Introduction

Herschel's Stars

> The Stars flourish, and in spite of all my attempts to thin them and . . . stuff them in my pockets, continue to afford a rich harvest.
>
> John Herschel to James Calder Stewart, July 17, 1834

In 2017, TRAPPIST-1, a red dwarf star forty light years from Earth, made headlines as the center of a system with not one or two but *seven* potentially habitable exoplanets.[1] This dim, nearby star offers only the most recent example of verification of the sort of planetary system common in science fiction: multiple temperate, terrestrial worlds within a single star's family of planets. Indeed, this discovery followed the announcement only a few years earlier of the very first Earth-sized world orbiting within the habitable zone of its star, Kepler-186, five hundred light years from Earth.[2] Along with other ongoing surveys and advanced instruments, the Kepler mission, which recently added an additional 715 worlds to a total of over five thousand exoplanet candidates, is revealing a universe in which exoplanets proliferate, Earth-like worlds are common, and planets within the habitable zone of their host star are far from rare.[3] Exoplanetary astronomy has developed to the point that astronomers can not only detect these objects but also describe the physical characteristics of many with a high degree of confidence and precision, gaining information on their composition, atmospheric makeup, temperature, and even weather patterns.

These worlds circling other stars were not unexpected phenomena —exoplanetary research today is confirming a long-held assumption about the universe. As modern historians of astronomy have shown, the idea of worlds orbiting stars has a long conceptual pedigree. To take one example among many, in the 1726 edition of *Elements of Physical and Geometrical Astronomy*, one of the first works to present the Newtonian system of the universe to a nonspecialized audience, the author recounted what ancient authority had held: that there were "Planets of a Terrestrial Nature, performing their Revolutions in the System of every Fix'd Star."[4] Throughout the eighteenth and nineteenth centuries the majority of practicing astronomers as well as the general public assumed that stars had unseen planets in train.[5]

The role of exoplanets in astronomy today is analogous to the role played by the stars themselves from the beginning of the nineteenth century to the advent of stellar spectroscopy in 1861. In the nineteenth century, astronomers believed stars were physical objects of the same nature as the sun. Yet, as with the existence of exoplanets up to the 1990s, this remained an assumption. In the period before the career of the British astronomer and natural philosopher Sir John Herschel (1792–1871), there was very little evidence upon which to base this solar-stellar identification. It was not until the period from roughly 1820 to 1860 that important strides were made in bringing a quantifiable physicality to the stars through measurements of their distance, luminosity, and, in the case of binary stars, their orbital parameters and relative masses. Just as contemporary discoveries are yielding glimpses of exoplanets as distinct and measurable physical realities, during the career of John Herschel, astronomers for the first time measured stars as physical objects and shared these discoveries in popular texts and professional publications. In so doing, they helped transform astronomy by connecting the practices of an older, traditional form of the science with new frontiers of physical discovery. As exoplanets in our lifetime have moved from speculation to quantification, so in the nineteenth century the stars became physical as astronomers measured stellar mass, distance, and luminosity. The stars, long assumed suns, became measurable physical objects and opened up new vistas for conceptualizing the nature of the universe and humanity's place within it.

The origins of this transformation, as stars transitioned from the static backdrop of traditional, positional astronomy to objects studied in their own right, lay in the pioneering work of John Herschel's father and teacher, William Herschel (1738–1822), who is rightly regarded as the founder of sidereal astronomy. William's work was central in initiating the "sidereal revolution," a shift of attention from the planetary system to the study of astronomical targets beyond the solar system, including nebulous regions in the heavens and speculations on the nature of the Milky Way and the sun's position within it.[6] Yet throughout William's lifetime his work remained well outside the practices of traditional astronomy. Indeed, his contemporaries were puzzled by his approach to the study of celestial bodies and his claims regarding the magnifying power of his telescopes—claims that were, according to some, "the conceptions of a madman."[7] It was only through the career of William's son, John, that stellar astronomy moved from the periphery of astronomical practice to be considered part of the scientific mainstream. Often relegated to the position of a simple extender or completer of his father's work, John Herschel in reality established the sidereal revolution that William had only begun. The younger Herschel rapidly achieved the status and credibility in the scientific community both in Britain and abroad that was necessary to transform the study of the sidereal heavens from the particular interest of a single astronomer with unique instrumentation into a coordinated, systematic, mathematically based research program involving numerous observers.

In the history of astronomy, the narrative of humanity's understanding of stars is often considered as not beginning until the birth of stellar spectroscopy near the close of the nineteenth century. Decades before the first pioneering work in spectroscopy, however, John Herschel made double stars and variable stars the subject of research efforts for the astronomical community, reconceptualized the nature of star catalogues, and promulgated the idea of stars as measurable, physical bodies to the wider public. Through his work, the stars moved from assumption and speculation to become viable targets of research. John Herschel thus did more than simply inherit and continue his father's work—he was instrumental in transforming the way astronomers and the public perceived the stars themselves.

John Herschel and Nineteenth-Century Science

When John Frederick William Herschel was made a baronet by Queen Victoria on the occasion of her coronation in 1838, he stood at the apex of the community of British natural philosophers in the nineteenth century, acknowledged throughout the world as a scientific authority. He played a leading role in scientific societies of the period: already a member of the Royal Society by 1813—the year of his graduation from

Cambridge as First Wrangler—he was elected to its council in 1820 and served as the society's secretary from 1824 to 1827. He was also a founding member of the Astronomical Society in 1820 and served as its foreign secretary until becoming president of the society in 1827. Perhaps surprisingly, accounts of John Herschel's early life agree that astronomy was not his first career choice. After graduating, the young Herschel went to London with the intention of becoming a lawyer. By 1816 he had decided to follow in his father's footsteps to become a natural philosopher; however, John Herschel made his initial mark on British natural philosophy by introducing the Continental form of analysis into mathematical physics. He spent his early experimental career investigating the nature of light and its interaction with various media, publishing a treatise in 1830 considered at the time the most developed account in English of the theory of light since Newton.[8] With the benefit of his father's international fame, he traveled extensively throughout Europe during this period and met the leading men of science abroad.

Though Herschel's initial scientific interests were optics and chemistry, he ultimately submitted to his aging father's desires that he assist in William's astronomical surveys. In this way, John was bequeathed a unique research project and the world's most advanced telescope with which to pursue it. He did not, however, initially believe that this work would be a long or defining undertaking. He wrote a correspondent in 1827, explaining his decline of the offer of the Plumian Chair of Astronomy at Cambridge:

> As to my intention of devoting myself in future chiefly or entirely to Astronomical pursuits—I really have, at present none such. I have a work in hand which I consider it a sort of duty to complete, I mean the review and redetermination of my Father's nebulae. I think this task devolves on me in an especial manner, as I believe no instrument competent to the work exists but my own. . . . At the same time I have no intention to tie myself to this should its prosecution ever become unpleasant or inconvenient to me, nor is it a thing which is at all likely to prove the work of a life.[9]

Herschel was mistaken in the importance astronomy would play in his career. Though his contributions to other fields of science were extensive, it was primarily as an astronomer that he became best known and would be remembered.

Herschel established himself as a popular writer in 1833 with his *Treatise on Astronomy*, a book that went through at least a dozen editions before the end of the century and became (along with its 1849 expansion, *Outlines of Astronomy*) one of the most important astronomy texts of the nineteenth century. Also in 1833, Herschel departed England for a four-year stay at the Cape of Good Hope in South Africa and became the first person in history to closely and systematically survey the entire sky by telescope. Upon his return to London, he was hailed by the royal family as "the most accomplished and the most devoted of our living philosophers."[10] Though he considered his observational career to have concluded after his time at the Cape, Herschel worked for years to reduce and publish the data he had gathered, which eventually resulted in his monumental *Cape Results* of 1847.[11] By this time he was securely ensconced as one of the leading British scientific lights, corresponding with all astronomers of note in Britain and with prominent natural philosophers around the world.

One historian has claimed that being scientific in Victorian England could be summed up as the goal of being "as much like John Herschel as possible."[12] The art critic John Ruskin (1818–1900) remarked in correspondence on meeting "the leading scientific men of the day, from Herschel downwards," whereas another contemporary wrote that Herschel's word was "the index of the opinions of the scientific world."[13] Herschel was the first to publish an explicit treatment of the philosophy of science in English, his *Preliminary Discourse on the Study of Natural Philosophy* (1830). This was the book of which Charles Darwin (1809–1882) would write, when sending Herschel a copy of his *Origin of Species*, that "scarcely anything in my life made so deep an impression on me."[14] Herschel's influence was such that upon his death he was buried in Westminster Abbey near the grave of Isaac Newton (and when Darwin died, he was laid to rest beside his hero Herschel).

Herschel's fame endures among historians of science. David Evans, an astronomer who published studies on Herschel's work, compared the esteem with which Herschel was held in Britain in the nineteenth century to that of Einstein in the following century. The writer of an introductory text on the philosophy of science acknowledges that Herschel became "*the* 'man of science' in early nineteenth-century England." As the subtitle of the recent popular history by Laura J. Snyder proclaims, Herschel is one of the natural philosophers who "transformed science and changed the world." He is also a prominent character in the sweeping narrative of Romantic science by Richard Holmes, who calls Herschel "the greatest astronomer and general scientist of his generation."[15] Yet the only book-length biographies of Herschel remain a 1970 work by a German librarian that is admitted by its author to be only a "sketch" and a manuscript by Herschel's great-granddaughter originally composed in the 1960s and recently published by the Herschel family.[16]

Scholarship on Herschel is as wide-ranging as Herschel's own scientific interests. For example, a bibliography on publications related to Herschel, prepared for the *Calendar of the Correspondence of Sir John Herschel* in 1998, extends over eight pages of small, double-columned print. The *Calendar* constitutes the most comprehensive published source of material from Herschel's life, representing a decade of labor in which nearly fifteen thousand of Herschel's surviving letters were read and summarized.[17] After completing work on the *Calendar*, Michael Crowe, its chief editor, surveyed remaining questions and noted that "much more needs to be known of [Herschel's] contributions to astronomy, especially of his extremely important role in raising stellar astronomy from being a specialty of a few figures on the fringe of traditional astronomy to the central, indeed dominant role that it occupied by the end of the nineteenth century."[18] My goal is to tell that story.

John Herschel's ideas regarding the physical nature of the stars were not formed in a vacuum. Since the generation after Copernicus, stars were assumed to be immense, spherical, fiery objects of the same nature as the sun, with astronomers offering multiple "proofs" for this identification. William Herschel in particular drew upon these assumptions about the stars throughout his work, and the younger Herschel's stellar astronomy built on these conceptions while both reinterpreting and quantifying them. John Herschel was also influenced by the work of his aunt, Caroline Herschel (1750–1848). Caroline's contributions to astronomy extended far beyond simply being an assistant and amanuensis to William. It was Caroline's careful calculations and organization that turned William's observations into useful astronomical knowledge. One way of understanding John Herschel's successful career in astronomy is that in his own person he combined the observational and instrumental acumen of his father with the mathematical and organizational diligence of his aunt. John followed his aunt in this careful reduction and presentation of data just as much as he followed his father in his selection of observational targets. As I outline in chapter one, the younger Herschel depended on the model provided by Caroline as well as her work preparing catalogues of observations that continued even after the death of her brother William.

Even as Herschel brought a new mathematical rigor to investigations of the stars, positional astronomy—the traditional practice of astronomy with the goal of exactly determining stellar positions—continued to flourish and reached new levels of precision in Britain and abroad. In chapter two, I examine Herschel's relationship with this dominant form of astronomical practice in Britain. For Herschel, positional astronomy was not of interest for showcasing instrumental precision, nor for its applications to timekeeping, surveying, or cartography. Instead, he viewed positional star catalogues as a tool for his stellar astronomy: they were "empirical nets" cast to chart motions and changes among stars and ultimately reveal more about the nature of these objects themselves. Moreover, Herschel wanted to make star catalogues and their organization more intuitive for observers not equipped with the instruments of positional astronomy. Catalogues needed to be useful to observers so that observers in turn could make measurements of objects like variable stars and double stars that were useful in constructing theories regarding their nature. To this end, he was willing to reorganize entire constellations in order to make catalogues more useful for astronomers, in particular those searching for objects outside of observatories and under the open sky.

In chapter three I begin my survey of Herschel's astronomical career with his double star research. John Herschel began his work in astronomy by revisiting double stars discovered by his father to confirm William's claim that these pairs were gravitationally bound. Though John Herschel often spoke of his work on double stars as secondary to continuing his father's surveys of nebulae, double stars remained a common theme throughout his career. Herschel's calculations of binary star orbits extended Newtonian gravitation to the sidereal realm. His work on these objects offers the clearest example of his scientific methodology, in which trained observers made observations and passed their data to Herschel, who used them to construct physical and mathematical models of these stellar systems.

Herschel's time at the Cape of Good Hope from 1834 to 1838 marks a transition in his focus from binary stars to variable stars, the topic of chapter four. Whereas binary stars offered insights into the masses and proper motion of stars, variable stars had the potential to yield information on stellar structure. Before Herschel's work, theories regarding the cause of variability in stars usually involved dark spots and stellar rotation. Herschel's observation of the dramatic eruption of the star η Argus shortly before his return from the Cape brought to the fore new questions regarding such objects. In particular, Herschel speculated whether stellar variation could be intrinsic or the result of an obscuring celestial medium. He believed that variable stars were an important and neglected topic, and for years upon his return to England he worked on simplifying methods for comparing stellar magnitudes and urging observers to take up this work.

Concurrent with his work on both binary stars and variable stars was Herschel's work on nebulae, discussed in chapter five. Herschel's research on nebulae is an excellent example of how his investigations formed a bridge between positional and physical astronomy, as he organized data and surveys in order to give observers tools necessary for useful observations. In this respect, his nebular catalogues were similar to his double star catalogues and stellar magnitude lists, though he also focused on ways to accurately represent the observed appearance of nebulae. These observations and representations, Herschel hoped, would address the question of change in nebulae, which had implications for stellar evolution as well as their possible stellar structure.

By the end of Herschel's lifetime, the spectroscopic analysis of starlight was ushering in the new science of astrophysics. Yet he had been aware of the fact that stars had specific arrangements of dark lines in their spectra from very early in his career, and he went on to conduct studies on the nature of light and the solar spectrum after the conclusion of his astronomical work. In chapter six, I examine what the fact that Herschel never turned spectroscopy to the examination of starlight reveals regarding the nature of his physical investigations. Herschel's optical work first involved creating a monochromatic light source to study the effect of crystals on polarized light. After his return from the Cape, he applied photography to the solar spectrum to investigate its chemical activity but never applied spectroscopic analysis to astronomy. Near the end of his lifetime he corresponded with those who were pursuing astronomical spectroscopy, including his sons, but remained skeptical regarding the claims of this new science.

One way of understanding the transformations in popular perception regarding the stars that took place during Herschel's career and through his work is by placing the stars in the context of perceptions of nature during this period. Herschel's writings on the nature of stars as physical objects throughout his lifetime were consistent with Romantic themes of the sublime in nature common in literature and nature writing, but his work moved stars from part of a sublime *landscape* to become sublime *objects* in their own right. In chapter seven I explore this transition in the case of double stars. With double stars, Herschel combined rhetoric of majestic physical bodies with the mathematical rigor of positional astronomy to motivate research that blurred boundaries between amateurs, professionals, and the reading public. This transformation made the stars an important part of popular conceptions of the universe in a new and rigorously physical way.

Herschel's stellar astronomy, which up to now has remained an unexplored aspect of the important prehistory of astrophysics, treated stars as physical objects with velocity, size, and mass decades before the advent of spectroscopy. Though he was not solely responsible for the advances during this period, Herschel enjoyed the widest renown of astronomers pursuing stellar astronomy, and his work was the earliest and most influential in Britain. Representations of Herschel's work changed throughout the nineteenth century, however, and his contributions to stellar astronomy became less obvious after the birth of astrophysics. By the end of the century, Herschel's work became overshadowed on one side by his father's pioneering work and on the other by the findings of spectroscopy, ultimately obscuring the work of one who was seen during his career as the "Copernicus of the sidereal heavens."

Locating Herschel among Amateurs and Professionals in Stellar Astronomy

William Herschel's pioneering labors rightly make him the father of astronomy directed beyond the boundary of the solar system. John Herschel, however, by means of his own observations, his popular esteem, and his position in the scientific community, transformed what had been the domain of a single individual with unique instruments into an accessible research program involving multiple observers and served as the primary spokesman and advocate of this new approach. In addition, he communicated the resulting view of the stars through his popular texts and their influence on the writings of others.

Herschel's stellar astronomy also sets the groundwork for further studies on the history of stars. There still exists no comprehensive work on stellar astronomy in the nineteenth century. Histories of solar and stellar physics most often begin with spectral analysis and its application to starlight and sunlight. By examining Herschel's stellar astronomy in the period leading up to spectroscopy, I make a start at filling the gaps in this narrative and showing the ways in which stars became physical prior to astrophysics.

Herschel's work also has implications for questions of professionalization and amateur astronomy during this period. Herschel's career and program of stellar astronomy complicate divisions often drawn between professional astronomers and amateur observers. Despite an extensive survey of nineteenth-century British amateur astronomers that classifies Herschel, "the undisputed *Grand Seigneur* of British astronomy," as "the grandest of the Grand Amateurs," Herschel's career shows the difficulty in making any clear *programmatic* divide between amateur and professional observers, between those who were paid to pursue astronomy and those who did so as a hobby or as self-funded research.[19] My expectation was to find that the relatively few professional astronomers in Britain pursued positional astronomy while Herschel's stellar astronomy found adherents among amateur observers. This was not in fact the case.

Herschel's classification as an amateur is unproblematic: he never received remuneration for his astronomical observations. He certainly considered himself an amateur, and valued the freedom his amateur status afforded, including the freedom to *not* do astronomy. As he wrote early in his career explaining his refusal of a university post, "I may work much harder and do better service as a private amateur than ever I should do as a Professor. . . . I have other pursuits to which I am at least as deeply devoted as to astronomy and which I am not sure that I do not *like* better and which, if I *profess* astronomy I must resign."[20] Likewise, this emphasis on freedom is expressed later in his career in his polite but firm refusals to accept government aid in his South African expedition: "I have made up my mind . . . to stand from first to last in the situation of an amateur embarking in a party of pleasure."[21]

Yet it is not clear that such a classification is helpful, as it complicates any professional-amateur distinction: Herschel was clearly one of the leading astronomers (if not *the* leading astronomer) during this period. Likewise, many of the observers Herschel influenced to begin work in stellar astronomy are difficult to classify according to this distinction. William Rutter Dawes (1799–1868), for instance, who reported binary star measures to Herschel, worked for a time as the paid director of the personal observatory of a wealthy enthusiast. John Russell Hind (1823–1895), who corresponded with Herschel regarding variable star research, later filled the same position. The correspondence networks by which Herschel motivated astronomers to take up stellar astronomy further renders amateur and professional distinctions problematic. For example, on separate occasions Herschel urged George Airy (1801–1892)—perhaps the epitome of the professional astronomer, directing the epitome of positional observatories—to turn his attention to double stars and variable stars, targets assumed to be the domain of amateurs.

Herschel's career shows that there are better ways to map the constellation of observers in nineteenth-century Britain than a division between amateur and professional based on pecuniary remuneration. Although variable star research was an area in which Herschel felt amateurs could most easily make important contributions, the astronomers with whom Herschel primarily corresponded on the topic held paid positions. Herschel himself perceived divisions among different types of observers, but those did not follow lines of financial support. Instead, he categorized observers based on mathematical training and instrumentation, both of which constrained the ways observers could contribute to astronomy. Regarding mathematical training, Herschel distinguished between observers who gathered data and mathematicians who constructed theories from those data, even though he himself bridged this divide.

A common thread in Herschel's stellar astronomy was an attempt to create forms and practices that would render the observations of others more useful. In this he was influenced by the example of Caroline, who for years had performed the meticulous calculations that transformed his father's observations from "raw data into publishable, error-free knowledge."[22] For example, in his double star work, for which Herschel needed a large amount of accurate observations to support his mathematical orbits, he pioneered and promulgated clearer and more intuitive methods for reporting measurements. This approach is even more apparent in his variable star research, in which his justification for reforming the constellations and ordering star magnitudes was to provide a means by which even naked-eye observers could contribute data on these objects. Whether it was amateurs or professionals who would make the requisite observations, Herschel wanted practices that allowed observers with no mathematical training to gather useful data.

For Herschel, these two components, structured observations of the stars coupled with mathematical interpretation, together composed an active and fruitful research program. This was the case with Herschel's binary star research, so much so that when he departed for the Cape of Good Hope and took his expertise with him, the program of double star observation largely ceased in England, only to begin again when he returned and renewed his mathematical attack. This was not the case with variable star research, for which a theory of stellar variation into which observation could feed never developed, nor was it the case with the nebulae. This, however, was not reason enough to leave off observations—given enough data, Herschel was certain, useful generalizations would arise. Finally, the distinction between observers and theorists also hints at Herschel's ultimate skepticism regarding the analyses of the amateur observer and pioneer of spectroscopy William Huggins (1824–1910) near the end of Herschel's life. Herschel did not doubt that Huggins was a highly trained observer, but he remained unconvinced regarding his results because neither Huggins nor anyone else could offer a physical or mathematical explanation for them.

The second divide Herschel made between types of observers was instrumental: between those with meridian instruments and those, like him, with telescopes of an altitude-azimuth mounting (such as his twenty-foot refractor) or with equatorial telescopes (such as his seven-foot reflector). Only astronomers with meridian instruments had the precision required to practice positional astronomy. Though these types of instruments were usually found in large, institutional observatories, amateurs had and used them as well. The stellar astronomy Herschel pursued, on the other hand, was suited for nonmeridian instruments. Astronomers with these instruments, which had less positional accuracy but greater range of motion, were more likely to pursue studies of specific objects in the heavens instead of purely positional astronomy. These were, of course, the types of instruments that his father had used for observing the heavens and that Caroline had used to search for comets. Likewise, Wilhelm Struve (1793–1864), a German astronomer who would correspond with Herschel extensively and conduct his own double star survey, used an equatorial telescope constructed by the optician Joseph von Fraunhofer (1787–1826), as did the astronomer Friedrich Argelander (1799–1875) in his extensive survey of northern stars.[23]

In the popular imagination, Herschel's name was associated with the stars. Yet Herschel's stellar astronomy was only one aspect of his long and varied career. Though this astronomical work was indeed central to both Herschel's scientific endeavors and his popular esteem, stars were not his sole interest. By the fifth decade of his life, he had published important work on chemistry, optics, and photography, had married Margaret Brodie Stewart (1810–1884), and with her had begun a family that would ultimately include twelve children. In 1841, while working to reduce his astronomical observations from the Cape of Good Hope, Herschel put his interest in astronomy into perspective when writing to Margaret about his inability to pursue photography: "You cannot grasp by what links *this* department of science holds me captive. I see it sliding out of my hands while I have been *dallying* with the stars. *Light* was my first love! In an evil hour I quitted her for those brute and heavy bodies which tumbling along thro' ether, startle her from her deep recesses and drive her trembling and sensitive into our view."[24] Ironically, though, it was Herschel's work on those "brute and heavy bodies" that allowed them to be so described: objects with measurable masses and velocities, physical properties that before Herschel's work had remained mere assumptions. And as a result of Herschel's work and writings, the physical properties of these objects became recognized and stellar astronomy evolved from the inheritance of William Herschel to the province of observers everywhere.