Caroline Herschel: Discoverer of Comets
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In this talk Dr Sheila Kanani combines the story of a pioneering woman astronomer, with an account of the science behind comets, asteroids and meteors.

Introduction

Caroline Herschel began her life in astronomy supporting the work of her amateur astronomer brother William. She was working with him when he discovered the planet Uranus. She went on to become the world's first professional woman astronomer, her salary provided by King George III of Great Britain. The catalogue of nebulae she produced brought her the Royal Astronomical Society's 1828 Gold Medal – the first awarded to a woman, the next gold medal awarded to a woman wasn't until 1996, and since then there still have only been a handful.

Caroline discovered 8 comets, personally discovering five of those, and she also was the second person to discovered Comet Encke. Working as a team, William and Caroline Herschel increased the number of known nebulae from about 100 to 2,500.

In this Cinderella story (where the prince is astronomy, not a man!) I will give you an account of Lina's life, showing you what a pioneering woman she was, even back in the 1700s and 1800s when being female was far more of a penalty than a success, interwoven with the science behind the astronomy she was famous for. And during this talk there will be a short demonstration of a kitchen comet, using dry ice!

Links to the RAS and Me

I am the first to admit that Caroline was only introduced to me about 6 years ago, when I started my job at the Royal Astronomical Society in 2014, but she quickly became a firm favourite in my storytelling, a role model in astronomy and a formidable creature to look up to. Of course, this really is said in the 'respect' sense of the word, as Caroline was only 4 foot 3, so even I, at a petite 4 ft 10 and a half, would be looking down on Lina, if I were ever to meet her!

Caroline was trained first to be the assistant to her astronomer brother, William Herschel. William discovered the planet Uranus and was the first president of the RAS, although he never actually chaired a meeting. His 40-foot telescope was the main symbol on our logo until a few months ago when the logo was updated to celebrate our bicentenary, and Caroline was the first woman to win the RAS's prestigious gold medal in 1828.

At that time however, women were not allowed formally to be members of the RAS, so Caroline wasn't allowed to become a Fellow, instead she shared an honorary membership with Mary Somerville in 1835, some time after she won her award.

Since learning about her incredible life and astonishing astronomy, including the legacy she has left behind, I take every opportunity to celebrate her work and her life, and use her as an

inspiration to all budding astronomers, from all walks of life. If one tiny, ill ridden, drudge can win a gold medal, anyone can!

Beginnings

Caroline Lucretia Herschel was born in the German town of Hanover on March 16, 1750, the eighth child of Isaac Herschel and Anna Ilse Moritzen.

Isaac was a talented musician while Anna was illiterate and vehemently opposed to the education of girls, believing they should work only at home. Isaac became a bandmaster in the army and was away with his regiment for substantial periods of time whilst Caroline was young. The family had to move house a lot because of financial reasons, and Anna, Caroline's mother, took on work wherever she could find it. Isaac suffered ill-health after the battle of Dettingen in 1743 and never recovered fully; he suffered a weak constitution, chronic pain, and asthma for the remainder of his life, and he was then home for longer periods of time than Caroline's mother.

Caroline suffered smallpox at age 3, leaving her face pock marked. At age 10, she suffered typhus, permanently stunting her growth. Her parents believed these physical issues would make it difficult for Caroline to find a husband, so her mother decided Caroline would learn how to do domestic chores and serve as the family house servant.

Anna objected to Isaac's attempts to educate his daughters – even opposing violin lessons. Isaac still taught Caroline directly when Anna was away from home or included Caroline secretly in her brother's French and Maths lessons. Not being allowed to learn French annoyed Caroline particularly, because it destroyed her chances of becoming a governess, which demonstrates Caroline's aspirations.

Caroline's accounts of her childhood show an intensive daily routine. Her schooling meant that she learned to read and write, unlike many women from the generation before her. It was typical of Caroline's education that this skill was immediately put to use writing letters for her mother and other illiterate army wives in their neighbourhood. She was sent to tutors after school to learn knitting and how to clean silk. Where opportunities arose to gain new skills, Caroline actively sought to capitalize on them! She was proactive even when she was young.

She was taught millinery and dressmaking and she enjoyed hard work – even as a child she wanted to be able to support herself one day. The lessons she sought for herself were those that might make her appear of a higher social class and could have led to paid employment; however, in the Herschel home such ambitions were forbidden.

When, for example, she had been allowed to attend these lessons in millinery and dressmaking it was under the strict agreement that it should be to make clothes for her and her family only, and not for commercial gain. To train girls for work outside the home was considered by the Herschel family very much a lower-class pursuit.

In 1771 Caroline, then aged 22 years, began to wonder where her future lay.

> *'I had by this time imbibed too much pride for submitting to take a place as a Ladies maid, and for a Governess I was not qualified, for want of knowledge in languages, and my father has cautioned me against all thought of marrying, as I am neither handsome nor rich'*, she said.

With marriage, service and teaching all ruled out, Caroline's options were extremely limited. William's offer to bring her to England to act as his housekeeper, and learn to become a singer,

gave Caroline an escape she could take. After Isaac's death in 1772, William managed to persuade their mother that Caroline should join him, and eventually Anna allowed Caroline to move to England.

In August 1772, William took Caroline with him to Bath. He agreed to pay his mother for a servant to replace Caroline. On the journey to England, she was first introduced to astronomy by way of the constellations and opticians' shops. During the trip, they sat atop the carriage and William showed Caroline the constellations for the first time.

Escape

Between 1772 and 1781 Caroline lived with her brother in Bath. There, Caroline took on the responsibilities of running William's household, and she also learned to sing.

William had established himself as an organist and music teacher at 19 New King Street, Bath, Somerset (now the Herschel Museum of Astronomy). He was also the choirmaster of the Octagon Chapel and a church organist. William was busy with his musical career and organising public concerts.

Life in Bath was not easy for Caroline: she was relatively poorly educated and spoke little English. She did housework for William, who taught her English and mathematics as well as singing. Breakfast was always taken with a math lesson! Geometry she learned the hard way; if she did not know the angle of the piece of cake she wished to eat, she had to go hungry.

Caroline was also given lessons in presentation, to learn how to perform and behave among the employers of musicians. This meant that she learned some of the rules of appropriate female behaviour that she would later apply in the presentations of her science. Nevertheless, it appears that Caroline did not blend in with the local society and made few friends.

Because Caroline had no friends, William introduced her to two popular ladies, and arranged for them to take Lina to London.

They stayed for six weeks, during which time Caroline was taken to the opera and the theatre numerous times, and to auctions and shopping. Although a little overwhelmed by the experience, and glad to be back in Bath, she did note in her autobiography that *'to Mrs Colbrook and to the Marchioness of Lothian I am indebted for all I ever saw of the Fashionable world.'*

At about the same time Caroline also learned an important lesson in self-presentation that she took to heart. She was told off for *'being her own Trumpeter'* by a lady in Bath, and from this point on seems to have taken exaggerated steps to avoid any future accusations of boasting or bragging.

Caroline took several singing lessons a day from William and within 5 years she was a notable soprano singer. She became the principal singer at his oratorio concerts and acquired such a reputation as a vocalist that she was offered an engagement for the Birmingham festival, but she declined to sing for any conductor but William. This mean that eventually people stopped requesting her and she found herself without concerts to perform in. Her career in singing began to decline.

Mrs Bulman, the housekeeper, had helped Caroline master English cooking. Teachers had been employed to teach her etiquette and presentation. William had helped her learn English, singing and some basic maths and accounting. Next the siblings turned their attention to other areas of mathematics.

After her initial accounting tutorials, Caroline's lessons evolved into something quite different. These ‘Little Lessons for Lina’ as they were called, subheaded ‘A little Geometry for Lina’, ‘A little Algebra for Lina’, and so on, started with algebra and geometry, including topics such as angles in a triangle and z-angles.

Both algebra and geometry were considered essential prerequisites for the study of fluxions (an area of mathematics that William was then studying, that we now called differentiation). The lessons also incorporated some of the astronomy that William was beginning to study. In one lesson, for example, certain trigonometric rules were taught; in the next, astronomy-related problems were set in which those rules might be used, such as finding the position of one star in relation to another.

It is unclear who initiated these lessons or why. For William, teaching Caroline offered him the opportunity to test how well he understood what he had learned so far. This was a style of learning he had been taught as a child. In addition, having a sister with some knowledge of advanced mathematics would have added to his family's reputation as Bath's mathematical musicians. For Caroline, her acquisition of mathematical skills allowed her to play a greater role in William's life and work, thus further securing her position in her new family home.

About a year after Caroline arrived in Bath, in the summer of 1773, William began a new hobby, building his own telescopes, that entirely changed the look of the house and the life of its inhabitants: ‘It was to my sorrow I saw almost every room turned into a workshop’, Caroline declared with regret!

Although initially appalled at what this meant for the house, Caroline later recognised the educational opportunity offered to her through this new hobby and took advantage of it. At first, however, her role in instrument making was minimal; her musical and domestic duties took precedence.

Throughout this period both William and Caroline were using their ability to absorb skills and knowledge to develop new roles for themselves. While William was gradually becoming more astronomer than musician, Caroline was busy making herself indispensable in every area of William's life.

<u>Astronomy</u>

William’s passion for music was decreasing and his passion for astronomy was increasing. He felt driven to understand the heavens better than anyone before; he desperately wanted to see objects so faint that nobody had seen them before. To achieve his goals, he needed the greatest telescopes in the world. The only way to get them was to build them himself!

Soon, the Herschel’s drawing room became a stand construction workshop; a bedroom became a glass grinding operation; and the whole house took on the odour of horse dung, which was pounded into a dried, non-porous loam mould for mirror casting. William became so obsessed with his goals that, in addition to helping him grind mirrors and lenses using horse dung, Caroline often had to prepare food and feed it into his mouth as he worked! She said, *"I did nothing for my brother but what a well-trained puppy dog would have done, that is to say, I did what he commanded me."*

William's reputation as a telescope maker grew to such an extent that he quit his job as a musician and devoted all of his time to the making of telescopes and to astronomy. Caroline began to help her brother in the manufacture of telescopes and to share his passion for astronomy. Caroline first

served as her brother's apprentice then began to function more and more on her own and went on to help her brother develop the modern mathematical approach to astronomy.

Although both Herschels maintained journals corroborating their joint work in their endeavours, when the story of Uranus's discovery is told, William is often credited as a male genius who had a "Eureka" moment on March 13, 1781, when in actual fact it was a collaboration.

When Uranus was discovered, it was a singular moment in the history of science: if a planet had remained unrecognized for so long, what else might be out there? After all, Uranus was actually visible to the naked eye! The mathematicians of the Royal Society concluded that Herschel had discovered a new planet, the first that was farther from the Sun than Saturn. The finding changed the perception of the solar system: it was larger than previously thought and could hide even more distant planets.

British scientists petitioned the king, asking that Herschel be paid a government pension to allow him to give up music and devote his life to the construction of his magnificent telescopes and the possibility of making further stunning discoveries.

The king agreed and William became a full-time astronomer. William was paid £200 per annum. He assumed Caroline would also be happy to give up her musical career to act as his assistant, which she did so, but initially, reluctantly.

In his new role as the king's astronomer, William was required to move to a house nearer Windsor and be on call to show the Royal Household the heavens whenever they wished. The pension was generous enough to allow William to take Caroline with him, and so the two of them packed up and moved to Slough.

Slough

Caroline was far from happy. She had escaped drudgery in Hanover to become a singer, praised and loved by audiences. She now had to abandon her singing and the excitement of Bath to live in Datchet, a small village, near Windsor Castle, closer to the king. Her first months as a full-time astronomer were miserable and lonely.

They moved several times in the first few years before eventually settling on a property later known as Observatory House. On arriving in their new home, Caroline states:

> *"I found I was to be trained for an assistant Astronomer; and by way of encouragement a Telescope adapted for sweeping was given to me. I was to sweep for comets. I began Aug 22, 1782, but it was not till the last two months of the same year before I felt the least encouragement for spending the starlight nights on a grass-plot covered by dew or hoar frost without a human being near enough to be within call."*

In instrument making, Caroline's approach to education showed itself to be a good complement to that of her brother, helping them to work as a unit and turn William's ideas about his telescope mirrors into reality, often by supervising the workmen when William was away.

Having carved out a role for herself within the family's instrument-making project, Caroline then began to take more control over other aspects of her education. In this period she actively pursued an understanding of the mathematics and astronomy that her brother was studying. Her 'little lessons for Lina' became answers to the questions that she put to her brother.

Caroline was now setting the topics herself, selecting areas of mathematics that she felt she needed to study, and quizzing her brother, although the content suggests that the questions came out of the broader tasks set by William.

Her notes contain, for example, ‘Theorem for determining the field of view by the passage of a star’, ‘Rules for making use of astronomical instruments’ and ‘Theorem for calculating the number of stars that have been seen in a sweep’. In each of these sections it is possible to see a direct relation between the rules and theorems laid out and the tasks she was assigned in her role as astronomical assistant.

On one page, for example, Caroline was introduced to ‘The 8 classes of Nebulae’ and ‘The 6 classes of Double Star’. This was from a new classification system devised by William, and these lessons offered an opportunity for him to test out and talk through his ideas.

William's interest in astronomy started as a hobby to pass time at night. At breakfast the next day he would give an impromptu lecture on what he had learned the night before. Caroline became as interested as William, stating that she was *"much hindered in my practice by my help being continually wanted in the execution of the various astronomical contrivances."*

Caroline possessed incredible dexterity in polishing mirrors and mounting telescopes. She learned to copy astronomical catalogues and other publications that William had borrowed. She also learned to record, reduce, and organise her brother’s astronomical observations. She recognised that this work demanded speed, precision and accuracy.

The new job proved to be a mixed blessing; although it left William with a lot of free time to continue his astronomical observations, it also meant a reduction in income and being called upon by the king for entertainment whenever he desired. During this time William perfected his telescope making, building a series of ever larger devices that ultimately ended with his famous 40-foot (12 m) focal length instrument, that was also used to house parties for the king!

The telescope was a local tourist attraction, visited by rich and famous people on their way to the nearby Windsor Castle to visit the King, and was featured on Ordnance Survey maps. It was the largest telescope in the world for 50 years.

William Herschel’s son, John, took down the telescope frame at the end of 1839. It was dismantled because it was feared that the frame might collapse due to rot, and John was worried for the safety of his young children. A small ceremony was conducted to commemorate its dismantling.

The tube was left lying horizontally in the garden, supported by stone blocks at either end, where it was crushed in 1867 by a falling tree. The remaining piece is a 10-foot (3.0 m) length of the mirror end, which was still located in the garden of Observatory House in 1955 but has since been moved and is now located in the Herschel Collection of the National Maritime Museum, in the Royal Observatory, Greenwich, London.

Caroline was William’s constant assistant in his observations, also performing the laborious calculations with which they were connected. During one such observation run on the large telescope in 1783, Caroline became caught on an iron hook and when she was helped off, she said *"...they could not lift me without leaving nearly 2 ounces (60 g) of my flesh behind."*

Caroline began to make observations on her own in 1782. During her spare time, she occupied herself with observing the sky with a 27-inch (690 mm) focal length Newtonian telescope and it was with this telescope that she detected a number of astronomical objects, during the years

1783–87, including her first independent discovery - M110 (NGC 205), the second companion of the Andromeda Galaxy.

Messier 110, or M110, also known as NGC 205, is a dwarf elliptical galaxy that is a satellite of the Andromeda Galaxy. Although Charles Messier never included the galaxy in his list, it was depicted by him, together with M32, on a drawing of the Andromeda Galaxy; a label on the drawing indicates that Messier first observed NGC 205 on August 10, 1773. The galaxy was independently discovered by Caroline Herschel on August 27, 1783.

Caroline became an effective sweeper of the sky using her Newtonian, ingenious in its simplicity. The tube rotated in a vertical plane, as Caroline wound a cord. By keeping her eye at the eyepiece and turning a handle, Caroline could search a vertical strip of sky as the tube moved from the vertical to the horizontal. In the time this took her, the rotation of the heavens had brought into view the next strip of sky, and so on. In a few evenings she could search the whole of the visible sky.

<u>What are Comets, Asteroids and Meteors?</u>
Asteroids are small, rocky objects that orbit the Sun. Although asteroids orbit the Sun like planets, they are much smaller than planets.

Meteoroids are significantly smaller than asteroids, and range in size from small grains to one-meter-wide objects. Most are fragments from comets or asteroids, whereas others are collision impact debris ejected from bodies such as the Moon or Mars.

There are two main kinds of meteoroid:
- Cometary meteoroids which are small particles shed by comets
- Asteroidal meteoroids which are particles fallen off or chipped off asteroids

There are also those that have their origins from other planets and larger bodies. Impacts on Mars has thrown up Martian debris into space and have landed on earth.

Comets ‘live’ at the edge of the Solar System, past Pluto, in the Kuiper Belt and Oort Cloud. They are made from remnants of materials when the solar system was formed, and because this area is so far away from the Sun, it is very cold, and the main component of a comet is ice, in fact comets are like huge dirty snowballs.

Comets are composed of rock, dust, ice and frozen gases such as carbon dioxide, methane and ammonia.

They have a highly elliptical orbit, unlike other solar system bodies, which means that they spend most of their time at the edges of the solar system, then shoot in towards the sun. As they approach the sun, the cometary material starts to alter from ice to gas, and the comet tail appears.

Radiation from the sun pushes the dust particles away from the comet, forming the dust tail, and charged particles from the sun convert cometary gases into ions, forming the ion tail.

The tails always point away from the sun, and get longer the closer the comet gets to the sun.

Humans have been able to witness comets for centuries with no equipment, so in the past it was thought that comets were ‘hairy stars’ which is where they get their name. People used to fear comets as harbingers of doom, as you can see in these paintings.

Modern technology has allowed us to view comets in a different light!

There have been various missions to comets, including Giotto, Star Dust and Deep Impact.

The most famous one recently was the Rosetta mission which orbited comet 67P for 17 months, and landed the Philae lander on the surface of the comet.

Because of missions like these, I can make a good analogy of a comet here in front of you!

One of the reasons we care so much about comets is because comets and the Earth were very similar when the solar system was formed. The Earth has changed a lot over the last 4 billion years, but comets, because they are so far away from the sun, have remained largely unaffected. So, if we learn more about comets, we can learn more about the Earth and where we have come from.

The other thing about comets that interests us is comet impacts. It could have been a comet impact 66 miliion years ago that caused the extinction of the dinosaurs, and perhaps a comet impact brought water to a barren Earth.

And here you go, a comet like 67P made before your very eyes!

Caroline's Astronomy

Between 1786 and 1797 Caroline discovered several comets and worked on a reorganization of John Flamsteed's star catalogue. Both projects gained her public recognition and praise within the astronomical community.

Beginning in October 1783, the Herschels used the 20-foot reflector to search for nebulae. Initially, William attempted to both observe and record objects, but this was inefficient, and he turned to Caroline.

When a nebula came into view, he would pull a cord that communicated with a bedroom overlooking the telescope, where Caroline was waiting at a desk. She would open the window and copy down William's shouted description of the appearance and location of the nebula. The location would be by reference to a nearby star, which Caroline would identify.

This was not a simple clerical task, however, because she would have to use Flamsteed's catalogue to identify said star. However, Flamsteed's catalogue was organised by constellation, which was less useful to the Herschels, so Caroline created her own catalogue organised by zones rather than constellations, which meant that William could use the catalogue in zonal sweeps of the sky. The morning after each session, Caroline would go over her notes and write up formal observations, which she called "minding the heavens."

This was, as she put it, a project that would give her something useful to do when William was busy. *'I had always in hand some kind of work with which I could proceed without troubling him with questions, such as the Temporary Index which I begun in June 1787, and some years after, the Index to Flamsteed's observations.'*

Like her catalogue, Caroline's comet discoveries came out of work she was doing with her brother. His project—to survey the sky for nebulae, star clusters and double stars—was an update of a catalogue originally produced by Charles Messier to identify and list these objects for the benefit of comet hunters, because such objects were frequently mistaken for comets. Caroline's comet

hunting was this project in reverse. It was about learning to tell the difference between one blurred object in the night sky and another.

Caroline discovered her first comet on 1 August 1786, the next in December 1788, two more in 1790, a fifth in December 1791, another in October 1793, her seventh in November 1795 and in August 1797, she discovered her eighth and final comet. The timing of these discoveries almost all occurred when William was away.

Caroline is often credited as the first woman to discover a comet; however, Maria Kirch discovered a comet in the early 1700s, but is often overlooked because at the time, the discovery was attributed to her husband, Gottfried.

By July of 1786, Caroline had set a strict routine for herself as an astronomer rather than a housekeeper. She checked the calculations of William's nebulae by day and made her own sweeps up on the roof by night. Using her specially constructed "hunter's telescope," on August 1, 1786, Caroline spotted an object moving through the sky. Caroline's triumphant finding (Comet C/1786 P1 [Herschel]) became known as the First Lady's Comet. Its publication by the Royal Society — an almost unheard-of rarity for a female correspondent — catapulted her to international fame. At the time, only about thirty comets had been identified and recorded.

In 1788, Caroline discovered the periodic comet 35P/Herschel–Rigollet. This comet will return in 2092. William was summoned to Windsor Castle to demonstrate Caroline's comet to the royal family. William recorded this phenomenon, himself, terming it "My Sister's Comet."

In 1795, Caroline rediscovered the remarkable Comet Encke, a comet on a 3.3 year orbit of the Sun. The comet was first discovered by Pierre Méchain in 1786. Her final comet, in 1797, was discovered without the aid of a telescope.

Caroline was given an annual salary of £50 by King George III for her role as assistant to William. This would be approximately £6k in todays money. Caroline's appointment made her the first woman in England honoured with an official government position, and the first woman to be paid for her work in astronomy.

Throughout her writings, she repeatedly made it clear that she desired to earn an independent wage and be able to support herself, and this was finally achieved.

Once each discovery was made, Caroline or her brother made it known, and a paper was read on her behalf to the Royal Society. Caroline's approach, the language she used, and her actions, all illustrate the tension between wanting to claim priority and the need to conceal that desire in non-ambitious, non-boastful, terms.

For example, on one occasion she asked Sir Joseph Banks, President of the Royal Society and a keen supporter of her brother, to make her discovery more widely known on her behalf, *'for the sake of astronomy'*.

On discovering her eighth comet, she got on her horse and rode through the night to Greenwich to ensure priority.

On 14 August 1797 at 9:30pm, Caroline had set down to her work, as the skies and her domestic life permitted, of "sweeping" the skies with her reflecting telescope – a slow and meticulous task.

However, on this occasion, having only performed the usual preparatory step of *"looking over the heavens with the naked eye",* she spotted her eighth comet. Given its prominence it was not

surprising to learn that others were also observing it that night, and she wanted to stake her claim first.

Her impatience to deliver her news, despite having already established her name as a discoverer, led her to rather extraordinary measures for an 18th-century woman, especially one who always presented herself as particularly shy and retiring.

> *"With only the preparation of one hour's sleep"* after her night of observing, she had ridden nearly 30 miles – despite *"having in the course of years never rode above two miles at a time"* – to reach the Royal Observatory in Greenwich and the Astronomer Royal.

Maskelyne greeted the news with enthusiasm and urged her to call on Banks to tell him personally.

It was typical of Herschel that the letter to Banks was couched in terms of deference, humility and weakness: a performance of an acceptable female role that was played, despite her extraordinary life as immigrant, singer, astronomical assistant and discoverer.

In the letter she stated that she was writing to Banks to excuse herself from not having called on him after Maskelyne, because the ride *"totally unfitted me for any action"* and because *"a woman who knows so little of the world ought not to aim at such an honour, but go home, where she ought to be, as soon as possible."*

All this posturing after such an extraordinary ride to Greenwich!

Therefore, perhaps Herschel also meant exactly the reverse of what she wrote in the opening of her letter to Banks:

> *"This is not a letter from an astronomer to the President of the Royal Society announcing a comet, but only a few lines from Caroline Herschel to a friend of her brother's, by way of apology..."*

In each comet case she passed on the information to prominent members of the scientific community and left them to deal with the details, carefully presenting herself as the discoverer and yet doing so with appropriate modesty and self-effacement. Her choice of recipient seems to have been individuals who were particularly accepting and encouraging of learned ladies.

Caroline's work elicited none of the condescension experienced by women in the previous century, partly to do with timing and definitely to do with Caroline's carefully crafted public image. It was during this period that Caroline was able to put all her training from working in the music industry into practice. She was able to use her practical and theoretical knowledge to aid her brother in his astronomical work, both directly and by devising projects to work on independently. At the same time, her understanding of appropriate modes of conduct and female modesty, mixed with a background in performance, meant that she knew just whom to tell of her independent achievements and how best to present them.

<u>Star Catalogue</u>

William's observations had shown that there were a great many discrepancies in the star catalogue published by John Flamsteed, which was difficult to use because it had been published as two volumes, the catalogue proper and a volume of original observations, and contained many errors. William realised that he needed a proper cross-index to explore these differences but didn't want to devote time to it at the expense of his more interesting astronomical activities.

He therefore recommended to Caroline that she undertake the task, which ultimately took 20 months! The resulting *Catalogue of Stars, Taken from Mr. Flamsteed's Observations Contained in the Second Volume of the* Historia Coelestis, *and Not Inserted in the British Catalogue* was published by the Royal Society in 1798 and contained an index of every observation of every star made by Flamsteed, a list of errata, and a list of more than 560 stars that had not been previously included.

Relationship with William

When William married a rich widow and their neighbour, Mary Pitt (née Baldwin), in 1788, the union caused tension in the brother-sister relationship. Caroline has been referred to as a bitter, jealous woman who worshiped her brother and resented those who invaded their domestic lives. But I think it was more complex than that, and the change in situation affected Caroline for various reasons.

Mary Herschel took Caroline's place in William's household, and Caroline was banished to the cottage next door. Such was the anger she expressed in her records of these days that she later destroyed her journals.

With the arrival of William's wife, Caroline lost her managerial and social responsibilities in the household and accompanying status. She no longer held the keys to the observatory and workroom, where she had done much of her own work. But because she destroyed her journals, her feelings about the period are not entirely known.

When her brother and his family were away from home, she often returned there to take care of it for them. In later life, she and Lady Herschel exchanged affectionate letters and she became deeply attached to her nephew, astronomer John Herschel.

William's marriage likely led to Caroline Herschel's becoming more independent of her brother and more a figure in her own right. Caroline made many discoveries independently of William and continued to work solo on many of the astronomical projects, which contributed to her rise to fame. She carried out her independent research from the flat roof of her new cottage home. Some significant discoveries included 2 of her 8 comets and NGC 253, the Sculptor galaxy, an almost edge-on spiral galaxy.

New General Catalogue

Over twenty years of ceaseless exertion, William and Caroline increased the number of known nebulae and clusters from about 100 to 2,500, and this catalogue, the "General Catalogue of Nebulae and Clusters of Stars", was published by the Royal Society.

At age 75, and in retirement, Caroline found out that William's son John wanted to re-examine these objects systematically. Her devotion to her nephew pushed her into a frenzy of work to produce a reformulated catalogue of nebulae and she arranged the two-and-a-half thousand nebulae and star clusters into zones of similar polar distances.

The list was eventually enlarged by John Louis Emil Dreyer and renamed the "New General Catalogue", and now contains almost 8000 objects. Many non-stellar objects are still identified by their NGC number.

Caroline, with the support of her brother, was glad to receive recognition for the discoveries she made and for her cataloguing, both of which came about through her work within this scientific family.

Unlike other celebrated male–female partnerships in science, the Herschels made little attempt to share credit for their work. Instead, in this family, Caroline's contribution was clearly acknowledged. That they were brother and sister rather than husband and wife perhaps goes some way to explaining this difference. Another plausible factor was their musical background, in which public recognition for each individual contribution was the norm.

Her motivation, as far as can be inferred from the evidence, was to play an integral role within William's astronomical project, to make herself indispensable to him and give herself something interesting to do. Within that framework, when she produced something that could reasonably be described as her own work, she was keen for that to be acknowledged and aware enough of her position to know how that might be achieved. She was ambitious for recognition and credit but not ambitious for independence. She was part of the Herschel family project, but within that she saw no reason not to quietly celebrate her specific role and achievements.

William died in 1822 and Caroline was grief striken. He left Caroline an annual income in his will, enough for her to live very comfortably. Believing she would soon die herself she sought the familiarity of her childhood surroundings in Hanover and returned there to live with her brother Dietrich and his family.

In fact, she lived for many more years, and unfortunately her life in Hanover was boring and she became bitter and restless. The only thing that gave her happiness was helping her nephew with his astronomy, and she wished she had remained in England to help him more prolifically.
On a visit to her when she was 82 years old, John noted:

> *"She runs about the town with me and skips up her two flights of stairs as wonderfully fresh at least as some folks I could name who are not a fourth of her age… In the morning till eleven or twelve she is dull and weary, but as the day advances she gains life, and is quite 'fresh and funny' at ten or eleven p.m. and sings old rhymes, nay, even dances to the great delight of all who see her."*

Later Life and Legacy

In 1828 the Royal Astronomical Society presented her with their Gold Medal for her work on the star catalogue – no woman would be awarded it again until Vera Rubin in 1996.

In February 1828, James South addressed the RAS meeting as follows:

> *"Who participated in his toils? Who braved with him the inclemency of the weather? Who shared his privations? A female! Who was she? His sister!*
>
> *Miss Herschel it was who by night acted as his amanuensis! She it was whose pen conveyed to paper his observations as they issued from his lips; she it was who noted the right ascensions and polar distances of the objects observed; she it was who having passed the night near the instruments, took the rough manuscripts to her cottage at the dawn of day, and produced a fair copy of the night's work on the subsequent morning; she it was who planned the labour of each succeeding night, she it was who reduced every observation, and made every calculation, she it was who arranged every thing in systematic order, and she is was who helped him to obtain an imperishable name.*

We stand indebted for the discovery of the comet of 1786…1788…1791…1793…1795…and many of the nebulae contained in Sir William Herschel's catalogues were detected by her…

In the year 1797, she presented to the Royal Society a catalogue of 555 stars…Shortly after the death of her brother, Miss Herschel…completed the laborious reduction of the places of 2500 nebulae…bringing to a close half a century spent in astronomical labour…

It was resolved unanimously, 'That a Gold Medal of this Society be given to Miss Caroline Herschel'…a vote which I am sure every one whom I have the honour to address, will most heartily confirm…since the foundation of this Society no one has been adjudged, which has been earned by services such as hers."

The Royal Astronomical Society elected her an Honorary Member in 1835, along with Mary Somerville, although women weren't officially allowed to be Fellows until 1916.

In 1838 she was notified by Sir William Hamilton, Astronomer Royal, Dublin that she had also been elected as an honorary member of the Royal Irish Academy in Dublin.

In 1846, at the age of 96, she was awarded a Gold Medal for Science by the King of Prussia *"in recognition of the valuable services rendered to Astronomy by you, as the fellow-worker of your immortal brother, Sir William Herschel, by discoveries, observations, and laborious calculations".*

Caroline Herschel died peacefully, almost aged 98, on January 9, 1848, in her home in Hanover. She was buried, with a lock of her brother William's hair, beside her parents' graves in a churchyard in Hanover.

Her tombstone reads *'The eyes of her who is glorified here below turned to the starry heavens'*, a sentence she chose before she died. And when her restless heart finally found rest, the "Honorary Membership of the RAS" accolade was proudly recorded on her tomb.

With her brother she discovered over 2,400 astronomical objects in 20 years. The asteroid 281 Lucretia (discovered 1888) was named after Caroline's second name, and the crater C. Herschel on the Moon is named after her.

Adrienne Rich's 1968 poem Planetarium celebrated Caroline Herschel's life and scientific achievements. Google honoured her with a Google Doodle on her 266th birthday (16 March 2016).

<u>Her Legacy and Links to the RAS Now (actor and primary children) and RAS at 200</u>

2020 marks the 200th anniversary of the RAS, of which William and Caroline Herschel were inextricably linked. In my work as Education, Outreach and Diversity officer at the RAS, along with the librarian Dr Sian Prosser, we celebrate Caroline Herschel with a programme of schools events. We bring primary age students into the building to learn about comets, watch a comet making demonstration like I did today, interact with Caroline's labbooks and comet notes that live in the library archives, read her journals and enjoy her beautiful handwriting, and best of all, meet Lina herself, in a wonderful interactive session that can inspire all ages and people from all backgrounds, just like Caroline did when she was alive.

Caroline, with the help of her brother, was able to build on the basic structure of her typically female childhood education and turn it into something scientific, and special.

Few women at the time, and even more recently, have managed to gain this type of public reputation in science, although work on scientific couples and on ‘invisible assistants’ has shown that large numbers participated but were not recorded. Caroline's example shows one way in which such things might be learned.

Eighteenth-century women had to rely on the men in their lives for access to scientific work and education, and in this sense Caroline was typical.

However, this barrier to participation, which meant that Caroline's lessons came from her brother and that her papers were read at the Royal Society on her behalf, did not prevent her from taking an active role in shaping her education and public image.

To make her education and participation meaningful, she had to carve out a niche for herself, pursuing certain lessons and identifying tasks that needed doing. Out of this came her catalogue and her comet discoveries.

Caroline Herschel's legacy is undoubtedly lasting. There are not only the discoveries in themselves, but she was also incredibly meticulous in cataloguing and recording her discoveries, and in the transcription of astronomical data. The New General Catalogue, largely based on her work, is an important tome for modern astronomy, and even today many galaxies are still identified by their NGC numbers.