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John Herschel's REFORM OF SCIENCE

Stephen Case

The son of the world's most famous astronomer, Herschel helped liberate science from the realm of aristocratic privilege.

William Herschel had doubts about Saturn. Viewed through his large reflecting telescope, the ringed planet had a curious shape: The northern pole was flattened and the southern was “curved or bulged outwards.” William was already known for pushing the observational limits of astronomy, whether it was because of his claims of telescope magnification or his speculations regarding life on the Sun. But his observations had also brought entire new classes of objects into astronomy: nebulae, star clusters, binary stars, and, most famously, the solar system's first new planet—Uranus, discovered in 1781.

On the night of 16 June 1807, however, William wanted confirmation of Saturn's strange shape. His sister, Caroline, had often assisted with and added to his observations. She typically recorded what he called out from the observing platform of the large telescope, but sometimes she even composed William's scientific papers for him. But on that particular evening, William called on a new set of eyes, those of his 15-year-old son, John Herschel. As William recorded, John also saw Saturn's strange curvature, marking a shape down on slate that “exactly delineated the appearance” William saw.¹ It was Herschel's first recorded astronomical observation. William no doubt hoped his son would continue his legacy but could not have predicted that Herschel would go on to help reform science itself.

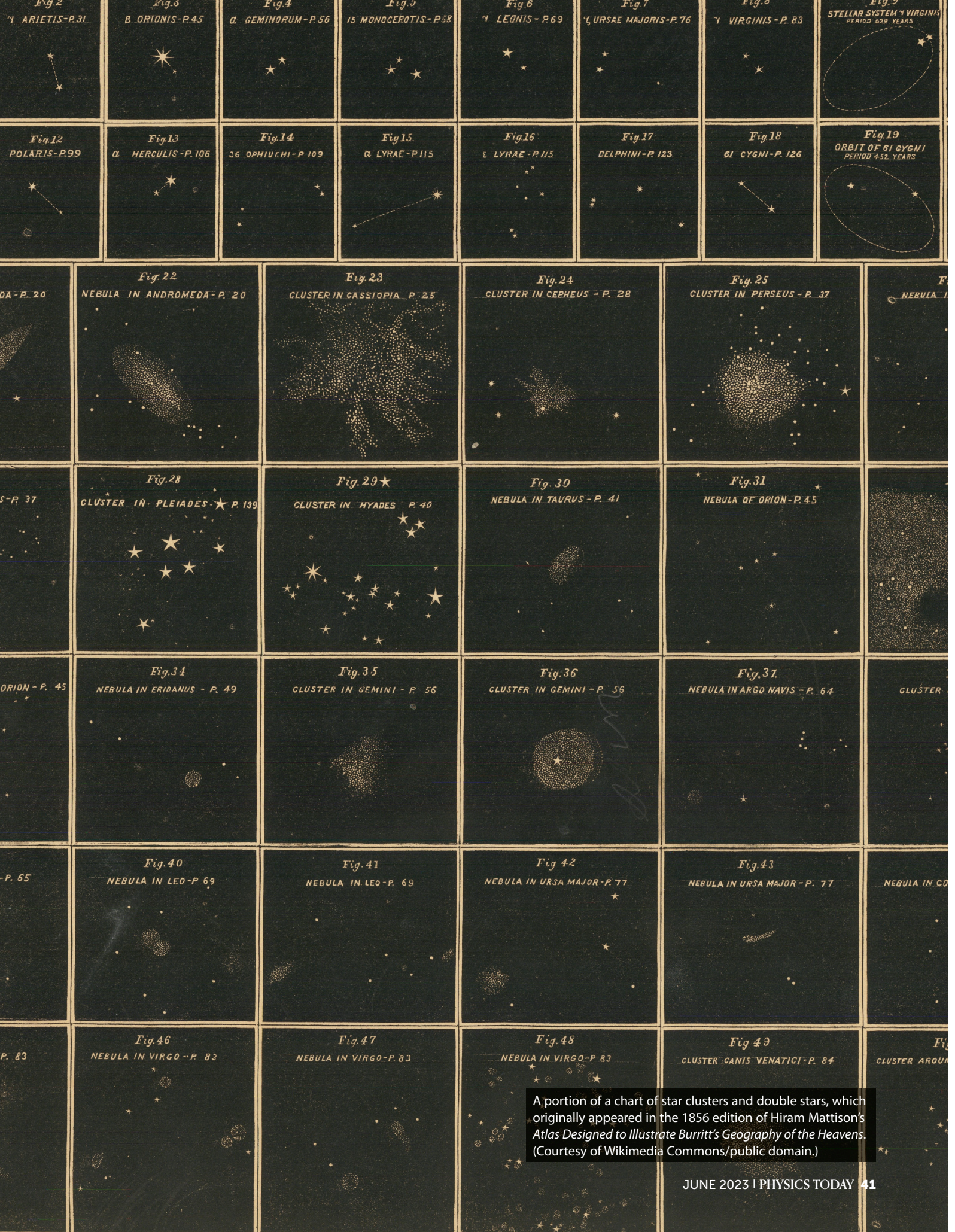
Herschel (see figure 1) was born on 7 March 1792, the only child of William and his wife, Mary Baldwin Pitt. By the time of Herschel's birth in Slough, England, his father had rocketed to fame from a musician who had emigrated from Hannover in Germany to Europe's best-known astronomer. What had begun as a hobby with homemade telescopes became something more after William's discovery of Uranus, which he originally named after King George III. As a result, he was appointed the “King's astronomer,” which gave William the chance to

pursue stargazing full time and funds to build a massive 40-foot telescope. William was best known for his method of telescopic “sweeps,” by which he discovered hundreds of new celestial objects. What he lacked, however, was the advanced mathematical training to turn his observations into coherent physical theories.²

The mathematical revolutionary

Things would be different for Herschel. William made sure that his son received the mathematical training he had lacked. By the time Herschel enrolled at the University of Cambridge, he had been privately tutored in the advanced techniques developed by continental mathematicians like Pierre Simon Laplace, Joseph Louis Lagrange, and Sylvestre François Lacroix, whose work connected algebraic





A portion of a chart of star clusters and double stars, which originally appeared in the 1856 edition of Hiram Mattison's *Atlas Designed to Illustrate Burritt's Geography of the Heavens*. (Courtesy of Wikimedia Commons/public domain.)

analysis with descriptions of the physical world in such areas as heat, vibrations, wave motion, and celestial mechanics. Yet that training simply set Herschel up for disappointment.

At Cambridge, Herschel found to his dismay an institution with little interest in mathematical developments outside of the UK. Like the University of Oxford—the only other university in England at that time—Cambridge was less an institution of research and discovery than a facility for training in law or the church and a place where young aristocrats learned the cultural polish needed to take their place among the landed elite. Instruction at Cambridge remained devoted to the “dot-age” of Newton’s calculus—namely, his notation of dots over variables—and geometrical representation. For many Cambridge scholars, that representational aspect was essential to a view of mathematics as reason mapped onto the cosmos.

Continental—and in particular French—mathematics had, by contrast, developed along lines forged by German polymath Gottfried Wilhelm Leibniz and used the “d-ism” of differential notation (which is still used today). Not only did French mathematics carry political baggage in a UK that had been at war with France for decades, but it was also seen as a mere manipulation of logical symbols that was disconnected from the geometrical representation that many Cambridge scholars believed gave mathematics its epistemological grounding.

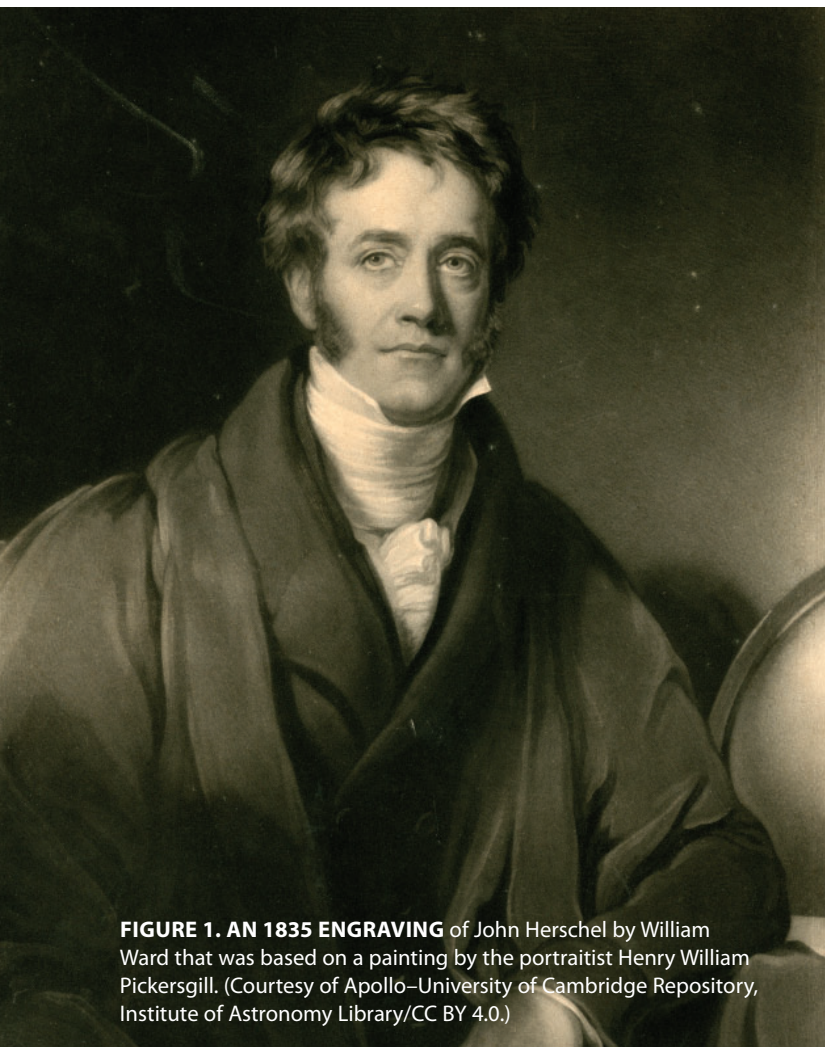


FIGURE 1. AN 1835 ENGRAVING of John Herschel by William Ward that was based on a painting by the portraitist Henry William Pickersgill. (Courtesy of Apollo—University of Cambridge Repository, Institute of Astronomy Library/CC BY 4.0.)

To Herschel, however, and to other like-minded students that included Charles Babbage, the logical methods of analysis were necessary to restore the UK’s prominence in mathematics. When a controversy arose at Cambridge over whether the dons would support a Bible society that wanted to distribute copies of the Bible without accompanying commentary from the Book of Common Prayer, the opportunity for spoof was too much for Babbage. He proposed an analytical society that would promote the gospel of the d-ism of analysis instead of the conservative dot-age of the university.

The group convened, and the spoof became a revolutionary reality. Herschel, even as he completed his university course of study, reserved his real intellectual efforts for the Analytical Society. He wrote papers for the members that showed how trigonometric functions could be transformed into series expansions, defined functional operators, and taxed the limits of the day’s typesetting technology with equations that marched across multiple pages. In the meantime, he passed his exams with top marks and received highest honors at graduation in 1813.

After producing a volume of mathematical memoirs with the Analytical Society, Herschel published a series of mathematical papers³ in the *Philosophical Transactions of the Royal Society*, a venue with a history of resistance to pure mathematics.⁴ He became one of the youngest fellows inducted into the Royal Society and was awarded its most prestigious prize, the Copley Medal, in 1821 for his contributions to mathematics. (He would win the award again in 1847 for his astronomical work at the Cape of Good Hope.) In those early publications, Herschel showed little interest in applying analysis to the natural world. Instead, his analysis illustrated the functioning of reason itself, divorced from geometrical restraint.

But at the time, Herschel’s initial efforts to use the Analytical Society to stimulate the reform of mathematics instruction at Cambridge seemed to have failed. Herschel’s friend William Whewell, who would eventually become master of Trinity College, complained, for example, that Herschel’s allies at the university had stripped “analysis of its application & turned it naked” among the students.⁵ Things were improved somewhat when Herschel (along with George Peacock and Babbage) published *Elementary Treatise on the Differential and Integral Calculus*, a translation of Lacroix’s 1802 influential work, but it was some time before the seeds of the analytical revolution would bear fruit and transform Cambridge into a mathematical powerhouse.

Natural philosophy in London

Herschel was disappointed by the short-term failure of the Analytical Society to transform British mathematics, but he learned an important lesson. The hidebound university was not the place to institute reform. London, rather than Cambridge, was the center of the UK scientific world. If change were to occur, it would be there, where it could flourish alongside the growing influence and wealth of a new mercantile class. But like mathematics at Cambridge, the practice of science in London remained a conservative, hierarchical endeavor. Under the long presidency of naturalist Joseph Banks, the Royal Society—which functioned as a clearinghouse for dis-



FIGURE 2. THE ARISTOCRATIC CHARACTER of the Royal Society during the early 19th century is readily apparent in this 1844 engraving by Harden Sidney Melville, which was based on a similar 1843 engraving by Frederick William Fairholt. It depicts a meeting of the society in Somerset House, the large governmental complex where it was headquartered until 1857. (Courtesy of the Wellcome Collection/public domain.)

coveries in astronomy, natural history, and botany—enshrined science as a privileged, gentlemanly pursuit (see figure 2).

At the same time, a growing middle class and new technologies, such as the steam press, created a new audience with the access, means, and leisure to pursue science. As the drive for political reform gained momentum in the 1820s, there was a parallel push to make science more egalitarian. Herschel was at the center of that effort, which helped transform natural philosophy into modern science and the natural philosopher into the modern scientist.

In London, Herschel moved from pure to applied mathematics and explored a science that still had no firm disciplinary boundaries. He became interested in chemistry, mineralogy, and optics. He built a laboratory, and he filled notebooks with the records of hundreds of experiments. During that time, he discovered the properties of sodium thiosulfate solution and set the foundation for what would become the primary method of fixing images in photography (see the box on page 44). During visits to Paris in 1819 and 1821, Herschel worked with Jean Baptiste Biot and François Arago, who helped him realize how mathematical equations were embodied in the interactions between crystals and polarized light. Later, when he became known as an astronomer, he would tell his wife, Margaret, that “light was my first love.”

In France, Herschel was also exposed to a new way of organizing science in which privilege was replaced by professionalization. In the French Academy of Sciences, natural philosophers were employees of the state and paid for full-time research. Positions were highly sought after, limited in number, and required scientific output. By contrast, London’s Royal Society had only an advisory role to the government and was open to anyone recommended and approved by the society’s

fellows. By the time Herschel joined, membership had ballooned to hundreds, of which only a small minority contributed scientifically. Like mathematics at Cambridge, Herschel found the scientific institutions of London moribund and in need of reform. And as at Cambridge, Herschel’s strategy involved a group of scientific rebels.

A sidereal revolution

After an abortive return to Cambridge as a tutor, Herschel finally acquiesced to become his aging father’s apprentice and take up his observational program. But Herschel was not content to remain observing at his family’s home in quiet Slough, 20 miles outside of London. Instead, astronomy became Herschel’s means of combining his mathematical agenda with the reform of science. Along with Babbage, he helped found the new Astronomical Society of London in 1820 to challenge the hegemony of the Royal Society.

Not only did the Astronomical Society (renamed the Royal Astronomical Society in 1831) provide a vehicle for applying new mathematics to the practice, but its members were primarily bankers, stockbrokers, and schoolmasters—namely, members of the new professional classes whose membership was resisted in the Royal Society. As foreign secretary of the nascent society, Herschel built a correspondence network with astronomers across Europe. London was becoming the commercial and banking capital of the world, and the Astronomical Society aimed to likewise become the clearinghouse for the world’s astronomical data.⁶

By taking up William’s observations, Herschel also inherited a unique astronomical legacy. Prior to William and Caroline’s work, astronomy had been primarily positional and concerned with establishing star positions as a background for measuring the Moon (for navigation and especially determining longitude)

Herschel and photography

After moving from Cambridge to London in 1814, John Herschel embarked on a series of chemical experiments. One of his early investigations was analyzing the properties of hyposulfurous acids. Herschel discovered a way to produce what he referred to as hyposulfite of soda, or what is today known as sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3$). In a series of papers in 1819 and 1820, Herschel outlined its properties, including its dissolving powers.¹⁴ His discovery that $\text{Na}_2\text{S}_2\text{O}_3$ in solution dissolved silver halides would be critical for the development of photography.

Twenty years later, in early 1839, Herschel learned of Louis Daguerre's method for producing images on plates coated with light-sensitive material. Although the details of Daguerre's process were not published, Herschel realized that Daguerre had used light-sensitive silver halides, such as silver chloride and silver iodide. Within days Herschel had created a similar process that could be used on paper. The crucial step, however, was to "fix" the image by deactivating the photosensitivity of the coating. Otherwise, the image would continue to darken.

Initially, Daguerre used a heated solution of sodium chloride to halt the exposure. Herschel, however, realized $\text{Na}_2\text{S}_2\text{O}_3$ would provide a better method of dissolving the silver halide. His experimental notebook records that he "tried hyposulfite of soda to arrest the action of light" and found that it succeeded.¹⁵ Because

$\text{Na}_2\text{S}_2\text{O}_3$ was referred to as hyposulfite at the time, the fixing agent became known as "hypo." Herschel's hypo became the standard fixer for modern film photography. Fittingly, Herschel's first image was the frame of his father's massive 40-foot telescope.

A few months later, Herschel presented a paper on his photographic process, along with an album of example images, to the Royal Society.¹⁶ Although the word "photography" had been used prior to his work, Herschel's paper popularized the term.

Herschel also pioneered what he initially referred to as "transfers" or "reversals"—making a permanent photographic template of an image or engraving that allowed the image to be produced over and over. Eventually he dubbed those "negatives" and "positives," terms that are also still used today.¹⁷

The photograph shown here, attributed to Herschel in 1842, depicts a model of the Moon's Copernicus Crater. (Courtesy of the Getty Open Content Program/public domain.)



and planets and comets (for refining the application of Newtonian gravity to the solar system). With his large reflecting telescopes, William expanded the scope of astronomy to include objects beyond the solar system.

But despite his exciting discoveries, William's pursuit remained the domain of an eccentric amateur. His observing program was suited to his own unique instruments. Although his catalogs included hundreds of new nebulae and double stars, they did not provide the accuracy or organization for other observers to find them easily—which became a necessity as larger telescopes were constructed that rivaled William's 40-foot one. In addition, William's catalogs lacked standardized descriptions that would allow later observers to measure signs of change in those newly discovered objects, which was important if observations of nebulae and star clusters were to provide evidence for dynamic change in the universe beyond the solar system. Herschel's career in astronomy would be built around addressing those requirements.

Herschel began with double stars, which were particularly

important objects because they provided a possible method for determining stellar parallax. If two stars were line-of-sight doubles—namely, stars that happened to appear close together along a line of sight from Earth but were actually distant from each other—measuring the annual variation in their apparent separation could provide the first means of directly determining stellar distances. But William's discovery that some double stars were in fact gravitationally bound pairs, or binary stars, complicated that picture because there was no easy method to determine whether any star pair was a line-of-sight double or a binary. The only way to know for sure was to carefully observe star pairs over years and decades.

Herschel decided to do just that. Along with James South, a London surgeon, he began revisiting all the double stars his father had cataloged. With the new catalogs, astronomers could determine which doubles were truly binary. Herschel would go on to publish double-star catalogs that included hundreds of additional doubles of his own discovery. His observations made double stars an active field for observers, and

the data he gathered allowed mathematicians to calculate the orbits of those bodies and make the first-ever measurements of stellar masses. Binary stars were so important that Herschel felt they were his father's true astronomical legacy, compared with which the discovery of Uranus was "but a trifle."⁷

Herschel also revisited the nebulae his father discovered, and again he created catalogs that provided both a means of locating those objects and a standardized empirical baseline from which to measure apparent changes over time. It was still an open question whether nebulae were formed of some luminous fluid that condensed to form stars or were merely collections of stars too distant to be clearly resolved. Before spectroscopy and astronomical photography, only painstakingly sketching nebulae against a background of precisely measured stars provided a means of confirming any potential change. Herschel's catalogs included such drawings, some of which were completed over years and contained hundreds of stars⁸ (see figure 3). Measurements of nebulae and double stars were the observational frontier of astronomy, and Herschel worked meticulously to bring uniformity and standardization to those difficult objects.

At the Cape

By 1833 Herschel had revisited all his father's targets in the northern sky. But there was an entire hemisphere not yet swept by telescope. Herschel had already begun considering extending his astronomical surveys to that new frontier, and after his mother's death in 1832—his aunt Caroline had moved back to her childhood home in Germany following William's death in

1822—Herschel decided the time had come. Because of a large inheritance, Herschel was able to relocate his wife and three young children, along with their nurse and a workman to help him with his large reflecting telescope, to the UK colony at the Cape of Good Hope, at the southern tip of Africa, where they arrived in January 1834 (see figure 4).

The UK's Royal Navy offered him passage aboard a warship, but he refused. The entire endeavor would be, as he told a friend, "an entirely irresponsible private adventure."⁹ Herschel wanted freedom to pursue his astronomical observations on his own terms. He ultimately spent four years at the Cape, where he continued his systematic sweeps and discovered and mapped new nebulae and double stars, and he became the first—and perhaps only—person in history to closely survey the entire visible sky by telescope. He also observed sunspots, variable stars, the moons of Saturn, and the return of Halley's comet in 1835. The product of that stay was the immense *Results of Astronomical Observations*—often referred to as the *Cape Results*—a massive volume published in 1847 that brought the wonders of the southern skies to view and which was distributed to observatories around the world.¹⁰

Upon his return to England in 1838, Herschel took his place at the head of the pantheon of UK science. He was given the title of baronet by Queen Victoria for his services to science, and a gala was thrown in London to welcome him home. By that point, Herschel's observing days were largely behind him, but he continued to write popular works that encouraged natural philosophers to apply his methods to the physical world. After spending 1850–55 as master of the mint, a post also held



FIGURE 3. A DRAWING of the Orion nebula by John Herschel that originally appeared in his 1847 volume *Cape Results*.¹⁰ This version of the image has been flipped and color inverted so that it is more legible. (Courtesy of Fabian RRRR, Wikimedia Commons/public domain.)

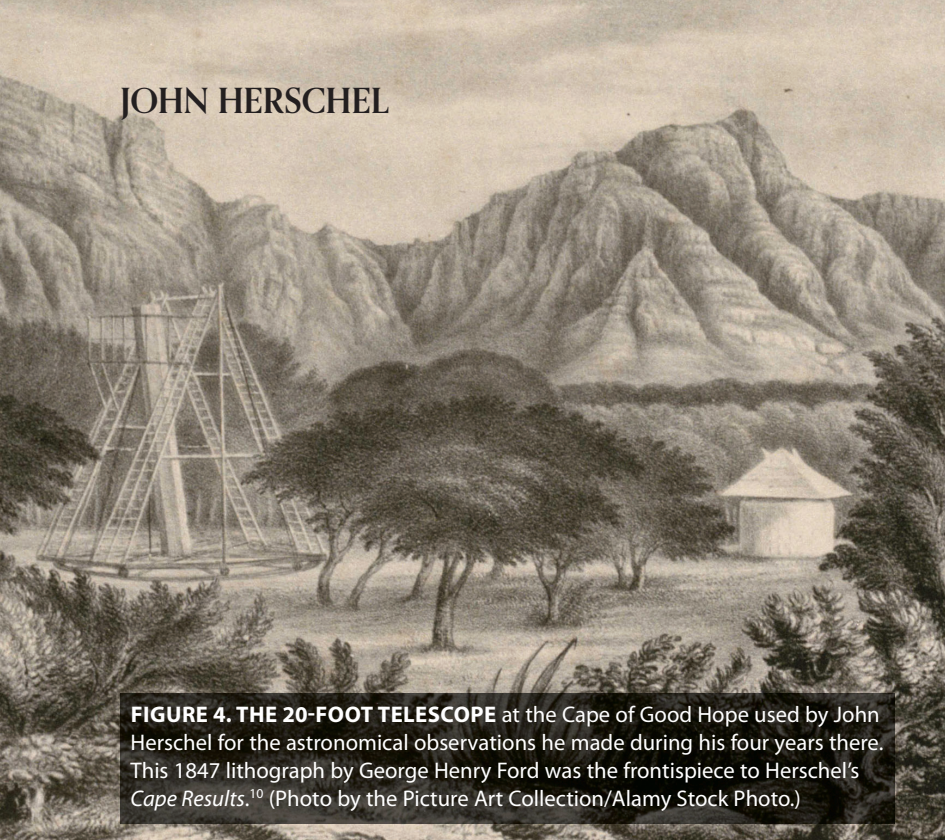


FIGURE 4. THE 20-FOOT TELESCOPE at the Cape of Good Hope used by John Herschel for the astronomical observations he made during his four years there. This 1847 lithograph by George Henry Ford was the frontispiece to Herschel's *Cape Results*.¹⁰ (Photo by the Picture Art Collection/Alamy Stock Photo.)

by Isaac Newton, Herschel retired so he could spend his days preparing a general catalog of all the nebulae he had discovered. The object numbers in that catalog, which was revised posthumously into the *New General Catalogue of Nebulae and Clusters of Stars*, remain the primary label by which astronomers refer to deep-sky objects. At the time of Herschel's death on 11 May 1871, he was held in high-enough esteem that he was buried in Westminster Abbey near Newton.

But Herschel was not simply celebrated as an astronomer. He was recognized by an entire generation of scientific practitioners—who were at the time of Herschel's death only beginning to be referred to as scientists—for helping define the practice of science itself. To understand how requires a return to the years before his self-imposed exile to the Cape.

The reformation of science

Although his early work with the Astronomical Society threatened the Royal Society's control over UK science, Herschel was active in both societies before his South African expedition. Whereas his colleagues Babbage and South thundered publicly that the Royal Society was stifling science, Herschel worked in the 1820s to reform the venerable society from within. The culmination of those efforts came in an 1830 confrontation between the reforming and conservative parties of the Royal Society over who would be its next president.

That year, the aristocratic wing of the society pushed for the election of King William IV's brother Augustus Frederick, Duke of Sussex. For the conservative leadership of the society, the duke was an ideal candidate: He was interested in science and, as an aristocrat, had beneficial social connections. For Herschel, those attributes were antithetical to the scientific endeavor. How could science progress on a meritocratic basis with a president who was royalty and whose mere suggestions could be construed as commands?

So radical were Herschel's views on the egalitarian nature of science that he suggested the bookish Francis Baily—a stockbroker who had gained recognition through his recalculation

of old star catalogs and who had risen to leadership in the Astronomical Society—as an opposing candidate. In a confrontation that mirrored the larger political landscape leading up to the parliamentary reforms of 1832, not only would Herschel not support the king's brother, but he supported a merchant commoner against him.

Herschel's reforming colleagues knew that Baily would not do. There was only one person whose scientific accomplishments and esteem could unify opposition to the duke: Herschel himself. At a meeting in October 1830, Herschel's colleagues urged him to allow his name to stand. He protested. He had no desire for leadership; he wanted the freedom to pursue his own scientific projects, not the responsibility of leading the Royal Society. Yet he agreed that the conservatives in the society should not be allowed to hand over the presidency through backroom dealings. Herschel ultimately allowed his colleagues to put his name forward, and soon the London newspapers were relishing in the scandal of the duke, son of the late King George III, being publicly opposed by the son of George's personal astronomer.

Although it was a close race, the reforming coup failed. The Duke of Sussex was elected and the aristocratic party retained its grip on the society. But the crisis reaffirmed in Herschel his belief that change must happen, and he channeled his efforts at reform into a new direction. If he could not transform the practice of science in the Royal Society, he would take his methods to the broader public.

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The book that invented science

In the days leading up to his failed bid for the presidency, Herschel was approached by science writer and editor Dionysius Lardner to author the preliminary volume of a new encyclopedia series focused on science. Eager to capitalize on the booming market among the middle class for popularizations of science, Lardner was looking for someone who could write with authority for a wide audience. Herschel, already well known for his writings, was the perfect candidate.

For Herschel, that book—first published in 1831 and titled *A Preliminary Discourse on the Study of Natural Philosophy*—was an opportunity to set out his vision of science. It did not matter if his reforming tendencies had been stymied in both Cambridge and London. Science, he argued, was bigger than what took place in the halls of the privileged elite. More than a static body of knowledge or aristocratic pastime, science was a matter of social and personal virtue. In addition to the practical benefits it provided, which were clear to his readers because of the Industrial Revolution unfolding around them, understanding science allowed people to reason clearly and cultivate character. Herschel went on in *A Preliminary Discourse* to outline what many consider to be the earliest modern formulation of the laws of scientific reasoning, thus providing a template for how investigators should search for lawlike behavior in nature.¹¹

A Preliminary Discourse articulated the relationship between mathematics and natural philosophy and showed how sci-

tific discoveries were made. It was both a defense of the scientific life and a manual for how to construct scientific theories. Apart from becoming a popular bestseller, it was read by those who would become the leading scientists of the next generation. Michael Faraday, for instance, wrote that he “continually endeavored to think of that book and to reason & investigate according to the principles there laid down.”¹² It convinced a certain young Cambridge naturalist to pursue the scientific vocation. And when that naturalist, Charles Darwin, began to create his own theory of the origin of species, he structured it—consciously or subconsciously—along the framework outlined by his scientific role model in *A Preliminary Discourse*.¹³

In all of Herschel’s pursuits—chemistry, astronomy, optics, and more—he pushed science toward standardization and mathematical analysis and away from traditions of prestige and privilege. Yet that effort bore most fruit through his *Preliminary Discourse*, which brought the ideals of science to the general public and articulated scientific methodology for a new generation. Although no theorem or discovery bears Herschel’s name, his work molded the contours of an age and helped shape the ideals of modern science.

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