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978-1-107-01838-9 - The Construction of the Heavens: William Herschel's Cosmology
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# Introduction

William Herschel (1738–1822) was a musician and composer for the first half of his life, and astronomer to the King of Britain for the second half. Astronomers of the time might distinguish themselves either as makers of telescopes, or as observers, or as theoreticians. Herschel distinguished himself in all three.

In November 1778, while a musician in the English spa resort of Bath, Herschel as an amateur observer ground and polished for his 7-ft reflector a mirror that was simply the finest anywhere; and using it he discovered the planet we know as Uranus. This won him the patronage of the King and with it the opportunity to give up music and dedicate himself to astronomy. With funding from the King he then built himself the biggest reflector ever seen, and he conducted a brisk trade in telescopes, the crowned heads of Europe competing to be allowed to buy a Herschel reflector.

As an observer, Herschel saw himself as a natural historian of the heavens, collecting and classifying specimens in vast numbers. While still an amateur he began collecting double stars by the hundred, and as a professional he published catalogues of 2,500 nebulae and clusters where only a hundred or so had been known before.

But it is as a theoretician that Herschel earned his pre-eminent place in the history of astronomy. Isaac Newton had envisaged the universe as a hugely-complex piece of clockwork, the creation of God the Clockmaker. Within this universe nothing really changed, just as in a clock the hands move but nothing really changes. But there was a problem. Forces generate motions, and Newton claimed that gravity was a universal force; yet when Newton was in his prime it seemed that the stars were as 'fixed' and motionless as they had ever been. His way out of the difficulty – known only to his intimates – was to argue that the stars were distributed (more or less) uniformly throughout infinite space, so that each star was pulled (more or less) equally in every direction by the other stars and thus remained at rest, at least in the short term. Over the long term (he believed) things did not go so well, and so from time to time Providence had to intervene and restore the original order to the universe of stars.

In 1785 Herschel invited the readers of *Philosophical Transactions* to imagine a universe that likewise began with a near-uniform distribution of stars throughout an indefinite space. Although Newton had never given a demonstration that gravitational attraction operated beyond the solar system, Herschel found clear proof of this in the existence of star clusters: the clusters must surely have formed as previously-isolated stars attracted each other and moved ever closer together.

Significantly, in some of the clusters that he encountered the stars were scattered, while in others they were tightly packed; and surely *in time* the scattered clusters would become ever more compact, as gravity continued to pull the stars towards each other. In other words, scattered clusters were young, and compact clusters were old. This insight, that individual clusters have a life history – that cosmogony is the key to the study of what Herschel termed "the construction of the heavens" – tolled the death-knell of the clockwork universe.

In his early years as a professional astronomer Herschel envisaged our Galaxy as a layer or 'stratum' of stars of limited extent, and, as we shall see, he devised a novel method for plotting its outline. There were also, he thought, other strata in the sky that were so extensive that they might even "outvie our milky-way in grandeur": these were what we would term 'galaxies'. Later he was forced to admit that the stratum of our Galaxy seemed in fact to be without bounds, and if so it was unique. Not only that, but it was evidently starting to fragment under the destructive force of gravity, and so its future existence was limited in time – and so, intriguingly, must be its past.

In the later 1780s Herschel convinced himself that the luminous bodies in the larger universe are exclusively stars, isolated or in clusters, but in 1790 a new observation persuaded him of the existence of 'true nebulosity', a luminous fluid out of which stars were born. This led him to take his cosmogony back in time to the period before stars had formed; in imagination he allowed gravity to work its magic first on this fluid, and then on the resulting stars. As it was not possible in the brief span of human life for an individual person to observe this evolution unfolding, in papers published in 1811 and 1814 Herschel offered the equivalent by arranging his nebulae and clusters sequentially by age, into 'articles'. These, he said, were comparable to a succession of portraits of an individual man as he went through life.

Like all astronomers of the period, Herschel knew that the speed of light though great was finite, and he was the first clearly to state what has become a commonplace in modern cosmology, that to see an object at distance is to see it in past time. Indeed, he believed that he personally had seen light that had been two million years on its way, and that if the source of the light had been annihilated soon after the light departed on its journey, Herschel would still see the object when its light eventually reached him.

In his years as an amateur astronomer Herschel had focused his efforts on the nearer stars. As he examined them one by one, he listed those that were 'double', two stars so close that at first inspection they appeared to be one – for he knew that Galileo had popularized a method of using doubles to establish the distances of the nearer of the two stars. But when he re-examined some of his doubles after another twenty or so years, he had a quite different reward for his labours: in some of the pairs, the two stars had performed a gyration around each other – they were companions in space, bound together by an attractive force, no doubt gravity. This was the first time that such a force had actually been seen in action in the stellar universe.

In these investigations, whether of double stars or of nebulae and clusters, Herschel's telescopes gave him the advantage over all other astronomers, for much of the evidence was available to him alone. But there was one question where he relied exclusively on evidence available to all: the direction in which the solar system is travelling through space. By the 1780s a small number of stars were known to be in motion, moving across the sky almost imperceptibly year by year; and surely the star we call the Sun (accompanied by its planets) must also be in motion. Now if we inhabitants of the solar system are travelling in a certain direction, we will expect the stars that we are approaching to appear to move to one side or the other, as do the trees that are in front of us as we walk towards a forest. Herschel was the first to identify such a pattern and to propose the actual direction in which the solar system is moving.

Astronomers of Herschel's day, amateur and professional alike, were preoccupied with the solar system and believed themselves to inhabit a clockwork universe. Today's universe could not be more different: the solar system is a minority interest, and we see ourselves as living in a 'biological' cosmos that itself was born out of a Big Bang. Herschel's published articles in *Philosophical Transactions* began this seismic shift. This book explains how his thinking developed, and reprints these articles, with footnotes drawing on what we have since learned about the objects he discusses.

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# PART I HERSCHEL'S EXPLORATION OF THE COSMOS

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# 1

# The making of an astronomer

William Herschel (Fig. 1.1) was born in Hanover on 15 November 1738 into a humble but musically talented family.[1] His father Isaac was a bandsman in the Hanoverian Guards,[2] and Isaac's infant son was baptized Friedrich Wilhelm Herschel in the Garrison Chapel. We know him as William because this is the name he always used after he fled to England in 1757 to escape the aftermath of the Battle of Hastenbeck, and in 1793 the name became legally his by Act of Parliament.[3]

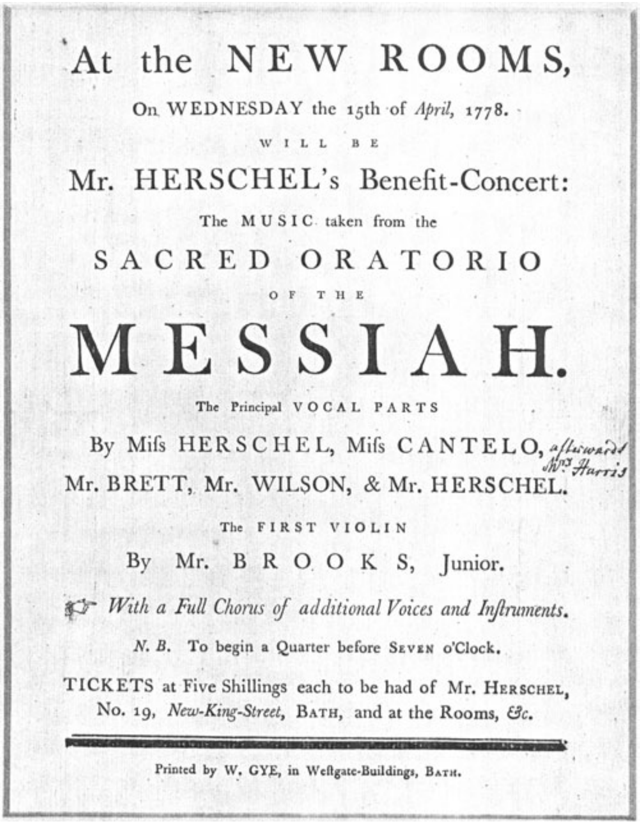
All the Herschel boys grew up to be musicians able to perform professionally on a range of instruments, and for more than half his life Herschel was a violinist, oboist, harpsichordist, organist and singer, whose ambition was to be remembered as the composer of symphonies and concertos. After his arrival in England, Herschel performed and taught music, first in London and then in the north of the country. In 1766 his fortunes took a turn for the better, when he was invited to become organist of the Octagon Chapel then under construction in the fashionable city of Bath. There the aristocracy came to take the waters and enjoy musical entertainment during the season, which lasted from the autumn through to Easter, and so there were rich pickings in Bath for an enterprising and hard-working musician – although the intense competition could sometimes lead to unseemly squabbles. Herschel soon established himself there as one of the two leading performers, and before long he was joined by his younger brother Alexander, a cellist whose remarkable talent as a brass-worker was later to prove invaluable in the construction of telescopes.

Herschel had two surviving sisters. The elder, Sophia, was long since married and had a large family of her own, but Caroline, eleven years William Herschel's junior, was languishing as a household drudge in the family home in Hanover. Their mother, Anna, enjoyed having reliable and unpaid help around the house

**Fig. 1.1** Miniature of William Herschel as a young man, artist unknown. Herschel probably gave it to his sister Caroline when he travelled from England to visit the family home in Hanover in 1764. In her old age, Caroline gave it to her brother's only son John. Herschel Family Archives.

and she did everything in her power to prevent Caroline acquiring the skills – in needlework, or in the French language – that might have allowed her to make her escape.[4] Caroline was diminutive and marked with the scars of smallpox, and her father (who died in 1767 of health problems brought on by war service) had long ago warned her not to expect an offer of matrimony. To bring Caroline to Bath her brothers invented an implausible excuse – that she might prove to have a good singing voice, and if so could play a role in the Handel oratorios that Herschel promoted. Anna was won over by the promise of an annuity to pay for substitute help in the home, and so it was that in 1772 Caroline joined her brothers in Bath.

It turned out that she could indeed sing (Fig. 1.2). But she had limitations. In childhood, as a female pupil of the Garrison School in Hanover, she had not been allowed to learn arithmetic, and so could not keep the household accounts – let alone play a future role in the astronomy that was fast becoming



At the NEW ROOMS,
On WEDNESDAY the 15th of *April*, 1778.
WILL BE
Mr. HERSCHEL's Benefit-Concert:
The MUSIC taken from the
SACRED ORATORIO
OF THE
MESSIAH.
The Principal VOCAL PARTS
By Mifs HERSCHEL, Mifs CANTELO, afterwards Mrs Harris
Mr. BRETT, Mr. WILSON, & Mr. HERSCHEL.
The FIRST VIOLIN
By Mr. BROOKS, Junior.
☞ *With a Full Chorus of additional Voices and Inftruments.*
*N. B.* To begin a Quarter before SEVEN o'Clock.
TICKETS at Five Shillings each to be had of Mr. HERSCHEL,
No. 19, *New-King-Street*, BATH, and at the Rooms, &c.
Printed by W. GYE, in Weftgate-Buildings, BATH.

**Fig. 1.2** Poster advertising a performance of Handel's *Messiah* in Bath, 15 April 1778. It was a 'benefit concert' promoted by Herschel, that is, one for which he took full financial responsibility, and both he and his sister Caroline performed as soloists. After the performance Caroline was invited to perform at Birmingham, an engagement that might have launched her independent career as a singer, but she declined. Herschel Family Archives.

a passion for her older brother. Herschel lost no time in remedying her lack of arithmetic. He also taught her some elementary geometry, the hard way: when cutting herself a slice of pudding, if she failed to estimate correctly the angle made by the slice, this grown woman was made to go hungry.

Although when Herschel was a boy his father had rarely had two *gutengroschen* to rub together, the admirable Isaac had somehow learned something about the ideas of Newton, Leibniz and Euler, and had shared these with his sons, not as truths to be learned but as subjects for critical debate. As a boy bandsman in the Hanoverian Guards Herschel had used his army pay to purchase the three volumes of John Locke's *On Human Understanding*. Later, when he was a musician in the north of England, Herschel had bought *Harmonics* by the Cambridge professor Robert Smith; and in Bath he decided to buy the same author's two-volume treatise on *Opticks*.[5] This told him a lot about how to build a telescope, and a little about what to see with the completed instrument. His appetite whetted, soon after Caroline's arrival he purchased the very successful introductory text *Astronomy* by the sometime shepherd-boy James Ferguson.[6] Although no more than a popularizer, Ferguson had been elected a Fellow of the Royal Society and granted a small 'pension' by the King, and Herschel therefore took him very seriously.

In the first edition of his book, Ferguson had little to say about the stars. Their Greek name of 'fixed stars' was still widely used, although everyone now knew that they were in fact isolated bodies in space and able to move freely. For most purposes they were still an unchanging and therefore uninteresting backcloth to the motions of the planets, moons and comets of the solar system; and so it was these nearer bodies that continued to preoccupy astronomers. Fortunately it was a later edition of *Astronomy* that Herschel had bought, one to which Ferguson had added a chapter "Of the fixed Stars".

Herschel was eager to see the sights described by Smith and Ferguson, and for this he needed telescopes.[7] He first experimented with refractors, in which a lens at the upper end of the tube bends the incoming light and brings it to a focus near the bottom where it is examined through an eyepiece. The problem was that the different colours are bent ('refracted') by the lens through slightly different angles and so come to a focus at slightly different distances. This results in a blurring ('chromatic aberration'), which can be reduced by making the tube as long as possible. But a telescope of excessive length is hard to direct and control, and Herschel soon abandoned refractors. The solution, as Newton had shown, was to have at the foot of the tube a mirror that reflected the light back to a focus near the top; this avoided the problem because all colours are reflected equally. At the top of the tube, a 'Newtonian' reflector has a small flat mirror set at an angle, and this directs the image sideways, where the observer examines it through the eyepiece. Somewhat surprisingly, therefore, in a Newtonian reflector the observer is positioned at the top of the tube looking sideways to the direction from which the light is coming. Guided by what Smith had to say, Herschel made himself reflectors of ever-increasing size: 5½-ft focal length, then 7-ft, then 10-ft, and finally, in July 1776, 20-ft. Mirrors that were of the same diameter and focal length were interchangeable, and Herschel experimented endlessly, grinding and polishing in search of the ideal shape and reflectivity, while Caroline read to him to relieve the boredom and sometimes put food into his mouth as though feeding a baby.