The Herschels and Bath: Music, Science and Social Climbing

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1 Introduction

In February 1781 William Herschel was a successful musician on the Bath social scene: as director of public concerts, and sought as a teacher, he was earning a very respectable £400 per annum[1]. The son of Hanover Guards bandsman, Wilhelm, as he was then known, had followed the family trade and by the age of fourteen was playing, like his father, in the regimental band. His subsequent life followed the fairly typical hand-to-mouth and precarious existence of a hard-working jobbing musician of some talent, with ambitions to be remembered as a composer, constantly on the move, always looking for better paid and more secure employment, finally reaching the 'promised land' of Bath in December 1766.

By the end of March 1781 he was famous all over Europe as the discoverer of a new planet—the first since antiquity. By 1782 the Royal Society had elected him as a Fellow and given him its most prestigious award, the Copley Medal, followed by the King appointing him as 'Court Astronomer' and awarding him a royal pension. In the following years that he devoted exclusively to astronomy he became increasingly regarded as a distinguished man of science, one of the most respected telescope makers in Europe and doing ground-breaking work until his death in 1822. Hershel defined, and was one of the first who tried to answer, many of the fundamental questions of cosmology that have set the research agenda until the present day,

As far as we know, he never again performed music in public.

Caroline Herschel was born twelve years after William, the forth daughter amongst ten children. The only other sister in the six children to survive childhood, Sophia, was sixteen years older and married by the time Caroline was five, so Caroline was inevitably destined for much of the household drudgery. It was made clear to her by her mother that since her face had been disfigured by smallpox and her early growth stunted by typhus she was unlikely to ever marry, so there was little point in giving her any education beyond that required for household management. Caroline would be required to stay at home to look after her ageing parents, and probably later to become unpaid housekeeper for one of the older brothers. It was a fate too common to cause any remark.

By 1787, however, she too was receiving her own royal pension—the first women ever to hold a UK Government appointment and probably the

[1] Comparing the value of money at different times is always subject to many caveats (Hume 2014). This, however, is clearly a decent middle class income, comparable to that of a country lawyer, or a clergyman in a good living, perhaps equivalent to at least £35-40,000 in current money

World's first professional female astronomer recognised in her own right[2]. As well as acting as her brother's astronomical assistant she is credited with a number of independent discoveries, including five comets, and in 1828 received the Gold Medal of the Royal Astronomical Society (RAS) for her work in cataloguing nebulae. The RAS did not admit female members at that time (and scandalously did not do so until 1916) but in 1835 Caroline, along with Mary Somerville, became one of a few female 'honorary fellows' with an independent European reputation.

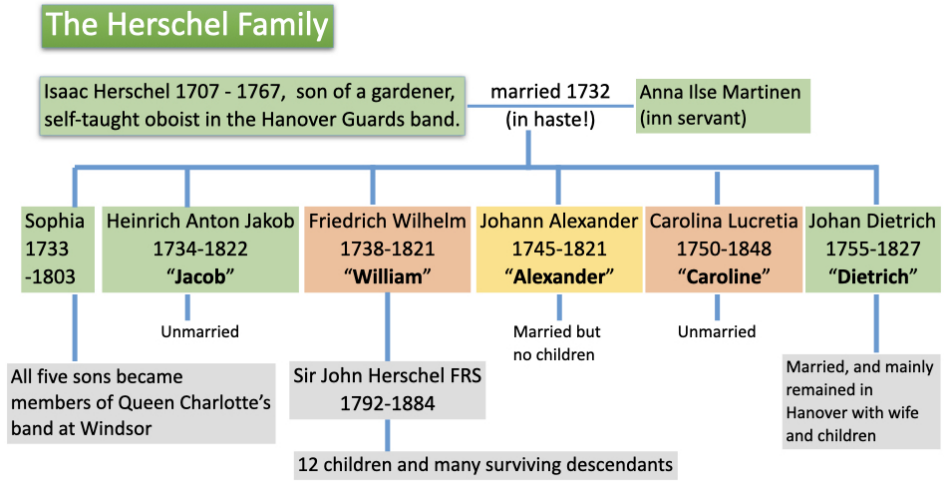
Let us also remember the 'forgotten partener' (Hoskin 2004), Alexander, a younger brother, who joined William in Bath in 1770 on a temporary leave of absence from his post in the Hanover court orchestra, but remained there as a musician for the next 46 years. Although he did not become scientifically distinguished in his own right, his mechanical ingenuity was important for his brother's telescope making enterprise. Alexander became an expert craftsman, fully the equal of professionals: he ground lenses and turned brass tube to produce eyepieces, made accurate clocks, and invented methods of controlling the pointing of the later larger instrument. Alexander *engineered* William's telescopes. Throughout his later life his idea of a holiday involved travelling to William's house near Windsor to spend weeks buried in a workshop. Poor Caroline, charged with housekeeping for the brothers in Bath, sometimes complained that every room in the house had been converted into a workshop.

Their father, Isaac, had been born the son of a gardener whose early death meant that there was insufficient money for Isaac to be be apprenticed even to this lowly occupation. He had, however, managed to teach himself the oboe sufficiently well to obtain a relatively secure, if somewhat musically limited, position as a bandsman in the Hanover Guards. Yet, within two generations nine of his descendants held court appointments, his son was a Knight of Guelph and William's own son, John, became an equally distinguished scientist, a Fellow or the Royal Society and a Baronet of the United Kingdom, with sufficient wealth to pursue his important research as an independent gentleman. His numerous children married widely into the British ruling class, and a son and grandson also became Fellows of the Royal Society through their astronomical research.

This is a remarkable story of social climbing, and some of it would not have occurred, were it not for the historical accidents that brought William to the relaxed and intellectually simulating social scene in Bath.

[2] Other women are known to have provided professional-level unpaid assistance to brothers and husbands, but had to forego public acknowledgement of their contributions.

Figure 1: The Herschel Family



All the siblings, apart from Sophia spent time in Bath. All, apart from Sophia, held court appointments at some time.

2 The Herschels before Bath

The Herschels came of a large family, in which four brothers and two sisters survived to adulthood. The eldest, Sophia, was born just a few month's after Isaac's marriage to an uneducated maid servant—probably a not uncommon event for young soldiers based far from home. Sophia will interest us little, though she also married a musician, and five of her sons later formed the nucleus of Queen Charlotte's own band at Windsor Castle.

Jakob, the eldest, was a highly talented violinist, who after a period in the band of Hanover Guards managed to obtain a coveted appointment to the Hanover Court Orchestra, where he eventually became the leader. Such appointments, in addition to prestige and a secure income, gave the opportunity to give and receive patronage, and the two youngest brothers, Alexander and Dietrich, followed Jakob into the same orchestra, while his sister's sons were also manoeuvred into royal appointments.

Caroline's birth came between Alexander and Dietrich, and her position in the family was not enviable. Her mother opposed any form of education that would allow Caroline opportunities outside the home, and though she had a fine singing voice, she alone of all the children was not allowed to benefit from her father's music teaching. (Caroline seems to have harboured some resentment against her mother throughout her life. Although she was eventually buried in the same grave as her parents, she gave instructions

that the new gravestone should only name herself and her father.)

Jakob was clearly the mother's favourite and had been encouraged to have a high opinion of his own talent, which he found entirely just and reasonable, though his demands sometimes made home life more difficult for the younger siblings. (Though, in truth, William always showed a distinct tendency to put his own interests first when he was in control: according to Hoskin (2011) this was one of the reasons why he achieved so much in his life. He just did it with more charm than Jakob.)

Alexander also became a fine musician, but had a difficult apprenticeship with Sophia's unsatisfactory husband which Caroline later blamed for his difficult personality and unwise friendships (including some troublesome romantic involvements), though her description of someone with "low spirits" tending always to look on the dark side might also make us now suspect a tendency to bipolar disorder.

Dietrich at one time ran away from his Court orchestra position, to eventually join William in Bath for a short period, perhaps finding it difficult to cope with the overbearing Jakob, who was now leader of the orchestra as well as dominating home life. Dietrich did ultimately resume his post in Hanover, and largely passes out of our history, though it has been speculated that Dietrich's strong interest in natural history was passed on to William during this period in the UK (Hoskin 2011, p.42), and also influenced some of William's attitudes to the practice of science (Schaffer 1980), in particular the compilation of extensive catalogues and classification of the objects of study.

In spite of the frictions normal in a group of people with strong personalities living on top of each other, the Herschel family always rallied strongly together in adversity. Michael Hoskin, the most prominent of the Herschel historians, was moved to step outside his academic detachment and state that '*..the Herschels are lovely people.*' (Hoskin 2011, preface).

William, like his elder brother Jakob, joined the Hanover Guards band immediately on leaving school. The role was relatively undemanding, playing oboe to support morale and a regular marching pace. Even when peace with the French started to become less certain, it was still a relatively safe occupation because bandsmen were regarded by both sides as non-combatants, expected to withdraw to safe locations as soon as the shooting started.

William and Jakob, however, both found themselves drafted to the UK when the French start flexing muscles prior to the start of the 'Seven Years War' (1756-1763). By this time Jakob had already applied for his release from the Guards, but it was formally approved only after his arrival in the UK, and he travelled back to Hanover alone. William remained with

the Guards in England until their return the Hanover in 1757, taking the opportunity to learn English, and gain a strong liking for the country

The Seven Years War (1756-63) was now in progress and the returned Hanover Guards were defeated by the French at the battle of Hastenbeck (1757) which left the city occupied and the regiment in disarray. As a young single man, out of uniform, Jakob was now vulnerable to being pressed into active militia service, so he went into hiding and the family arranged for him to travel to safety in the UK. They also encouraged William—at this time still just 18—to join him in Hamburg and make the journey together. The tenuous justification was that, as a minor, William had not taken an oath on entering the Guards. (In later life William rarely talked about the circumstances of his migration to England: he was in fact a military deserter.)

William and Jakob now had to scratch a living in the UK as a jobbing musicians. After the eventual defeat of the French and their expulsion from Hanover, Jakob soon found it possible and convenient to return to Hanover, but William had to stay in the UK or risk a military prison. His route to the Hanover Court Orchestra was therefore closed. Although his position was regularised in 1762 through Jakob's connection with a friendly general—a former musical pupil—by this time he found the musical opportunities in the UK more to his taste.

The next few years are obscure and what little we know about them from comes from letters to Caroline, recorded in her journal, and a few newspaper reports of concerts. At some point he accepted a position as bandmaster of a small militia band in Durham (just four members) which provided a very modest but steady income he could supplement with teaching and performing. He also pops up in various northern towns, including as 'Director of Concerts' in Leeds, but also giving private concerts in the homes of wealthy patrons. In 1766 he was appointed to the desirable post of organist in Halifax (organists were a notch up the social scale—more respectable than mere jobbing musicians) but almost immediately receives a recommendation to the even better post of organists at the Octagon Chapel in Bath.

William had arrived in the promised land! Although the remuneration may not have been more generous, to a musician Bath had many attractions not available in Leeds or Halifax. It was one of the few places outside London where there was sufficient work for a substantial number of active professional musicians—but without the cut-throat competition or the expense of living in the capitol. In London one might, if one was talented and lucky, aspire to riches but in Bath it was easier to make a decent living.

18th Century England was becoming increasingly prosperous on the back

of the improved agriculture, colonisation and, of course, the slave trade. The new opportunities were especially improving the financial positions of the 'middling sort' who now had the time, money and inclination for elegant leisure. There was an increasing desire for musical entertainment, and musical societies were springing up all over the country which often involved gentlemen amateurs with a sprinkling of professionals. In order to hear the best music, however, one needed to go to one of the relatively small number of places with a significant musical culture, mainly spa towns and cathedral cities. Bath in particular had the largest nucleus and highest standard of music outside London. (Some said, particularly towards the end of the Century, that its standard equalled that of the capitol. London soloists could make mini-tours taking in Bath, Bristol and Oxford between weekend performances in the capitol.)

Bath in the later part of the 18th Century was still very fashionable as a socially relaxed place where people could let their hair down (within reason), and unlike London, the different classes mixed freely at dances and concerts. The social exclusiveness of the upper classes in England have always been tempered by the obvious advantages of bringing new money into a family, preferably in large amounts. The 'match-making mamas' may have averted their eyes and issued the occasional "tut", but would have been perfectly well aware that if they brought young people together nature would take its inevitable course. Bath was one of the places where children and money were traded for social position.

Daughters on marriage mart would, of course, require music lessons, and the charming and intelligent organist of the exclusive private enterprise Octagon Chapel would be able to advertise his talents to the more socially select—or at least wealthy—layers of Bath society. It was the right place to be.

3 The Herschels in Bath

3.1 The Bath Musical Scene

At the time William arrived in Bath, in 1766, Thomas Lindley ('the elder') was the undoubted cock-of-the-walk on the musical scene. He was leader of the orchestra in the Lower Assembly Rooms and had a finger in every musical pie. Five years after Williams arrival in Bath, the Upper Assembly Rooms also opened. These were larger and more modern than the Lower Rooms, and closer to the recently built and more prestigious residential areas, such the Circus and Royal Crescent, now attracting the wealthier of

Bath's visitors. William may have had some hopes of being appointed to lead the music here, but lost out to Thomas Lindley. (At one point a bad tempered spat between the two was played out in news-paper advertisements. The modern age of social media allows us to exchange insults more easily, but 'Trolling' is not a modern invention.) He did, however, have the opportunity to take over in the now less attractive position at the Lower Rooms.

Thomas, besides his established position, had the advantage of numerous children that he had coached into musical prodigies, especially his eldest son, Thomas ('the younger'), who was playing violin concertos at the age of seven[3]. His eldest daughter, Elizabeth, had appeared at Covent Garden at the age of 13, and was by the age of 18 a highly regarded soprano, able, when singing as a duo with her younger sister, to command fees of 100 guineas for a performance. (The historian Charles Burney, whose daughter Fanny studied with Thomas, called the family a 'Nest of Nightingales', so one suspects that they might have specialised in rather showy coloratura pieces. There were certainly bitchy comments from the Italian sopranos about the material that the elder pair sang in public.) He could therefore mount attractive concerts without have to pay the exceedingly high fees demanded by London soloists (especially the Italian sopranos and castrati).

The income from 'benefit' concerts (that is, those promoted by the performing musicians) could be substantial if everything went well. Although modern fire regulations would limit the capacity of the Assembly Rooms to perhaps 500 people, back in 1779 there are reports (Wollenberg 2017) of concerts of 800 with most of the audience sitting elbow-to-elbow on hard benches.) It is worth reading Tobias Smollett's jaundiced description of Bath social events in *The Expedition of Humphrey Clinker*, which I suspect are more revealing than those in Jane Austen. These could be seriously warm and smelly occasions!

At the typical ticket price of the time (half a guinea—deliberately priced to exclude the undesirable) that implies possible takings of about £400 for the evening. From this it would be necessary to pay for use of the Rooms, and the musicians (though you could probably hire an entire 40-piece or-

[3] Thomas was, by contemporary accounts, a very talented composer, sometimes known as the 'English Mozart'—and Mozart himself gave him considerable respect. They became firm friends when as teenagers—age 14—both were studying in Italy. Charles Burney wrote, '*The "Tommasino", as he is called, and the little Mozart, are talked of all over Italy, as the most promising geniuses of this age.*' His music is little known because of two events: Thomas died at the age of 22 in a boating accident, and many of his manuscripts were lost in a fire at the Drury Lane Theatre, where he lead the orchestra.

chestra for less than £50). While the most expensive soloists might ask for 100 guinea fees, most would demand rather less, so there was the prospect of making substantial profits from a well-attended concert. Thomas Lindley was rumoured to have accumulated a fortune of £10,000 from his promotions[4]

It is certainly true that by 1776 he was able to join with his son in law, Thomas Brinsley Sheridan, and pay £35,000 for a half share in London's Drury Lane Theatre. Nevertheless, if the concert happened to clash with a different social event, such as a private ball, or an attractive theatre performance, and the Rooms were only half full, then the soloists fees could eat up the entire income. It was not unusual for concerts to be moved to a new date at short notice when the promoters became aware of such clashes. In fact, it became increasingly difficult to make ends meet towards the end of the century, as inflation caused by the Napoleonic wars made soloists demand higher fees, while financially strained audiences resisted increases in subscriptions, and Herschel's successors sometimes made a loss over the year.

After Lindley's move to London in 1776 Herschel was himself appointed 'Director of Concerts' in Bath, responsible for music in both Upper and Lower Rooms. He was less financially successful than Lindley. Nevertheless, with the fees for music lessons (in 'the season', which ran from late Autumn to Spring, he taught more than 40 hours a week in addition to his performing work) Herschel was reported to be earning about £400 per annum by 1780 (Hoskin 2016), putting him firmly in the top 1% of the income distribution in the UK (Hume 2013, Hume 2014). By most standards this was a successful musical career, and one he would have been pleased to aspire to a few years earlier.

Of course, even though his income placed him well within the range of the professional classes, with very few exception (such as Handel and some university educated cathedral organists) a professional musician would never quite be regarded as a 'gentleman', and there were still aristocratic ladies who would be severely offended if one sat down in her presence. Even actors—themselves of dubious social status—regarded musicians as occupying a lower social order. (Thomas Brinsley Sheridan married Elizabeth Lindley against the wishes of his family—in fact they eloped— who in spite of long-standing family and professional connections, considered it a misal-

[4] Thomas Lindley's life was, nevertheless, in some respects tragic: of the eight children who reach adulthood, only one son survived him, the rest, apart from the drowned Thomas, successively fell victim to tuberculosis, or 'consumption' as it was then known.

liance.) Only dancers were held in less respect[5].

It was only in a place like Bath, with its notably relaxed social atmosphere, that William could expect to have any intellectual interaction with philosophically inclined members of the leisured classes.

Once established, William received a visit from Jakob, who, since the Elector of Hanover spent the winter months in the UK as King, was released from his orchestral duties and able to take part in the profitable Bath winter 'season'. He succeeded so well that he returned the following year with Alexander, who found Bath life so much to his taste that he first requested leave of absence from the Hanover Court Orchestra, and then simply stayed on for the rest of his working life.

Caroline was later tempted to leave her domestic drudgery in Hanover for housekeeping duties in Bath, looking after her favourite brothers, by the promise of singing lessons and the opportunity to perform if her voice proved useful. (Her mother had to be bought off with an annuity to pay for a replacement maid, and Jakob, who was away at the time, was simply not consulted until it was too late to object.)

3.2 Science in Bath

William Herschel was now comfortably established in Bath, probably feeling secure for the first time in his life. Although he had read widely in philosophy and astronomy, it was only after he achieved some stability in Bath that he could develop an active interest. We know that he hired a refracting telescope, and by 1773 had acquired a copy of Smith's *Optics* (Smith 1738) which included instructions for telescope building, and in 1774 purchased the means to construct his own reflecting telescope.

The Bath Philosophical Society (forerunner of the current Bath Literary and Scientific Institution) was first founded in 1779, after morphing from a society devoted just to agricultural improvement (which was indeed a major concern, and source of increasing wealth, at the time). Early members included Joseph Priestley the chemist and William Smith the geologist. After five years of experience of mirror grinding William was now producing excellent mirrors and while observing with one of his 7-foot telescopes in

[5] Dancers were frequently assumed to have loose morals, and a young man 'on the town' might well look to the stage when he wished to acquire a mistress with an offer of *Carte Blanche*. This caused a problem for the famous actor David Garrick, normally welcome everywhere, who married a dancer (of acknowledged blameless reputation) from the opera chorus. Even so, certain aristocratic ladies found it difficult to invite Garrick into their homes because they felt that they could not meet a former opera dancer.

the street outside his house, encountered a founding member of the new society, Dr William Watson. He was impressed by Herschel's instrument and possibly also by his well-known charm and invited William to join the society.

Scientific interests were to some extent fashionable amongst a small population of gentlemen (and some ladies) with time on their hands. Many clergymen, for example, were able to pursue serious scientific work, particularly in natural history, though also in astronomy. There were even celebrity science popularisers: James Ferguson—the 'Patrick Moore' of his day—had self-educated to the point of making a decent living out of touring the country giving popular science lectures. He came to Bath in 1776 to give a course of lectures on astronomy which William may well have attended. (William is known to have owned and read the influential *Astronomy Explained* (Ferguson 1757), which may well have been the initial stimulus for his astronomical enthusiasms. Fergusson was eventually himself elected to the Royal Society.)

Herschel's first paper dealt with corals—probably influenced by his brother Dietrich's interest in natural history and he may have been one of the first people to point out that they were not plants. His first significant original astronomical observations concerned the shadows of lunar mountains, from which he was able to deduce their height. Dr William Watson was sufficiently impressed by this work to forward the paper to his influential father Sir William Watson FRS, who could arrange for the work to be presented before the Royal Society.

Herschel was at first a puzzle to the science establishment: his observations appeared to reveal detail not visible to better known people using professionally made instruments, but his speculations on lunar forests and the lunar inhabitants did not create a good initial impression. (It should, however, be noted that even serious philosophers sometimes argued for the 'principle of plenitude', taking the view that God would not have created so many planets without also providing them with inhabitants. To have only the Earth supporting life, seemed unnecessarily profligate.) After a visit to Bath by some Royal Society notables, it soon became clear, however, that Herschel was able to make telescopes superior to any others then available, and he was a real talent that needed to be mentored into the paths of scientific righteousness. With suitable modification his paper was read to the Royal Society.

His major project, however, was the compilation of a catalogue of double stars, that is pairs of stars that appear close together in his telescope eyepiece. He had a sound—though ultimately mistaken—reason for his ob-

servational programme. Deducing the distance to the stars was one of the major unresolved issues in astronomy, and it was clear that the only viable approach to solving the problem would involve measuring the apparent shift in the position of nearby stars against a background of more distant stars as the Earth progressed round its orbit—an effect known as parallax. All attempts to reliably measure this shift had so far failed, though astronomers had discovered a number of systematic effects that make the precise absolute measurement of star positions exceedingly difficult[6]. William was pursuing an idea dating back to Galileo, who pointed out that nearly all the systematic measurement errors could be eliminated if we could find pairs of stars with chance alignment on the sky—one near, one more distance—and it might then be possible to accurately observe changes in the separation over the course of a year, which could be reliably assigned to the parallax effect.

The method relied on the not unreasonable assumption that stars were randomly distributed in space. Unfortunately, John Mitchell, Professor of Geology at Cambridge, by the time Herschel was starting his work, had already argued convincingly that there were simply too many of these close doubles to be consistent with stars being distributed randomly. It became apparent that many visual double stars really were physically in close orbits around each other.

William was at this point unconnected with the wider scientific community and unaware of Mitchell's reasoning, fortunately, as it turned out, and commenced an observational programme, which required systematic survey of the entire night sky visible from Bath. Although his purpose was misconceived it gave him an increasing familiarity with the sky's appearance through his telescope. He was therefore well primed to notice any unusual changes, such as the advent of the comet—or an undiscovered planet.

[6] James Bradley (1692-1762), a former Astronomer Royal, who was born in Chalford near Stroud and is buried in the Minchinhampton churchyard attempted to measure stellar parallax. He failed but as a result in 1727 discovered the much larger shift in apparent positions of all stars as the Earth moves round its orbit now known in physics textbooks as the 'Aberration of Light'. It is an effect of the finite speed of light analogous to the apparent change in direction of falling raindrops as you cycle through a shower. This was, in fact, the first *definitive* physical evidence that the Earth actually does move through space and around the Sun, though most thinkers had already been converted to the heliocentric view by the end of the 17th Century, probably more because of philosophical reasons rather than hard observational evidence.

3.3 William Herschel's Telescopes

Improvements in instruments have always been (and still are) an important factor in astronomical discoveries: we need to understand why William's telescopes were so much better than those of other contemporary astronomers.

Most of us are familiar with the typical refractor telescope: you point one end at the sky and look through the other. Such telescopes had been used for astronomy since Galileo[7] constructed his first instruments. They did, however, suffer from a number of problems which made them difficult to use for this purpose, particularly *spherical* and *chromatic* aberrations.[8] Spherical aberration occurs when you increase the diameter of the object lens at the front of the telescope without increasing the telescope length: light rays from the edge of the lens are bent rather too much towards the axis compared to light rays close to the axis, so the light from a star does not converge to a point and the image becomes blurred, though this only becomes noticeable when the 'focal ratio' (which is the focal length divided by the lens diameter) becomes smaller than about f12.

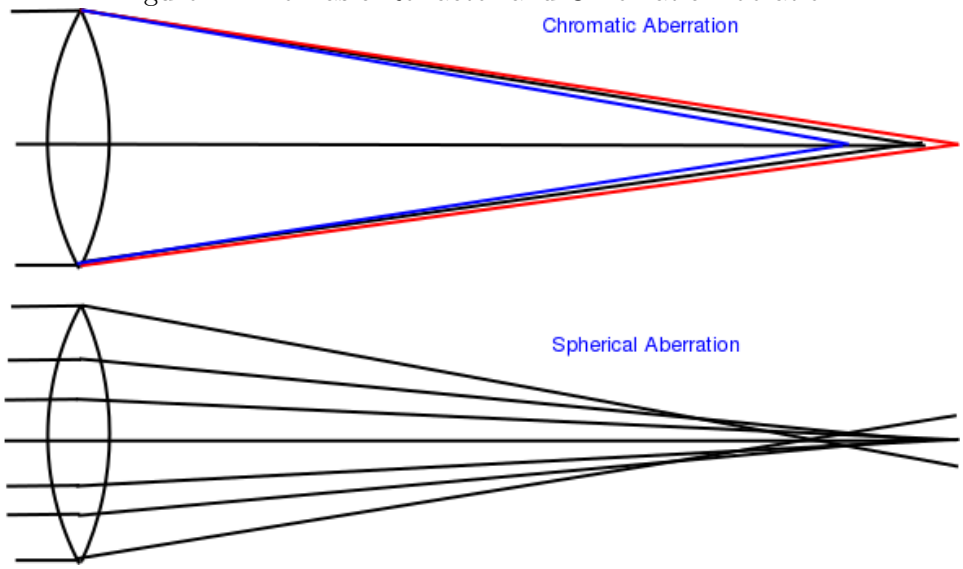
Chromatic aberration is caused by different colours of light being bent by different amount as they pass through glass lenses, so red light has a longer focus point compared to blue light. This effect also becomes visibly worse as the focal ratio decreases and light needs to be bent through sharper angles. Up until the later part of the 18th Century, therefore, the only way to make refractor telescopes usable was by limiting the diameter of the object glass, which unfortunately also limited to amount of light they could gather (reduced their effectiveness for astronomy), or by extending the distance between the object glass and the eyepiece. This was carried to extreme lengths with so called 'aerial telescopes' where the lenses were mounted on long beams suspended from tall poles, such as that used by Johannes Hevelius at the Paris observatory, where the a lens of 8 inches diameter had a focal length of 150 feet.

Although methods of correcting the optics both for chromatic and spherical aberration became available through the developments marketed by the Dollands (father and son) in London, their instruments were expensive (es-

[7] An English astronomer, Jeremiah Horrocks, actually had priority with studies of the Moon, but Galileo was a much better publicist.

[8] The original Galilean telescope configuration, with a diverging lens for the eyepiece, also had a remarkably small field of view—I have looked through a reproduction—and it is a wonder to me how any useful science was achieved. Galileo's critics who claimed that they could not see what he saw through his telescopes were probably telling the truth. It takes practice to get and keep your eye exactly aligned with the 'exit pupil' and interpret what you see in spite of the visual distortions.

Figure 2: The Basic Refractor and Chromatic Aberation.

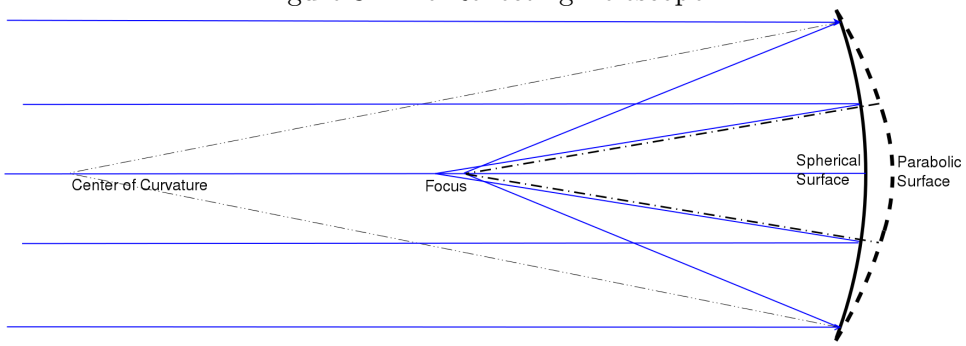


pecially after they obtained—and enforced—valuable patents). Such instruments were affordable only by those with considerable disposable incomes and amounting to a substantial part of annual earnings for someone like William Herschel.

Astronomers turned towards reflector telescopes which could be made in larger diameters more cheaply, and whereas the construction of a large refractor would always need professional tools, the construction of a large reflector was (and still is) well within amateur capabilities. Reflectors do not suffer from chromatic aberration because light does not pass *through* the mirror, but only touches the outer surface. Spherical aberration can also be dealt with, in principle, by polishing the mirror surface into the shape of a parabola, rather than the spherical profile which is the normal outcome of the initial mirror grinding methods.

It is remarkable that one can produce such accurate mirror figures using such basic methods (essentially all you need is successively finer grades of grit—Herschel would have probably used sand—and lots of patience). Good optical performance needs the surface to be accurate to significantly less than the wavelength of the light you are using. Visible light has a wavelength of about 5000 angstroms, which is 5/10,000 of a millimetre. Modern amateur makers are reasonably happy if they get a surface accuracy below 1/10,000 mm—that is accurate to one quarter of the wavelength—but no-

Figure 3: The Reflecting Telescope



ticeable improvements occur below this and modern high-quality commercial instruments sold to amateurs are claimed to be about twice as good, with the best professional instruments (which need to work well with shorter-wavelength blue light) good to 1/20 wavelength. Herschel would probably be achieving a spherical shape with something like the quarter-wavelength accuracy.

This, however, is easier said than done, and it was only in the middle of the 19th Century that reliable and practicable optical tests were developed to measure the precise shape of mirrors. Up until then the shape achieved in the final polish depended on the care taking during the grinding and the interpretation of the only viable test then available: putting the mirror in a telescope and looking at stars.

The 'star test' is still used by amateur telescope makers as the first and easiest test to check that the focal length and mirror shape are about where they should be. The most experienced modern amateur makers have also demonstrated that with skill and persistence it is possible to use the star test to diagnose some of the most common (but not all) mirror faults. particularly if you repeat the test while masking off parts of the mirror during the process (so one can, for example, separately measure the focal length of the inner and outer regions). It is a delicate business: even perfect telescopes do not focus a star's light to a perfect dot but errors in the shape of a mirror introduce additional distortions. Nevertheless, by carefully examining the distortions of a star's image as one moves a high-magnification eyepiece slightly in and out of focus, it is clear that in careful and experienced hands a good deal can be achieved. This, I think, is sufficient to account for William's results. All this takes time, and contemporary commercial makers probably did just enough to meet the expectations of their rich dilettantes

customers. There would be little point in spending excessive time correcting optics beyond the point where improvements would not be noticed by the purchasers.

In practice, 18th Century telescope makers, including William Herschel, still hedged their bets by making telescopes with relatively small mirrors compared to their focal lengths. (William's 'seven-foot' telescopes used six-inch diameter mirrors.) We would say that they had a focal ratios of $7/0.5 = 14$. At f14—typical for William's instruments—the effect of spherical aberration on the image is almost negligible, and it is much more important to achieve an accurate spherical shape over the whole surface of the mirror. (For comparison, modern professional telescopes appear very squat, with focal ratios as small as f4 and are sometimes colloquially called 'light buckets'.)

This degree of optical performance really matters: inaccuracies in the mirror's shape spread unwanted light around inside the telescope and you cannot see faint objects because of the background glare, while other distortions to the shapes of images can loose detail.

The large focal ratios do come with a disadvantage (well known to all photographers): it reduces the surface brightness of the image. This is not so important if you are observing stars, which are always unresolved points of light. It becomes important if you wish to study the faint nebulae that became William's life's work. It is a particular disadvantage when your reflecting surfaces have be ground from speculum metal which absorbs almost half of the light falling on the mirror. All of WIlliam's early telescope used the standard 'Newtonian' design with two mirrors, which mean that three quarters of the light entering the telescope did not reach the eyepeice.

William needed to strike a balance: he would not see the nebulae clearly against stray background light caused by the mirror distortions of small focal ratios, but nor would he see them if using a long focal length spread the light over a larger image. In the absence of photography one had to rely on verbal descriptions and sketches of nebulae, probably made from memory, since using any form of light by the telescope would in itself reduce the sensitivity of their eyes to light. Hence, different astronomers gave widely different account of nebulae and it more than likely that they were simply unable to see the dimmer parts that show up so well in modern images.

Herschel's answer to obtaining brighter images was a determination to 'increase the size of the telescope', eventually culminating in his great 40-foot telescope, with its four foot diameter mirror—the most powerful of its time, until the Earl of Ross commissioned his instrument at Burr Castle with its six-foot mirror. With this telescope he also found a way to do away

with the second mirror and achieved much brighter images—sufficient to find a number of small and very dim moons round the outer planets.

William was clearly an obsessive maker who constantly strived for the perfect results, and he claimed to have made hundreds of mirrors[9]. When he started making telescopes to sell we can assume that as he tested each new mirror, he would keep the best for his own use and sell those which while they were considered excellent by the standard of the time were not quite as good.

It is certainly the case that Nevil Maskelyne, the Astronomer Royal, in a side by side trial, shortly after William's discovery of Uranus, acknowledged that Herschel's instruments were superior to those in the Royal Observatory because they could resolve close double stars that his own telescopes merged together. They were soon generally considered to be the best then available, and William was able to sell as many as he cared to make, at substantial prices (100 guineas for one of his 'seven foot' telescopes ranging up to thousands of guineas for the larger 1twenty foot' models.)

Most of the non-optical structure of his telescopes could be made by a competent carpenter, and other mechanical parts were designed and made by his brother. Although they were somewhat inflexible in their movements compared to modern instruments, they were fit for the type of observations that the Herschels' were pursuing, which mainly involved surveying the skies rather than following one object for an extended period of time. William would simply point the telescope south, at a certain selected elevation and watch the sky drift past, noting what he saw.

3.4 The State of Astronomy in 1781

The Astronomer Royal (and his opposite numbers in Paris and other capitals) were employed to improve the accuracy of marine navigation. Sailors measured the altitude of the Sun and various stars above the horizon, and then referring to the known stellar positions in published standard star catalogues to to determine their own latitude. As the world-leading instrument makers of London produced increasingly accurate navigation instruments (the sextant appeared in essentially its modern form at about this time) there was a constant need to update the accuracy of the positions in the catalogues (and William and Caroline were discovering that there were significant errors in some of the earlier catalogues).

[9] The claim may be a little dubious according to Hoskin (2011), but he clearly made a great many, and if you make a large number of mirrors some are bound to be better than the rest.

Navigators also faced the problem of deducing longitude. The standard star catalogues tell us *when* particular stars will pass across the *meridian*[10] at Greenwich (when they also reach their maximum altitude above the horizon) and we know that this time become progressively later the further west you go. Hence, if you can determine when a chosen star reaches its maximum altitude at some other place according to the time at Greenwich it is possible to work out how far west (or east) you have travelled.

John Harrison's marine chronometers provided a partial solution to the problem in the 1760s, but errors would still build up over long voyages (e.g. to Australia). It was therefore still very desirable to accurately fix the longitude of certain geographical points using precise astronomical methods (e.g. the Cape of Good Hope) to allow recalibration of the chronometers at intermediate points on a journey. For this we need universally visible 'clocks in the sky', such as the motion of the Moon or the satellites of Jupiter. Hence, at the end of the 18th Century, a major preoccupation of Nevil Maskelyne was devising methods of using such astronomical 'clocks' to determine Greenwich time with high precision anywhere on the Earth Although the use of such techniques would be impossible on the rolling deck of a ship, and beyond the practical skills of most navigators, specialist chart makers such as Captain Cook would be able to provide accurate geographical coordinates of easily recognisable landfalls (such as the Cape of Good Hope). The expansion of the British Empire was accompanied the establishment of astronomical observatories at strategic location including in South Africa and India for the purpose of supporting navigation but defining the local time (and hence the precise longitude) allowing mariners to recalibrate their chronometers.

The professional astronomers did not tend speculate on the nature of the stars because in the absence of observational evidence it was a profitless exercise. Planetary observations and searches for comets were the particular province of the amateur astronomer (and it should be remembered that some rich amateurs had better equipped observatories than some astronomy professors). Amateur astronomers of the time particularly strove to identify new comets (you might even achieve immortality by having your name associated with an especially bright object). Comets have two distinguishing features: they are resolved into a distinctly cloudy patch of light, unlike the centrally concentrated point of light of stars (at least, as seen through a good

[10] The meridian is the imaginary line passing from the horizon due south of the observer and continuing overhead to the *zenith* and the *north celestial pole*. The Greenwich meridian is taken to be the zero of geographical longitude.

telescope), and eventually develop a characteristic tail as they approach the Sun. They also move with respect to the 'fixed' stars.

During the 18th Century, as telescopes improved, it also became clear that some of the light clouds—or *nebulae*—remained fixed with respect to the stars, and the French astronomer and comet hunter, Charles Messier did a service to astronomy by mapping the brightest nebulae in his famous catalogue of 1774, mainly to avoid continuously mistaking such clouds for new comets. We know that William obtained an early copy of this catalogue.

3.5 The Discovery of a new Planet

We remember William Herschel as the discoverer of Uranus, the first new planet identified since antiquity. (All the other planets are visible to the naked eye.)

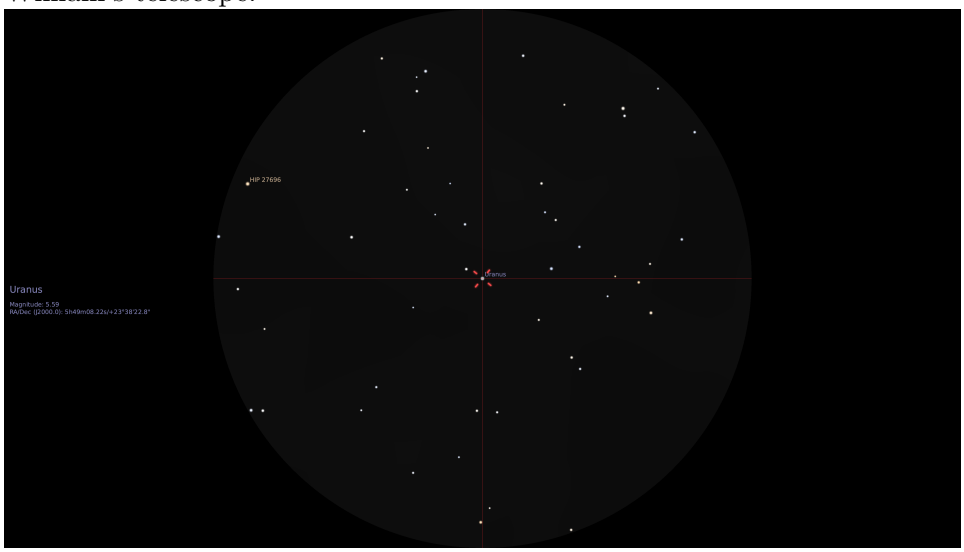
At this time William was undertaking 'sweeps' of the sky in his search for double stars, that is, a programme of observations that would systematically cover the entire sky visible from his house in Bath. With his superior instruments he would be able to observe previously uncatalogued objects, and stood a good chance of finding comets prior his peers. He had, by this time, been regularly observing the sky for some seven years and would have a reliable visual memory of the patterns of all the brighter stars (tens of thousands) that would be visible in his telescopes: new objects, especially ones that moved would stand out. He always claimed that his discovery of Uranus was not an accident, but would have been inevitable at some point in his observing programme. I believe that this is a reasonable claim. Modern comet-hunting amateur astronomers achieve similar feats.

Uranus was unusual: it was clearly not a star because it has a visible disk (through William's excellent optics) but neither did it look like a typical comet, and while it was moving with respect to the stars, it was moving rather slowly. He reported his observations to the Royal Society and some of the professionals, including the professor of astronomy at Oxford, eventually confirmed the discovery[11], and were furthermore able to calculate an approximate orbit. This turned out to be a very distant object—in a circular orbit outside that of Saturn—and therefore, given its brightness, of planetary size.

At this point the scientific establishment decided that Herschel needed

[11] At this point Herschel had still not mastered the art of determining accurate astronomical coordinates, so the professionals had at first a frustrating time trying to make sense of Herschel's report, especially as through their inferior telescopes the planet might not appear so very different to a star.

Figure 4: Uranus in March 1782, as it would have appeared through William's telescope.



to be extracted from his full-time musician/part-time astronomer role and his exceptional talents given wider scope. Within months he was elected to the Royal Society, awarded the Copley Medal, and appointed to as 'Court Astronomer' (a position created for him by the King, who was himself an amateur astronomer). This was a generous sinecure of £200 a year (the Astronomer Royal had to work hard for his salary of £300). As a *pension* it was his for life, though he was expected to reside near Windsor and be available on demand to entertain royal guests with his telescopes. He also obtained other grants allowing him to build larger instruments. In addition, the King ordered from him de-luxe telescopes—at highly inflated prices—to be presented as gifts to his royal peers.

It is worth remembering William's origins at this point: when he was interviewed by the King prior to his appointment, he was clearly being checked-out to see if his manners and social skills were appropriate for someone who would be introduced to, and expect to converse with distinguished royal visitors. Others had noted William's charm of manner and it clearly met the requirement, but what a leap for the son of a lowly bandsman.

Although William appears to be accepting a substantial reduction of income (he was previously earning about £400 per annum) in reality the position had many advantages. The income of musicians is always precarious and he would be well aware that many who had been very well known and

able to command high fees for a time often fall into poverty when they can no longer perform or they fall out of favour. £200 per annum was now securely his, and it is worth remembering that this income was higher than that of more than 97% of the population of England at the time (Hume 2014). He also had prospect of expanding his income via the construction and sale of his famous telescopes. Most importantly: he would have a substantially higher social status, regularly meeting with the Royal Family, and would be interacting with his scientific peers on terms of social equality.

William was, I have no doubt, a sufficient good musician to realise that he was never going to be amongst the 'greats' and that he had already achieved as much in his profession as he was ever likely to do. His symphonies are pleasant listening, and clearly the work of a competent professional, but not remotely in the same league as a Haydn or even some of the less well-known composers active on the London scene in the 1780s. In truth there were aspects of his musical life that he never enjoyed, and about which he had previously complained, particularly in the earlier days when he had to travel long distances (often in bad weather and at night) for performances in country houses. The public in Bath were also beginning to notice a falling off in the quality of the concerts, sometimes due to lack of adequate preparation. His heart was not longer in music and there were growing complaints! He could now devote himself to astronomy full time, a field in which he was beginning to understand that he excelled over his peers.

The change fell more heavily on Caroline. She had begun to have a life outside the home as a musical performer in her own right, or as a coach for William's choirs. Furthermore, life in Bath was lively and convenient. The move to a village near Windsor closed down her nascent career (William and Caroline never performed music in public again) and her diary suggests some resentment at the reversion to being William's housekeeper. They were now a rural location cut off from near neighbours—very unlike life in the vibrant city of Bath. (Caroline complained about how much more difficult it was to shop.) William also demanded from her increased efforts as his astronomical assistant, which at first she did not welcome, though before long she became as involved and obsessive as William. (Nevil Maskelyne was impressed by her skills as an observer and became her enthusiastic supporter. It is also said that no one who subsequently examined her extensive cataloguing work ever found any transcription errors.)

William's marriage[12], at the age of 50, to a rich local widow cause further

[12] The family records are mostly silent on William's other romantic involvements—though there is a suggestion of at least one previous proposal, which met the frequent fate

disruption to Caroline's world: now she could no longer even be William's housekeeper and carer. Caroline later destroyed some of her diaries dealing with this period and it seem likely that they gave vent to her resentments. The event led to the King being petitioned to provide Caroline with her own Royal Pension of £50 per annum, and she chose to live separately from the Herschel family After William's wife, Mary, gave birth to a son, John, Mary and Caroline did, however, become good friends allowing Caroline to develop a close and lasting relationship with her nephew, first as part of the family and later as a valuable co-worker continuing William's astronomical work.

4 Caroline and William's Scientific Contributions

William popular reputation is based on the discovery of a new planet, but his subsequent work with Caroline was of more substantial scientific worth. Astronomers appreciate that William posed the major questions that set the research agenda over many subsequent decades, and to some extent still do.

Although these notes are particularly focussed on the Herschels' connection with Bath, we need to look briefly at their record after leaving the city in order to understand their place in scientific history. It was this period in particular when Caroline developed her independent reputation as an astronomer, and we would not be so interested in the Herschels were it not for their outstanding work during subsequent forty years.

For a while, Caroline's role was simply to be William's assistant, writing down the observations he called out from the telescope, while noting the time. (She could do this in a lighted room, while William preserved his night vision outside: they eventually evolved a sophisticated signalling system involving strings.) Caroline also 'reduced' the observations, that is, converted the raw observations, including the time into standard astronomical coordinates. Her hard work in this area, continuing after William's death is in a large part responsible for the accuracy of their catalogues.

Both William and Caroline took significant risks, climbing ladders on dark nights to observing platforms that would give a modern health and safety inspector nightmares. There were accidents: Caroline, which running between two telescopes managed to impale herself on an anchoring spike,

of the charming music master falling for the pretty daughter from a higher social status. His name was also coupled for a time with that of a Bath widow, which eventually came to nothing. Musicians were simply not good marriage risks.

and given the medical science of the time was lucky not to loose a leg or her life. In spite of her childhood illnesses, however, she turned out to be a very tough lady, rarely unwell, and still running up and down stairs in her 70s.

William eventually constructed a telescope of a size appropriate for her limited height and she carried out an independent observation programme, discovering five new comets.

William and Caroline's life work became the compilation of catalogues of nebulae that were visible through their improved instruments. While Messier's catalogue listed only just over one hundred objects, their 'General Catalogue of Nebulae' initially had by 1802 2,500 objects, and eventually had 5,000 entries. In later revisions, it became the 'New General Catalogue' (NGC) and to this day NGC objects are the continuing focus of many research papers.

Such catalogues are important because of the way they are compiled, containing, for example, every object meeting certain observable criteria; in the case of William and Caroline it would be pragmatically be everything visible from the UK through a telescope of a certain size. If it is well-compiled such a collection can be treated (with care) as a statistically complete sample, and used to address cosmological research questions.

William was not simply satisfied with listing observations: he always claimed that he was motivated by a need to understand the nature and origin of the things he observed. In particular, the nature of the nebulae was an on-going subject of debate in the astronomical world. Were they really just 'clouds' as the name suggested, or did they just appear like this because they consisted of unresolved masses of stars?

The issue could be settled in a few cases by better instruments: it soon became clear that 'Globular Clusters' were indeed masses of stars, but William also identified a new class of object now know as *planetary nebulae*. Through small telescopes they did indeed look something like a planet, that is, more-or-less circular. Through larger instruments it became clear that they consisted of a diffuse cloud with a bright star at its centre. (We now know that the glowing gas has been thrown off the star as it approaches the end of its life.) There was no single simple answer.

In most cases the issue remained unresolved throughout the 19th Century, until Sir William Huggins used spectroscopy to demonstrate that some nebulae were indeed glowing clouds of gas, and we now know that many such clouds are star forming regions in our own galaxy. In the meantime, the 7th Earl of Rosse constructed a large reflector at Birr Castle in Ireland and determined that many of the nebulae appeared like whirlpools. (William missed this discovery, though he also had a sufficiently large telescope, pos-

sibly because of the fading enthusiasm for late night observing perhaps not unconnected with his marriage.) It was not until the giant telescopes of the 20th Century became available that it became possible to resolve stars in these 'spiral' nebulae, which turned out to be distant galaxies probably similar to our own Milky Way. It is now possible to see that all sides in this argument had some right on their side: the universe turned out to be complicated.

William constantly speculated on the nature of the universe and was probably the first astronomer to attempt to investigate the matter by observation. His counts of the density of stars visible in different directions were a reasonable attempt to define the shape of our own galaxy (he did not realise, of course, that our own Milky Way was just one of many galaxies). As it happens, he was unaware of the light-extinguishing dust that obscures the galactic plane, so his conclusions are in substantial disagreement with the equivalent modern work. The idea was, however, fundamentally sound and 'source counting' became a staple of cosmological observation right up to the present day. William asked the right question and correctly identified a suitable method of addressing the problem. Pursuing this line of investigation by subsequent generations of astronomers using better instruments led to many important discoveries.

William also has a discovery in basic physics to his credit: he was the first to observe infrared radiation.

We should not forget one further achievement: he fathered John (later Sir John) Herschel who became a considerable scientist in his own right, with a justified polymath reputation ranging over most of practical and theoretical science. John went to the Cape of Good Hope, at his own expense, and set up an observatory to extend his father and aunt's catalogue to the southern hemisphere. During what was later described as his 'happy time' in South Africa he and his wife also carried extensive and important work in natural history. (It was for work during this period that he rewarded on return by being made a baronet.) He also made improvements in photographic chemistry.

Caroline outlived William and was honoured for her contributions to science, especially the publication of the 'New General Catalogue of Nebulae' (with 7000 entries) which was honoured with medals from both the Royal Astronomical Society and the Prussian Academy of Sciences. She was also probably the first female professional astronomer in the history of the World. (We should also recognise, however, that there were other women who contributed significantly to astronomy under the names of their menfolk, some known, other suspected and many probably unrecorded by history.)

5 Sources

I have relied extensively on three excellent modern books, and some extracts from older books as well as various articles in primary literature.

- Michael Hoskin is undoubtedly the leading UK scholar on Herschel's work. A lifetime of research, with many primary publications, has been well summarised in his definitive history *Discovers of the Universe: William and Caroline Herschel* (Hoskin 2011). Hoskin, in the introduction to the book, partly explains his fascination by claiming that Herschels were clearly 'lovely people'—well liked by their contemporaries *and* the historians who study them. (In contrast, students of Isaac Newton's life and works, Hoskin claims, usually end up hating him.)

- In order to put the Herschel's work in the context of a wider history of astronomy I recommend Allan Chapman's *Comets, Cosmology and the Big Bang. A History of Astronomy from Edmund Halley to Edwin Hubble.* (Chapman 2018). Allan Chapman is an Oxford historian (and a Fellow of the Royal Astronomical Society) who has researched, written and lectured extensively (and fronted a TV series) on the history of astronomy. His books and talks are always entertaining.

- Richard Holme's book *The Age of Wonder* (Holmes 2010) places developments in British science in the late 18th and early 19th Century in an even wider social context, particularly the interaction with the 'romantic' movement. Although the book deals extensively with the influence of Sir Joseph Banks and Sir Humphrey Davy, it has a substantial focus on Sir William Herschel and his equally distinguished son, Sir John Herschel.

- Much of the research on the Herschels eventually ends up back at Caroline Herschel's diaries and letters. Michael Hoskin's edited editions are now out of print (and hence only accessible if you have right of entry to a university library) but the *Memoir and Correspondence of Caroline Herschel* edited by Mrs. John Herschel (the wife of William's son) is available in Project Gutenberg[13] Although this is not a complete transcript, it is very informative [14]

[13] See http://www.gutenberg.org/ebooks/52923—available for Kindle or to read on-line. The book is also available from a number of other sources easily found via Google.

[14] Michael Hoskin does, however, point out in his history that the Herschels, like perhaps

In addition, it is now possible to obtain access via the Internet to the book from which William Herschel learned his optics and the principles of telescope making (Smith 1738). The hyperlink given *here* brings up Volume II, which deals with the basic instructions for telescope making.

For information on musical life in 18th Century, we mainly have to go to primary sources. These are cited as and when referred to.

A Timeline

1707 Birth of Isaac Herschel, the father of William, Caroline and Alexander, youngest son of Abraham Herschel, a gardener, who was remarkable for his fondness for arithmetic, writing, drawing and music.

1718 Abraham dies, when Isaac is 11 years old. Isaac cannot be apprenticed to gardening because the family have no money but he teaches himself the rudiments and gets employment tending the garden of an aristocratic widow.

1728 Isaac quits his gardening job and having taught himself the oboe attempts to gain employment as a musician in Berlin, which fails.

1731 August 7. Isaac gains a post in the band of the Hanoverian Guards.

1732 October 12. Isaac marries Anna Ilse Maritzen who is pregnant with Sophia.

1733 April 12. Birth of Sophia Elizabeth Greisback (née Herschel), William's elder sister.

1734 November 20th, birth of Heinrich Anton Jacob Herschel ('Jacob'), Williams older brother.

1738 April 25th, birth of Wilhelm Heinrich Herschel ('William').

1743 (June) Battle of Dettingen (War of the Austrian Succession.) Hanoverian Guards are victorious, but Isaac suffers ill-health after spending the night lying in a wet field.

1745 November,13th, birth of Johann Alexander Herschel ('Alexander').

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many families of the time, tended to completely ignore in the written record significant events that for whatever reason they found unpleasant or embarrassing—such as William's desertion from the Hanover Guards, his possible dismissal from his post of organist at the Octagon Chapel, and the unexplained death by strangulation of their older brother, Jakob.

1746 In February Isaac applies for 'dismission' from the Guards (but finds life in Hamburg as a jobbing musician too hard). Returns to Hanover and applies to rejoin the guards band having been given assurances by General Georg August von Wangenheim that there would likely be a long period of peace.

1750 March 16th, Birth of Caroline Lucretia Herschel ('Caroline').

1753 William (age 14 in May) joins the Guards band.

1755 Sophia marries Joachim Heinrich Greisbach (1730-1773).

1756 Hanoverian Guards regiment ordered to London in Spring (Wilhelm and Jakob were oboists in the band).

1756 Jakob applies for formal discharge from the Guards, hoping for an appointment to the Court Orchestra, which he had been promised. He had expected approval before the Guards left for England. Unfortunately the necessary letters need to come from London, Jakob has to go to London. and he misses the next opening and has to wait. Jakob is formally discharged from the guards while in London and returns to Hanover. It is unclear a what point Jakob finally obtains his Court appointment, but he is certainly in post by 1762 (see below).

1756 Start of the Seven Years War.

1757 Regiment moves back to Hanover, with Wilhelm and Isaac part of the marching band. In July the regiment is defeated in the battle of Hastenbeck (part of the 'Seven Years War'). The battle was curious because at one point both commanders thought they had lost and started to withdraw from the field. Wilhelm is age 19 at this point. He is sent back to Hanover by his father Wilhelm at age 19 still a 'boy' and not in fact under oath for his service, or so his father argues.

1757 Jakob is in hiding because Hanover is creating a city militia and pressing able bodied men. Wilhelm decides that he is better off in the guards band because musicians are treated as non-combatants by both sides and rejoins the regiment. In the confusion after the battle he is again encouraged to leave with the connivance of his father (who is later imprisoned for a short while). Wilhelm joins Jakob in Hamburg they move to England to take refuge from war. (William has, in fact, deserted from the Guards!)

1759 George Friederich Handel dies.

1760 Accession of George III.

1760-61 Head of the Durham Militia band. He resigns this position expecting an appointment in Edinburgh, which in fact does not materialise.

1761 Symphony No 8.

1761 Moved to Sunderland - engaged by Charles Avison as first violin and soloist for Newcastle orchestra.

1761 William Herschel's Symphony No 8.

1762 Milsom Street constructed.

1762 Jakob uses his influence as a member of the Hanover Court Orchestra to secure William's formal dismissal. (Hoskins, 2011, p11.) William is now free to visit Hanover.

1762 Spring - gives well received concerts in Leeds and is offered a post as 'director of concerts'. Moved to Leeds.

1764 April 1st. Return of Alexander to Hanover. End of Alexander's musical apprenticeship to Sophia's husband—where he has not been well treated.

1764 April 1st. William visits Hanover.

1765-66 Alexander takes position in the regimental band of Prince Charles—brother in law to George III—(who was taught by Jakob). Later gets half-salary position in the Court Orchestra.

1766 William moves to Halifax. In August 1766 offered the post of organist at the parish church. Almost simultaneously offered the appointment to the organist of the Octagon Chapel in Bath.

1766 December 9th. Moved to Bath to become organist of the Octagon Chapel.

1767 Jan Gives introductory concert on violin, oboe, harpsichord because the organ was incomplete. Also joins the band that plays in the Assembly Rooms and the Pump Rooms.

1767 Elizabeth Lindley make a public debut (with her brother Thomas) at Covent Garden (age 13). Mary Dewes who attended concerts thinks that the Lindley children are overworked and Elizabeth is singing material too difficult for her age.

1767 Isaac (William's father) dies.

1767-1774 Construction of Royal Crescent.

1767 August 4 Official opening of the Octagon Chapel.

1767 October 19 Performs for inauguration of the organ. Now also Director of Public Concerts in Bath.

1769 July. Jakob returns from an extended visit in Bath. (1768/69 Winter season?).

1770 Jakob returns to Bath with Alexander - Alexander stays for the next 46 years.

1771 New Assembly Rooms open—and William is *not* appointed as director of music. The job goes to Thomas Lindley (the elder), William's great rival and the established leader of musical life in Bath.

1772 January: William employed as an "extra" musician in the New Rooms orchestra. Lindley does not give him a music stand. The public dispute lasts for the rest of the season.

1772 Elizabeth Lindley (age 18) elopes with Thomas Brindsley Sheridan to France. It is not clear that they married in a form recognised under English law.

1772 August 24 Caroline arrives in Bath. Brothers Dietrich, Alexander and Jakob also appeared as musicians in Bath.

1773 Jan Death of Sophia's husband.

1773 By the Spring of 1773 Herschel is known to have had a copy of Robert Smith's *Optics* (Smith 1738). in his possession (in which, amongst other technical matters the making of telescopes is described).

1773 May 10th - William purchases Fergusson's astronomy (Ferguson 1757). Ferguson was a believer in the 'Principle of Plenitude' and therefore held that the heavenly bodies including the Moon were likely to have

been 'populated by God'. These speculations influenced William. At this point so little was known about the stars that Ferguson gives them only twelve pages in the second edition of his book (Ferguson 1757). (The first edition of 1756 did not mention them at all.)

1773 May: Herschel buys an object glass of 10' focal length and constructs a refractor (probably with a cardboard paste tube made by Caroline. He performs his first astronomical observations.

1773 September 22: purchases the means of constructing reflecting telescopes from a Quaker living in Bath who had no more need of them. It involved casting his own mirror blanks from speculum. By October he had cast disks for a small (2') telescope shortly followed by a $5\frac{1}{2}$' telescope.

1773 The Lindley family are commanded to entertain the Royal Family at Buckingham Palace, in a five-hour concert, for which Lindley is paid £100 (equivalent to perhaps £12,000 in modern money).

1773 Elizabeth Lindley (now age 19) marries Thomas Brindsley Sheridan under UK law. It is estimated that by this time she and her siblings had earned £10,000 for her father.

1773 Thomas the younger is leader of the orchestra at Drury Lane.

1774 Thomas the elder is directing, writing and organising music for the Drury Lane Theatre in London.

1774 Pultney Bridge built.

1774 March 1st Herschel opens his first observing book and starts by observing Saturn and the Orion Nebula.

1774 Age 36 Herschel constructs first large telescope—a seven foot with a 6" diameter mirror.

1776 US Declaration of Independence.

1776 The two partners who had built the Octagon Chapel parted company, with the partner who had not appointed William being left in control. William was replaced as organist.

1776 Thomas Lindley purchases a share in the Drury Lane theatre in London and relocates from Bath, leaving the field in Bath clear for Herschel.

1776 William is working on a 10' telescope with a mirror 9" in diameter (i.e. f13). On May 28th observes the Moon with this instrument, and thinks he sees evidence of 'growing substances'.

1776 July 30: observes and eclipse of the Moon with a 20' telescope (12" mirror - i.e. f20) but as he has to use an 'aerial' support he finds it easier to work with his 10'.

1777 March 5th, Caroline performs as a principle soloist in *Judas Maccabaeus*, with the compliments of prominent audience members but the Bath 'season' ends soon afterwards.

1777 Autumn: Lindley returns to lead music at the New Assembly Rooms, but departs at the end of the year.

1778 April 15th, Caroline again performs as a principle soloist in *Messiah*. Caroline is offered a singing engagement in Birmingham, which she declines without consulting William. This appears to be a definite decision that she will not pursue an independent career, but sing only when accompanied by her brother.

1778 Thomas Lindley the younger dies in a boating accident at the age of 22. Mozart says 'Linley was a true genius; and he felt that, had he lived, he would have been one of the greatest ornaments of the musical world'.

1779 William starts a systematic search for double stars, aiming to examine at least all naked-eye stars, in order to supports attempts to measure stellar parallax. At best this would be possible only with a few nearest stars. Furthermore, given the very narrow field of view of telescopes at that time, the stars (or at least one star) would need to be a small angular distance away. (William did not know about a 1767 paper by John Mitchell which used statistical arguments to demonstrate that the excessive numbers of double stars meant that they had to be physically close together in space.)

1779 Invited to join the recently founded Bath Philosophical Society by Dr William Watson FRS (whose father was Sir William Watson—the secretary of the Royal Society).

1780 Director of the Bath Orchestra with his sister appearing as a soprano soloist.

1780 May 11 William's papers on the variable start Mira Ceti and a second on the height of lunar mountains are read to the Royal Society in London (Herschel 1780*a*),(Herschel 1780*b*). (The papers were first read the Bath Philosophical Society, but forwarded by Dr Watson to his father, as worthy of consideration.) Both papers were considered for publication in the Royal Society's *Philosophical Transactions* but William has to remove speculations on lunar inhabitants from the second paper.

1781 March 13, Age 42 William discovers Uranus - reported as an object larger but less bright than a typical comet and moving slowly. Unfortunately, William had not yet mastered the process of producing accurate astronomical coordinates in the standard format and it is some time (April 23rd) before the Astronomer Royal confirms the observation with his inferior instrument. determines that its orbit is circular and at such a distance that the object must be a planet.

1781 William has a catalogue of 269 double stars, but other observers are unable to resolve these a separate and his credibility is questioned.

1781 May 2nd: William is a guest of Nevil Maskelyne at Greenwich where they compare William's telescope with those constructed for Maskelyne by London makers. William's instrument is able to resolve close double stars (e.g. the Pole Star) that are merged as one in Maskelyne's telescope.

1781 November: awarded Copley medal of the Royal Society.

1782 March: Alexander Aubert confirms William's observation that Polaris is a double star.

1782 May 1st Last public musical performance of Caroline and William, in one of William's anthems (St James' Bath) in which Caroline sings the treble solo.

1782 Pardoned for desertion from the Hanover Regiment by George III.

1782 Appointed court astronomer and moved to Datchet near Windsor. Paid £200 a year. (He earned £400 a year as a musician.) Continued to manufacture and sell telescopes to supplement income. (Hoskin 2016) (Note that the Astronomer Royal, Maskelyne, is paid £300 pa, so William's sinecure of £200 is generous given that there were no fixed responsibilities.)

1783 20' telescope in service.

1788 May 8th William marries Mary Pitt. Caroline gets 50 annual pension from the King.

1789 William discovers Enceladus (28th August) and Mimas (17th September) using his new 40 foot telescope.

1792 March 7th John Herschel is born.

1792 Jakob is found strangled in a field. His death is never mentioned by the family other than indirectly (Dietrich thanks William in a letter for assigning him William's share in his estate).

1792 Elizabeth Lindley (now Sheridan) dies at the age of 38 from TB.

1793 Bought ten-foot long 30" telescope from the estate of Rev John Mitchell of Thornhill.

1793 'Wilhelm Herschel' formally becomes 'William Herschel' by Act of Parliament.

1795 Thomas Lindley the elder dies.

1800 Feb 11 William discovers infrared radiation. (Testing filters to observe sunspot, but found lots of heat, which registered on a thermometer.)

1802 Age 64 First catalogue of 2500 objects.

1816 Herschel was made a Knight of the Royal Guelphic Order in 1816. (Gave him the honorary title of 'Sir William'—though this conferred no advantage in the UK order of precedence.) Has William remained a citizen of Hanover?

1816 February - Alexander sustains an accident to his knee which means that he cannot teach for several months. Having lost his income, he accepts aid from William to discharge his debts and on 31st of July moves back to Hanover, to live with Dietrich, supported by William.

1820 Age 81/82 First catalogue of 5000 objects published.

1820 Age 81/82 William becomes the first President of the Royal Astronomical Society.

1821 16th March - death of Alexander. Funeral expenses paid by William.

1822 William dies, August 25th, Age 83/84 - Caroline moves back to Hanover.

1848 Jan 9th Caroline dies after publishing the New General Catalogue of Nebulae.

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