape of Good Hope in the 1830s for his visual survey of the southern sky. Note the aperture stops seen hanging from the railing at the front of the observing platform before the telescope (Image reproduced with permission of the Harry Ransom Center, University of Texas at Austin)

> *applied to Planets or objects of a sensible diameter. The appearance of a bright single star with such an aperture is*…[a]…*very small and perfectly circular* [disk], *the rays of surprising length, delicacy and straitness* [sic], *and the intervals between them totally devoid of all irradiation. In consequence a much better chance is afforded of detecting a very minute or very close companion than when (as in the case of circular apertures) the disc is surrounded by a series of dark and bright rings which are almost never at rest.*[227]

It is clear from this statement that what is depicted on John's pencil drawing of the 20-ft, shown here in Figs. 4.38 and 4.39, is in fact his set of aperture stops, perhaps even those previously mentioned from his "20-feet Memoranda" book. John's work at the cape extended across the years 1834–1838. But already beginning in 1825 he had begun a systematic re-survey of the northern hemisphere of the sky from England using the refurbished 20-ft, which continued for 8 years until 1833.[228] In the course of "re-sweeping" the sky, John discovered many new double stars and

---

[227] Warner, B., (*op. cit.* ref. 122), pp. 101–102.

[228] Herschel, J.F.W., "Observations of nebulae and clusters of stars, made at Slough, with a twenty-feet reflector, between the years of 1825 and 1833," *PT*, cxxiii (1833), 359–505.

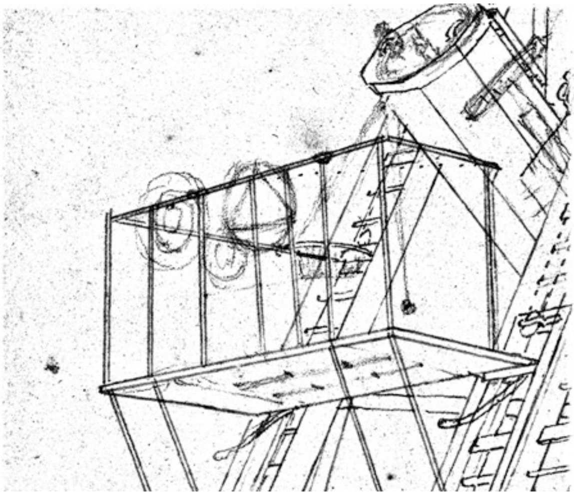


**Fig. 4.39** Close-up showing the aperture stops used by John Herschel on the 20-ft front-view during his observations in the 1830s in Southern Africa. On left is what appears to be a set of concentric circles; to the right of them a stop in the shape of an equilateral triangle (Image reproduced by permission of the Harry Ransom Center, University of Texas at Austin)

from time to time published catalogs of these starting in 1826. The first of these catalogs gives some information about his telescope and mode of observing:

> *Its light with its full aperture is such as to reach with facility the faintest nebulae of the 3rd class in my father's catalogs, and even to add to their number, while its distinctness with an aperture limited to 12 inches is sufficient for the definition of Double-Stars of the first class of an average degree of closeness, and when turned on objects of a sensible diameter, as the moon and planets, yields in distinctness to no telescope I have yet seen…provided the atmosphere be favorable, and the magnifying power be not carried beyond 300. When the whole aperture is used, a lower power becomes necessary to keep down the aberration, and that which I generally employ, as a sweeping power, is about 150 or 160, being produced by a single lens of an inch and a half focus.* [emphasis added][229]

Double stars of his father's "first class" included William Herschel's most difficult pairs. So this was high praise for the improved performance of the 20-ft, when stopped down from 18.5 in. to 12 in. Indeed, in 1834 after arriving at the cape and observing for some months, John went still further. In a letter he wrote to Francis

---

[229] Herschel, J.F.W., "Account of some observations made with a 20-feet reflecting telescope, *etc.*," *MmRAS*, ii, part ii (1826), 459–497, pp. 459–460. *Cf.* also, *idem*, "Approximate places and descriptions of 295 new double and triple stars, *etc.*," *MmRAS*, iii, part i (1827), 47–63; *idem*, "Observations with a 20-feet reflecting telescope-third series, *etc.*," *MmRAS*, iii (1829), 177–213; *idem*, "Fourth series of observations with a 20-feet reflector, *etc.*," *MmRAS*, iv (1831), 331–378; *idem*, "Fifth catalogue of double stars, *etc.*," *MmRAS*, vi (1833), 1–81; and *idem*, "Sixth catalogue of double stars, *etc.*," *MmRAS*, ix (1836), 193–204.

Baily, president of the Royal Astronomical Society, he reported himself: "…perfectly satisfied with the efficacy of [the 20-foot], as you may judge I have reason to be, when I mention powers of 480, 800, and 1200, *as giving perfectly round and well-defined discs with an aperture of twelve inches*…[emphasis added]".[230]

The reason why John found it so effective to stop down the aperture of the 20-ft telescope can be seen by considering the equations that define the extent of the so-called third order of coma and astigmatism. Although higher optical orders of these aberrations also influence the size and shape of the aberration blurs produced by a front-view telescope, the third order terms dominate. The equations defining these aberrations may be expressed as follows:

$$Coma = \frac{1}{2}u\left[\frac{\left({}^{D}\!/_{2}\right)^{3}}{f^{2}}\right]; \tag{4.1}$$

and

$$Astigmatism = u^{2}\left[\frac{\left({}^{D}\!/_{2}\right)^{2}}{f^{3}}\right], \tag{4.2}$$

where $u$ is the field angle, $D/2$ is the semi-diameter of the aperture, and $f$ is the focal length.[231]

From these equations, we can easily deduce several relations of interest. First for a given front-view mirror, in which the diameter and focal length are fixed, doubling the mirror tilt – and hence doubling the field angle $u$ – will cause coma to double, and astigmatism to quadruple. So reducing the mirror tilt to a minimum reduces coma and especially astigmatism in any front-view telescope. Second, for a given mirror diameter and field angle, doubling the focal length reduces coma by a factor of four and astigmatism by a factor of eight. If we assume that William Herschel's 20-ft and Johann Schroeter's 27-ft front-views both had essentially the same mirror diameters, and imaged at the same field angles, then Schroeter's telescope experienced ($20^2/27^2$), or about 55% as much coma as Herschel's telescope, and ($20^3/27^3$), or about 40% as much astigmatism. So the aberration blurs in Schroeter's telescope should have been only about half as long as those in Herschel's telescope. This accords with what can be seen directly in Fig. 4.37 above.

And thirdly, if a given front-view telescope is stopped down by half, then the coma decreases by a factor of eight and the astigmatism by a factor of 4. So in John

---

[230] Herschel, J.F.W., "Extract of a letter from Sir John Herschel to Francis Baily, Esq., dated Cape of Good Hope, October 22, 1834," *The London and Edinburgh philosophical magazine and journal of science*, vi (1835), 450–452, p. 452.

[231] Equations derived from Wilson, R.N., (*op. cit.* ref. 45), p. 80.

Herschel’s refurbished 20-ft front-view, the coma when stopped down from 18.5 in. (the diameter of his mirrors) to 12 in., becomes ($6^3/9.125^3$), or about 28% as much, and the astigmatism becomes ($6^2/9.125^2$), or about 43% as much. So the third order aberrations seen in John’s front-view when stopped down should in principle have been even smaller than those of Schroeter’s 27-ft. In fact, the head area of the aberration blur is only about 50 μm across, which is about twice the diameter of the Airy disk in the stopped-down system. This corresponds to 1.7 arcsec on the sky, potentially giving resolution of double stars down about about one-half that value or 0.85 arcsec, comparable to the resolution of a good 6.5-in. telescope, although with 3.4× as much light.

The results were so good that John did not need to burden himself with separate long-focus 7- and 10-ft Newtonian telescopes for high-resolution views when he went to the Cape of Good Hope. He brought – in addition to his entire family and a good polishing machine! – his 20-ft front-view, a low-power comet-sweeping reflector formerly belonging to Aunt Caroline (for the purpose of familiarizing himself quickly with the southern sky), and James South’s erstwhile 5-in. Tulley and Sons refractor for astrometric work. John had purchased the refractor from South and had already made considerable use of it in England in the early 1830s, after South had purchased his large Cauchoix objective and the fatal Troughton and Simms equatorial mounting, as previously noted.

It proved a fortunate choice that John Herschel did not bring a Newtonian telescope to the cape because he soon discovered that the climate there greatly accelerated the tarnishing of his speculum mirrors compared to what he had been accustomed to at home. And since his business was not making mirrors but observing, the less time spent repolishing the better. His father, on the other hand (as well as Schroeter and Schrader), had better luck against tarnishing in general and were not so pressed for time. Hence they largely maintained the distinction between front-views for deep-sky viewing and Newtonians for planets and double stars.

However, William Herschel did gradually come to see the value of aperture stops on front-view telescopes and that when masked down by one-half they could rival Newtonians in giving sharp views of planets and even replace them. This realization evidently impressed itself upon him most strongly in the case of a 25-ft front-view telescope that he constructed around the turn of the nineteenth century for the government of Spain. This contained a 24-in. diameter mirror – or rather two mirrors intended for different purposes (see below) – and the instrument was so successful that in later years Herschel praised it in contrast to the 40-ft by saying:

> *The difficulty of repolishing* [the 40-foot] *mirror, which is tarnished, and preserving or restoring its figure when lost, is so great that if a larger telescope than a 20 ft. should ever be wanting, I am of opinion that one of 25 ft. with a mirror of 2 feet in diameter, such as I have made and which acted uncommonly well, should be a step between the 20 and 40 feet Instruments.*[232]

---

[232] *Cf. TSP*, i, p. lv.

And in a published paper, he noted: "twenty-five feet reflector, power 200. The Georgian planet is better defined in this instrument than I have ever seen it before. With 300, its disk is as sharp and well defined as that of Jupiter. The second satellite is brought to a sharp point." In his observing journal he stated: "25 feet Telescope. 2d mirror. It shows Saturn very well. By limitting [*sic*] the aperture to one half of its dia.$^{m}$ it shews the planet in higher perfection of distinction than my 10 feet." It is not quite certain which telescope Herschel means by 10 ft, but presumably he refers to one of his 8.8-in. diameter f/13 Newtonians, since as we have seen already his 24-in. f/5 Newtonian ("large 10-feet") was intended for low-power deep-sky views.

Herschel's "limitting" of the aperture in the 25-ft front-view was not an accident. According to the terms of his contract with the king of Spain, he was to supply a 7-ft Newtonian and a 25-ft front-view. For the latter he sent a lengthy set of instructions as well as a series of beautiful watercolor paintings depicting the telescope as erected in England. Both were meant to guide and assist the Spanish scientists in erecting and using the instrument in Madrid. The watercolors still survive there; a copy of the instructions is to be found in the RAS Herschel archive. It contains an informative set of "Directions for the observer and assistant":

> *The principal use of this Instrument is to view and discover objects that are out of the reach of smaller telescopes. Its power therefore consists not in magnifying much, but in penetrating farther into space than instruments that are constructed upon a smaller scale….This being the case it may be asked why we still should use a 7 feet telescope when we are in possession of the 25 feet one. But the answer is very obvious, namely that if the latter has the advantage in space penetrating power, the former has it in magnifying power, distinctness and convenience. It should be laid down as a rule in astronomical observations never to use a large instrument when a small one will answer the end. No higher a magnifying power therefore than what is consistent with space penetrating power should be applied to the 25 feet reflector. For where magnifying power alone will answer the end, the 7 feet instrument ought to be used. For instance to view a very close double-star which requires no space penetrating power, the 7 feet will do better than the 25 feet; but to resolve Nebulae into stars, to view the Satellites of the New planet and those of Saturn, the 7 feet telescope will fall short, and no less an instrument than the 25 feet reflector of the Herschelian construction; that is to say without a second reflection, will shew these objects in perfection. For this reason also no other eye pieces than those mentioned in* [packing box] *No. 46… belonging to the telescope have been given.* For by a misapplication of the instrument its real use would be much perverted. [emphasis added][233]

When this instrument was sent to Madrid, it was the second largest telescope in the world. For the honor of having a "Herschelian" telescope, the Spanish paid over 3000 British pounds – in other words, the equivalent of 15 years of Herschel's salary as Royal Astronomer – and yet he imposed strict rules on how they might use their expensive instrument, allowing only such magnifications as he deemed acceptable.[234] To observe at high power they must employ a puny 6.3-in. Newtonian. To do otherwise would be "much perverted," Herschel declared.[235]

---

[233] RAS MS Herschel W.5/11.3, pp. 8–9.

[234] For the price, *cf. TSP*, i, p. l.

[235] Herschel gave similar instructions to the Russian government of Catherine the Great about the 20-ft front-view that they purchased in the 1790s. Their instrument, however, was not fitted for an

Yet, as it turns out, a partial reprieve existed to "telescope perversion." The Spanish might make use of an aperture stop to view the planets. The 25-ft was equipped with two mirrors, one being called the "best mirror" and the other – logically – the "second best mirror." Since it was "second best," it was suitable to be stopped down.

Elsewhere in his instructions, Herschel enjoined: "Diaphragm: when the second mirror is in the tube, the front of the telescope is to have the diaphragm put upon it; which will reduce the aperture; *but this should only be used for the planets, which thus will be seen in very high perfection.* [emphasis added]" Presumably, the diaphragm sent to Spain was the very one that Herschel had earlier used to observe Saturn, contracting the telescope's aperture by one-half and giving a view of the planet in "higher perfection of distinction than my 10 feet." This would effectively give access to a 12-in. reflector with imaging capabilities nearly identical to John Herschel's refurbished 18.5-in. front-view similarly stopped down. Had the Napoleonic Wars not intervened (the Spanish telescope was shipped in 1802), the telescope might have been used to great purpose. As it was, the mounting was destroyed by French troops in 1808. An impressive replica has recently been erected in Madrid.[236]

It is worth digressing a moment to consider further details regarding the performance of front-view telescopes. We have already quoted the Herschels' various descriptions, as well as those stemming from Schroeter, Schrader, von Zach, and finally South and Robinson. These indicate that at a fast focal ratio of f/9 to f/12, the front-view configuration although usable for its original purpose, namely to increase light-grasp by suppressing a second reflection on speculum metal, does not yield sharp views of bright objects. Figures 4.36 and 4.37 show why. But equally, if the focal ratio is increased to f/15, or still better to f/20 or f/25, then the image sharpness greatly improves, rendering planetary imaging good.

In recent years, the American amateur telescope maker and historian Thomas A. Dobbins has also recommended the long-focus Herschelian as an easy-to-build, attractive, and inexpensive alternative to costly apochromatic refractors or complex tilted component telescopes (such as Schiefspieglers) for crisp, high-definition planetary imaging. In 2004, Dobbins published a review article concerning a 6-in. f/25 Herschelian telescope, which he shortened ("folded") by means of a small flat mirror. Although in external appearance Dobbin's instrument resembles a Kutter Schiefspiegler (a type of tilted Cassegrain), it lacks the convex secondary mirror meant to reduce aberrations. So Dobbins' telescope is optically equivalent to a very slow front-view used rather far off-axis. About the performance of his instrument, Dobbins wrote:

---

aperture stop since they also bought a standard 10-ft Newtonian, and there was little to be gained by the complication of a diaphragm.

[236] *Cf.* Hoskin, M., [*op. cit.* ref. 4, (2011)], p. 155–156; and Planesas, P., "Elementos ópticos del telescopio de Herschel de 25 pies del Observatorio Astronómico de Madrid," *Observatorio Astronómico Nacional Informe técnico OAN 2001-14*, (Madrid, 2001).

> *…the Herschelian is a satisfying performer.* The field of view is unusually dark and free from scattered light. *The limb of the Moon illuminated by earthshine two days after first quarter is easily visible on a night of good transparency, and the planets look as crisp as if they were cut out of paper and pasted onto black velvet. During satellite transits, the tiny, bright disks of Io and Europa can be distinguished against the backdrop of Jupiter's zones, and Saturn's low-contrast belts and delicate crepe ring stand out more prominently at 280x in the Herschelian than at 180x in my 8-inch catadioptric Cassegrain.* [emphasis added][237]

The thrust of Dobbins' comments is that his telescope gave excellent performance for its size on difficult-to-see low-contrast extended objects, such as Saturn's inner ("crepe") ring – which was never discerned at all by William Herschel or Johann Schroeter – the illuminated disks of Jupiter's moons against Jupiter's cloud deck (as opposed to their easily seen dark shadows) and the nighttime side of the Moon, when only faintly illuminated by earthshine 2 days after first quarter. In private correspondence with the author, Dobbins further indicated that this admirable level of performance on extended objects, which surpassed that of a larger untilted Cassegrain-type telescope used at a lower power, did not apply to the resolution of close double stars. Coma and astigmatism were still in evidence. Nevertheless for crisp imaging of extended objects, Dobbins (like William Herschel before him) found that a high focal-ratio front-view gives a "higher perfection of distinction" than standard types of centered telescope systems. Other modern users of very slow front-view telescopes corroborate these assertions. [238]

In addition, we should note the words in the quotation: "*The field of view is unusually dark and free from scattered light.*" As was suggested earlier, it may be in part this tendency toward a darker background, freer from stray light that persuaded some observers that the front-view – even in forms producing highly aberrated image blurs – showed *brighter* stars. Notably improved contrast between an object under study and better-suppressed sky background might have created the impression that the object itself was brighter in the front-view telescope. Both Dobbins and South noted the enhanced visibility of the nighttime side of the Moon near first quarter, when earthshine becomes weak. South had said of Rosse's 36-in. front-view: "…when the moon was seven days and a-half old, I never saw her unilluminated disk so beautifully….".

More recently, Austrian amateur telescope maker Guntram Lampert constructed a small front-view telescope in order to test its performance experimentally. Lampert is an expert builder of modern TCTs, such as Kutter Schiefspieglers, as well as more complex designs of even better performance. Lampert constructed his experimental front-view in summer 2009, employing a 155-mm f/11.75 spherical mirror of excellent quality, tilted 1.8° laterally. He examined telescopic images using a battery of eyepieces, old and new – concave and convex singlets, as well as multi-element designs (Kellners, orthoscopics, and Plössls). Lampert issued a report, some of

---

[237] Dobbins, T.A., "A folded Herschelian reflector," *Sky and telescope*, cvii, (March 2004), 132–135, p. 135.

[238] *E.g.*, Pawlick, J.R., "An unusual off-axis reflector," *Sky and telescope*, xxxii, (1966), 231–232; and *idem*, "A folded Herschelian off-axis reflector," *Sky and telescope*, xxxix, (1970), 191–192.

whose chief points may be summarized as follows: (1) the sky background in the field of view seemed unusually dark; (2) tilt-induced aberrations were clearly and immediately visible; (3) the resolution roughly equaled that of a 60-mm refractor employed in comparison testing; and (4) the front-view might be useful for low-power survey observations, but was greatly inferior to a modern Newtonian or multi-component TCT for the resolution of double stars and for studying planetary detail, unless the front-view is drastically stopped down.

Applying a modern orthoscopic eyepiece, Lampert also noted: "Soon after first light, it became evident that image quality was worst in the center of the field of view, and could be improved by looking obliquely into the eyepiece." By "obliquely" Lampert meant that objects of interest showed improved sharpness when viewed not at the center of the eyepiece field but near the field edge. This occurred only in the tangential optical plane, that is, the plane of the mirror tilt. He produced a hand-drawn illustration showing the shape of point-source objects: distant LED lights on a mountaintop restaurant near his home in Dornbirn, Austria. His illustration is reproduced by permission as Fig. 4.40.

Most notable is that his sketch marked "Best Focus: Field Center" bears a strong resemblance to the tangential *foci* of Figs. 4.34, 4.35, and 4.36. Furthermore, on racking his eyepiece a little outside this focus position ($\Delta f \sim 2.5$ mm), he obtained an image at field center that resembled a star with a bright lateral flare, like the sagittal *foci* of Figs. 4.34, 4.35, and 4.36. So indeed an actual front-view telescope, recently constructed, confirms the general image forms presented earlier in this paper for large front-view telescopes.

Lampert also noticed that when objects were positioned near the field edge of his orthoscopic eyepiece, the aberrations decreased somewhat. This probably occurred in part because the off-axis aberrations of the eyepiece partially compensated the coma and astigmatism induced by the mirror tilt. The compensation is closely dependent on the precise design of the eyepiece, which varies from manufacturer to manufacturer. In the next section of this study we will examine eyepiece compensation more closely and show how William Herschel, too, might have noticed that his eyepieces could compensate somewhat for the aberrations he found in his 40-ft reflector.

Lampert further noticed in regard to his small front-view: "On faint stars, the aberrations don't look much worse at first glance, but just about every critical observation leads to disappointment." By stopping down the instrument, he found: "Observing at 90-mm aperture…revealed much improved images. The aberrations were, however, still easily seen, especially at the higher magnification. Astigmatism made double star observation, especially of close or unequal pairs, still a challenge. But the improvement was evident. Only when stopped down to an aperture of 72 mm, did the telescope begin to perform satisfactorily. At 121×, the residual aberrations were still easily visible, but for the first time, acceptable."[239]

---

[239] Lampert, G., "Some notes on the performance of a 155mm f/11,75 Herschelian Telescope," (2009). Report in the author's possession.

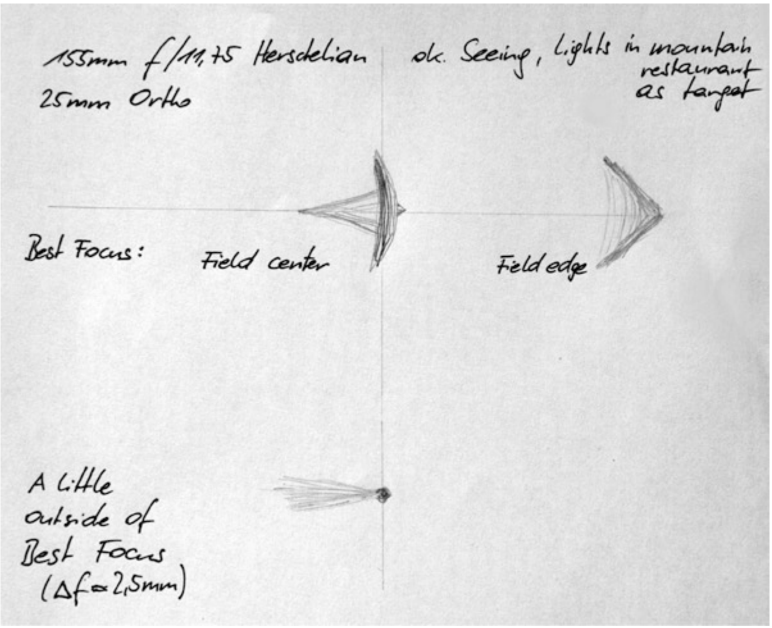


**Fig. 4.40** Amateur telescope maker Guntram Lampert's page of observing notes, showing his visual impression of point sources (distant LED lights on a mountaintop restaurant near his home in Austria), as seen in his experimental 155-mm f/11.75 Herschelian front-view reflector at 73× through a modern 25-mm orthoscopic eyepiece

Thus, Lampert confirmed experimentally that front-view aberrations are not very noticeable when viewing faint stars – however obvious they are when viewing bright ones (or distant bright LED lights) – and that images become far more acceptable when the focal ratio of an f/11.75 front-view is increased to f/25. His work confirms for a small instrument what William and John Herschel had discovered in much larger ones, and also accords with the findings of Dobbins.

## *Improving Performance by Lenses: "Drawing the Eye Sideways"*

Another means to improve the performance of a front-view telescope, without directly contracting its aperture, is to scrutinize the focal images by means of a tilted or decentered eyepiece. Guntram Lampert quickly discovered the possibility of eyepiece compensation empirically when observing through his 155-mm f/11.75 front-view and a modern 25-mm orthoscopic eyepiece. William Herschel, too, may have been aware of eyepiece compensation, as is shown by a private comment he recorded in his observing logbook, dated Oct. 24, 1788: “40 feet Reflector…I tried my second new Speculum upon Saturn….The speculum is much affected with lateral faults, but by drawing the eye sideways I saw very well.” This appears to constitute his only acknowledgment of the same sort of compensation for the coma and astigmatism, which must have been amply in evidence at his every use of the behemoth instrument. Whether Herschel availed himself of compensation very often cannot be proven, but is a possibility.

Other telescope users have also noticed the possibility, and its optical basis will be illustrated below. In 1794, Johann Schrader, after acutely noting that even small errors in the formation of Newtonian mirrors (especially the secondary mirrors) could lead to an agonizing process of alignment in a effort to find just the right combination of tip and tilt to compensate those errors, and after next praising Herschel for finding a means to avoid this alignment process by his invention of the front-view, noted that the annoying residual aberrations (“slight sideways gleam”) could be diminished: “I feel persuaded, however, that many a practical man will long since have noted that a somewhat tilted placement of the eyepiece lenses removes that gleam so that greater sharpness ensues.”[240]

By “somewhat tilted placement” Schrader evidently meant more than just a little. In fact it was enough so that he had to alter the mechanical construction of his eyepieces in order to avoid vignetting the cones of light proceeding through them:

> *Because the bundle of light emanating from the forward eyepiece-aperture is cut off at the aperture-edge due to the tilt of the glass and accordingly some light would be lost, I have essayed to make that aperture unusually large. It seemed to me that in this way the light bundle would maintain its round shape and that sharpness would be achieved by means of the tilted placement without a loss of light.*[241]

Although, in fact, Schrader was referring to the compensation of a defective Newtonian, the aberrations involved were just the same as in a front-view, since optically a front-view is just a very badly aligned Newtonian, such that the converging bundles of rays entirely miss the flat secondary mirror, which is accordingly ejected from the system as useless. So Schrader’s observation about the value of a tilted eyepiece also applies to a front-view.

Later users of front-view reflectors noted this application explicitly. In the nineteenth century, Vojtěch (Aldebert) Šafařik (1829–1902), a professor of chemistry and astronomy at Charles University in Prague, spoke of this in a talk he gave to the German Astronomical Association at its biennial meeting held in September 1879, a report of which was later published in their quarterly journal[242]:

> *As to the second point, the lecturer first of all studied the Herschelian front-view construction and found that the deterioration of the images, which occurs through the tilting of the mirror against the axis and which until now made this construction usable only at low*

---

[240] Schrader, J.G.F., (*op. cit.* ref. 15), pp. 17–18.

[241] Schrader, J.G.F., (*op. cit.* ref. 15), p. 18.

[242] On Šafařik, *cf*. Polášek, C., “The 8-inch Alvan Clark object glass at the Ondřejev Observatory,” *JBAA*, cxi, 3 (2001), 145–149.

> *magnifications, can be almost perfectly removed by tilting the eyepieces, the image being immensely improved.*[243]

The famous German optician, Hugo Schroeder (1834–1902), concurred, giving additional details in 1896 in the British technical magazine, *English Mechanic and World of Science*:

> *The same principle of oblique correction (as I call it) can also be used in the Herschelian front view, and carried out by tilting the eyepiece a little against the slightly oblique pencil emanating from the large mirror; but it cannot be sufficiently good carried out* [sic] *by employing a Huyghenian eyepiece, as it has to be a* perfect *achromatic eyepiece, where the different-colored images have to meet, and have to be of the* same size*. Also, the coma and astigmatism of such an eyepiece has to be (at least at small declination) identical in character to that produced by the large mirror. Again, an eyepiece, as my aplanatic eyepieces… cannot be used, as they do not produce aberration when tilted; but the* old *Steinheil aplanatic (not the new one) will be found useful for this purpose.*[244]

And finally, even as late as the 1930s, the idea of eyepiece compensation of Herschelian aberrations was not forgotten. It was reported in 1935 by Albert G. Ingalls (1888–1958), in his well-known book, *Amateur Telescope Making*. Ingalls quoted Capt. M. A. Ainslie, whose work on Herschel we met earlier: "Captain Ainslie of England has stated that 'Herschel always used single biconvex lenses as eyepieces and with these a very small displacement from the center of the field, in the proper direction, would go a long way toward correcting the image.'"[245]

Ainslie's general notion about eyepiece compensation is correct. His specific claim that William Herschel always used *biconvex* lenses is not correct. Since this is important to the question of optical compensation of front-view images, we should note that in fact, Herschel expressly preferred single *concave* (so-called negative or "Galilean") eyepieces for certain types of observing, despite the much narrower field of view they gave in comparison to convex forms. Single convex (so-called positive or "Keplerian") eyepieces cannot be used to compensate front-view reflectors, while single concaves can. So if Herschel at least occasionally availed himself of eyepiece compensation, then he must have done it using *concave* eyepieces.

Herschel explained his preference for concaves as follows:

---

[243] *Anon.*, "Bericht über die Versammlung der Astronomischen Gesellschaft zu Berlin, 1879 September 4 bis 8; Dritte Sitzung, Montag Sept. 8," *Vierteljahrschrift der Astronomischen Gesellschaft*, xiv (1879), 340–356, p. 347: "*Was den zweiten Punkt betrifft, so hat der Vortragende zuerst die Herschel'sche Frontview-Construction studirt und gefunden, dass die Verschlechterung der Bilder, welche durch die Neigung des Spiegels gegen die Axe entsteht, und welche bis jetzt diese Construction nur für schwache Vergrösserungen brachbar machte, durch Neigung der Oculare fast völlig gehoben und das Bild ungemein verbessert werden kann*."

[244] Schroeder, H., "The oblique Cassegrainian telescope," *English mechanic and world of science*, mdcxxviii (June 5, 1896), 353–354, p. 354. On Schroeder, *cf.* Riekher, R., (*op. cit.* ref. 29), pp. 201–203 and von Rohr, M., "Zur Erinnerung an Hugo Schröder," *Central-Zeitung für Optik und Mechanik*, xlviii (1927), 275–277.

[245] Ingalls, A.G., *Amateur Telescope Making*, (New York, 1935), 450; reprinted in *ATM*, i, 515.

> *With regard to the eye glasses, when merely the object of saving light is considered, I can say from experience that concaves have greatly the advantage of convexes; and that they give also a much more distinct image than convex glasses.*
>
> *This fact I established by repeated experiments about the year 1776, with a set of concave eye glasses I had prepared for the purpose, and which are still in my possession. The glasses, both double and plano-concaves, were alternately tried with convex lenses of an equal focus, and the result, for brightness and distinctness, was decidedly in favor of the concaves.*
>
> *For the cause of the superior brightness and sharpness of the image which is given by these glasses, we must probably look to the circumstance of their not permitting the reflected rays to come to a focus.*
>
> *Perhaps a certain mechanical effect, considerably injurious to clearness and distinctness, takes place at the focal crossing of the rays, which is admitted in convex lenses.*

This explanation appears in a paper of 1815 in which Herschel describes his researches on the satellites of the planet Uranus, as well as his search for additional satellites beyond the first two that he had found in January 1787. In a footnote to the paper, he expanded on the suggestion of “a certain mechanical effect” by saying:

> *About the same time that the experiments on concave eye glasses were made, I tried also to investigate the cause of the inferiority of convex ones; and it occurred to me that an experiment might be made to ascertain whether the rays of light in crossing, jostled against each other, or were turned aside from the right lined course by inflections or deflections.*[246]

It seems clear from this that Herschel formed his belief in the superiority of concave eyepieces from the Newtonian corpuscular theory of light. If light consists of particles – like tiny billiard balls – then there is a chance that as the particles converge to focus and draw very close to each other, they might brush and scrape one another, changing course as they proceed through focus. Since convex singlet eyepieces (as well as their multi-element modern descendants) were situated in use beyond the telescope’s focal point, these eyepieces might all suffer diminished performance *vis-à-vis* concave singlet Galilean eyepieces, which were situated prior to the telescope’s focus. Unfortunately, Herschel’s theory is at variance with modern physics, and his belief in the superior sharpness and brightness of concave eyepieces *versus* convex is at variance with modern geometrical optics – at least in regard to well-constructed Newtonian telescopes. There should be no noticeable difference in use on the score of sharpness, if we assume correctly made optical components.

To Herschel’s credit, when he performed his proposed experiment, he found no evidence that light rays crossing one another at right angles became visibly “jostled” or turned out of their courses. In other words, images were not visibly blurred in his experiment. Nevertheless, the texts quoted above show that Herschel did prefer concave eyepieces for observing situations which demanded the highest image brightness and sharpness (such as searching for faint moons), even if this preference

---

[246] Herschel, W., (*op. cit.* ref. 5), p. 297–298 [*TSP*, ii, p. 544].

cannot be justified by modern theory in the case of well-made, centered telescopic systems. On the other hand as we have seen, eighteenth-century reflecting telescopes were not well-made by modern standards, not even the best of them, and front-view reflectors in particular were afflicted with severe aberrations – of just the sort that could be compensated by concave eyepieces. Since nearly all the individual observations that Herschel recorded in his 1815 paper on the satellites of Uranus were made with his 20-ft front-view, it is not incredible to suppose that many of them profited from image compensation *via* concave eyepieces, the effects of which we shall illustrate in a moment. Herschel noted in his paper:

> *I have occasionally availed myself of the light of concave eye glasses, but a great objection against their constant use is that none of the customary micrometers can be applied to them, since they do not permit the rays to form a focal image. Their very small field of view is also a considerable imperfection; in observations, however, that do not require a very extensive field, such as double stars or* the satellites of Saturn and the Georgian planet, this inconvenience is not so material. [emphasis added][247]

Although in general Herschel does not indicate the magnification or eyepiece type used in his individual observations, the suggestion of the passage just quoted and of his praise for concave eyepieces is that he tended to use them in his observations of Saturn's and Uranus's moons, which of course formed but a limited *corpus* of work compared to the vast number of low-power observations he made in his sky survey using convex eyepieces.

Be that as it may, let us next consider the technicalities of compensating front-view aberrations. Many possibilities exist, using lenses or mirrors or both. It lies beyond the scope of the present work to explore the entire variety of tilted component telescopes based on the Herschelian front-view. Readers may consult an extensive literature for more information on that.[248]

For present purposes we restrict ourselves to lenses alone, and in particular to singlet plano-concave eyepieces. These may be used either to view an object off the optical axis of the eyepiece when it is untilted, or by tilting and looking through the eyepiece's center. Figure 4.41 below illustrates both arrangements.

At the top of the Fig. 4.41a, a plano-concave eyepiece is applied untilted. The telescope is assumed to be Herschel's 20-ft front-view. A star viewed along the axis of the eyepiece would have the size and shape shown in Fig. 4.37. But when the same star is viewed near the edge of the eyepiece field it will show the blur pattern seen at the right of the Fig. 4.41a. That blur consists of three nearly identical teardrop shapes. The reason why there are three spots separated from one another is that three different colors of light – red (656 nm) at top, green (547 nm) in the middle, and blue (486 nm) at bottom – have been ray traced, in order to sample the spectral range to which the human eye is sensitive. For comparison, the scale bar on right subtends 50 arcmin, the same as in Fig. 4.37.

In a correct image, the three spots ought to be superimposed on one another, as they are in Fig. 4.41b, where the same three colors of light have also been ray traced.

---

[247] Herschel, W., (*op. cit.* ref. 5), p. 298 [*TSP*, ii, p. 545].

[248] *Cf.* Smith, G.H., *et al.*, (*op. cit.* ref. 24), pp. 323–371 and 564–567.

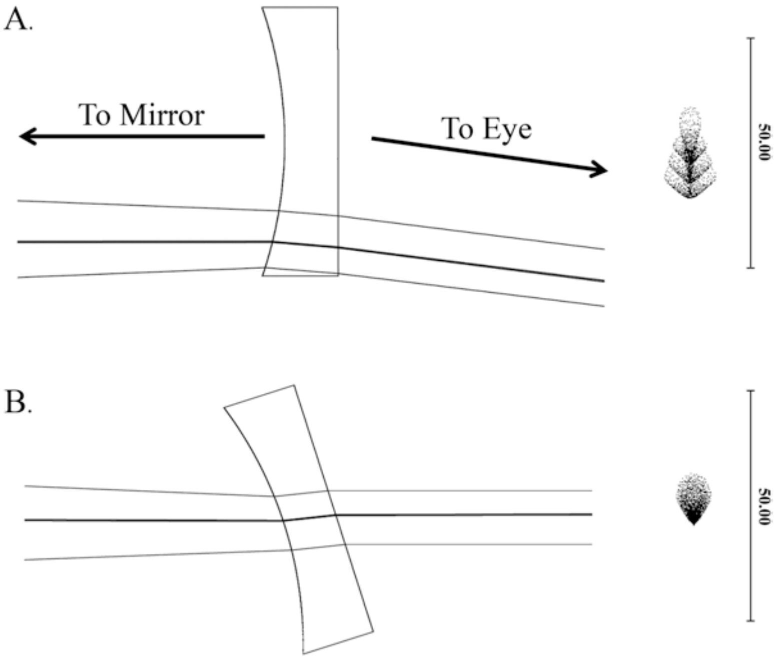


**Fig. 4.41** Two ways of using a plano-concave eyepiece to compensate for aberrations in a front-view telescope. The eyepiece may be applied to the converging beam, untilted (**a**), or tilted (**b**). If untilted, then the star should be viewed near the edge of the field of view. The telescope assumed is Herschel's 20-ft. Compare these blur spots to Fig. 4.37

Unfortunately, in Fig. 4.41a the three blurs fall side by side. This occurs because of an optical error called "lateral chromatic aberration," which causes a star to appear stretched out into a spectrum. The actual image seen under the conditions of Fig. 4.41a would contain many more colors of light than just three; in fact, there would be a continuous succession of teardrop-shaped images stretched out between red and blue. This succession in itself would greatly blur the object under view.

Two things come to the rescue. One is that the human eye is far more sensitive to green light than to red and blue, so that in fact some of the spectral stretching of the image would only be faintly seen by the human observer. And second, the eye itself can to some extent compensate for lateral chromatic aberration, if the observer regards the object not through the center of his or her eyelens but through its marginal area. This use of the eye to compensate for lateral chromatic aberration is well known to practised astronomical observers and has been in use for a long time.[249]

Hence, although the lateral chromatic aberration is a bad effect, it can be at least partially mitigated in practice, so that when William Herschel wrote: "…by drawing

---

[249] *Cf.* Taylor, H.D., *The adjustment and testing of telescope objectives*, 4th ed., (Newcastle, 1946), pp. 18–19.

the eye sideways I saw very well," it is not inconceivable that he was referring to an observing situation like that depicted in Fig. 4.41a. Herschel, of course, was an enormously practised and resourceful astronomical observer. Guntram Lampert found with his experimental front-view when using concave (negative) singlets:

> *I felt that the image quality was definitely better than with positive singlets. There was less axial color, and a good amount of lateral color could be corrected by proper placement of the eye pupil. Compensating for lateral color was, however, a delicate affair, for the eye had to be kept at a precisely defined position with respect to the eyepiece.*

As for the teardrop shape of the image blurs in Fig. 4.41 (especially Fig. 4.41b), this is the classic sign of coma. Although the eyepiece when used off its optical axis almost nullifies the astigmatism from the mirror tilt, it does not do the same for coma. Nevertheless, the individual (monochromatic) blurs are much smaller than the combined (polychromatic) blurs seen in Fig. 4.37 for the 20-ft front-view.

Finally, it is also possible that Lampert and Herschel were unconsciously clipping the emerging ray bundles with the pupil of their eyes so as to screen off (vignette) the most aberrant rays. This has the effect of combining an eccentrically placed aperture stop (pupil of the eye), eyepiece compensation, and use of the eyelens itself to diminish lateral color. However, only a very adept and experienced visual observer can hope to make such skillful use of his or her eye. The untrained will simply fail.

A better way to proceed would be to use a multi-element positive eyepiece, which has not been corrected for off-axis coma and astigmatism but has been fully corrected for lateral color. When used off its optical axis, such an eyepiece can act rather like the untilted plano-concave of Fig. 4.41a, compensating both the coma and astigmatism of the front-view but without giving rise to the lateral color aberration. This is the type of correction to which Hugo Schroeder referred in 1896 in the passage previously quoted. Since, however, most modern eyepieces are corrected for coma and many for astigmatism, too, only certain simple types can be used. Schroeder suggested using an older form of the Steinheil "monocentric."[250]

Still another way to compensate front-view aberrations is by viewing an object through the middle of a *tilted* plano-concave singlet lens, as is shown in Fig. 4.41b. The effect of this is much like using the same eyepiece off-axis, except that the tilting of the eyepiece now compensates lateral chromatic aberration so that the blur spots are correctly superimposed. Although, as we previously saw, there is some evidence that Johann Schrader was aware of this type of correction, there is no evidence that William Herschel used it. On the contrary, Herschel advised Johann Schroeter in January 1794, when the latter was in process of converting his 25-ft Newtonian to a 27-ft front-view, to point his eyepieces straight at the center of the concave mirror. Schroeter went to great lengths to do that and later described in intricate detail a kinematic focuser he designed to allow precise tip-and-tilt adjustment of his eyepieces for just this purpose.[251]

---

[250] For the monocentric eyepiece, *cf.* Smith *et al.*, (*op. cit.* ref. 248), pp. 494–497.

[251] Schroeter, J.H., (*op. cit.* ref. 142), pp. 224–225.

Thus, although there is some surviving evidence to suggest that Herschel at least on one occasion may have employed eyepiece compensation and perhaps pupil vignetting to diminish the aberrations of his 40-ft front-view, there is no evidence that he did it extensively. Instead, when he wanted to improve image sharpness in a front-view, he (and later John more extensively) contracted the aperture *via* a mechanical stop placed at the upper end of the telescope tube. Still, given William Herschel's resourcefulness and bent for experimentation, and given that he was not averse to occasionally holding an eyepiece at the focus of a front-view telescope and manipulating it by hand, it is not impossible that he was aware of the advantages of tilted eyepieces, but he left no trace of it in his writings.[252] It might be awkward to explain to others why his telescopes worked better with eyepieces twisted out of their "correct" orientation – before the advent of modern aberration theory. In any event, Herschel used his standard Newtonians for high-resolution observing, and the amount of compensation achievable on the 40-ft by means of tilted eyepieces was not enough to render this ungainly instrument suddenly a superb performer.

## Controversy and Conclusion: Performance of Herschel's 40-Ft Front-View

There were many reasons why Herschel's 40-ft front-view despite its sensational appearance could never have performed well in practice. Alone the tilting of the f/10 primary mirror guaranteed a vast amount of coma and astigmatism to degrade the images. Even Lord Rosse, Thomas Robinson, and James South, although impressed by the increased image brightness (or at least contrast) of Rosse's smaller 36-in. f/9 telescope in front-view configuration, nevertheless were strongly disturbed by the aberrations, so that they could only conceive of such an instrument being useful if the mirror were converted to an off-axis parabola. As we saw in Fig. 4.37 earlier, the aberrations in Rosse's instrument were comparable to those of Herschel's 40-ft.

One feature of Rosse's Newtonians which marked a vast improvement over Herschel's was the whiffle-tree mirror support. This was the first engineered load-support system for a telescope mirror ever devised, and it opened the door to the vast reflecting telescopes of today, which far and away exceed any conceivable refracting telescope in resolution and performance. William Herschel's use of a simple supporting flange (as in a lens cell) to hold his dense speculum mirrors was evidently adequate for small examples, but to support a 2000-lb mirror it must make a modern optical engineer wince. The addition of iron crossbars on the back hardly improved matters. Already Robinson recognized this problem, and it figured in an acrimonious exchange of letters between him and John Herschel, which we will examine in a moment.

---

[252] For hand manipulation of an eyepiece, *cf. TSP*, i, p. xlvii.

Another improvement associated with Rosse was his method of testing elliptical secondary mirrors so as to give them the flat surfaces they needed for use at 45°. This made it feasible for the first time to build large speculum-metal Newtonians that gave critical definition. Front-views were thereafter consigned to the history books.

However, beyond aberrations induced by tilt, poor flats, or inadequate support, a host of mechanical problems existed with the 40-ft. Herschel's first mirror blank was so thin that it flexed easily, and he could never figure it well. The second thicker blank had so much copper in it that South uncharitably compared it to the color of mahogany. This drastically accelerated tarnishing from the dew and ice that frequently settled on it. Hence the mirror frequently needed repolishing.[253]

This was arduous at best. Not only did the blank have crystallizations and numerous pores making it very susceptible to "burs" in polishing, but Herschel's method of polishing with the mirror on top of the pitch lap necessitated an enormously strong polishing machine to move the one-ton mass back and forth across the polishing lap. Even so, the polishing machine broke more than once and had to be repaired and strengthened. Sometimes, too, the polishing laps could not be built strong enough to support the mirror, and the immense pressure of its mass created scratches, "heat spots," "lunar appearances," and stains of various colors on the metal from the friction.

In addition, the mirror was obviously very dangerous to move on and off the polisher and into and out of the telescope tube. In fact it was nearly lethal. Caroline Herschel recalled of the 1807 repolishing: "In taking the forty-feet mirror out of the tube, the beam to which the tackle is fixed broke in the middle…Both my brothers [William and Alexander] had a narrow escape of being crushed to death." It is no wonder that the 40-ft – in the words of eminent Herschel scholar Michael Hoskin – soon became for William Herschel "a rod for his own back."[254]

After extolling the glories of the telescope in print in 1795, Herschel later admitted to its mechanical problems. Caroline confirmed these privately to John decades later. The vast wood and iron structure was of course hard to move by hand, and being exposed on a continuous basis to all kinds of weather, it grew stiff and required hours of lubrication and preparation for a night's observing. Ropes might break and need replacing. The observer had to be winched high in the air and use a speaking tube to communicate with assistants on the ground. It was, after all, an immense instrument. The far more compact 20-ft front-view by contrast could be ready in ten minutes, according to Herschel. And since the image quality of the 40-ft, even if the mirror was perfectly polished and paraboloidal, could never have been very good and the minimum useful magnification was at least 189×, in order to take advantage of the full aperture, the field of view was inevitably restricted, and finding and following objects was difficult. Sweeping was possible, and Herschel tried to use the instrument for sweeping but soon discontinued the practice. He later claimed that it

---

[253] Hoskin, M., [*op. cit.* ref. 4, (2003)], pp. 19-20; *idem*, [*op. cit.* ref. 4, (2011)], p. 171–174; and *TSP*, i, p. lii–liv.

[254] Hoskin, M., [*op. cit.* ref. 4, (2011)], p. 128. For pores, burs, and polishing defects, *cf.* RAS MS Herschel W.5/12.1, Exp. 423.2; W.5/12.2, Exp. 103.2.7, Exp. 483, and Exps 527–528, *etc.* For the machine breaking, *cf.* RAS MS Herschel W.5/12.2, Exp. 117.2; and W.5/12.3, Exps 5–7; and for problems with the pitch laps, *cf.* RAS MS Herschel W.5/12.3, Exps 194–214 and 232.

would take over 800 years to sweep the entire sky (if that were possible) with the 40-ft. Obviously, he preferred (and conducted) a more directed line of research.[255]

Yet at the same time Herschel was loath to give up on the beast. Since he was never in a position to comprehend how much of his imaging difficulties lay in the irreducible geometrical aberrations, and since expelling the secondary from the 20-ft either had improved or at least done no harm to its images, whatever imaging problems Herschel saw in the 40-ft he attributed either to the figure or to surface blemishes. He spent much time between 1789 and 1808 battling these, as the *Experiments on the construction of specula* show, and persuaded himself that he was making progress in the ordeal.[256] But even if he could have succeeded to the extent he hoped, tarnish would soon have robbed him of his trophy.

In the meantime, he needed a tactical victory. Since already in 1787 Herschel strongly suspected that Saturn had additional moons beyond the five then known, as soon as the second 40-ft mirror was semi-polished, he quickly confirmed and proclaimed the existence of a sixth satellite (Enceladus) to meet the pressing demand for a spectacular discovery. He had in fact already seen Enceladus in his 20-ft reflector, and it is visible in a modern 8-in. telescope under good conditions.[257] But Herschel didn’t follow up the moon, since, as he later insisted, he was too busy with research on the moons of the Georgian Planet. Of course, since spectacular discoveries don’t grow on trees, it might prove a sagacious policy to retain one in one’s pocket for presentation on demand. The second spectacular “find,” hardly a month later, was a

---

[255] Ironically in June 1795 when Herschel’s paper on the 40-ft was read before the Royal Society, the instrument was not in a fit state for use. The mirror was tarnished and had a poor figure, as the polishing log shows. Even though Herschel struggled with it into the fall of 1795, it was no better: cf. RAS MS Herschel W.5/12.3, Exp. 232, 235, 254, *etc*. For the time needed to sweep the whole sky with the 40-ft, *cf.* Herschel, W., (*op. cit.* ref. 170), p. 85 [*TSP*, ii, 52]. For its mechanical problems, *cf.* Herschel, W., (*op. cit.* ref. 5), p. 295–296 [*TSP*, ii, p. 543–544]; and Herschel, Mrs. J., (*op. cit.* ref. 155), pp. 210.

[256] Already in August 1789, during the first trials of the 2nd, thicker speculum, Herschel privately recorded: “The Speculum gives a pretty sharp image of the stars. The large ones are affected with a very small burr, or rather scattered light, owing to the remaining scratches in the speculum.” *Cf.* RAS MS Herschel W.2/4, f. 1v. This, however, seems to be hopeful thinking. The log in which it is recorded (“Observations with the 40 feet Telescope”) has been characterized as “a brief to justify the monster’s existence,” and indeed the entries in its remarkably petite compass of eight pages seem tendentiously selected. No other log book for a particular telescope in Herschel’s collection exists. *Cf.* Hoskin, M., [*op. cit.* ref. 4, (2003)], p. 15.

[257] For Herschel’s “pre-discovery” sighting of Enceladus with the 20-ft, *cf.* RAS MS Herschel W.3/1.8, p. 63 (28-July-1789): “$22^h\ 31'$ I now perceive between the nearest satellite [Rhea] and [Saturn] on the following side, a small lucid point like an emerging satellite…$22^h\ 37'$ The last discovered point not quite half way between the 3d [satellite] and the body [of Saturn]. May be (it is) a 6th satellite.” *Cf.* also Herschel, W., (*op. cit.* ref. 170), p. 77 [*TSP*, ii, 47]: “…both satellites are within the reach of the 20-feet telescope….” The author has often seen Enceladus with an 8-inch refractor. It was seen in *ca.* 1796 by Giuseppe Cassella in Naples using a 7-ft Herschel Newtonian belonging to Lord Acton. *Cf.*, Cassella, G., “Aus einem Schreiben des Herrn Cassella, König. Astronomen in Neapel,” *AJJ 1799*, (1796), 244; and Gargano, M., “The development of astronomy in Naples: the tale of two large telescopes made by William Herschel,” *Journal of astronomical history and heritage*, xv.1, (2012), 31–42, p. 35.

seventh moon of Saturn (Mimas). This, too, was visible in the 20-ft, and may be seen in a modern 16-in. reflector under good conditions.[258]

The finding of Enceladus and Mimas in August and September 1789, as well as seeing Saturn's ring on edge when it is normally invisible to small Earth-based telescopes, and finally seeing some Saturnian spots "better than before" – this constitutes *the entire catalog* of discoveries made with the 40-ft telescope. Far more productive was the 20-ft with which thousands of new objects were first seen. Inevitably, after the initial fanfare of doubtful discoveries with what Sir James South later called "The George the Third Telescope," Herschel fell silent.[259] Schroeter and Schrader in the meantime after 1792 were busily trumpeting the successes of ever larger telescopes, with Schroeter penning lengthy articles and books proclaiming his planetary discoveries – to the great annoyance of Herschel, who lashed out publicly in 1793. But no one heard of anything more done with the largest telescope in the world. Repeated requests from eminent scientists and instrument makers, such as Jérôme de Lalande (1732–1807), Edward Troughton (1753–1835), Georg Christoph Lichtenberg (1742–1799), and even Schroeter himself to come and look through the instrument were refused or went unanswered.

Very few people were ever allowed that unique experience. Finally, it began to dawn on perceptive minds that the instrument must not perform very well. Herschel's lengthy description of it, published in the *Philosophical transactions* for 1795, and his dedication of the instrument to the king in a magnificent engraving may have delayed the perception, but nevertheless it was only a few years later that the first intimations of "failure" were hinted at in public.

A short anonymous biography of Herschel appeared in 1798, in the first volume of the series, *Public characters*. This book consisted of biographical sketches of contemporary Britons, and the first volume described the lives of such luminaries as Horatio Lord Nelson, the Archbishop of Canterbury (John Moore, who had clambered through the tube of the 40-ft with the king during its construction), Lord Hood, William Pitt the Younger, Joseph Priestley, and Herschel's friend, Dr. Charles Burney, FRS, music historian and father of the novelist, Fanny Burney. It was distinguished company. Three editions of *Public characters* were soon issued, and sales were said to be brisk.

Toward the end of the seven-page sketch of Herschel's life and activity, we read the following statement:

> *[S]ince his residence in the neighborhood of Windsor he has far exceeded this design, and completed an instrument of no less than forty* [feet]*! The irregularities in the speculum, and the impossibility of rendering the parts of so enormous an instrument as this mathematically exact,* have hitherto prevented his being able to make any actual observations with it. *It is a vulgar error, that the discoveries of Dr. Herschel have been occasioned by the*

---

[258] The author has seen it several times in a 16-in. f/4.5 Newtonian. On the suspicious history of discovery of both moons by Herschel, *cf.* Hoskin, M., [*op. cit.* ref. 4, (2011)], pp. 123–128. That the 2nd (thicker) 40-ft mirror was not yet fully polished can be seen at RAS MS Herschel W.5/12.1, p. 124, exp. 393.4 (22-Aug-1789): "The polish is still very far from being complete but I shall try the speculum on celestial objects before I polish any more."

[259] South, J., (*op. cit.* ref. 16).

> *enormous magnifying power of his telescope; the fact is, that no such large power is necessary, or useful; and that all Dr. Herschel's discoveries have been made with reflectors of from ten to twenty feet, and with powers of from sixty to three hundred. His discoveries are to be ascribed to his laudable perseverance, and not to the size of his grand telescope,* which is rather an object of curiosity than of utility. [emphasis added][260]

It is true that the *Public characters* sketch contains numerous errors of detail, but its appraisal of Herschel's telescopes, and the reasons for his success, is essentially correct. Indeed, the 40-ft *was* little more than "an object of curiosity": a landmark and sightseeing destination for the many royal visitors coming to visit the Majesties at Windsor Castle. It even became an object of reference on an ordnance map! At the same time, the appraisal was no doubt too frank to sit well with the Herschel family, and William above all (if he ever saw it), who needed to keep up the appearances of success in order to avoid embarrassing or further outraging the Royals.[261]

Alas, the sketch caught the eye of no less a publicist than Franz von Zach, who soon translated it into German and inserted it into his widely read scientific journal, the *Monatliche Correspondenz*, in the year after his glowing account of Schroeter's astronomical telescopes.[262] Decades later, this translation came under the eye of Caroline Herschel, who was incensed. In a surviving folder of the RAS Herschel archive, there is to be found her copy of Zach's translation. Precisely at the point where Zach has reiterated the *Public character's* statement that the 40-ft was little more than a curiosity, she has inserted three pages of commentary and corrections, saying: "What does he mean?"

> *Finding Zach's translation (of a very imperfect and erroneous Biography of Wm. Herschel published…in England) not what ought to be expected from one who had enjoyed for several years* [Herschel's] *personal acquaintance; I intended to have Noted the places where he is too ready with asserting what he thinks or supposes; because he will not confess his ignorance.*
>
> *But having found among a collection of* "Denkmäler verdienstvoller Deutschen *etc*." ["Memorials of Meritorious Germans"] *the same Biography translated by H. C. Maseberg and published in* Neues Hannöverisches Magazin…*Augt. 10, 1804, and in comparing the two translations I found after Note 1.2.3 that the latter is furnished with Notes by my youngest Brother Dietrich Herschel; which will by referring to the same; save me the trouble of making them over again.*
>
> ….
>
> *Zach mixes the discoveries of* [Saturn] *and* [Uranus]. *The latter has 6 satellites but no Rings are as yet discovered; But a Quintuple belt and a 6th and 7th Satellite of* [Saturn] *have been discovered with the 40 feet reflector since Zach has been in England; for in March 1786 the Foundation was only laid for the erection of the 40 ft. and since that time I have not seen*

---

[260] The three editions of the first volume of *Public characters* are: *Anon*., *British public characters of 1798*, (London, 1798), 358–366; *idem*, *Public characters of 1798*, (Dublin, 1799), 251–257; and *idem*, *Public characters of 1798–9. The third edition*, (London, 1801), 384–392. The text quoted comes from the revised 3rd edition, p. 391. For the brisk sales see the advertisement to that edition.

[261] Hoskin, M., [*op. cit.* ref. 4, (2011)], pp. 175–176.

[262] Von Zach, *MC*, v, (1802), 70–77.

> *him at my Brother's house where he met since the year 1782–3 with a friendly reception whenever he had a mind to see what he could pick up.*
>
> C.H. Ap$^{l}$. 20, 1838[263]

The peevish tone may be excused when one reflects that Caroline was at this point 88 years old and had been living a joyless life of exile back home in Hanover, her native city, having departed from England (to her lasting regret) 16 years earlier, after the death of her beloved brother, William, in 1822. Nevertheless, the tone and circumstances serve to show the continued Herschelian sensitivity to the 40-ft, a full 50 years after its erection.

Equally important is Caroline's mention of a second German translation of the *Public characters* sketch. This was composed by H. C. Maseberg and published, as Caroline noted, in the August 1804 issue of the *New Hanoverian magazine.* Maseberg, although taking no notice of Zach's earlier translation, was clearly aware of it and consulted it. Structural and verbal reminiscences exist – as well as obvious corrections and amendments. It may be that Maseberg's edition was intended to be just as much a polemic against Zach as a correction to the *Public characters* itself. Indeed, since Maseberg was apparently in close contact with the Herschel family, it seems he might just as well have produced an entirely new biographical sketch, sanctioned by the family, rather than follow the British text which he spends much time disparaging in lengthy footnotes – if it were not for Zach's earlier translation of it, published in a widely read German scientific news journal.

Maseberg was assisted in his edition by an anonymous person, who was "precisely acquainted with the life circumstances" of William Herschel and in possession of copies of Herschel's papers.[264] As we have seen, Caroline states that this was her youngest brother, Dietrich Herschel. Maseberg calls his informant "H." Since Dietrich was living in Hanover in 1804 (alone of the surviving brothers), it is likely that Caroline is correct. By 1838 she could not ask him directly, because he had died 10 years previously.[265]

Be that as it may, while Zach produced a straightforward translation of the *Public Characters* sketch, Maseberg did what he could to recast its most damning sentences without blatantly lying. Thus, Maseberg's version of the first two sentences in the English text quoted above is as follows:

> *…thus, now in the neighborhood of Windsor he had further extended his plan, and completed a telescope of no less than 40 feet. Yet the irregularities of the mirror and the diffi-*

---

[263] RAS MS Herschel C.4/5 (between Zach's pp. 76–77). Caroline's faulty spellings have been corrected here. The notion that William discovered 6 satellites of Uranus is mistaken, as is the notion that the "quintuple belt" of Saturn was found with the 40-ft. William thought he found four additional satellites (he did not) with the 20-ft; and the quintuple belt was observed with a 7-ft Newtonian. *Cf.* Hoskin, M., [*op. cit.* ref. 4, (2011)], pp. 147–148; and *TSP*, i, pp. 452 and 459–461.

[264] Maseberg, H.C., "*Versuch einer Lebensbeschreibung Fr. Wilh. Herschels, Doctors der Rechte und Mitglied der königl. Societät der Wissenschaften in London*," *Neues Hannöverisches Magazin*, xiv (1805), 1009–1030, cols 1011–1012, note *. His full name was probably Heinrich Christoph Maseberg: *cf.* Hamberger, G.C. & J.G. Meusel, *Das gelehrte Teutschland*, x (1803), p. 253.

[265] Hoskin, M., [*op. cit.* ref. 4, (2011)], p. xv.

> *culty of rendering the parts of so immense an instrument mathematically exact and correct, as is required,* have made it unfeasible for him up to the present to be able to effect certain precise observations with it. [emphasis added][266]

So although the English text and Zach's translation frankly state that Herschel had made no actual observations with the 40-ft up to 1798, since it is *impossible* to make a 48-in. telescope precise enough – which at the time was certainly true – Maseberg has reshaped his translation of the English to minimize this and say instead that Herschel has been unable "to effect certain precise observations," because it is *difficult* to make them using a 48-in. telescope. Clearly Maseberg wishes to blunt the effect of the English and Zach's translation and to hint that Herschel might yet succeed.

Maseberg further attempted to blunt the original by altering its title from simply "Dr. Herschel" to "Attempt at a Biography of Fr. Wm. Herschel, Doctor of Law and Member of the Royal Society of the Sciences at London." At a stroke, Herschel thus became more important than *Public characters* intimated in its title, and the article was after all just a trial essay. In his massive initial footnote, Maseberg then quoted from a review of the *Public characters,* which expatiated on the futility of demanding accuracy in contemporary biography, since living people are not fit objects of history, *etc*. Obviously, the effect is to prepare the German reader to doubt the assertions of *Public characters* at every turn.

When the reader finally arrives at the discussion of the 40-ft, Maseberg employs his dissimulation more directly. Whereas the English text says: "His discoveries are to be ascribed to his laudable perseverance, and not to the size of his grand telesecope, which is rather an object of curiosity than of utility," which Zach translates as "One owes [his discoveries] to his unusual perseverance and not to the extraordinary performance of his 40-ft reflector, which is rather an object of curiosity than of true utility," Maseberg by contrast recasts the sentence to misrepresent the original and misdirect the reader: "His discoveries are to be ascribed *simply and solely* to his laudable perseverance in observing, and not to the size of his *telescopes, which have been* up to now more an object of curiosity than of utility. [emphasis added]" So Maseberg would have his German readers think that the *Public characters* has indicted *all* of Herschel's telescopes as mere curiosities, rather than just the 40-ft.[267]

---

[266] Maseberg, H.C., (*op. cit.* ref. 264), cols 1025–1026: "*…so hatte er nun in der Nachbarschaft von Windsor seinen Plan noch erweitert, und ein Teleskop von nicht weniger als 40 Fuß zu Stande gebracht. Doch die Unregelmäßigkeiten des Spiegels, und die Schwierigkeit, die Theile eines so ungeheuern Instruments so mathematisch genau und richtig zu machen, als erforderlich ist, haben es ihm bisher unthunlich gemacht, einige genaue Beobachtungen damit anstellen zu können*."

[267] Von Zach, (*op. cit.* ref. 262), 76: "*Man hat [seine Entdeckungen] seiner seltenen Beharrlichkeit und nicht der außerordentlichen Wirkung seines 40 füßigen Reflectors zu danken, welcher eher ein Gegenstand der Neugierde, als von wirklichem Nutzen ist*"; and Maseberg, H.C., (*op. cit.* ref. 264), col. 1028: "*Seine Entdeckungen sind einzig und allein seiner lobenswerthen Beharrlichkeit im Beobachten, und nicht der Größe seiner Teleskope zuzuschreiben, welche bisher mehr Gegenstand der Neugier als der Nützlichkeit gewesen sind.*"

Having now set up a straw man, Maseberg (in another long footnote) swings to knock him down, but in so maladroit a way as to be almost comical:

> *Unjustly the author says of Herschel's great telescopes, and particularly the 40-foot, that it has been more an object of curiosity than of utility, since indeed he himself earlier admitted that he made his discoveries with reflectors of 10 to 20 feet, and to be sure constructed by his own labor. Perhaps, the author wrote down his biography before Herschel had brought his grand telescope to the greatest possible perfection. Since, however, he dates the completion to the 28th of August 1789, and this collection of biographies first appeared in 1798–1801 (that is, 9 years later), this rash assertion should have justly been omitted. And moreover, since he could have known that with the same 40-foot telescope he discovered the 6th satellite on the 28th Aug. 1789, and saw the spots on Saturn, as H. himself says, better than before.*[268]

The incoherence of this English translation reflects the incoherence of Maseberg's German original. Moreover, it does not help Maseberg's credibility that he elsewhere mistakenly says that William Herschel discovered not only a sixth moon of Saturn but "two others." And the notion that the anonymous biographer of the *Public characters* wrote down his appraisal of the 40-ft before it was completed and never bothered to revise for 9 years is clearly preposterous, especially when the third edition of the book expressly notes that it has been revised and three alterations can easily be found in the Herschel biography alone compared to the earlier editions. One of these is a citation of the latest Herschelian contributions to the *Philosophical transactions* in the years 1799 and 1800.[269]

It would appear that H. C. Maseberg was a local Hanoverian writer and a previous contributor to the *New Hanoverian magazine*. Whether he was not a disinterested party in the transaction but had in fact been paid by the family to publish this piece of misinformation may be answered perhaps by future research. His efforts, if valiant, seem not altogether commendable.

Yet worse was yet to come for William Herschel and the 40-ft – criticism from a well-known, widely read scientific colleague. Jérôme de Lalande, one of the foremost astronomers of the age and frequent correspondent with Herschel, composed an annual review of events and publications in astronomy. He called it his "history of astronomy." Originally published in French, Lalande's "History of Astronomy

---

[268] Maseberg, H.C., (*op. cit.* ref. 264), cols 1027–1028, note i: "*Mit Unrecht sagt der Verfasser von Herschels großen, und besonders dem 40schuhigen Teleskope, daß es mehr ein Gegenstand der Neugierde, als der Nützlichkeit gewesen sey, da er doch vorher selbst eingesteht, daß er seine Entdeckungen mit Reflectoren von 10 bis 20 Fuß, und zwar von eigener Arbeit, gemacht habe. Vielleicht schrieb der Verf. seine Biographie so früh nieder, ehe Herschel noch sein großes Teleskop zur größtmöglichsten Vollkommenheit gebracht hatte; da er aber doch die Vollendung desselben vom 28sten August 1789 datirt, und diese Sammlung von Lebensbeschreibungen erst 1798 bis 1801, also 9 Jahre später erschien, so hätte billig diese voreilige Behauptung wegbleiben müssen. Da er überdies wissen konnte, daß er mit demselben 40schuhigen Teleskop den 6ten Trabanten am 28sten Aug. 1789 entdeckte, und die Flecken des Saturns, wie H. selbst sagt, besser dadurch sah, als zuvor.*"

[269] For the "two other" moons, *cf.* Maseberg, H.C., (*op. cit.* ref. 264), cols 1025–10,287, note h); for the Herschelian bibliography, *cf. Anon.*, *Public characters of 1798–9. The third edition*, (London, 1801), 392, note *.

for the Year 1806” appeared in the February 1807 issue of the *Magasin encyclopédique*. It was soon picked up, translated into English, and republished in London during July 1807 in Tilloch’s *Philosophical magazine*, a widely read journal of arts, literature, and science. Buried deep within Lalande’s article is a paragraph stating:

> *The 40-foot telescope of Mr. Herschel has not yet furnished the extraordinary results we expected from it. I wrote to him that I was desirous of coming to England to visit this prodigious instrument, as soon as he wrote me that he had no objections: I have not yet received his answer. As Mr. Herschel is now 68 years of age, I am afraid he will not be able to satisfy himself, and that he will not find a successor capable of terminating completely so difficult an enterprise.*[270]

Coming from an authority as highly placed as Lalande and now published in English, this must have mortified William Herschel, the greatest telescope maker of his day. It certainly incensed his close friend, Prof. Patrick Wilson, who soon penned a rejoinder. He informed Herschel of Lalande’s criticism in a letter, dated August 10, 1807:

> *I don’t know if as yet you have met with De La Lande’s History of Astronomy for the Year 1806. Those annual Bulletins, by that self-created oracle I have always disliked, as abounding with Impudence, disgusting Vanity, and envious Misrepresentation. You may remember of my having more than once so condemned this contemptible Publication, & the injustice frequently shown in it to Your own Discoveries, by partial and oblique statement, and unwilling qualified Approbation, when the author durst not withhold Praise.*
>
> *In the said History of Astronomy for 1806 there is a Paragraph, concerning You and the 40 Feet Telescope, evidently calculated to impress the belief of the total Failure of your noble Instrument; and resting the proof on his correspondence with Yourself.*
>
> *The structure of the whole Paragraph appears to me very base, and an outrage against the Decorums which govern men who stand upon their good Characters – I have often wished that, for former provocations of a similar nature, You had denounced this Hater of Merit, in the face of Europe, as unworthy of your Correspondence.*[271]

The vehemence of Wilson’s letter is remarkable. In his published rejoinder to Lalande, also printed in the *Philosophical magazine*, Wilson was more restrained though still openly biting, comparing Lalande to a bird flitting from topic to topic with “…that giddiness which sometimes overtakes very good people, when, either in

---

[270] *Cf.* de Lalande, J., “History of Astronomy for the Year 1806,” in A. Tilloch (ed.), *The philosophical magazine*, xxviii (1807), 69–79, 121–129, and 234–244, p. 129. For the French original, *cf.* de Lalande, J., “Histoire de l’astronomie, pour 1806,” in A.L. Millin (ed.), *Magasin encyclopédique, ou journal des sciences, des lettres et des artes*, (Janvier, 1807), 354–395, p. 379: “*Le télescope de 40 pieds, de M. Herschel n’a point encore fourni les résultats extraordinaires que nous en attendions. Je lui ai écrit que j’irois en Angleterre pour voir ce prodigieux instrument, aussi-tôt qu’il m’écrirait qu’il en seroit content; je n’ai point encore reçu cet avis. Comme M. Herschel a 68 ans, je crains qu’il ne puisse se satisfaire et qu’il ne trouve pas un successeur capable de terminer complettement une aussi difficile entreprise.*” *Cf.* also “Simplex,” “Correction of an error in La Place’s *System of the world*,” *European magazine and London review*, lxi (1812), p. 183: “La Place…seems to have placed too implicit a reliance on Dr. Herschel’s magnificent telescope; which indeed, has never proved of any service to astronomy.”

[271] RAS MS Herschel W.1/13, W.166, 1.v-2.r.

reality or imagination, they are lifted up far above the level of their fellow-mortals." Wilson then protests his surprise at Lalande's treatment of the 40-ft, saying:

> *I really should have expected, when so celebrated and so unique an object came in sight, that it would have arrested our historian in his airy career, and have lured him to hover a while in its zenith, that, by some competent examination, he might have represented it very differently in his bulletin. But in place of that, he brushes away after a short flourish, the evident tendency of which is to spread the belief that Dr. Herschel has failed of success in constructing this noble instrument, so much exceeding all former example.*[272]

Wilson continues in the same vein for three more pages, reviewing Herschel's publications in detail to defend the success of the 40-ft. When all is said and done, however, his principal proof is once again the claimed discovery of Enceladus and Mimas with the 40-ft. Wilson signed the article under the *nom de plume*, "Arcturus."

Herschel finally replied to Wilson's August letter on October 20, 1807:

> *At length I have succeeded in obtaining a copy of the paper written by the elegant author who signs himself Arcturus. It is evident that his name is very appropriate…He looks down on the flight of volatile Historians with an eye that will make them shrink into a nutshell. If every reviewer were reviewed as De la Lande has been reviewed we should have less detraction in the literary world, and a more liberal plan of reviewing in general would take place.*[273]

It is clear from the letter that Herschel was pleased with Wilson's rejoinder, and gratefully in his debt, even if Wilson's words mainly consisted in invective and rehashed as proof the doubtful claims about Saturn's moons. Lalande's fundamental suggestion that no other astronomer was allowed to look through the 40-ft and that extraordinary discoveries had not been forthcoming was true. But for the moment, the controversy ended. In subsequent years, Herschel's allies, such as the Rev. William Pearson, counterattacked, publicly categorizing the 40-ft as a "transcendent instrument" on which powers in excess of 6000× had been used – which was completely false. Eventually the instrument was even incorporated into the emblem of the Royal Astronomical Society, whose first president Herschel had been.

However, not everyone was fooled. After Herschel's death, the controversy resurfaced in the 1840s in an acrimonious exchange of letters between John Herschel and Thomas Romney Robinson, published in the British literary journal, *Athenaeum*. The September 23, 1843 issue contained a report of an address that Robinson had given to the British Association for the Advancement of Science at its annual meeting held that year in Cork, Ireland, during August. The address concerned in part the completion of Lord Rosse's 36-in. reflector. Robinson, an ardent Irish patriot, explained the enormous difficulties of making large telescopes and took obvious delight and pride that it was an Irish lord who first mastered them perfectly, as evidenced by the excellent imaging capabilities of the 36-in. In the course of his explanations of how Rosse achieved his enormous advancements, Robinson stated:

---

[272] Arcturus, "An examination of what Jérôme de Lalande has published, in his *History of astronomy for 1806*, concerning Dr. Herschel and his 40-feet telescope," in A. Tilloch, (ed.), *The philosophical magazine*, xxviii (1807), 339–344, p. 339–340.

[273] RAS MS Herschel W.1/1, p. 271.

> *Up to the size of six, or perhaps nine inches diameter, these difficulties are overcome by skilful* [sic] *workmen; but very few have ventured beyond the latter limit, and still fewer succeeded, so that in that field Lord Rosse stands alone. Even Sir William Herschel himself is no exception; his twenty-feet telescopes, of 18 inches aperture, being comparatively diminutive; and the forty-feet, of 4 feet aperture, however honorable to the astronomer and the king who constructed it,* must be regarded as a failure. [emphasis added][274]

Robinson then explained the four ways in which Rosse had advanced greatly beyond William Herschel as a mirror maker. First, Rosse utilized special means to cast huge speculum blanks in the best mixture of copper to tin without having them crack during cooling. Herschel had had to increase greatly the proportion of copper to tin in his large mirrors for this purpose, and above all in his thick 48-in. blank. But this greatly elevated its propensity to tarnish. So Herschel had had a never-ending struggle to keep this mirror bright. Rosse's mirrors tarnished far more slowly. Second, Rosse ground and polished his mirrors underneath their laps, and partly submerged in a tank of water. This stabilized the speculum's temperature, especially during polishing, which greatly helped to control the figuring. Third, Rosse employed an extensive whiffle-tree support system, both during fabrication and also in the telescope. Such a load-support system greatly diminished mirror flexure and change of figure from mechanical stress. And fourth, Rosse's steam-powered grinding and polishing machine could be regulated precisely in its various stroke lengths and speeds so as to achieve the automatic figuring of his f/9 paraboloidal mirrors.

Although Robinson was quite correct in this overview, his blunt indictment of Herschel's 40-ft "as a failure" caused an immediate, pained reaction in John Herschel, who was duty-bound to take up the defense of his father's honor from public attack. Moreover, Aunt Caroline (now 93 years old) still lived in her Hanover exile, and was of sound mind and aware of doings in the scientific world. The success of Rosse's work greatly displeased her, since it seemed to detract from the glory of her brother.[275] Thus John Herschel undertook the disagreeable task of responding at length to Robinson in two letters to the editor of the *Athenaeum*.

The first letter is dated September 27, 1843, just 4 days after the initial notice of Robinson's speech to the British Association. John begins by excusing himself for troubling the editor and wishes that nothing he says should seem to detract from the admiration of Lord Rosse's astonishing achievements. He then instantly turns to Robinson's remark on the "failure" of the 40-ft. In essence, John argues just as others before him had done, that the discoveries of Enceladus and Mimas proved the 40-ft to have been a success. But he attempted to go further than others, and here he made a grave mistake: he cited a published observation of his father's in which William Herschel perceived Enceladus and Mimas approaching transit across Saturn's disk, during the ring-plane crossing in the fall of 1789: "October 16, I

---

[274] *Anon.*, "British Association," *Athenaeum*, dccccxxx, (23-Sept-1843), 866–867, p. 866, col. 3 *infra*.

[275] Hoskin, M., [*op. cit.* ref. 4, (2011)], p. 202; and Herschel, Mrs. J., (*op. cit.* ref. 155), pp. 335.

followed the sixth and seventh satellites up to the very disk of the planet, and the ring, which was extremely faint, opposed no manner of obstruction to my seeing them gradually approach the disc…."[276] The elder Herschel did not indicate which telescope he used for this observation, and John initially assumed that it had been the 40-ft. Hence he triumphantly paraded his father's observation "…as a *tour de force*, an unequivocal proof of great perfection having been attained in the *figure* of the mirror [author's emphasis]."[277] It is true that seeing these faint moons approach and begin to cross the disk of Saturn would be a sign of outstanding performance.

Alas, after penning these words, John discovered in scrutinizing his father's observations more closely that William had made them not with the 40-ft but with the 20! Robinson was not aware of the error and did not cite it in his reply to John's letter, which was printed a month later, on October 21, 1843. Nevertheless, Robinson gave no quarter, and pugnacious as ever renewed the assault, introducing a host of old and new arguments to show that the 40-ft must have been a failure. He noted that William Herschel had made the 40-ft mirror faster than the norm for his high-performance mirrors; that he "showed a marked reluctance to let others inspect it"; that the mirror cell (circular flange and cross piece) was very inadequate to support a large mirror, which therefore must have flexured; that despite scrutinizing the Trapezium ($\theta$ Orionis) twice with the 40-ft, William Herschel had missed the fifth and sixth stars, though both were visible in Rosse's 36-in. *even when stopped down to 18 in.*; that Herschel had not used the 40-ft in his search for rings and new satellites around Uranus; and that he hardly even used it for researches on faint nebulae. Robinson added an acute point that if the 40-ft had really worked, instead of Herschel's many complaints about not having a usable duplicate mirror, "…so zealous an observer would soon have recast that duplicate."

Robinson expatiates on these points and more, citing Wilson's anonymous letter against Lalande in Tilloch's *Philosophical magazine* as a rude reply that "makes the matter worse; it was probably done by some injudicious friend"; and Pearson's excuses for why "so few persons have been in a situation to form an estimation of the merits of this transcendent instrument," as proof that Herschel did keep expert observers away from the 40-ft, saying: "I see no probable motive except the imperfection of the image." Robinson closes:

> *On these grounds I think myself justified in concluding that this telescope was deficient in defining power; that it had not light in proportion to its size, and that it was inconvenient in use. I think no unprejudiced person, who reads Sir William's papers with care, can think otherwise,* and I know that others are of the same opinion. *In stating my sentiments, I trust I have not forgotten the respect due to his virtues and talents. With the exception of this weakness on the subject of his telescopes,* which excited him to an attack on Schroeter that cannot be justified, *his moral character seems to have been without a stain; the friends who survive him cherish his memory, and he fills a place in the records of Astronomy, more*

---

[276] Herschel, W., "Account of the discovery of a sixth and seventh satellite of the planet Saturn, *etc.*," *PT*, lxxx, (1790), 1–20, p. 7 [*TSP*, i, 370–381, p. 373].

[277] Herschel, J.F.W., "Sir John Herschel on the reflecting telescope of the late Sir William Herschel," *Athenaeum*, dcccxxxi, (30-Sept-1843), p. 884, col. 2.

> *brilliant, if not more high, than that held by any other individual. His son himself does not feel this more strongly than I do…*[emphasis added].[278]

The accumulated weight of Robinson's arguments – even though all probabilistic – and the force of his eloquence were massive, even overwhelming. John valiantly attempted to reply in early November 1843, but his own honesty and integrity forced him to acknowledge his earlier mistake, though Robinson had never noted it. In a prologue, John begins his second letter by saying: "Dr. Robinson could not, I think, be reasonably surprised at my feeling pained by the epithet he applied to a work I had always been accustomed to regard with no small degree of veneration." The dutiful only son who had sacrificed an independent career to become his father's apprentice and complete the work of his lifetime could naturally feel nothing but hurt to hear his father's greatest instrumental achievement openly derided as a "failure." The rod William had inadvertently made now flogged the back of his own son.

What came next for John was a public heaping of humble pie – uncomfortable even for his readership 170 years later to peruse – when he acknowledged that his father had not made the "triumphant" observations of Enceladus and Mimas going into transit across Saturn with the 40-ft but rather with the 20. There was no "unequivocal proof of…excellent performance" for the larger instrument. John acknowledged:

> *I have a great, though of course unintentional, mis-citation to correct, which most materially alters the position in which I stand as…opponent* [to Robinson]*.…On a careful perusal of my father's papers in vol. 80 of the* Philosophical Transactions *relative to Saturn and his satellites, I find that I have ascribed a much greater superiority of action to the* [40-foot] *over the* [20-foot] *reflector than was its due. The important observation of the 16th October* [1789]*, which I have cited as a triumphant proof of this superiority, was in fact made with the twenty-feet reflector – the ring was seen with that reflector during its "disappearance"* [*viz.* at the Earth's crossing of Saturn's ring plane], *and* the motions of both the satellites followed out *to the determination of the periods and the calculation of their tables, by the aid of observations solely made with that telescope.*
>
> *I can only account for this oversight (for which I must apologize to you and your readers, and especially to Dr. Robinson) from having taken up what appears to have been an exaggerated idea of the difficulty of seeing the seventh satellite with an eighteen-inch aperture, arising from my own want of success.…*
>
> *I admit, therefore, that the discovery of these satellites does not afford that proof I had assumed of first-rate action*, in the sense of the word in which we now use it, *and in which the truly marvellous powers of the then twenty-feet reflector authorize it to be used. From that position I recede* [author's emphasis].[279]

Although John attempted in continuing his letter to recover from this devastating confession, the damage was done. It was the *coup de grace* in the altercation, and precluded anything beyond specious pleadings in favor of the 40-ft. The reader

---

[278] Robinson, T.R., "Dr. Robinson's reply to Sir John Herschel," *Athenaeum*, dcccxxxiv, (21-Oct-1843), 945–946.

[279] Herschel, J.F.W., "Sir John Herschel's reply to Dr. Robinson," *Athenaeum*, dcccxxxvi, (4-Nov-1843), 983–984, p. 983, cols 1–2.

comes away with profound sympathy and respect for John Herschel's honesty and filial piety in attempting to defend his father's honor, and simultaneously a deep regret that the cover-up for the 40-ft's failure had ricocheted onto this innocent man.

But continue the letter John did, arguing that even if the 40-ft did not have sharp definition, at least it gave a much brighter image than the 20-ft, and this was progress; and that the metal used to make the two 40-ft mirrors, though far from optimum was "real speculum" – a thing Robinson had sneered at; that his father had taken a long time to finish the second (and better) mirror because first he had had to develop machinery to do the immense job and learn to use it profitably; and finally, that both he himself and F. G. W. Struve (1793–1864) had scrutinized $\theta$ Orionis many times before they saw the new stars, and were accordingly stunned to think how they could previously have missed them.

None of this rescues the 40-ft from failure, however much it helps with William Herschel's honor as craftsman and observer. John concluded the letter with an earnest wish for Lord Rosse's continued success, depicting – with some truth – Robinson as scanting the difficulties and heartbreaks of the pioneers who made present-day triumphs possible, while he himself venerated the hallowed ground on which they had trudged with weary step:

> *To conclude – there are two ways of looking through Time's Telescope at inventions and improvements. Dr. Robinson has stationed himself in advance, on the high ground of subsequent achievement – of improvement all but miraculous in every branch of theory and practice – in a scientific age…without parallel in history. In all these respects a new world has arisen within the last fifty years. In the pride of such advantages, we may, indeed, look back through the large end of the perspective, and see the steps of our predecessors shrink under our eye. For my part, I prefer the inventor's end, viewed through which, every step appears gigantic, as it seems to lead on to the unknown and the infinite.*[280]

So ended the contention in the pages of the *Athenaeum*. Though factually correct, Robinson appeared as something of a bully, and John Herschel was seen as having fought the good fight, even if he was defeated on the question of the 40-ft's success as an instrument.

**Acknowledgments** I would like to thank Alan Agrawal, Richard Berry, Owen Gingerich, Michael Hoskin, John Koester, Guntram Lampert, Woody Sullivan, and Walter Stephani for commenting on and helping to proofread this chapter. Especially I would like to thank Woody Sullivan for alerting me to the existence of the letters that passed between John Herschel and T. R. Robinson, and finally Cliff Cuningham and the editors at Springer for bringing the chapter to publication. Whatever errors remain, naturally, belong to me alone.

---

[280] Herschel, J.F.W, (*op. cit.* ref. 279), p. 984, col. 1.

# Chapter 5
# William and John Herschel's Quest for Extraterrestrial Intelligent Life

**Michael J. Crowe**

The contributions to astronomy made by Sir William Herschel (1738–1822; Fig. 5.1) place him among the leading astronomers of modern times. His son, Sir John Herschel (1792–1871), does not rank far behind. The goals of the present study are to document from their published and unpublished writings the intense interest they shared in the question of the existence of extraterrestrial intelligent life (hereafter ETI). To put it somewhat differently, we shall attempt to show that a quasi-religious, quasi-metaphysical doctrine – belief in a plurality of inhabited worlds – at times motivated their labors, influenced their theories, and in some cases may have had an impact even on their observations. Earlier historians, including this author, have treated aspects of this topic, but it seems timely to draw these researches together into a single study.[1]

---

[1] Among earlier publications that have touched on the Herschels' involvement with ideas of extraterrestrials, some of the most important are: Steven Kawaler and J. Veverka, "The Habitable Sun: One of William Herschel's Stranger Ideas," *Royal Astronomical Society of Canada Journal, 75* (1981), 46–55; Simon Schaffer, "'The Great Laboratories of the Universe': William Herschel on Matter Theory and Planetary Life," *Journal for the History of Astronomy, 11* (1980), 81–111; Daniel A. Beck, "Life on the Moon: A Short History of the Hansen Hypothesis," *Annals of Science, 41* (1984), 463–70; Laura Snyder, "'Lord only of the Ruffians and Fiends'? William Whewell and the Plurality of Worlds Debate," *Studies in History and Philosophy of Science*, *38* (September 2007), 584–592, Michael Hoskin, "William Herschel and God," *Journal for the History of Astronomy, 45* (2014), 247–252, and M. J. Crowe, "The Surprising History of Claims for Life on the Sun," *Journal of Astronomical History and Heritage, 14:3* (Nov., 2011), 169–179. I have also written on this topic in my *The Extraterrestrial Life Debate 1750–1900: The Idea of a Plurality of Worlds from Kant to Lowell* (Cambridge Univ. Press, Cambridge, England,1988) and in *The Extraterrestrial Life Debate, Antiquity to 1915: A Source Book* (Univ. of Notre Dame Press, Notre Dame, IN, 2008). Relevant materials can also be found in my *Calendar of the Correspondence of Sir John Herschel* (Cambridge Univ. Press, Cambridge, England,1998). Not only do new materials appear in this study, it also draws together researches that I have carried out over the last forty years. My most recent publication relating to the Herschels is my "William Whewell, the Plurality

M.J. Crowe (✉)
Rev. John Cavanaugh Professor Emeritus, Program of Liberal Studies, University of Notre Dame, Notre Dame, IN 46656, USA
e-mail: Michael.J.Crowe.1@nd.edu

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_5

**Fig. 5.1** William Herschel by Lemuel Abbott, 1785

We shall also suggest that although it is widely assumed that present-day astronomers are more concerned with extraterrestrials than their eighteenth-century predecessors were, the reverse is nearer the truth.

## Part I: Sir William Herschel

### *Background*

Persons interested in William Herschel have frequently seen him as a tireless telescopic technician, as a model empiricist who, as Edwin Hubble put it, did not, like Kant, speculate about the nebulae but rather observed them by the thousands. Herschel has also been seen as eschewing the philosophical doctrines of the Enlightenment to concentrate on what his telescopes would teach him about the timeless night sky, which he studied with a detachment less easily detected in the earlier cosmological writings of such authors as Wright, Kant, and Lambert. In contrast to this conceptualization of William Herschel, we shall suggest: (1) that he was less an isolated empiricist than a speculatively inclined celestial naturalist,

---

of Worlds, and the Modern Solar System," *Zygon: Journal of Religion and Science, 50:2* (June, 2016), 431–49. Finally, mention should be made of Richard Holmes's *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science* (Pantheon, New York, 2008), esp. chs. 2 and 4. A significant portion of this very engaging book draws on the writings of Michael Hoskin as well as my writings on the involvement of the Herschels with ETI to show how engaged persons during the romantic period were by developments in astronomy. The Royal Society recognized the success of this book by awarding it a prize of £10,000 for science writing. See http://new.bbc.co.UK/2/science/nature/8256979.stm, viewed 17 Sept. 2009.

quixotically caught up in a quest for evidence of extraterrestrials; (2) that some of his efforts make most sense when seen as attempts to transform the doctrine of a plurality of worlds from being a delight of poets, a doctrine of metaphysicians, and a dogma of natural theologians into being a tool of the astronomers; and (3) that the search for ETI was a core component in Herschel's research program and as such influenced many aspects of his work, especially, although far from exclusively, in his early years. A brief review of the life and career of William Herschel will set the stage for a discussion of the place of ideas of ETI in Herschel's research program.

Herschel was born in 1738 in Hanover, the son of a musician in the Hanoverian military band. At age fourteen, William joined his father's regiment, serving as an oboist in the Hanoverian Guard until 1757, when he immigrated to England, where for over 25 years he performed, taught, and composed music. In 1766, he moved to Bath in southwestern England. Around this time he began to take an interest in astronomy, making his first recorded observation in 1766. In 1772, he brought his younger sister Caroline to Bath to manage his household, to help him in music, and eventually to assist him in his astronomical endeavors. In 1773, in an effort to learn astronomy, he purchased *Astronomy Explained upon Sir Isaac Newton's Principles,* written by James Ferguson, a shepherd turned popularizer of astronomy. By 1774, Herschel's growing passion for astronomy led him to construct his own telescopes; in fact, by 1776, he had finished a 12-in. aperture reflecting telescope, which was already one of the best telescopes then in existence. By 1783, he had constructed an 18.7-inch reflector of 20-ft focal length. In 1781, this amateur astronomer became internationally famous for discovering the planet Uranus, the first planet discovered in modern times.

This accomplishment moved King George III to provide funding so that Herschel could work full time in astronomy and also build the largest telescope that had ever been constructed, a 48-in. aperture, 40-ft focal length reflector**,** which he completed in 1789. Important as Herschel's discovery of Uranus was and significant as his other results regarding the planets were, his greatest achievement was his pioneering work in stellar astronomy.

Central to this contribution was Herschel's interest in a class of celestial objects that he called *nebulae*, which appear as nebulous patches of light. Astronomers before Herschel took relatively little interest in these objects, of which about a hundred had been observed by 1780. One indication of the level of interest that eighteenth-century astronomers had in these objects is the fact that in 1780 the French astronomer Charles Messier published a catalog of 103 nebulae, all that were known at that time. Messier himself was not much interested in the objects. He had compiled his catalog so that astronomers could distinguish these objects from comets, which were Messier's dominant interest.

Herschel, however, somehow became interested in nebulae; in fact, by 1784, he had discovered 466 new nebulae, adding a thousand more nebulae by 1786. The significance that Herschel and some of his contemporaries saw in his detection of so many nebulae is indicated by a comment made by the poet Fanny Burney, who after a 1786 visit to Herschel exclaimed: "He has discovered fifteen hundred universes!

How many more he may find who can conjecture?”[2] By the time of his death in 1822, Herschel had discovered and cataloged about 2500 new nebulae. The study of these nebulous objects, which are now known to number in the billions and most of which are in galaxies outside of our Milky Way, has become a main activity of modern astronomy.

Much more might be said about Herschel’s achievements in telescope making, planetary astronomy, and stellar astronomy, but with this background, let us turn to a less well known feature of his life and thought: his interest in ETI.

## Lunar Observations

The main source of Herschel’s early interest in extraterrestrials seems to be the book by Ferguson, who repeatedly advocates for ETI. For example, Ferguson notes that Earth’s similarities to the Moon and the planets “leave us no room to doubt but that all the Planets and Moons in the System are designed as commodious habitations for creatures endowed with capacities of knowing and adoring their beneficent Creator.”[3] Ferguson was so confident in life on the Moon that he describes Earth as a “moon to the moon,” adding that Earth, by having a more or less fixed position in the Moon’s sky, allows lunarians to determine lunar longitude.[4]

Although most intellectuals in the late eighteenth century accepted the widespread existence of life in the Solar System, many backed off from life on the Moon because of evidence that the Moon lacks an atmosphere. One can imagine that Ferguson’s charming and pious conception of the planets and moons appealed to Herschel as he began to learn astronomy.[5]

---

[2] As quoted in Constance Lubbock, *The Herschel Chronicle* (Cambridge Univ. Press, Cambridge, 1933), p. 170. On his discoveries, see also Mark Barton, *The Complete Guide to the Herschel Objects: Sir William Herschel’s Star Clusters, Nebula and Galaxies* (Cambridge, Cambridge University Press, 2011).

[3] James Ferguson, *Astronomy Explained upon Sir Isaac Newton’s Principles*, 2nd ed. (London, 1757), p. 4.

[4] Ferguson, *Astronomy*, pp. 16–18.

[5] Although Ferguson seems to have been his chief source, other sources can also be mentioned. Herschel’s biographers note that after initially arriving in England, Herschel purchased John Locke’s *Essay Concerning Human Understanding.* In discussing the human senses, Locke remarks: “we cannot believe it impossible to God to make a creature with other organs and more ways to convey into the understanding the notice of corporeal things than those five…which he has given to man.... [W]hether yet some other creatures, in some other parts of this vast and stupendous universe, may not have this, will be a greater presumption to deny. He that will not set himself proudly at the top of all things, but will consider the immensity of this fabric, and the great variety that is to be found in this little and inconsiderable part of it which he has to do with, may be apt to think that in other mansions of it there may be other and different intelligent beings of whose faculties he has as little knowledge or apprehension, as a worm shut up in one drawer of a cabinet hath of the senses or understanding of a man: such variety and excellency being suitable to the wisdom and power of the maker.” See Locke’s *Essay Concerning Human Understanding*, vol. 1

Herschel's scientific debut dates not from his 1781 discovery of Uranus but from May 1780, when two of his papers were read to the Royal Society, the longer of these being his "Astronomical Observations Relating to the Mountains of the Moon." Behind that paper is a fascinating story, which we have uncovered from Herschel's unpublished manuscripts. These manuscripts provide evidence that at that time Herschel believed he was on the verge of a discovery even more revolutionary than his discovery of Uranus.

Herschel's lunar mountains paper must have appeared rather strange to the scientists of the Royal Society. On the one hand, it showed that this amateur astronomer possessed significant observational ability and, if he could be believed, had constructed remarkable telescopes. On the other hand, Herschel's amateurism was all too evident. These concerns led Nevil Maskelyne, England's Astronomer Royal, to request details from Herschel on his methods of measurement and to ask about his statement in this paper that a "knowledge of the construction of the Moon leads us insensibly to several consequences…such as the great probability, not to say almost absolute certainty, of her being inhabited."[6]

No doubt Maskelyne meant to suggest the impropriety of including such a statement in a formal scientific paper, especially at a time when astronomers were aware that observations of the sharpness with which the Moon occults stars made it difficult to believe that the Moon possessed an appreciable atmosphere.[7] Nonetheless, Herschel, rather than accepting Maskelyne's implicit suggestion, included in his response a discourse on lunar life**.** Herschel admits to being "young in the Science of Astronomy" and asks Maskelyne not to label him a "Lunatic" (Herschel's pun). Then Herschel quotes from a document he had composed eighteen months earlier. He begins by urging the legitimacy of arguments from analogy; in particular, Herschel asks, given the similarities between Earth and the Moon and the fact that Earth is inhabited:

> [W]ho can say it is not extremely probable, nay beyond doubt, that there must be inhabitants on the Moon of some kind or other. Moreover it is perhaps not altogether so certain that the moon is out of the reach of observation in this respect. I hope, and am convinced, that some time or other very evident signs of life will be discovered on the moon.[8]

Maskelyne's dismay at this amateur astronomer's assertions cannot have diminished when later in the letter he encountered Herschel's statement:

> The earth acts the part of a Carriage, a heavenly waggon to carry about the more delicate moon, to whom it is destined to give a glorious light…. For my part, were I to chuse

---

(John Carfare and Thos. Nelson, Edinburgh, 1819), Book II, Ch. 3, pp. 121–22. In 1761, Herschel read G. W. Leibniz's *Théodicée*, another book embracing extraterrestrials. Regarding Leibniz, see Crowe, *Extraterrestrial Life Debate, 1750–1900*, pp. 27–30, 62.

[6] *The Scientific Papers of William Herschel,* 2 vols., ed. by J. L. E. Dreyer (The Royal Society and The Royal Astronomical Society, London, 1912), vol. I, p. 5.

[7] Herschel had himself made observations of this type. See Herschel, *Papers,* vol. I, pp. xci–xcii.

[8] Herschel, *Papers,* vol. I, p. xc.

> between the Earth and Moon I should not hesitate a moment to fix upon the moon for my habitation.[9]

Maskelyne judiciously deleted Herschel's lunar life discourse from the portion of this letter that was appended to his published paper. It first became public only in 1912, when Herschel's collected writings were published.

As unrestrained as this letter appears, Herschel must have had to exercise considerable restraint in order to avoid even more incredible claims. This at least is the conclusion drawn from examining Herschel's unpublished compilation of his lunar life observations, which reveals that in 1780 Herschel believed that he was already in possession of substantial observational evidence for lunar life. For example, among the earliest of his lunar observations is one dated May 28, 1776, when he turned a new telescope to the Moon with a startling result (Fig. 5.2):

> … I was struck with the appearance of something I had never observed before, which I ascribed to the power and distinctness of my Instrument, but which perhaps may be an optical fallacy – I believed to perceive something which I immediately took to be growing substances. I will not call them Trees as from their size they can hardly come under that denomination, or if I do, it must be understood in that extended signification so as to take in any size how great soever…. My attention was chiefly directed to Mare humorum, and this I now believe to be a forest, this word being also taken in its proper extended signification as consisting of such large growing substances.[10]

Herschel proceeded to sketch the forest and to analyze the credibility of his observations. His concluding statement is:

> However, not to lay too much stress on these appearances till they have been better confirmed since I can hardly imagine that any growing Substance could be long enough to be visible from the Earth to the Moon. Our tallest trees would vanish at that distance. It is not impossible but that the vegetable Creation (and indeed the animal too) may be of a larger size on the Moon than it is here; tho' perhaps not very likely. And I suppose that the borders of forests, to be visible, would require Trees at least 4, 5, or 6 times the height of ours.
>
> But the thought of Forests or Lawns and Pastures still remains exceedingly probable with me, as that will much better account for the different Color, than different colored soils can do.[11]

Herschel's ambivalent feelings about these observations led him in late 1778 to compose a new analysis of the situation. Portions of this analysis are quoted in his Maskelyne letter, but the following passages, which show that Herschel believed he had evidence not only of forests but also of lunar towns, were not included.

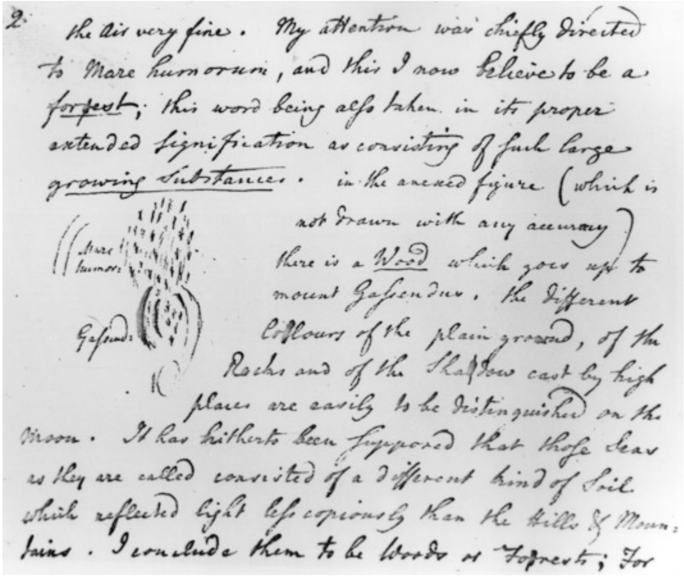
> As upon the Earth several Alterations have been, and are daily, made of a size sufficient to be seen by the Inhabitants of the Moon, such as building Towns, cutting canals for Navigation, making turnpike roads &c: may we not expect something of a similar Nature on the Moon? – There is a reason to be assigned for circular-Buildings on the Moon, which is that, as the Atmosphere there is much rarer than ours and of consequence not so capable of refracting and (–by means of clouds shining therein) reflecting the light of the Sun, it is

---

[9] Herschel, *Papers,* vol. I, p. xc. In this and the subsequently cited passages from Herschel's manuscripts, I have preserved his spellings.

[10] Microfilm (Reel 17) of the Royal Astronomical Society Herschel MSS, W. 3/1.1, pp. 1–2.

[11] Microfilm (Reel 17) of the Royal Astronomical Society Herschel MSS, W. 3/l.1, p. 4.



2. the Air very fine. My attention was chiefly directed
to Mare humorum, and this I now believe to be a
foreſt; this word being alſo taken in its proper
extended ſignification as conſisting of ſuch large
growing Subſtances. in the anexed figure (which is
not drawn with any accuracy)
there is a Wood which goes up to
mount Gaſsendus. the different
Collours of the plain ground, of the
Rocks and of the Shadow cast by high
places are easily to be distinguished on the
Moon. It has hitherto been ſupposed that thoſe Seas
as they are called consisted of a different kind of Soil
which reflected light leſs copiously than the Hills & Moun:
tains. I conclude them to be Woods or Foreſts; For

**Fig. 5.2** From William Herschel's 1776 lunar notebook

> natural enough to suppose that a Circus will remedy this deficiency. For in that shape of Building one half will have the direct and the other half the reflected light of the Sun. Perhaps, then on the Moon every town is one very large Circus? … Should this be true ought we not to watch the erection of any new small Circus as the Lunarians may [watch] the Building of a new Town on the Earth. Our telescopes will do this…. By reflecting a little on this subject I am almost convinced that those numberless small Circuses we see on the Moon are the works of the Lunarians and may be called their Towns…. Now if we could discover any new erection it is evident an exact list of those Towns that are already built will be necessary. But this is no easy undertaking to make out, and will require the observation of many a careful Astronomer and the most capital Instruments that can be had. However this is what I will begin.[12]

Having adopted this remarkable research program, which no doubt would fit with his efforts to build better telescopes, Herschel set about making numerous lunar observations. His lunar observation book shows that to classify the lunar "circuses," he chose at first the labels "Metropolis, Cities, Villages," but thinking better of it, he satisfied himself with the more prosaic terms "Large places, Middling places, Small places"![13] His June 17, 1779, entry records his observation of "a Cut or Canal that seems evidently to be the effect of Art rather than of Nature," and a month later, seeing a new spot in the Mare Crisium region, he wrote: "…I find it is a city."[14] He recorded extensive lunar observations from 1780 and 1781, many from the earlier year being devoted to measuring the height of lunar mountains. The latter

---

[12] Microfilm (Reel 17) of the Royal Astronomical Society Herschel MSS, W. 3/1.1, pp. 8–10.

[13] Microfilm (Reel 17) of the Royal Astronomical Society Herschel MSS, W. 3/1.1, p. 17.

[14] *Ibid.,* p. 17.

year produced richer results concerning lunar life, the observations of late June yielding numerous patches of "vegetation," "turnpike roads," and "circuses."[15] On other evenings he reported regions "tinged with green."[16] In 1783, he recorded that a star passing behind the Moon disappeared slowly, indicating a lunar atmosphere and, also in 1783, he espied "two small pyramids."[17] Herschel's lunar observations seem to be far less frequent after 1783, even though in that year he confided to a Scottish astronomer, Alexander Wilson what he had done and his hope to establish the existence of life on our Moon:

> The attempt of finding traces of animation in the moon has now been 5 or 6 years one of those I have endeavored to render practicable, and tho' I have met with no self evident or occular demonstration of the moon[']s being inhabited, yet do I still hope that a good many of my observations will at least render the reasons we may alledge from analogy more forcible. The highest power I have hitherto been able conveniently to use in viewing the moon is 932. Hence it is easy to calculate what sort of Objects we may expect to see. However the many interruptions I have within these last two years met with have prevented my Observations on this subject to be so frequent as I now, with improved instruments, hope to make them.[18]

What caused the interruptions about which Herschel complained? It must have been his discovery of Uranus!

Although it is impossible to determine how many other astronomers were aware of Herschel's hopes for detecting lunar life, one suspects that part of the process of his becoming a professional was to learn that discoursing on such matters would give support to those who thought him "fit for bedlam."[19] Whatever may have been the case, it is a mark of Herschel's professionalism that never in his published writings did he lay claim to the discovery of observational evidence of lunar life. Possibly he dismissed his observations of "forests," "cities," "turnpike roads," and such as among those tricks of the telescope that he lamented in a 1782 letter to the astronomer Alexander Aubert:

> These instruments have played me so many tricks that I have at last found them out in many of their humors…. I have tortured them with powers, flattered them with attendance to find out the critical moments when they would act, tried them with specula of a short and of a long focus, a large aperture and a narrow one; it would be hard if they had not been kind to me at last.[20]

In the last few years, new information has emerged that indicates that Herschel did not succeed in foregoing his commitment to observing lunar life, indeed lunar

---

[15] *Ibid.,* pp. 65–8.

[16] *Ibid.,* pp. 65 and 69.

[17] *Ibid.,* pp. 71–2. See also p. 75 for a 1793 observation of a lunar twilight.

[18] See Reel 12 of the Royal Astronomical Society Herschel MSS, W. 3/1, pp. 66–7.

[19] See Lubbock, *Herschel Chronicle,* pp. 99, 103–4, and 179 and Simon Schaffer, "Herschel in Bedlam: Natural History and Stellar Astronomy," *British Journal for the History of Science, 13* (1980), 211–39.

[20] Herschel, *Papers,* vol. I, pp. xxxiii–xxxiv.

buildings. In 2011, Michael Hoskin published *Discovers of the Universe: William and Caroline Herschel*. Therein Hoskin reported:

> Nevil Maskelyne had long ago taught William not to mix science and religion, and in his great papers of the 1780s, William had been careful not to so much as hint at the conviction that every star and planet is peopled with intelligent beings. In private he – or perhaps Alexander [Herschel's brother] was less discreet – for the *Bath Chronicle* in April 1793 informed its readers that William "is now said, by the aid of his powerful glasses, to have reduced to a certainty, the opinion that the moon is inhabited." Indeed, "he has distinguished a large edifice"; this building, it seemed, was comparable in size to St. Paul's Cathedral. Not only that, but he "is confident of shortly being able to give an account of the inhabitants."[21]

## Herschel's Uranian Moons and Their Inhabitants

Herschel's contemporaries were deeply impressed by his discovery of Uranus, the first planet discovered in modern times. They were further impressed when in 1787 he announced his discovery of two moons of Uranus, which he named Oberon and Titania. Herschel was helped to this discovery by an improvement he made to his telescope. Another factor that contributed was his commitment to finding moons for Uranus, a commitment that was stoked by the belief of various earlier astronomers that the more distant a planet is from the Sun, the greater is its need for moons. It was striking that neither Mercury nor Venus had satellites, but because of their nearness to the Sun, they were less needful of light than Earth, which had one Moon. Mars, whose moons were first discovered only in 1877, did not fit this pattern, but astronomers were very aware that Jupiter and Saturn have multiple moons, and indeed Saturn possesses a ring. Numerous early advocates of extraterrestrials, including Bernard Fontenelle, James Ferguson, and Emanuel Swedenborg, cited this pattern as evidence of extraterrestrials inhabiting the planets of our Solar System. For example, Swedenborg, in his *Earths in the Universes* (1758) in discussing the planets, states:

> [S]ome of them have moons, which are called satellites, and which perform their revolutions round their central globes, as the moon does round our earth; the planet Saturn has besides a large luminous belt, as being furthest distant from the sun, which belt supplies that earth with much light, although reflected. How is it possible for any reasonable person, acquainted with these circumstances, to assert, that such bodies are void, and without inhabitants?[22]

Given this background, it is not surprising that Herschel set out to find moons for his new planet, a quest that succeeded in 1787 when he discovered Oberon and

---

[21] Michael Hoskin, *Discoverers of the Universe: William and Caroline Herschel* (Princeton University Press, Princeton, 2011), 147–48.

[22] As quoted in M. J. Crowe (editor), *The Extraterrestrial Life Debate, Antiquity to 1915: A Source Book* (Univ. of Notre Dame Press, Notre Dame, IN, 2009), p. 218. For passages from Fontenelle and Ferguson, see pp. 80 and 172–73.

Titania. Herschel's great telescopes contributed to this discovery of these two satellites, which few of his contemporaries could see in their telescopes.

This story takes a rather different turn in 1790 and 1794 when Herschel announced his discovery of four more Uranian moons. As Clifford Cunningham, who has completed a thorough study of the history of these moons, notes, "Herschel left no doubt about the reality of the four new satellites," citing Herschel's statement:

> …in such delicate observations as these of the additional satellites, there may possibly arise some doubts with those who are very scrupulous; but, as I have been much in the habit of seeing very small and dim objects, I have not been detained from publishing these observations sooner, on account of the least uncertainty about the existence of these satellites, but merely because I was in hopes of being able soon to give a better account of them, with regard to their periodical revolutions.[23]

Moreover, in 1789 Herschel published a sketch of the rings of Uranus.[24] This detection as well as his detection of the four other moons of Uranus was widely seen as evidence of the Deity's design in providing for the inhabitants of the Uranian system. It is true that between the discovery of the four smaller moons and of the Uranian ring and the 1850s, no other astronomer had succeeded in sighting these objects. We now fully understand why they did not succeed; it was not because of the limitations of their telescopes but because these four moons and the ring Herschel believed he had sighted do not exist. This was finally recognized in the 1850s after the astronomer William Lassell in 1851 discovered two additional moons of Uranus (Ariel and Umbriel), neither of which fit with the orbits Herschel believed he had detected. It thus seems clear that Herschel's enthusiasm for extraterrestrials had misled him into concluding that he had actually seen the four additional objects that he believed he had sighted.

Herschel was far from alone in claiming that these four moons and the ring reported by Herschel were realities. Cunningham in his study cites Pierre Simon Laplace, Margaret Bryan, John Payne, Robert Patterson, James Challis, Olinthus Gregory, Frances Barbara Burton, Thomas Dick, John Stevens Abbott, Hugh Miller, Joseph Littrow, and Johann Wurm as those who accepted Herschel's defective observations of the four last Uranian moons, some even embellishing the total number to eight. Moreover, a few dozen poets, as Cunningham shows, also celebrated the Uranian moons and their discoverer.

---

[23] Clifford J. Cunningham, *Herschel's Spurious Moons of Uranus: Their Impact on Satellite Orbital Theory, Celestial Cartography and Literature* (in preparation) as quoted from William Herschel, "On the Discovery of Four Additional Satellites of the Georgium Sidus. The Retrograde Motion of Its Old Satellites Announced; and the Cause of Their Disappearance at Certain Distances from the Planet Explained." *Philosophical Transactions*, *88* (1798), 66.

[24] Cunningham, *Herschel's Spurious Moons*, p. 3.

## Possible Links Between William Herschel's Early Interest in Extraterrestrials and His Contributions to Stellar Astronomy

This section is devoted to an exploration of whether Herschel's passion for extraterrestrials influenced his pioneering work in stellar astronomy, including his efforts to build ever better telescopes. In a highly regarded study of Herschel's telescopes, J. A. Bennett provides relevant information on the history of Herschel's endeavors to make telescopes. After mentioning that in 1773, Herschel started to grind mirrors for telescopes and in 1774, began a journal of observations, Bennett states: "It was the beginning of a unique career in astronomy; original speculations on the nature of stellar objects and the construction of the heavens would be paralleled by equally bold designs for improving telescopes."[25] Bennett adds that by 1776, Herschel had progressed to constructing a reflector as long as 20 ft. in focal length. By 1779 and 1780, he had constructed improved 20-ft. reflectors, with mirrors of over 6 in. in diameter, and by around 1780, he had produced a mirror of 12 in. in aperture. In 1781, he attempted to construct a telescope of 30 ft. in focal length and 3 ft in diameter, but this project failed. In October 1783, Herschel began observations with the telescope that proved to be the most productive of the hundreds he built. This was a 20-ft focal length, 18.7-in. aperture reflector.[26] Herschel's success with the nebulae was spectacularly evident in a paper that he read to the Royal Society in June 1784, in which he noted that he had resolved into individual stars "most of the nebulae" in Messier's list of 103 nebulae and reported that he has discovered "466 new nebulae."[27] Such information certainly gives plausibility to the idea that Herschel constructed his powerful telescopes in order to discover and study nebulae.

At least two problems, however, raise questions for this interpretation. The first can be seen from a paper by Mari Williams titled "Was There Such a Thing as Stellar Astronomy in the Eighteenth Century?"[28] Writing at a time when various historians of astronomy, e.g., Michael Hoskin, had recently worked out the history of the founding period of stellar astronomy in the late eighteenth century, Williams points out that stellar astronomy during this period was a very minor area of astronomy, which had attracted the interest of only a handful of authors, including Thomas Wright, Immanuel Kant, Johann Lambert, and William Herschel. These four attained results that are now recognized as so important that these four figures are now seen as the pioneers of stellar astronomy. Rather than contributing to stellar

---

[25] J. A. Bennett, "'On the Power of Penetrating into Space': The Telescopes of William Herschel," *Journal for the History of Astronomy, 7* (1976), 75–108:75.

[26] Bennett, "Telescopes of William Herschel," 76–84.

[27] William Herschel, "Account of Some Observations Tending to Investigate Construction of the Heavens," *Philosophical Transactions of the Royal Society, 74* (1784), 437–57 as reprinted in Herschel, *Papers*, vol. I, 157–66:158, 160.

[28] M. E. W. Williams, "Was There Such a Thing as Stellar Astronomy in the Eighteenth Century?" *History of Science, 21* (1983), 369–85.

astronomy, they were creating it. Such information raises the question: What could have led Herschel to his interest in nebulae? One suggestion is that Herschel came to see the nebulae not as simply vast conglomerations of stars but rather as island universes filled with extraterrestrial beings more or less comparable to us, especially in their significance in the cosmos. This is what led to Fanny Burney's exclamation that Herschel "has discovered fifteen hundred universes!"[29] The idea that Herschel did in fact view nebulae in this manner and was influenced by this view is supported by the fact that the other three pioneers of stellar astronomy were similarly enthused about extraterrestrials. A case can be made that a non-anachronistic reading for their books in this area leads to the conclusion that their volumes are as much tracts on extraterrestrials as they are pioneering documents of stellar astronomy.[30]

The second problem with the traditional view as to what led Herschel to his passion for telescope making is this. Detailed researches of Michael Hoskin raise problems for the view that Herschel's desire to observe nebulae led to his telescope-making activity. In a paper on Herschel's early observations of nebulae,[31] Hoskin shows how gradually his interest in observing nebulae emerged. In particular, Hoskin reveals that Herschel's observation books indicate that Herschel observed Orion on a number of occasions in 1774, but then observed no other nebulae until 1779, although he did observe Orion seven times in that period.[32] In 1781, Herschel observed three more (already known) nebulae (M11, M13, and M31). Moreover, between July 1781 and 2 August 1782, he observed no nebulae whatsoever. Between that date and September 30, 1782, he observed about five more. This carefully researched information makes it doubtful that Herschel's motivation for building his giant telescopes (at least before 1782) was nebular observation. This opens the way for the suggestion that Herschel may have been constructing these telescopes not so much for stellar observations, in which few of his contemporaries took interest, but rather in hopes of confirming a discovery, which would have delighted his contemporaries and immortalized Herschel's name even more than his discovery of Uranus: the discovery of satisfactory evidence for life on the Moon. Hoskin has also supplied an additional explanation of why in very late February 1783 Herschel began to take such interest in nebular discovery and observations. What happened was that on September 30, 1782, his sister, Caroline, using a telescope inferior in quality to those employed by her brother, managed to spot a nebula. Then, in October she found three more (all previously known), but on February 26, 1783, she discovered an unknown nebula. Hoskin comments:

> The consequences of this night's work were little short of epoch-making: [Caroline] had demonstrated to her brother that the mysterious nebulae and clusters were so numerous that

---

[29] As quoted in Lubbock, *The Herschel Chronicle*, 170.

[30] For a fuller discussion of this thesis, see Ch. 2 of my *Extraterrestrial Life Debate* (1986).

[31] Michael Hoskin, "William Herschel's Early Investigations of Nebulae: A Reassessment," in Hoskin's *Stellar Astronomy: Historical Studies* (Bucks, England, 1982), pp. 125–36. First appeared in *Journal for the History of Astronomy, 10* (1979), 165–176.

[32] Hoskin, "Early Investigations," p. 128.

> specimens could be discovered by an inexperienced observer using the most rudimentary of instruments. And so, a week later, on 4 March William recorded the momentous decision 'to sweep the heaven for Nebulas and Clusters of stars'. Astronomy was soon to be transformed.[33]

In short, our suggestions are (1) that Herschel's passion for extraterrestrials may have been a major factor in giving him the interest in nebulae that most of his contemporaries lacked, and (2) that Herschel's enthusiasm for confirming his ambiguous detection of evidences of lunarians played a major role in his quest to build the finest telescopes available. It is true that those telescopes failed to detect lunar life, but he consoled himself with the idea that these instruments might nonetheless suffice for observations of other universes, which Caroline's successes suggested might be numerous. The period between March 1783 and June 1784, when Herschel presented the Royal Society with a list of 466 newly discovered nebulae – to Herschel, universes – must then have been not only exciting but also sufficiently engaging to console him for the fact that his efforts to establish lunar life had not succeeded.

It is an intriguing conjecture, for which I have not succeeded in finding any direct evidence, whether as part of the negotiations between Herschel and King George III leading to the king providing funding for Herschel's largest telescope (his 48-inch aperture reflector), Herschel might have confided to George III, who had so recently lost his American colonies, that Herschel had promising observations of lunar life, which awaited only adequate instrumentation for their confirmation.

## William Herschel's Populations for the Moons and Planets

Herschel was convinced that not only the Moon but also the planets and their satellites are inhabited. For example, in a paper on Mars, he repeatedly mentioned its inhabitants, and in another paper he casually referred to "the inhabitants of the satellites of Jupiter, Saturn, and the Georgian planet [Uranus]."[34] Moreover, when one finds that after the discovery of the asteroids Ceres and Pallas, Herschel reported his observations that they "have an atmosphere of considerable extent,"[35] one suspects that his passion for extraterrestrials may have influenced this spurious observation.

Herschel believed, at least during the 1780s, that stars are suns surrounded by inhabited planets. For example, in a 1789 paper, he stated that stars are suns and commented that each sun "is probably of as much consequence to a system of planets, satellites, and comets, as our own sun…."[36]

Herschel was very interested in variable stars. In a 1779 manuscript, for example, Herschel attempted to explain the variability of the star Mira Ceti by associating

---

[33] Michael Hoskin, *The Herschels of Hanover* (Science History Publications, Cambridge, England, 2007), p. 110.

[34] Herschel, *Papers,* vol. I, pp. 422 and 481.

[35] Herschel, *Papers,* vol. II, p. 194.

[36] Herschel, *Papers*, vol. I, p. 33.

a giant planet with it, the planet eclipsing the star. Moreover, in a 1783 publication, Herschel justified his observations of the variable star Algol by claiming that such observations could serve to verify the existence of "a plurality of solar and planetary systems."[37] Although admitting in a 1791 paper that such extra-Solar System planets "can never be perceived by us,"[38] he nonetheless stated in 1795 that:

> [S]ince stars appear to be suns, and suns, according to the common opinion, are bodies that serve to enlighten, warm, and sustain a system of planets, we may have an idea of numberless globes that serve for the habitation of living creatures.[39]

## William Herschel's Theory of the Sun

Let us now turn to another aspect of Herschel's thought: his theory of the Sun. As background for this, consider an event reported in the *Gentleman's Magazine* for 1787. A certain Dr. Elliot was brought to trial in London for having set fire to a lady's cloak by firing a pair of pistols near it. A plea of insanity was made for Elliot, in support of which a Dr. Simmons recounted examples of Elliot's bizarre behavior, especially his having prepared a paper for submission to the Royal Society in which he maintained that the Sun is inhabited.[40]

This incident leads one to wonder what may have been the reaction among readers of the Royal Society's *Philosophical Transactions* when in 1795 and 1801 they encountered papers in which Herschel theorized that the Sun consists of a cool, solid, dark, spherical interior above which floats an opaque layer of clouds. In the 1795 paper, Herschel suggested that separate rays carry heat and light and that heat rays generate a rise in temperature only when in contact with special material. In his 1801 paper, he expanded the theory by proposing two exterior layers, the upper of which consists of the glowing matter, the lower being a reflecting shield that keeps the inner surface cool (Fig. 5.3).

Concerning his theory, Herschel commented:

> The sun, viewed in this light, appears to be nothing else than a very eminent, large, and lucid planet, evidently the first, or in strictness of speaking, the only primary one of our system…. Its similarities to the other globes of the solar system…leads us to suppose that it is most probably also inhabited, like the rest of the planets, by beings whose organs are adapted to the peculiar circumstances of that vast globe.[41]

---

[37] On Mira Ceti, see Michael Hoskin, *Stellar Astronomy: Historical Studies* (Chalfont St. Giles, 1982), p. 54 and also Royal Astronomical Society Herschel MSS, W.4/1, f.32; regarding Algol, see Herschel, *Papers,* vol. I, p. cvii.

[38] Herschel, *Papers,* vol. I, pp. 416–17.

[39] Herschel, *Papers,* vol. I, p. 482; see also p. 330.

[40] See *Gentleman's Magazine, 57* (1787), 636. For information on Elliot, see Robert J. Manning, "John Elliot and the Inhabited Sun," *Annals of Science, 50* (1993), 349–64.

[41] Herschel, *Papers,* vol. I, p. 479. On Herschel's theory, see Steven Kawaler and J. Veverka, "The Habitable Sun: One of William Herschel's Stranger Ideas," *Royal Astronomical Society of Canada Journal, 75* (1981), 46–55.

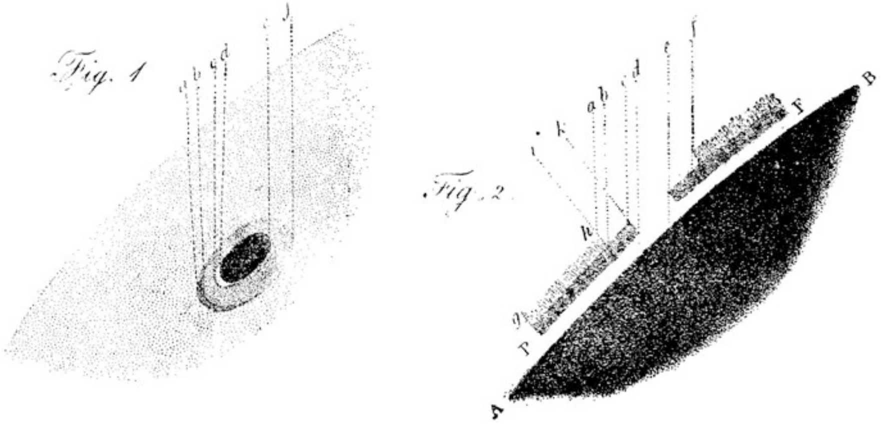


**Fig. 5.3** Herschel's 1802 diagram of the Sun's surface

Herschel contrasted his theory with that of the "fanciful poets" who portray the Sun "as a fit place for the punishment of the wicked," urging that his claim rests "upon astronomical principles."[42] In presenting his case, he once again drew upon the argument from analogy. He noted that the telescope reveals that the Moon has numerous similarities to Earth; the obvious differences he dismissed by stating that terrestrial beings flourish in a variety of circumstances:

> …man walks upon the ground, the birds fly in the air, and fishes swim in water; we can certainly not object to the conveniences afforded by the moon, if those that are to inhabit its regions are fitted to their conditions as well as we on this globe are to ours. An absolute or total sameness seems rather to denote imperfections, such as nature never exposes to our view…[43]

Similarly for the Sun: its inhabitants, he maintained, must have characteristics suited to its climate. Moreover, he urged that just as it would seem absurd for the inhabitants of a planetary satellite to deny life to its primary, so also we err if we do not ascribe solarians to the Sun. Such arguments suggest the correctness of E. S. Holden's statement that Herschel's arguments for solar and lunar life "rest more on a metaphysical than a scientific basis…."[44]

Holden's conclusion needs, however, to be qualified in one important way, which helps explain why the premier astronomer of that day adopted such a strange theory. Although as early as 1780 Herschel had considered a form of this solar model,[45] he had between then and 1795 accumulated astronomical evidence that, when viewed in terms of his strong belief in the plurality of worlds doctrine, substantially

---

[42] Herschel, *Papers,* vol. I, p. 479.

[43] Herschel, *Papers,* vol. I, p. 481.

[44] Edward S. Holden, *Sir William Herschel: His Life and Works* (Charles Scribner's Sons, New York, 1881), p. 149.

[45] Herschel, *Papers*, vol. I, p. xcvi.

increased the attractiveness of that model. In particular, during this period Herschel's stellar researches had led him to observe what he described in his 1795 solar paper as "very compressed clusters of stars." Many of these are what we would call globular clusters. Herschel went on to argue that stars in such clusters are too tightly packed to accommodate inhabited planets. This did not lead Herschel to abandon the region as a home for extraterrestrials; rather it led him to conclude that the stars themselves must be "very capital, *lucid*, primary planets" so structured as to allow habitation.[46] Thus Herschel had found a way to save these stars from being "mere useless brilliant points."[47] That Herschel's solar theory was no passing fancy in his thought is shown by his having elaborated on it further in his 1801 paper in which he referred to the Sun as "a most magnificent habitable globe"[48] and by his 1814 description of stars as "so many opaque, habitable, planetary globes."[49] However bizarre Herschel's solar theory may seem today, there is evidence that it persisted as the preferred theory of the Sun until the 1850s.[50]

## William Herschel's "Insulated Stars" and Exoplanets

In 1802, Herschel published a paper that consisted mainly of a catalog of 500 new nebulae that he had discovered.[51] Early in the commentary with which he prefaced this catalog, he described a type of star that he called an "insulated star." By this he meant stars not in clusters and consequently relatively free of gravitational attraction from surrounding stars. He commented regarding these stars:

> From the detached situation of insulated stars, it appears that they are capable of being the centers of extensive planetary systems. Of this we have a convincing proof in our sun, which, according to this classification, is one of these stars. …
>
> The question will now arise, whether every insulated star be a sun like ours, attended with planets, satellites, and numerous comets? And here, as nothing appears against the supposition, we may from analogy admit the probability of it. But, were we to extend this

---

[46] In particular, Herschel stated: "it will hardly be possible to assign any sufficient mutual distance [to them] to leave room for crowding in those planets, for whose support those stars have been, or might be, supposed to exist. It would seem, therefore, highly probable that they exist for themselves; and are, in fact, only very capital, lucid, primary planets, connected together in one great system of mutual support." Herschel, *Papers*, vol. I, pp. 482–83.

[47] Herschel, *Papers*, vol. I, p. 484.

[48] Herschel, *Papers*, vol. II, p. 147.

[49] Herschel, *Papers*, vol. II, p. 529.

[50] Actually, this issue does not seem to have been carefully studied or documented. A number of historians have said that this is the case, but they rarely provide documentary evidence that this was in fact the case. See A. J. Meadows, *Early Solar Physics* (Pergamon, Oxford, 1970), pp. 4–6. See also Crowe, "The Surprising History of Claims for Life on the Sun," *Journal of Astronomical History and Heritage, 14:3* (Nov., 2011), 169–179.

[51] William Herschel, "Catalogue of Five Hundred New Nebulae, Nebulous Stars, Planetary Nebulae, and Clusters of Stars, with Remarks on the Construction of the Heavens," *Philosophical Transactions*, (1802), 477–528.

> argument to other sidereal constructions, or, still farther, to every star of the heavens, as has been done frequently, I should not only hesitate, but even think that, from what will be said of stars that enter into complicated sidereal systems, the contrary is far more likely to be the case; and that, probably, we can only look for solar systems among insulated stars.[52]

This contrasts with the position regarding extra-solar planets that Herschel had espoused in 1789.[53] In that year after explaining that stars are suns, he added that every star "is probably of as much consequence to a system of planets, satellites, and comets, as our own sun…." In any case, the passage from 1802 suggests Herschel's matured view of extra-solar planetary systems.

## Conclusion to Part I

In concluding this discussion of William Herschel, we shall summarize it by providing a brief reconstruction of Herschel's career in such a way as to highlight his involvement with ideas of ETI. This professional musician was drawn to astronomy by reading such books as that of Ferguson, which was filled with ideas of extraterrestrial life. Captivated by Ferguson's claims for lunar life, Herschel boldly if naively sought to detect it directly, being encouraged in this by his early, albeit ambiguous, observations. Although it is unknown whether Herschel after Maskelyne's rebuke shared his hope of detecting lunar life with other astronomers besides Wilson, one can conjecture that the munificence of the monarch may have been motivated by Herschel confiding to the king that his discovery of Uranus was only a prelude to a more dramatic discovery toward which his progress had been halted by the limitations of his instruments.

Herschel's hopes that improved instrumentation would yield direct evidence of extraterrestrials went unfulfilled. Nevertheless, when those telescopes and his energies were turned in different directions, they ushered in a new era in astronomy, especially stellar astronomy.

To put the point somewhat differently, we may ask whether Herschel's passion for extraterrestrials leads to the conclusion that he should be labeled a "lunatic," as he feared Maskelyne might do. At a time when historians of science have documented in detail Kepler's passion for Pythagoreanism and Newton's attachment to alchemy, such a label for Herschel is surely unsuitable. Herschel, like Kepler and Newton, was a remarkable genius, but, like them, he was also a person of his times.

---

[52] Herschel, *Papers*, vol. II, p. 201.

[53] See Herschel, *Papers*, vol. I, p. 330.

# Part II: Sir John Herschel

## *Background*

The early years of John Herschel's life[54] are in striking contrast to those of his father. Whereas the father was largely self-educated, the son (Fig. 5.4) received the best scientific training available in early nineteenth-century England. He graduated from Cambridge University in 1813 as Senior Wrangler and First Smith's Prizeman. The Royal Society elected him to membership when he was 21 and when he was 38 nearly elected him president. Whereas the father, despite his brilliance, had always remained somewhat on the fringe of British science, the son soon established himself at its center and made contributions to almost every area of science. We shall see, however, that great as the differences between father and son were, they shared a deep commitment to belief in extraterrestrial life.

## John Herschel's *Treatise on Astronomy* and *Outlines of Astronomy*

In 1833 Herschel published his *Treatise on Astronomy*, which, when published in a revised and expanded form in 1849 as his *Outlines of Astronomy*, served as the authoritative exposition of astronomy during the Victorian period. Readers interested in extraterrestrials no doubt turned to Herschel's *Treatise*, wondering whether the father had passed on his enthusiasm for extraterrestrials to the son. They perhaps knew that in 1830, John Herschel had published a philosophical volume[55] advocating an empiricist methodology for science. And in the opening paragraphs of both his *Treatise* and *Outlines* John Herschel urges readers to set aside prejudice so as to be ready to accept astronomical conclusions "supported by careful observation and logical argument…."[56] A reader might, however, have been taken aback to find among the immediately presented examples of such carefully supported conclu-

---

[54] The only full-length biography of John Herschel is Günther Buttmann, *The Shadow of the Telescope: A Biography of John Herschel,* trans. by B. E. J. Pagel (Charles Scribner's Sons, New York, 1970). An older but still useful study is Agnes M. Clerke, *The Herschels and Modern Astronomy* (London, 1901). See also M. J. Crowe (ed.), David R. Dyck and James J. Kevin (associate editors), *Calendar of the Correspondence of Sir John Herschel* (Cambridge Univ. Press, Cambridge, England, 1998) and M. J. Crowe, "John F. W. Herschel," *Oxford Dictionary of National Biography*, ed. H. C. G. Matthew and Brian Harrison, vol. 26 (Oxford Univ. Press, Oxford, 2004), pp. 825–31.

[55] John Herschel, *A Preliminary Discourse on the Study of Natural Philosophy* (Longman, London,1830).

[56] John Herschel, *A Treatise on Astronomy* (Longman, Rees, Orme, Brown, Green & Longman, London, 1833), section #1; John Herschel, *Outlines of Astronomy*, 3rd ed. (London, 1850), section #1.

**Fig. 5.4** Sir John Herschel, by Alfred Edward Chalon in 1829

sions the following two: (1) "the planets…are…spacious, elaborate and habitable worlds; several of them vastly greater and far more curiously furnished than the earth…," and (2) "the stars…are…suns of various and transcendent glory – effulgent centers of life and light to myriads of unseen worlds…."[57] Later in the book he reveals the chief source for this conviction. After asking, "For what purpose are we to suppose such magnificent bodies scattered through the abyss of space?"[58] and after answering, "Surely not to illuminate our nights," he asserts that a person:

> …must have studied astronomy to little purpose, who can suppose man to be the only object of his Creator's care, or who does not see in the vast and wonderful apparatus around us provision for other races of animated beings. The planets, as we have seen, derive their light from the sun; but that cannot be the case with the stars. These [stars] doubtless, then, are themselves suns, and may, perhaps each in its sphere, be the presiding center round which other planets, or bodies of which we can form no conception from any analogy offered by our own system, may be circulating.[59]

By 1833, William Herschel's claims concerning the habitability of the Sun and Moon had become increasingly problematic, as his son no doubt realized. Nonetheless, in both John Herschel's *Treatise* and his later *Outlines*, he endorses his father's doctrine that the Sun has a large solid nucleus, which becomes visible through the "openings"[60] (sunspots) in its exterior layer. John Herschel does not directly discuss solarians in this *Treatise* or *Outlines*, resting content with having supplied the previously indicated provisions for their existence, of which David

---

[57] Herschel, *Treatise* #2; *Outlines*, #2.

[58] Herschel, *Treatise*, #592; *Outlines*, #819.

[59] John Herschel, *A Treatise on Astronomy* (London, 1833), #592; *Outlines*, #819.

[60] Herschel, *Treatise*, #332; *Outlines*, #389.

Brewster[61] and others availed themselves later in the century. Concerning the Moon, the younger Herschel in his *Treatise* admits that its surface fluctuates between extremes of hot and cold, depending on whether the Sun is over a specific region. Nonetheless, he adds:

> The consequence must be absolute aridity below the vertical sun, constant accretion of hoar frost in the opposite region, and, perhaps, a narrow zone of running water at the borders of the enlightened hemisphere. It is possible, then, that evaporation on the one hand, and condensation on the other, may to a certain extent preserve an equilibrium of temperature, and mitigate the extreme severity of both climates.[62]

This speculation was soon employed by Patrick Scott to legitimate the lunarians in his dreamy poem *Love on the Moon* (London, 1853). We shall see shortly that in the 1850s John Herschel provided another provision for lunar life, but let us continue with his *Treatise*.

## The Habitability of the Planets

In one way at least, John's attachment to placing ETI on the planets is surprising. If one looks at present-day astrobiology books, one often finds an analysis of the habitability of our Solar System based on the inverse square laws for gravitation, light, and thermal radiation. The first of these was available to Newton and second and third were widely known by the time of Herschel's *Treatise*. Let us examine what Herschel knew regarding these laws.

Newton in his *Principia* had used the gravitational inverse square law to produce the following information.

| | Sun | Jupiter | Saturn | Earth |
|---|---|---|---|---|
| Mass | 1 | 1/1076 | 1/3021 | 1/169,282 |
| Density | 100 | 94.5 | 67 | 400 |
| Weight of person on | 10,000 | 943 | 529 | 435 |

Information from the 3rd edition of Newton's *Principia*
Newton's values as given in the first edition were somewhat different

This table created problems for the ETIs of the Sun, Jupiter, and Saturn. Were we transported to Jupiter, for example, our weight would more than double and would increase over twenty times on the Sun. Moreover, we see that Earth is far denser than these other bodies.

By 1830, the inverse square laws for light and heat had indicated that Mercury receives seven times more light and heat than the Earth, whereas Uranus receives

---

[61] On Brewster, see Miguel de Asúa, "Sir David Brewster's Changing Ideas on the Plurality of Worlds." *Journal of Astronomical History and Heritage*, *9*, no. 1 (2006), 83–92.

[62] Herschel, *Treatise*, #364; also *Outlines*, #431, but weakened by the qualification: "this process... must...be confined within very narrow limits."

over 300 times less. To prove that this information was publicly available before 1850, here are quotations from Herschel's *Treatise on Astronomy.* Regarding the heat/light problem, Herschel states: "The intensity of solar radiation is nearly seven times greater on Mercury than on the earth, and on Uranus 330 times less; the proportion between these two extremes being that of upwards of 2,000 to one."[63] Moreover, regarding gravity, Herschel declares "the intensity of gravity, or its efficacy in … repressing animal activity on Jupiter is nearly three times that on the Earth, on Mars not more than one third, and on the four smaller planets probably not more than one twentieth; giving a scale of which the extremes are in the proportion of sixty to one."[64] Regarding the density issue, Herschel states that Saturn's density is about one eighth of Earth's, "so that it must consist of materials not much heavier than cork."[65]

Did such facts force Herschel to conclude against ETIs in our Solar System? Instead he remarks on "what immense diversity must we not admit in the conditions of that great problem, the maintenance of animal and intellectual existence and happiness, which seems…to form an unceasing and worthy object of the exercise of the Benevolence and Wisdom which presides over all!"[66] Thus Herschel falls back on religious thought, especially the Principle of Plenitude, and thereby passes over important scientific evidence against ETIs.

In other words, he urges that God must have created extraterrestrials suitable to the dim and frigid wastes of Uranus and the high temperature of Mercury's surface. In general, he interprets the observational evidence concerning the planets in such ways as to be most supportive of their habitability. And he delights in dramatic descriptions of how the heavens must look to lunarians or to the Saturnians, the latter of whom revel in the rich spectacle of their planet's rings. In regard to the asteroids, he remarks that observations indicate that Pallas may possess an atmosphere and adds with respect to the low gravitational forces on these small bodies that on such objects "giants might exist; and those enormous animals, which on earth require the buoyant power of water to counteract their weight, might there be denizens of the land. But of such speculations there is no end."[67] In the section of his book on stellar astronomy, he admits the problems that double stars present for inhabited planets. Nonetheless, he proposes that their planets are "closely nestled under the protecting wing of their immediate superior…."[68] And this leads him into a presentation of the "charming contrasts" and "grateful vicissitudes"[69] of the spectacle seen by planetarians located in a double star system composed of colored stars.

Mention was made earlier of the strong interest that William Herschel had in what are now called extra-solar planets, or exoplanets, i.e., planets orbiting other

---

[63] Herschel, *Treatise,* #435.

[64] Herschel, *Treatise,* #435.

[65] Herschel, *Treatise,* #435.

[66] Herschel, *Treatise*, #435; *Outlines*, #508.

[67] Herschel, *Treatise*, #448; *Outlines*, #525.

[68] Herschel, *Treatise*, #609; *Outlines*, #847.

[69] Herschel, *Treatise*, #610; *Outlines*, #851.

stars. William had searched diligently for such objects, as had others. John Herschel shared this interest. In fact, in the same year (1833) that John Herschel published his *Treatise,* he published a paper on double stars, in which he specified five double star systems as cases in which the dimmer partner may shine by reflected light, in other words, that it may be a planet.[70] It is my suspicion that John Herschel's strong interest in discovering double stars, of which he discovered hundreds, may in part have been motivated by a hope of detecting extra-solar planets.

## John Herschel and the Moon

In general in his *Treatise* and *Outlines*, John Herschel advocates extraterrestrials repeatedly, albeit with a greater caution than is evident in his father's published writings. The Moon presented especially delicate issues in this regard. One example of this delicacy is evident in an unpublished letter dated May 17, 1827, that John Herschel sent to Joseph Johann Littrow, an important German astronomer. Part of the letter concerns another astronomer, Franz von Paula Gruithuisen,[71] who had created a sensation and much controversy shortly before this time by reporting that he had observed fortifications on the Moon. We can read Herschel's comments in his letter either as expressing genuine interest in Gruithuisen's results or as conveying serious reservations about his extraordinary claims, the latter seeming to be more probable. Herschel's statement:

> I am much in hopes that Dr. Gruithuisen whose strange observations about the moon have caused a good deal of talk here, will some of these days pay us a visit in England, and bring his telescope with him which has shewn him such wonders. No one here has been able to see the phenomena [?] he describes but as I understand your expressions, you have satisfied yourself of their reality, and I therefore much wish he would come and shew us his discoveries with his own instruments.[72]

In the same year (1833) in which John Herschel published his *Treatise*, he left England for South Africa to observe the heavens of the southern hemisphere. He stayed there for four years. While there, he learned that in 1835 a New York newspaper, the *Sun,* had published a series of widely believed articles reporting that he had done nothing less than to discover a civilization on the Moon. I have elsewhere[73] built a case that this event, usually called the "Great Moon Hoax,"[74] was not in fact

---

[70] John Herschel, "Remarks on a Fifth Catalogue of Double Stars, Communicated to the Royal Astronomical Society, June 7, 1832," *Royal Astronomical Society Memoirs, 6* (1833), 74–81:78.

[71] On Gruithuisen, see Crowe, *Extraterrestrial Life Debate, 1750–1900,* pp. 202–4.

[72] Herschel's letter is available at the National Library of Scotland as NatLibScot MS.582, no.667.

[73] Crowe, *Extraterrestrial Life Debate, 1750–1900*, pp. 210–15 and for important supplementary information, Crowe, *Extraterrestrial Life Debate, Antiquity to 1915*, pp. 294–95.

[74] For a recent, very informative study of this famous event see Matthew Goodman, *The Sun and the Moon: The Remarkable True Account of Hoaxers, Showmen, Dueling Journalists, and Lunar Man-Bats in Nineteenth-Century New York* (Basic Books, New York, 2008).

a hoax at all. Put overly briefly, my claim is that the author of these articles, Richard A. Locke, had intended them not as a hoax but as satire. Various writings by astronomers, religious writers, and journalists had, however, so thoroughly convinced the public of the existence of extraterrestrials that they took the articles as literally true, missing Locke's satirical intention. Although it is clear that the excessive claims made by the astronomical popularizer Thomas Dick were the chief object of Locke's satire, this does not preclude the possibility that Herschel was himself to some degree an object of Locke's satirical pen – or, alternatively, that the enthusiasm for extraterrestrials expressed by both Herschels may have influenced Dick to make the bold claims that inspired Locke's satire (Fig. 5.5).

Locke's skillfully written articles were at first widely accepted as true. Moreover, even after it was learned that they were a fabrication, the articles were translated into the main European languages, including Welsh, and in some cases illustrations were added. Even now, they continue to be reprinted and discussed. To trace the history of Locke's Moon publications is beyond the scope of this study; in fact, it would take a long book, but we can sketch some of Herschel's reactions to it.

It is no doubt true that Locke selected Herschel for the leading role in his Moon story not only because he was the leading astronomer in the English-speaking world but also because Locke felt safe that the deception would not be *immediately* exposed, this being due to the fact that Herschel, residing then in Cape Town, was nearly as distant from the centers of civilization as he would have been had he traveled to the Moon itself. The literature on the history of the "hoax" records that Herschel first learned of Locke's articles from Caleb Weeks, an American owner of a menagerie, who had traveled to Africa in search of exotic animals.[75] We do not know when this occurred nor does an exact record of their conversation exist, but one can imagine something along the following lines.

> Weeks: "Sir John, are you the astronomer who is credited with making the most important discovery ever?"
>
> Herschel (surprised and engaged): "Which discovery is this?"
>
> Weeks: "The discovery of a civilization on the Moon."
>
> Herschel (apprehensive and suspicious): "What makes you think I made this discovery?"
>
> Weeks: "Here, I'll show you the publication!"

One report from 1852 states that Herschel, during the conversations with Weeks, remarked that he "feared the actual results of his telescopic observations at the Cape would be very humble, in popular estimation, at least, in comparison with those ascribed to him in the American account, as he was unfortunately unprovided with any such instrument as it admitted to be necessary to achieve them."[76]

Although it is unknown when the Herschel-Weeks meeting took place, it is certain that Herschel had been informed of the articles by January 5, 1836. A Herschel letter with this date and addressed to a "Captain C" survives. In the letter, Herschel

---

[75] Goodman, *Sun and the Moon,* pp. 223–27.

[76] William N. Griggs, *"Moon Story," The Origin and Incidents* (Runnell and Price, New York, 1852), p. 39.

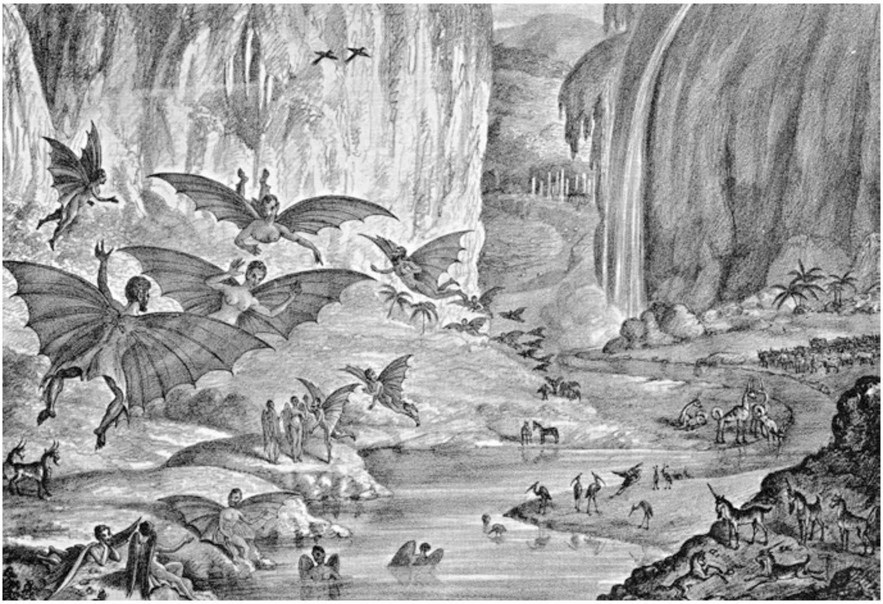


**Fig. 5.5** An image of the ‘flying Lunarians’ as printed in 1835

thanks his correspondent for informing him of the articles.[77] It seems a curious fact that no mention of the Moon hoax can be found in two of the three detailed and document-rich books recounting Herschel’s four plus years at the Cape of Good Hope, and only a few lines in the third.[78]

Studies of Locke’s articles provide substantial information on their initial reception and eventual exposure in the United States, but less is known about the situation in Britain, which must have been of some concern to Herschel. A key statement appeared in the April 2, 1836, issue of the *Athenaeum*, a weekly magazine, in which Herschel at times had published. The statement, which follows, reveals as much about what was then *not* known as it does about what was known.

> *Extraordinary Discoveries by Sir John Herschel.* – The absurd accounts lately referred to in our daily papers, about some extraordinary discoveries made by Sir John Herschel, are now said to have been originally put forth in America. How this may be, we know not, but a cor-

---

[77] This letter is preserved in the Herschel papers at the Harry Ransom Library of the University of Texas as TxU:H/L-0120; Reel 1054 and a copy of the letter is at the Royal Society in the Herschel Papers as RS:HS 25.15.1.

[78] These are: Brian Warner (ed.), *Margaret Herschel: Letters from the Cape 1834–1838* (Friends of the South African Library, Cape Town, 1991); Brian Warner and Nancy Warner (eds.), *Maclear and Herschel: Letters and Diaries at the Cape of Good Hope, 1834–1838* (A. A. Balkema, Rotterdam,1984); David S. Evans, Terence J. Deeming, Betty Hall Evans, and Stephen Goldfarb (eds.), *Herschel at the Cape: Diaries and Correspondence of Sir John Herschel, 1834–1838* (Univ. of Texas Press, Austin, Texas, 1969). The last does supply some items of information, the main one of which will be cited shortly.

> respondent has obligingly forwarded to us copies of the *Granada Free Press* newspaper, in which we find a "full, true, and particular" report, professedly copied "from a Supplement to the Edinburgh Journal of Science," and as it occupies not less than *eighteen columns*, and was "to be continued," we presume that the mystification must have been originally circulated in the form of a pamphlet. The papers are admirably written, and we would willingly have given our readers a taste of their quality, but it should have required more space than we could conscientiously spare for a mere joke.[79]

The next appearance of the "Moon Hoax" in Herschel's correspondence is in a letter dated April 12, 1836, written by Sir Francis Beaufort, hydrographer for the Admiralty, who asks whether Herschel has seen the articles.[80] In his response, Herschel replies that he has seen them and, moreover, has heard that an American clergyman had expressed concern that he might soon have to make an appeal to his congregation for funds for bibles for the lunarians.[81]

Robert Treat Paine, an American astronomer, in a letter mainly about other matters sent to Herschel from Boston, briefly mentioned the Moon articles. The fact that Herschel sent off his response more than three months later suggests how long it took for American letters to reach Cape Town.[82]

In 2002, Herschel scholar Steven Ruskin discovered a previously totally unknown Herschel letter on the Moon hoax; in fact, it was a letter to the *Athenaeum* that Herschel drafted but never sent. Although playful in parts, the letter's key section makes a strong statement:

> [I]t appears to me high time to disclaim all knowledge of or participation in the incoherent ravings under the name of discoveries which have been attributed to me. I feel confident that you will oblige me therefore by inserting this my disclaimer in your widely circulated and well conducted paper, not because I have the smallest fear that any person possessing the first elements of optical Science (to say nothing of Common Sense) could for a moment be misled into believing such extravagancies, but because I consider the precedent a bad one that the absurdity of a story should ensure its freedom from contradiction when universally repeated in so many quarters and in such a variety of forms.[83]

It seems that by January 10, 1837, Herschel had learned that he had overestimated the ability of people to recognize the absurdity of Locke's articles; on that date, he ended a letter to Caroline Herschel by lamenting "I have been pestered from all quarters with that ridiculous hoax about the Moon – in English French Italian & German!!"[84]

---

[79] *Athenaeum*, #440 (April 2, 1836), 505.

[80] Letter is preserved at the Royal Society Herschel Papers as RS:HS 3.345.

[81] Joseph Crampton, *The Lunar World: Its Scenery, Motions, etc., Considered with a View to Design* (Adam and Charles Black, Edinburgh, 1863), pp. 83–84. Crampton attributes the letter to Sir Frederick Beaufort, but it is clear that it must have been Francis Beaufort.

[82] Paine's letter is preserved in the Herschel Papers at the Royal Society as RS:HS 13:209; Herschel's response is preserved at the Herschel papers at the Univ. of Texas Ransom Library as TxU:H/L–0291; Reel 1054.

[83] Steven S. Ruskin, "A Newly-Discovered Letter of J. F. W. Herschel Concerning the 'Great Moon Hoax,'" *Journal for the History of Astronomy, 33* (2002), 71–74.

[84] As quoted in Evans, *Herschel at the Cape,* p. 282.

Information about the reception of the Locke articles in France is available and has a surprising link with the first public statement by John Herschel on the articles to appear in English. The director of the Paris Observatory, François Arago, not only learned of the articles in 1836 but also was angered by them to the point that he called them to the attention of the Académie des Sciences of which he was secretary. His distress led him to read the entire articles (ca. 11,000 words) to the members of the academy, who reacted differently from what he expected. As Matthew Goodman has recently described it, "The other members…found the story less invidious than did Arago; his reading was met by 'repeated interruptions from uncontrollable and uproarious laughter.' In the end, however, Arago got his wish; the French Academy of Sciences passed a resolution that officially declared the lunar discoveries 'utterly incredible.'"[85]

Herschel, after learning of Arago's efforts on his behalf, wrote to his fellow astronomer to thank him, which letter appeared in the journal of the academy. Moreover, this letter, when translated into English and published in the December 24, 1836, *Athenaeum,* constituted the first time that Herschel's countrymen learned in his own words his view of the articles.

> Captain Hall had the kindness to contribute to my amusement by sending me the different journals, containing the history of my pretended discoveries in the moon, and also some remarks, among which I think I recognize your style. Captain Hall has not forgotten to inform me of your friendly eagerness in trying to undeceive the good people of Paris on this head; and I beg you to accept my sincere thanks for your kind offices, although I must regret that such precious moments as yours should have been so employed. Since there are people silly enough to believe every extravagant tale which is set before them, we ought to hope that these tales may be as harmless as that now in question, and under all circumstances I am not disposed seriously to complain of anything which has recalled me to your recollection, and made you my champion.[86]

The final Herschel letter to be examined is from Margaret Herschel to Caroline Herschel. Although undated, evidence suggests that it was probably written in June 1836.[87]

> Have you seen a very clever piece of imagination in an American Newspaper, giving an account of Herschel's voyage to the Cape…and of his wonderful lunar discoveries[?] Birds, beasts & fishes of strange shape, landscapes of every coloring, extraordinary scenes of lunar vegetation, & groups of the reasonable inhabitants of the Moon with wings at their backs, all pass in review before his & his companions' astonished gaze – the whole description is so well clenched with minute details of workmanship & names of individuals boldly

---

[85] Goodman, *Sun and Moon,* p. 230.

[86] John Herschel, [Letter to François Arago], *Athenaeum, #478* (Dec. 24, 1836), 907–8. For what appears to the French original, see *Comptes rendus hebdomadieres des Seances des l'Académie des Sciences*, *3* (Juillet-Décembre, 1836), 505.

[87] Evans notes that it arrived in London on 26 September 1836. Evans, *Herschel at the Cape*, p. 235. One comment in the letter indicates that it was written in the winter season in Cape Town and another comment mentions an observation made on May 20, 1836. From the fact that the time for the Herschels' voyages between London and the Cape of Good Hope was over two months, we can set the date range of the letter between May 20 and July 26 of 1836. Thus June 1836 seems a reasonable approximation.

> referred to, that the New Yorkists were not to be blamed for actually believing it as they did for forty eight hours.

It concludes with a comment that should just possibly be taken seriously: "It is only a great pity that it *is not true* but if grandsons stride on as grandfathers *have* done, as wonderful things may yet be accomplished."[88]

It is a little known fact that by 1858 John Herschel had emerged as a proponent of lunar life, in particular, life on the far side of the Moon. This remarkable story begins in 1854 with a most unlikely person and at a very improbable place.[89] In particular, in that year Peter Andreas Hansen, whom Simon Newcomb called "the greatest master of celestial mechanics since Laplace,"[90] presented a long, very technical paper at the Royal Astronomical Society in which he accounts for certain discrepancies between lunar observation and theory by hypothesizing that the center of gravity of the Moon is about 33 miles more distant from Earth than the Moon's center of figure. Such an asymmetric distribution of the Moon's mass would cause any atmosphere or fluids on the Moon to retreat to its remote side.

In his paper, Hansen explicitly notes the implications of this for lunar life: "One can no longer conclude that the [remote] hemisphere may not be endowed with an atmosphere, and that it has no vegetation and living beings."[91] Hansen's hypothesis, which the twentieth-century historian of astronomy Willy Ley has described as "probably the wildest astronomical hypothesis ever advanced,"[92] drew some immediate criticism, and by 1868 had been refuted by Simon Newcomb, who showed that even if the Moon had such a remarkable distribution of matter, this would not account for the effect that Hansen had sought to explain.[93] Nonetheless, this provided time for John Herschel to embrace and embellish Hansen's hypothesis in the fifth edition (1858) of his *Outlines of Astronomy*, describing it as "not improbably what takes place on the moon,"[94] and using it to argue for the possibility of life on the Moon's farside.

Moreover, the 1862 issue of the *Cornhill* magazine contains an essay, almost certainly by Herschel, in which the author finds support for Hansen's hypothesis in an 1860 study by the Russian astronomer H. Gussew, who from an examination of

---

[88] As quoted in Evans, *Herschel at the Cape*, pp. 236–37. Emphasis in original.

[89] For an excellent account of this development, see Daniel A. Beck, "Life on the Moon: A Short History of the Hansen Hypothesis," *Annals of Science, 41* (1984), 463–70.

[90] Simon Newcomb, *Reminiscences of an Astronomer* (London, 1903), p. 319 as quoted in Daniel Beck, "Life on the Moon: A Short History of the Hansen Hypothesis," *Annals of Science, 41* (1984), 463–470:464.

[91] Peter Andreas Hansen, "Sur la figure de la lune," *Memoirs of the Royal Astronomical Society, 24* (1856), 29–90:32.

[92] Willy Ley, *Rockets, Missiles, and Men in Space* (New American Library, New York, 1969), p. 31.

[93] Simon Newcomb, "On Hansen's Theory of the Physical Constitution of the Moon," *American Association for the Advancement of Science Proceedings, 17* (1868), 167–171:171.

[94] Herschel, *Outlines*, 5th ed. (London, 1858), #436a and b. Herschel's discussion was described as "one of the most remarkable additions" to that edition in the review of it in *Eclectic Review, 47* (1859), 33–39:36.

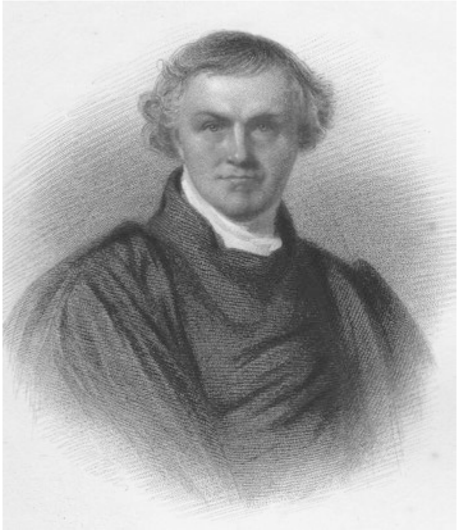


**Fig. 5.6** William Whewell

stereoscopic photographs of the Moon had concluded that the Moon's figure is asymmetric, in particular, that the Moon is shaped somewhat like an egg, with its narrow end inclined toward Earth. Gussew, according to Herschel, estimated the Moon's center of figure to be about 59 miles nearer to us than the Moon's center of mass, or about twice Hansen's value. Herschel, delighted to find such support for Hansen's bold claim, asserts: "Either result, but especially M. Gussew's…would be quite compatible with the existence of [air and water], and of a habitable hemisphere on the [Moon's] opposite side…."[95]

Herschel was not the only advocate of extraterrestrials who championed Hansen's hypothesis; a dozen or so other authors also adopted it before Newcomb's 1868 demolition of its basic premises. Nor was Hansen's claim without its critics. For example, William Whewell, recognizing that a portion of its support came from those attracted to it as a method of saving God from the charge of having wasted portions of material creation, asked if an inhabitant of the Moon's far side who wandered to our side would not be "woefully perplexed (especially if he were a philosopher jealous of waste in the creation) to see this great luminary placed exactly in that single point of the universe in which it could not possibly be of use to his race."[96]

---

[95] [John Herschel], "Figure of the Moon and of the Earth," *Cornhill Magazine*, *6* (1862), 548–550:549. Internal evidence and Walter E. Houghton (ed.), *Wellesley Index to Victorian Periodicals*, vol. I (Toronto, 1966), p. 332 support ascription of this essay to Herschel.

[96] [William Whewell], *Of the Plurality of Worlds: An Essay,* 5th ed. (London, 1859), pp. 412–13.

## John Herschel and William Whewell

Let us turn now to an exchange of letters between John Herschel and his good friend William Whewell (1794–1866), the Master of Trinity College, Cambridge. Herschel's undated letter to William Whewell (Fig. 5.6) must have been written in January or February of 1854. In late 1853, Whewell published anonymously his *Of the Plurality of Worlds: An Essay*, in which he called into question many of the ideas of those who advocated extraterrestrials.[97] On January 3, 1854, Whewell sent his close friend John Herschel, who was then serving as Master of the Mint, a copy of his book, describing it as the work of a "friend" whose ideas, although "so much at variance with opinions which you have countenanced,"[98] deserve not to be suppressed. In words that scarcely reveal the cosmic holocaust that Whewell had attempted in his *Essay*, he suggests: "Perhaps you would not take it much to heart if the inhabitants of Jupiter, or of the systems revolving about double stars which you have so carefully provided for, should be eliminated out of the universe."[99]

John Herschel's remarkable response is simultaneously a fine example of his commitment to the idea of extraterrestrial life and of his willingness to consider contrary evidence. Moreover, it suggests which quasi-religious ideas influenced his commitment.[100] The first two points are evident early in the letter when Herschel admits:

> I should not have thought there was so much to be said on the non-plurality side of the question. True, Humboldt drew attention to the fact of the Classification of the planets into heavy & light and shewed that the little ones are heavy & the large ones light. – But peoples thoughts (most people's) are sluggish – and really though somewhere I have myself stated that taken in a lump Saturn might be regarded as made of Cork – it never did occur to me to draw the conclusion that ergo the surface of Saturn must be of extreme tenuity – though I long ago came to the conclusion that the rings were fluid (for the same reason that others have done so – that if solid they would tear themselves to pieces) – and that the streaks on them were mere lines of cloudiness or other liquid streakinesses.

After proceeding to speculate freely on the aquatic creatures that must exist on Saturn, he turns in a more religious or metaphysical direction by suggesting:

> So *this* then is the best of all possible worlds – the *ne plus ultra* between which and the 7th heaven there is nothing intermediate. Oh dear! Oh dear! 'Tis a sad cutting down. Look only at the Russians & Turks.[101] – Look at the revelations of the Blue Books & the Police Courts

---

[97] On this book, see chapter 11 in both my *Extraterrestrial Life Debate, 1750–1900* and my *Extraterrestrial Life Debate, Antiquity to 1915.*

[98] Isaac Todhunter, *William Whewell* (London, 1876), vol. 2, p. 399.

[99] Todhunter, *Whewell*, vol. 2, p. 399.

[100] For a full transcription of the letter along with extensive notes on it, see my *Extraterrestrial Life Debate, Antiquity to 1915*, pp. 358–60. The original of the letter is at Trinity College Library (Cambridge) Whewell Papers Add.Ms.a. 20,790 and I have compared my transcription with the transcription at the Royal Society Herschel papers RS:HS.23.140.

[101] This phrase "Look only at the Russians & Turks" needs some commentary. Recently another scholar has not only made a very different transcription of this portion of the letter, but also made her reading quite prominent by featuring it in the title of her publication. Dr. Laura Snyder's pub-

> I can't give in my adhesion to the doctrine that between this and the angelic there are not some dozen or two grades of intellectual and moral creatures.
>
> You say (I mean the Author says) that of millions of germs only a few are reproductive that for thousands of flowers there are hardly units of fruits (if he does not say so in words 'tis his argument). Ergo among all the stars there is (not a *few* but) *one* Sun. Among all the planets not a *few* but only *one* Earth.–
>
> Dissentions & Protesting. – The whole theory is destroyed if there can be two cases produced in which the process has gone on to its completion in the production of that ne plus ultra – An Earth! inhabited by Men!! for if two why not 2,000!

The letter concludes with Herschel again praising a number of the arguments that his close friend Whewell had formulated.

We learn even more of Herschel's beliefs from an unpublished letter that he sent to the Cambridge geologist Adam Sedgwick on March 11, 1854, in which he again links the issue to the Crimean War:

> Whewell's book is clever but wrong, i.e. as wrong as my contrary belief can make it. Why there should not be very intellectual and moral fishes in Jupiter it puzzles me to imagine. I am loth [sic] to fancy that a world in which Russians and Turks are pounding one another for conscience sake is after all the best thing going throughout creation. However we shall know more about it someday.[102]

The degree to which Herschel was troubled and puzzled by Whewell's book is further evident from comments he sent to his wife in this same period:

> *Somebody* (Whewell is *most anxious* that it should not be thought to be he) has written a book (and sent it to me) to prove that the earth is the only inhabited body not of the solar system only but of the universe. There is much in it of very remarkable and novel speculation – and certainly so far as our own system goes there is much force in what is urged. Yet though the author denies the fixed stars to be suns *like* ours I cannot bring myself to admit [?] that among them there may not be many that are so, and that round them there may be planetary systems, in some of the bodies of which the conditions that prevail on the earth & which make it habitable to such creatures (for better or worse) than us [?] poor humanities – may subsist. It seems remarkable & likely that such should be the case though whether

---

lication is "'Lord only of the Ruffians and Fiends'? William Whewell and the Plurality of Worlds Debate," *Studies in History and Philosophy of Science*, *38* (September, 2007), 584–92. When her paper was at an early stage—announced as a paper to be read at a conference—I emailed her suggesting that this was a mis-transcription and suggesting my own transcription. She acknowledged the email but did not directly deal with the suggestion or change her transcription. Having devoted ten years of my research career to working on John Herschel correspondence, I know the difficulties of his handwriting. In this case, however, I am quite certain of the correctness of my transcription. At least three reasons support this confidence. First, my transcription agrees with that made shortly after John Herschel's death under the direction of his son, Col. John Herschel, which transcription is preserved in the John Herschel papers at the Royal Society. Second, I have run tests with four other professors who are experienced in nineteenth-century orthography, all of whom support my reading. Third, Herschel's letter to Sedgwick, which is quoted later in this essay, also mentions the Russians and Turks, who were much in the news at that time because of the Crimean War. Persons interested in this issue may wish to examine the original at the Wren Library (Cambridge) and the transcription at the Royal Society (London). These are referenced in the previous footnote.

[102] Letter from John Herschel to Adam Sedgwick of 11 March 1854 preserved in the Herschel letters at the Royal Society as RS:HS 15.445; a transcription is available as RS:HS 23.146.

> such beings exist there is another matter. – The Geological evidence of former absence of nature's [?] on the Earth itself is well handled & powerfully argued.[103]

Herschel got the last word in his discussions with Whewell on this topic and with it revealed yet another aspect of his view of Whewell's book. When Whewell died in 1866, Herschel wrote an obituary, which contains the revealing remark:

> The essay on the 'Plurality of Worlds'…can hardly be regarded as expressing his deliberate opinion, and should rather be considered in the light of a *jeu d'esprit*, or possibly, as has been suggested, as a lighter composition on the principle of "audi alteram partem," [hear the other side] undertaken to divert his thoughts in a time of deep distress. Though it may have had the effect I have heard attributed to it, of "preventing a doctrine from crystallizing into a dogma," the argument it advances will hardly be allowed decisive preponderance against the general impression which the great facts of astronomy tend so naturally to produce.[104]

One of the chief theses I am developing in this section can be clarified by examining an explanation of why Whewell changed his mind. In her very engaging *Philosophical Breakfast Club*, Laura Snyder comments on this: "Whewell drew heavily upon the most recent astronomical studies of Jupiter. The observational evidence pointed to Jupiter being composed mainly of water and water vapor. Given the known density of the planet, gravity on its surface would be 2.5 times that on the earth; therefore it is not likely that any of its inhabitants could have a skeletal system."[105] It is true that Whewell was aware of and cited this information about Jupiter, but this was not from "the most recent astronomical studies of Jupiter." This information had already been available for more than a century, having been set out by Newton in his *Principia.* In other words, in this case what Whewell had done was take seriously information available for well over a century. John Herschel and many of his fellow astronomers, on the other hand, were so deeply committed to the Principle of Plenitude that they remained unable to see that the evidence pointed in an entirely different direction.

## John Herschel's Relations with Richard Proctor and Camille Flammarion

The most prolific British astronomical author during the Victorian period was Richard A. Proctor (1837–1888), who produced dozens of books on astronomical topics. Nearly simultaneously with Proctor's emergence in Britain as its most popular and prolific astronomical writer of the last third of the nineteenth century, Camille Flammarion (1842–1925) came to the fore in France with comparable effect. Not only did each draw on the writings of John Herschel, both came directly

---

[103] Letter 1.101 in the collection of family letters owned by John Herschel Shorland.

[104] *Proceedings of the Royal Society, 16* (1867–68), lxi.

[105] Laura Snyder, *The Philosophical Breakfast Club: Four Remarkable Friends Who Transformed Science and Changed the World* (Broadway Books, New York, 2010), 307. The four friends are John Herschel, Charles Babbage, William Whewell, and Richard Jones.

into contact with him, especially in regard to ideas of extraterrestrial life. These relationships (which did not last long because of Herschel's death in 1871) can be traced to some extent through their correspondence.

Proctor, a graduate of Cambridge University, first attempted to launch his career as a writer with his *Saturn and Its System* (1865), which received approval from experts but commercially was, as Proctor put it, a "dismal failure."[106] Five subsequent books fared only slightly better. Then Proctor discovered a way of reaching the public – to enter the extraterrestrial life debate, which he did in 1870 with his *Other Worlds than Ours.* This book attracted a large audience and went through dozens of printings, remaining in print until 1909. This strategy led him to be involved with both John Herschel and William Whewell. After his book was published, Proctor, who was well acquainted with Herschel's writings, sent him a copy of the book. Herschel responded by a detailed four-page letter, agreeing with and praising some of Proctor's claims, but criticizing others. It is clear from the letter that Herschel approved of Proctor's pro-plurality of worlds position and also his dismissal of Whewell's critique.[107]

The success of Proctor's *Other Worlds than Ours* made it clear to him that the inclusion of discussions regarding extraterrestrials would attract readers. Thus it is not surprising that in 1875 he devoted a chapter of his *Our Place among Infinities* to extraterrestrial issues. What is surprising is that in this chapter, which is titled "A New Theory of Life in Other Worlds," he reports a major change in his views. In particular, he suggests that Whewell was in many ways correct. Proctor had come to believe that life on the planets of our Solar System and on planets elsewhere must be quite rare. One reason for this is that he took Whewell's notion that our Solar System has a "temperate zone," a relatively small zone where life is possible, but that the intensity of the solar radiation nearer to the Sun and paucity of heat and light beyond the temperate zone make life extremely unlikely. Another reason for Proctor's opposition to the omnipresence of life claim was that he came to believe that planets have a history, during which they may after a long period of time develop life, but then also as their sources of light and heat diminish, life will die out. Nonetheless, because of the immensity of the universe and the vast number of suns, at any point of time there must be a very large number of inhabited planets. In summing up his new theory, Proctor states:

> Have we then been led to the Whewellite theory that our earth is the sole abode of life? Far from it. For not only have we adopted a method of reasoning which teaches us to regard every planet in existence, every moon, every sun, every orb in fact in space, as having its period as the abode of life, but the very argument from probability which leads us to regard any given sun as not the center of a scheme in which at this moment there is life, forces upon us the conclusion that among the millions on millions, nay, the millions of millions of suns which people space, millions have orbs circling round them which are at this present

---

[106] For more information on Proctor, see Crowe, *Extraterrestrial Life Debate, 1750–1900*, pp. 359–67.

[107] Copies of Herschel's letter are preserved at the Royal Society in London where the reference indicator is RS:HS 14.123C and a transcription is available at RS:HS 24.312. Proctor's response is at RS:HS 14:134.

> time the abode of living creatures. If the chance is one in a thousand in the case of each particular star, then in the whole number (practically infinite) of stars, one in a thousand has life in the system which it rules over: and what is this but saying that millions of stars are life-supporting orbs? There is then an infinity of life around us.[108]

Herschel, who had died in 1871, would have been delighted; Whewell, who had died in 1866, would have been aghast.

Yet this is not the entire story. In the same essay, Proctor criticizes authors who naively champion the pluralist point of view, making specific mention of John Herschel:

> It is worthy of notice that this view has been entertained even by astronomers who, like the Herschels, have devoted their lives to the scientific study of the heavens. So completely has the theory been identified, as it were, with modern astronomy, that we find the astronomer passing from a statement respecting some observed fact about a planet, to the consideration of the bearing of the fact on the requirements of living creatures on the planet's surface, without expressing any doubts whatever as to the existence of such creatures. For example, Sir John Herschel, writing about the rings of Saturn, after discussing Lardner's supposed demonstration that the eclipses caused by the rings would last but for a short time, says, "This will not prevent, however, some considerable regions of Saturn from suffering very long total intervention of the solar beams, affording to our ideas but an inhospitable asylum to animated beings, ill compensated by the feeble light of the satellites; but we shall do wrong to judge of the fitness or unfitness of their condition from what we see around us, when perhaps the very combinations which convey to our minds only images of horror may be, in reality, theatres of the most striking and glorious displays of beneficent contrivance.[109]

In 1894, Simon Newcomb commented regarding Camille Flammarion that at first he "wrote so much like a French Proctor that, could a man have a legal copyright on his own personality, the Englishman might have brought suit on the ground of infringement."[110] Newcomb was certainly correct in perceiving similarities between these two prolific astronomical authors. Each had established his reputation (and to a significant extent sustained it) based on their writings about extraterrestrials. In fact, Flammarion's rise to fame was not only more dramatic than Proctor's but also earlier. In 1862, Flammarion published a 54-page booklet titled *La Pluralité des Mondes Habités,* on the title page of which he had listed himself as "*Ancien calculateur à l'observatoire imperial de Paris, professeur d'astronomie, membre de plusiers sociétés savantes, etc.*" In fact, he was a 20-year-old in his fourth year at the Paris Observatory as an apprentice astronomer. Nonetheless, his book was an immediate sensation; as Flammarion himself put it, the book "at once made my reputation."[111]

---

[108] Richard Proctor, "A New Theory of Life in Other Worlds" in Proctor's *Our Place among Infinities* 2nd ed. (Henry S. King, London, 1876), pp. 69–70. This essay is excerpted in Crowe, *Extraterrestrial Life Debate, Antiquity to 1915*, pp. 387–404.

[109] Proctor, "New Theory," pp. 44–45.

[110] Simon Newcomb, "A Very Popular Astronomer," *Nation, 59* (Dec. 20, 1894), 469–70:469.

[111] As quoted in R. A. Sherard, "Flammarion the Astronomer," *McClure's, 2* (May, 1894), 569.

As Proctor would do some years later, Flammarion immediately sent his plurality of worlds book to John Herschel, along with a very complimentary letter suggesting that he believed that Herschel shared his enthusiasm for extraterrestrials.

> Permit me to be so bold as to present to you a small work of philosophic astronomy, of which the subject is not perhaps foreign to your admirable work. I have attempted to demonstrate scientifically the plurality of existing humanities among the distant earths that soar through space; I have learned from the reading of your works that you are specifically of this ancient belief; I would be pleased, Monsieur, but I dare not hope for it – if the number and importance of your works allow you the time to read this humble dissertation of which I have the honor to pay homage to you.
>
> Would you be so kind as to pardon, Monsieur, the liberty I have thus taken to introducing myself to you in this circumstance and receive the expression of my deep esteem and of my inalterable admiration for your very productive studies of astronomy.[112]

Because Flammarion in a letter preserved at the Royal Society and dated October 13, 1863,[113] thanks Herschel for responding to the above letter, we know that Herschel did respond to Flammarion's first letter request, but the location of Herschel's letter, if it exists, is not known to this author.[114]

Flammarion's 1862 pamphlet was a great success; by 1864, he had expanded it to 570 pages, sending Herschel a copy.[115] It continued in print in France until the 1920s, going through dozens of editions, and was translated into six or more foreign languages.[116] Like Proctor, Flammarion learned from the success of his first book that the public possesses great interest in this subject and continued to deal with this topic in many later publications. Having placed himself in 1862 near the center of the extraterrestrial life debate in France, he relinquished that position only with his death in 1925.

## John Herschel and the Sun

Our final example of John Herschel's involvement with extraterrestrials comes from the 1860s. It is especially striking in that it involves life on the Sun and by implication life on all the stars. Moreover, it carried John beyond even the incredible claims

---

[112] The original of this letter is preserved at the Royal Society in the Herschel Papers as RS:HS 7.267. Translation is my own.

[113] Preserved at the Royal Society in the Herschel Papers as RS:HS 7.268.

[114] Actually, we have a fragment of the letter. In some later editions of his *Pluraité des mondes habités*, for example, the 8th edition, published in 1866 by Didier (Paris), pp. 53–54, Flammarion not only quoted a pluralist passage from Herschel's *Treatise*, but also added a quotation from the letter: "In a subject of this nature, each person ought to be impressed by the particular views that he can be led to draw from the à priori probabilities of the question and thereupon to base his views. For my part, although I do not think that the Moon may be inhabited, I strongly incline to the side that you have argued: to believe that the planets, at least some among them, are inhabited." Crowe translation.

[115] Preserved at the Royal Society in the Herschel Papers as RS:HS 7.269.

[116] For details, see Crowe, *The Extraterrestrial Life Debate 1750–1900*, pp. 378–9.

for life on the Sun made by his father. In a lecture presented by John Herschel in 1861, and subsequently twice published, he discussed solar observations made around 1860 by the respected astronomer James Nasmyth, who, having used one of the best telescopes then available, reported that he had observed the surface of the Sun to be covered with intensely luminous objects in constant motion and shaped like gigantic willow leaves.

In his lecture, John Herschel not only accepts this "most wonderful discovery," which by the mid-1860s had been discredited, but goes far beyond it to argue for the solidity of the willow leaves and to state that they are "evidently the immediate sources of the solar light and heat…."[117] Then he adds the sensational claim regarding these objects, each of which he states "can hardly be less than a thousand miles in length," that "we cannot refuse to regard them as *organisms* of some peculiar and amazing kind; and though it would be too daring to speak of such organization as partaking of the nature of life, yet we do know that vital action is competent to develop both [sic] heat, light, and electricity."[118] Herschel specifies somewhat more precisely, and certainly more vividly, what he had in mind when in an unpublished letter of July 14, 1861, to Augustus De Morgan he states: "By the bye what a very odd place the sun must be according to Mr. Nasmyth's Willow-leaved discovery. Are they huge phosphorescent fishes of white hot platina or what in the world else?"[119] The view later authors took of this idea is suggested by the fact that the American astrophysicist Samuel Pierpont Langley in his 1884 *New Astronomy* introduced his presentation of solar physics by describing Herschel's giant solar organisms and commenting that "nothing else can so forcibly illustrate the field of wonder and wild conjecture solar physics presented even a few years ago…."[120]

## Conclusion to Part II

In concluding this paper, we offer one comment that, although scarcely necessary for persons who already know of the numerous achievements of William and John Herschel, seems appropriate for those less informed. The comment is that it would be a serious misunderstanding of this paper to see it as in any way directed to undermining the reputation of either William or John Herschel. William Herschel is deservedly regarded as the most creative astronomer of modern times. Moreover, it

---

[117] John Herschel, "The Sun" in Herschel's *Familiar Lectures on Scientific Subjects* (George Routledge & Sons, New York,1871), p. 84. This volume was first published in 1868, but a footnote (p. 79) indicates that this lecture was delivered in late 1861. The lecture was, according to the Preface, published in the journal *Good Words*. See C. F. Bartholomew, "The Discovery of the Solar Granulation," *Royal Astronomical Society Quarterly Journal, 17* (1976), 263–89.

[118] John Herschel, "The Sun," p. 84.

[119] A copy of this letter is preserved in the collection of Herschel Letters at the Royal Society as RS:HS 23.334.

[120] Samuel Pierpont Langley, *The New Astronomy* (Houghton, Boston, 1889), p. 14.

seems that Professor Cannon's description of John Herschel as not only the leading scientist of the early Victorian period but also as the person who implicitly defined for his contemporaries what it meant "to be scientific"[121] is accurate. John Herschel's contemporaries did not mistake his importance when they buried him next to Newton in Westminster Abbey. The author's own conviction of the importance of John Herschel led me to devote 10 years of research to him.

What this essay does attempt to show is that both William and John Herschel, to a far greater degree than has previously been recognized, were involved with ideas of extraterrestrial intelligent life. This belief appears to have importantly influenced William Herschel's entry into astronomy and his efforts to build giant telescopes. Moreover, this paper suggests that John Herschel, so often presented as an empiricist and as an opponent of the hypothetical, was deeply involved throughout his life with ideas that can only be seen as very hypothetical.

---

[121] Walter Faye Cannon, "John Herschel and the Idea of Science," *Journal of the History of Ideas, 22* (1961), 215–39, esp. pp. 215, 238.

# Chapter 6
# The Actions of a Well-Trained Puppy Dog: Caroline Herschel's Modest and Useful Life

**Emily Winterburn**

William and Caroline Herschel made an unlikely pair. He was a showman; a musician, a performer, a maker of iconic, tourist-attracting telescopes. She in contrast was quiet and spiky. She was conscientious, diligent, and did not suffer fools – or worse, the idle and pretentious – gladly. Growing up she had nothing but disapproval for her elder brother Jacob and his love of luxury and extravagant living. As an old lady she could be harsh about those who did not meet her exacting standards. Describing her Hanoverian sister-in-law (the wife of Dietrich) to her English nephew John Herschel, Caroline wrote disapprovingly that she is "a short corpulent woman upwards of 60, dressed like a girl of 20 without cap, her brown hair mixed with gray plaited and the temples covered in huge artificial curls I almost shuddered back from her embrace."[1] But for those with a genuine need or interest she always had time and patience and encouragement.

Caroline and William began working together in astronomy in the 1780s (Fig. 6.1) at a time when women's roles in scientific work (and there were many) were almost always invisible and unacknowledged. This was a decade before Mary Wollstonecraft published her famous *A Vindication of the Rights of Women* (1792), a book in which Wollstonecraft had argued against the commonplace notion that women were naturally inferior – especially intellectually inferior – to men. Women, it was still assumed in the late 1700s, did not have the mental capacity to handle an education equivalent to that of men, much less participate in scientific research as equals. Roles that women typically occupied then – assistant, scribe, social networker – all essential to the pursuit of science, were deemed less scientific than those typically carried out by men in order to fit with this theory of inferiority. Historians have sometimes looked at this the wrong way around, trying to understand

---

[1] Caroline Herschel to John FW Herschel, April 18, 1832, British Library HERSCHEL PAPERS 1822–1866 VOL 1Eg.3761 f154–157.

E. Winterburn (✉)
Carnegie School of Education, Leeds Beckett University, Leeds, UK
e-mail: Ewinterburn1974@gmail.com

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_6

**Fig. 6.1** A late nineteenth century portrait of Caroline coming to William's aid as he worked. This image of Caroline, as William's passive, selfless helpmate has long endured. Caroline was keen to encourage it in her own lifetime, aware of the limited roles available to women and the importance of fitting a respectable stereotype in order to be heard.

why women ended up in lower status position without realizing they were lower status because it was women carrying them out.[2]

Caroline Herschel's place within the history of science has long been contested along these lines of what constitutes proper science and the hierarchy of value allocated to different roles. Although some historians have selected particular achievements to celebrate and so present her as an early pioneer, others have questioned whether or not her role was strictly speaking that of a full-fledged astronomer.[3] Research over the last 40 years on the role of women in science has highlighted a plethora of roles carried out by women over the course of history and how they were understood and presented in their own time. Often these roles, like the roles of servants, technicians, and artisans, were regarded as invisible and not "proper" science. Women moreover were complicit in hiding their contributions from the public gaze, careful to present themselves and their work as conforming to a feminine ideal and not tipping into areas traditionally seen as masculine for fear of ridicule and exclusion.

Émilie du Châtelet for example is today celebrated as a great mathematician, but in her own time she was careful to disguise her research as "just" translation and writing for children, both roles seen as acceptable for women. Marie-Anne Paulze Lavoisier, wife of the famous chemist, Antoine Lavoisier, worked with her husband, translating for him, writing up his notes, adding diagrams, editing and publishing his work after he died, and assisting in the laboratory. Without this work, Antoine Lavoisier's legacy would look very different to how it does today, yet she never demanded formal acknowledgement in his papers, and history tends to present her as less of a chemist than her husband because of it.

Recent studies on a number of learned women across Europe in the eighteenth century show not only how rare they were as public figures but also the strict rules that were applied to their behavior. The work of historians such as Bertucci, Findlen, Zinsser, Schiebinger, among others, bring fresh new perspectives to the study of women in science in the eighteenth century.[4] Through their work we see the choices

---

[2] Feminist historians such as Londa L. Schiebinger and Evelyn Fox Keller have been instrumental in transforming how historians have approached this problem. See for example Londa L. Schiebinger, *The Mind Has No Sex?: Women in the Origins of Modern Science*, (Harvard University Press, Boston, 1989) and Evelyn Fox Keller, "Gender and Science: Origin, History and Politics", *Osiris, 2nd Series, Constructing knowledge in history of Science*, **10** (1995), pp. 26–38.

[3] Was she a 'mere assistant', Michael Hoskin, *The Herschel Partnership: As Viewed by Caroline* (Science History Publications, Cambridge, 2003), p. 4. Or a 'practising astronomer in her own right', Claire Brock, *The Comet Sweeper: Caroline Herschel's Astronomical Ambition* (Icon Books, London, 2007), p. 138.

[4] Paola Bertucci, 'The In/visible Woman: Mariangela Ardinghelli and the Circulation of Knowledge between Paris and Naples in the Eighteenth Century', *ISIS*, **104**, 226–249 (2013); Paula Findlen, 'The scientist's body: the nature of a woman philosopher in Enlightenment Italy', 211–136 of (ed) Gianna Pomata & Lorraine Daston, *The Faces of Nature in Enlightenment Europe* (Berlin, 2003); Mary Terrall, 'The uses of anonymity in the age of reason', 91–112 of (ed) Mario Biagioli & Peter Galison, *Scientific authorship: credit and intellectual property in science* (London, 2003); Judith Zinsser, Mentors, the Marquise Du Chatelet and Historical Memory, *Notes and Records of the Royal Society,* **61**, 2, 89–108 (2007); Londa Schiebinger 'Maria Winkelmann at the Berlin Academy: A turning point for women in science', *ISIS*, **78**, 174–200 (1987).

made by women, the roles they took on, and the ways in which they presented themselves and their work against a backdrop of historically and geographically specific social conventions. They would write translations, albeit ones heavily footnoted with results of their own research. They would present their findings as lessons for their children. They would run salons, bringing together scientifically interested men and women and voice their opinions as polite conversation rather than as formal lectures or contributions to the debates in learned societies. They would seek out chances to learn and participate in science, too, through helping a husband or brother or father or uncle.

In terms of education, it is well documented that eighteenth-century women were reliant on the men in their lives for their access to education and participation in science.[5] However this was very often as true for eighteenth-century men as for women. Men, too, had to meet the right tutors and cultivate the right contacts; though unlike their female contemporaries they also had the opportunity to be invited to join various male-only societies. Caroline's story, as we will see, suggests that for her, access to education and participation in science was not a straightforward problem of simply being forbidden to join certain societies. Her limited access was instead the result of time constraints and of experiencing a very different education that not only limited her knowledge of academic subjects but also taught her a different way of learning.

It is important to understand the historical circumstances in which Caroline's story was played out. Women were expected to be modest, self-deprecating, and to see and present any role they might have in the scientific world as being somehow less than their male counterparts. Women, like children (and as Patricia Fara has pointed out), like newly domesticated pets such as puppy dogs, were considered weaker, more innocent, and less intellectual than men.[6] They needed protecting and guiding; whether they wholeheartedly bought into this belief or not, successful women learned how to indulge this view for their own survival.

It is with this background that we need to consider Caroline Herschel's remarkable story and the way in which she chose to tell it. This was a woman who, as we will see, grew up to regard her role as being one of servitude; she was trained to serve her family and to see her education as a means to that end. Yet, by the end of her life she was a revered astronomer, visited by academics and dignitaries on an almost daily basis. Not only that, but even long after she died, she was and still is an inspiration to many women looking to try their hand at astronomy but not always sure where in that world they fit in.

---

[5] Ruth Watts, *Women in science: a social and cultural history*, (Routledge, 2007) p. 196, Patricia Fara, *Pandora's Breeches: Women, Science and Power in the Enlightenment* (Pimlico, London, 2004); Pnina G. Abir-Am and Dorinda Outram, *Uneasy Careers and Intimate Lives: Women in Science, 1789–1979* (Rutgers University Press, New Brunswick, 1987); M. Jeanne Peterson, *Family, Love, and Work in the Lives of Victorian Gentlewomen* (Indiana University Press, Bloomington, 1989).

[6] Patricia Fara, "Portraying Caroline Herschel", *Endeavour*, **26**, 4 (2002), 123–124.

## A Hanoverian Childhood

Caroline Herschel was born in the town of Hanover in Lower Saxony (in modern day Germany) on March 16, 1750. She was the youngest surviving daughter in a family of ten. Of her surviving siblings she had one older sister, Sophia, who left home first as a governess and then to get married when Caroline was very small. Caroline had three surviving older brothers – Jacob, William and Alexander – and one younger, Dietrich born in 1755. As the youngest daughter in a lower class Germanic family, custom dictated that Caroline should, in time, become the caregiver of her parents as they aged, and before that a helpmate to her mother as she looked after her growing family.[7]

Her brothers were all taught music intensively with a view to this becoming their source of income in adulthood. Their training was designed with their future destinies in mind. Similarly, Caroline was taught to look after her family, to run a home, and to master a broad range of domestic skills since these were expected to be useful to her in adult life. This had been the tradition for generations. Yet Caroline's generation differed in one important respect to the women of her class who had come before. Caroline was sent to school to learn how to read and write. There is some uncertainty as to what besides literacy Caroline learned at the Garrison school to which she and her brothers were sent. Michael Hoskin has asserted that while the boys were taught reading, writing and arithmetic, the girls were "taught simply 'to read and write and be informed of our religious duties.'"[8] He concludes this from a discrepancy between the siblings' descriptions: William listed arithmetic in his description, Caroline did not. In a different passage, however, Caroline remembered all the siblings learning much the same. When writing to her nephew in 1827 about some complaints made by Dietrich that he had "received too scanty an education," she dismissed his claims out of hand, stating unsympathetically "he had the same schooling we all of us had."[9]

It is difficult to deduce from the very limited extant evidence on the Garrison school they attended who exactly was taught what. Very little has been written about the Hanoverian Garrison schools, besides that left by the Herschels themselves. There were Garrison schools in Russia, elementary schools set up by each regiment to teach the boys of military men that predate drives toward universal education. Garrison schools in Hanover are less well documented but were perhaps an extension of this system.

Peter Petschauer, who has written extensively on women's education in Germany in the eighteenth century, suggests that most elementary schools taught both sexes reading, writing, arithmetic, and religion, but beyond that subjects varied according

---

[7] S. C. Ogilvie, *A bitter living: women, markets, and social capital in early modern Germany* (Oxford University Press, 2003).

[8] Hoskin, *The Herschel Partnership: As viewed by Caroline* (Science History Publications, Cambridge, 2003), p. 7.

[9] Caroline Herschel to JFWH, Hanover, Sept 25, 1827, British Library HERSCHEL PAPERS 1822–1866 VOL 1 Eg.3761 f71–72

to gender and class.[10] Typically middle class (middling sort) girls were taught "accomplishments," that is decorative and performing arts that might make them appear refined and talented and desirable as marriage material. Lower class girls meanwhile would be taught more prosaic skills – how to sew and knit and other functional and domestic skills that might earn them a living outside their own family home. The Herschels' reports on their Garrison school suggest this school may have focused solely on academic lessons, but Caroline was nonetheless taught all the skills she needed to care for her family and home outside of school.

The boys were taught by their father outside of school time to help them follow him into his profession. This was common practice regardless of what that profession might be. It was much less common for girls to be taught their father's work. In professions covered by the guild system many expressly forbid the teaching of their craft to daughters; others were less formal in their disapproval but nonetheless did not condone the practice.[11] Caroline was unusual in that she did occasionally receive violin lessons from her father after his pupils had gone home. These, however, were an indulgence; most of her time at home was spent helping and learning from her mother all the many domestic skills needed to run a home and care for a large family.

Caroline's education was different from her brothers not only in its content but also in its style. While they were given time to practice, to master, to perfect their skills, Caroline was only taught what might make her useful, and was then expected to apply what she had learned as soon as possible. At 7 she had learned enough needlework to help her mother fulfill a commission for tents and linen for the army.[12] By aged 8 she was applying what little literacy she had gained at school by reading and writing letters sent by members of her father's regiment to their illiterate wives, including letters between her own parents.[13] After a brief course of lessons around 1764 she had mastered working with silk and the sewing of various decorative embellishments sufficiently that she could carry out this work at home, presumably working with her brothers' performance outfits, so the family would no longer need to send this work out.[14]

It was a hard and busy existence. Caroline describes days of getting up early, working in the house before school, returning home to help her mother, or occasionally attending lessons teaching her extra domestic skills that she would then quickly be expected to apply. In the evenings she described sewing or knitting as her mother sat by her spinning and one of her brothers played music or read or drew or fiddled with making scientific instruments.[15] In all these accounts she rarely complained.

---

[10] Peter Petschauer, *The Education of Women in Eighteenth Century Germany: New directions from the German female perspective, bending the ivy*, (Edwin Mellen Press, Lamperter, 1989); Peter Petschauer, "Improving educational opportunities for girls in eighteenth century Germany", *Eighteenth Century Life*, **3** (1976), pp. 56–62.

[11] S. C. Ogilvie, *A bitter living,* p. 130 and p. 131.

[12] Michael Hoskin (ed), *Caroline Herschel's Autobiographies* (Science History Publications, 2003), p. 107.

[13] Hoskin (ed), *Autobiographies*, p. 108.

[14] Hoskin (ed), *Autobiographies*, p. 37 & p. 114.

[15] Hoskin (ed), *Autobiographies*, p. 42, 45

Rather she simply listed all that needed doing, every day, and acknowledged the importance of her role in getting things done. Her complaints where they did emerge tended to be toward her brothers and their expensive tastes or toward any interruption in her daily routine that lost her the few moments she had to herself to read or practise the violin.

Throughout her childhood Caroline was taught to see her family as her priority. Her job, from a very young age, was to help her mother care for, and make life comfortable for, her family. Her education was an extension of this role: she was provided with lessons – and sometimes sought lessons out for herself – that would help her become more useful and indispensable to her family. When the family found themselves sharing their home with another family, Caroline sought out the young girl in the family, Mademoiselle Karsten, and arranged for them to meet early each morning so she could teach her "ornamental and fancy works."[16] On a later occasion, Caroline begged her mother to let her go to classes to teach her about millinery. Her mother agreed and managed to negotiate with the teacher for her to go at a reduced rate so the family could afford it.[17]

As she grew older Caroline began to recognize both the usefulness of her role and its precarious nature. Her help was needed. When she came down with typhus fever in 1761 her main worry was about how her family might manage without her.[18] On another occasion, as the date of her confirmation approached, she was aware that her family was missing out as her preparation for this ceremony left her with less time than usual to help them.[19] At the same time, the older she got, the more she became aware of her uncertain future. Her brothers would not remain in the family home forever, her parents were getting older, there would come a time when she had no one left to look after. She was, she describes, too proud to become a maid, and not sufficiently well educated to become a governess. Her father, she wrote, had warned her that she was neither pretty nor rich enough to marry. Her future looked bleak.

Hope however was on the horizon. Ever since William had first settled in Bath in 1766, Caroline's brothers had been traveling back and forth earning some extra money in England teaching music and playing concerts with William. Jacob had gone first in 1767, the summer after their father died. In 1768 young Dietrich went over, too, aged just 14, against his mother's better judgment but with reassurances from Jacob and William that he would be well looked after. In 1769 Jacob and Dietrich returned, and the following year it was Alexander's turn. Alexander decided to stay. Caroline and Alexander had always been close; they were the middle siblings, were only 5 years apart in age, and had shared much of their childhood together. William in contrast hardly knew Caroline. He was 12 years her senior and had left home when she was only 7, but Alexander knew her and liked her and worried about her, and not long after he arrived in England, he persuaded William to help her out. William wrote home to his mother. In his letter, he asked if Caroline

---

[16] Hoskin (ed), *Autobiographies*, p. 39.

[17] Hoskin (ed), *Autobiographies*, p. 41.

[18] Hoskin (ed), *Autobiographies*, p. 33.

[19] Hoskin (ed), *Autobiographies*, p. 35.

might come over to join them, as a trial, to help him out and train as a singer to accompany him in his concerts and oratorios. To soften the blow, he suggested the trial would be for just 2 years; if it didn't work out, he would send her home.

Caroline was delighted. Her brother Jacob was not so keen. Although she was anxious to go, and full of renewed hope for her future, she was nonetheless concerned for the family she would leave behind and aware of the gap her absence would cause. In preparation she not only practiced singing but also busied herself knitting ruffles for Jacob and "for my mother and brother D. I knitted as many cotton stockings as were to last two years at least." With stocks replenished, Caroline set off for her new life in England.

## A Musician in Bath

Caroline arrived in Bath on August 27, 1772. William had traveled to Hanover to collect her and they traveled home together. The journey took 12 long, eventful, and uncomfortable days. They traveled via Holland, via Utrecht and Leyden, crossing a very stormy sea at Helvoets Sluice in which their boat lost its mast. From the English coast (they landed in Yarmouth) they took a horse-drawn cart, only for the horse to bolt and leave the cart overturned in a ditch. When they eventually arrived in London, William dragged her round the shops so he could visit some opticians, looking for ideas on telescope making. When they finally arrived in Bath, Caroline had some tea and went straight to bed, waking sometime the following afternoon.[20] After 22 years remaining almost exclusively in her hometown of Hanover, it was an alarming start to her new life.

Once arrived and settled, Caroline set to work training for her new career in this new country. "I had 2 or 3 lessons every day," she recalled, "and the hours which were not spent at the harpsichord were employed in putting me in the way of managing the family."[21] It quickly became evident that she had been brought over not only to learn to sing, but also to act as her brother's housekeeper. Just 6 weeks after she arrived, she was given a sum for weekly expenses and sent out alone – with only the English she had mastered in that time – to shop for food. Rather desperately she wrote of bringing home "whatever in my fright I could pick up."[22] Later she discovered her brother Alexander had followed her on these early shopping trips, hiding from sight but staying close to keep a watchful eye and to keep her safe.[23] The housekeeper William had brought with him from Leeds – Mrs. Bulman and her family – remained with them until 1774. By then Caroline had learned enough to take over, and the Bulmans returned home.

---

[20] Hoskin (ed), *Autobiographies*, p. 49; p. 117–8.

[21] Hoskin (ed), *Autobiographies*, p. 50.

[22] Hoskin (ed), *Autobiographies*, p. 50.

[23] Constance Lubbock, *The Herschel Chronicle: the life-story of William Herschel and his sister Caroline Herschel* (Cambridge University Press, 1933), p. 51.

Caroline's lessons began the day after she arrived in Bath. From that day on, she would meet each day with her brother William at breakfast. He would begin the day with lessons in English and arithmetic, which suggests that her earlier schooling, if it included any mathematics, did not stretch to that needed for English bookkeeping. William taught her how to deal with English currency in bookkeeping and how to keep the household accounts. In the afternoon she would practice singing and in the evening, "by way of relaxation," they would talk about astronomy.[24]

After 6 weeks of this routine, however, the Bath "season" began taking William away from these activities and toward the more lucrative activity of teaching and playing concerts, leaving him little time to help his sister. Ever resourceful, Caroline took this as an opportunity to look around her new environment and experiment with ways of making herself more useful to her family by learning new skills and seeking out tasks. She persuaded Mrs. Bulman to teach her English cooking, how to make pies and puddings, and how to pickle and preserve. She learned to deal with staff, giving orders to their servants and assessing new employees. She continued to practise, too, improving her English and her musical skills, and soon joined the chapel choir on a Sunday.

After Easter the number of pupils and concerts started to dwindle as the season came to an end. Caroline had hoped this might mean a return to her lessons, but William had moved on. With Caroline taking over the running of the house, and the season over, William now had sufficient free time to think seriously about taking up astronomy. He began to read up on astronomy and telescope making, bringing in materials and taking lessons from a local amateur telescope maker. In the summer of 1773 she described with some regret the changes this new hobby brought to her home. "It was to my sorrow" she declared, "I saw almost every room turned into a workshop." As ever, Caroline wrote about this new development with a strong sense of irritation. "I was much hindered in my practice" she writes, "by my help being continually wanted in the executing of the various contrivances." At one point she found herself "making a Tube for a 15 feet refracting Telescope of pasteboard sometimes assisted by my brother Alexander."[25] In Hanover her music practice had been constantly disturbed by the needs of her family; in Bath, even though music was now supposed to be her new profession, her position within the family remained the same. Despite her rather bleak interpretation of events however, William had not completely neglected his duties to her. He kept an eye on her progress, helping her now and then with her practice, though not perhaps as intensively as before, and by the end of 1773 considered her sufficiently proficient to take the next step in her musical education.

To complete Caroline's education as a society performer, Caroline needed to master more than simply the technical skills of how to sing. She needed to learn how to perform, how to hold herself, how to present herself within society in a way that was very different from how she had grown up. In order to teach Caroline these new, gender-specific skills, William introduced his sister to "two ladies both great critickers on singers and musical performers," Mrs. Colbrook and Lady Elizabeth Kerr, the Marchioness

---

[24] Hoskin (ed), *Autobiographies*, p. 119.

[25] Hoskin (ed), *Autobiographies*, p. 122.

of Lothion, and arranged for the former to take her to London. Mrs. Colbrook took her to plays and operas and auctions. Lady Kerr sent her tickets to a play. Caroline returned 6 weeks later "indebted [to the two women] for all I ever saw of the Fashionable world" but in no great hurry to return. She now knew, from whispered advice and constant small correction from these ladies, how women were to behave in society. She knew enough to put her new knowledge into practice.

Her next set of performance lessons, before she was ready to step on stage, were with a much celebrated dance mistress called Miss Fleming. For a whole year she had two lessons a week from Miss Fleming, designed to "drill me for a Gentlewoman." While Mrs. Colbrook and Lady Kerr had taught Caroline etiquette and how to behave and speak, these dancing lessons taught Caroline the more physical aspect of appearing as a society lady and singer. She taught her – for 2 years – how to hold herself and how to move. She was not being trained to dance, only to act and hold herself appropriately for her new role in life.

Somewhere along the way, between telescope building and performance practice, the siblings managed to fit in a few more academic lessons. These followed on from those earlier bookkeeping and accounting sessions that had marked the beginning of Caroline's stay in Bath. In keeping with William's new interests, these new lessons had a vaguely astronomical theme. Entitled "Little Lessons for Lina," they progressed through algebra and geometry, inching toward (though never quite reaching) fluxions. Interspersed between each new rule or theorem were practical examples to practice and consolidate learning, and very often these were on an astronomical theme. In one lesson for example Caroline was asked to use some trigonometric rules newly learned to find the position of one star in relation to another. These "Lessons for Lina" helped Caroline understand William's work and so enable her to think up new ways to help. They were useful to William, too, helping him to better his understanding of his new subject by trying to teach it. The terminology the family used for these lessons gives some indication as to the traditions they were on some level trying to emulate. Michele Cohen uses the term "a little learning" taken from Winifred Peck's school day reminiscences, to highlight the gendered differences in how children were educated in the late eighteenth century.[26] Girls, she shows, were taught "a little learning," meaning a smattering of a broad range of subjects to make them conversationally versatile; boys in contrast were taught a narrow syllabus in great depth to train the mind. What is interesting about the way the Herschels employ a very similar phrase here is that it is used specifically in relation to high-level mathematics, as though they were trying to feminize what might otherwise be seen as a very masculine pursuit. This was mathematics that according to J. H. Plumb was taught only to prospective military personnel in the army or navy.[27] It was not a part of a typical schoolboy's education much less a girl's.

---

[26] Michele Cohen, '"A little learning"? The curriculum and the construction of gender difference in the long eighteenth century', *British Journal for Eighteenth-Century Studies*, **29**, 321–335 (2006).

[27] J. H. Plumb, 'The New World of Children in eighteenth-century England, *Past & Present*, **67**, 64–95 (1975), P. 96.

Toward the end of the 1774–1775 season Caroline's role of helping her brother and relieving him of time-consuming work had extended into his musical life, as she found herself "practicing with the Chapel-boys, the Chorusses of the Oratorios; and afterwards by frequent Rehersels of all the Choristers."[28] Finally, by the very end of that season, Caroline was given money to buy her first outfit for the stage, and her first performance was given. In her later accounts, she described some of the compliments she got for this debut, only to add in a footnote some rather harsh advice she had been given by a well-meaning, if tactless, lady. The lady had told her not to be her "own Trumpeter." At the time Caroline had quipped back that she had to be as she could not afford to keep one, but it was advice nonetheless that seems to have colored much of her later attitude to her own self-promotion.

For the next few years, Caroline busied herself singing for her brother's concerts, housekeeping, studying, and gradually finding more and more ways to make herself an indispensable asset to her brother's home. She helped with the choir, began to copy music out for him, and helped make molds for casting telescope mirrors. Yet despite her keenness to find useful work, she would also, now and then, let slip her annoyance at having to devote so many hours to the wants of others and so few to her own study. "In short" she declared after a long description of various problems with servants that of course fell to her to sort out, "I have been throughout annoyed and hindered in my endeavors at perfecting myself in any branch of knowledge by which I could hope to gain a creditable livelihood; on account of continual interruption in my practice by being obliged to keep order in a family on which I was myself a dependent."[29]

In light of this, and similar outbursts found throughout her autobiographies and letters, it is then surprising that when she was offered the chance to leave her family in 1778 to sing in Birmingham she turned it down. This decision has puzzled historians. Some suggest it was "devotion to William" that drove her thinking. Others have suggested she may have lacked the confidence to take such a bold step. It is impossible to know for sure. Her training to date had always encouraged her to see herself as under-qualified for work outside the family, yet at the same time indispensable to her loved ones. Although she complained about her position, it was always in terms of its effects on her education and her ability to learn enough to leave, rather than directly on preventing her from leaving. Similarly, when she worried about her choices, it was always in terms of the effects they would have on her family. When she chose to move to England, for example, she made sure she left her mother and brother well stocked with newly made clothes. It is likely, then, that she did not go to Birmingham for fear she was not good enough, and that her family would suffer without her. She may, too, have worried about what might happen next, if she were to leave her family and then have the Birmingham job come to an end. Where might she go then?

Although she presents her decision as unproblematic, it seems the Birmingham offer may have prompted some discussion within the family about her desire for

---

[28] Hoskin (ed), *Autobiographies*, p129.

[29] Hoskin (ed), *Autobiographies*, p. 53.

independence. Three years later, there is evidence that she was, with the safety net of her family behind her, beginning to explore ways of becoming more independent. It is a brief mention, but in 1781 Caroline referred to a milliner's business her brother had invested in and in which she had been given a share.[30] Back in Hanover she had learned a little about this type of business in her classes with Madame Küster.[31] This was knowledge she could now put to use in Bath, in an attempt to gain independence while retaining her role within her family. The business sadly failed. It was not, she concluded, in the right part of town; her business partners were not the most trustworthy, either. Today this brief business venture is remembered not for the glimmer of independence it offered Caroline, however, but because it kept her away from home on a very important night. She was not at home on the night of March 13, 1781, when William first spotted – discovered no less – the planet Uranus.

## An Astronomer in Slough

The year that followed William's discovery of the planet Uranus was chaotic but eventually ended in a royal appointment and a move to Slough. After his discovery, William sent a letter (announcing discovery of a "comet") to William Watson in London, the father of a friend in Bath, who passed on news to the Royal Society. Soon after Nevil Maskelyne, the Astronomer Royal, and Thomas Hornsby, professor of astronomy at Oxford, were puzzling over it. Next Maskelyne talked to astronomers abroad, and gradually both he and the scientific community became more and more convinced the new object was not a comet but a planet.

In May 1781, 2 months after his first letter on the subject, William was invited to Greenwich as an honored guest. He had officially discovered a planet, and as the first to be discovered since antiquity, it was the first to have a named discoverer, and that rightly made him a celebrated figure. In November he traveled to the Royal Society to be awarded their Copley Medal and was soon after elected a Fellow. On the advice of the Royal Society president, Sir Joseph Banks, William decided to name his new planet George or Georgium Sidus, after the king, and the king having accepted the honor, was now expected to offer something in return.

The post of superintendent of the king's observatory at Kew seemed the obvious choice, especially after the current holder Stephen Demainbray had just died, but unfortunately that post had already been promised to Demainbray's son. There then followed many behind the scenes negotiations by William's friends and admirers in London trying to concoct a plan to gain some form of royal patronage for him. While he waited, William went back to his musical work in Bath playing concerts and teaching until May 1782, when William and Caroline played what was to be their very last musical performance, a service at St. Margaret's Chapel in Bath.[32]

---

[30] Hoskin (ed), *Autobiographies*, p. 60.

[31] Hoskin (ed), *Autobiographies*, p. 42.

[32] Michael Hoskin, *Discoverers of the Universe* (Princeton University Press, 2011), p. 61.

William was then asked to bring his telescopes to London for inspection. He stayed throughout June, meeting and showing his telescopes to the great and the good across the city and eventually to the king. In July 1782, 1 year and 3 months after he first spotted his planet, William was offered a paid position as the king's astronomer. His duty was primarily to entertain. He was to live nearby and bring over his telescopes to the palace to show the royal household and guests the heavens whenever they wished. For this he was given £200 per year, around half what he had been earning as a musician in Bath.

With his new post established, William hunted around for somewhere to live, and found a house in Datchet, a village near to Windsor and the king's castle. He then left Bath, leaving his brother Alexander behind but taking Caroline with him. On arriving in the new house, Caroline declared, with typically overt passivity, "I found I was to be trained as an assistant Astronomer." Her wording was always careful. "I found I was to be" neatly removed any trace of personal ambition from her telling of the story. Having established that this state of affairs was something imposed upon her, she then went on to admit that in time she came to enjoy it. "I was to sweep for comets" she wrote, giving the activity a pleasingly domestic air:

> I began Aug 22, 1782… but it was not till the last two months of the same year before I felt the least encouragement for spending the starlight nights on a grass-plot covered by dew or hoar frost without a human being near enough to be within call.

In astronomy and observing, William had decided the direction Caroline's education should take. Just as she had been taught various domestic tasks back in Hanover to make herself more useful to her family, now she was being taught the skills necessary to assist William in his new line of work. At the same time, as she had in Hanover and then in Bath, Caroline began to look around and see what other skills she might learn to make herself more useful, more indispensable to her family. Her search took her to instrument making, or more specifically, the way in which her brothers communicated with one another on instrument making.

When William first began making telescopes in Bath, he had been able to draw on all the skills of his family. His brother Alexander was an able mechanic, and had willingly taken on the role of eyepiece maker, dabbling, too, in other types of detailed metal, lathe, and clockwork. William meanwhile preferred to consider the bigger picture. He was interested in the whole telescope, in the most prestigious components (which in a reflector telescope was the primary mirror), and what the telescope could do. These very different spheres of interest sometimes led the brothers to have communication problems. The brothers might be both working on the same instrument, but in such different ways as to make themselves almost entirely incomprehensible to the other. They may have been only dimly aware of the problem, but Caroline could see it clearly and made a point of understanding both points of view. This made her an excellent translator, and by 1785 it had become her primary role within the family's instrument-making business.

So when, for example, Alexander wrote to William with detailed information about a "bell machine" he had designed for him, he was able tell him that while "I do not wunder at your not being able to make anything of it, for after I had with a great deal of pains finished it, I could hardly understand it myself when I came to read it over." He was confident that "if you was to get Carolina to read it over and see what she can do for she is perhaps better acquainted with my round about way of describing things."[33]

As historians gradually unpick the various historically invisible roles – assistant, technician, instrument maker – that made science possible, Caroline's story offers one more to add to the list: that of technical translator.[34] The clock that was finally produced, as a result of these three siblings and their collective skills, the "bell machine" is now housed at the National Maritime Museum, a physical demonstration of the success of this collaborative process. In a similar role, Caroline played a part, transforming William's ideas about how he wanted his telescope mirrors transformed into reality by supervising the workmen when William was away.

Alongside her observing practice, her technical translation work, and her domestic tasks, Caroline also continued her academic education, though this time she was far less ambiguous about who instigated the lessons. While in Bath, she had described her mathematics lessons from William as her "Little lessons for Lina," implying they were given to her. These new lessons, which Caroline later sent to her nephew, she labeled unequivocally "chiefly answers of your father's to the inquiries I used to make when at breakfast, before we separated, each for our dayly tasks."[35] They were answers to her inquiries: she had instigated them. The lessons were a combination of mathematical rules and exercises, including their application to astronomy, but there was a new element, too. William's latest ideas, theories and categorizations were starting to creep into these new lessons. Caroline in one lesson is introduced to "The 8 classes of Nebulae" and "The 6 classes of Double Star." These were new classification systems William was in the process of developing, as was the new category "asteroids." The lessons had become discussions of current research, and while there was a teaching component to them, there was also a strong sense of testing out and discussion of new ideas.

Although these lessons, coupled with her observing books, show Caroline's increasing immersion into William's astronomical work over time, there were still limits imposed on her as to how far she might take her education. She never learned fluxions. She complained once that her education was flawed, "having been obliged to learn too much without any one thing thoroughly – for my dear Brother Wm H was my only teacher and we begun generally with what we should have ended."[36] Learning to observe made Caroline a better assistant to William, and learning instrument-making made Caroline better able to translate and so helped William

---

[33] Alexander Herschel to William Herschel, 1785, National Maritime Museum: MS/79/118.

[34] See for example Steven Shapin, "The invisible technician", *American Scientist*, 77 (6), (1989) pp. 554–563; Special issue of *Notes & Records of the Royal Society* on "Technicians", ed. Rob Iliffe (2008), vol **62**, issue 1.

[35] Set of papers titled 'chiefly answers of your fathers to the inquiries I used to make when at breakfast, before we separated, each for our dayly tasks, &c. &c.', British Library: microfilm M/588(5).

[36] Caroline Herschel to John's wife, Hannover, May 14, 1831, British Library HERSCHEL PAPERS 1822–1866 VOL 1 Eg.3761 f136–137.

make better telescopes. Further, learning some mathematics and astronomy helped William talk through his ideas, but there were no obvious benefits to William from Caroline learning fluxions. How much she minded is debatable, but she certainly thought it worthy of comment in a brief exchange with the French mathematician and astronomer Madame du Piery. Passing her words via William to their friend Joseph-Jérôme Lalande to Madame Piery, Caroline had William write:

> On behalf of my sister to give my best wishes to Mad. Du Piery and to tell her that she would feel only too happy to be already able to do fluxional calculations, as she hears her fortunate rival can do at present: but following so glorious an example she will constantly beg her brother to teach her that sublime science.[37]

A common theme running through all of Caroline's education in Hanover, in Bath, and then in Slough, was that her education was primarily a means of gaining for her the skills she needed to serve her family. Her education was designed with the needs of her family in mind rather than her own interests or ambition. Her brothers had been taught to look outward, to master skills and learn to excel, first in music, then in instrument-making and astronomy. Caroline, like most women in the eighteenth century, was educated differently. Her education was about breadth more than depth, about learning many things, and making use of that knowledge and those skills within her immediate environment. The world she was trained for was much smaller than her brothers'. In the eighteenth century, developing narrow technical expertise was not seen universally as a desirable goal of education. Anything too technical smacked of professional use, and therefore the need to work, which was frowned upon by the upper classes. However, depth of learning, gained through a thorough training in a narrow curriculum, was considered the best way to help boys' brains to develop and teach them to think critically, strategically, and analytically. In the upper classes this took the form of teaching classics and grammar by "the method."[38] Further down the social hierarchy, that narrow teaching took the form of professional training or apprenticeship. Girls meanwhile were taught a multitude of academic and decorative subjects in the upper classes, and lower down a broad range of domestic skills. Caroline's education in its breadth and limited depth was typically female.

## The 'First Lady's Comet'

In 1786, after just 4 years of snatched practice, of observing in her moments free from helping her brother, Caroline discovered her first comet. She discovered this comet while William was away. All her discoveries, as Claire Brock has pointed out, occurred when William was away, or otherwise engaged, giving her greater freedom

---

[37] RAS archives; reproduced in Constance Lubbock, *The Herschel Chronicle: the life-story of William Herschel and his sister Caroline Herschel* (Cambridge University Press, 1933), p. 252.

[38] Michele Cohen, '"A little learning"? The curriculum and the construction of gender difference in the long eighteenth century', *British Journal for Eighteenth-Century studies*, **29**, 321–335 (2006).

and time to observe.[39] Years of helping William had taught her what she must do next; having decided what she had seen was genuinely new Caroline realized an announcement must be made. Her training as a female society musician meanwhile had taught her to carefully present her findings in feminine, self-effacing yet confident terms:

> In consequence of the friendship I know to exist between you and my Brother I venture to trouble you in his absence with the following imperfect account of a comet.[40]

This is how she began her letter to Charles Blagden, secretary of the Royal Society, which was to become her first paper published in the *Philosophical Transactions of the Royal Society*: An Account of a Comet. This would be the first paper by a woman to be published in this, the longest running scientific journal in the world. Her wording was careful – "I venture to trouble you"; later in the same paper she asks if he "will do me the favor of communicating these observations to my brother's astronomical friends." This careful wording shows her astute recognition of the role it was acceptable for her to play. She was polite, deferential, and made several references to social rather than scientific relationships. She was asking her brother's friend, and asking that news be passed to other of his friends. On the one hand, her linguistic focus on family, friendships and favors allowed her as a woman to speak up and be heard. These were perfectly acceptable concerns for a woman, and demonstrated that she knew her place. At the same time, she very neatly and succinctly – the paper contains only two pages of text – gave all the necessary scientific detail to make hers a valid priority claim for the discovery of a comet.[41]

Although many comets had been discovered before, this was the first with a named lady discoverer, a fact that understandably made both it and Caroline (Fig. 6.2) a source of some public interest. The novelist Fanny Burney described it as "the first lady's comet" and was keen to see it, though when she did remarked that it "was very small, and had nothing grand or striking in its appearance."[42] The women within the royal household were keen to see it, too (this was where Burney made her observations), and further afield it also attracted attention. So much so that a caricature of "The Female Philosopher: Smelling out the Comet" appeared after a few more of her comet discoveries had reached public ears (see Fig. 2.1).

After this first comet (now named Comet C/1786 P1, Herschel) Caroline discovered another 2 years later. This time William was newly married and preoccupied with domestic concerns, leaving Caroline greater freedom to observe alone. This comet,

---

[39] Claire Brock, *The Comet Sweeper: Caroline Herschel's Astronomical Ambition* (Icon Books, London, 2007).

[40] An Account of a New Comet. In a Letter from Miss Caroline Herschel to Charles Blagden, M. D. Sec. R. S. *Phil. Trans. R. Soc. Lond.* **77**, 1–3.

[41] Emily Winterburn, "Learned modesty and the first lady's comet: a commentary on Caroline Herschel (1787) 'An Account of a New Comet'", *Philosophical Transactions A*, **373**, 350th Anniversary Edition.

[42] Quoted in Constance Lubbock, *The Herschel Chronicle* (1933), p. 169.

**Fig. 6.2** Caroline Herschel, age 92. Courtesy Wellcome Library, London

although she discovered it alone, with her priority unchallenged, is known to modern astronomers as Comet 35P Herschel-Rigollet, after Roger Rigollet rediscovered it in 1939. Calculations on the comet's orbit were made following Rigollet's rediscovery, and it was found to be the same comet discovered by Caroline nearly 150 years earlier.

In 1790 Caroline discovered two more comets: Comet C/1790 A1 (Herschel) in January, and then Comet C/1790 H1 (Herschel) in April. It was at this point that she really captured the imagination of the scientific community, inspiring members of it to call her "sister astronomer," "most noble and worthy priestess of the new heavens," and “the celebrated Miss Caroline.” It was at this point, too, that the press began to notice her a little more as the cartoon in Fig. 2.1 signifies.

In December 1791 Caroline found her fifth comet, using a new, larger telescope her brother had made for her. At this point, one of her supporters – the French mathematician Joseph-Jérôme Lalande – nominated her for a scientific prize. The nomination failed, and the prize went to her brother instead, but it was a step. It is interesting to look at who chose to openly support Caroline and speak up for her within the scientific community. As a woman, most doors to societies, to publications, to prizes were if not formally then certainly informally closed to her. To gain entry and be considered within this world Caroline needed supporters. She had her brother, but she was helped too by other men, who, by and large, supported not just her but other women. Lalande as one such individual; Maskelyne was another.

After her first five very successful discoveries, Caroline had a couple of near misses. In October 1793 (at a time when her daytimes were frequently taken up with the care and entertainment of her toddler nephew, John Herschel), she discovered her sixth comet, only to find it had already been found by Charles Messier. In November 1795 she discovered her seventh, which she later found out had been seen almost a decade earlier by Pierre Méchain. Neither Caroline nor Méchain feature in the name we know this comet by today. Instead it is named after the German astronomer Johann F. Encke, who calculated its orbit in 1818, finding it has a very short period of 3.3 years.

In August 1797 Caroline discovered her last comet. William was away, and with two near misses preying on her mind, she decided to leave nothing to chance. After 1 h sleep, she saddled her horse and rode from one side of London to the other, a journey from Slough to Greenwich of around 30 miles. Her intention was to deliver the news to Maskelyne in person and then ride on to the Royal Society and tell the society’s president Sir Joseph Banks. Maskelyne however persuaded her that her announcement to him was enough, and a letter to Banks would be more than sufficient. As she told Banks, she had before this point rarely ridden more than 2 miles at a time, an admission that gives some sense of her drive for recognition despite her carefully chosen, self-deprecating words.

Despite her best efforts, Caroline had not managed to secure absolute priority for this, her last comet discovery, but her actions did at least mean her name was included. At the same time that she spotted the comet in Slough, it was seen by two other astronomers, Eugene Bouvard and Stephen Lee. In the end, the comet became known as Comet C/1797 P1 (Bouvard-Herschel). Not long after this discovery, Caroline moved out of her brother’s home, to live, for the first time in her life, independently. Although it was an important move for this 47-year-old woman, it did mean she was further away from her telescopes, and less able to observe when she had a few minutes to spare. It may be too that she had started to run out of enthusiasm for comet hunting. While her first five comets had been huge triumphs, her successes with the later ones were more strained. It maybe that she felt it was time to move on.

## Vanity and Ambition

Comet hunting was arguably Caroline's most high profile, fully independent work in astronomy. However, it was never her main occupation; she was always busy, often with astronomy, but only very occasionally sweeping for comets. More often her time was spent sitting alongside one of William's telescopes, noting down his observations, and recording their times using clocks made by their brother, Alexander. She would copy out papers in her neat handwriting and work on the problems set for her by her brother in their occasional lessons. When even this wasn't enough to fill her day, she designed other projects. "I had always in hand some kind of work with which I could proceed without troubling him [William] with questions," she wrote, "such as the Temporary Index which I begun in June 1787, and some years after, the Index to Flamsteed's Observations."[43]

Some historians have argued that this index or catalog was Caroline's greatest gift to astronomy. "Does it make sense" Patricia Fara asks, "to celebrate her eight comets rather than the many years she devoted to systematic research? Methodical work lies at the core of scientific progress, yet we still celebrate the unusual, the breakthrough, the single spectacular event."[44] Caroline's catalog was a reworking of John Flamsteed's original 1725 catalog of all the stars (visible with the telescopes at the Royal Observatory, Greenwich) in the northern hemisphere. In her version, she reordered the original to make it more usable for her brother's way of observing and added over 500 additional stars. When Maskelyne suggested it might be useful to others and that she should have it published, she replied:

> I thought the pains it had cost me were and would be sufficiently rewarded in the use it had already been, and might be of in future, to my brothers. But your having thought it worthy of the press has flattered my vanity not a little.

She then added a comment that demonstrated both her trust in her friend Maskelyne and her calculated awareness of social convention and the rules of female behavior within which she needed to operate in order to succeed:

> You see Sir, I do own myself to be vain because I would not wish to be singular, and was there ever a woman without vanity? – Or a man either? Only with this difference, that among gentlemen the commodity is generally stiled ambition.[45]

Men, she recognized, were allowed, indeed applauded, for proudly presenting their work to the public; the same desire in a woman was considered a character flaw that must be shamefully hidden. Caroline hid her ambition for her work to be recognized by always referring to herself in excessively modest terms, always

---

[43] Constance Lubbock, *The Herschel Chronicle: the life-story of William Herschel and his sister Caroline Herschel* (Cambridge University Press, 1933), p. 171 quoting *Autobiographies*.

[44] Patricia Fara, *Pandora's Breeches: Women, Science and Power in the Enlightenment* (Pimlico, London, 2004), pp. 151–152.

[45] Constance Lubbock, *The Herschel Chronicle: the life-story of William Herschel and his sister Caroline Herschel* (Cambridge University Press, 1933), p. 257. Ref letter from Sept 1798.

downplaying her contribution, always drawing any attention away from her desire for that contribution to be noticed. Her comet announcements asked simply that her discoveries be better known "for the sake of astronomy." To those asking about her life, she claimed only to have done "what a well-trained puppy dog would have done." Elsewhere she described herself "as useful a member of the workshop as a boy might be to his master in the first year of his apprenticeship."[46]

Her brother sometimes helped her with this negative image. There are places in his introduction to her catalog that can seem to modern ears unnecessarily arrogant and undermining. His opening line referred not to her work but to his; he implied the catalog was all his idea, and ended by assuring the reader that while his sister might seem to lack sufficient "habits of an astronomer" he had checked her work and was happy with its accuracy.[47] Seen within the context of eighteenth century rules on female modesty, however, these words could be read as helping to shield Caroline from accusations of vanity. William was in effect raising the status of the book by assigning her the role of his helper; he was vouching for her, allowing readers to approach the work as though it were written by a man.

Caroline continued to work with William for the rest of his life, though after 1797 when she left the family home, she discovered no more comets. Her decision to leave was probably down to a number of factors, but a major one was that her beloved nephew John was in that year sent away to begin his boarding school career. After William died in 1822 Caroline moved back to Hanover to be with her youngest brother Dietrich and his family. Although her name had been put forward for awards earlier on in her career, it was not until she was well into her old age that societies began to officially celebrate, as opposed to simply publish, her and her work. She was awarded the Gold Medal for Science from the king of Prussia (via Alexander von Humboldt) when she was 96 years old. A little earlier she was also awarded the Gold Medal of the Royal Astronomical Society (in 1828) and made an honorary fellow of both the Royal Astronomical and the Royal Irish Societies in 1835 and 1838, respectively. Most of these honors were general, for a lifetime of important work, but the Royal Astronomical Society Gold Medal was awarded specifically for work she carried out completing William's final works after he died.

## A Well-Trained Puppy Dog

Caroline Herschel was unusual in her generation for gaining public recognition for her work in astronomy. Countless wives, daughters, sisters, and servants participated in science in some capacity, but to carve out a role that was considered both properly scientific and sufficiently ladylike as not to attract ridicule took a very particular set of skills and circumstances. A small number of seventeenth and early eighteenth century scientific women had helped to map out the boundaries of acceptable public displays

---

[46] Hoskin (ed), *Autobiographies*, p. 55.

[47] Caroline Herschel, *Catalogue of Stars: taken from Mr. Flamsteed's Observations* (1798), pp. 1–5.

of scientific interest and competence. Margaret Flamsteed, Maria Winkelmann, and Elizabeth Hevelius had all encountered problems trying to continue their husband's work after they had been widowed, but each had eventually managed to publish that work. Margaret Cavendish had been ridiculed for trying to participate in public debate at the Royal Society, with attacks on her mainly directed at her lack of femininity, focusing as they did on her appearance or on her assumed ignorance. Caroline suffered none of these problems. Instead she found ways of winning over supporters, mixing her lessons in female deportment and etiquette with those in observing and scientific writing. She was careful in her self-presentation but also, as we saw in her comments to Maskelyne on vanity and ambition, acutely aware of what she was doing.

It is with that self-awareness in mind that we now return to that earlier quote of Caroline's description of herself as like "a well-trained puppy dog." Eighteenth-century attitudes to animals had changed significantly over the century. The wild and dangerous wolves of fairytales were becoming less common in real life, as people moved away from the woods and countryside and into the towns. Domestic animals – as pets, not as hunting dogs or rat catchers – were becoming more popular and more indulged. Pet portraiture was extremely popular. A well-trained puppy dog then had a rather particular meaning in Caroline's world. Puppies, like accomplished wives, were loved, but essentially valued for their role as status symbol. By aligning herself with this decorative, passive, adoring beast, she was making herself entirely unthreatening and dutifully feminine. She was taming the image of the female savant, presenting herself as a harmless helpmate rather than a potentially dangerous and ambitious interloper.

The image Caroline created for herself has proved remarkably enduring. In her lifetime her work and her presentation of that work earned her publications, praise, a pension (she was given her own annual income for life as part of William's royal grant for the building of his 40-ft telescope) and many awards and honorary memberships of societies across Europe. Her story was retold first by her nephew's daughter-in-law in 1876, and then by her nephew's youngest daughter, Constance Lubbock in 1933. Michael Hoskin has written many books and articles featuring Caroline Herschel. Most recently he published a full length biography of her in 2013.[48]

In the twentieth and now twenty-first century Caroline has proved a favorite with compliers of lists and biographies of women in science. Each new telling reveals something different. In this chapter, putting Caroline's story within the context of other eighteenth-century women and their experience of education, science, and public recognition, Caroline's quiet determination emerges. Caroline became a celebrated woman of science in part because of the comets she discovered and the help offered to her brother through assistance in his observing and through her writing. Just as important however was her ability to use skills learned through domestic work and music to seek out projects and present herself and her work carefully in a manner that both conformed to and transformed public opinion on what might constitute female work.

---

[48] Michael Hoskin, *Caroline Herschel: Priestess of the New Heavens* (Science History Publications, Sagamore Beach, Massachusetts, 2013).

# Chapter 7
# Accolades and Barbs: William Herschel in Poetry and Satire

**Clifford J. Cunningham**

## Introduction

The relationship between poetry and science is an appropriate matter to elucidate at the outset, as poetry does not often appear amongst the usual topics considered in scholarly works on the history of astronomy. In the context of William Herschel (Fig. 7.1) studies, the topic has been almost entirely ignored. Here I will look briefly at the works of two of England's most eminent writers. The philosopher Thomas Hobbes (1588–1679) considered curiosity "a delightful appetite of knowledge, and a basic impulse towards learning." As Reik explains in his study of Hobbes, "It is the intellectual passion which makes us educable, which is ultimately responsible for our development of language and science, and it is the fulfillment of this 'lust of mind' [in the words of Hobbes] that poetry promises."[1] In his tract *Answer to the Preface of Gondibert* of 1650, Hobbes specifically address the works of great men. While his focus was on heroic poems, it can certainly be read here as applying to Herschel and the many worthy aspects of his career.

> As the description of great men and great acts is the constant design of a poet; so the descriptions of worthy circumstances are necessary accessions to a poem, and being well performed, are the jewels and most precious ornaments of poesy.[2]

At the turn of the nineteenth century the link between poetry and science was expounded in a famous passage by the Poet Laureate, William Wordsworth:

> If the labours of men of science should ever create any material revolution, direct or indirect, in our condition, and in the impressions which we habitually receive, the poet will sleep then no more than at present; he will be ready to follow the steps of the man of

---

C.J. Cunningham (✉)
University of Southern Queensland, Toowoomba, QLD 4350, Australia

National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
e-mail: Cliff.Cunningham@usq.edu.au

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3_7

**Fig. 7.1** William Herschel, a pastel portrait by John Russell, c1795. Herschel holds a map showing "The Georgian planets and its Satellites." (Courtesy of the Herschel Museum, Bath)

> science, not only in those general indirect effects, but he will be at his side, carrying sensation into the midst of the objects of science itself.[3]

Here we see Wordsworth (1770–1850) emphasize the third sense of poetry identified by Horace (Ars Poetica 333): to delight, move, and instruct.[4] The sometimes awkward poems (some mere trifles) considered in this chapter about Herschel and his studies of the heavens also rely on this third sense for their inspiration, but it remains the purview of the finer poets quoted here to both move and delight the reader.

It must also be admitted at the outset that few of these poems do well under the critical eye and vastly different taste of the twenty-first century. In this regard, it is wise to be aware of what was written about the changing taste in poetry from two nineteenth century writers. The state of poetry from the turn of the nineteenth century was regarded with disdain by mid-century. "Poetry fifty years since was in a languishing condition," writes an anonymous author in the 1852 issue of *The Quarterly Review*.[5] In a passage that engages directly with the subject under discussion here, we find this from another anonymous reviewer in *The North British Review.*

> It is with our poetry as with our friends and wine, the longer we live, the more inclined are we to murmur over the new–'the old is better.' We don't say absolutely better, but better to us–the old agrees better with us. One result of this taste of ours is an unwillingness, not quite reasonable, to read new poems, or to acknowledge the rise of new poets, or, indeed, new any things,–even planets; we stuck to our old ones, beginning with Mercury, and ending with Georgium Sidus. Doubtless, poetry is perpetual, as are flowers and stars.[6]

This passage concludes on a botanical note, which we will encounter several times in this chapter. There was a day, some 60 years before the *North British Review* article was written, when the Georgium Sidus was not amongst the 'old ones' but a new entry into the truly old ones known since ancient times. It is this era of the late eighteenth and early nineteenth centuries where we find most of the poetry collected in this chapter.

## The Herscheliad

While Wordsworth deliberately failed to engage with "the telescopic probing of the heavens," he did try to effect a happy marriage between science and poetry.[7] John Keats (1795–1821) adopts a more overtly hostile stance about the effect of natural philosophy on poetry. "For Keats, 'cold philosophy' (science) is the enemy of poetic wonder."[8] Keats wrote in "Lamia"

> Do not all charms fly,
> At the mere touch of cold philosophy?
> Philosophy will clip an Angel's wings,
> Conquer all mysteries by rule and line,
> Empty the haunted air, and gnomed mine.[9]

Thus the zeitgeist in England at this time was defined by these competing approaches to the intersection between science and poetry, and it is here we find Herschel. However, we do not find him here merely as the subject of poetic inspiration, but as an active participant in one of the grandest epics of poetry ever conceived. Herschel was personally involved in the inclusion of astronomical discoveries in verse! He collaborated with his close friend the musicologist Dr. Charles Burney Sr. (1726–1814) in the creation of a lengthy astronomical poem "The Herscheliad," which Burney (Fig. 7.2) later abandoned and largely destroyed. As I discovered in 2013, it was Burney's son, the Greek scholar Charles Jr., who coined the word 'asteroid' for Herschel in 1802 to distinguish Ceres and Pallas from the major planets.

As William Hepworth Dixon relates, King George III (1738–1820) himself evinced some considerable interest in Dr. Burney's poetic work with Herschel. This account of an evening with Herschel at Windsor Castle in July 1799 was related by Burney to his daughter Fanny (Madame d'Arblay):

> "At length he [The King] came directly up to *me* and Herschel, and the first question he asked me was, 'How does astronomy go on?' I, pretending to suppose he knew nothing of my poem, said 'Dr. Herschel will better inform your majesty than I can.' George replies, 'Ay, ay, but you are going to tell us something with your *pen*;' and moved his hand in a writing manner. 'What progress have you made?' 'Sir, it is all finished, and all but the last of twelve books have been read to my friend, Dr. Herschel.' The King, then looking at Herschel, as who would say "How is it?" "It is a very capital work, Sir, says H… 'How long have you been at it?' 'Two or three years, at odd and stolen moments, Sir'.[10]

**Fig. 7.2** Charles Burney Sr. (Portrait by Sir Joshua Reynolds, 1781)

Herschel's Scottish biographer James Sime (1843–1895; 1900: 216) mourns the fate of Burney's effort, and the lack any suitable prose to commemorate Herschel:

> A man who filled the world with his renown as Herschel did, and who charmed all who happened to meet him as we know he charmed Miss Burney, [the poet] Thomas Campbell, and [August Hermann] Niemeyer [Chancellor of the University of Halle], could not have been expected to leave this life without worthy commemoration from a poet's pen. Dr. Burney's Herscheliad was never published; Campbell preserved silence except in poetic prose, written while the astronomer was still living; and no one seems to have addressed himself to what was almost a duty of the age, except a writer, who hailed from Teveral Rectory, and was unable to force Uranus with its proper quantity into a line of poetry:
>
> Herschel, alas, great astronomic sage,
> Has sunk in death, yet full of honoured age,
> Through widest space the heavenly orbs he viewed,
> The comet's track, and stars unnumbered shewed;
> Ouranus first he saw, with all its train,
> And fires volcanic found in Luna's plain.[11]

"The Herscheliad," laments Sime, "could scarcely have contained poorer or more unworthy lines."[12] The poet, whom Sime does not deign to name, was William Rawlins. He dated his poetic tribute Dec. 31, 1822, but it really had little to do with Herschel. The portion Sime quoted was embedded in a poem dedicated "To Sylvanus Urban, on completing the second part of Volume XCII" of the *Gentleman's Magazine*, one of several poems to mention Herschel's supposed discovery of lunar volcanoes. The important point, however, is that Sime was apparently unaware of any other poetic tribute to Herschel. This chapter identifies nearly 50 eighteenth and nineteenth poems relating to Herschel; some can be classified as tributes, while others are satirical attacks. Examined first are a few examples of poetry that were inspired by Herschel's discoveries, while the others are offered according to topic:

**Fig. 7.3** Percy Bysshe Shelley by Alfred Clint (National Portrait Gallery (NPG1271), London)

the discovery of Uranus, Herschel's telescopes, stellar research, his theory of lunar volcanoes, his musical career, how he was regarded by posterity, and finally a host of satiric barbs sent his way. Even though he pioneered the scientific study of asteroids, this aspect of his research does not get mentioned in any poem.

## Poetic Inspirations: Shelley, Tennyson, Keats, and Byron

### *Percy Bysshe Shelley*

On the subject of epic creations of the early nineteenth century, certain astronomical imagery in the grand verse-drama of 1820, *Prometheus Unbound* by Percy Bysshe Shelley (1792–1822; Fig. 7.3), was inspired by Herschel's cosmological discoveries. No surprise here, as I believe some of Herschel's own scientific papers contain descriptions that could just as easily have been written by a poet. Consider his description of nebula from the second catalogue in 1789. "This method of viewing the heavens seems to throw them into a new kind of light. They are now seen to resemble a luxuriant garden, which contains the greatest variety of productions, in different flourishing beds" .[13] Such astrobotany finds similar expression in the 1791 "Botanic Garden" of Erasmus Darwin, and the 1892 work of Benjamin Ball, considered further below.

In a masterful study of Shelley's use of scientific imagery in *Prometheus Unbound*, Carlo Grabo (Professor of English at the University of Chicago), identifies several links with Herschel. One possible connection relates to the line "...and how the sun changes his lair." Grabo says "If the sun's actual movement is meant, Shelley alludes to the discovery made by Herschel that our solar system is moving towards the constellation Hercules."[14] Grabo also divines inspiration from Herschel's belief in lunar volcanoes. "Therein lies, in part, Shelley's justification for his picture of Prometheus of the reanimation of the moon, when in the Promethean age, its frozen veins are thawed."[15]

In papers presented to the Royal Society in 1811 and 1814, Herschel discussed nebula, star clusters, and cosmic evolution where stars and planets would form from nebula and eventually group into star clusters. "Shelley's astronomy is in harmony with Herschel's findings prior to June 11, 1818, upon which date Herschel read a paper seriously altering his conception of the universe"[16]. He identifies the lyrics of the fourth act of *Prometheus Unbound* as defined by these pre-1818 views of Herschel, which, says Grabo, supposed the universe to be finite in extent and age. This, however, may be a mis-reading according to Michael Hoskin, who quotes Herschel as writing in the 1811 paper that in the development of nebulae "we have an eternity of past duration to resort to."[17] Hoskin says "whether we are to take 'eternity' literally is uncertain."[18] With this element of interpretation in mind, Shelley's lines read:

> Our spoil is won
> Our task is done,
> We are free to dive, or soar, or run;
> Beyond and around,
> Or within the bound
> Which clips the world with darkness round.
>
> We'll pass the eyes
> Of the starry skies
> Into the hoar deep to colonize;
> Death, Chaos and Night,
> From the sound of our flight,
> Shall flee, like mist from a tempest's might.
>
> And Earth, Air and Light
> And the Spirit of Might,
> Which drives round the stars in their fiery flight;
> And Love, Thought and Breath,
> The powers, that quell Death,
> Wherever we soar shall assemble beneath.
>
> And our singing shall build
> In the void's loose field
> A world for the Spirit of Wisdom to wield;
> We will take our plan
> From the new world of man,
> And our work shall be called the Promethean.[19]

Grabo sees an allusion to Herschel's belief in a finite universe in the expression "the bound which clips the world with darkness round," where 'world' signifies the universe. The phrases "hoar deep" and "void's loose field," Grabo says, "must refer to the nebulous stuff fringing the stellar universe. From this nebulous matter, verifying the nebular hypothesis, Herschel traced numerous groups of stars and solar systems

**Fig. 7.4** Alfred Lord Tennyson

in various degrees of evolution."[20] A few years after Shelley penned these words, Alfred Lord Tennyson likewise evoked the imagery of nebula and star clusters.

## *Alfred Lord Tennyson*

While a child, Hallam Tennyson said to his brother, who suffered from shyness: "Fred, think of Herschel's great star-patches, and you will soon get over that."[21] The young Hallam may very well have got his inspirational talk about Herschel through his father, the Poet Laureate, Alfred Lord Tennyson (1809–1892; Fig. 7.4). Roger Ebbatson has traced the influence of Herschel's nebular studies in the works of Tennyson, who used astronomical imagery as early as his 1829 poem "Timbuctoo." It ultimately derives from Herschel where he published his first catalogue of nebula and star clusters.[22] "William Herschel's theory," Ebbatson writes, "began with diffuse clouds of nebulosity which would eventually condense into star clusters...The original 1832 version of 'The Palace of Art' had echoed these astronomical speculations: in the Ur-text [of Tennyson's poem] the female 'soul' scans the heavens with 'optics glasses' to observe

> Regions of lucid matter taking forms,
> Brushes of fire, hazy gleams,

**Fig. 7.5** John Keats by William Hilton, c1822 (National Portrait Gallery (NPG194), London)

Clusters and beds of worlds, and bee-like swarms
    Of suns, and starry streams."[23]

We see here an allusion to a garden, with bees swarming over beds of celestial life taking form.

## *John Keats*

Nor greater pleasure could Columbus feel
When first beyond the transatlantic deep
His wandering eye beheld another world,
Than I, when in my wanderings I have found
Some sweet sequestered spot unknown before.

As Khan[24] has suggested, Keats (Fig. 7.5) may have read these lines from the 1811 poem "Naiad's Complaint" by Isabella Lickbarrow (1784–1847), written five years before he penned the Petrarchan sonnet "On First Looking Into Chapman's Homer," which contains these famous lines

Then I felt like some watcher of the skies
    When a new planet swims into his ken;
Or like stout Cortez when with eagle eyes
He star'd at the Pacific.[25]

Keats compares his joy on reading the works of Homer translated by George Chapman to that of an astronomer at the discovery of a new planet. It has been noted by the scholars Tom Fulford, Marolyn Gaull and Bruce Graver that Keats had in mind here Herschel's discovery of the planet Uranus. Like many other poems considered in this chapter, Keats and Lickbarrow enlist the names of famous explorers on Earth to draw parallels with the discovery of new worlds. Day, who gives the full text of the sonnet, draws our attention to the first four words of the title: "The poem's governing metaphor is one of exploration."[26] In the case of Keats the new world is more explicitly in the heavens. Even so, he did not mention Herschel by name. Brothers says "the astronomer remains unnamed because any astronomer prior to Herschel could have seen it, but did not. The other astronomers who looked at that object in the night sky, maybe even noticed its movement, were unwilling, or unable, to destroy the comfortable model of the solar system they knew."[27] All the more reason in my opinion for using his name, but like much poetic analysis it embodies speculation.

The discovery of Uranus was described in John Bonnycastle's *Introduction to Astronomy* (1807 edition) that Keats won as a school prize in 1811[28]. It has long been stated that the two were linked – Keats got his inspiration from reading the Bonnycastle book.

However, this-long held assumption has been seriously compromised by the research of Nicholas Roe, who claims that both gazing through his school telescope and a "living orrery may have contributed more to Keats' creative life than his celebrated prize copy" of Bonnycastle's book, which he says contains little but "dessicated prose." So what was this 'living orrery'? It was the creation of Herschel's friend John Collett Ryland (1723–1792), who taught lessons in astronomy at Enfield, the school Keats attended. Ryland gave all the instructions for others to recreate it, in a book of 1768.

> He demonstrated the movements of planets and moons in the solar system by encouraging pupils to create a 'living orrery' (as the termed it) in the school playground. Individual pupils were given a card identifying one of the planets or a moon, and listing some information to be learned. With their cards, the pupil-planets and moons took up their stations in an appropriate circle of orbit around the classmate representing 'the great Sun.' The living orrery was then set in motion.[29]

Jon Klancher has further explored the lines of Keats by adopting the paradigm proposed by Simon Schaffer.[30] A key application of his paradigm – that discovery is a retrospective label – results in a denial that Uranus was discovered by Herschel on 13 March 1781. While that may be true within Schaffer's paradigm, every text dealing with Uranus says it *was* discovered by Herschel on that date. Klancher's assertion that the discovery of Uranus was not regarded as authentic for fifteen years (from 1781 to 1796) is not supported by any contemporary text I have read, nor does he refer to any such text. It is true there were questions about the extreme magnifications Herschel used, but this 'range of vision' issue cannot be conflated with the certainty of his 1781 discovery. Thus the "protracted process of discovering Uranus" that he pins this analysis on is not reflected in the historical record.

> This is the center of a poem that compares discoverers in their great domains—poetic, scientific and geopolitical—and likewise their instruments: editions, telescopes, expeditionary forces…The Herschel analogy has escaped scrutiny because it so effectively overdetermines the trope of "discovery." And it does so by marvelously economic poetical means. The Anglo-Saxon word "ken" in the sonnet's tenth line usually means "range of vision," but

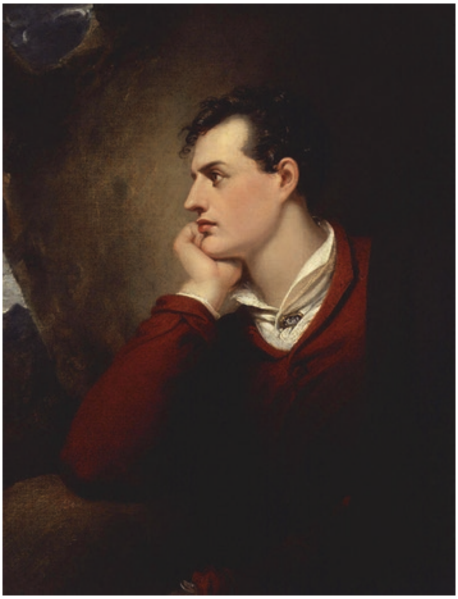


**Fig. 7.6** George Gordon, Lord Byron by Richard Westall, 1812 (National Portrait Gallery (NPG4243), London)

> it can also mean "range of knowledge." The word silently encloses the fifteen years after 1781 during which Herschel's telescopic "range of vision" was disputed by rival researchers and denied the status of authentic discovery. Not until the late 1790s was Herschel's claim finally certified as belonging to the "range of knowledge," or effectively authorized as a "discovery" rather than an extravagant claim. By 1816 its discovery status had become so assured that Keats could generalize all the specificities of the case in a single phrase "some watcher of the skies." For literary purposes, to use the language of the sociology of science, Keats had effectively "black-boxed" the protracted process of "discovering" Uranus in order to secure more visibly complicated discoveries – one literary (of Homer), the other colonial (South America).[31]

The word ken was used in the sense 'range of vision' in poems by Edward Church and William Hayley, given later in this chapter.

## *Lord Byron*

The most direct link between Herschel and a poet can be found in the person of none other than George Gordon, Lord Byron (1788–1824; Fig. 7.6), one of the greatest English poets of the age. While others praised Herschel, or were inspired by his research, Byron actually met him and peered through his telescope. Without exaggeration, one may divine a profound inspiration in his poetic soul in what Byron wrote after this visit in 1811. "The night is also a religious concern; and even more so, when I viewed the Moon and Stars through Herschel's telescope, and saw that they were worlds."[32] I say poetic soul as Byron was dismissive of religion.

Michael Rowan-Robinson sees an expression of Byron's meeting with Herschel in these lines from the poem "Don Juan":

And though so much inferior, as I know,
To those who, by dint of glass and vapour,
Discover stars and sail in the wind's eye
I wish to do as much by poesy[33]

He also sees in Byron's 1816 poem "Darkness" a description of "the projected death of the Sun that Herschel's vision of an evolving cosmos implied."

I had a dream, which was not all a dream.
The bright sun was extinguished, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air.[34]

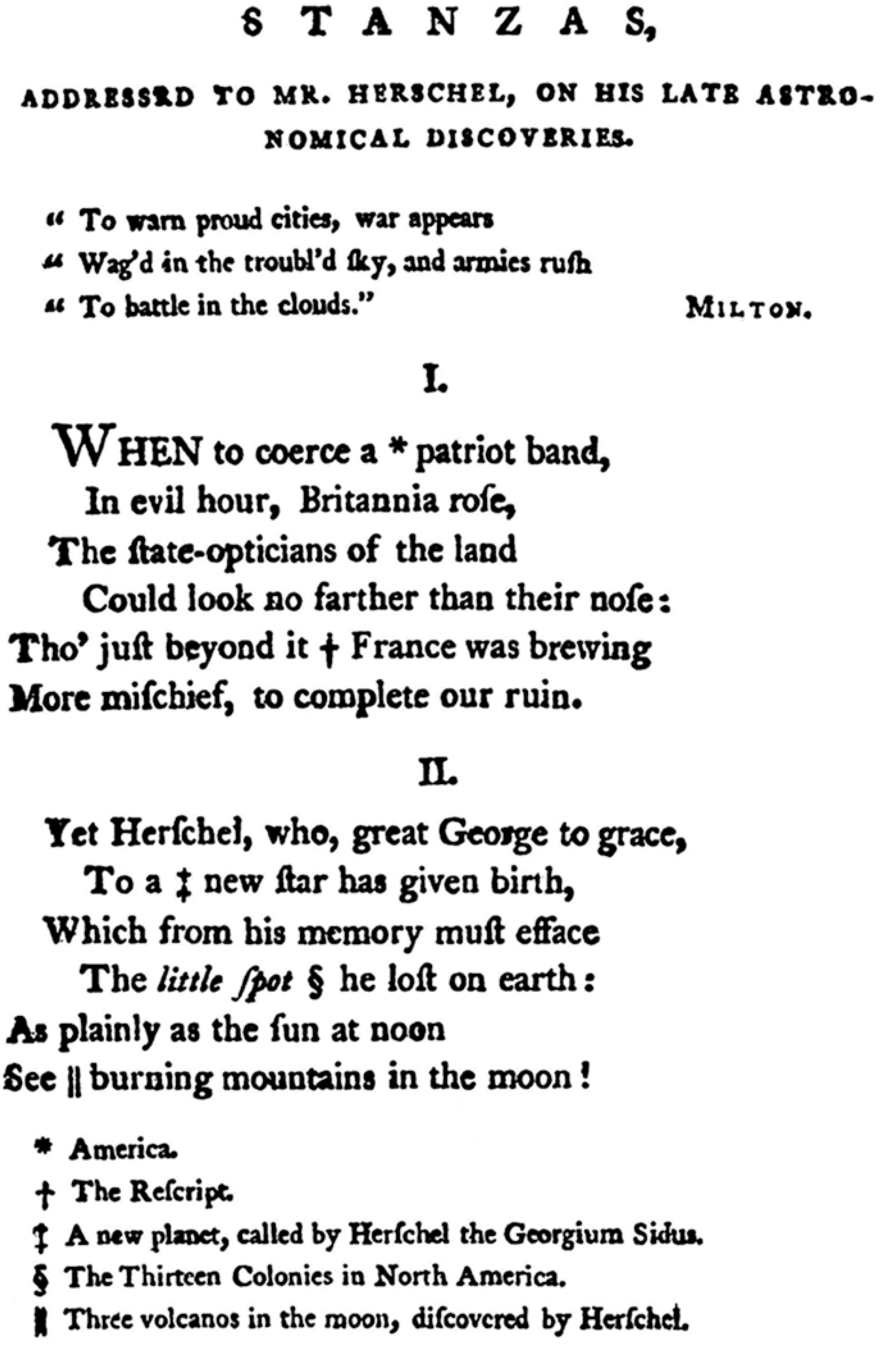
This interpretation by Rowan-Robinson is, however, a case of over-reaching to prove a point as Herschel said nothing directly about the life cycle of stars. Kathleen Lundeen, a Professor of English at Western Washington University, claims "The evidence that Byron's view of the cosmos was agitated by Herschel's forty-footer [telescope] is overt in his poem 'Darkness'."[35] This claim, less specific than Rowan-Robinson's, seems closer to the actual synergy between Herschel, Byron, and the poem.

## Stanzas Addressed to Herschel

An anonymous 8-stanza poem dealing with Herschel was published in a collection of unrelated poems.[36] In 'Some Thoughts on the English Language,' the poet Christopher Smart (1722–1771) praised the English language, saying it displays "superiority over all the modern languages at least." The prose of his native language is, according to Smart, "admirably adapted to express the sentiments of a brave, sensible, sincere people in a resolute, determinate, and open manner."[37] These sentiments are the very ones expressed in this poem, which embodies the most overtly patriotic verse in this collection.

The poet invokes the names of two immortal English political figures, exemplars of the brave and sensible Englishman: Sidney Godolphin, 1st Earl of Godolphin (1645–1712) and Thomas Osborne, the Marquess of Carmarthen (1632–1712). Godolphin was First Lord of the Treasury (equivalent to the position of Prime Minister). Carmarthen was Lord President of the Council under King William III and Queen Mary II, monarchs he was instrumental in putting on the throne during the Glorious Revolution of 1688. Even though Herschel cannot be considered a political figure, the poet feels him to be so worthy as to merit a place on the pedestal of power beside Sidney and Carmarthen. According to him, Herschel did the state a great service in the scientific sphere by compensating King George for the loss of the American colonies with a "new star." He likens this new object to another of Herschel's 'discoveries', lunar volcanoes. Prime Minister William Pitt the Younger (1759–1806) also makes an appearance here; he spent much of his career waging war against the French; the danger posed by the French finds expression at the outset of the poem. The poet returns to this theme when he warns of cometary portents that are being ignored by contemporary politicians who are primarily concerned with retaining their Parliamentary seats. The setting of a celestial battlefield is established at the outset with a passage from *Paradise Lost* by John Milton (1608–1674). As I discovered by applying an astronomical analysis to *Paradise Lost*, this quote depicts not a battle but a literal description of the aurora borealis.[38]

The mention of Charles's Wane in the context of portents is curious. Evidence exists for a supernova becoming visible at the birth of King Charles II, but not at the start of his 'misfortunes' which refers to his exile on the Continent before assuming the throne. The northern grouping of stars known as Charles's Wain seems to outline a wagon, but this refers to the Emperor Charlemagne, not Charles II; perhaps he is equating the two. Whatever the poet means, the last two stanzas take an unexpected turn as he hopes Herschel will name his next planetary discovery after the great Parliamentarian Charles James Fox (1749–1806), an inveterate foe of both King George and Pitt. He says this action would shock the King, an understatement to put it mildly. The last line contains the real shocker for the reader, who is told Fox would outshine the King himself in the sky!



# STANZAS,

## ADDRESSED TO MR. HERSCHEL, ON HIS LATE ASTRONOMICAL DISCOVERIES.

“ To warn proud cities, war appears
“ Wag'd in the troubl'd ſky, and armies ruſh
“ To battle in the clouds.” MILTON.

### I.

WHEN to coerce a * patriot band,
In evil hour, Britannia roſe,
The ſtate-opticians of the land
Could look no farther than their noſe:
Tho' juſt beyond it † France was brewing
More miſchief, to complete our ruin.

### II.

Yet Herſchel, who, great George to grace,
To a ‡ new ſtar has given birth,
Which from his memory muſt efface
The *little ſpot* § he loſt on earth:
As plainly as the ſun at noon
See ‖ burning mountains in the moon!

* America.
† The Reſcript.
‡ A new planet, called by Herſchel the Georgium Sidus.
§ The Thirteen Colonies in North America.
‖ Three volcanos in the moon, diſcovered by Herſchel.

Sydney! Carmarthen!—pray make room
Among you for this wond'rous man:
And to avert poor England's doom,
See henceforth clearer—if you can.
Fierce conteſt, brooding in the ſky,
He marks to Pitt—for Pitt *looks high.*

## IV.

The * *Balance trembles* in its ſphere!
With rage the hoſtile * *Lion*'s † red!
The * *Virgin* cannot calm our fear:
Alas—‡ Elizabeth is dead.
And in the * *Crab* we read our fate;
Sad emblem of our *backward* ſtate!

## V.

Yet tho' ſtern § *Mars* with angry glare,
Wide-threatens this devoted ground;
And " Comets from their horrid hair
" Shake war and peſtilence around;"
Our ſtateſmen heed them not, but ſtare
At || *Caſſiopea's eaſy Chair!*

---

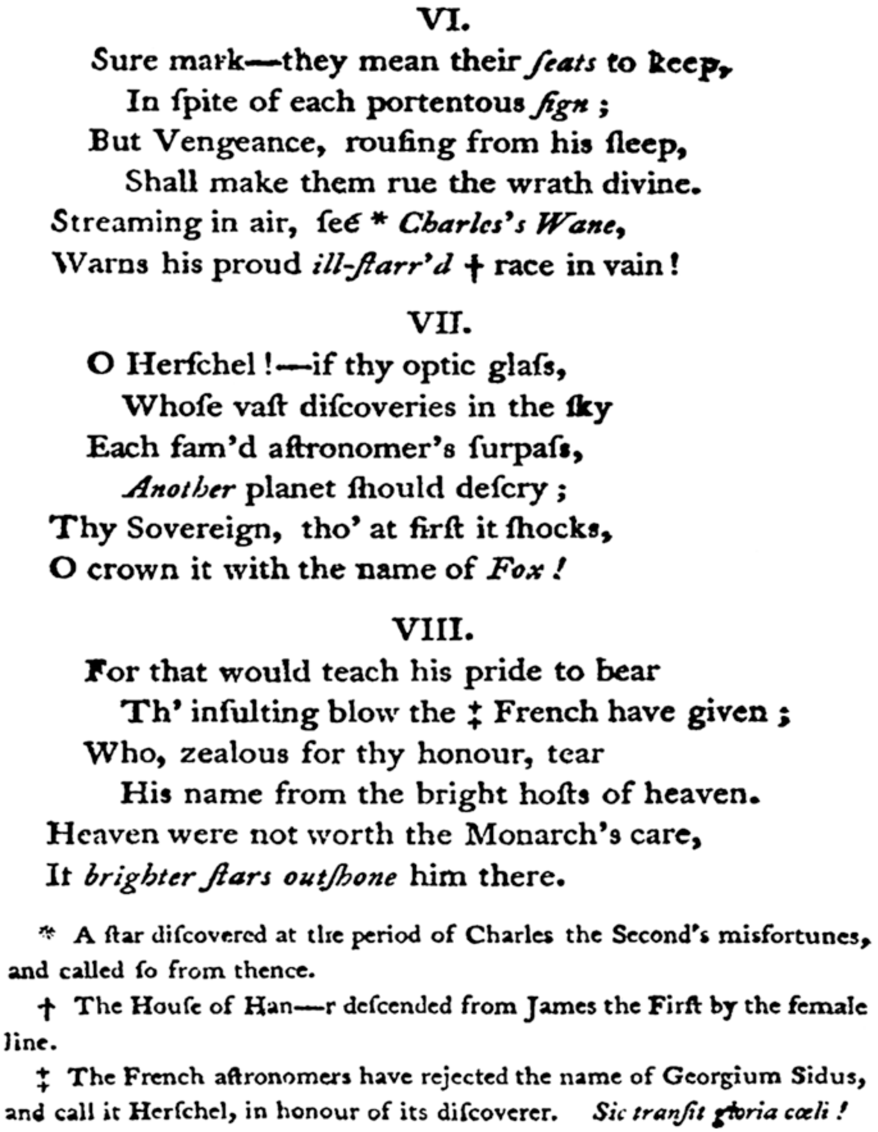
* Signs in the Zodiac.

† The arms of Holland are the Lion.

‡ Queen Elizabeth was in a manner miſtreſs of Holland. She had what were called the cautionary towns belonging to the Dutch in her poſſeſſion, who feared and courted her.

§ A planet as well as the god of war.

|| Caſſiopea's Chair is a conſtellation.



VI.

Sure mark—they mean their *ſeats* to keep,
In ſpite of each portentous *ſign* ;
But Vengeance, rouſing from his ſleep,
Shall make them rue the wrath divine.
Streaming in air, ſee * *Charles's Wane*,
Warns his proud *ill-ſtarr'd* † race in vain!

VII.

O Herſchel!—if thy optic glaſs,
Whoſe vaſt diſcoveries in the ſky
Each fam'd aſtronomer's ſurpaſs,
*Another* planet ſhould deſcry ;
Thy Sovereign, tho' at firſt it ſhocks,
O crown it with the name of *Fox!*

VIII.

For that would teach his pride to bear
Th' inſulting blow the ‡ French have given ;
Who, zealous for thy honour, tear
His name from the bright hoſts of heaven.
Heaven were not worth the Monarch's care,
It *brighter ſtars outſhone* him there.

* A ſtar diſcovered at the period of Charles the Second's misfortunes, and called ſo from thence.

† The Houſe of Han—r deſcended from James the Firſt by the female line.

‡ The French aſtronomers have rejected the name of Georgium Sidus, and call it Herſchel, in honour of its diſcoverer. *Sic tranſit gloria cœli!*

In the stanzas just quoted, the reader encounters an aspect of poetry from this age rarely encountered today – a large number of footnotes to elucidate what the poet means. "If an explanatory gloss is withheld from the reader," says K. K. Ruthven, "etymological conceits tend to become riddles."[39] In the case of this poem, the gloss on Charles's Wain does little to make this allusion any more meaningful, although the genealogical footnote does remind one that the House of Hanover (beginning with King George I, great grandfather of George III) was descended from Stuart King James I, grandfather of Charles II.

## The Georgian Star: Uranus

While Europe adopted the name Uranus for Herschel's 1781 planetary discovery, the appellation *Georgian Star* or the Latinised *Georgium Sidus* was the only one accepted in England. It was celebrated in verse under this name for decades, appropriately enough as it owes its very origins to an ode, as we learn in a letter from Dr. William Watson to Herschel on July 20, 1782.

> My dear Friend,–I will now tell you the result of my consultation with our friends Mr. Collings and Mr. Webb. In the first place we think the star should be called not Georginum Sidus, but Georgium Sidus, in the same manner as Horace Liber I, Ode XII,
>
> Micat inter omnes
> Julium Sidus–
>
> Mr Webb recommends that either in the print or at the bottom with some mark referring to the star the words Georgium Sidus should be written, and under it these words, 'jam nunc assuesce vocari.' The quotation is taken from the first book of the Georgics, line 42, where Virgil after invoking Caesar as a future God among other things tells him he must now accustom himself to be call'd upon with vows, or, as Dryden has it, 'And use thyself betimes to hear our prayer.' [40]

Herschel did in fact use the words from Virgil when he announced his choice, and it appeared in verse just a year after the discovery. In this survey, I am including only poems that include the name of Herschel, or allude to him, with the exception of the ode by the Poet Laureate Pye as it spotlights the highly charged political ramifications of naming the planet after the British monarch. Thus, poems such as a Greek Ode by George Pryme published in 1804[41], or "To the Georgium Sidus" by Elihu Goodwin Holland[42] do not appear here as they merely allude to or name the Georgium Sidus without mentioning Herschel. In this extract from a long poem by the English Rev. William Tasker (1740–1800) on the subject of the year 1782, the "thou" referred to is the Muse of Glory.

> Thou, who each Planet in his Orbit guide'st,
> While round the Sun, on wings of light, thou ride'st,
> Stop, ruling Angel, in thy rapid round,
> And, at thy Solar-System's utmost bound,
> For one short moment, from thy native skies,
> View the concluding Year with fav'ring eyes:
> Beyond the search of NEWTON's heav'nly eye,
> Behold ambitious HERSCHEL dare to spy
> (Aided by wond'rous Optic Glass) from far
> The dim faint splendours of the GEORGIAN STAR.[43]

The lines just quoted are an addition to a poem Tasker completed on Jan. 1, 1783; the second edition was done on July 16. This appears to be the first poem ever published on the new planet, discovered on March 13, 1781. One element it shares with many other poems about Herschel in subsequent years is its inclusion of Sir Isaac Newton (1643–1727), and by this juxtaposition aligning Herschel's worth with that of the greatest scientist of all. A contemporary review of Tasker's poem was insightful, not just for this composition but what was expected at the time to constitute a proper poem:

> The author possesses some portion of genius, but does not appear to submit willingly to the limae labor. His rhimes [sic], however, are generally chaste, and his versification harmonious. But yet the ear is not quite satisfied. It is neither the jingle of rhime, nor a certain number of syllables in a line, which constitutes poetry. Force and comprehension in the conception of ideas, elegance and animation in the expression of them, and plans well digested, are necessary requisites.[44]

*The Gentleman's Magazine*, in a review of the first edition, said in this poem "we often meet with frequent flashes of genius, sudden corruscations that cast a brilliancy over it."[45] The magazine later gave itself credit for the revision of the poem. "Having lately reviewed the former edition of this work, we take this opportunity of observing that the author has availed himself of our hint...and has improved the whole poem, which now includes a compliment to 'ambitious Herschel'."[46] Another magazine, The *Monthly Review*, adopted a more exasperated tone in its review. "To point out the faults of this poem would be a tedious and invidious task."[47]

Two years later the music of the spheres was coupled with a faster-than-light trip to Jupiter and a mention of Herschel in this light-hearted poem entitled "The Air Balloon." It is simply signed "T." and dated Nov. 20, 1784

> "John, fill the large balloon (my lady cried)
> I want to take an airing in the skies:"
> Nimbly she mounts her light machine, and in it
> To Jupiter's convey'd in half a minute;
> Views his broad belt, and steals a pattern from it.
> Then stops to warm her fingers at a comet:
> The concert of the spheres she now attends,
> Hears half an overture, and then descends.
> Trade too, as well as love and dissipation,
> Shall profit by this airy navigation:
> Herschel may now with telescopes provide us,
> Just fresh imported from the Georgium Sidus.[48]

Another very early poem that mentions Herschel (spelled Herschall) comes from the prologue to a play entitled "Orphan of China" by the dramatist Samuel Jackson Pratt (1749–1814; Fig. 7.7). This 1789 production was an English adaptation of a thirteenth century Chinese play, "The Orphan of Zhao." The prologue, spoken by the noted actor William Fector (born 1764), opens with these lines (italics in original):

> From Herschall gazing on his Georgian star,
> To daring Jeff'ries balancing in air,
> The law supreme that governs human kind,
> *Pleasure to give and take* we still shall find,
> *Social* the source whence all our passions flow.[49]

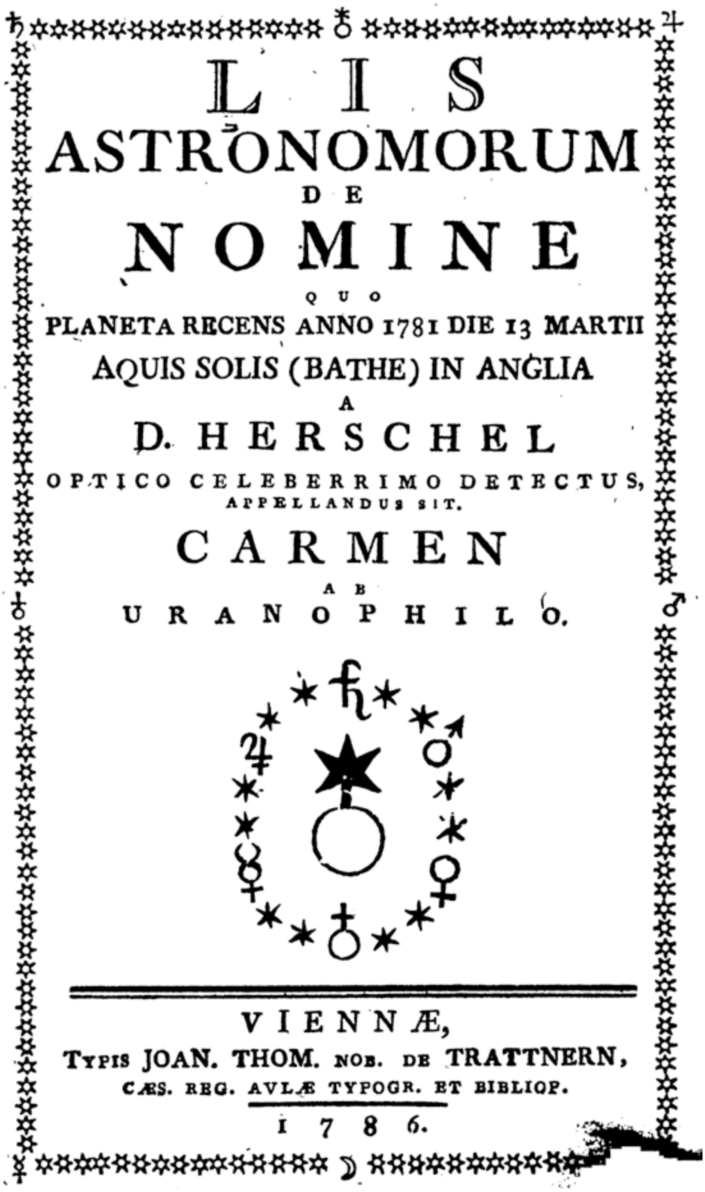
Here he mentions John Jeffries (1745–1819), who became famous for crossing the English Channel in a balloon in 1785. It was particularly apropo that Fector delivered this prologue, as he had also ascended in a balloon.[50]

**Fig. 7.7** Samuel Jackson Pratt by Thomas Lawrence

The first verse of an anonymous German poem from 1786 refers to Herschel as a German (he was born in Hanover) on the shores of Avon, a reference to England. This may also be a reference to the river Avon, which runs through the city of Bath, from where Herschel discovered Uranus. Additionally, the first verse makes a pointed reference to the fact that King George III was abandoned by America.

> Der neue Planet
>
> Der Deutsche, der, an Avons Strand,
> Des Himmels jüngsten Liebling fand,
> Grüßt' ihn entzückt: „Georgia!"
> Damit in dieser weiten Sphäre
> Dem besten Herrn Amerika,
> Das ihn verließ, ersezet wäre.[51]
>
> The New Planet
>
> The German, who, on Avon's beach,
> Found sky's youngest darling,
> Greets him delighted: "Georgia!"
> So that in this vast sphere
> Worthy Mr. America,
> Who abandoned him, should be replaced.

For the text of the entire poem, see Cunningham and Oestmann.[52] Also in 1786, an author who employed the name Uranophilo, published a lengthy Latin poem (Fig. 7.8) on the nomenclature controversy surrounding Herschel's discovery. Uranophilo is a pseudonym employed by Constantin Gabriel Hecker (1670–1721), who wrote an astronomical ephemerides. This pseudonym was adopted by Georg Szerdahely (1740–1808), Jesuit and Professor of Rhetoric, who taught aesthetics at the University of Buda. We also read wordplay here: when Hecker used that name,



LIS
ASTRONOMORUM
DE
NOMINE
QUO
PLANETA RECENS ANNO 1781 DIE 13 MARTII
AQUIS SOLIS (BATHE) IN ANGLIA
A
D. HERSCHEL
OPTICO CELEBERRIMO DETECTUS,
APPELLANDUS SIT.
CARMEN
AB
URANOPHILO.

VIENNÆ,
Typis JOAN. THOM. NOB. DE TRATTNERN,
CÆS. REG. AVLÆ TYPOGR. ET BIBLIOP.
1786.

**Fig. 7.8** Title page of the 1786 Latin book by Uranophilo (Courtesy Google Books/University of Michigan)

he meant lover of astronomy, Urania being the muse of astronomy. When employed by Szerdahely, it means lover of Uranus, the planet.

> Herschelio, clarisque viris, quos anglia censet,
> nomina regnantum, qui celebrata volunt,

Hisce Georgius est nomen, signare planetam,
quo cupiunt; sit Rex, duxque planeta novus.[53]

For HERSCHEL, and the famous men, whom England numbers,
who will that the names of rulers be celebrated --
To these the name is GEORGE, by which they want
to designate the new planet; that he be King and Leader.

On March 17, 1789, one of England's leading poets of the century, William Cowper (1731–1800), wrote of The Queen of England (wife of George III):

With more than astronomic eyes
She view'd the sparkling show;
*One Georgian star adorns the skies,*
*She myriads found below*.[54]

The 'show' viewed by Queen Charlotte (1744–1818) was a pageant held in honour of George III's recovery from a serious illness. In quoting this verse, Jennnet (sic) Humphreys (1875: 787) says it was done "with manifest connection with Herschel and other telescopic doings at Windsor."

The English scientific instrument-maker Edward Nairne (1726–1806) took time out from his workshop to pen some humorous verses. This comes from "Irregular Address to the Moon":

Hath Herschel's bonfires play'd thee tricks,
And lighted up thy old man's sticks?
Hath Georgium Sidus never been
At court, to bow to thee his queen?
Then let him take, with conscious pride,
The star of Brunswick for his guide,
And to acquire immortal fame,
Join GEORGE'S MANNERS to his NAME![55]

Hanover was located in the Electorate of Brunswick-Lüneberg, part of the realm of King George, hence the star of Brunswick. Another portion of Nairne's poem can be found in the section on Herschel's telescopes.

As part of the conservative backlash against those who had denigrated King George in the middle part of his reign comes this poem from 1795 by Thomas James Mathias (1754–1835). Mathias, who was educated at Trinity College, Cambridge, published this anonymously in 1795 but an edition of the following year includes his name. In the 1780s he was a minor member of the Royal household, so he was certainly acquainted with the King. Couched in a presumed epistle from the (fictitious) Emperor of China to George III, Mathias "predicts that the popularity of the British monarchy will overcome the threat of French political theory... In the event, of course, the throne of George III was vindicated."[56] Here Mathias envisions Herschel himself pointing at the Georgian star from a celestial 2-wheeled chariot.

The cluster'd radiance of the fields above,
And pictur'd planets in their orders move,
Seraphic emblems! And in azure car
Thy Herschel pointing to his Georgian Star.[57]

The reference to 'pictur'd planets' is attended in the book with a note by George Spencer, the 4th Duke of Marlborough (1739–1817), a well-respected amateur astronomer. He writes: “After these twenty-four banners upon which are painted the signs of the Zodiac; and fifty six other banners, on which are represented different clusters of stars, according to their arrangement in the heavens.”[58]

In the 12th stanza of a poem addressed to the Prince of Wales (later King George IV) on his marriage to Caroline, Princess of Brunswick, a reviewer in *The Gentleman's Magazine* says that here “the Georgian star blending its lustre with the nuptial planet has been judged a happy originality.” The reviewer says he quotes this stanza because of its “boldness and spirit.” One might less charitably describe it in modern terms as soft porn, and most assuredly in poor taste, but hardly shocking by the standards of the day.

*“Go, happy Pair,” a Spirit cries,*
*(The Pow'r that rules o'er British skies,)*
*“Go, where the nuptial planet blends*
*Its lustre with the Georgian star,*
*And to the couch of Hymen lends*
*The chasten'd influence, which alone*
*Loosens, unchek'd, the virgin zone*.[59]

While he did not mention Herschel, the Poet Laureate Henry James Pye (1744–1813) did include a mention of the new planet (and its size) in a work he created for the commencement of the new century. Pye here alludes to King George III as a monarch who favours science. Mathesis refers to mathematical/astronomical science which solved the problem of determining longitude at sea, thus allowing mariners to plot their tracks through the ocean. While posterity has not bestowed great laurels on Pye, in these lines he does approach the sublime.

Rais'd by the Monarch's favouring smile,
Severer Science hails the happy isle.
Mathesis with uplifted eye,
Tracing the wonders of the sky,
Now shews the mariner to guide
His vessel through the trackless tide;
Now gazing on the blue profound,
Where whirl the stars in endless round,
Beholds new constellations rise,
New systems crowd the argent skies;
Views with new lustre round the glowing pole.
Wide his stupendous orb the Georgian planet roll.[60]

A review of this poem in the periodical *Critical Review* (which favoured the French Revolution) drew a sharp rebuke from its ideologically opposite number, *The Anti-Jacobin Review and Magazine*, which was wholly in favour of the British monarchy:

> Our Critic cannot conclude without a contemptible sneer at Mr. Pye's loyalty, insinuating that he introduced Astronomy for no purpose but to mention the Georgium Sidus. By this time our readers must be fully sensible of the malignant disposition, as well as folly, of the Critical Reviewer.[61]

Despite its repudiation of King George, the discovery was commemorated in America. John Leeds Bozman (1757–1823) of Maryland wrote an ode on the

*Discovery of the Georgian* Star, but an archival search has not located the text. From 1802 comes *The Inquisitive Traveller: A Poetic Essay*, by Edward Church (died 1816) of Boston, consul for the United States in Lisbon until 1797. His 1802 book was published during his stay in London. Uniquely, it mentions Herschel's sister Caroline, and the Milky Way. Church employs the word welkin which means the vault of heaven.

Let HERSCHEL with his SISTER *ken* the skies,
And sweep the *concave* with their *optic* eyes;
Leave *strutting udders* and *full flasks*, to stray,
With *unslak'd thirst*, o'er the *dry milky way*;
With crabbed names, like *zodiac*, crack their skulls,
And change, FOR SIGNS, live *Rams, Crabs, Twins*, and *Bulls*;
Brush with keen scent o'er thick-sown fields of light,
Till a *wee* GEORGIUM SIDUS pops in sight;
Then *down* the *steep* with eager haste descend,
To show their *game* to each *star-gazing* friend;
Up the blue welkin then retrace their way,
To hunt fresh game, or *Georgia sidera*.
But of such strangers–all I wish to know
Is–from their influence on affairs below![62]

Church thus appears to praise the discovery of the new planet, but then says his only interest in it and other possible planets is their astrological influence! After enumerating the influence of the various planets, Church further belittles the discovery of a 'new spark' in the sky in these lines

For me, I choose to stay in my own sphere,
And trace the various works of *nature* here;
This little globe contains enough for me,
And more alas! than one man's eyes can see;
Then thro' a *telescope* why should I *pore*,
When with my naked eyes I see much more?
Why with long toil *above, one spark* pursue
Among a thousand *brighter*, 'cause tis NEW?[63]

One can scarcely imagine a more sweeping dismissal of astronomical observations! Church here employs erotesis, a figure of rhetoric by which he infuses the poem with his emotional ardor for the wonders of the Earth by posing counterfactual questions about the value of employing a telescope to make discoveries in the heavens. The Liverpool native William Colquitt, by contrast, appears quite content in an ode to Herschel entitled *The Astronomer* to merely report on Herschel's use of a telescope to make a planetary discovery, without passing any value judgement.

Herschel, with his large telescope, has seen
Another planet in the blue serene,
Which Georgium Sidus he has pleas'd to term,
This eighty years takes to her course perform.[64]

The preface to Colquitt's book tells the reader 'The Astronomer' "is the first poem on this subject ever completed in this country...The solar system, as well as the discoveries of modern astronomers, are here recorded."[65] This poem is one of only two offering the period of revolution of the planet (the real figure being 84 years).

In 1801 Paul Philippe Gudin de la Brenellerie (1738–1820) published a prose poem "L'astronomie, in three chants." Diplomatically, Gudin, an associate member of the Institut National, does not assign a name to the discovery, so neither Uranus nor Georgium Sidus makes an appearance.

L'amour propre si vif, et si souvent déçu,
Prétendait dans les cieux avoir tout apercu;
Quand soudain on apprend du fond de l'Angleterre,
Qu'il s'offre un nouvel astre aux regards de la terre;
Que par-delà Saturne il brille dans la nuit;
Qu'*Herschel* l'a découvert, qu'il l'observe et le suit.[66]

Self-esteem so lively, and so often disappointed,
Pretended to have seen everything in the skies;
When all of a sudden one learned from the heart of England,
That a new star presented itself to the world;
That beyond Saturn it shines in the night;
That Herschel had discovered it, observes and follows it.

Nine years later Gudin expanded the poem with the addition of a fourth chant. This revised text includes a few lines about the Uranian satellites. He writes that Herschel, armed with a powerful telescope, looks at Uranus and finds first one, then two, then four more satellites:

D'un plus fort télescope Herschel armant ses yeux
Suit cet astre enfoncé dans l'abîme des cieux;
Trace ses mouvements, en dessine l'orbite,
Découvre à ses côtés un premier satellite:
Un second se fait voir; quatre autres plus lointains,
Fuyant à ses regards, en sont encore atteints.[67]

Using a larger telescope, Herschel
Follows this body through the heavens' depths
Traces its motion, draws its orbit,
Discovers by its side a first satellite:
A second is seen; four others more distant,
Fleeing from his view, are still met.

A few pages later Gudin writes Herschel has achieved immortal glory:

Des émules d'Herschel les noms recommandables
Des astres qu'ils ont vus seront inséparables:
La Gloire en traits de feu les inscrivit aux cieux,
Les Muses les diront à nos derniers neveux;
L'Histoire avec orgueil en ornera ses pages;
Ils seront honorés, et chers dans tous les âges.
On saura que jamais, jamais aucun mortel
Ne nous a découvert autant d'astres qu'Herschel.[68]

Of Herschel's followers the acknowledged names,
Are forever linked to the bodies they saw:
Glory with glowing letters wrote them in the heavens,
The Muses will tell them to our last nephews;
They will adorn with pride the pages of History;
They will be honoured and beloved through the ages.
One will know that never a mortal
Discovered as many celestial bodies as Herschel.

This verse from Canto IV (Of Good and Evil) in "The Temple of Nature" by Erasmus Darwin (1731–1802) commemorates the discovery of the moons of Uranus, which are depicted in the chart Herschel is holding in Figure 7.1. While the Frenchman Gudin avoided naming the planet, Darwin celebrates the English connection; he deploys not one but two monikers for the planet: Herschel and the Georgian star.

> Delighted Herschel, with reflected light,
> Pursues his radiant journey through the night;
> Detects new guards, that roll their orbs afar,
> In lucid ringlets round the Georgian star.[69]

Raleigh Trevelyan, a Lincoln's Inn barrister who died around 1867, composed a Greek poem in 1806 entitled "Creation":

> In Solar font, as yet by sage unseen,
> Others their virgin purity will lave.
> Thou star, that bear'st our Country's monarch name,
> Remotest on the confines of the gloom,
> Thou loveliest bud of chaos, gav'st new life,
> When seen, to philosophic gaze.[70]

The first two lines quoted here refer to other planets in the solar system beyond Saturn which have not yet been discovered. This expectation is answered in the following lines, on the discovery of the planet that bears the monarch's name. A reviewer in the *Anti-Jacobin Review* was none too happy with this. "The description of the Georgium Sidus is rather awkward."[71]

As we can easily discern from the poem of Trevelyan, the British were quite proud that a planet had been named for their monarch; how it was regarded north of the border was enshrined in the Scots dialect from an unknown poet (English equivalents are given following the poem). Thomas C. Latto, the editor of the book it appeared in, described his discovery: "In rummaging last summer among the musty papers of a garret in Fife, he discovered a manuscript dated 1815, a slight perusal of which satisfied him that, however humble the theme, its conduct and style evinced no ordinary powers. The author's name being adhibited to the manuscript, the Editor had no difficulty in discovering him, and ultimately prevailed on him to allow its publication, under the express proviso that he was to remain a 'veiled prophet.'"[72] The poem paints an amusing simile between Herschel searching the skies for a planet, with a range of cattle searching for grass. Both, in this case, are in scant supply. Here follows an excerpt from canto 2 of "The Minister's Kail-Yard," the poem Latto claims was written in 1815:

> As Herschel, wi' his telescope,
> Ranging 'mang stars wi' ardent hope,
> Hunting for planets- ferlies queer,
> Till Georgium Sidus did appear,-
> Saw owre the field the cattle pass,
> Wi' eydent ee, in search o' grass;
> Stibble, like stars, they found in plenty,
> But grass, like planets, unco scanty;
> Consider, then, how joy'd the stot,

Wha got at last a glimm'ring o't![73]

| | |
|---|---|
| Ranging 'mang stars | Searching the stars eagerly |
| ferlies queer | an unusual or strange oddity, a wonder or marvel |
| Saw owre | so over |
| eydent ee | diligent searching |
| stibble | stubble, like stumps of a corn stalk |
| unco scanty | remarkably scanty |
| stot | steer |
| glimm'ring o't | sight of it |

The English schoolmistress Richmal Mangnall (1769–1820) of Crofton–Hall, near Wakefield in Yorkshire, wrote a poem entitled "The Planetary System," which was widely reprinted in subsequent decades. She draws attention to the six moons of Uranus, only two of which proved later to be real. This poem is also noteworthy for its mention of the period of revolution of the planet, the only other example being the one by Colquitt:

The Georgium Sidus next appears,
By his amazing distance known;
The lapse of more than eighty years,
In his account makes one alone.
Six moons are his, by Herschel shown,
Herschel, of modern times the boast;
Discovery here is all his own,
Another planetary host![74]

In an 1821 book that contains 165 lessons for school children, the Englishman Rev. John Platts prefaces his discussion of the new planet with this verse, which he likely wrote himself.

Last of the splendid planetary throng,
See Georgium Sidus gently glides along;
For ages from the world conceal'd he stray'd,
Till noted Herschel the discovery made;
His worth should be for ever known to fame,
So let the new found planet bear his name.[75]

'Alfarabi' by the English poet Thomas Lovell Beddoes (1803-1849) has been dated by Edgecombe to 1827. The poem embodies numerous astronomical allusions, and ends with these lines:

        The necromancer
Puffed from his pipe a British climate round,
And stars and moon, and angels beamed upon it.
Just as it joined the midnight choir of worlds,
It chanced a bearded sage espied it's sweep,
And named it GEORGIUM SIDUS.[76]

Edgecombe surmises Beddoes superimposed a beard on Herschel (the 'sage') because a close friend of his sported one.

"Address to the Moon," by John Lofland (1798–1849) of Milford, Delaware, contains the following lines. Both this poem and the next are by American poets, and both link the name of Newton with that of Herschel:

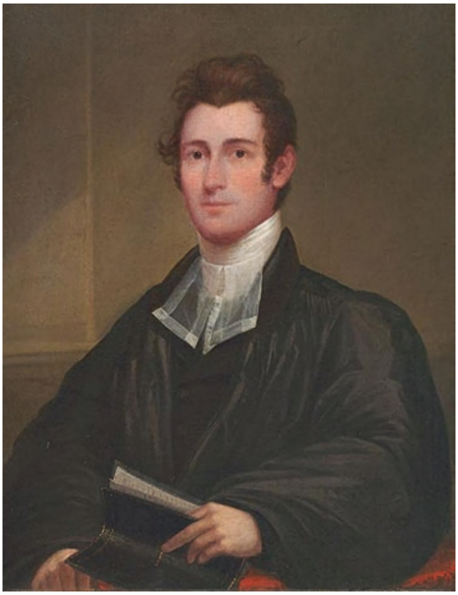


**Fig. 7.9** Samuel Gilman by Alvan Fisher, c. 1820 (Harvard University Portrait Collection)

Nor have I yet a Newton's eye to see
Ten thousand worlds fill up the realms of space-
Nor yet a Herschel's, who with magic glance
Drew from obscurity another ball,
And named it Georgium Sidus.[77]

Sometime between 1806 and 1829 an American poet and Unitarian pastor, Samuel Gilman (1791–1858; Fig. 7.9), composed an inventive piece entitled "History of a Ray of Light." He brings Galileo Galilei (1564–1642) into the mix with his telescope, and mentions the splitting of white light by Newton:

Nor yet have poetry and painting shared
My sole regards–for science I have cared.
When Galileo raised his glass on high,
Me first it brought to his astonish'd eye;
When Newton's prism loosed the solar beams,
I help'd to realize his heaven-taught dreams;
When Herschel his dim namesake first descried,
I was just shooting from that planet's side.[78]

The editor of the book Gilman's poem appears in, Samuel Kettell, has this to say about the author.

> Mr Gilman is a native of Gloucester, Massachusetts, and was graduated at Harvard University in 1811. He has been for several years, settled as a clergyman in Charleston, S.C. He is understood to be the author of *Memoirs of a New-England Village Choir*, a prose work of great merit.[79]

The French had no problem applauding Herschel for his discovery of Uranus, as in this poem by Count Pierre Antoine Noel Bruno Daru (1769–1829) where England

**Fig. 7.10** Count Pierre Daru by Antoine-Jean Gros. Musée national des châteaux de Versailles et de Trianon

is termed Albion. Daru (Fig. 7.10) had a colourful career as a soldier and statesman during and after the Napoleonic era, but he still had time to write a didactic poem about astronomy published posthumously in 1830. These lines are in the fifth of six chants of his work "L'Astronomie" which runs to 300 pages (with notes), thus putting it in the category of epic poetry:

> Herschel ajoute un monde à la création,
> Et la France applaudit à l'orgueil d'Albion.[80]
>
> Herschel adds a world to creation,
> and France has applauded the pride of Albion.

The year 1849 saw a children's poem entitled Georgium Sidus from the pen of Louisa Watts. Here is the last of the three stanzas, alluding to Queen Victoria, granddaughter of George III:

> Herschel discover'd it we know,
> Not very many years ago;
> The name he gave it, perhaps you've heard,
> Of the Queen's grandfather, George the Third.[81]

## Herschel's Telescope

The American President John Adams (1735–1826) wrote "A prospect into futurity in America is like contemplating the heavens through the telescopes of Herschel."[82] The poem by Colquitt prominently mentions Herschel's great telescope in connexion with Uranus. Other poems extolled his powers of sight with the aid of a telescope in a more general sense. The earliest allusion to this can be found in a Latin poem by Szerdahely. In a book he published in 1788 (*Historia Urania Musae*) he tells of the Muse of Astronomy, Urania, twinning the muse with Herschel in the same line:

Quam nec Dii poterant, nec tot iam Secula Pacem,
Et Lucem URANIAE reddidit HERSCHELIUS.
Ille dedit nobis Oculos, et Sidera, quo sint
Astronomis iam nunc proximiora, facit.
Is quoque, quae quondam perierunt, Astra reducet,
Et nova, quae nunquam visa fuere, dabit.
Fallor, an Excubias nacta est, fortasse satelles
Errat, et excubias unus et alter agit.[83]

What neither the Gods could grant, nor so many Ages Past,
Peace and Light has HERSCHEL rendered unto URANIA.
He has given us Eyes, and makes Stars
to be now closer to Astronomers.
Also he brings back [stars] that were once lost,
and new ones too, which have never been seen, he shall grant.
I am deceived, or else she has gotten guards – perhaps an attendant
wanders, and one or two act as guards.

The ‘he’ referred to is Herschel, while the ‘she’ refers to the muse of astronomy, Urania.

The ‘Eyes’ refer to Herschel’s telescopes, and the ‘bringing back stars’ to John Flamsteed’s and Christian Mayer’s earlier sighting of Uranus, as the footnotes make clear. The ‘guards’ in the last two lines are an allusion to the two Uranian satellites discovered by Herschel.

Herschel and his telescope make an unlikely entrance in an 1810 poem by Mrs. Hannah Cowley about the Siege of Acre. Here she neatly draws an analogy between the elliptical orbits of planets and the path of an arrow:

Those thunder at the Walls, these reach the Tower,
One aims aloft, one sends the mischief lower,
This an Ellipsis makes, that, darts a line
True as the Telescope’s whose aim divine
For Herschel searches some discover’d sun
Or finds where planets their Aphelion run.[84]

In her introduction, Cowley says “this poem celebrates one of the most important Events of the French Expedition under General Bonaparte to Egypt and Asia– the effectual stop put to their progress, through British aid, at Acre.”[85]

Thomas Gisborn begins his 1813 poem “Futurity” by imagining a seaman trying to gaze into a faint horizon, uncertain of what he sees. His solution? A telescope made by Herschel:

Lead but his faltering powers to Wisdom’s light,
Through Herschel’s wond’rous tube direct his sight.[86]

Lydia Sigourney (1791–1865) was a native of Norwich, Connecticut. In her 1827 poem “To The Moon” she follows a familiar trope in linking Herschel with another great name, in this case Johannes Kepler (1571–1630):

Cans’t thou boast, like

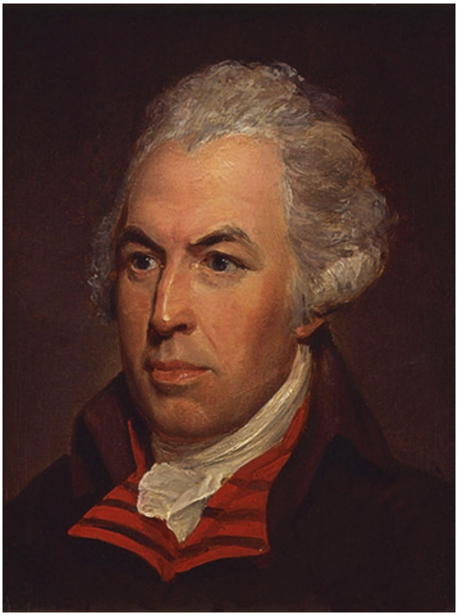


**Fig. 7.11** William Hayley by Henry Howard (National Portrait Gallery (NPG662), London)

A Kepler, skillful pioneer and wise?–
A sage to write his name among the stars
Like glorious Herschel?[87]

Two poems praise the acuity of Herschel using the same vocabulary, with the word 'even' poetically spelled as e'en. William Hayley (1745–1820; Fig. 7.11) first published his book-length poem "The Triumphs of Temper" in 1781, but it was not until a later edition of his book in 1799 that he inserted some lines on Herschel into his text.

My young Serena shines per peers above,
Pride of my hopes, and darling of my love.
Hence I to thee such mysteries unfold,
As Man's pedantic eye shall ne'er behold;
Whose narrow science, tho' it proudly boast
To pierce the sky, and count the starry host,
Sees not the lucid band of airy Powers,
Who flutter round him in his secret hours:
But if to me, thy guardian now display'd,
Thy duteous orisons are justly paid,
Thou to those realms shalt pass with me thy guide,
Where Spleen's pale victim, after death, reside;
Then to that orb, in vision shalt thou rise,
(Not seen by mortal astronomic eyes,
Not e'en by Herschel, whose angelic ken
Finds a mute star, and bids it speak to men)[88]

Hayley was described by the contemporary poet Anna Seward (1742–1809) as "the transcendant English Bard of the present era."[89] The poem just quoted was, according to Brewer, "an enormously popular and frequently reprinted poem intended to teach young women the virtues of good humour."[90]

Thomas Green Fessenden wrote "Epistle Excusatory." A footnote says it was "addressed to Mr. Dennie, Editor of *Laypreacher's Gazette*, as an apology for not more frequently writing for his poetical department."

> Some knowing-ones presume to say
> The poet tours the other way,
> Borne high on Fancy's air-balloon,
> Soars many a league beyond the moon,
> Engag'd in some sublime affair
> In building castles, in the air–
> Gone where e'en Herschel cannot find him,
> And leaves his partizans behind him.[91]

In addition to the planet Uranus, Herschel's telescope was mentioned in "Irregular Address to the Moon" by Edward Nairne in 1791. The 'thy' of these lines is the Moon:

> Now as thy light progressive spreads,
> Its influence maddens mortal heads,
> Vexes with whims their curdled brains,
> And lunacy or folly reigns;
> Else how could some so silly be
> To speak obloquiously of thee!
> If Herschel's tube should come this way,
> I'll tell thee through it what they say,
> If not, I'll wait upon thee soon,
> Wafted in Blanchard's new balloon.[92]

Nairne here mentions Jean-Pierre Blanchard (1753–1809), the French balloonist who made his first flight in 1784; the following year he achieved the first crossing of the English Channel.

Herschel's telescope even made its way into one of the most famous novels of the nineteenth century, *Moby Dick* by Herman Melville (1819–1891):

> Is it not curious that so vast a being as the whale should see the world through so small an eye? ... But if his eyes were broad as the lens of Herschel's great telescope; …would that make him any longer of sight? Not at all.[93]

Jacques Delille (1805) in *The Gardens*, aside from the usual linkage with Newton, expresses the hope the Duke of Marlborough might discover a new planet. Marlborough had a private observatory at his residence, Blenheim Palace, thus the line about Urania dwelling among her towers.

> Still Blenheim brings new prodigies to view,
> Sublime Urania dwells among her towers,
> Where oft her Herschel spends his midnight hours,
> Immersed in heavenly contemplation soars,
> And adds news planets to a Newton's stores.
> Haply, ere long, a star shall Marlborough rise,
> And Herschel trace his progress through the skies.[94]

**Fig. 7.12** Erasmus Darwin by Joseph Wright of Derby, 1791

After enumerating observations from the Greek astronomer Eudoxus (390–337 BCE) to Nicolas Copernicus (1473–1543) that reached as far as Saturn, Daru (in a passage from the fifth chant of *L'Astronomie*) anoints Herschel as a conqueror of a more distant world thanks to his telescope of "powerful force":

> Mais depuis que, doués d'une force puissante,
> Nos yeux ont pu sonder les profondeurs du ciel,
> Un monde plus lointain fut conquis par Herschel.[95]
>
> But since, endowed with a powerful force,
> Our eyes could weld the depths of the sky,
> A more distant world was conquered by Herschel.

## Stellar Research

In 1791, Erasmus Darwin (Fig. 7.12) wrote a poem in the epic genre entitled *Botanic Garden*. Keeping in mind the passage I quoted in the Introduction, John Holland (1867) cites *Botanic Garden* "as a specimen of the glittering style of a once fashionable poet."[96]

> Sylphs! as you hover on ethereal wing,
> Brood the green children of parturient spring!–
> Where in their bursting cells my embryons rest,
> I charge you, guard the vegetable nest;
> Count with nice eye the myriad seeds, that swell
> Each vaulted womb of husk, or pod, or shell;
> Feed with sweet juices, clothe with downy hair,
> Or hang, inshrined, their little orbs in air.[97]

A contemporary reviewer of the work said "The parts of the Botanic Garden worthy of admiration, are—without an exception that strikes us, —only those passages that are subsidiary to the main object of the poem, and introduced by way of simile, or for the purpose of illustration. We do not think of the embryo seeds, but of Herschel and the starry firmament."[98] It was wryly noted by Tucker that "The mischief behind Darwin's poker-faced scientific innocence in retailing such matters [ie vegetable love] lay in the way he flushed out the human imagination from its hiding place in Enlightened objectivity."[99] The passage immediately following the one just quoted flushes out that imagination by making it clear the embryo reference is linked to Herschel's work on stars, celestial objects Darwin terms 'flowers of the sky' (Economy of Vegetation, Canto IV):

So, late descry'd by HERSCHEL'S piercing sight,
Hang the bright squadrons of the twinkling Night,
Ten thousand marshall'd stars, a silver zone,
Effuse their blended lustres round her throne;
Suns call to suns, in lucid clouds conspire,
And light exterior skies with golden fire.[100]

By invoking a conversation between suns, and by drawing the simile between them and the bursting life of spring, Darwin employs the rhetorical device prosopopeia which endows inanimate nature with life and intelligence.

In 1810, the English poet Anna Laetitia Barbauld (1743–1825) used Herschel's name as a prop in one of her poems:

Mortals, wouldst thou know the grains
That Ceres heaps on Libya's plains,
Or leaves that yellow Autumn strews,
Or the stars that Herschel views.[101]

In a study of Barbauld's work, Dometa Weigand has noted that "her pieces contain references to the Transit of Mercury, speculation on the age and nature of the cosmos, the origin of stars, and direct references to the astronomer William Herschel."[102] Through her friendship with the chemist Joseph Priestley she had ties to the Lunar Society and was well aware of the state of science and Herschel's place in it. In her poem "Eternity," Weigand says Barbauld mentions Herschel's current astronomical projects, including his work to "count the stars/And measure distant worlds."[103] Some caution must be used here, as Herschel's name does not appear in the poem.

I have only discovered one poem that alludes to Herschel's double star observations. It is by Thomas Crossley (died 1843), who lived near Halifax in West Yorkshire. This comes from "A Winter's Night" in 1828:

Next on the planets, and the stars so bright,
    We argue;– these have lustre of their own;
While planets from the Sun receive their light–
    It has by deep astronomers been shown,-
And, if what Herschel has advanc'd, is right,
    They on their axes turn–the time unknown;
He also has advanc'd–(it may be true,)
That he has seen ONE SINGLE STAR, FORM TWO![104]

In another poem by Crossley, "Lines Written in a Beautiful Valley on the Banks of Calder," he makes particular mention of the fact that Herschel studies the Milky Way. After first suggesting he might, on a winter's night, read Milton or other authors, Crossley goes on to suggest a nobler use of his time:

> But if nobler themes invite,
> When come on the shades of night,
> Then with Herschel I can stray
> O'er the ample milky way;
> View each planet in its sphere,
> Rolling thro' the tardy year.[105]

Crossley's book was summarily dismissed by *The Literary Gazette and Journal of Belles Letters, Arts and Sciences*. "Juvenile trifles, written to pass the idle hours, these compositions can hardly hope to excite notice beyond the author's own circle of friends."[106] The American Benjamin West Ball (1823–1896) wrote "Herschel's Star Clusters" that invokes the botanical trope to describe nebula. An earlier stanza on "force and matter" is referred to in the first line quoted here.

> The same unwearied forces work
>         And make whole systems blossom
> In stellar clusters like the flowers
>         Upon our planet's bosom;
> For nebulous vapors far away,
>         On optic glasses looming,
> Are garden-beds of nascent worlds
>         Like banks of violets blooming.[107]

## Lunar Volcanoes

The theory that meteorites were of lunar origin was first broached in 1660 by the Italian philosopher Paolo Terzago[108]. Prompted by the fall of a meteorite at Siena on June 16, 1794, Olbers was led "to investigate the amount of the initial tangential force required to bring to the earth masses projected from the moon."[109] Herschel[110] believed he had observed lunar volcanoes, as critiqued by Holden[111]. The possible link between meteorites and the lunar volcanoes reported by Herschel's observations through his telescope 'tube' was such a powerful one that it supposedly inspired a few lines in the iconic poem from 1798, "The Rime of the Ancient Mariner" by Samuel Taylor Coleridge (1772–1834). King-Hele makes the link thus:

> One evening when [James] Lind and his wife were visiting Herschel, Mrs Lind saw a bright spot on the dark part of the Moon. This led to Herschel's series of observations of 'volcanos in the Moon', which in turn led to the modern study of transient lunar phenomena as well as to Coleridge's 'star within the nether tip' of the Moon in the Ancient Mariner.[112]

Here are lines 209-211 in the poem referred to by King-Hele:

> Till clomb above the eastern bar
> The horned moon, with one bright star
> within the nether tip.[113]

It seems to me unlikely these lines inspired Coleridge. It was stated by Ogilvy that Coleridge made a particular record in his personal notebook of volume 5 of the *Philosophical Transactions of the Royal Society*. At the top of a page in that tome, a report by Cotton Mather in Boston says "in November 1668, a Star appear'd below the Body of the Moon within the Horns of it." This surely is what led to the lines in the poem, although it cannot be ruled out that Herschel's report of lunar volcanoes nudged Coleridge further.[114] The most relevant point to consider about King-Hele's book on Erasmus Darwin and the Romantic poets is that Herschel only gets mentioned once; he does not consider what influence Herschel had on Keats or Darwin.

An undoubted reference to Herschel's volcanoes features in an 1844 book about geology by John Selby Watson (1804–1884) headmaster of a grammar school in Stockwell, London from 1844 to 1870. The preface to his book gives his location on March 30, 1844 as Elizabeth College, Guernsey.

Many such rocky lumps,
Or small or great, are known by men to fall,
And many doubtless fall that ne'er are known.
Nor is it known of any whence they fall;
Whether, far heav'd from forth the fiery hills
That Herschel's tube shows flaming in the moon,
They lose th' attraction of their native orb,
And feel themselves resistless urg'd to earth.[115]

Selby has the distinction of being the only person considered in this chapter who was convicted of murder. He killed his wife in 1871, and died in prison.

We have already seen the 1822 work by Rawlins that includes a nod to the lunar volcanoes, but the first such poem was composed by Rev. William Windle Carr (1735–1791 fl.), who was educated at Sidney Sussex College, Cambridge. Carr also alludes here to the discovery of Uranus as a 'world unknown.' These lines are from "Epistle to the Rev. Mr. S. P."

How Herschel hit, with telescopic aim,
A world unknown, (whose equal rules proclaim,
In science once awak'd how Newton shone,)
Who shews th' Almighty's wonders and his own,
In other orbs how other mountains rise,
And how an Aetna fires the lunar skies.[116]

Like many others he invokes the name of Newton to provide a gloss of superiority to Herschel's name. Herschel's lunar volcanoes were also the subject of derision, an interpretation considered in the section on satire, where the first use of Sicily's Mt. Aetna in this regard can be seen in a poem from 1788.

## Musical Career

The English poet Charles Lamb (1775–1834), instead of mentioning Herschel's career in astronomy, alludes to his musical career in this poem entitled "Free Thoughts on Several Eminent Composers." Music was Herschel's first love, and "it was as a composer that he hoped one day to be remembered."[117] Here Lamb chooses to link Herschel's name with that of another great astronomer, Tycho Brahe (1546–1601); a curious choice, since Tycho had no link to the world of music. The title of this amusing ditty is "Free Thoughts on Several Eminent Composers."

> Old Tycho Brahe, and modern Herschel,
> Had something in them; but who's Purcel?[118]

The answer to this musical question is Henry Purcell (1659–1695), the English Baroque composer who by this time had fallen out of fashion.

## Reputation

Despite tensions between England and France, the French in the 1790s were ready to extol the virtues of Herschel. This can be seen in an excerpt from Chant II of the lengthy poem in eight chants "La Sphere" by Dominique Ricard (1741–1803), a teacher of rhetoric at the college of Auxerre:

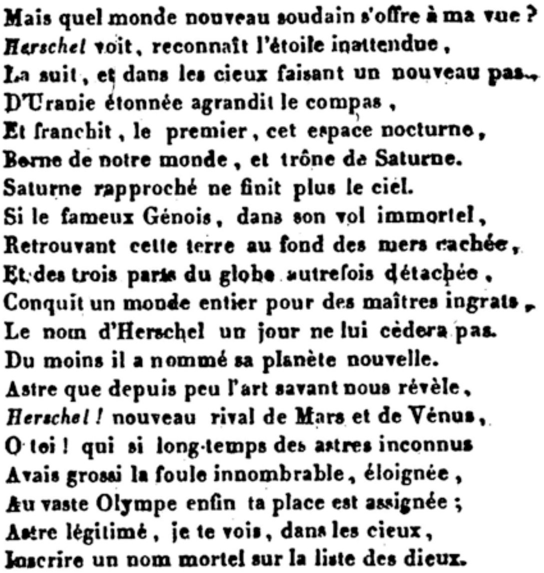
> Et toi, dont les travaux consacrés par l'histoire,
> Assurent à ton nom une immortelle gloire,
> Laborieux Herschel, dont les efforts heureux
> D'une nouvelle sphere ont enrichi les cieux.[119]
>
> And you, with the works consecrated by history,
> Assure to your name an immortal glory,
> Laborious Herschel, through whose happy efforts
> A new sphere has enriched the heavens.

Chant II concludes with these lines about the new planet, which in this case is said to be named Herschel:

> Tout le monde savant consacrant ta conquête,
> Honore de ton nom la nouvelle planete.[120]
>
> All the learned world consecrate your conquest,
> Honor thy name in the new planet.

A French poem by Charles-Julien Lioult de Chênedollé (1769–1833; Fig. 7.13), "l'Astronomie ou Les Cieux," set a high bar for extolling the name of Herschel, even as war raged between his country and England. The 'Genoese' is Christopher Columbus, positioning Herschel as a member of the same ilk: a 'great explorer'.[121]

**Fig. 7.13** Charles-Julien de Chênedollé (Engraving by Charles Devrits, 1844)



Mais quel monde nouveau soudain s'offre à ma vue ?
*Herschel* voit, reconnaît l'étoile inattendue,
La suit, et dans les cieux faisant un nouveau pas,
D'Uranie étonnée agrandit le compas,
Et franchit, le premier, cet espace nocturne,
Borne de notre monde, et trône de Saturne.
Saturne rapproché ne finit plus le ciel.
Si le fameux Génois, dans son vol immortel,
Retrouvant cette terre au fond des mers cachée,
Et des trois parts du globe autrefois détachée,
Conquit un monde entier pour des maîtres ingrats,
Le nom d'Herschel un jour ne lui cèdera pas.
Du moins il a nommé sa planète nouvelle.
Astre que depuis peu l'art savant nous révèle,
*Herschel !* nouveau rival de Mars et de Vénus,
O toi ! qui si long-temps des astres inconnus
Avais grossi la foule innombrable, éloignée,
Au vaste Olympe enfin ta place est assignée ;
Astre légitimé, je te vois, dans les cieux,
Inscrire un nom mortel sur la liste des dieux.

> But what new world suddenly appears before my eyes?
> Herschel looks, discovers an unexpected star,
> follows it, through the skies taking another step.

Surprised by Uranus, he extends the compass,
and is the first to cross this nocturnal space,
border (stone) of our world, and throne of Saturn.
Saturn, brought closer, is no longer the end of the sky.
And if the famous Genoese, in his immortal flight,
finding this hidden land at the end of seas,
and detached of three parts of the globe,
Conquered an entire world for the ingrate masters,
the name Herschel will one day not be forgotten.
At least, he has named his new planet.
Star that only recently the learned art revealed to us,
Herschel! new rival of Mars and Venus,
Oh, you! who for so long of the unknown stars
has added to the innumerable, far away crowd,
in the vast Olympus finally your place has been assigned;
Legitimate star, I see you, in the skies,
Inscribing a mortal name on the list of the gods.

Daru revisits Herschel again in the fifth chant of *L'Astronomie*, showing that his discovery of Uranus is now joined in the heavens by the name of Piazzi for his discovery of Ceres in 1801.

Grands dieux! vous comblez mon espoir;
Un monde est découvert, ma carriere est remplie;
Piazzi peut maintenant abandonner la vie.
Juste orgueil! noble joie! oui, ton nom glorieux,
Avec le nom d'Herschel est écrit dans les cieux.[122]

Great gods! You tantalize my hope;
a world is found, my career is filled;
Piazzi may now abandon the life.
Just pride! Noble joy! Yes, thy glorious name,
with the name of Herschel is written in the heavens.

In the sixth chant, Daru trods familiar ground by linking Herschel with the greats of the past. Like Chênedollé, he enlists Columbus, but makes a distinction between the world below, and the world above where Galileo exemplifies human genius:

  Oh! du génie humain succès toujours croissants!
Colomb ajoute au monde, et Galilée aux sens;
L'un agrandit la terre et l'autre l'Empyrée:
Herschel peuple de feux cette voûte azurée ,
Et Copernic, Kepler, Newton, à tous ces corps
Marquent leur rang, leurs lois, leur force et leurs rapports.[123]

Oh! of human genius ever growing success!
Columbus adds to the world, and Galileo to the senses;
One enlarges the ground and the other the Empyrean
Herschel fills this azure vault with light
And Copernicus, Kepler, Newton, all these men
Mark their rank, their laws, their strength and their reports.

Herschel's name was used as an icon when T. Enort wrote a "Sonnet to Capel Lofft," in which he says the English poet Lofft is "the Herschel of poetic skill."[124] An anonymous book of 1860 includes an enigma poem that links Herschel's name with Ptolemy (100–170), Tycho, Copernicus and the English explorer of the southern hemisphere Captain James Cook (1728–1779). The answer to the identity enigma of ‘me’ in the poem is unhelpfully given as “the letter O”:

> When Herschel first aspired to fame,
> And sought, like me, immortal fame,
> By telescopic aid;
> He saw me in the moon on high,
> And in that comet in the sky.
> Which made fierce Turks afraid,
> Cook saw me in the southern ocean,
> And Ptolemy in solar motion;
> But never in the sun.
> Copernicus and Tycho claim
> From me such consequence and name,
> Ere they their schemes begun.[125]

The linkage with these great luminaries was also evident in a poem by a Scottish chemist; *The Dublin University Magazine* published an article on the scientific work and poetry of Samuel Brown (1817–1856). The anonymous article paints a delightful picture, telling us that Brown, under the general title “The Humanities of Science,”

> ...has strung a necklace of fifteen sonnets on astronomy, every one of which is a diamond worth a minor poet’s ransom...The astronomical sonnets touch on the age of Ptolemy, of Copernicus, of Kepler, and of Newton. The two sonnets on Herschel are quite unique for their depth of thought and beauty of language. All that has been written on the plurality of worlds is here anticipated, if the controversy is not set at rest.[126]

The sonnet on Herschel was published posthumously; the book indicates “The Humanities of Science” was written in 1850:

> HERSCHEL
> I.
> But who is this that spurns the solar day,
> And treads with buoyant feet yon ether thin?
> An eye outside his eye, and one within,
> The dim of night grows clear before his ray.
> Three-sighted mortal! Is the Milky Way
> A single thing?—a crystal made of stars,
> A separate gem among celestial spars;
> Within whose glittering bounds our earth doth play
> A tiny part, and like an atom shines,
> Yet seeks, and so runs round a sparkling dot?
> Poor little world, and poorer still our lot,
> Were Reason not a Power beyond the suns:—
> Eternal thanks to Herschel and to Thought,
> The widening reach of sense the Soul outruns.
>
> II.
> FULL-HEARTED swimmer through the ambient main!
> Our firmament behind, one billow past,
> The starry surge will never yield a last.
> Outward they sound for ever, their refrain
> Not to be caught or written down. In vain
> Shall man, ay, or archangel, struggle o’er

Their gleaming crests to find a further shore.
Coast there is none, nor sky, nor pleasant rain;
No usual limit, no accustomed thing;
Nothing but glory, glory poured until
Infinity is full. Back, venturous Will,
Back to our homely rock;— and with thee bring
This word of truth from space, for me to sing:—
'Tis all too little yet poor Man to fill![127]

The first stanza represents a paean to Reason as much as it is a panegyric of Herschel. To provide necessary texture to the sonnet, we must look back to the eighteenth century. The great Scottish poet James Beattie (1735–1803) divined the elements embodied by the sonnet in his own composition "Minstrel." After some lines about the muse of history, philosophy (accompanied by science) comes under examination

The mind untaught
Is a dark waste, where fiends and tempests howl;
As Phoebus to the world, is Science to the soul.

And Reason now, through Number, Time, and Space,
Darts the keen lustre of her serious eye,
And learns, from facts compared, the laws to trace,
Whose long progression leads to Deity.
Can mortal strength presume to soar so high!
Can mortal sight, so oft bedimm'd with tears,
Such glory bear!—for, lo, the shadows fly
From nature's face; confusion disappears,
And order charms the eyes, and harmony the ears.[128]

The application of reason through time and space can be found at the heart of the sonnet of 1850. Both poets invoke the soul, and a higher being, whether an archangel or a deity. Beattie wonders if a mortal, soaring too high, could bear the sight. The poet of 1850 says a mere mortal would have to come back to earth when faced with infinity, a glory that could not be borne. He realises that only through song could the truth of space be conveyed. Beattie likewise invokes a harmony conveyed through the sense of hearing as the path to understand nature. Thus we can understand the 1850 creation as an extension of thoughts that were already current in the previous century. Herschel may have been the driver of the poem, but the vehicle he rode had been made long before.

The line 'three-sighted mortal' in the sonnet refers to Herschel's two mortal eyes, plus the telescope. After the first stanza which addresses the nature of the Milky Way, the second stanza embodies a grand allusion to Herschel's extra-solar research that saw no end, or coast, in sight. It conveys a message brought back to earth from space: Man cannot grasp the immensity of the cosmos. Infinity is explicitly named here, in the sense of numberless stars ('the starry surge' that will never yield). The poet also uses the imagery of our 'homely rock,' which evokes Herschel's description of our 'retired corner' of the cosmos. These very elements formed the core of a letter written September 23, 1785 by the former Member of Parliament Sir Horace Walpole, the Earl of Orford (1717–1797). Here he addresses the Earl of Buchan (his *emphasis set* in regular type):

**Fig. 7.14** Thomas Hood (National Portrait Gallery (NPG855), London)

> The discoveries made by Herschell(sic), which you have been so good as to communicate, are stupendous indeed: You have launched my meditations into such a vast field, that if I tapped one channel, I should write a volume, and perhaps finish in the clouds. How puny, how diminutive are those discoveries we used formerly to boast of, when compared to those of Herschell, who puts up millions of covies of worlds at a beat...Stupendous as Mr. Herschell's investigations are, and admirable as his talents, his expression of our *retired corner* seems a little improper. When a little emmet standing on its ant-hill, could get a peep into infinity, how could he think he saw *a corner of it*? A retired corner! Is there a bounded side to infinitude? If there are twenty millions of worlds, why not as many and as many more? Oh! One's imagination cracks![129]

This letter's value lies in giving us a sense of how an intelligent reader of the 1780s viewed Herschel's discoveries, which were far from over at that early period of his career. The poets who wrote the eighteenth century verses considered in this chapter were, to a large extent, writing for the audience represented by Walpole. As the nineteenth century progressed, that poetic audience broadened to include youngsters, women and an increasingly literate populace.

An example comes from the mid-century in a light-hearted and slightly naughty poem by the wit and humourist Thomas Hood (1799–1845; Fig. 7.14) entitled "The Comet." Here Juno doubly refers to the asteroid, and the Queen of the Heavens, wife of the god Jupiter.

Amongst professors of astronomy,
Adepts in the celestial economy,
    The name of Herschel's very often cited;
      And justly so, for he is hand and glove
      With every bright intelligence above;
      Indeed it was his custom so to stop,
      Watching the stars upon the house's top,
      That once upon a time he got benighted.
      In his observatory thus coquetting
      With Venus, or with Juno gone astray.[130]

## Satire and Barbs

When one thinks of eighteenth century satire, English satire is almost exclusively meant. The French political philosopher Montesquieu (1689–1755) discerned "The character of the nation is more particularly discovered in their literary performances." In England, he singled out their satirical writings, which are "sharp and severe."[131] Thus the criticism levelled at Herschel must be placed within the context of late eighteenth century/early nineteenth century English society. In 1781 Thomas Warton famously said "Satire is the Poetry of a Nation highly polished."[132] According to the English satirist and scholar of Italian, Thomas James Mathias,

> **…** all publick men, however distinguished, must in their turns submit to satire … [and] satire can never have effect, without a personal application … [since] it must come home to the bosoms, and often to the offences of particular men.[133]

At the core of satire was a way of looking at whatever events life might value, and telling the truth about them to what Bucknell terms a "perverse degree. Satire scourged, exposed and illuminated...Satire stripped back, pared down and zoomed in."[134] In 1786 Charles Abbott identified four types of satire: personal, political, moral and critical.[135] The satire directed at Herschel was primarily personal.

Herschel's reputation as England's most prominent astronomer, which was lauded in the verse just considered, made him a ready target not just for satire but its ugly stepsister the lampoon. Dr Samuel Johnson, in his famous *Dictionary* of the 1780s, defined lampoon as a "personal satire" that aimed "… not to reform but to vex."[136] It must have vexed Herschel personally that some critics were convinced he was truly unhinged and worried over his tendency to irreligion.

According to Mathias: "It (satire) never has its full force, if the author of it is known or stands forth; for the unworthiness of any man lessens the strength of his objections."[137] As a leading light of the scientific establishment, it is thus not surprising to find Herschel one of its victims, and it started quite early. The first satiric use of Herschel's name (mis-spelled as Herschal) appeared in an anonymous publication of 1788. The scene is an outdoor cricket event, and the King has just left the crowd. A 'shrewd wit' attempts a meeting with the King before he returns home, but a royal courtier, contemptuously referred to here as a 'fawning sycophant', says he has already left:

> If thou, thou fawning sycophant, are right,
> Then, say, what cloud has ta'en him from the fight?
> Has he, with distant comets, wander'd far?
> Or ta'en an airing, Herschal, to thy star?
> To see his cool intention thus succeed,
> Was, to a wit, all that a wit could need.[138]

Wit is an essential ingredient in a satire. Wit, and the parlous state of poetry in the 1780s, was a central theme in *The People's Answer to the Court Pamphlet*, part of a cycle of politically motivated publications revolving around King George III. The sobriquet Georgium Sidus was bandied about between *The People's Answer* and its rejoinder. We do not know what Herschel thought of his planetary name becoming

**Fig. 7.15** King George III by Allan Ramsay, 1762

politicised, but one can reasonably expect he was dismayed. *The People's Answer* in 1786 begins with these lines (Baeotian means without cultural refinement):

> When a new face, a new carriage, a new play, a new poem, a new novel, or even a new pamphlet appears; if the stile of the features, the pannels, the plot, the versification, the story, or the politics, be really new; a thousand busy inquiries are instantly on foot, to analyse and to criticise its merits. But so few are the classics of the Court, in modern times, so completely Baeotian are the talents that St. James's can boast, that even a Charade from one of the King's Friends would excite more admiration than a dozen Probationary Odes from Opposition. The circle at the Levee, like the orbit of the Georgium Sidus, is so distant from the Sun of Wit, as scarcely to admit its feeblest light, with difficulty partake its least animating ardour.[139]

The *Rejoinder to the People's Address* by its opposing (and pro-monarchist) forces was published in short order; it took exception to the last sentence just quoted.

> Now, it is certain that Herschell's planet is a great way removed from the sun: but whether or not that sun be the sun of wit, remains to be proved. He cannot surely mean Apollo? Because, even allowing master Apollo to be a wit, as he is the god of verse, to form a simile by a figure, is beyond the comprehension of either Burke or Longinus. Very likely he meant the sun of wit to be [Richard Brinsley] Sheridan, and the Georgium sidus our gracious monarch.[140]

A satiric swipe against the King and Sir Joseph Banks (1743–1820), President of the Royal Society, appeared in 1788. David Williams writes that King George (Fig. 7.15) confesses "I love fame, but can obtain none!" He saw his chance when Herschel discovered a planet:

> When Herschel discovered a planet, I took him under my protection, on condition it should be called by my name. All Europe have revolted at the absurdity; and not an astronomer out of England (and the astronomer royal only in England) will call it Georgium Sidus. I directed Banks to have proper papers in the royal society to secure this appellation; and to magnify the importance of the discovery, as compensating the loss of America. Banks did

**Fig. 7.16** John Wolcot by John Opie (National Portrait Gallery (NPG830), London)

> all in his power; but declared no good could be done with the society until all the old independent members were gone, who were in habits of intimacy with [Benjamin] Franklin; and they would render the society the instrument of my pleasure in any thing. That Banks is an odd animal...–he is a servile courtier. A spy on the philosophical world – he enables me, unperceived, to direct my influence against impertinent and innovating genius.[141]

The imagery invoked here, linking as it does the result of the American Revolution with the naming of the new planet, paints the King as a cynical but calculating fool. "To satirists, George's sidereal translation, especially at the hands of a Hanoverian in his service, was an apt emblem of regal pretence and of British imperialism."[142]

Herschel was one of the astronomers targeted in a scathing satire written by the famous John Wolcot (1738–1819; Fig. 7.16), who wrote "more than sixty satires of varying length from 1782 to 1817" under the name Peter Pindar. His works were wildly popular, with upwards of 30,000 copies printed daily.[143] In a supposed conversation with Banks, Pindar, in his 1788 work "Peter's Prophecy," takes an opportunity to mock lunar volcanoes, suggesting Herschel may next discover not only more volcanoes like Mt. Aetna on Earth, but mail coaches on lunar roads! Like the satire by Williams, Pindar uses Banks as a foil to reflect his own splenetic thoughts.

Sir Joseph Banks
God bless us! What to HERSCHEL dare you say,
The astronomic genius of the day,
Who soon will find more wonders in the skies,
And with more *Georgium Siduses* surprise?

Peter Pindar
*More* Aetnaes in the moon–more cinder loads!
Perhaps mail-coaches on her turnpike roads,
By some great LUNAR PALMER taught to fly,
To gain the gracious glances of the eye

Of some *penurious man* of high degree
And charm the monarch with a *postage free*...
But, voluble Sir Joseph–not so fast–
The fame of Herschel is a dying blast:
When on the moon he first began to peep,
The wond'ring world pronounc'd the gazer, *deep*:
But wiser now th' *un*-wondering world, alas!
Gives all poor Herschel's glory to his *glass*;
Convinced his boasted astronomic strength,
Lies in his *tube's*, not *head's enormous* length.

Sir Joseph
What, niggard! Not on Herschel's fame bestow,
So curious a discoverer ?–

Peter
No! Man, no!
Give it MUDGE, whose head contains more
Than (trust me) ever lodg'd in HERSCHEL's house.[144]

He refers here to Dr. John Mudge (1721–1793) of Plymouth. Like Herschel, Mudge also made telescopes, so Pindar strikes at a incendiary issue by suggesting Mudge's intellect – and by implication his telescopes – are superior. Also mentioned is John Palmer (1742–1818), who proposed to the government in 1782 a way to speed mail delivery by coach. A footnote to this portion of the satiric verse represents the real plunge of the knife into Herschel's abilities, just in case the nearly libellous intent of the verse was not clear:

> We would not detract from Mr. Herschel's real merit. —By a true German cart-horse labour, he made a little improvement on Dr. Mudge's method of constructing mirrors: such are this gentleman's pretensions to a niche in the temple of Fame—As for his mathematical abilities, they can scarcely be called the shadows of science.[145]

This final 'swipe' goes to the heart of the fact that no contemporary astronomer in England performed any serious mathematical calculations on the orbits of the asteroids or any other aspect of celestial mechanics.

Wolcot began a long series of satires on scientists–and Banks in particular–in 1788.[146] His most outrageous satire involving Herschel appeared in the *Lousiad*, where a louse is saved from the King's fingers and transported to the sky "which is thereupon discovered by Herschel, and solemnly named the Georgium Sidus."[147] Thomas Arnold, Professor of English in the University College, Dublin delivered a devastating critique of Pindar and this satire. "The natural vulgarity of his mind was never corrected, nor his irrepressible conceit ever rebuked, by the association with his betters at a university...It would be difficult to name a literary work exhibiting a more pitiful debasement of the human intellect than the *Lousiad*, published in 1786."[148] Pindar pillories Herschel for his lunar volcano writings in the second canto of the *Lousiad*:

Charm'd with the cadence of a lucky line,
Who taste a rapture equal, GEORGE, to thine;
When blest at DATCHET, through thy HERSCHELL'S glass,
That brings from distant worlds a horse, an ass,
  A tree, a windmill, to the curious eye,

> Shirts, *stockings*, blankets, that on hedges dry;
> Thine *eyes*, at evenings late and mornings soon,
> Unsated *feast* on wonders in the moon;
> Whilst *Herschell* on volcanos, mountains, pores,
> And *happy* Nature's true sublime explores;
> Whilst *thou* so modest (wonderful to tell!)
> On *LUNAR trifles* art content to dwell,
> Flies, *grasshoppers*, grubs, cobwebs, cuckow spittle,
> In short, *delighted* with the world of *little*,
> Which *West* shall paint, and grave Sir Joseph Banks
> Receive from thy historic mouth with thanks.[149]

In this unremitting assault, Pindar questions Herschel's much vaunted modesty, and takes a swipe at Banks as one who will gladly receive any little trifles of knowledge from Herschel. Pindar mentions here the history painter Benjamin West (1738–1820). A modern scholar sees geopolitical implications in this work. "So the louse is Germanized, and in its person Germany dominates Britain from the sky."[150] Wolcot also alleges here the King is not interested in the majesty of the heavens, but only in the everyday objects he imagines seeing through Herschel's telescope while looking at the Moon.[151]

Another satiric blast against Herschel was penned in 1789 by someone calling himself Tom Plumb.[152] Like Pindar, his work was printed by the Fleet Street publisher George Kearsley who was arrested for publishing seditious libel in 1763. A measure of Herschel's fame may be gauged by the fact Plumb's publication was noted in a major London-based magazine, and reviewed in three others (see Appendix 1 for the full text). Plumb's work was listed in *The Town and Country Magazine* as "A satire on Mr. Herschel's late marriage, the consummation of which event is handled with much pleasantry."[153] *The General Magazine and Impartial Review* offers the most concise (and damning) notice:

> Mr. Herschel's late marriage gives birth to this ludicrous composition, in which the poet makes the astronomer often quit his bride in the night in order to watch the stars. This performance has more waggishness than wit to it.[154]

The reviewer emphasizes the word waggishness, which means playful in a facetious manner. *The Monthly Review* in 1789 has this to say about it:

> Tom Plumb, like his favourite model, Peter Pindar, who was sometimes very unhappy in his choice of subjects for his satire, has here unluckily stumbled on a most improper object for ridicule, viz. the very meritorious and inoffensive Dr. Herschel; whom he laughs at, and treats as a mere star-gazer—a Partridge, or a Gadbury—busying himself o'nights in peeping at the heavens, through his vast telescope, instead of remaining in bed with his wife. On this last circumstance, all the wit of the poem turns; —but surely this is too poor for a grave and formal censure![155]

Partridge was John Partridge (1644–1715), who was ridiculed by the great British satirist Jonathan Swift (1667–1745). "Partridge acted for some time as assistant to [John] Gadbury (1627–1704): he commenced astrologer on his own account in 1679."[156] *The English Review* offers a fuller exploration of the satire, but also finds the work full of faults.

> This poem, which is founded on the circumstance of Mr Herschel the astronomer having lately married a widow of his neighbourhood, is obviously written on the model of the long reprobrated, yet still imitated Peter Pindar! It is not in general without whim, and there occurs at intervals a point of particular merit; if it be written by a young man, as we have some reasons to presume it is, we shall willingly receive it as a presage of something better.
>
> But with the flights we must observe he has also many of the faults of juvenility. Of these the most prominent is, that when he hits on a good point, he pursues it too far, and quits it with seeming reluctance. 'These players, when they get hold of a good thing, never know when they have enough of it.'
>
> Thus, after saying that on the wedding-night he should not have left his bride, though all the stars in the firmament were to change their places; and that
>
> 'The Bear, from his fast-fixed pole
> To which he is staked, had burnt his chain
> Ere I from bridal bed had stole
> To bring old BRUIN back again!'
>
> Then the waggoner, and the scales, the virgin and the lock of Berenice, the bull, the ram, and goat, are all brought down until not a constellation is left, and criticism is compelled to yawn out its
>
> 'O he! jam satis!'[157]

The first few stanzas of this lengthy poem bemoan the fact no serious poet had commemorated Herschel and his discovery. While a few poems did mention Herschel prior to 1789, it remains true the dearth of a landmark poetic tribute was remarkable: "not of praise a single line," he laments. Since the noted poets he names have been silent, Tom Plumb himself steps up to fill the gap: "Herschel, thou shalt not want a fiddle." He then mentions the telescope that has enabled Herschel to make his great discoveries, "The wond'rous tube with which you spy," including not just volcanoes on the Moon but sentient beings there – Herschel had maintained since the 1780s his belief in the existence of life on the Moon. This was one of several "lunatick visions" that pervaded thought in London at the time.[158] In another aspect of the poem, Plumb rightly gives credit to Herschel for making the mirror himself.

Up to this point the poem has been one praise for Herschel, but Plumb then churlishly accuses Herschel of quickly marrying Mrs. Pitt for money: a "widow rich in guineas." The poem then descends to farce instead of satire when he says Herschel sprang from his bed on the wedding night no less than seven times. Why? To gaze at the heavens! Plumb feigns sympathy with the new Mrs. Herschel: "Thy wife I pity from my soul," suggesting she take him to the court of love for violating Cupid's rules. Plumb tells Herschel he must choose: "By night *your wife*, or else *the stars*." While not a bitter attack on Herschel, even the contemporary reviewers found it in poor taste; their assessments quoted earlier remain valid.

Early in the next century, the English physician John Coakley Lettsom (1744–1815), who founded the Medical Society of London, wrote this tripe in 1801:

> When Herschel fixed the site of the Georgium Sidus in the great volume of the heavens, you raised the theme of ardent praise to this unrivaled astronomer; but what is the Georgium

> Sidus, in competition with the Jennerian discovery? Has it conveyed to one human being a single ray of advantage?[159]

Lettsom here makes a comparison between Dr. Edward Jenner (1749–1823), pioneer of the smallpox vaccine in 1796, and Herschel's discovery of a planet. The author goes on state Jenner's discovery will save 210,000 lives annually in Europe alone. While he was quite right to imply an astronomical discovery has no tangible effect on human life, he thus completely ignores the advance of reason to increase our knowledge of the universe. The extreme utilitarianism of the good doctor may have given expression to the thoughts of some of the ill educated, but it can hardly be regarded as an opinion widely held by the intelligentsia. The editor of *The Critical Review* printed a review of Lettsom's book in 1802, which included the following stinging rejoinder. It shows the strategic perils of penning a satire under one's own name:

> …We think he merits no slight punishment for the pompous, inflated language of this tract, for the fulsome flattery which it contains, and the ridiculous exaggeration of every part of the subject….With respect to the exaggerated panegyric on Dr. Jenner, we must again repeat that it was no discovery; it was at least no discovery which he could claim – a fact well known among milkmen. He tried under his own eye, and published, the experience of others as well as of himself...On the whole, we are greatly disgusted with this flimsy performance, and can only remind Dr. Lettsom, that greater efforts are often necessary to preserve than to gain a character.[160]

This contretemps is all the more remarkable in light of an anonymous epigram published six years earlier.

> Compar'd with *great* Lettsom, how *little* is Herschel,
> A world he discover'd, but Lettsom the Wurzell;
> That far distant orb with contempt we should treat,
> What good will it do? Now the root we can eat,
> Herschel's *star* is thus prov'd much inferior to *beet*.[161]

While at first blush it appears to be a slap at Herschel's discovery, I believe it is actually a thinly veiled attack on Lettsom's promotion of the ingestion of the root vegetable mangel-wurzel, also known as a field beet (or, as termed in Pindar when he pokes fun at Lettsom, a horse beet).[162] The fact the word 'great' is emphasized in relation to Lettsom signals just the opposite to be the case – the satirist mocks Lettsom, who by his numerous public diatribes on a wide range of topics set himself up as one who knew everything. He was the perfect foil for satire. Likewise the satirist tells us that Herschel's discovery should not be treated with contempt, even though his actual words say the opposite. This clearly upset Lettsom, who later penned his own words to belittle Herschel's discovery in comparison to that of Jenner. This backfired spectacularly, as he was savaged in the very public pages of *The Critical Review*.

The *Monthly Review* ran a piece about an 1808 satirical book (An Heroic Epistle to Mr. Winsor) lampooning Frederick Albert Winsor (1763–1830; Fig. 7.17), "the patentee of the Hydro-carbonic Lights, and Founder of the National Light and Heat Company." The reviewer writes the "satire is directed with great skill…When the poet's satirical car has been for some time in motion, it acquires a momentum"

**Fig. 7.17** Frederick Albert Winsor

which eventually sees the poet standing up to read a lecture at the Royal Philosophical Lecture-Shop.[163] The epistle concludes with these lines:

> Perhaps, translated to another sphere,
> Thy spirit like thy light refin'd and clear,
> Balloon'd with purest hydrogen shall rise,
> And add a PATENT PLANET to the skies;
> Then some sage Sidrophel, with HERSCHEL-eye,
> A bright WINSORIUM SIDUS shall descry;
> The VOX STELLARUM shall record thy name,
> And THINE outlive ANOTHER WINSOR'S fame![164]

Sidrophel was an astrologer in "Hudibras," a satirical polemic composed in the 1660s and 70s by Samuel Butler (1630–1680). The Win[d]sorium Sidus is none other than the 1807 founder of National Light, which the poet opines might outlive "another Winsor," namely King George III whose largest abode was Windsor Castle. The *British Critic* was ecstatic about "An Heroic Epistle." "We hail this effusion as one of the happiest, most pointed, and most witty pieces of satire on a temporary delusion, which has appeared since the days of [Jonathan] Swift."[165] According to Hunt, "It is quite conceivable that the attacks on Winsor did, as he asserts, actually help his cause, by bringing it into notoriety."[166] These lines also embody in poetic verse the potential of earth-bound companies to reach the heavens, a prospect envisioned with some horror by the radical English writer Thomas Spence in a letter he wrote in London on October 8, 1800.

> Monopoly is injustice, let it be of what kind it will, whether of government, land, or trade, therefore I cannot help abhorring that national thirst of ours, after the universal trade of the world, to the prejudice of all other nations. But this external monopoly is plainly the offspring of our internal monopoly. For the same covetousness which is nourished at home, by the oppression of fellow-citizens expands like ambition in its maturity till it grasps at the whole earth. Neither would the moon or planets elude our harpy claws, could we but find a passage thither, and we should soon hear of companies established to monopolise the celestial trade also.[167]

Satire was a dying art by the late 1820s, so it is no surprise to find a rather scatological limerick that tests the limits of poor taste, which we find in a book by R. Machan:

> *Herschel*, to acquire renown great as a *Milton's*,
> To number the Stars once an enormous *Tube made*;
> And because plac'd on th' stage t' be supported at *Ease*,
> Was called by an impudent *Wag, a Toilet.*[168]

The English literary critic T.S. Eliot (1888–1965) observes that in the type of poetry he identifies as discursive exposition or an argument, "Immense technical skill is necessary to make such discourse fly, and great emotional intensity is necessary to make it soar."[169] He mentions both Pope and Dante as exemplars who possessed this skill. A dispassionate examination of the poetry quoted in this chapter that expounded arguments to explain Herschel's discoveries will conclude most had their wings clipped, Shelley and Byron being notable exceptions. This deficiency was not lost on analysts of the early nineteenth century. Speaking of Erasmus Darwin's poetry in "Botanic Garden," one reviewer caustically wrote. "Darwin displays no intensity of emotion, and no intimate acquaintance with the latent springs of human conduct."[170] Thus he did not fully capture the exalted themes inherent in the subject of gardens that Mara Miller so ably grasps: "Gardens combine cosmic time...biological time... and often geological time."[171]

I noted near the beginning of this chapter the lament of Herschel's biographer that no suitable poem had been written to commemorate him. So ultimately we must ask why Sime felt this was even necessary. The answer can be found in the Roman poet Ovid, who wrote of the gods that "...their great majesty needs the poet's voice."[172] If the gods themselves need such a voice, surely the first mortal to expand the cosmos with the discovery of a new planet needed it too. As the Italian philosopher Franco Berardi writes, "Rhythm is the inmost vibration of cosmos, and poetry is an attempt to tune in to the cosmic vibration."[173] The century-long quest to tune poetry to match the cosmic vibration revealed by the discoveries of William Herschel explored in this book has been the subject treated here.

I conclude on the uplifting note that original poetry about William and Caroline Herschel is not entirely a thing of the past. The Australian poet Alec Derwent Hope wrote "Sir William Herschel's Long Year" in 1985[174] (Table 7.1); in the 1968 poem "Planetarium," the American Adrienne Rich (1929–2012) discovered in Caroline Herschel a role model[175]; and in 2013 Laura Long published a short book, *The Eye of Caroline Herschel: A Life in Poems*.[176]

**Acknowledgements** Thanks to Roger Ceragioli for his translation of the Latin texts, and James Lequeux for the French texts except for that of Ricard. Special thanks to Wayne Orchiston, who supervised my thesis which largely dealt with William Herschel. A portion of the text in this paper dealing with Peter Pindar previously appeared in a book I published in 2016.[177]

**Table 7.1** A list of 47 poems related to William Herschel

| Author | Year | Language | Main focus, allusion or reference |
|---|---|---|---|
| Tasker | 1783 | English | Georgian Star |
| T. | 1784 | English | Georgium Sidus |
| Pratt | 1785 | English | Prologue to a play |
| Anon | 1786 | German | Alludes to Herschel |
| Wolcot/(Pindar) | 1786 | English | Satire |
| Uranophilo | 1786 | Latin | Nomenclature |
| Szerdahely | 1788 | Latin | Telescope, Uranian moons |
| Williams | 1788 | English | Satire |
| Plumb | 1789 | English | Satire |
| Nairne | 1791 | English | Georgium Sidus, telescope |
| Carr | 1791 | English | Lunar volcanoes, Uranus |
| Darwin | 1791 | English | Stellar research |
| Anon | 1795 | English | Discovery of Uranus, lunar volcanoes |
| Mathias | 1795 | English | Discovery of Uranus |
| Ricard | 1796 | French | Reputation, discovery of Uranus |
| Anon | 1796 | English | Royal verse |
| Hayley | 1799 | English | Herschel’s acuity |
| Gudin de la Brenellerie | 1801 | French | Discovery of Uranus |
| Lettsom | 1801 | English | Satire |
| Colquitt | 1802 | English | Georgium Sidus, telescope |
| Fessenden | 1804 | English | Herschel’s acuity |
| Darwin | 1803 | English | Georgian star |
| Delille | 1805 | French | Discovery of planets, mention of Newton |
| Trevelyan | 1806 | English | Georgium Sidus |
| Chênedollé | 1807 | French | Reputation |
| Anon | 1808 | English | Satire |
| Mangnall | 1808 | English | Orbital period; satellites |
| Gudin de la Brenellerie | 1810 | French | Satellites of Uranus; Reputation |
| Gisborn | 1813 | English | telescope |
| Anon | 1815 | Scots | Georgium Sidus, telescope |
| Wolcot | 1816 | English | Satire, telescope |
| Keats | 1816 | English | Inspired by discovery of Uranus |
| Platts | 1821 | English | Discovery of Uranus |
| Rawlins | 1822 | English | Lunar volcanoes |
| Machan | 1824 | English | Satire |
| Beddoes | 1827 | English | Discovery of Uranus |
| Sigourney | 1827 | English | Reputation of Herschel |
| Lofland | 1828 | English | Georgium Sidus |
| Crossley | 1828 | English | Looking at Milky Way, viewing planets; double stars |

(continued)

**Table 7.1** (continued)

| Author | Year | Language | Main focus, allusion or reference |
|---|---|---|---|
| Daru | 1830 | French | Discovery of Uranus; Reputation of Herschel |
| Lamb | 1836 | English | Musical career |
| Watson | 1844 | English | Lunar volcanoes |
| Watts | 1849 | English | Georgium Sidus |
| Brown | 1850 | English | Reputation |
| Anon | 1860 | English | Reputation |
| Chapin | 1866 | English | Reputation |
| Hood | 1867 | English | Reputation |

## References

1 Reik, M.M. 1977. *The golden lands of Thomas Hobbes*, 152. Detroit: Wayne State University Press.

2 Molesworth, W. 1840. *The English works of Thomas Hobbes of Malmesbury*. Vol. 4, 452. London: John Bohn.

3 Wordsworth, W. 1800. *Lyrical ballads*. 2nd ed. London: Longman and Rees.

4 Hunter, D. 1838. *The satires and Epistles of Horace*, 226. London: John W. Parker.

5 Recent epics. 1852. *The Quarterly Review* 90: 333–362.

6 Home ballads and poems. 1861. *The North British Review* 34(67): 210.

7 Lundeen, K. 1789. On Herschel's forty-foot telescope. *Branch*: *Britain, representation and nineteenth-century history*. *Extension of romanticism and victorianism on the net*, ed. Dino Franco Felluga. Web 27 Feb 2017.

8 Chatelain, D., and G. Slusser. 2009. The creation of scientific wonder: Jules Verne's dialogue with Claude Bernard. *Verniana* 2: 89–123. p. 91.

9 Stillinger, J., ed. 1990. *John Keats: Poetry manuscripts at Harvard*, 212–214. Cambridge: Belknap Press of Harvard University Press.

10 Burney, F. 1893. *Diary and letters of Madame d'Arblay*. Vol. 4, 100. New York: Swan Sonnenschein & Co.

11 Rawlins, W. 1822. To Sylvanus Urban, on completing the second part of volume XCII. *Gentleman's Magazine* 92: ii.

12 Sime, J. 1900. *William Herschel and his work*, 216. New York: Charles Scribner's Sons.

13 Gossin, P. 2007. *Thomas Hardy's novel universe*. Burlington: Ashgate.

14 Grabo, C.H. 1930. *A Newton among poets: Shelley's use of science in Prometheus unbound*, 170. Chapel Hill: University of North Carolina Press.

15 footnote 14, pg. 88.

16 footnote 14, pg. 85.

17 Herschel, W. 1811. Astronomical observations relating to the construction of the heavens. *Philosophical Transactions* 101: 269–336.

18 Hoskin, M. 2013. William Herschel on the galaxy and the nebulae. In *The harmony of the sphere*, ed. S. de Bianchi. Newcastle upon Tyne: Cambridge Scholars Publishing.
19 Shelley, P.B. 1820. *Prometheus unbound*, 129. London: C. and J. Ollier.
20 footnote 14, pg. 166.
21 Crowe, M. 1999. *The extraterrestrial life debate 1750–1900*, 232. Mineola: Dover Publications.
22 Herschel, W. 1786. Catalogue of one thousand new nebula and clusters of stars. *Philosophical Transactions* 76: 457–499.
23 Ebbatson, R. 2013. *Landscape and literature 1830–1914: Nature, text, aura*. Basingstoke: Palgrave Macmillan.
24 Khan, J. 2015. *Perspectives: Romantic, Victorian and modern literature*, 205. Newcastle upon Tyne: Cambridge Scholars Publishing.
25 Day, T. 2013. Sensuous and scholarly reading in Keats's 'On First Looking Into Chapman's Homer'. *Glossator* 8: 115–122.
26 see footnote 23.
27 Brothers, D.W. 2015. *The romantic imagination and astronomy*, 99. Basingstoke: Palgrave Macmillan.
28 see footnote 23, p. 205.
29 Roe, N. 1997. *John Keats and the culture of dissent*, 36. Oxford: Oxford University Press.
30 Schaffer, S. 1986. Scientific discoveries and the end of natural philosophy. *Social Studies of Science* 16 (3): 387–420.
31 Klancher, J. 2013. *Transfiguring the arts and sciences*, 139. Cambridge: Cambridge University Press.
32 Rowan-Robinson, M. 2013. *Night vision: Exploring the infrared universe*, 22. Cambridge: Cambridge University Press.
33 see footnote 32
34 see footnote 32
35 see footnote 7
36 Anon. 1795. *An asylum for fugitive pieces in prose and verse, not in any other collection*. Vol. 3. 2nd ed, 248. London: J. Debrett.
37 Smart, C. 1767. *Some thoughts on the English language*, The Annual Register for the Year 1766, 194–197. London: J. Dodsley. p.197.
38 Cunningham, C.J. 2016. Milton's Paradise Lost: Previously unrecognised allusions to the Aurora Borealis, and a solution to the comet conundrum in book 2. *Renaissance and Reformation* 39 (1): 5–33.
39 Ruthven, K.K. 1969. The poet as etymologist. *The Critical Quarterly* 11 (1): 9–38.
40 Dreyer, J.L.E. 1912. *The scientific papers of Sir William Herschel*. Vol. 1, xxxvi. London: The Royal Society and the Royal Astronomical Society.
41 Review of a Graecian Ode by George Pryme. 1806. *The Critical Review* 7(third series): 29–35, p. 29.
42 Holland, E.G. 1861. *Niagara. And other poems*, 55. New York: Rudd and Carleton.

43 Tasker, W. 1783. *Annus Mirabilis*. 2nd ed, 45. Exeter: Baldwin & Dodsley.
44 The London Magazine 1, September 1783. 241.
45 The Gentleman's Magazine 53, February 1783. 156.
46 The Gentleman's Magazine 53, August 1783. 691–692, p. 692.
47 The Monthly Review 68. 1783. 120–123, p. 121.
48 The London Magazine 3, November 1784. 378.
49 Pratt. 1785. Prologue to the orphan of China, written by Mr. Pratt and spoken by Mr. Fector, at his private theatre in Dover. *The London Magazine* 4: 190.
50 An account of William Fector. May 1789. *The European Magazine and London Review* 15: 347–348.
51 Der neue Planet. 1786. In *Deutsches museum*, Vol. 1. Leipzig: Weygand, 563.
52 Cunningham, C.J., and G. Oestmann. 2013. Classical deities in astronomy, the employment of verse to commemorate the discovery of the planets Uranus, Ceres, Pallas, Juno and Vesta. *Culture and Cosmos* 17 (1): 3–29.
53 Uranophilo. 1786. *Lis Astronomorum de Nomine quo planeta recens anno 1781 die 13 Martii aquis solis (Bathe) in Anglia a D. Herschel*. Vienna: Joan. Thom. nob. de Trattnern.
54 Standfast, G. 1856. On the queen's visit to London the night of the seventeenth of March, 1789. In *The poetical works of William Cowper*. New York: J.C. Derby, 482. Humphreys, J., 1875. The King: God Bless Him. *The New Monthly Magazine* 8: 781–791, 787.
55 Nairne, E. 1791. Irregular address to the moon. In *Poems, miscellaneous and humourous*, 91–113. Canterbury: Simmons and Kirkby, 107.
56 Carretta, V. 1990. *George III and the satirists from Hogarth to Byron*, 242. Athens: University of Georgia Press.
57 Mathias, T. 1798. *The imperial epistle from Kien Long, Emperor of China, to George the Third*. 4th ed, 81. London: T. Becket.
58 see footnote 57
59 The Gentleman's Magazine 80, July 1796. 562.
60 Pye, H.J. 1800. *Carmen seculare for the year 1800*, 26–27. London: J. Wright.
61 Review of Carmen seculare by James Pye. 1800. The *Anti-Jacobin Review and Magazine* 6(23): 100–103, p. 103.
62 Church, E. 1802. *The inquisitive traveller: A poetic essay*. London: J. Ridgway.
63 see footnote 62, pg. 51.
64 Colquitt, W. 1802. *The astronomer, in poems*, 14–25. Chester: W. C. Jones. p. 21.
65 see footnote 64. Quote from Preface.
66 Gudin de la Brenellerie, P.P. 1801. *L'Astronomie, Poëme en trois Chants*, 23. Auxerre: Laurent Fournier.
67 Gudin de la Brenellerie, P.P. 1810. *L'Astronomie, Poëme en quatre Chants*, 60. Paris: Didot.
68 see footnote 67, pg. 66.
69 Darwin, E. 1803. *The temple of nature*, 148. London: J. Johnson.
70 Trevelyan, R. 1806. Creation. In *Prolusiones partim Graecè, partim Latinè Scriptae*. College of Divinity Johan Cantabrigae. London: Mawman. Published

in English in his book *Essays and Poems*. (Hatchard & Son, London, 1833), 53–61, p. 55.

71 The Anti-Jacobin Review, 27. 1807. 150.

72 Latto, T.C., ed. 1845. *The minister's Kail-Yard, and other poems*. Edinburgh: J. Menzies.

73 footnote 72, pg. 18.

74 Mangnall, R. 1808. *Historical and miscellaneous questions for the use of young people*. 6th ed, 341. London: Longman, Hurst, Rees, and Orme.

75 Platts, J. 1821. *The literary and scientific class-book*, 186. London: G. and W.B. Whittaker.

76 Edgecombe, R.S. 2015. *A reader's guide to the narrative and lyric poetry of Thomas Lovell Beddoes*, 18. Newcastle upon Tyne: Cambridge Scholars Publishing.

77 Lofland, J. 1828. *The harp of Delaware; or, the miscellaneous poems of the Milford Bard*, 65. Philadelphia: Atkinson & Alexander.

78 Kettell, S. 1829. *Specimens of American poetry*. Vol. 2, 407. Boston: S. G. Goodrich.

79 see footnote 78

80 Daru, P. 1830. *L'Astronomie, poeme en six chants*, 211. Paris: Chez Firmin Didot Frères.

81 Watts, L. 1849. *Pretty little poems for pretty little people*, 127. Cheapside: William Milner.

82 Dickey, J.M. 1892. *Christopher Columbus and his monument Columbia: Being a concordance of choice tributes to the great Genoese*, 327. Chicago: Rand, McNally & Co.

83 Szerdahely, G. A. 1788. Historia Uraniae Musae Quam inter Deos, Deasque, Planetarias recens detexit Herschelius. In *Silva Parnassi Pannonii*. Vienna: Mathiae Andreae Schmidt, 147–174.

84 Cowley, H. 1810. *The siege of Acre: A poem in four books*, 108. London: G. Wilkie and J. Robinson.

85 see footnote 84, pg. v

86 Gisborn, T. 1813. *Walks in a forest, and other poems*. 8th ed, 163. London: T. Cadell & W. Davies.

87 Sigourney, L.H. 1827. To the moon. In *Poems*. Boston: S. G. Goodrich, 13–15. For a survey of her work see footnote 78, pg. 204–207.

88 Hayley, W. 1799. *The triumphs of temper: A poem in six cantos*. 10th ed, 88. London: T. Cadell.

89 Brewer, J. 1997. *The pleasures of the imagination: English culture in the eighteenth century*, 605. New York: Farrar, Straus and Giroux.

90 see footnote 89

91 Fessenden, T.G. 1804. *Original poems*, 149. London: Albion Press.

92 see footnote 55, pg. 93.

93 Melville, H. 1851. *Moby Dick, Chapter 74: The sperm whale's head–contrasted view*, 369. New York: Harper & Brothers.

94 Delille, J. 1805. *The Gardens, a Poem, translated from the French of the Abbé de Lille by Mrs. Montolieu*. 2nd ed, 37. London: T. Bensley.

95 see footnote 80 pg. 185.

96 Holland, J. 1860. *Evenings with the poets by moonlight*. (Privately printed), 18.

97 Darwin, E. 1791. *Botanic garden*, 116. London: J. Johnson.

98 On the Darwinian School of poetry. 1818. *The Edinburgh Magazine*, 313–316, p. 314.

99 Tucker, H.F. 2008. *Epic: Britain's heroic muse 1790–1910*, 59. Oxford: Oxford University Press.

100 see footnote 97, pg. 117.

101 Oliver, G.A. 1874. *A selection from the poems and prose writings of Anna Laetitia Barbauld*. Vol. 2, 364. Boston: James R. Osgood & Co.

102 Weigand, D. 2011. Embryo Systems and Unkindled Suns. In *The New Science and Women's Literary Discourse Prefiguring* Frankenstein, 205. J. Hayden (ed.). New York: Palgrave MacMillan.

103 see footnote 102.

104 Crossley, T. 1828. *Poems, lyric, moral and humorous*, 8. London: Hurst, Chance & Co.

105 see footnote 104, pg. 42.

106 The Literary Gazette and Journal of Belles Letters, Arts and Sciences no. 625, January 10. 1829. 24.

107 Ball, B.W. 1892. In *The Merrimack River, hellenics, and other poems*, ed. Frederick F. Ayer, 245–247. New York: The Knickerbocker Press.

108 Terzago, P.M. 1664. On selenic origin of aerolites. In *Musaeum Septalianum Manfredi Septalae Patricii Mediolanensis, Industrio Labore Construction*. Tortona: Typis filiorum qd. Elisei Violae, 44.

109 Timbs, J. 1869. *Curiosities of science, past and present*, 90. London: Lockwood and Co.

110 Herschel, W. 1787. An account of three volcanoes in the moon. *Philosophical Transactions* 77: 229–232.

111 Holden, E.S. 1888. Regarding Sir William Herschel's observations of volcanoes in the moon. *The Observatory* 11: 334–335.

112 King-Hele, D. 1986. *Erasmus Darwin and the romantic poets*, 188. London: Macmillan Press.

113 Coleridge, S.T., and Wordsworth, W. 1798. *Lyrical ballads*, 118. London: J. & A. Arch.

114 Ogilvy, C.S. 1949. Lights on the moon. *Popular Astronomy* 57: 229–232. p. 229.

115 Watson, J.S. 1844. *Geology: A poem*, 89. London: William Pickering.

116 Carr, W.W. 1791. *Poems on various subjects*, 135. Printed for the author, and sold by Messrs. Edwards: London.

117 Hoskin, M. 2011. *Discoverers of the universe: William and Caroline Herschel*, 11. Princeton: Princeton University Press.

118 Lamb, C. 1836. *The poetical works of Charles Lamb*, 235. London: Edward Moxon. Charles Burney Sr. equated Purcell with such luminaries as

Shakespeare, Milton, Locke and Newton, but even he qualified this praise. "Unluckily for Purcell! He built his fame with such perishable materials, that his worth and works are daily diminishing." Quoted from Burney, C., *A General History of* Music, vol. 3. (Printed for the author, London, 1789), 485.

119 Ricard, D. 1796. *La Sphere, Poëme en huit Chants*, 58. Paris: La Clere.

120 see footnote 119, pg. 59.

121 Chênedollé, C.-J. 1807. *Le genie de l'homme, poëme*, 19. Paris: H. Nicolle.

122 footnote 80, p. 211.

123 footnote 80, p. 247.

124 Enort, T. 1803. Sonnet to Capel Lofft. *The European Magazine, and London Review* 44: 57.

125 Anon, 1860. *The Boy's Own Conjuring Book*, 354. New York: Dick and Fitzgerald.

126 Lectures on atomic theory. 1858. *The Dublin University Magazine* 52: 463–475.

127 Brown, S. 1858. The humanities of science. In *Lectures on the atomic theory and essays scientific and literary*, Vol. 1. Edinburgh: Thomas Constable and Co., 356.

128 Beattie, J. 1809. *The works of James Beattie: The Minstrel with some other poems*, 48. Philadelphia: Hopkins and Earle.

129 Walpole, H. 1840. *The letters of Horace Walpole, Earl of Orford*. Vol. 6 of 6, 257. London: Richard Bentley.

130 Hood, T. 1856. *The poetical works of Thomas Hood*. Vol. 2, 270. Boston: Houghton, Mifflin and Co.

131 Montesquieu, Baron de. 1762. *The spirit of laws*, vol. 1 of 2 volumes, 3rd ed. (I. de Secondat, tr.). Edinburgh: A. Donaldson and J. Reid, 346. Original French edition published 1748.

132 Warton, T. 1781. *History of English poetry*. Vol. 3, 950. London: Ward, Lock & Co..

133 Mathias, T.J. 1798. *The pursuits of literature: A satirical poem*. 5th ed, vi. London: J. Milliken.

134 Bucknell, C. 2017. Oven-ready children. Review of Jonathan Swift: The reluctant rebel, by John Stubbs. *London Review of Books* 39 (2): 9–12. p. 9.

135 Abbott, C. 1786. *An essay on the use and abuse of satire*. London: No publisher.

136 Johnson, S. 1766. *A dictionary of the English language*. Vol. 2. London: A. Millar.

137 see footnote 133, pg. vii.

138 Anon. 1788. *Royal magnificence; or the effusions of ten days; A descriptive and satirical poem, in three cantos. On the subject of his Majesty's late visit to Worcester, on the Sixth of August, 1788*. Printed for the Author, London, 32.

139 The people's answer to the court Pamphlet: Entitled a short review of the present state of Great Britain. 1786. London: J. Debrett, 1–2.

140 Reply to a short review of the political state of Great Britain, at the Commencement of the Year 1787. With a rejoinder to the people's answer. 1786. London: John Bell, 76.

141 Williams, D. 1788. *Royal recollections on a tour to Cheltenham*, 61–62. London: James Ridgway.

142 Carretta, V. 1990. *George III and the satirists*, 172. Athens: University of Georgia Press.

143 Kerr, D. 2004. 'Satire is bad trade' Dr John Wolcot and his publishers and printers in eighteenth-century England. *Cardiff Corvey* 12: 29–61. p. 33.

144 Pindar, P. 1788. *Peter's prophecy; or the president and poet*, 31–32. London: J. Kearsley.

145 see footnote 144, p. 31.

146 Jones, W.P. 1966. *The rhetoric of science*, 195. London: Routledge and Kegan Paul.

147 Arnold, T. 1873. *A manual of English literature*. 3rd ed, 447. Boston: Ginn Brothers.

148 footnote 147, p. 446.

149 Pindar, P. 1787. *Lousiad: an heroi-comic poem*. 7th ed, 155. London: G. Kearsley.

150 Robertson, R. 2009. *Mock-epic poetry from Pope to Heine*, 126. Oxford: Oxford University Press.

151 footnote 150, p. 120

152 Plumb, T. 1789. *The royal astronomer*. London: Kearsley.

153 The Town and Country Magazine 21. 1789. 274.

154 The General Magazine and Impartial Review 3. 1789. 363.

155 The Monthly Review 80. 1789. 366.

156 Craik, G.L. 1842. In *London astrologers*, ed. C. Knight , vol. 3, 246. London: Charles Knight & Co.

157 The English Review 14, 1789. 467. "O he! jam satis est!" is a quote from Horace, Epistles, I. 5. 12. It means "Now, that's enough."

158 Knox, K.C. 1999. Lunatick visions: Prophecy, signs and scientific knowledge in 1790s London. *History of Science* 37: 427–458.

159 Lettsom, J.C. 1802. Review of *Observations on the Cow-Pock,* published by Mawman, London. *The Critical Review* 36: 102–103. p. 103.

160 see footnote 159, pg. 102.

161 Anon. 1795. *An asylum for fugitive pieces in prose and verse, not in any other collection*. Vol. 3. 2nd ed, 248. London: J. Debrett.

162 footnote 144, p. 36-37.

163 The Monthly Review 56, 1808. 97–99.

164 Anon. 1808. *An heroic epistle to Mr. Winsor*. London: R. Spencer. quoted in footnote 163, pg. 98.

165 The British Critic 32, October 1808. 352–356, p. 352.

166 Hunt, C. 1907. *A history of the introduction of gas lighting*, 111. London: Walter King.

167 Spence, T. 1982. The restorer of society to its natural state. In *The political works of Thomas Spence*, ed. T. Dickinson, 80. Newcastle-upon-Tyne: Avero.

168 Machan, R. 1824. *A new system of astronomical mnemonics*, 38. London: Longman, Rees, Orme, Brown and Green.
169 Eliot, T.S. 1996. In *The varieties of metaphysical poetry*, ed. Ronald Schuchard, 53. San Diego: Harvest.
170 see footnote, 98, pg. 316.
171 Miller, M. 1993. *The garden as an art*, 40. Albany: State University of New York Press.
172 Pontic Epistles book 4, epistle 8, line 56. 2015. Quoted in Newlands, C.E., *Ovid*. London: I.B. Tauris.
173 Private communication from Dr. Berardi. May 15, 2017.
174 Hope, A.D. 1985. *The age of reason*. Melbourne: Melbourne University Press.
175 Burnell, J.B. 2006. Astronomy and poetry. In *Contemporary poetry and contemporary science*, ed. R. Crawford, 133. Oxford: Oxford University Press.
176 Long, L. 2013. *The eye of Caroline Herschel: A life in poems*. Georgetown: Finishing Line Press.
177 Cunningham, C.J. 2016. *Early investigations of Ceres and the discovery of Pallas*. Cham: Springer.

## Appendix 1: The Royal Astronomer, &C.

### As how, a star-gazer cannot smell the rose of beauty and con. The blue star-book, at one and the same time.

What Phoebus, ho!–thou god of quavers,
    Of ballads sung from three-leg'd crickets,
What has befell thy tuneful shavers?
    Have all thy babes, Sol, got the rickets?

No bag-pipe, lute, or Jews'-harp shrill,
    No music-grinding organ speak;
No flagelet, horn, pan, or quill,
    To Herschel's praise no fiddle squeak!

God of the bowels of the cat,
    This is the oddest of all odd things!
Odd as one eye–a three cock'd hat–
    One goose–nine taylors–and seven bodkins!

Zooks, Phoebus!–why's thy belfry dumb,
    Where poets us'd to ring for wagers?
What makes thy nine sweet bells so mum?
    To Herschel's praise no grand bob-majors?

Star-gazing, Sir! What, not one note?
    Methinks 'tis dev'lish hard upon ye,
That shut is ev'ry tuneful throat,
    Is it for lack of love or money?

What, not one Muse of all the nine
    To thee, O gazer! strike the lyre?
Jades! not of praise a single line!
    What dev'l hath silenc'd ev'ry wire?

Great, Sir, for wonder, or for grief,
With much ado I lift my head
Of Poetry, what, not one leaf?
The thing's enough to strike me dead!

On such a theme, that no Muse ope's
Her mouth, I cannot guess the cause;–
What ails, ye bards, your tuneful chops?
What hath thus giv'n ye all lockt-jaws?

'Slife! inch by inch, from head to heel
Of Herschel, boys, ye shou'd have sung!
Silent each bard as spitchcockt-eel,
A dead wife, or a dry'd neat's tongue!

Sons of the tuneful art, O say
At once the reason frank and freely,
Why not one bard will found his A–
But locks his voice up in his belly?

Where's merry Pindar? he who cracks,
With merc'less hand, his lyric whip
On kings, queens, artists, laureats backs,
And makes the Antiquarians skip?

Teaches grown gentlemen, like peas
Upon tobacco-pipes, to caper,
And *dance* like scorch'd lice, bugs, or fleas*[1],
Upon a sheet of burning paper.

Silent is laurel'd Tom? Will. Mason?
Hayley? Pye? Crusca? Dame Piozzi,
Who whilom clapp'd so bold a face on,
And at th' Italian cast a goat's eye?

Dumb Seward? Williams? Hannah Moore?
Who, in a courtly part of speech,
With envy viewing Yearly, soar
Above her, nam'd her DRUNKEN BITCH?

Where's Woodstock's tuneful flogging shaver?
He, who of learning *drives the nail*
*With birchen hammer*, Parson Mavor,
Into each throbbing school-boy's tail?

Anstey*[2] with mortar choak'd? and he*[3]
Silent, who roar'd in verse a BULL!
Who trac'd the Sofa's pedigree
Up to the primitive joint-stool?

All mute as fishes, dead, and dumb,
As if DEATH's Foot were on their throats,
Had bid them cry for ever mum–
To trill no more the plaintive notes?

Why then, behold, Tom Plumb, unknown
Among Apollo's roaring boys,
Step forth:–make room, my lads, for one
Who means to make some little noise!

Herschel, thou shalt not want a fiddle–
  If thou hast worth, the world shall know it.
*Hoping thou wilt not say I did ill*–
  Lo! May I crave to be thy poet?

I'll tell the world, and all her sons,
  In a full peal of thy great name;
Out of Apollo's nine vast Guns,
  I'll thunder glory, praise, and fame!

Hors'd upon Panegyric's back,
  I'll lift thee, Herschel, to the moon–
Higher than e'er Lunardi's hack
  Soar'd yet, yclep'd an air-balloon:

Higher than e'er the cannon-ball,
  Which once was fir'd into the air,
And *ne'er* again to earth did fall,
  And which thou now may'st view–a star!

Your fitting up whole nights together,
  Sleeping like bats, or owls, by day,
Sweeping the heav'ns in frosty weather,
  Leaving your wife *to sleep or pray*,

Curse the clear nights, and wish for clouds,
  Curse moon, stars, husband, telescope,
And wish in flames, with all its goods,
  And spy-glasses, your working-shop;

Are, Herschel, rich and fruitful themes,
  Rare veins and mines of poesy;
Wou'd furnish out the sweetest dreams,
  Herschel, between my Muse and me;

Of which, anon, we mean to treat;
  But first, 'tis meet that Muse and I
Raise, Sir, upon poetic feet,
  The wond'rous tube with which you spy.

That cannon which, from world below,
  Thou level'st -a good waggon-load!
At the clear heav'ns above, that glow
  *With some four thousand stars and odd*.

With which you thro' yon' crystal wall
  Shoot into heav'n your curious eye,
And can, with perfect ease, see all
  That's done by people in the sky.

With which you found a star *ne'er lost*;
  And made us all with wonder swoon
At burning Etna's, that did roast
  All people near them, in the moon.

Of which the angels well aware,
  When after meals they wing aside,
Behind a thunder-cloud take care,
  *In such a case, their bums to hide*.

O Muse! the wonders of his tube,
Sing thou to ages yet to come!
The glass of which, with many a rub,
Was polish'd only with his thumb!*[4]

Fair gentlemen, now in the womb
Of time, fast button'd up from day,
With indefatigable thumb,
Tell how be rubb'd whole years away!

Tell them his belly was in debt
Long time for all its butter'd crumbs,
Which, whilst he polish'd glass, it ate,
Supply'd and spread by other thumbs!

For, as the smoothed glass did glow
Beneath his thumbs, Sir, let me tell ye,
Those thumbs had something else to do
Than wait upon their KING, the belly.

Next to his wife, as next in love,
*After his telescope,* she stands,
Turn thou thy song, my tuneful dove;
She next in turn thy song demands.

Without the help of spying-glass,
He saw the dame with naked eye;
And for the rich Uptonian*[5] lass
Of purest, breath'd the purest sigh.

Dim wou'd appear a starless sky;
Dim, without gold, rich Wor'ster china;
Dim were a lass without *an eye*;
Dimmer yet still without *a guinea*.

Keen saw the Gazer this–A star
The widow rich in guineas shone;
Quoth Herschel, hand on heart–"my fair!
"We'll wed, no more be said or done.

"Some lovers fire you off a TIRE
"Of oaths,–what mummery!– 'Odsblood,
"Lo! once, and once for all I swear–
"I love thee, dame, so help me God!"

Thus brief and sweet he spake, and place
Took in the widow's heart for *one*.
Reader! the thing, without wry face,
Was finish'd–soon as 'twas begun.

'Tis said the stars, with vast amazement,
That night did marvel where he was!
Each peeping from its little casement
With wond'ring eyes, and wond'ring face.

'Tis said, the stars did dance and sing!
You, reader, might, I saw nor heard 'em:
So will not swear to such a thing;
For that, thou know'st, wou'd be *absurdum*.

But, if the stars did skip like frogs,
I'll swear, Sir, with an honest face,
Not one of all the dancing dogs
Hath leap'd into another's place.

What ballad else they might have sung,
Faith, I can't tell; but this I know,
That not one star, the stars among,
Sang the *Black Joke*, or *Mary Rose*.

Sev'n times the Gazer sprang from bed,
Says Fame, and left the widow's side,
Thrusting from window forth his head,
To view the stars above him glide!

Fame's a damn'd liar–known of old–
I need not tell the sons of men–
With her false trumpet to make bold–
Reader, she'd truly said sev'nteen.

O heav'nly Muse! what married man,
On's wedding night, e'er made some pother?
From bed quick to his casement ran,
Without being fluxt some way or other?

Miser of stars, as others gold,
He oft stept out of bed to tell 'em;
Keeping strict watch, lest robbers should–
Damn'd dogs!–come fly by night *and steal 'em*.

Herschel, high steward of the stars
Made over all to him in trust,
Kept good look out amongst his wares,
*To see that ne'er a star was lost*.

Herschel, I own, thou hadst, that night
Hard work, thus bound to double duty–
To see that all thy stars were right
At once, and pay thy debt to beauty.

Suppose some fingering Mercury
Had nimm'd from heav'n a *fiver penny*;
One little twinkler, Herschel?–why–
*'T had ne'er been miss'd among so many*.

O keeper of the ethereal park!
Well stock'd with rams, and bulls, and horses;
The beasts had wander'd in the dark,
Broke thro' their pales, or ta'en strange courses.

The Bear*[6], from his fast-fixed pole
To which he's stak'd, had burst his chain;
Ere I from bridal-bed had stole,
To bring old Bruin back again.

The Scales*[6] been purloin'd by a grocer,
To weigh out butter, cheese, or candles;
The brace of Pointers*[6] by a poacher,
Against the law a gun that handles:

The Wagg'ner*[6], by advance of wages
Been tempted to have left the sky,
At Winsor market cry'd "*Green-gages*,"
Or, "*Cherry-ripe, ho! come and buy?*"

The Virgin*[6] too, by some old strumpet,
Been coax'd and wheedl'd to've come down,
Had been proclaim'd by blast of trumpet–
"*A wonder! seen for half a crown!*"

A barber, Herschel, shoul'd have stole
The wig of Berenice*[6] so fair,
To've grac'd on earth some duchess' pole
Unfruitful in a crop of hair;

Ere I had left the lost warm side
Of bride, upon her wedding night,
With eyes, as saucers, staring wide,
To see if all above were right.

Old women, Herschel, with their brooms,
Had swept down aprons-full of stars;
Disfurnish'd all the azure rooms
Of golden urns, and silver jars.

Young bloods, with silken-tassell'd sticks,
Broke every lamp in heav'n that hung;
Lamp-lighters seiz'd the oil and wicks–
To earth each ravish'd lantern flung!

Angels unchain'd, again got loose,
With planets pelted one another,
Had broke the back of Pegasus*[6],
Hurl'd master Pollux*[6] at his brother:

Tied Bull*[6] and Dragon*[6] tail to tail,
Halloo'd the Dog*[6] about their ears:
Upon a COMET broil'd the Whale*[6];
And made rough music of the spheres.

Play'd *butter'd pea*s upon the Lyre*[6];
And taught the Bears*[6] to rigadoon;
O'erturn'd the Waggon*[6] in the mire;
Spik'd back to back the sun and moon!

Turn'd Berenice's perriwig
The hinder part thereof before;
Seiz'd Hercules*[7] his club so big,
Broke ope' of Heav'n the very door!

Skin'd the old Ram*[7], and wrapp'd his fleece
About the neck of scowling NED;
Planted the horns–a better brace–
Than those already on his head.

Put Venus*[7], stript first to her skin,
To bed to blushing Billy Pitt;
Seiz'd the bright Crown*[7], and beat it in–
To make the ring *his finger* fit.

Herschel, the stars, Heavn’s golden grain,
Had been put all into a sack;
By hawker, up to Windsor ta’en,
And fold at *eighteen-pence a–peck*;

Ere I had left the widow’s breast,
That pillow soft of soft delight!
Budg’d half an inch from Cupid’s nest,
For all the stars that grace the night.

But, Herschel–so the world, alas!
Declares–thou think’st it much too hard,
To *lose one* night torn from thy glass,
With wife in nuptial pleasures shar’d.

If this be true, upon my soul,
Thy wife I must commiserate;
And if the woman’s not a f—l,
Herschel, she will adorn*[8] that pate.

A man of law, by band and gown,
A bishop’s by lawn sleeves exprest:
By his cockade a soldier’s known;
Th’ astronomer by Dian’s crest*[9].

Dear madam! much I’m sorry for ye,
And much for you in heart I feel!
And hope, by publishing your story,
To bring a grist into your mill.

Dame, bring thine action in the court
Of Love; the Muse shall plead thy cause–
The man deserves to answer for’t,
Who dares thus break king Cupid’s laws.

As thou thine evidence shall give,
Five hundred and odd lashes, he
Shall strait be sentenc’d to receive
At the *carts-arse* of poetry.

But dame, perhaps things aren’t so bad–
I’m told, he says to Heav’n this prayer:
“O Lord that ruleth over-head,
“O change my wife into a star!

“O fix her somewhere in the skies;
“And, if such good luck might betide us,
“Thro’ spy-glass, in thy servant’s eyes,
“She’d far out-shine the *Georgium Sidus*.”

A pretty pray’r! methinks you cry–
Sweet madam! so indeed it is;
What proof of husband’s amity,
To *wish his wife in heav’nly bliss*!

Ah! well he knows you to excel
All women in celestial grave,
That, whilst some with their wives in hell,
He prays for you a *better place*.

Ah! well I ween great Herschel knows,
No earthly husband can do duty
To your wide merits full–no spouse
Pay what is due to so much beauty.

To wish in heav'n so good a woman,
Springs from *pure conjugal regard*,
Since worth, like your's, he's sure that no man–
But only Heaven can reward!

It is not for the paltry pleasure
Of nailing wife in oak so stout,
With spikes of full a yard in measure,
For fear the woman shou'd get out.

It is not for the joy of heaping
A ton of marble on her bones,
That on death's bed, ma'am, they may sleep in
Sweet peace beneath the quilt of stones.

Not for the satisfaction, ma'am,
Of weeping o'er thy *much-lov'd* urn;
For that indeed's not worth a damn! –
But, O, that wife shall ne'er return

To drink the bitter cup of life,
And eat the bitter bread of care,
Vex her dear soul in worldly strife,
Hence leaps of joy the sparkling tear!

O! the first bliss on earthly sphere,
Which husband's soul alone can know,
That she on earth he held so dear,
Is snatch'd, at last, from human woe!

Th' extatic thought! that his dear wife
With saints in song her rapture joins,
That blest with everlasting life
She everlasting joy combines!

You miss'd the meaning of this pray'r,
Which, well explain'd, is found most kind,
And which, dear ma'am, is monstrous far
From being with ill-nature join'd.

But Herschel, by the star of noon!
Thy wife I pity from my soul:
Who, whilst *you gaze* up at the moon,
Hop, step, and jump from pole to pole,

I fear spends many a stupid night!
"Ah, me!" on lonely pillow sighing,
"That I shoul'd ever wed a wight
"*So vastly fond, alas, of spying!*"

O Royal Gazer, lack-a-day!
I must proclaim the thing too bad,
Thus from her bed whole nights to stray–
Enough to drive a WIDOW mad!

On cloudy nights–*you polish glass*:
  On starlight nights–*you gaze in air*:
Were I thy wife, in such a case
  I shoul'd run madder than March hare.

Grant that for *half a night* you do
  As you are bound by Hymen's laws–
Once in a month, perhaps, or so–
  Yet for complaint there's still wide cause;

For half a night!–against Love's God,
  Thou are a miserable sinner!
An alderman, Sir, better wou'd
  Be satisfi'd with half a dinner!

A doctor's fist with half a fee;
  With half a pudding, Sir, a parson;
Less satisfied than ye would be,
  *Criticks! –without a rhyme for–arson–.*

Nan Moore with half a grove of bays;
  And she, who published her FOLLIES*[10],
A play, which, *by b'ing damn'd*, was prais'd,
  With half a house, poor Lady Wallace!

A greedy wife with half the breeches–
  With half his bribe a pettifogger–
He, who with birch *tres linguas* teaches,
  With half an arse th' Etonian FLOGGER*[11].

For dinner, Banks, with half a bat;
  With half a child a cannibal;
A rav'nous bard with half a sprat;
  Queen Kate with half a pot of ale*[12.]

With half a man a hungry shark;
  With half his mast a German swine;
An empty kite with half a lark;
  Warton with half his butt of wine!

"Mens' names, by swarths, the world's sharp tongue,
  "Doth, like a scythe, at once mow down
"Without distinction–right or wrong."–
  'Tis given to scandal, Sir, I own.

To hold 'twixt wife and spying-glass
  Your dish, as may become you, even,
Is a hard matter, Sir, I guess:–
  The thing's scarce possible, by Heav'n!

By night *your wife*, or else *the stars*,
  Must, *one or t'other*, be forsaken:–
At once–or you shall pull my ears, –
  You cannot both ways save your bacon.

You are dilemma'd, Sir:–you owe
  The stars three hundred pounds-a-year*[13],
Wife a good jointure: 'twixt the two
  You must sign bankrupt, Sir, I fear.

No man at once can shave and fiddle;
  Jig a courant, and couch an eye;
Ride horse full trot, and thread a needle;–
  Nor you at once, Sir, kiss and spy.–

No bard on earth, how keen soever,
  Can pen an ode, and mend his breeches;
Betwixt the two, the tuneful shaver
  Must spill his verse, or spoil his stitches.–

Of bishops, Sir, not one in seven,
  How staunch soe'er and good the man,–
Can lift, at once, his soul to heav'n,
  *And sop his crust i' th' dripping-pan.*

Nor you, or else I aim awry
  My arrow widely of the scope,
At once so pat, Sir, have an eye
  *To widow, and to telescope.*

If, Sir, you can do both at once–
  Forward, may I ne'er dine or sup hence;–
The C———y–loving Q— of F——
  Shall show her b— for four and two-pence.

To purchase such a husband, Sir,
  That Pitt shou'd pay down all her riches!
She'd better bought, or much I err,
  In gingerbread, the COCK and BREECHES.

*Explicit* Tom.

*Peroratio.*

Thou'rt a good temper'd dog!–nay, come–
  Thou wilt not bite me?–*I'm but stroking.*
Herschel, thine hand–Lord! merry Tom
  Means thee no harm in all his joking.
    ABRACADABRA.
    FINIS.

Footnotes in the original text:

*1. In this simile, the Poet alludes to a merry species of gambling, as it is practiced in most of the fashionable jails in Great Britain: half a dozen, or more gentlemen, join in a sweep-stakes, each entering his RACER at the post. The signal for starting is setting fire to the race-course, or sheet of paper.–N.B. The bug, flea, or louse, that shall be burnt through his proper laziness, shall be adjudged distanced by the steward of the race.

*2. The Bath Sons of Brick and Mortar have absolutely built poor Mr. A. out of doors! They gave him his choice, either to run for his life, or tarry and be intombed. Mr. A. wisely chose the former.

*3. Cooper, author of the Sofa, a Poem.

*4. The Poet has been informed, by good authority, that for whole days and nights together, has this unwearied Astronomer sat polishing of glass with his thumbs! and, *mirabile dictu*! lest the work might *cool* from interruption [sic],

his breakfasts, dinners, and suppers were lifted into his mouth by a servant paid for the purpose!
*5. The Royal Gazer married Mrs. Pitt, a widow, and rich, of Upton, near Slough.
*6. Signs and Constellations in Heaven.
*7. Planets and Constellations.
*8. Some read "ad-horn thy pate."---*Fortasse melius* [perhaps better].
*9. The new moon she wears on her forehead thus---☾
*10. The Poet alludes to Lady Wallace's Follies of Fashion, a Comedy, which, though damn'd, was not worth a damn.
*11. The Reverend Doctor Davies, *head* master of Eton School.
*12. The Empress of Russia tosses of a shipful of Burton Ale *per annum*.
*13. The Doctor's star-gazing wages from the Crown.

The poet employs obsolete phrases, or words now not well known:

"Jig a courant, and couch an eye" means: to dance a jig and remove a cataract.
"Bob-major" is the method ringing of bells
"cock and breeches" is old slang for sturdy little man
"pettifogger": a person who quibbles over details, a hair-splitter
"sprat": a small herring

A list of people whose names appear in the poem or footnotes:

Anstey, Christopher (1724–1805), English poet who wrote the satirical *The New Bath Guide* in 1766.
Banks, Joseph (1743–1820), President of the Royal Society.
Catherine, Empress of Russia (1684–1727).
Crusca, Della (1755–1798), pseudonym of the English poet Robert Merry.
Davies, Jonathan (c.1736–1809), Headmaster of Eton College from 1773 to 1792.
Hayley, William (1745–1820), English poet.
Lunardi, Vincenzo (1754–1806), Italian balloonist.
Mason, William (1724–1979), English poet.
Mavor, W., co-author of Classical Poetry (1807).
Moore, Hannah (1745–1833), English poetess.
Pindar, Peter (1738–1819), the pseudonym of John Wolcot, English satirist.
Pitt, Mary (1749–1832) first married John Pitt in 1773. He died in 1786. She married William Herschel in 1788.
Piozzi, Hester Lynch (1741–1821) poetess, born in Wales.
Plumb, Tom: pseudonym of an English satirist.
Pye, Henry James (1744–1813), Poet Laureate of England from 1790 to 1813.
Seward, Anna (1742–1809), English poetess.
Warton, Thomas (1728–1790), Poet Laureate of England from 1785 to 1790.
Wallace, Lady Eglantine (died 1803). Her comedy "Follies of Fashion" dates from 1788. It was acted at the Theatre Royal, Covent Garden.
Williams, Anna (1706–1783), English poetess.

# Index

C.J. Cunningham (ed.), *The Scientific Legacy of William Herschel*,
Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-319-32826-3