The Antiquarian Astronomer

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Mars through the ages

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The phantom planets of Barnard's Star

Our contribution in this issue about the early days of exoplanet discovery (see page 51) brings to mind the story of the planets-that-never-were around Barnard's Star. The story started in 1963 when Peter van de Kamp (1901–95), a genial Dutch-American astronomer who was director of the Sproul Observatory at Swarthmore College in Pennsylvania, announced that the nearby Barnard's Star had a companion only about 50 per cent more massive than Jupiter orbiting it every 24 years. At a time when no planets of other stars were known, this inevitably created a storm of interest.

Barnard's Star, a 9th-magnitude red dwarf lying just under 6 light years away, has the largest proper motion known of any star, over 10 arcseconds a year, meaning that it covers the apparent diameter of the Moon every 180 years. While tracking the movement of Barnard's Star on photographic plates taken over more than two decades with Sproul's 24-inch refractor, van de Kamp discovered a slight wobble in its motion that seemed to indicate the presence of an unseen companion in a highly eccentric orbit (Figure 1). This technique had already been used to find low-mass stellar companions of stars, but in this case the wobble was so small that it could only be caused by a planet.

After another six years of tracking Barnard's Star at Sproul van de Kamp published a new analysis which he claimed revealed the existence of not one but two planets with masses similar to Jupiter and Saturn orbiting the star every 26 and 12 years in near-circular orbits (Figure 2).

Unfortunately there was a problem. Other observatories could not confirm van de Kamp's results. Worse still, re-examination of the Sproul plates showed that other stars exhibited similar zig-zag motions to those of Barnard's Star, suggesting that the cause was not in the stars but lay closer to home.

Gradually it became clear that adjustments to the Sproul telescope's lens in 1949, when a new cell for the 24-inch objective was installed, and in 1957, when the lens was readjusted, had combined with tiny errors in measuring the photographic plates to cause spurious movements of the image of Barnard's Star. Van de Kamp himself never lost hope and continued to publish analyses based on further years of data, but most other astronomers dismissed his results as being due to these instrumental and measurement errors. It is now accepted that while van de Kamp's technique was sound in principle, he was let down by the accuracy (or inaccuracy) of the observations he was using.

In an ironic footnote, in 2018 an international team announced the detection of a possible super-Earth around Barnard's Star, this time using radial-velocity measurements rather than the side-to-side wobble. However, this purported planet turned out not to exist either. The radial velocity changes were instead due to surface activity such as starspots and plages. Exoplanet searchers still need to beware of false positives.

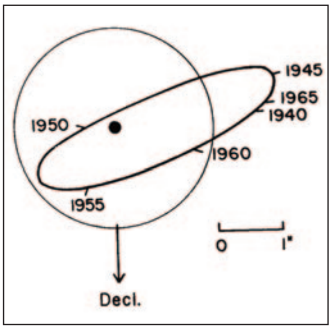

Figure 1. Proposed orbit of a planet with large eccentricity around Barnard's Star. The circle represents the size of the image of the star. From van de Kamp, Peter, 'Astrometric study of Barnard's Star from plates taken with the 24-inch Sproul refractor', The Astronomical Journal, 68 (1963), p. 521.

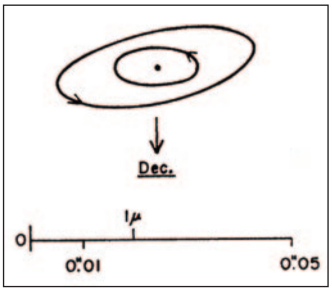

Figure 2. Alternative solution of two planets with near-circular orbits around Barnard's Star. Adapted from van de Kamp, Peter, 'Alternate dynamical analysis of Barnard's Star', The Astronomical Journal, 74 (1969), p. 758.

COVER: The Syrtis Major region of Mars from Christiaan Huygens's drawing of 1659 at top left to T. E. R. Phillips's view in 1899 at bottom right. See 'The imagery and science of Mars' starting on page 64 of this issue. (Joel Hagen)

From the Editor

When does history start? Today is tomorrow's history. And, in the world of exoplanet discovery, 1989 is ancient history indeed. That is the year in which a paper was published reporting that observations of the main-sequence star HD 114762 had thrown up evidence of a low-mass companion orbiting it every 84 days, at a time when no planets of other stars were yet known. In their discovery paper the observing team described the companion as a probable brown dwarf, while leaving open the possibility that it might have a lower mass that would make it the first-ever known exoplanet. How this discovery was made, how it influenced later searches, and how the initial hopes of the first identification of an exoplanet were finally dashed, is explained in this issue by John Harrington from interviews with the main participants.

The planets in our own Solar System have been scrutinized since the invention of the telescope. The first smudgy marking on Mars were recorded by the Dutch astronomer Christiaan Huygens in 1659. Since then the changing albedo markings of the red planet have been a constant source of fascination and interpretation (or misinterpretation). In this issue historian William Sheehan, imaging specialist Joel Hagen, and planetary astronomer William Hartmann review Martian topographic observations extending back to the mid 19th century and explain how, even in the spacecraft age, they remain useful for the continuing study of Mars.

For the first eleven years of its existence, from 1820 to 1831, the Royal Astronomical Society was known as the Astronomical Society of London. Many of its members during these formative years were officers in the army or navy. On pages 81–103 Steven Phillips surveys those early members with a military background who included famous names such as Beaufort, Franklin, and FitzRoy as well as Captain Marryat, the author of classic Victorian novels such as *Children of the New Forest* and *Mr Midshipman Easy*.

Another astronomer from the 19th century whose adventures rivalled those of any military man was Ralph Copeland. He is best remembered as the third Astronomer Royal for Scotland, but what is less well-known is that he was a first gold-digger in Australia and then an Arctic explorer before a period at Lord Rosse's observatory in Ireland where he used the world's largest reflector to discover galaxies including the group now known as Copeland's Septet. Peredur Williams tells the remarkable life story of Copeland beginning on page 28.

Our issue opens with the first of a major two-part study by Paul Haley on Mary Whitney, the successor to Maria Mitchell at Vassar College Observatory, while we end with the transcript of an insightful interview with one of Georges Lemaître's pupils at the University of Louvain in the 1940s.

Ian Ridpath

About the Society for the History of Astronomy

The Society for the History of Astronomy (SHA) was formed in June 2002 with three main aims:

- To provide a forum for those with an interest in the history of astronomy and related subjects;
- To promote the history of astronomy by academics, educators, amateur astronomers, and local historians;
- To encourage research into the history of astronomy, especially by amateurs, and to facilitate its collation, interpretation, preservation, publication, and dissemination.

To implement these aims, the Society organizes regular meetings and publishes its twice-yearly *SHA Bulletin* and an annual Journal, *The Antiquarian Astronomer*. These provide opportunities to publish research by members and others into all aspects of the history of astronomy and related subjects. Because most members are amateur astronomers and amateur historians, much of their research is likely to be outside the scope of professional journals.

Papers for *The Antiquarian Astronomer* should contain original research, new interpretation, insights of material in the public domain, or bring to a wider audience material of limited availability or that is available only in dispersed locations. Papers offered to *The Antiquarian Astronomer* should not have been previously published and are subject to external peer review. Back issues of *The Antiquarian Astronomer* appear on the SAO/NASA Astrophysics Data System (ADS) two years after publication; to access them, go to https://ui.adsabs.harvard.edu/paper-form and type our official abbreviation, antas, into the box marked Journal Name/Code.

The Society also publishes a Bulletin which usually appears twice per year. The scope of the Bulletin includes, but is not necessarily limited to: news and developments in the history of astronomy, meeting reports, articles, obituaries, book reviews, and members' letters. Articles for the Bulletin can be on any aspect of the history of astronomy and are usually up to 2,000 words in length. They normally do not contain significant new research (such research should be published in *The Antiquarian Astronomer*) and are not peer reviewed. Contributions for the Observatory Scrapbook series are particularly welcome; these items consist of a brief description (typically 500 words or fewer) and an illustration of some historical observatory. It is prudent to discuss contributions for the Bulletin, particularly book reviews, with the Editor(s) in advance to avoid duplication. Addresses can be found on the inside back cover of this Journal.

Timely information, particularly about forthcoming events, both SHA and other, is communicated to members via the quarterly e-News, which most members will receive by email.

Mary Watson Whitney and the Vassar College Observatory 1880–1901

Paul A. Haley

Vassar College Observatory (VCO) was initially directed by America's first professional woman astronomer, Maria Mitchell. Her successor, Mary Watson Whitney, in turn nurtured a strong partnership with her student Caroline Ellen Furness. Like their famous predecessor they too devoted decades of their working lives to developing Vassar's international reputation, while educating thousands of young students. In this paper the astronomical work of Mary Whitney is examined across each lustrum (5-year period) for the years 1880–1901. Five perspectives are reviewed: observatories and instruments; observations; curriculum and pedagogy; networking; and publications. Analysis of departmental annual reports from the Archives and Special Collections Library of Vassar College are linked with other primary sources, providing further insights into how the life of Maria Mitchell inspired successive generations of women trained in America.

1. Early years and training

Mary Watson Whitney (Figure 1) was born in Waltham, Massachusetts, on 1847 September 11, the eldest daughter of Samuel Buttrick Whitney (1814–67) and Mary Watson Crehore (1823–93). She had three brothers and two sisters and her father's success in real estate helped pay for the education of the family. After public high school in Waltham, a year's private tuition prepared Mary for enrolment in 1865 September at Vassar Female College in Poughkeepsie, New York state.

During her three-year liberal arts degree there, the Whitney family suffered a double tragedy: first, the death of her older brother Elisha during a shipwreck (1866 May) in the South Seas (Pacific Ocean), and then, a year later, the death of her father in 1867 May. With her mother also in poor health Mary at age 19 became the effective head of the Whitney family, which then consisted of: mother (aged 44), sister Adaline (15), and brothers Charles (12) and Laurence (10). Another sister, Anna, had died in 1852 in infancy.[1]

At Vassar Mary's expertise in mathematics led to scientific training and the encouragement of Maria Mitchell (1818–89), the professor of astronomy and director of the Observatory. In Mitchell's junior class (1866–7) Mary was taught analytical geometry and calculus which led in the Senior class of 1867–8 to a calculation of the Besselian elements for the forthcoming 1869 solar eclipse.

Mary became a leading member of the so-called Hexagon group of six students in Vassar's class of 1868.[2] During her AB degree she became proficient at timing the meridian passage of bright stars, using a

Fig. 1: Mary Watson Whitney in 1865, the year she enrolled at Vassar Female College in Poughkeepsie, New York state. (Vassar College Archives & Special Collections Library)

chronometer with the 3.7-inch f/18 Young transit telescope in the east wing (Figure 2).[3] Unlike the excellent meridian instrument, the 12-inch f/17 Fitz equatorial beneath the main dome had three significant problems: the optical quality of the 12-inch objective (improved by Clark in 1868); difficulty opening and closing the dome shutter (partially improved using a windlass system in 1878); and the mechanical limitations of the Fitz equatorial mounting (replaced by Warner & Swasey in 1886). Maria Mitchell provided a few smaller portable telescopes for her students; in 1869 Mary purchased her own 3.0-inch f/15 Clark refractor on an altazimuth mount (Table 1).

At Vassar she played a full part in college life, becoming president of the math club, a keen croquet and chess player, contributing to student publications, and performing in dramatic productions. A classmate later recalled: 'From the first day of her college life she moved through her appointed orbit as serene and calm and as true to the line as the stars she loved so well.'[4]

Classes in botany and zoology underpinned her keen interest in nature studies. However, mathematics remained her passion and Mitchell presented her with her own annotated copy of *Theoria Motus* by Gauss to continue her studies after graduation.[5] Maria's father, William Mitchell (1791–1869), noted of the class of 1868: 'Cara Glover and Mary Whitney… [both from Waltham] …had in a manner adopted us as step parents, are a great miss to us… Mary Whitney is to be awarded the palm of unrivalled qualities.'[6]

Fig. 2: Mary Whitney observes the meridian transit of Capella with the 3.7-inch Young meridian circle at Vassar College Observatory on 1866 April 3 while Julia Bush holds the chronometer. (Vassar College Archives & Special Collections Library)

1.1. *Studying for a Master's degree*

Mary was keen to further her studies and gain an AM degree.[7] After graduating she returned to Waltham for a time to support her mother. She gained some teaching experience at the nearby Lasell Female Seminary, in Auburndale, Massachusetts.[8] The total solar eclipse of 1869 August 7, observed from Iowa, enabled most of the Hexagon group to reunite with their former teacher at the Burlington Collegiate Institute.[9]

During the initial wet days the graduates determined their exact position from the US Coastal Survey (USCS) base station. By eclipse day conditions had improved and the totality of nearly three minutes was observed with the Sun at high altitude. Mary used her new telescope to describe four flame-coloured protuberances around the Sun's limb together with the irregular outline of the corona. Maria Mitchell was justly proud of her team of observers who had travelled 1,200 miles to participate in the first all-female solar eclipse expedition.

Mitchell encouraged Mary to attend some Harvard lectures of the distinguished mathematician Benjamin Peirce (1809–80) which included a small class in celestial mechanics. Since Harvard was not open to women she attended as his guest, initially meeting him outside the college gate.[10] Mitchell also arranged for Mary to spend a few months at the Dearborn Observatory of the old University of Chicago in autumn 1870 which housed an 18.5-inch f/15 Clark refractor (1862), the largest in America at the time.

Mary's research at Dearborn, with fellow graduate Sarah Glazier, was guided by mathematician Truman Henry Safford (1836–1901), a former observer at Harvard College Observatory (HCO) in Cambridge, Massachusetts.[11] The writer has previously suggested that Safford helped develop the innovative heliostat apparatus that Mitchell funded (1871) for her students to photograph sunspot activity during solar cycle 11.[12] Mary brought the design to her mentor's attention and used the apparatus extensively at Vassar during the 1880s.

Mary's involvement with Vassar also included supporting her younger sister Adaline who enrolled in 1869 fall and graduated with the class of 1873. When Vassar's alumnae association was formed in 1871 June, Mary was elected president and fund-raised for student scholarships and also alumnae representation on the board of trustees.

Mitchell needed to determine the precise location of Vassar College Observatory (VCO). Occultation timings were used for longitude while for latitude a 3¼-inch f/14 zenith telescope was borrowed from USCS and erected in a temporary wooden shed. Mitchell had used it on Nantucket but now preferred to rely on the keen

Table 1						
Instruments used by Mary Watson Whitney from 1865 to 1901						
Year	**Diameter** (inches)	**Maker**	**Mount**	**Focal length** (inches)	**f/ratio**	**Notes**
1865	n/a	Bond	Sidereal clock	n/a	n/a	Observatory clock, $300
1865	n/a	Bond	Drum chronograph	n/a	n/a	Recorded sidereal clock beats for 2 hours
1865	n/a	Bond	Chronometer	n/a	n/a	Portable timepiece, $500
1865	12.0	Fitz	Refractor	198	17	Objective, $1,600
1865	3.7	Young	Meridian instrument	66	18	30-inch transit circle, 30-inch meridian circle, c. $1,800
1869	3.0	Clark	Altazimuth	45	15	Mary Whitney's telescope
1870	18.5	Clark	German equatorial	277	15	Dearborn Observatory, Chicago
1870	6.0	Repsold	Meridian instrument	90	15	Dearborn Observatory, Chicago
1871	3.5	Clark	Equatorial	144	40	Heliostat for 2½-inch solar images. MM funded, c. $200, for students
1872	12.0	Clark	n/a	201	17	Objective refigured, $500
1872	3.2	Troughton & Simms	Altazimuth	46	14	Zenith telescope loaned by USCS for VCO latitude determination.
1874	1.0	Clark	Collimators	n/a	n/a	Two small telescopes on piers to north and south of the meridian instrument
1879	3.0	Clark	Equatorial	45	15	Donated by Mr McDonald, $200
Whitney's first lustrum (1886–91)						
1886	n/a	Warner & Swasey	German equatorial	n/a	n/a	Stronger mounting, powerful driving clock, c. $1,000
1888	2.7	Herbst Pulkovo	Transit	32	12	Harvard College Observatory
1888	4.0	Warner & Swasey	Meridian instrument	40	10	Smith College Observatory
1888	5.0	Clark	German equatorial	75	15	Donated by Cora Harrison
1889	n/a	Fauth & Co.	Meridian instrument			New level, $200
1890	n/a	Brashear	Spectroscope	n/a	n/a	Rowland grating for solar work and glass prisms for stars, $260
Whitney's second lustrum (1891–96)						
1893	1.5	Wanschoff	Universal instrument	n/a	n/a	Student instrument for 'exact measurements', $360
1896	n/a	Repsold	Measuring machine	n/a	n/a	Measurement of star positions on Helsingfors Observatory plates, $700
Whitney's third lustrum (1896–1901)						
1898	n/a	Warner & Swasey	Filar micrometer	n/a	n/a	Electrical illumination, $320
1899	3.0	Clark	Altazimuth	45	15	Donated by Mary Mineah

eyesight of her young graduate.[13] Mary's measurements of latitude effectively guaranteed her AM degree in 1872 June, the first year that Vassar began awarding master's degrees.[14] For a list of Mary Whitney's key astronomical contacts and students mentioned in this paper see Table 2.

1.2. *Studies in Zurich*

Sadly, the Whitney family tragedies continued a year later when, in the same month as Adaline graduated, their youngest brother Thomas drowned two months before his 16th birthday. A letter in 1873 October from Mitchell to Elizabeth Rebecca Coffin (1850–1930) mentioned that 'Sarah Glazier has gone west and Mary Whitney has her place'.[15] However, after ensuring their one surviving brother, Charles, aged 18, was suitably apprenticed as a wood turner and draughtsman, the two sisters and their mother chose to travel to Europe.

Adaline wished to study medicine at the University of Zurich while Mary also pursued her own mathematical and celestial mechanics training at the same university from 1873 to 1876. Caroline Furness later recounted: 'Life in Zurich … proved very fascinating to the Whitney family. Many of their Vassar friends passed through the city on their travels abroad and there were other brilliant women in the medical school from several European countries as well as from America.'[16]

After gaining her medical degree Adaline embarked on a three-year hospital practice in Switzerland while Mary and her mother returned to Waltham. For the next five years (1876–81) Mary taught at Waltham High School, conscious that her qualifications should earn her a more prestigious position but also aware of her family responsibilities. Her interests led to an extensive study of the grasses growing in the Waltham area and, with her mother, collecting specimens until she had identified all the plants and ferns that grew in the neighbourhood.[17]

After six years abroad her sister Adaline returned from Switzerland in 1879 to become resident physician in the New England Hospital in Roxbury, Massachusetts.[18] Mary considered moving west to lecture in Minnesota and sought an endorsement from her mentor.[19] Her gender limited her opportunities for employment in astronomy, as Furness later reflected: 'She could not help feeling resentful … at the prejudice existing against the progress of women'.[20]

In the autumn of 1880 Mitchell fell ill and was absent from Vassar for two months. Mary covered this period at VCO and then, in late January when Maria returned looking very frail, agreed to become her private assistant and companion. Coincidentally, just three months later, in 1881 April, a young Scottish woman disembarked at Boston to begin her astronomical career in Cambridge, Massachusetts: Williamina ('Mina') Paton Fleming (1857–1911). The writer has previously described the life of 'the sixth female assistant at HCO'; the parallel career paths of Mary Whitney and Mina Fleming would underpin many of the achievements of American female astronomers for the next three decades.[21] Mitchell's salary was then c. $1,500 (c. £30k today); Mina Fleming and Mary Whitney both started at c. $600 (c. £12k today).

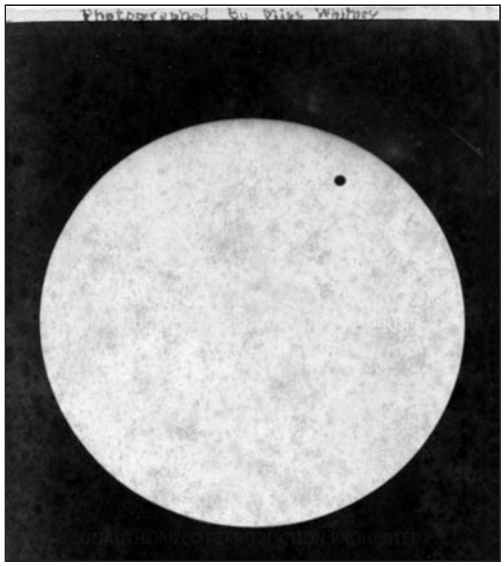

Fig. 3: Transit of Venus of 1882 December 6 photographed by Mary Whitney with the Vassar heliostat installed by Maria Mitchell. (Nantucket Maria Mitchell Association)

1.3. *Whitney's initial role at VCO (1881–6)*

At VCO Mary assisted with the teaching and took over the transit observations for the Vassar time service, which had been extended to the Poughkeepsie post office (1874) and included the midday dropping of a target on a signal pole.[22] Mary maintained accurate time for the locality for the next 15 years.

She accompanied Maria Mitchell on some of her educational outreach work and presented her own paper, 'Scientific Study and Work for Women', at the ninth annual congress of the Association for the Advancement of Women (AAW) in Buffalo (1881 October).[23] Unfortunately, the large Fitz equatorial mounting at VCO had deteriorated, making accurate work with the 12-inch refractor impossible. Another disappointment for Mary was that, throughout this period (1881–87), Vassar College regarded her only as a 'graduate student' rather than a member of staff. Despite these handicaps she completed a significant amount of observational work. Her most impressive project involved four hundred glass plates of sunspot images, taken with the heliostat apparatus, including the second and last transit of Venus of the nineteenth century on 1882 December 6 (Figure 3).[24]

2. Whitney's first five years (1886–91)

On the Tuesday evening of 1888 July 3 Mary Whitney, then aged 40, began timing star transits across the Cambridge meridian at Harvard Observatory – her career as an independent astronomer was at last underway. Over 700 miles to the south-west, in Cincinnati, Ohio, Caroline Ellen Furness (1869–1936), an undergraduate aged

Table 2

Mary Whitney's contacts and students at Vassar College Observatory 1865 to 1901

Class of	Name	Life dates	Notes
	Maria Mitchell	1818–1889	Nantucket 1818–61; Lynn 1861–89; VCO 1865–87. First director of VCO. Retired to Lynn end of 1887
1868	Mary Watson Whitney	1847–1921	Iowa solar eclipse 1869; AM 1872; VCO asst. 1880–87. i/c VCO 88–89; second director VCO 1889–1915
1868	Sarah Mariva Glazier	1846–1919	Iowa solar eclipse 1869; Wellesley Observatory
1868	Julia Electra Bush	1844–1928	Teacher/artist
1868	Achsah Mount Ely	1845–1904	Iowa solar eclipse 1869 with MM; professor of mathematics at Vassar College 1887
1876	Cora Harrison	1852–1888	5-inch Clark at 1878 Denver solar eclipse with MM
Whitney's first lustrum (1886–91)			
	Truman Henry Safford	1836–1901	Dearborn Observatory, Chicago
	Edward Charles Pickering	1846–1919	Harvard College Observatory (HCO)
	Williamina Fleming	1857–1911	Sixth computer at HCO; Curator of Astro Photographs 1899
	Mary Emma Byrd	1849–1934	Smith College
	Charles Augustus Young	1834–1908	Princeton College
	Benjamin Apthorp Gould	1824–1896	Editor, *The Astronomical Journal*
	James Monroe Taylor	1848–1916	Fourth president of Vassar College (1886–1914)
1887	Margaretta Palmer	1862–1924	VCO assistant 1887; VC Latin instructor 88–89; Yale Observatory 89–24; PhD Yale 1894
1887	Antonia Caetana Maury	1866–1952	Teacher; HCO 1888–1933 (part time); stellar spectra
1889	Helen Honor Tunnicliff	1870–1933	Lawyer/historian
1890	Hannah Fancher Mace	1870–1958	*Nautical Almanac* computer to 1940
1891	Rose Marion Kavana	1867–1941	Teacher/author
1891	Caroline Ellen Furness	1869–1936	VCO assistant 1894–98; PhD Columbia 1900; third director VCO 1915–36
1891	Julia Maria Ober	1866–1944	VCO weather records
Whitney's second lustrum (1891–96)			
	Garrett Putnam Serviss	1851–1929	Astronomy popularizer; 'Urania' stage show
	Mary Swain Wagner	1869–1937	VCO assistant 1892–93; HCO 1893

18, was reflecting on her freshman year at Vassar College. Her four-year scholarship might lead to a teaching career, as her father desired, but having briefly met the famous Maria Mitchell outside VCO she had begun to wonder if studying astronomy might also be worthwhile. Within a few months Caroline had her answer: sophomore lectures delivered by Professor Whitney ignited her passion for the subject and initiated their partnership which would continue for over two decades.

2.1. *Transition time (1886–87)*

In 1886 August Warner & Swasey completed installation of their German equatorial mounting at VCO in time for the new academic year. Mitchell had campaigned for two decades to obtain a stronger mount with a powerful driving clock; the 12-inch refractor now also had electric illumination for the wires of the micrometer eyepiece. During the year the telescope was used for timing occultations and micrometric measures of the positions of

Table 2 (continued)			
Mary Whitney's contacts and students at Vassar College Observatory 1865 to 1901			
Class of	**Name**	**Life dates**	**Notes**
	Henry Martyn Parkhurst	1825–1908	Amateur astronomer – variable stars
	Percival Lowell	1855–1916	Flagstaff Observatory, Arizona
1895	Lillian Clark Weaver	1873–1957	AM 1896; teaching to 1936, in US and Munich
1896	Lillian A McAllester	1874–1959	Teacher
1896	Mary Edith Tarbox	1873–1963	Columbia computer 1898–1902; teacher
Whitney's third lustrum (1896–1901)			
	George Ellery Hale	1868–1938	Kenwood Observatory 1890; Yerkes Observatory 1897
	Johann Georg Hagen	1847–1930	Georgetown College Observatory
	Susan Jane Cunningham	1842–1921	Swarthmore College Observatory
1897	Annie Lyndesay Wilkinson	1875–1961	AM 1898; teaching
	Harold Jacoby	1865–1932	Columbia University Observatory
	Anders Donner	1854–1938	Helsingfors Observatory
	Florence Ellen Harpham	1860–1925	AB 1888 Carleton; Smith College; Columbia computer
	Alice Everett	1865–1949	MA 1889 Girton; RGO 1890–89; Potsdam computer; VCO assistant 1898–99
	Edwin Brant Frost	1866–1935	Yerkes; editor, *The Astronomical Journal*
	Ernest Fox Nichols	1869–1924	Dartmouth College physicist
1898	Mabel Reed Benway	1877–??	Graduate – variables; teacher
1898	Ethel May Serviss	1874–1954	Graduate – orbits; niece of Garrett Putnam Serviss
1899	Helen Lee Davis	??–1930	Columbia computer 1899–1908
	Catherine Wolfe Bruce	1816–1900	American philanthropist and amateur astronomer
1899	Blanche Martin	1879–1958	Graduate; teacher
1899	Eda C Bowman	1877–1965	AM 1900; teacher
1900	Louise Wheaton Ware	1875–1953	VCO computer; teacher; Yerkes 1903–5; Mount Wilson Solar Observatory 1906–42
1900	Alice Estep Davis	1879–1923	AM 1901 (first major in astrophysics); teacher

This table lists Mary Whitney's astronomical contacts and students during her Vassar College years from 1865 to 1901, the period covered by this paper. For Vassar students the 'class of' column gives their graduating year; the third column their years of birth and death, where known; and the notes column their astronomical contributions and later careers.

planetary satellites. Mary again patiently waited for an opportunity, her loyalty to her increasingly frail mentor pitted against her growing need for some independent work. Maria Mitchell's salary had now increased to \$2,000 (£40k today), enabling her to pay Mary c. \$800 (c. £16k today). The increase in salary was welcome but significantly less than the \$1,000 (£20k today) salary that Mina Fleming began earning at Harvard Observatory at the end of 1886.

After five years' work both ladies were succeeding in their chosen career paths, but at Cambridge Mina Fleming now had five roles: recruiting, training, and monitoring a team of women computers; operating as Pickering's unofficial secretary, editing papers for publication, and managing workshops; beginning to make her own astronomical discoveries, of Wolf–Rayet stars; responsible for the storage and retrieval system of thousands of glass plates; and, most importantly, leading the

Fig. 4: A class of unidentified students using the 3.7-inch f/18 Young meridian telescope at Vassar College Observatory. This view is thought to date from the 1880s. Maria Mitchell began a Vassar time service in 1865 and extended it to the Poughkeepsie post office in 1874 where a target on a signal pole was dropped at midday. Mary Whitney (seated left) continued this work for fifteen years (1881–96). The meridian telescope was used by each Senior class in the first half of their final year. (Vassar College Archives & Special Collections Library)

day-to-day work of classifying stellar spectra for the Henry Draper Memorial Catalogue.[25]

At Vassar, one senior student, Margaretta Palmer (1862–1924), had shown a keen interest in astrometry and also related well to Mitchell. By 1887 June Mary had resolved to take a sabbatical break at Harvard College Observatory (HCO) and Margaretta agreed to assist Mitchell after her graduation.[26]

2.2. *Harvard, Vassar, and Smith College (1887–88)*

HCO's director, Edward Charles Pickering (1846–1919), assigned Mary to the Russian transit instrument under the direction of Professor Arthur Searle (1837–1920).[27] Pickering had just secured two new bequests, for developing a mountain peak photographic observatory and for HCO expenses. These were additional to instruments and funding from Mary Anna Palmer Draper (1839–1914) who had established a Memorial Fund the previous year to honour her husband, the pioneering astrophotographer Henry Draper (1837–82).

At Cambridge Mary marvelled at the ambitions of Pickering in charting the heavens across both hemispheres with an army of instruments. A shrewd judgement enabled him to avoid entrapment within the international Carte du Ciel project, whose Astrophotography Congress in Paris (1887 April) resulted in so many observatories being engulfed in work for decades.[28]

Additionally, Mary noted how skilfully Mina Fleming had positioned herself at HCO: responsible for the Draper Memorial Catalogue; overseeing HCO publications; recruiting a loyal team of female computers; maintaining their etiquette, efficiency, and discipline; designing an efficient storage and retrieval system for the glass plate library; and classifying stellar spectra. Given that Mina was ten years her junior and had no academic background, Mary would have been impressed and motivated by her success.[29]

Sensibly Mary selected a project to utilize her own experience with meridian instruments and her mathematical competence. The challenge involved close collaboration with another female astronomer, working in Northampton, Massachusetts. Smith College was a private liberal arts college for women founded by Sophia Smith (1796–1870) which had opened in 1875 with fourteen students and six faculty.

Between 1878 and 1887 professors from nearby Amherst College delivered an astronomy class for three hours a week. A single-storey brick observatory with a 21-ft steel dome was completed in 1886; an 11-inch f/15 Clark telescope was mounted by Warner & Swasey, and a 4-inch f/10 meridian circle was installed the following year.

The first full-time astronomy teacher at Smith College was Mary Emma Byrd (1849–1934), whose career had already included a year at HCO in 1882. As the incoming director of a new observatory her first task was to accurately determine its geographical location.[30] The two astronomers agreed their plan of action, but a delay of several months was necessary after Mary received an urgent Vassar recall during the Christmas vacation of 1887 with appeals from both Mitchell and president James Monroe Taylor (1848–1916).[31]

Mary skilfully negotiated a salary increase to c. $1,200 (c. £24k today), with full staff recognition, before accepting her appointment. She arrived back at Vassar in 1888 January to familiar surroundings, having already spent over a decade of her life there. Mitchell remained in Lynn under the care of her sister's family, her planned retirement now an impossibility. Once again Mary needed to be patient, but at long last she now had sole use of a powerful telescope.

As she familiarized herself with the fully restored 12-inch equatorial she renewed her liaison with Professor Safford, spending time at Williamstown with her mother on their way to and from Boston to seek his advice on how best to use her instruments.[32] Her HCO experience had broadened her networks so she also now contacted Charles Augustus Young (1834–1908) at Princeton College and Benjamin Apthorp Gould (1824–96), editor of *The Astronomical Journal*.

2.3. *Collaboration with Mary Byrd*

A month after her return the annual winter reunion of Vassar alumnae took place in New York City on 1888 February 4 with two hundred attending. Mitchell sent her apologies from Lynn: 'An attempt to grow young at seventy was not often successful…I long for rest after a half century of labor'.[33] Vassar trustees extended Mitchell's full professorship until 1888 June before finally accepting her retirement decision. Ever optimistic they offered her a home in the college and free use of the observatory, which she graciously declined.[34]

The winter of 1887–88 proved severe with icy blizzards continuing into March. Little observing was practical at VCO, where Mary now had a full teaching load, so instead she lectured on the work of the Cambridge Observatory (February 11) and the work and life of Professor Maria Mitchell (April 9, Brooklyn women's club).[35] Between these two presentations Mary anonymously penned a paper on bird songs for the *Vassar Miscellany* entitled 'The Birds of Vassar' and organized a few nature rambles around the campus grounds.[36] She encouraged her students to develop observational skills in complementary pastimes, explaining that since a trained ear could learn to identify different bird calls it could equally become proficient at the hand-eye-ear coordination needed for using a drum chronograph.

An early recruit to one of her Sunday morning ornithology workshops, and probably where they first met, was freshman student Caroline Furness, who also had a passion for nature. Writing to her sister, Mary Baker Furness (1867–1930), she explained: 'I have been much interested in Evolution…re-reading the *Origin of Species* and my old friend *Descent of Man*.'[37] College events continued to June when the class of 1888 graduated; class president Grace Rideout (1866–1954) organized an engraving of Mitchell for alumnae to commemorate her time at Vassar.[38]

Mary next looked forward to her summer collaboration with Mary Byrd. The aim of their project was to determine the exact difference in longitude between the observatories of Smith College and Harvard College. The telegraph was used in conjunction with meridian instruments at both sites. The observations occupied ten nights. On 1888 July 3 and 6, and August 2, Mary Whitney observed at Cambridge, and Mary Byrd at Northampton. For the nights of July 24, 25, and 29 they exchanged stations. Differences in personal equation were measured at Cambridge on July 13 and 14 and at Northampton on July 30 and August 1.[39]

Transit times of stars from 2nd to 4th magnitude were observed with power ×70. The Russian transit (1870) at Cambridge was of a 'broken' design with a 2.7-inch f/12 objective and a reflecting prism in the middle of the axes.[40] The reduction of the measurements was eventually deemed a suitable task for undergraduates at each college, but a lack of funds delayed publication until 1893 (Section 3.2).

During her summer project Mary met an undergraduate of the Massachusetts Institute of Technology who was also volunteering at HCO. George Ellery Hale (1868–1938) was just beginning his research investigating the solar spectrum and two years later he would set up the Kenwood Solar Observatory in Chicago. She and Hale maintained their friendship for over two decades, during which time he made several lecture visits to VCO and Mary reciprocated by training many computers for both the Yerkes and Mt Wilson observatories.[41]

2.4. *Normal business resumes (1888–89)*

Vassar opened in 1888 September without a preparatory department for the first time. President Taylor was keen to improve Vassar's reputation for academic excellence. His 28-year tenure as the fourth Vassar president, from 1886 to 1914, saw the student body treble in size. Among the beneficiaries of his vision was sophomore student Caroline Furness who found the eight lectures delivered by Mary Whitney inspiring. As she wrote to her sister Mary that autumn: 'I find everything easy this year so far – I like the mathematics course and find that Astronomy is just exactly what I want; everything in it is just as easy and clear to me as anything I ever studied.' And in the spring, 'I will drop Latin next year [and] devote myself entirely to Mathematics and Science, and when I develop into a second Mary Somerville or Maria Mitchell, then you will be proud of me…I am going to take a second degree, probably a Ph.D. as far as I can.'[42]

Mitchell left some provision for the future of VCO in her will.[43] Mary suggested in her first annual report of 1889 May: 'A part of the income of the Maria Mitchell [endowment] fund may be devolved to the repair of the transit instrument. In its present condition it serves only for time purposes.' She estimated $200 (c.£4k today) would cover costs.[44] She also evaluated: 'The remounting of the Equatorial, as tested by observations for constants, has been found to be good. Only one readjustment has been found desirable.'[45]

A valuable new acquisition involved a bequest from Cora Harrison of a five-inch portable telescope: 'The glass is an excellent one, of Clark manufacture, and has been of much service in the practical instructions of the department.'[46] Mary would enjoy using the instrument for the next two decades.

Annual dome parties, a Vassar tradition, were reinstated, including some 'in-house' poetry. Mary used the occultation of Jupiter by the Moon on 1889 March 23 to compose her contribution:

O Jupiter, O Jupiter,
  Where have you been all winter?
We've seen old Saturn with his whirls.
We've followed round his boys and girls,
  But Jupiter, O Jupiter,
Where have you been all winter?

Red Mars could meet our searching gaze
  And did not seem to fear us.
Venus has graced our evening sky
And twinkled with her brilliant eye.
  E'en Mercury has stayed o'er night
Before he hied him out of sight.

But you o'er Sunrise Hill have peeped,
  While yet we were asleeping,
And once when we got up too soon
You hid yourself behind the Moon.
  O Jupiter, O Jupiter,
Why need you be so bashful.[47]

Mary Whitney initially continued the tradition of two astronomy groups: 'The Junior class numbered thirteen in the first semester, and fourteen the second, meeting four hours per week during the year. Godfray's treatise, including all the branches of elemental practical Astronomy, has been the basis of instruction…supplemented by Salmon on 'Conic Sections' & descriptive astronomy. The Senior class numbered eight in the first semester and met three hours per week, seven in the second, for two hours per week [with lectures on] Time by transit observations, Transits of Moon & Planets, occultations of stars, Least Squares, Introduction to Gravitational Astronomy and Comets' Orbit' (Figure 4).[48]

During this academic year Mary was particularly impressed by Junior student Hannah Fancher Mace (1870–1958), with whom she took ten sunspot images

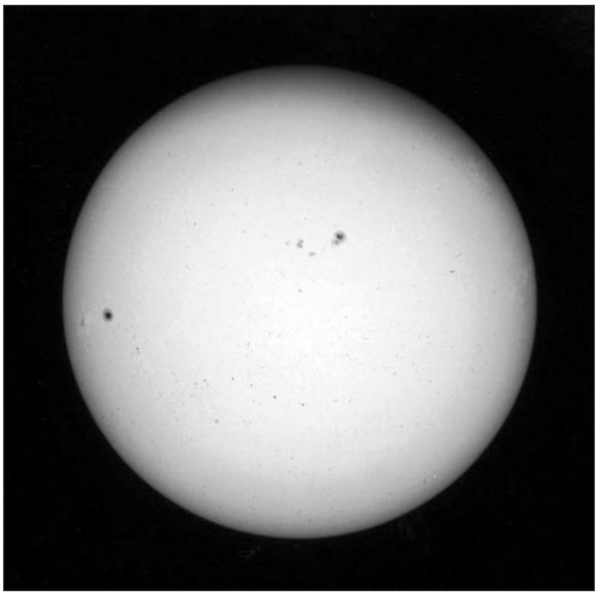

Fig. 5: Over seven hundred glass plates containing solar images taken between 1871 and 1890 using the weight-driven heliostat were discovered at VCO in 1995. Mary Whitney took four hundred of these sunspot photographs, working with a variety of Vassar students. This image was one of the last taken at VCO, on 1889 June 8, just three weeks before the death of Maria Mitchell. (Vassar College Archives & Special Collections Library)

with the Vassar heliostat (Figure 5). Like Mary, Hannah was a mathematical astronomer and was keen to learn how Mitchell had worked for the *Nautical Almanac* for two decades.[49]

A fortnight after the college year ended, on 1889 June 28, Maria Mitchell died at Lynn. Mary was formally confirmed as professor of astronomy and director of the Observatory for the new academic year, on a salary of c.$1,500 (c.£30k today).

2.5. *Students living at VCO (1889–90)*

President Taylor and Mary Whitney attended Maria Mitchell's funeral on Nantucket at the end of June. In 1889 October Mary published a tribute to her in the *Vassar Miscellany*: 'For twenty-three years she was identified with the life and work of the college … she had struggled against odds in the acquirement of her own education … she stood firm for a high level of education in the early struggle of the college … she drew sharp distinctions between the essential and the unessential … she was as brave as she was true.'[50]

On November 17 an evening memorial service was held at Vassar, with the president noting of her character: 'Independence and absolute truth. These were the strong traits that made her a queen among women… depths of affection in that great, strong soul of hers.'[51] A bequest in her will revealed another example of her kindness: 'By the will of Prof. Maria Mitchell, the college receives a legacy of one thousand dollars for the aid of needy students…this bequest was made…in the name of her father.'[52] Mary completed her tributes to her mentor at the end of the year with a paper in the *Sidereal Messenger*, a publication issued by Carleton College Observatory.[53]

As the 25th academic year at Vassar began Mary revived another VCO tradition, introduced originally by Maria Mitchell, and invited two Junior students to live at the Observatory. These were Caroline Furness and Rose Marion Kavana (1867–1941).[54] Mary delegated them responsibility for helping process her transit observations from Cambridge and Northampton.' [55] Another tradition, the photography of sunspots, came to a conclusion as the solar cycle reached its minimum. By 1890 the heliostat technique had involved 60 undergraduates and produced 700 glass plates.

The new year brought a special visitor: Professor Charles Young from Princeton College gave two lectures on the Sun in mid-January and also valuable advice on purchasing a spectroscope. As Caroline described it in the *Vassar Miscellany*: 'His charming manner and happy faculty of putting the subject in the most interesting way made these lectures thoroughly enjoyable … we were introduced to the spectroscope as 'the hero of the evening' … a discussion of the form and structure of prominences in their principal classes of quiescent and eruptive, with several [stereopticon] illustrations, bought to a close two of the most delightful lectures ever listened to in Vassar.' [56]

In her annual report of 1890 May Mary noted that while evenings had been unusually cloudy 'a daily record of sun-spots [had been kept] by Miss Furness of the Junior class; comet of 1889 – 6 evenings – the positions of this comet, requiring quite extensive reductions, have been determined by Miss Furness; double stars – 25 evenings; Neptune – 5 evenings; comet of 1990 – 2 evenings.' She continued: 'The meteorological apparatus has been replaced by maximum & minimum thermometers and a new rain-gauge.' Monthly returns for temperature and precipitation began for both the New England and New York Meteorological Societies by Julia Maria Ober (1866–1944) of the Junior class.[57]

Smaller classes (13 juniors and 8 seniors) used a new textbook: 'Young's *General Astronomy* has been substituted for Godfray's, as it better embodies the later progress of the science … the [senior] class has predicted a star's occultation for Vassar College & has completed the full process for computing the orbit of a comet.' [58]

2.6. *Family pressures (1890–91)*

When Caroline Furness returned to Vassar again in 1890 September for her senior year, she knew her academic life was under review at home. Several letters to her father argued the case for her further education in a remarkably modern tone: 'I only want to prepare myself for the highest place – just as any young man might … I want to prepare myself to live a useful and happy life without marriage, and then, if the right one comes along, well and good, I shall take him, but I shall not be obliged to take a man just for the sake of a home … if I were your son instead of your daughter, you would fully approve of my ambition.' [59]

She was again invited to live at VCO and as there were only two in the Senior class she shared the accommodation with Julia Ober; in the Junior class there were twenty students. Mary Whitney was also facing family pressures as her mother's health continued to decline.

Significant improvements in VCO accessory instruments were achieved during the fall: 'Additions of new level instrument and diagonal eyepiece for the transit circle … improvements in the mounting of the transit circle made last year have added greatly to the usefulness of that instrument.' [60] Astronomical visitors to the vine-clad observatory included Professor Safford and his wife Elizabeth Marshall Bradbury Safford (1834-1919), who spent several days at Vassar while he looked over the instruments.[61]

Following Young's advice Mary received in 1890 December a spectroscope made by John Alfred Brashear (1840–1920) of Pittsburgh, Pennsylvania [$260, c. £4.2k today], 'excellent for … the instruction of students. It is provided with a diffraction plate, made by Professor Rowland of Johns Hopkins University, for the study of the sun's spectrum, and with a prism for the study of star spectra. The means for measuring the position of lines is conveniently planned, and a comparison prism is attached.' Other useful items included a ring micrometer for the portable telescopes and a dynamometer for measuring magnifying power.[62]

Funding for these additions came from the Maria Mitchell Endowment Fund, whose aim was to make VCO self-supporting. The Vassar Alumnae Department published a financial summary (1890 November) which revealed that $26,302 had been raised towards the $50k target, including Maria's initial $5k donation and $18k from present and past students; $1,132 [c. £22k today] of that had already been allocated for 'repairs of the Observatory'.[63] During 1891 Mary and Vassar professor of mathematics Achsah Mount Ely (1846–1904) were among the first seven women to join the New York Mathematical Society, later to become the American Mathematical Society.[64]

Observations during the year included a daily record of sunspots; solar prominences; a few double stars; while comet 1890a (C/1890 F1 Brooks) was followed for twelve evenings.[65] Arrival of the Brashear spectroscope enabled Mary to promote 'astronomical physics' for the first time; Vassar would soon be one of the first American colleges to develop astrophysics.

The first beneficiary of this approach was Caroline Furness, who took on the role of assistant during the year. She became proficient in the use of the transit circle and a competent user of the accessory equipment used on the equatorial. She studied Chauvenet's *Theoretical Astronomy* and computed the orbit of Comet 1890a. Notes regarding sunspots and double stars were sent to the *Sidereal Messenger* and the places of Comet 1890a were published in *The Astronomical Journal*.[66]

In line with president Taylor's drive for higher academic standards, in the spring of 1891 faculty heads were asked to nominate students for the honour society Phi Beta Kappa (φβκ). President Taylor noted: 'Though numbering but thirty-five members, [the class of] '91 has eight 'Honor Girls'… [including] … Miss Furness, Miss Kavana.'[67] Caroline Furness was the first female astronomer to receive the award, marked by the presentation of a gold key, although her modesty prevented her announcing it widely.[68] Caroline completed her degree with a Commencement week paper entitled 'Lockyer's Meteoric Hypothesis', before conforming to her father's insistence that she enter a high school teaching career.[69]

3. Whitney's second five-year period (1891–96)

During her second lustrum Mary Whitney provided palliative care at VCO for both her mother and sister, recruited two private assistants, developed new astrophysical courses, began teaching graduate students, founded a Wake Robin club, and agreed an exciting collaboration between VCO and Columbia University Observatory.

3.1. *Vassar numbers begin to rise (1891–92)*

President Taylor welcomed the new collegiate year with its record intake of 172 freshmen, as they were called. The increasing intake boosted his plans to expand the Vassar curriculum and faculties were invited to research potential new courses for their departments. Mary Whitney taught classes of 29 juniors and five seniors and anticipated her numbers would increase further.

She continued to improve the accessory instruments: a direct-vision spectroscope, a new eyepiece for the equatorial telescope for the study of sunspots, and an anemometer with self-recording apparatus to secure daily records of wind velocity in that section of the Hudson valley.[70] She adeptly used the 'observatory repair fund' to update VCO resources and additionally requested $360 (c.£7.2k today) for a 'Universal Instrument' for her students (Section 3.3).

Mary remained uncertain which observational projects to undertake. Following her predecessor's example she began with planetary studies, especially Jupiter and Saturn, together with a continuous series of observations of Nova Aurigae and Comet *a*1892.[71] Nova Aurigae (now known as T Aurigae) had been discovered on 1892 January 31 by an Edinburgh amateur, Thomas David Anderson (1853–1932). It was subsequently detected on twelve HCO plates by Mina Fleming, for the period December 10 to January 20, appearing brightest at magnitude 4.4 on the former date.[72]

Mary reported: 'A series of comparisons in magnitude between Nova Aurigae and neighbouring stars was carried on by myself and my students during the interval from Feb. 9th to April 6th.'[73] She followed the nova over six weeks, using initially an opera glass, then her 3-inch refractor, and finally the 12-inch equatorial, as the magnitude changed from 5.3 (February 9) to 9.5 (March 26), after which moonlight prevented further work. She enjoyed the challenge and wondered if the study of variable stars might not be a worthwhile pursuit at VCO.

During this period Mary undertook an unusual expedition involving a 'trip to the moon' on 1892 March 19. She was invited to take a group of students to the Carnegie Music Hall, New York City, by astronomy popularizer Garrett Putnam Serviss (1851–1929). Three years before the first motion picture would be screened by the Lumière brothers in Paris the audience watched a live stage show entitled 'Urania' which had been imported from Berlin. Highlights included a total solar eclipse, with a golden corona and fiery prominences; views of the lunar surface from five thousand miles, zooming in to just three miles to show Aristarchus, Herodotus, and Copernicus; a lunar sunrise; and views of the Earth from space – all for a $1 ticket. The scientific lecture employed state-of-the-art special effects technology including optical lanterns, eight hundred and fifty incandescent lamps, screens, reflectors, and planetary models.[74]

What of Caroline Furness during this time? After graduation she took up a teaching post sixty miles north-east of Vassar. West Winsted High School was located in a suburb of Winchester, Connecticut. She was one of five instructors and responsible for teaching mathematics to a hundred secondary students.[75] It served her well for a probationary year but provided no opportunities to further her own academic ambitions.

Caroline resolved to return to her home state of Ohio and for the next two years taught at the Central High School, Columbus. Close proximity to the Ohio State University enabled her to pursue some graduate studies in mathematics, but although the situation pleased her father it did not excite Caroline; she tracked events at Vassar from afar, noting the changing family circumstances that were about to befall her mentor.

3.2. *A family emergency (1892–93)*

Byrd and Whitney's paper on *The Longitude of Smith College Observatory* (Section 2.3) appeared in the Harvard Annals in 1893.[76] The 28-page report concluded: 'The difference in longitude between Cambridge and Northampton is, 6m 2s.063 ± 0s.015. The meridian circle of Smith College Observatory is, therefore, in longitude, 4h 50m 33s.096 ± 0s.044 west of Greenwich.'[77]

To have calculated both the accurate longitude and given its uncertainty to three decimal places was a considerable achievement for both astronomers; publication by Professor Pickering gave further endorsement. Many years later Furness reflected on the significance of this moment: '[Mary] was restive after her many years of unproductiveness… she felt her responsibility to the science of astronomy but more than that she felt her obligation as a woman. It was said that while women might be able to acquire a college education… they were not

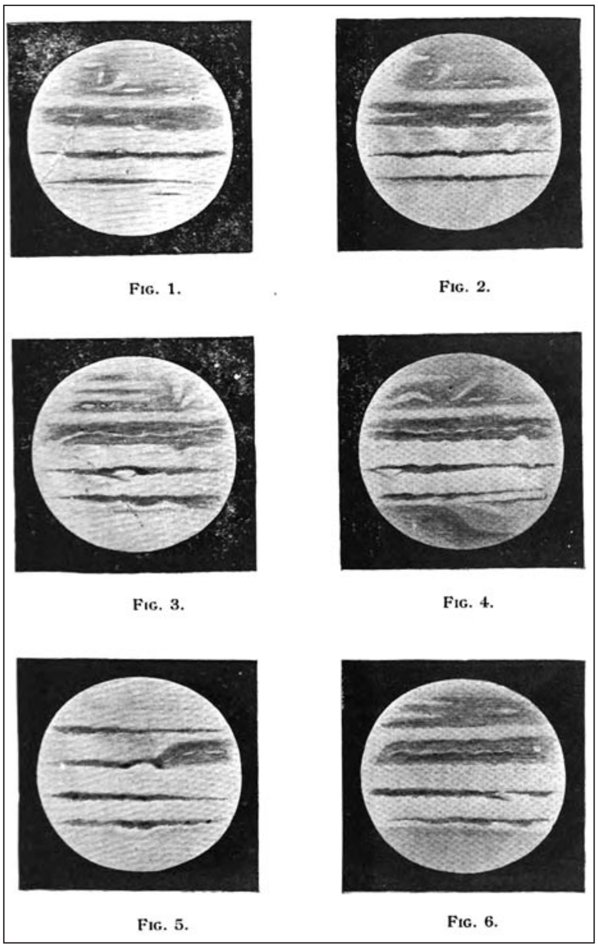

Fig. 6: A series of drawings of Jupiter was made in 1892 October and November by Mary Whitney's assistant Mary Swain Wagner through the 12-inch Vassar equatorial (from ref. 79).

equal to carrying on sustained scientific researches…she felt that her position at Vassar was a distinct challenge to her… at first she worked falteringly, hardly daring to dignify her results by such a name as research and dreading to send away an article for fear it might be faulty, but she received steady encouragement from her astronomical friends.' [78]

During 1892–93 Mary had less time for independent work and employed a private assistant, Mary Swain Wagner (1869–1937), who made drawings of the planet Jupiter (Figure 6). 'We have secured better views of Jupiter than I have ever before seen', commented Whitney.[79] Miss Wagner also reduced comet observations and prepared a series of short papers for publication in *The Astronomical Journal*.[80]

Events within the Whitney family then took precedence with Mary's sister Adaline retiring from her Boston medical practice in 1893 with a serious illness. As their mother was also poorly a decision was taken for both women to move into rooms at VCO. Mary took two months leave of absence in 1893 May and June and no annual report was submitted. During her absence completion of the $50,000 [c. £1m today] Maria Mitchell Endowment Fund was announced.[81]

3.3. *Comets and planets (1893–94)*

With her mother and sister settled in at VCO Mary took stock of the changes underway at the College. There were now 460 students enrolled. The overflow was being temporarily accommodated in the Windsor Hotel, Poughkeepsie, while the new residence hall, Strong House (1894) with its one hundred dormitories, was being completed. At the front of Main the Thompson Annexe, popularly known as 'Uncle Fred's Nose' after its benefactor, had been built as a library and study centre.[82] Mary was teaching three classes, with 24 Juniors, four Seniors, and seven students taking her new course. 'Solar Physics' was an experimental option operating for two hours per week, with each student receiving supervised use of the Brashear spectroscope on the Equatorial throughout the year (Figure 7).[83]

Another new departure involved the arrival in 1893 September of the so-called Universal Instrument, a small table-top theodolite used for latitude measurements, made by Wanschaff of Berlin: 'A very fine piece of apparatus, easily handled and affording a simple and commodious means of practice in exact measurement.' [84] Between 1892 April and 1893 February the Senior class made observations of comets 1892a (Swift), 1892f, 1892g (Brooks), and 1892 III (Holmes) as well as the features of Mars, Jupiter, and Saturn.[85]

On 1893 December 31 Mary's mother died, aged 70, an event that led to a momentous decision. Mary persuaded Caroline Furness to end her high-school teaching work and return to Vassar. As Caroline later recounted: 'She decided to secure [an assistant] out of her own means … sixteen years we worked together with wonderful harmony of purpose and a permanent exclusion of outside interests.' [86]

At the end of the academic year (1894 June) Mary summarized VCO instruments in a short paper in the *Publications of the Astronomical Society of the Pacific*; this proved a good strategy as it resulted in more visits to VCO by American astronomers.[87]

3.4. *A partnership renewed (1894–95)*

Caroline Furness, by then aged 25, was excited to be returning to Vassar. To help prepare she visited her local observatory in Cincinnati where she spent a few evenings with the director, Jermain Gildersleeve Porter (1852–1933), 'always a generous friend [who later] furnished us many times with positions of comparison stars until the Gesellschaft zones were all finally issued.' [88]

Although not yet on the college staff Caroline received a warm welcome, which would continue for the next four decades. Mary outlined their plans: 'To facilitate our observations [of comets and minor planets] a new filar micrometer was ordered from Warner and Swasey to replace the old one which dated from 1865.' [89] Junior class observations continued unchanged with similar numbers, but for the first time the Senior class began observing variable stars.

Mary and Caroline visited Henry Martyn Parkhurst

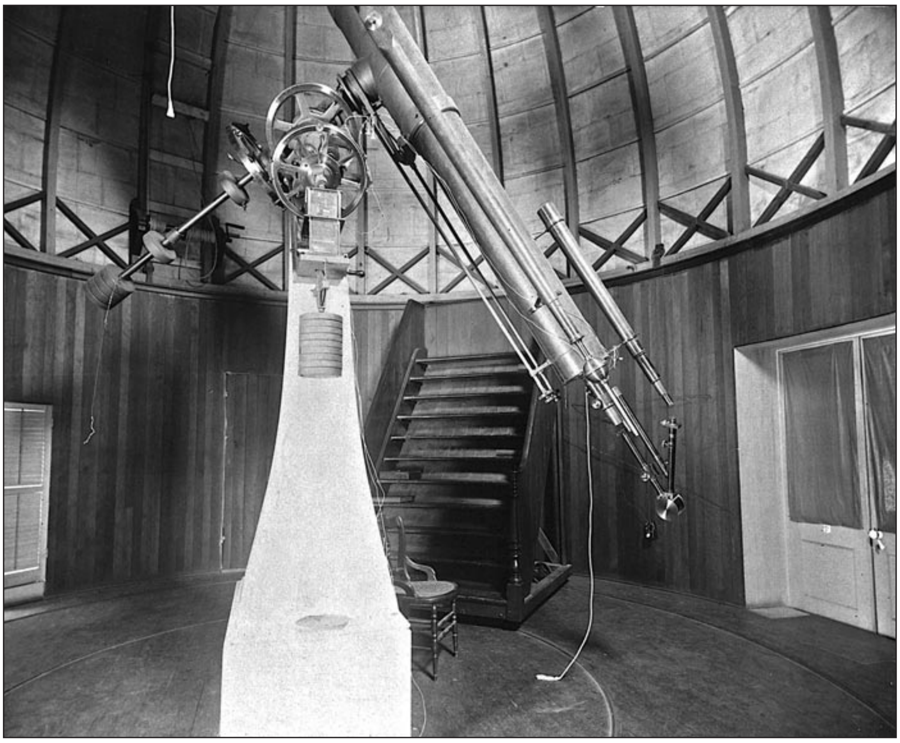

Fig. 7: The 12-inch equatorial at Vassar College Observatory was fitted with a Brashear spectroscope in 1890 (lower right). This specialized instrument facilitated stellar, solar, and laboratory spectral work and heralded the arrival of new astrophysics courses at Vassar College. A Rowland grating with 14,400 lines per inch could be used or there was a choice of three glass prisms. Note also the windlass mechanism for opening/closing the shutter (visible behind the declination axis counterweight) which caused problems until it was improved five years later (1895). (Vassar College Archives & Special Collections Library)

(1825–1908) of Brooklyn. 'Variable stars were his avocation … his drawings and figures were neatness itself … but the aids to identification were so inadequate at that time.' [90] Despite an extremely cold winter and the uncertainty over magnitudes of comparison stars the two astronomers practised using the 12-inch equatorial to observe variable stars passing through their minimum brightness. They persevered with the old filar micrometer, making 26 measurements of the positions of four minor planets.[91] With students they observed the transit of Mercury on 1894 November 10 and the total eclipse of the Moon on 1895 March 10.

The recurring problem of opening and closing the dome required an appeal (1895 May) for help: 'A widened door would add much to the success and ease of our work. It would improve the quality of the air in the dome and would make us more independent of College service … the watchman can come to close dome at 10, 11 & 12.30 … if our series of observations is completed at 11.30 there is nothing for us to do but to sit up till 12.30 for the closing of the dome. We can open the dome and frequently do it, but for closing some sort of platform is needed to give us the necessary purchase upon the windlass.' [92]

In a second request Mary suggested a small alteration to the rear of VCO to improve the accommodation space for her graduate assistant, which was duly granted.

Visiting astronomers at VCO were always welcomed. 'In 1895, Percival Lowell lectured on Mars, winning all the young hearts in his audience by his gracious and debonair manner… not long after came Mr George E Hale, a new light in the astronomical world from the Kenwood Observatory.' [93] Hale, who Mary had first met at Harvard in the summer of 1888 (Section 2.3), would become an invaluable ally in their future work.

In the spring of 1895 President Taylor announced two exciting initiatives: a broadened curriculum and graduate scholarships, both of which would impact favourably on VCO work. In the spring Mary founded a Wake Robin club, encouraging students to study the birds of Dutchess County, New York; later activities would include an annual pilgrimage to the home of the naturalist John Burroughs (1837–1921), near West Park, New York.[94] Burroughs became a frequent visitor to Vassar, serving as an advisor to the club until his death.

During 1894 Vassar graduate Hannah Mace was appointed to the Nautical Almanac Office in Washington. She became their fourth woman computer; Maria Mitchell had been the first. Two years later she married fellow computer Henry Benjamin Hedrick (1865–1936) with whom she had three children. Mitchell would have been impressed that Hannah continued her NAO work until her retirement in 1940.[95]

On the 30th anniversary of Founder's Day at Vassar College, 1895 April 28, Mary Whitney gave a personal appraisal of the first professor of astronomy:

> Maria Mitchell, the astronomer, did great service to the Vassar College of the initial years through her widespread reputation. To many people for whom Vassar would have been only a name, another girl's school, it became known as the place where Maria Mitchell lived. Maria Mitchell, the teacher, was an abiding force within our walls; but her greatest power lay outside of both reputation and profession. It lay in the unique quality of her character; it lay in her unparalleled combination of simplicity and strength … Her devotion to Vassar

College was second only to her devotion to the general progress of woman in all lines of improvement, in professions, in occupations of all kinds … 'Be yourself and be of some value in your world!' That was her message.' [96]

3.5. *A new curriculum (1895–96)*
In the summer of 1895 Caroline Furness attended a summer school at the University of Chicago. On returning to Vassar she was appointed an instructor in mathematics in addition to assisting Mary in the Observatory. On September 3 Caroline observed a total eclipse of the Moon with the 12-inch equatorial and timed a series of occultations before and during totality.[97,98]

The observation benefitted from the new dome opening which, she noted with relief, 'has worked most successfully … and has so much reduced the burden of our evening work.' [99] Another bonus was the ending of the need for the Observatory to supply College time.

At the beginning of the 1895–6 academic year Mary announced a new investigative area for VCO: 'Professor Jacoby of Columbia University Observatory has asked our observatory to cooperate with Columbia in a scheme of photographic investigation … a measuring machine is needed costing $700 … it will form an excellent basis for graduate work … through the generous gift of Mr Frederick Thompson … I regard this scheme as a very valuable one for the reputation of our Observatory.' [100]

Mary's networks were broadening and she appreciated that Vassar's reputation would be enhanced if her graduate students could find relevant work. Writing to Pickering at HCO in 1896 February she asked: 'I would like to enquire if next fall there will be any opening in your Observatory for an intelligent young woman … Miss Macallester will be graduated at Vassar next June … she is now taking the introductory course in Astrophysics which we offer.' [101]

During 1895 and 1896 graduate student courses began across Vassar, enabling Mary to secure a further salary increase to c. $1,600 (c. £34k today). In astronomy, Lillian Clark Weaver (1874–1959) completed a course on planetary motions while Antonia Caetana Maury (1866–1952) returned to Vassar for seven weeks to acquire a familiarity with the spectroscope and visual spectra.[102]

The backlog of observations of eclipses, occultations, comets, and asteroids made with the 12-inch equatorial were analysed: 'Miss Furness has had entire supervision of the reduction of these observations for publication & has been assisted by three undergraduates … for two or three hours per week … an opportunity [for them] to earn a little money.' [103] This marked the resumption of the 'remunerative labour' policy initiated by Maria Mitchell.[104]

Papers were published in three outlets: *Astronomische Nachrichten*, *The Astronomical Journal*, and *Popular Astronomy*. In the latter publication Caroline further developed her interest in the history of astronomy with a paper on Tycho Brahe[105] while Mary explained the use of filar, ring, and square-bar micrometers on comets.[106] Comet results and measurements of eight minor planets appeared in *The Astronomical Journal*.[107,108]

4. Whitney's third five-year period (1896–1901)
During her third lustrum Mary Whitney developed her international collaborations, introduced new astrophysics courses, trained several graduate students, attended the dedication of Yerkes Observatory, became a founder member of the American Astronomical Society, supported her assistant through her PhD, mounted a solar eclipse expedition, and visited several European observatories. Throughout this period the Whitney–Furness partnership grew ever stronger.

4.1. *International links (1896–97)*
Six astronomy courses were being offered at Vassar by 1896–97. Mary introduced a course on spherical trigonometry and also expanded the non-mathematical and popular descriptive astronomy option. She reflected: 'In many Colleges the effort is being made to place Astronomy on a par with other laboratory subjects as a training of the process of observation. Prof Byrd of Smith College is about to publish a book called 'Laboratory Methods in Astronomy' which is the result of several years' experience in this type of instruction. It is my purpose to carry out & develop course B in this direction.' [109]

The new graduate student was Mary Edith Tarbox (1873–1963) who attended part of the year and attained 'an unusual accuracy in observations … has a desk in the Observatory Clock-room which she occupies all day and she is at liberty at any time to call upon Miss Furness or myself for assistance in key reading or calculations. She observed every evening when the telescopes are not in use by under-graduates … she uses the glass up to 10 o'clock; then Miss Furness and I begin our special work, the study of comet and asteroid movements, and carry it on to 1 or 2 a.m.' [110]

'Only two comets have appeared this season within our range. Dr Chandler, editor of the *Astronomical Journal*, has written and telegraphed us during the year for certain values needed in haste.' [111] For minor planets, 'the Rechen Institut of Berlin has sent us their publications … we are following out the plan suggested by this astronomical centre'. The plan involved 72 measurements of 23 minor planets during the academic year.[112]

A new venture arose: 'Through the generosity of Miss Catherine Bruce and our own trustee Mr Thompson a Repsold measuring machine (costing $700 [c. £14k today]) has been added to our equipment. The machine is constructed for the purpose of measuring the positions of stars upon photographic plates' (Figure 8).[113]

In 1896 VCO linked up with Columbia University who were measuring and reducing plates taken by the pioneering astrophotographer Lewis Morris Rutherfurd (1816–92), some of the earliest celestial photographs taken in America. Harold Jacoby (1865–1932) had attended the International Astrographic Congress in Paris in 1887 where he asked the Finnish astronomer Anders Donner (1854–1938) at Helsingfors to make a set of twelve overlapping plates of the north polar region. Astronomers were keen to test the accuracy of photographic emulsions and Jacoby wished to also test the optical distortion of the Helsingfors objective.

Caroline later explained: 'Four of his plates had been measured by Mrs Jacoby and Mrs Davis … there were no funds for the completion … Professor Jacoby invited the astronomers at Vassar to a conference and suggested that we take up this piece of work and that I enter Columbia as a candidate for the Ph. D degree.' [114]

Mary was keen to facilitate an important research topic for her assistant as it linked directly with the new Repsold machine and also her plans for the remunerative labour scheme:

> Miss Furness is in charge of the measurements and reduction of the plates and is conducting the investigation under the advice and suggestions of Prof. Jacoby of Columbia University. The investigation may cover two or three years and will result in a valuable catalogue of Northern Stars. A single plate contains from 60 to 70 stars. Of these only five or six have come under study by the methods hitherto employed. The work of reduction involved is laborious but in this we are able to receive considerable aid through students…We are deploying three students regularly for ten hours a week and we have given irregular work to two others.[115]

Seven years after becoming director Mary began to demonstrate VCO's efficiency in both investigating comets and minor planets. Astronomical publications were received annually from the observatories of Greenwich, Harvard, Washington, and Lick. She realized it was important to extend her links to more observatories and also to begin issuing VCO publications: 'Lick Observatory is sending out a fine series of lunar photographs and Harvard a series of stellar photographs taken at Arequipa, Peru. By special request I have secured important publications from Cordoba Observatory, Argentina Republic (4 vols), Cape of Good Hope (3 vols); from Göttingen observatory several pamphlets including two valuable catalogues and from Helsingfors (2 vols).' [116]

University networks were also targeted. When Jacoby announced he was forming a new computing bureau at Columbia Mary recommended Florence Ellen Harpham (1860–1925), a graduate of Carleton College but then teaching at Smith, who had been a fellow summer student of Caroline's in Chicago.[117] Computers subsequently recruited for Columbia from Vassar graduates included Mary Tarbox and Helen Lee Davis (?–1930).[118] Around this time Mary Whitney became interested in the problem of solar motion and wrote a historical review of the topic for *Popular Astronomy*; she would later contribute two further papers, illustrating her mathematical expertise.[119]

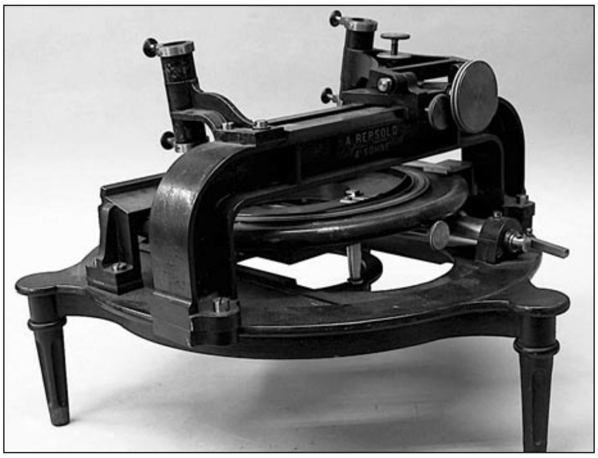

Fig. 8: Plate measuring machine by Repsold & Sons, Hamburg, originally produced to measure transit of Venus plates. The design was used at Columbia University Observatory and Harold Jacoby encouraged both the University of Minnesota and Vassar College to purchase these instruments. For VCO, Mary Whitney secured the $700 funding from college trustee Frederick Ferris Thompson and the philanthropist Catherine Wolfe Bruce. (Vassar College Archives & Special Collections Library)

Alongside their astronomical interests Mary and Caroline continued to lead the Wake Robin club during the spring months. Meetings were held in the college museum, where the stuffed specimens could be examined, and field trips were organized on Sunday mornings. Membership had grown to 43, partly due to the promotion of the Audubon Society during the year.[120]

Following a very successful year the two Vassar astronomers teamed up with Elizabeth Bickford, Vassar professor of biology, to attend a meeting of the British Association for the Advancement of Science (BAAS) at Toronto in the summer of 1897, where they saw and heard such distinguished British scientists as Lord Kelvin, Lord Lister, William Ramsay, Oliver Lodge, James Bryce, and Conwy Lloyd Morgan, along with Americans such as Simon Newcomb.[121]

4.2. *Yerkes dedication (1897–98)*

Mary Whitney skilfully modified her six-course offer each year to meet both student demand and the developing needs of the large American observatories. For 1897–98: 'I feel that course B [the stellar Universe and astrophysics] is very valuable to the students since it comprises the newest methods and most recent results in astronomical investigation. It combines chemistry and physics with astronomy…since the two largest observatories in America, Yerkes and Harvard, are so largely devoted to astro-physical work I believe our students should have the opportunity to study this subject which is so highly valued and carefully investigated.' [122]

Curriculum delivery was principally by Mary: 'Miss Whitney was successful as a lecturer…her thought clear and logical…a wide and well trained imagination, and a remarkable gift of language, so that she was able to present a distinct and vivid picture to her students.'[123] Mary was also a confident adult lecturer; she delivered a talk in 1897 October 7 in Brooklyn entitled 'The Surface Phenomena of the Moon'.[124]

Two years after his first visit to VCO, George Ellery Hale contacted them again with a major networking opportunity: 'At the invitation of the director of Yerkes Observatory, Miss Furness and I attended the conferences held at the dedication of this observatory in Lake Geneva [Wisconsin], October 1897.'[125]

The two women made the thousand-mile journey west to participate in the first conference of astronomers and astrophysicists, held the week of October 18–22, which proved to be the forerunner of the American Astronomical Society. Among nearly thirty papers presented across eight sessions those most pertinent to VCO activities were: Harvard variable stars (E. C. Pickering); motion of the Solar System in space (Simon Newcomb); theoretical researches on minor planet 334 (Kurt Laves); and solar investigations (G. E. Hale).[126]

Another presentation, by the Jesuit astronomer Johann Georg Hagen (1847–1930), director of the Observatory of Georgetown College, Washington, D.C., proved of most interest to the Vassar astronomers. Entitled 'an atlas of variable stars' it described his work with a 5-inch and 12-inch equatorial for the *Atlas Stellarum Variabilium* (ASV). Written in Latin, the first three series included accurate star charts for 128 variable stars together with lists of suitable comparison stars down to magnitude 13.5.[127] Mary and Caroline undoubtedly recalled their visit to Henry Parkhurst three years earlier, when the lack of such a resource was so evident. Hagen further explained that his 'series four' atlas would contain another hundred variables, with minima above the tenth magnitude, and so be very suitable for observation by students at colleges.

Twenty-five years later Caroline vividly recounted her Yerkes experience:

> Not knowing whether women would really be welcome, but fortified by Miss Cunningham of Swarthmore … we three were entertained by Mrs. Wilmarth of Chicago, who opened her house on the lake especially for us, and each day a private yacht waited upon us to transport us to the Observatory … the events of that first evening, as we landed at the old Y.M.C.A. pier in the pitchy darkness, and, led by a lantern bearer, walked in single file, picked our way along a rough path and up a steep hillside to the plateau, where we saw the great dome looming over us, and heard its rumbling. To enter the octagonal hall, and see groups of strange faces, each of which probably belonged to some famous astronomer whose name was perfectly familiar to us, was like the fulfillment of a dream. What an eerie feeling it gave one, to see the long telescope tube pointed heavenward, and take one's place in line for a glimpse through it. It was a solemn occasion, almost too wonderful to be true! The social informality of the occasion was delightful … we were not yet sure of the place which women held in the astronomical world and did not dare to be unscientific or frivolous even for a moment![128]

Mary and Caroline observed a few double stars and nebulae with the giant 40-inch refractor and experienced the motorized rising floor of the Yerkes observatory beneath the impressive 90-ft dome. They also visited the workshops and saw demonstrations of solar phenomena, optics, and spectroscopy.

In contrast to her recognition in America her application in 1897 to join the Astronomische Gesellschaft (the German Astronomical Society) was rejected on the

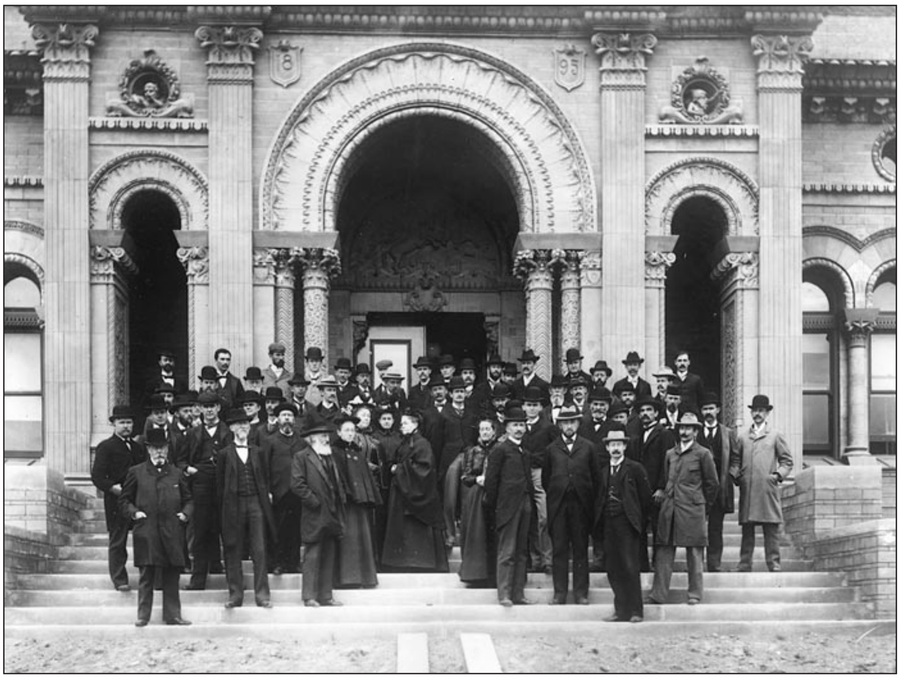

Fig. 9: The dedication gathering of the Yerkes observatory in 1897 October proved to be a major networking opportunity for Mary Whitney. She skilfully developed her astronomy curriculum to enable Vassar graduates to secure employment as computers. Within a few years she was supplying the majority of women astronomers to the Mount Wilson Solar Observatory. (University of Chicago Yerkes Observatory/American Institute of Physics)

grounds that 'The admission of ladies is forbidden in the by-laws.'[129] This was despite VCO's co-operation with the Astronomisches Rechen Institute of Berlin for minor planet observations, and the measurement of plates for the Helsingfors observatory.

4.3. *More opportunities at VCO*

Meanwhile, at Vassar the student roll continued to increase. Mary researched possible buildings so that her larger classes could observe more frequently with the Clark equatorial that had been donated by Cora Harrison a decade earlier: 'In regard the mounting and housing of the Clark five-inch telescope … I am at present in communication with Prof Pickering and others in reference to a cheap form of dome. The mounting will cost from $180 to $200. A regular spherical dome will cost $300. But there are cheaper forms, not so symmetrical, but equally useful & secure.'[130]

Caroline Furness later described the chosen housing, built in or around the summer of 1898: 'It has a gable roof, the two halves of which can be run off on tracks, leaving the sky entirely unobstructed.'[131] Warner & Swasey supplied a new filar micrometer with electric illumination ($320, c. £6.4k today).[132]

Another challenge involved Vassar's astronomical clock.[133] 'The sidereal clock will need cleaning this summer,' wrote Mary in her annual report for 1898. 'A man must come from New York about once a year to polish a certain point of electrical contact & the clock must be stopped…with the modification I could myself clean the point of contact without stopping the clock or effecting its rate… [I need]…an appropriation of $75 for cleaning clock & changing the contact apparatus, for repairing circles in dome and a few more slides.[134]

During the year two comets were observed (1897b and 1898b), together with 52 measurements of 23 minor planets, as suggested by their colleagues at the Astronomisches Rechen Institute in Berlin.[135] Measurement and reduction of four plates of the polar regions included the 'invaluable assistance rendered to us by students who have been employed on the Thompson fund. Five students have been working at various times, averaging ten hours per week. The calculating machine, the recent gift of trustee Thompson has been of great use, and is operated with facility by the assisting students.'[136]

4.4. *A British assistant at VCO (1898–99)*

The second annual conference of astronomers and astrophysicists was held at HCO on 1898 August 18–20, hosted by director Edward Pickering.[137] It was attended by 92 delegates including 17 women. Two key discussion areas of interest to Mary and Caroline were the proposed formation of an astronomical and astrophysical society for America as well as plans for observers to cooperate on the forthcoming total solar eclipse of 1900 May 28.

At the end of the conference the two Vassar astronomers parted, with Caroline headed to New York for her doctorate work at Columbia University. Awaiting Mary at VCO was a donation of $255 [c. £5k today] from the class of 1878 which funded purchase of a full set of Hagen's charts for variable stars.[138]

The Cambridge visit enabled Mary to see how Mina Fleming's career had progressed. Mina's salary had increased, to $1,500 (1898), with the expectation of further rises once she moved on to Harvard Corporation scales. Fleming was officially now the Curator of Astronomical Photographs and deservedly had an international reputation.[139]

Both astronomers had excellent eyesight: Mina was highly skilled at interpreting tiny spectra on glass plates, while Mary's vision facilitated the observation of exceedingly faint stellar images. With the astronomical world requiring further investigation of variable stars it increasingly became obvious to Mary the direction her work might follow. Two and a half years later an unexpected visitor in the night sky would confirm her intentions and launch VCO into uncharted territory. A time delay would be inevitable, however, as Mary's curriculum demands continued to dominate her activities.

In 1898–99 she delivered five astronomy courses and supported three graduate students. Like her predecessor Maria Mitchell she encouraged naked-eye observations and grilled her incoming students with questions such as 'Have you ever seen the Sun north of your zenith?', or 'Have you noticed at what time the full Moon rises?' finding that nearly twenty-five per cent of her class of 44 claimed to have seen the Sun north of their zenith. 'So much for their education of eighteen years or more under this sun seen almost every day of their lives,' she wryly noted.[140]

To cover Caroline's absence Mary appointed an experienced British computer, Alice Everett (1865–1949) from Girton College, Cambridge, as her assistant for the year. She reported in 1899 May: 'Miss Everett has done very well indeed as computer and observer, being a correct, rapid and suggestive worker … she has lectured several times to the classes B and D giving accounts of the work done at Greenwich and Potsdam … is carrying out a thorough investigation of the error of the measuring machine.'[141]

During her AB degree Mary had been inspired by Maria Mitchell's prediction of a Leonid meteor storm for 1867 and despite a full Moon had witnessed from the VCO roof a magnificent display.[142] Now, with the peak of their 33-year cycle returning, Mary reinstated annual meteor watches in 1899 November. The first two nights were cloudy but on the third night Mary, Alice Everett, and graduate Mabel Reed Benway (1877–?) counted and located meteors from midnight to dawn, sending their results to Harvard Observatory.[143]

In another new observing strand, Mabel Benway worked on variable stars and asteroids.[144] During the year 42 measurements of 14 minor planets were made, along with observations of comets 1898b and 1898i, all published in *The Astronomical Journal*.[145]

Fig. 10: Mary Whitney at her desk in the clock and chronograph room of Vassar College Observatory c.1898. The Repsold plate-measuring machine (1896) is visible at far left, and the Vassar sidereal clock (1865) behind her. On the cabinet to her left is a small picture of Maria Mitchell, with Étienne Léopold Trouvelot's lithograph of the zodiacal light behind it. (Vassar College Archives & Special Collections Library)

VCO computers continued working on glass plates. 'The second set of Helsingfors plates, 2° from the pole, is now in process of measurement,' wrote Mary in 1899. 'We are much aided by students who give us assistance through Mr Thompson's fund. At present we are employing six students. I trust Mr Thompson's death [1899 April 10] will not cut short this excellent form of his charity.' [146]

During the summer VCO received another donated telescope, a 3-inch f/15 refractor by Alvan Clark on an altazimuth mount, this time from Mary Anna Mineah (1846–1938), who had been one of Maria Mitchell's students some 30 years earlier.[147]

4.5. *More collaboration with Yerkes*

In 1899 September, just before the new academic year started, Mary and Caroline again journeyed to the Yerkes Observatory in Wisconsin for the inaugural meeting of the Astronomy and Astrophysics Society of America (A&ASA). Thirteen women attended this event and the two Vassar astronomers became charter members.

The Solar Eclipse committee advised delegates on the most useful types of observation needed for 1900 May. Of even greater significance were the private conversations the two women had with host George Ellery Hale, as these would lead to many opportunities for Vassar graduates to work for him over the coming decade.[148]

At Vassar student numbers continued to rise, with 88 in course A and 61 in course B. Mary proposed the addition of a new course, C, 'which will give even further scope for my much hoped for development of observational astronomy…A will become mainly a reading or library course, C almost wholly an observing course. The two together will meet the demands of the two types of mind, that which likes best to deal with books & that which likes best to deal directly with Nature.' [149] She added: 'the graduate scholars, Miss [Blanche] Martin and Miss [Eda] Bowman, are taking a minor in Astronomy… [including] … the measurement and discussion of some photographs of star spectra sent to us by the Yerkes Observatory.' [150]

A pleasant surprise greeted the astronomy students of 1899–00: 'The new students' observatory has been of much service in both course A and course B… course D, the first of the mathematical courses, has profited especially… its excellent structure by Mr Van Vliet and Mr Downing… is better built and the telescope [5-inch f/15 Clark] is more secure from rain and snow than in the case of the one at Harvard, from which it was copied.' [151]

Meteor observations from the Observatory roof were again possible for the November Leonids. Three clear nights in 1899 November enabled Mary and her students to observe between 25 and 37 meteors per night.[152] In December, four occultations of stars of magnitudes 8.2 to 9.5 were observed using both the 12-inch and 5-inch refractors. Sixty-five measurements of sixteen minor planets were completed, along with observations of comets 1899a and 1900b.[153]

In 1900 Caroline's thesis (Section 4.6) was published as the first major publication of VCO, with the financial support of Vassar trustee Samuel Decker Coykendall (1837–1913). Two Vassar graduates were credited for their contributions: Mary Tarbox (Section 4.1) and Louise Wheaton Ware (1875–1953). Both women later had successful future careers as computers, at Columbia and Yerkes/Mount Wilson respectively.

Further plans were afoot. In her annual report of 1900 May Mary announced:

> Miss Furness & I propose to go to Wadesboro, N.C. for the solar eclipse of May 28 1900. At this station the observers of Yerkes Observatory, Princeton College Observatory, the Smithsonian Institute & the British Association will be assembled … Miss Furness has been appointed voluntary research assistant at Yerkes Observatory for the summer term of 1900. She has also been appointed a fellow of the American Association for the Advancement of Science. Both Miss Furness & I are charter members of the newly formed 'Astronomical and Astro-physical Society of America' … one of our graduates of last year [Helen Lee Davis, Section 4.1] employed through the Thompson self-aid fund … now holds a position in Columbia College Astronomical department, obtained through our recommendation. Miss Tarbox has held such a position there for two years. Prof Rees jokingly alludes to us as an intelligence office for assistants.[154]

4.6. *Solar eclipse expedition (1899–1900)*

Three decades after observing the 1869 solar eclipse with Maria Mitchell in Burlington, Iowa, Mary again travelled with her 3-inch f/15 Clark refractor on an eclipse expedition, this time 700 miles south-west to Wadesboro, North Carolina, in 1900 May, accompanied by Caroline Furness.

The site chosen included groups from Yerkes, the Smithsonian Institute, Princeton, and the British Astronomical Association. Mary explained:

> I also carried a pair of large field glasses, provided with a direct-vision spectroscope. With this I observed for the distribution of Coronium in the corona of the Sun. Miss Furness used the three-inch for observing the color of the prominences during totality. Both of these observations were included in the scheme proposed by the committee of the Astronomical and Astrophysical Society. The trip was successful in every way. While the other observers were crowded into one small hotel of the village, we, through the kindness of one of the seniors of Vassar, secured accommodation in the home of Capt. McLoughlin, of the Confederate Army, who helped us most effectively in getting our apparatus to the place of observation.[155]

Through her 2-inch field glasses the whole rim of the hidden Sun could be seen. All prominences were rose-coloured apart from a triangular-shaped one in the middle of the south-east quadrant which appeared more pinkish than the others. What she described as 'a very large and beautiful prominence in the form of the banyan tree' was observed in the south-west quadrant. Through the McClean spectroscope the continuous spectrum of the corona was so bright that the green coronium image could not be separated from it. 'The inner corona was much more brilliant than I had expected,' she reported.[156]

Mary lectured on the eclipse at the Pratt Institute, Brooklyn, in June and then joined Caroline, who proudly showed her around the Columbia facilities.[157] They attended the second annual conference of the Astronomical & Astrophysical Society which was held at Columbia University. Its president, Simon Newcomb, allowed a brief resume of eclipse observations and then focused delegates' attention on the next challenge: plans for an international campaign to observe the minor planet Eros during its close opposition in 1900 October to improve measurement of the solar parallax.[158]

Mary spent the rest of that summer at home in Waltham, while Caroline was appointed voluntary research assistant at Yerkes Observatory from July 1 to September 10 where she participated in the study of β Lyrae and assisted Edwin Brant Frost (1866–1935) in testing the new spectrograph.[159] Establishing a link with Professor Frost proved useful as it facilitated work placements for Vassar graduates, especially after he later became director at Yerkes (1905). The transfer of George Hale to the Mount Wilson Solar Observatory (MWSO) would similarly provide major opportunities for VCO at Pasadena.

In 1900 Caroline was awarded her doctorate from the Faculty of Pure Science, Columbia University. Her thesis was published as Volume 1 of the new *Publications of the Vassar College Observatory* (Figure 11).[160] The newly qualified Dr Furness was duly appointed Instructor in Astronomy, with a salary c. $1,000 (c. £20k today). During the year 35 measurements of 11 minor planets were completed, with results published as usual in *The Astronomical Journal* and sent to their Berlin colleagues.[161]

4.7. *European observatories (1900–01)*

In 1900–1 course B, with 30 astrophysics students, began to observe the spectra of terrestrial elements, whose absorption spectra were visible in the Sun – 'the most stimulating to the imagination of the courses offered in our department,' as Mary put it. An introductory lecture

PUBLICATIONS OF THE VASSAR COLLEGE OBSERVATORY, No. 1.

MARY W. WHITNEY, *Director.*

CATALOGUE OF STARS

WITHIN

ONE DEGREE OF THE NORTH POLE

AND

OPTICAL DISTORTION OF THE HELSINGFORS ASTRO-PHOTOGRAPHIC TELESCOPE

DEDUCED FROM

PHOTOGRAPHIC MEASURES

BY

CAROLINE E. FURNESS.

ASSISTANT IN THE OBSERVATORY.

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University.

POUGHKEEPSIE, N. Y.

1900.

Fig.11: Volume 1 of the Publications of the Vassar College Observatory, issued in 1900, was Caroline Furness's PhD thesis, consisting of a catalogue of stars within 1° of the north celestial pole measured on photographic plates taken at Helsingfors, Finland.

on the solar spectrum was given by Ernest Fox Nichols (1869–1924) of Dartmouth College.[162]

Course C was changed from spherical trigonometry to observational astronomy. Mary proudly announced: 'In our graduate work this year Miss Davis has, for the first time, taken astrophysics as a major.' Photographs of ten stellar spectra and one of Jupiter were loaned to them for measurement by Yerkes Observatory.[163]

Between October and January minor planet Eros was regularly observed (44 evenings). In 1901 February Mary wrote a paper on Eros for the *Vassar Miscellany* noting that 'the labor and the patience of astronomers are heavily taxed [by] the whereabouts and motions of this crowd of minor planets … part of the work which our Vassar College Observatory is doing, giving the nod of recognition to our small neighbours.'[164]

The annual Leonid watch took place on 1900 November 14 and 15, logging 43 and 50 meteors between 1 and 5 a.m., together with some Orionids and Geminids.[165] In early 1901 VCO responded to an unexpected new star in the sky, Nova Persei, by observing its spectrum and light curve.[166]

Senior student Ida Watson spotted it at 11.00 p.m. on 1901 February 21. Three cloudy nights then interrupted observations. On February 25 the new star was found to have faded from the brightness of Capella to that of Pollux. That same evening the spectrum was seen to be crossed by broad lines, giving evidence of great outbursts of hydrogen and helium. The discovery, credited to Edinburgh amateur Thomas David Anderson (1853–1932), convinced Mary that VCO work should also include variable stars.

In her annual report of 1901 May Mary proudly announced: 'The most important feature of our work has been the issuing of our first Observatory publication. This publication has been sent to one hundred and fifty observatories and astronomers in our own country and to two hundred and fifty in Europe, Asia, Africa & Australia … one result of this distribution has been a marked increase of publications received from other observatories. Already fifteen over my usual number have come to us since the pamphlets were sent out.'[167]

In the summer of 1901 Mary Whitney, accompanied by Caroline, made the first of her two visits to leading observatories in Europe, which she described as 'a most profitable experience, both in its suggestions and in its pleasant friendly relations established with other observatories'.[168] The two women visited Potsdam, Prague, Heidelberg, Strassburg, Paris, Meudon, Greenwich, Tulse Hill (Huggins), Cambridge, South Kensington (Lockyer), the Royal Observatory at Edinburgh, and the Royal Astronomical Society, London. Caroline's account provided further insights:

> Landing at Hamburg, our first visit was to the [Royal Astrophysical] Potsdam Observatory, where we saw [Julius] Scheiner and [Karl Hermann Gustav] Müller, two very pleasant plump gentlemen… our next visit was a real pilgrimage, to the ancient city of Prague and the old observatory of Tycho Brahe. Here the Weineks [Ladislaus Weinek (1848–1913), director of the Klementinum observatory in Prague, and his wife] received us most cordially, showing us Tycho's fine old instruments, and taking us up to the high balcony upon which he used to draw out his sextant… Professor Max Wolf… called upon us in person at our hotel to arrange for a visit to Königstuhl… [he and Mrs Wolf] were both very much interested in Vassar as a typical American college for girls, and asked many questions about the work done by its students… at the Paris Observatory we met Dr Loewy, the Director, but were especially pleased to see Dorothea Klumpke who had made such a name for herself by her work on the theory of Saturn's rings. She was in charge of the reduction of the Paris astrographic plates, and we were interested to compare her computing bureau with the one at Columbia. She offered to escort us to Meudon to visit the venerable Janssen… the indomitable old Frenchman, who in spite of his eighty years, was planning to make another ascent of Mont Blanc that summer,

even if he had to be carried to the summit in a chair. He also asked many questions about the college in America where young girls studied mathematical astronomy … [in 1901] … the American college girl was an almost unknown specimen of humanity to the European … in London the two Miss Clerkes, Agnes and Ellen … in their home in Redcliffe Square … Miss Ellen … played the [guitar] accompaniment, while Miss Agnes beat time with her hand and they sang together some simple melodies in their thin old voices … a lovely picture of English life … visiting the Hugginses … approaching the long row of houses on Upper Tulse Hill … what a wealth of beauty and poetry lay hidden behind those monotonous piles of red brick! There could not be a more picturesque old couple, he with his soft white beard and poetical dark eyes, and she with her halo of short grey hair and gentle voice. He a musician and she an artist … their house was filled with artistic treasures … he was the owner of a genuine Stradivarius … their garden, Lady Huggins explained in a delightful manner … pointing out her bee-hive … the motto she had chosen … 'Nil nisi Labore' … in London there was also the Greenwich Observatory to visit, and in Cambridge we saw Sir Robert Ball, and arranged to have him lecture at Vassar on his forthcoming visit to America.[169]

Conclusion

Mary Watson Whitney began cautiously at VCO, initially repeating many of the practices of her mentor Maria Mitchell: sunspot photography, planetary study, time measurement, dome parties, meteor watches, and a solar eclipse expedition. She had the advantage of a fully restored 12-inch equatorial and skilfully selected a range of specialist accessory instruments to maximize its usefulness.

Donation of smaller telescopes added to the opportunities her students could undertake and her inspiring teaching quickly increased course numbers. Curriculum development was encouraged by Vassar's President Taylor and Mary extended her initial solar physics course into a complete introduction to astrophysics. By the turn of the century Mary Whitney was both contributing internationally to the advance of astronomy and training an impressive number of graduates ready for employment at American observatories. The recruitment and mentoring of Caroline Ellen Furness proved a special case as Mary was effectively nurturing her own successor.

To counterbalance astronomical work Mary developed her love of natural history, encouraging both students and staff to celebrate the diversity of bird life across the Vassar campus. Throughout the period covered Mary steadily developed her networking skills, achieving international recognition. To some extent Mary benefitted from the HCO model at Cambridge, where Williamina Fleming's career paralleled her own development. Her meeting with George Hale led to her invitation to both the Yerkes dedication and the inaugural meetings of the A&ASA. To have achieved so much, despite the series of family tragedies which she experienced, is testimony to the determination of one of America's greatest astronomers.

This paper continues the writer's quintet of contributions to *The Antiquarian Astronomer* on the female astronomers in the United States. The last part will focus on Whitney's final years at VCO from 1901 until 1915, when she finally retired after fifty years, and how her successor Caroline Furness ensured that Professor Whitney's legacy would be maximized.

Acknowledgements

Contributing to the number of historical papers for women astronomers continues to be a motivating factor for the writer. The experience of working with Vassar College Archive primary material has proved especially rewarding. I am particularly grateful to: Ronald Patkus (Head of Special Collections, Vassar College); Dean Rogers (Special Collections Assistant, Vassar College); Debra Meloy Elmegreen (former Professor of Astronomy on the Maria Mitchell chair at Vassar College); and Jascin Leonardo Finger (Deputy Director, Maria Mitchell Association), all of whom have provided encouragement, access to archives, or responded to various queries.

The research presented here has made extensive use of the Hathi Trust Digital Library; the Biodiversity Heritage Library; Vassar College Archives; Smithsonian/NASA Astrophysics Data System; and various sources retrieved online through Google Books. I would also like to thank my wife Ann who has contributed significantly to the many discussions about Mary Whitney's life during the past five years.

References and notes

1 Mary's five siblings were: Elisha Crehore Whitney (1846–66), Anna Maria Whitney (1849–52), Adaline Stearns Whitney (1852–96), Charles Abijah Whitney (1855–1909), and Thomas Laurence Whitney (1857–73).

2 The other five members of the Hexagon were: Sarah Louise Blatchley; Sarah Mariva Glazier; Clara Eaton Glover; Mary Reybold; and Helen Landon Storke. See p. 7 and Figure 3 in Haley, P. A., 'Maria Mitchell and the Vassar College Observatory', *The Antiquarian Astronomer*, 16 (2022), 2–36.

3 The AB degree stood for *artium baccalaureus* – the Latin name for a Bachelor of Arts (BA) degree, providing general knowledge across a wide range of subjects.
Furness, Caroline, E., 'Mary W. Whitney and the Vassar College Observatory', *Vassar Quarterly*, 6.3 (1921 May). The earliest entry in the Observatory record book reads: 'April 3rd, 1866. Observation of the meridian passage of Capella … Julia Bush at Instrument, Mary Whitney at Chronometer'. They

appear to have swapped places for the photograph in Figure 2.

4 Furness (1921, ref. 3).

5 Gauss, Karl Friedrich, *Theoria Motus* (1809), a treatise on celestial mechanics, in Latin.

6 Furness (1921, ref. 3).

7 The AM degree stood for *artium magister* – the Latin name for a Master of Arts (MA) degree, which Vassar College began awarding from 1872.

8 The Lasell Female Seminary was founded in 1851 by chemist Edward Lasell. It catered for c.100 female students, with about 10% drawn from Auburndale. Mary's Hexagon colleague Sarah Glazier also taught briefly there. Today it operates as the Lasell University.

9 Haley (2022, ref. 2), 8–9.

10 Christine Ladd (Franklin) also attended Peirce's celestial mechanics class. Mary enjoyed the challenge but was frustrated by the lack of opportunities for women to progress in this field.

11 Johnson, Colton, and Brown, D. B., *The Commencement of Vassar's 'First Collegiate' Class: June 24, 1868*
https://www.vassar.edu/stories/2018/180509-first-collegiate.html
Sarah Glazier had moved to Chicago in 1870. Also at Dearborn was astronomer Ormond Stone (1847–1933) who described Mary as 'attractive and handsome, gentle and refined, affable but dignified'. [1922PA..30..597F].

12 Haley (2022, ref. 2), 11–12 and Figure 5.

13 Haley, P. A., 'Maria Mitchell (1818–89): from Nantucket to Vassar', *The Antiquarian Astronomer*, 15 (2021), 49–50 and Figure 8. Mitchell displayed the painting of her sister Kate and father William with the zenith telescope in the Clock Room at VCO. Both paintings (1851) were by Herminia Borchard Dassel (1821–57).

14 Vassar awarded four AM degrees in 1872 to four members of the Hexagon group: Isabella Carter, Sarah Glazier, Helen Landon Storke, and Mary Whitney.

15 Sarah Glazier was professor of Natural Science at the new Buchtel College, Akron, Ohio (1873–74) and then in a similar post at Vassar (1874). When Wellesley College opened (1875) she was appointed the first professor of mathematics and astronomy. Five years after her first visit to Chicago she returned and in 1876 married John Mallory Bates (1846–1930). See also Johnson, Colton, and Brown, D. B., *The Commencement of Vassar's First Collegiate Class* (2018)
https://www.vassar.edu/stories/2018/180509-first-collegiate.html

16 Furness, Caroline E., 'Mary W. Whitney', *Popular Astronomy*, 30 (1922), 597–607, and 31 (1923), 25–35. Mary 'kept her notes in the blue covered blank books so familiar to the continental students of those days … two on calculus, differential and integral, three on synthetic geometry and two on 'Mechanik des Himmels' [celestial mechanics].

17 Furness (1921, ref. 3). Mary would later lead natural history tours around the Vassar campus.

18 *Vassar Miscellany* 25.7 (1896 April 1). Roxbury is 13 miles east of Waltham, across the city of Boston, so it is probable that Mary provided the bulk of the support for their mother in Waltham.

19 Booker, Margaret Moore, *Among the Stars: The Life of Maria Mitchell* (2007), p. 559. Mary applied to the University of Minnesota (1880 spring) and Mitchell wrote a letter of recommendation to president William Watts Folwell (1833–1929), dated 1880 May 24: 'Miss Whitney is invaluable … the best student I have had (taking into consideration general culture and well-balanced character) … very lady-like, refined and well-bred … a tendency to reticence and distrust of herself.'

20 Furness (1921, ref. 3).

21 Haley, P. A., 'Williamina Fleming and the Harvard College Observatory', *The Antiquarian Astronomer*, 11 (2017), 2–32.
Research suggests the salary of Maria Mitchell was c. $1,500 in 1881 (c. £30k today), and that Mina Fleming and Mary Whitney both started at c. $600 (c. £12k today). The writer has used a currency conversion of £1 = $5 for this paper, with the assumption that costs have risen by a factor of 100 since 1890.

22 *A Documentary Chronicle of Vassar College, Years 1870–79*, 1874 August 6: 'Collaboration between Prof MM at the VCO and Theophilus Mayhew, a Poughkeepsie watchmaker … a magnificent dial in the post office … propelled by electricity from the regulator … on the roof of the Morris building a signal pole … dropping of a target at precisely noon … operated from the observatory … [MM] and her successor [MWW], and their students, sustained this local collaboration for several years … the Vassar Time Service.'

23 Booker (2007, ref. 19), p. 454. 'Remunerative labour' for women was strongly advocated by Mitchell. Mary reintroduced the scheme (1996) using part-time women computers at VCO.

24 Haley (2022, ref. 2), 11–12 and Table 2. Seven hundred glass plates with solar images were found in 1995 at VCO. Mitchell funded the innovative apparatus but only took around a dozen images herself.

25 Haley (2017, ref. 21), 7–10.

26 Margaretta Palmer (1862–1924) worked as a Latin instructor at Vassar (1888–9) then became an assistant at Yale Observatory (1889). She completed her doctorate at Yale (1894) with a dissertation on the orbit of comet C/1847 V1, which Mitchell had discovered.

27 Furness (1922, ref. 16). Technically not a 'sabbatical' as she had no official Vassar position. Arthur Searle was born in London; in addition to his HCO work he also taught astronomy at Radcliffe (1891–1912).

28 Haley, P. A., 'Entente céleste: David Gill, Ernest Mouchez, and the Cape and Paris Observatories', *The Antiquarian Astronomer*, 10 (2016), 15–39.

29 Mina Fleming and Mary Whitney were both good chess players. Given the way she developed her career at HCO Mina was undoubtedly a positional (rather than combinative) chess player. It is unknown if they ever battled over the chessboard.

30 David Peck Todd (1855–1939) was professor of astronomy at Amherst College 1881–1917 and also at Smith College 1882–87. He chose the instruments and oversaw the observatory construction.

31 James Monroe Taylor (1848–1916) served as Vassar's fourth president for 28 years, 1886–1914. Under his leadership the college tripled in size to over 1,000 students and broadened its curriculum.
32 Safford had left the Dearborn Observatory in 1874, two years after the Great Fire severely curtailed funding for astronomical research there. He then worked for the USCS before being appointed professor of astronomy at Williams College, Massachusetts, in 1876.
33 *Vassar Miscellany*, 17.5 (1888 February), 204–5.
34 1888 June 12, Minutes of annual meeting of Board of Trustees, Vassar College. By this date Maria already had a new observatory in Lynn with her 5-inch f/15 Clark equatorial installed. It would be little used as her health declined.
35 *Vassar Miscellany*, 17.6 (1888 March), p. 268 (HCO) and 17.8 (1888 May), p. 348 (Maria Mitchell).
36 *Vassar Miscellany,* 17.7 (1888 April), 277–82.
37 Caroline's parents were Henry B. Furness (1836–1911) and Caroline Sarah Baker (1840–79); her mother had died when she was only 10 years old. Vassar Archives include 130 letters from her father between 1877 and 1911, 168 letters to her family (1887–92), and 1,077 letters and postcards from Mary Whitney – plenty of primary material for a future researcher.
38 *Vassar Miscellany,* 17.9 (1888 June).
39 Byrd, Mary E., and Whitney, Mary W., 'Longitude of Smith College Observatory', *Annals of Harvard College Observatory*, 29 (1893), 35–63.
40 The portable transit instrument used by Mary at Cambridge was made for HCO by Pulkovo engineer Mr Herbst, and was mounted on a granite/marble pier in the west transit room.
41 Wright, Helen, Warnow, J. N., and Weiner, C., eds., The Legacy of George Ellery Hale (MIT Press, 1972).
42 *Vassar Encyclopedia*, 'Caroline E. Furness'. https://vcencyclopedia.vassar.edu/distinguished-alumni/caroline-e-furness/
43 The writer is grateful to Jascin Leonardo Finger (Maria Mitchell Association, Nantucket) for a copy of Maria Mitchell's will.
44 VCO AR 1889. AR = Annual Report, produced in early May each year. Maria had begun the Endowment Fund four years earlier, with a contribution of $5k; by the end of 1886 $10k had been raised.
45 Ibid. See also: Haley (2022, ref. 2), p. 26.
46 Ibid. See also: Haley (2022, ref. 2), p. 21 and Figure 9; and *Vassar Miscellany*, 18.4 (1889 January), p. 133. Cora Harrison (1852–88) attended Harvard mathematics classes of Peirce in 1879, but then became ill and she died 1888 December 16. Her 5-inch f/15 Clark refractor became a favourite instrument of Mary Whitney's at VCO.
47 Furness (1922, ref. 16). Versions of this poem steadily increased in length as each cohort added verses.
48 VCO AR 1889. 'Godfray's treatise' referred to Hugh Godfray's *A Treatise on Astronomy* (1866). Mitchell began using this book in 1875.
49 Mitchell worked for the *Nautical Almanac* from 1847 for two decades; she was their first female computer.
50 *Vassar Miscellany* 19.1 (1889 October), 24–26.
51 *Vassar Miscellany* 19.3 (1889 December), 106–8.
52 Ibid., p. 114.
53 Whitney, Mary M., 'Maria Mitchell', *Sidereal Messenger*, 9 (1890), 49–51.
54 Rose Kavana became an educator/writer.
55 Byrd and Whitney, op. cit (ref. 40).
56 *Vassar Miscellany* 19.5 (1890 February), 186–8.
57 VCO AR 1890.
58 Young, C. A., *A Text-book of General Astronomy for Colleges & Scientific Schools* (1889).
59 Letter from Caroline to Henry Furness, in 1890–1 (exact date unknown), quoted in *Vassar Encyclopedia*. Her parents had been high school teachers and her father expected his youngest child to follow their example.
60 VCO AR 1891. The meridian instrument was improved by George Nicholas Saegmuller (1847–1934), of Fauth & Co., Washington, D.C.
61 Furness (1922, ref. 16).
62 VCO AR 1891. Brashear supplied his versatile spectroscope to many American observatories during the 1890s. It was suitable for revealing stellar, solar, and laboratory spectra and could either be mounted on an equatorial or used as a table-top instrument for calibration purposes. The grating, made by Henry Augustus Rowland (1848–1901), had 14,438 lines per inch and measured 1.3 × 1.8 inches. The cost of the Brashear spectroscope was c. $260, based on a price paid by Ohio State University in 1896.
63 *Vassar Miscellany* 20.3 (1890 December), 114–5. The endowment fund target was $50k.
64 The first seven women in the NYMS, which had begun in 1888, included two other astronomers – Mary Byrd (Smith College) and Susan Jane Cunningham (Swarthmore College).
65 VCO AR 1891.
66 *Sidereal Messenger*, 10 (1891), p. 155; Whitney, Mary W., 'Observation of Comet a1890', *The Astronomical Journal*, 10 (1890), p. 55.
67 *Vassar Miscellany* 20.7 (1891 April), p. 272. Phi Beta Kappa (φβκ) nominations each spring were introduced in 1891 by President Taylor. The honour celebrated 'a high level of academic achievement, breadth of study, requiring substantial work in several areas of the liberal arts curriculum, and general evidence of intellectual adventurousness.' Seven years later Vassar college was granted a national charter for φβκ.
68 Haley (2017, ref. 21), p. 15. Henrietta Swan Leavitt (1868–1921) graduated from Radcliffe in 1902 and was the second woman astronomer to receive a φβκ nomination.
69 *Vassar Miscellany* 20.9 (1891 June), p. 348. The Lockyer mentioned was the English astronomer Joseph Norman Lockyer (1836–1920). A decade later Mary and Caroline met him at the Solar Physics Observatory, South Kensington, London.
70 VCO AR 1892. The wind-speed equipment was donated by New York Meteorological Society. Meteorological records continued until 1901.
71 Whitney, Mary W., 'Filar-micrometer observations of Comet a1892 (Swift)', *The Astronomical Journal*, 12 (1892), 93. These micrometer measures made using the 12-inch refractor show that Mary was working alone at VCO during the summer vacation.
72 Haley (2017, ref. 21), p. 13. Mina Fleming checked plates back to 1885 November. Today Nova

Aurigae is known as T Aurigae, with a quiescent magnitude of 13.5.

73 Whitney, M. W., 'Observations of Nova Aurigae at Vassar College Observatory', *Astronomy and Astro-Physics* (formerly *The Sidereal Messenger*), 11 (1892), 461–2.

74 *Vassar Miscellany* 21.7 (1892 April), 382–3.

75 *Vassar Miscellany* 21.1 (1891 October), p. 45, gives her name as Carrie Ellen Furness. The writer has not found other evidence of her being known as 'Carrie'.

76 Byrd and Whitney 1893 op. cit. (ref. 39). Byrd used three female undergraduate students to help reduce her observations.

77 Todd had given the longitude of Smith Observatory as 4h 50m 32.9s west of Greenwich.

78 Furness (1922, ref. 16), p. 605. See also Whitney, Mary W., and Furness, Caroline E., *Publications of the Vassar College Observatory*, 3 (1913), 216–9, for a list of publications issued by the staff of VCO during Mary Whitney's directorate.

79 Whitney, Mary W., 'Some Recent Markings on Jupiter', *Astronomy and Astro-Physics*, 12 (1893), 22–3. Mary regretted that her assistant chose not to live at VCO, which limited their observing time together. See also: Mack, Pamela Etter, *Women in Astronomy in the US: 1875–1920*, BA thesis Harvard University (1977), p. 138, for a series of letters in 1893 May to December from Mary Wagner to Pickering and Searle seeking work which suggests she was at HCO from September to December but then returned home to Minneapolis to care for her mother. She returned to Poughkeepsie in 1902.

80 VCO AR 1893–94. Whitney, Mary M., 'Filar-micrometer observations of Comet a1892 (Swift)', *The Astronomical Journal*, 12 (1892), pp. 48 and 93; 'Observations of Comet f1892', *The Astronomical Journal*, 12 (1892), p. 133; 'Filar-micrometer observations of Comet g1892', *The Astronomical Journal*, 12 (1893), p. 175; 'Observations of Comet g1892 (Brooks)', *The Astronomical Journal*, 12 (1893), p. 188, and *The Astronomical Journa*l, 13 (1893), p. 7; 'Observations of Comet 1892 III (Holmes)', *The Astronomical Journal*, 13 (1893), 38–9.

81 The Maria Mitchell Endowment Fund reached $34k in 1893 February; four months later the Vassar board of trustees added $10k to complete the $50k target.

82 Philanthropist and trustee Frederick Ferris Thompson (1836–99) funded several Vassar projects at this time.

83 VCO AR 1894. Mary developed non-mathematical astronomy courses to maintain her student numbers; with the expansion of Vassar College new courses such as economics (1890) became popular.

84 Ibid. A $100 request (1892) for a Michelson interferometer was not approved.

85 Ibid.

86 Furness (1922, ref. 16). Mary's sister Adaline died on 1896 February 13, aged 44.

87 Whitney, Mary W., 'Vassar College Observatory', *Publications of the Astronomical Society of the Pacific*, 6 (1894), 151–2.

88 Furness (1922, ref. 16). Porter was director of Cincinnati Observatory from 1884 to 1930. He published three star catalogues useful for measuring the positions of comets and asteroids.

89 Ibid. See also: Smithsonian National Museum of American History, micrometer, ID No. 1980.0318.09

90 Ibid. Parkhurst used a 9-inch f/12 Fitz refractor together with a variety of home-made stellar photometers to observe long-period variable stars and asteroids. His meeting with Mary and Caroline helped them identify potential areas of research for VCO.

91 Whitney, Mary W., and Furness, Caroline E., 'Observations of minor planet (372) Palma, *The Astronomical Journal*, 15 (1895), 162; and 'Observations of minor planets [Unitas, Dembowska, and Henrietta]', *The Astronomical Journal*, 16 (1896), 47. Mary realized that this was an excellent use for the Vassar equatorial.

92 Letter from Mary Whitney to Dr Taylor, dated 1895 May 14. Mitchell had campaigned hard for the windlass but the dome shutter problems continued to undermine the Observatory operation.

93 Furness (1922, ref. 16). Percival Lowell (1855–1916) infamously hung his hat on the Vassar equatorial during his reception. Hale had run the Kenwood Observatory since 1890.

94 Ibid. American naturalist John Burroughs wrote an ornithology book *Wake-Robin* (1886). The Vassar club continued for many years.

95 After graduating from Vassar in 1890 Hannah Mace taught for two years before taking a mathematics fellowship at Vassar (1892–3). She then transferred to Yale for a year before joining the NAO in 1894. Henry Hedrick worked at NAO from 1886 to 1908, producing the *Catalogue of Zodiacal Stars* (1905), a standard reference work for 35 years. The family then moved to Yale (1909) where Hedrick worked as assistant astronomer, gaining his PhD in 1915. When she retired in 1940 Hannah was working on a catalogue of occultation stars.

96 Whitney, Mary W., 'The Founders of Vassar', Address delivered at Vassar College on Founder's Day 1895 April 26. https://vcencyclopedia.vassar.edu/interviews-and-reflections/the%20founders%20of%20vassar%20college/

97 Whitney. Mary W., 'Total Lunar Eclipse of September 3, 1895', *Astronomische Nachrichten*, 139 (1895), p. 79.

98 Furness, Caroline E., 'The scientific value of a total lunar eclipse', *Popular Astronomy*, 3 (1895), 109–114. She noted that stars down to the 11th magnitude were easily followed until they disappeared, testifying to the quality of the (improved) Vassar equatorial.

99 VCO AR 1896.

100 VCO AR 1896.

101 Mack, Pamela, *Women in Astronomy*, p. 132, letter from Mary Whitney to E. C. Pickering, dated 1896 February 29. Lillian McAllester took a teaching post in Milton, New Hampshire.

102 VCO AR 1895–6. Lillian Weaver from New York became an educator, opening schools for girls at Andrebrook (US) and Munich (Germany). Antonia Maury, the niece of Henry Draper, combined a teaching career with intermittent work at Harvard College Observatory. See also Haley, Paul A., 'Williamina Fleming and the Harvard College Observatory', *The Antiquarian Astronomer*, 11 (2017), 2–32.

103 VCO AR 1896.
104 Mitchell had promoted a strong work ethic to her students and paid them for their contributions to *Scientific American*.
105 Furness, Caroline E., 'Tycho Brahe', *Popular Astronomy*, 3 (1896), 221–6.
106 Whitney, Mary W., 'Determination of the Position of Comets', *Popular Astronomy*, 4 (1896), 177–81.
107 Whitney, Mary W., 'Observations of comet c1895 (Perrine)', *AJ*, 16 (1896), p. 38; 'Observation of comet g1896 (Perrine)', *AJ*, 17 (1896), p. 56.
108 Whitney, Mary W., and Furness, Caroline E., 'Observations of minor planets', *AJ*, 16 (1896), p. 47; 'Observations of comet a1896' *AJ*, 16 (1896), p. 72; 'Observations of comets a1896a and b1896', *AJ*, 16 (1896), p. 103; 'Observations of comet b1896 (Swift)', *AJ*, 16 (1896), p. 119; 'Observations of minor planets and comets, *AJ*, 17 (1896), p. 37.
109 VCO AR 1897.
110 Ibid. Mary Tarbox attended part time because of the prolonged illness and subsequent death of her mother. Her observations of minor planets 313 (Chaldaea) and 113 (Amalthea) were published in *AJ*, 18 (1897), pp. 8 and 109.
111 Ibid. Seth Carlo Chandler (1846–1913) worked part time for the USCS and HCO. He is best known for his work on the Earth's polar motion.
112 Ibid. Twenty-three asteroids were measured in 1896–7: Whitney, Mary W., and Furness, Caroline E., *AJ*, 17 (1897), pp. 77, 144, 181; Tarbox, Mary E., *AJ*, 18 (1897), p. 8.
113 Ibid. See also Scheiner, Julius, *Photographie der Gestirne* (1897), p. 151 (Figure 35) for details of the design of the Repsold instrument. The 12-inch equatorial at VCO used a visual objective and had no correcting lens for photographic work. The measurement and reduction of photographs taken elsewhere fitted well with VCO facilities.
114 Furness (1922, ref. 16). Annie Maclear Jacoby (1868–1945) was the daughter of astronomer Sir Thomas Maclear (1794–1879); Jacoby had met her during a visit to the Cape Observatory. Mrs Davis was the wife of Herman Davis, a member of the Columbia University staff.
115 VCO AR 1897.
116 Ibid.
117 Furness (1922, ref. 16).
118 Mary Tarbox was at Columbia from 1898 to 1902 but returned to VCO in 1903 summer while also working as a teacher. Helen Davis worked as a Columbia computer from 1899 to 1908.
119 Whitney, Mary W., 'Problem of Solar Motion', *Popular Astronomy*, 5 (1897), 309–15; 'The Determination of Solar Motion', *PA*, 12 (1904), 226–30 and 311–18.
120 *Vassar Miscellany*, 26 (1897 June), p. 495. The Massachusetts Audubon Society began in Boston in 1896, initially concerned with the use of bird feathers in millinery. Protection of water birds from plume hunting and creation of national wildlife refuges followed, before the creation of a national society in 1905.
121 Furness (1922, ref. 16). Elizabeth E Bickford obtained her doctorate in the University of Freiberg with a major in zoology and minors in botany and geology. She was professor of biology at Vassar and a regular participant in the Wake Robin club. For the Toronto BAAS see *Report of the 67th meeting of the British Association for the Advancement of Science* (BAAS, 1898).
122 VCO AR 1898.
123 Furness (1922, ref. 16). Mary's teaching load allowed Caroline to prepare for her doctorate training.
124 *Vassar Miscellany,* 27 (1897 November), p. 83.
125 VCO AR 1898.
126 Hale, George Ellery, 'The Dedication of the Yerkes Observatory', *Astrophysical Journal*, 6 (1897), 353–62.
127 Hagen, Johann Georg, 'The New Atlas of Variable Stars,' *Publications of the Astronomical Society of the Pacific*, 10 (1898), 100–103. See *Astrophysical Journal*, 8 (1898), 160–2, for an example of a chart for U Puppis. Mary chose not to observe this variable as its minimum was too faint for the 12-inch equatorial. After Georgetown College Observatory Hagen became director of the Vatican Observatory in Rome (1906–30); Caroline Furness visited him there in 1914.
128 Furness (1922, ref. 16). 'Miss Cunningham' was Susan Jane Cunningham (1842–1921) of Swarthmore College Observatory. 'Mrs Wilmarth' was Mary Jane Hawes Wilmarth (1837–1919), a women's rights activist, whose summer home was on Lake Geneva.
129 Ibid. The Astronomische Gesellschaft was founded in 1863 in Heidelberg. Whitney's application had been endorsed by Safford, Young, and Jacoby. In 1921 Julie Marie Vintner Hansen and Helene Marie Emilie Kempf became the first women members.
130 VCO AR 1899.
131 Furness, Caroline E., ed., 'Observations of Variable Stars made during the years 1901–12', *Publications of the Vassar College Observatory*, 3 (1913), p. 2.
132 VCO AR 1898. See also Plate V, 'position micrometer', in *A few astronomical instruments* (Warner & Swasey, 1900). https://babel.hathitrust.org/cgi/pt?id=uc2.ark:/13960/t12n5114x&view=1up&seq=21
133 *Vassar Encyclopedia*, 'The Maria Mitchell Observatory Clock'. https://vcencyclopedia.vassar.edu/buildings-grounds-technology/buildings/maria-mitchell-observatory/the-observatory-clock/
134 VCO AR 1899.
135 'Observations of Comet b1897', *AJ*, 18 (1898), p. 80; 'Observations of Comet b1898 (Perrine)', *AJ*, 19 (1898), p. 8; 'Observations of Comet b1898', *AJ*, 19 (1898), p. 39; 'Observations of minor planets', *AJ*, 18 (1897), p. 109; *AJ*, 18 (1898), p. 178; 'Observations of minor planets and Comet i1898', *AJ*, 19 (1899), p. 187; 'Observations of minor planets', *AJ* 20 (1899), p. 29.
136 VCO AR 1898.
137 Haley (2017, ref. 21), p. 16. The 17 female astronomers included most of Mina Fleming's computing team at HCO.
138 *Vassar Miscellany,* 28 (1898 November), p. 87.
139 Haley (2017, ref. 21), 12–18.
140 VCO AR 1899.
141 VCO AR 1898–99, dated May 10. Alice Everett worked as a computer at Greenwich from 1890 to 1895 and then Potsdam in 1895–98 before becoming Assistant Astronomer at Vassar for a year. She then returned to London, working with her father on

optics and, later, the development of television.
142 Haley (2022, ref. 2), p. 5. Mitchell had estimated the 1867 storm as having around a thousand meteors per hour.
143 VCO AR 1899.
144 Ibid. Mabel Benway received her AB at Vassar in 1898 and AM in 1899; she then moved to Albany college prior to teaching in high schools until 1917.
145 Ibid. 'Observations of Comet b1898 (Perrine)', *AJ*, 19 (1898), p. 8; 'Observations of minor planets and Comet i1898', *AJ*, 19 (1899), p. 187; 'Observations of minor planets', *AJ*, 20 (1899), p. 47; 'Observations of minor planets and Comet a1899', *AJ*, 20 (1899), p. 76.
146 Ibid. Mary added that communication with Professor Donner at Helsingfors Observatory was being delayed due to 'the trouble in Finland'. The country operated as a 'Grand Duchy' under Russian rule (1809–1917) until it gained its independence.
147 *Vassar Miscellany*, 29 (1899 October), p. 65. Mary Mineah also donated a compound microscope to Vassar in 1899.
148 Ibid., p. 62. Caroline Furness officially received her doctorate from Columbia University in 1900.
149 VCO AR 1900.
150 Ibid. Blanche Martin, graduate student from Little Rock, Arkansas, went on to a teaching career.
151 Ibid. Benson Van Vliet (1837–1905) was General Superintendent of Vassar College.
152 Whitney, Mary W., 'Observations of Leonids', *AJ*, 29 (1900), p. 148. Three nights observing on 1899 November 13 to 16, from midnight to dawn, recorded 25, 27, and 37 meteors; no meteor storm this time.
153 VCO AR 1900. 'Observations of minor planets and Comet a1899', *AJ*, 20 (1899), p. 76; 'Observations of comets and minor planets', *AJ*, 20 (1900), p. 159; 'Observations of minor planets and comets', *AJ*, 21 (1901), p. 116; 'Observations of Minor Planet 1899 EY', *AN*, 152 (1900), p. 171.
154 Ibid. John Krom Rees (1851–1907) was an astronomer/geodesist at Columbia.
155 VCO AR 1901.
156 Whitney, Mary W., 'The eclipse of May 28th', *Science*, 11 (1900), 992–3.
157 The Pratt Institute is a Brooklyn college founded in 1887 by the businessman Charles Pratt (1830–91) to provide an education for all, regardless of class, colour, or gender.
158 VCO AR 1901.
159 Ibid. Edwin B. Frost had studied stellar spectroscopy at Potsdam Observatory and worked at Yerkes from 1898 to 1932, succeeding Hale as director in 1905. In 1899 Catherine W. Bruce funded $2,300 for a new spectrograph for the 40-inch refractor. When Caroline went to Yerkes the Bruce Spectrograph was operational and the first stellar motions in the line of sight were being measured. Frost would later use radial velocities to study spectroscopic binaries.
160 Furness, Caroline Ellen, 'Catalogue of stars within one degree of the North Pole and optical distortions of the Helsingfors astro-photographic telescope deduced from photographic measures', *Publications of the Vassar College Observatory*, 1 (1900), i–74. It contained measures and reductions of 58 stars on four plates and in 1905 was extended to 408 stars within 2° of the pole.
161 'Observations of minor planets', *AJ*, 21 (1901), p. 160; 'Observations of Minor Planet 1901 GV', *AN*, 157 (1901), p. 147; 'Observations of minor planets', *AJ*, 22 (1902), p. 104.
162 Ibid. Professor Nichols was an educator and physicist, specializing in the use of the Crookes radiometer to investigate the infra-red spectrum. He was a professor at Dartmouth College (1898–1903), returning after six years at Columbia College to become president (1909–16).
163 Ibid. Alice Estep Davis (1879–1923), from Glenshaw, Pennsylvania, was the first Vassar student to major in astrophysics, completing her AM in 1901. She became a teacher in Pittsburgh.
164 *Vassar Miscellany*, 30 (1891 February), 228–32.
165 'Leonids at Vassar College', *Popular Astronomy*, 8 (1900), p. 566.
166 VCO AR 1901. Nova Persei (GK Persei) reached magnitude 0.2 at maximum around 1901 February 24 before fading below naked-eye visibility a few months later.
167 VCO AR 1901.
168 VCO AR 1902.
169 Furness (1922, ref. 16). See also Makemson, Maud W., 'Caroline Ellen Furness 1869–1936', *Popular Astronomy*, 44 (1936), 233–8. The motto of Lady Huggins for her beehive was 'Nil nisi Labore' – 'Nothing without work'.

The author

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Ralph Copeland (1837–1905): Versatile astronomer and resourceful traveller

Peredur Williams

On 1853 July 7 Ralph Copeland, two months shy of his 16th birthday, left Liverpool on the clipper ship *Star of the East*, bound for Melbourne and the Australian gold rush. Forty years later he was Astronomer Royal for Scotland responsible for the Royal Observatory on Calton Hill in Edinburgh and the development of the new Royal Observatory nearing completion on Blackford Hill to the south of the city. In between, he worked on a sheep farm, participated in a German Arctic expedition, discovered galaxies with the largest telescope in the world, made pioneering astronomical observations in the Andes, and observed the spectra of numerous novae and comets. He participated in two expeditions to observe transits of Venus and four to observe solar eclipses. Yet for all his many remarkable achievements Copeland appears to have been largely neglected by biographers, and this paper is an attempt to rectify that.

1. Introduction

Ralph Copeland (Figure 1) was born on 1837 September 3 at Moorside Farm, Woodplumpton, in Lancashire.[1] His parents, Robert Copeland (1797–1840) of Blackburn, and Elizabeth Milner (1802–59), of Kirkham, had married in St Michael's, Kirkham, on 1819 November 16. Robert was recorded as 'grocer' on the marriage license and reported to be the only son of Mr Thomas Copeland of Clifton, near Preston.[2,3] Elizabeth was the youngest daughter of Mr William Milner of Newton, near Kirkham.

Robert and Elizabeth's first six children were baptized at Chapel Street Independent, Blackburn, which tells us that the family were Dissenters. Their abode was given as Blackburn for the first four baptisms, up to 1828 August, and as Woodplumpton for the last two, from 1830 July. The last baptism was also recorded as having taken place at Zion Chapel, Kirkham, when Robert's occupation was given as 'farmer'.[4] One more child was baptized there but the Zion Chapel records end in mid-1837, before Ralph was born, so we have no record of his baptism.

In 1840, when Ralph was three years old, he lost his father.[5] His mother, Elizabeth, took over the farm and was recorded as a farmer in the 1841 census.[6] Ralph received his first instruction from a hand-loom weaver and then, aged 8, went to grammar school at Kirkham.[7] The census for 1851, however, records Ralph, age 13, to be boarding, along with two other boys, in the household of Thomas Hayes, Vicar of Bracewell, Skipton.[8] This was the Bracewell Boarding School, said 'to have sent forth several good scholars, including Clergymen, and also the late Astronomer Royal for Scotland, Sir [*sic*] Ralph Copeland'.[9]

Bracewell seems a long way from Woodplumpton but Ralph's uncle, Rev. Richard Milner, was the Perpetual Curate of Gill, very near by, and probably knew Thomas Hayes from their student days at St John's College, Cambridge.[10] It is likely that Milner was responsible for this arrangement, helping with Ralph's upbringing after the death of his father. Ralph must have visited the Milner family often and got to know his cousins – including Susanna Milner, whom he married some years later.

In 1853 July, two years after being recorded as boarding in Bracewell and two months before his 16th birthday, Ralph Copeland left Liverpool on the *Star of the East* for Melbourne. In 1851, gold had been discovered at Ballarat, then at Mount Alexander and Bendigo, and there was a steady rise in interest in Britain, which rose to a frenzy when eight tons of gold arrived from Victoria in 1852 April.

In May, an issue of *Household Words*, a popular weekly 'conducted by' Charles Dickens, gave a lively account of the beginnings of the gold rush and a vivid description of conditions in the gold fields,[11] but reassured readers that 'The contrast is very great between the orderly

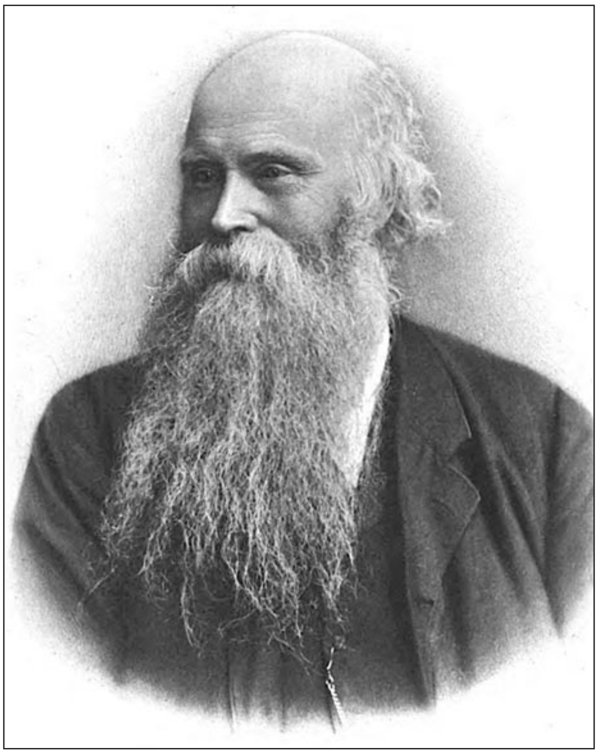


Fig. 1: Ralph Copeland seen c.1895, when he was in his late fifties, from J. L. E. Dreyer's obituary of him in the German journal Vierteljahrsschrift der Astronomischen Gesellschaft (ref. 1).

behaviour at the gold fields in Australia, and the disorders of California'.

Another issue of *Household Words* gave advice to emigrants as to what to take with them: 'A single man should be in light marching order, and should endeavour to take no more clothes than he could, at a pinch, make up in a bundle and carry, groaning, on his back for a mile.' [12] Stirring words for anyone with a sense of adventure, which Ralph evidently had. Whether or not he read *Household Words*, he breathed the excitement in the air and preferred the Gold Rush on the other side of the world over apprenticeship to his oldest brother Thomas at a cotton mill in Blackburn.[13]

2. Formative Years: Australia, Gorton, and Göttingen

The Unassisted Inward Passenger Lists to Victoria 1852–1923 in the Public Records Office of Victoria has the entry: 'COPELAND RALPH SEP 1853 STAR OF THE EAST'. Frustratingly, we know nothing about the arrangements for his travel apart from the fact that the full fare was paid, and that he turned 16 during the voyage. Did he travel on his own or with a group?

We do at least have an account of the journey from another passenger in a letter home.[14] The writer considered the *Star of the East* to be a fine vessel but was not impressed with its operation:

> Our ship was so badly stowed that it took all hands every day, from the day we left Liverpool until we arrived in Melbourne, to break out provisions and water for the passengers so that the Captain had no chance to take advantage of the winds, for there were no men to work the ship. I'm sure if our ship had been worked as she ought to have been ... instead of 75 days to Melbourne, she would have done it under 60 days. I shall never want you to step your foot on board an emigrant ship, unless in the 1st cabin, for all the places of iniquity my eyes ever beheld, an emigrant ship is the worst, men and women packed indiscriminately together, married couples and young girls, and I am sure some of the girls will have cause to remember the STAR OF THE EAST.

The cramped and chaotic conditions on the emigrant ships, their hasty conversion from cargo ships to pack in as many emigrants as possible, and the scramble to get berths on them during the gold rush are breathlessly described in *Household Words*.[15]

Another issue of *Household Words* described the conditions awaiting the 16-year-old Ralph in Melbourne:

> From every part of the world as well as from Great Britain, vessels are daily pouring in, filled with living cargoes, to swell the houseless number. I have, not once, but frequently within the last month, counted in the daily returns of published arrivals, from two to three thousand passengers and emigrants in a single day, and we are told that this is as yet but the commencement. What to do with this superabundance of population is now the great question – where to lodge them, and how to feed them? Immense numbers, it is true, hurry at once to the mines without delaying in Melbourne, and the once lonely road from thence to Forest Creek and the Bendigo Diggings, is now little less thronged than that between London and Epsom on a Derby day, although with a somewhat different-looking class of travellers.[16]

Ralph Copeland did not go to Bendigo, but to Omeo, about 250 miles north-east of Melbourne.[17] In 1851 alluvial deposits of gold had been found in tributaries of the Livingstone Creek, Omeo, and he may have known of the 1852 report in the *Manchester Times*: 'A new place, called Lake Omeo diggings, has come to light lately, said to exceed all former discoveries. It is somewhere near the boundary between Sydney and Victoria districts; and should it become true, gold will become quite disgusting'.[18] How Copeland got to Omeo, and what he did when he got there, we do not know; although he wrote extensively about his later travels, he could not be persuaded to write about his early adventures.[19]

We do at least know how he came to leave the diggings. According to his daughter Fanny's unpublished autobiography, Copeland's adventures in the goldfields ended with a shot wound in the leg. 'His companions put him to bed in a stuffy little cabin, tied up the wound anyhow and sat around sympathetically waiting for blood poisoning to set in.' [20] Fortunately, a grizzled Zulu strode into the cabin and took command, demanding clean water and clean rags. He washed the wound thoroughly, bandaged it carefully, and repeated the process on the following day.

The wound soon healed and, shortly afterwards, Copeland and the Zulu went to work on a sheep farm run 'by a hefty amazon called Mother Brown'. His obituary in *The Scotsman* names the owner of the sheep farm as Mr Malcolm M'Farlane and states that Copeland returned to the Omeo diggings in 1856, where he was made a member of the 'Vigilance Committee' among the miners – a handful of young men who constituted an unofficial, secret court 'which enforced respect for life and property with a strong hand'.[21,22]

From his RAS obituary by J. L. E. Dreyer we learn that Copeland developed his interest in astronomy while working on the sheep farm – probably inspired by the clear skies – and that, at his request, his mother sent him some books and a small telescope with which he made 'his first acquaintance of the heavens'.[23]

2.1. *Return to England from Australia*

In 1858 he decided to return to England. He left Melbourne on the *Sultana* on June 24, reaching Liverpool, via Cape Horn, on October 1.[24,25] On the voyage he extended his astronomical interests, making experiments on the visibility of stars in daylight in the tropics and studying the appearance and rapid development of Donati's Comet.[26] Soon after his return to England his mother died, in 1859 January, and in July the farm was put up for sale.[27,28]

Copeland had wished to enter Cambridge University, perhaps at the suggestion of his uncle and future father-in-law, the Rev. Richard Milner, who was himself a Cambridge graduate. Instead, he entered the works of Beyer, Peacock & Co., locomotive engineers, as a volunteer-apprentice.[29] What prompted this change of plan we do not know;[30] but he was described as 'engineer' in the report of his marriage to his cousin Susanna Milner on 1859 December 26 at the Parish Church of St Mary-le-Gill where her father was the incumbent.[31] The engineering know-how he gained during this apprenticeship would stand him in good stead later in his career, particularly when dealing with astronomical instrumentation.

Together with some fellow-apprentices, including Fred Holloway with whom he corresponded into his last years,[32] Copeland set up a small observatory having a 5-inch refractor by Cooke at West Gorton near Manchester. Copeland's first recorded observation was of a staggered occultation of Kappa Cancri by the Moon on 1863 April 26, which was communicated to the Royal Astronomical Society by W. R. Dawes.[33] The report was followed by a series of confirmations and contradictions in the *Monthly Notices*. The *Bright Star Catalogue* lists Kappa Cancri as a double with a magnitude difference of 0.2 and separation of 0.3 seconds of arc; Copeland's estimate of a half-second step in the timing of the occultation is compatible with this separation.[34]

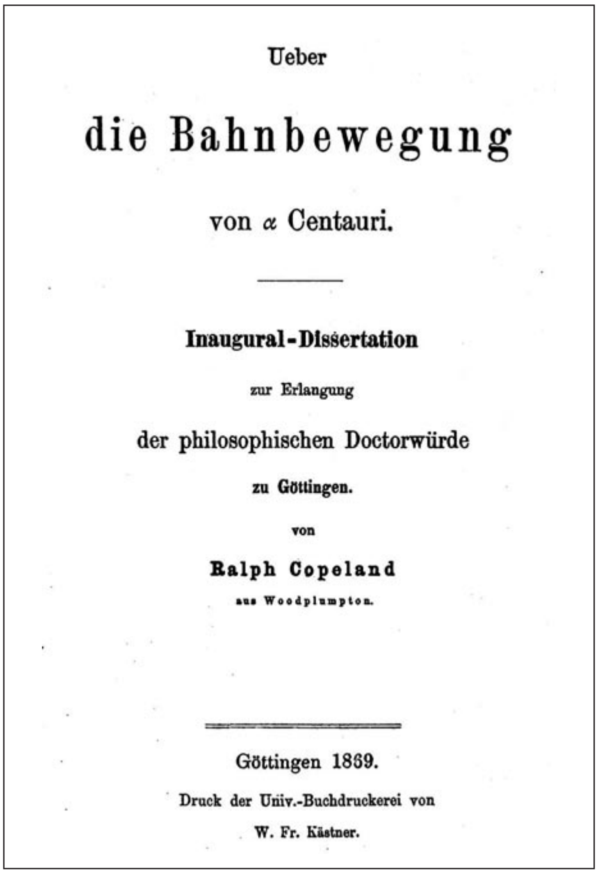
The Copelands' first child, Elizabeth, was born in Gorton in early 1861. A second child followed three years later, and was baptized John Herschel Copeland at St Mark, Gorton, on 1864 February 24,[35] but died later in the year. Sir John Herschel was then the grand old man of British science, and the naming of the Copelands' son after him clearly indicates Ralph's admiration, but there is no record of any contact between the two.

At around this time Copeland decided to devote his life to astronomy, being also influenced by the bad prospects for trade in Lancashire due to the cotton famine during the American Civil War. His first move was to obtain training in astronomy suited to his observing and instrumental interests. He did this not in England but at the University of Göttingen in Germany.

2.2. *Move to Göttingen*

In the mid-nineteenth century German universities were attracting students from all over the world to their graduate schools, where they could study for the modern PhD degree under academics who themselves had research experience.[36] After spending the winter in the house of a country clergyman in Hesse-Cassel in order to become familiar with the German language, Copeland moved his young family to Göttingen where he enrolled in the University in the spring of 1865. There he attended lec-

Fig. 2: Title page of Copeland's thesis on the orbital motion of Alpha Centauri, undertaken at the University of Göttingen.



Ueber

die Bahnbewegung

von α Centauri.

Inaugural-Dissertation

zur Erlangung

der philosophischen Doctorwürde

zu Göttingen.

von

Ralph Copeland

aus Woodplumpton.

Göttingen 1869.

Druck der Univ.-Buchdruckerei von

W. Fr. Kästner.

tures by Ernst Friedrich Wilhelm Klinkerfues (1827–84) and Wilhelm Eduard Weber (1804–91) and gained practical experience with astronomical instrumentation.[37] Copeland developed a life-long friendship with Klinkerfues. Fanny Copeland recalled that, when the family was at Dun Echt, they received huge parcels of Christmas presents from 'Uncle Klinkerfues'.[38]

Another son, Richard Ralph Copeland, was born at Göttingen in 1866 July. Tragically, Susanna died four months later of tuberculosis, leaving Ralph with an infant son and a five-year old daughter.[39] We do not know what arrangements he made for care of the children – there is no record of any family involvement – which became ever more pressing when he participated in an arduous observing programme and was then absent for 15 months on an Arctic expedition.

2.3. *Zone catalogue and PhD*

The University Observatory at Göttingen was equipped with two meridian circles, built by Repsold and Reichenbach in 1818 and 1819 respectively. In 1867 June, Copeland and a fellow student, Carl Börgen (1843–1909), embarked on a major project using the Reichenbach meridian circle: a survey of all stars down to 9th magnitude in the −1° and −0° zones of the Bonner Durchmusterung (BD), intended to be part of the programme being organized by the Astronomische Gesellschaft (AG) to observe all stars north of −2°. Observing continued through 1868, when Copeland took up residence in the observatory, and was completed in 1869 January, a total of 131 nights of observation having been shared between the two men.

Because the details of the AG programme had not yet been settled at the time the two students started, they consulted Professor Carl Bruhns (1830–81) of Leipzig as to the observing procedure adopted there and decided to follow it themselves. In the event their catalogue, 'Mean places of stars in zones −0° and −1° in the Bonner Durchmusterung brighter than $9^{m}0$ reduced to 1875',[40] published in 1869, was not accepted by the Council of the AG as part of their undertaking, because it used stars from the *Nautical Almanac* as standards. The zone was later assigned to Nikolajew Observatory in the Ukraine, but the Göttingen catalogue remained the modern authority for their zone for the next 30 years, until the Nikolajew catalogue was finally published.[41]

At the same time, Copeland completed his PhD thesis on the orbital motion of Alpha Centauri in which he derived its orbital elements from historical and modern data (Figure 2).[42]

2.4. *Call of the Arctic*

Also studying astronomy at Göttingen in the winter of 1867–8 was the German polar explorer Carl Christian Koldewey (1837–1908).[43] He had led the first German Arctic Expedition in the summer of 1868 and, in planning the second, consulted Börgen as to the feasibility of measuring an arc of meridian as part of it. Börgen

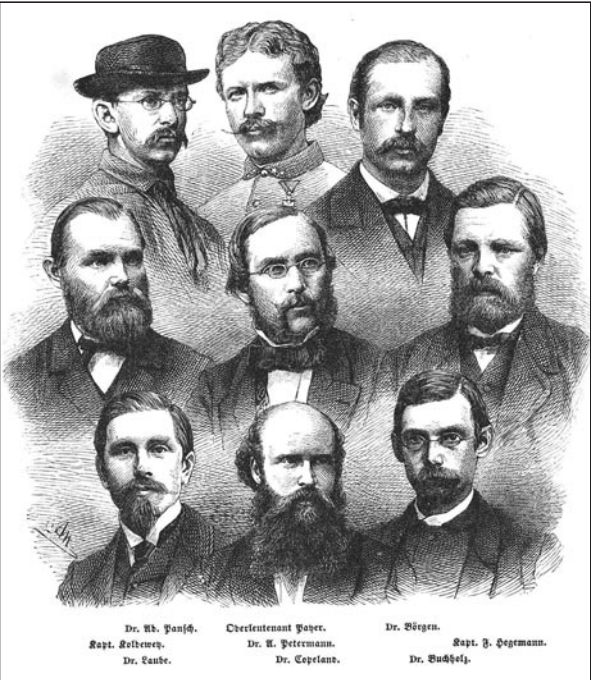


Fig. 3: Copeland seen bottom centre among the officers and scientists of the Second German North Polar Expedition in 1869–70. This is apparently the earliest surviving image of Copeland. Pansch, Payer, and Börgen are in the top row, and Koldewey at centre left (ref. 48).

pointed out that it would be impossible to reach results of permanent value, since the expedition would not be devoted to this work alone. However, noted Börgen, it would be most useful to make a detailed geodetic reconnaissance on which at some future time a regular measurement of an arc could be based. He would be disposed to join the expedition, together with Copeland, since one astronomer could not carry out the work alone.

On hearing this the same evening, Copeland was at once fired with enthusiasm at the prospect of taking part in a scientific investigation of a novel kind, and spent half the night talking about the methods to be followed and the instruments to be used.[44] His enthusiasm could well be traced back to his earliest recollection: that of two ladies, sisters of Captain Henry Foster (1796–1831), a native of Woodplumpton, who had accompanied William Edward Parry (1790–1855) on his third Arctic voyage in 1821–3.[45]

As part of their preparation, Börgen and Copeland compiled a short history of over-wintering in polar regions.[46] It referred to the imminent expedition which was planned to over-winter and presented reports of previous experiences to show how unfounded was the widespread belief that Europeans could not endure winter in that climate. They also set out the scientific work that would be carried out by the forthcoming expedition, pointing out that wintering in the Arctic region would give the best opportunity to study the nature of the northern lights with appropriate instruments. The discussion included the geodetic programme: there had long been a desire to determine the physical length of a degree at high latitudes, on either Spitsbergen or Greenland, and they gave reasons why the east coast of Greenland would be a good location for such a survey as part of the expedition.

3. The second German North Polar Expedition

The second German North Polar Expedition departed from Bremerhaven on 1869 June 15, seen off by King William of Prussia. The principal ship, the *Germania*, was specially built for the expedition, having a hull reinforced with iron plates to withstand the ice and, as well as sails, an engine and screw for manoeuvring in the ice. The second ship, the *Hansa*, carried stores for the *Germania*, and was intended to return to Germany at the end of the summer. Besides Copeland and Börgen the other scientific members of the expedition on the *Germania* were Lieutenant Julius Payer (1841–1915), Alpine explorer and topographer, and Adolf Pansch (1841–87), surgeon to the *Germania*, who was to cover zoology, botany, ethnography, and anthropology.[47] An engraving of the officers and scientists on the two ships forms the frontispiece of the popular edition of the expedition report (Figure 3).[48]

Their first destination was Sabine island on the east coast of Greenland (latitude 74½° north) but the *Germania* and *Hansa* became separated in ice and fog on July 20 due to misunderstanding of a signal, never to meet again. Unknown to those on the *Germania*, the *Hansa* was subsequently caught and crushed in ice but its crew survived on an ice floe for seven months before rescue and eventual return to Germany.[49]

The *Germania* continued to Greenland, which they reached on August 5. After it became clear that the *Hansa* would not be joining them with its stores, including coal for *Germania's* boiler, it was necessary to curtail exploring with the ship to save fuel and instead make do with sledge expeditions. Later in August the two astronomers, together with a crew member, explored Shannon Island (north-east of Sabine) with a view to finding sites for a baseline and triangles for the geodetic survey, but without success.[50]

Copeland also contributed with his rifle: he gives an exciting account of a hunt during which he and the ship's stoker, Louis Wagner, shot three musk oxen.[51] They cut their throats and rolled them some hundred feet down a steep slope. Then followed the work of skinning, falling mainly to Copeland, who was more experienced. They were approached by a large polar bear. Copeland shot him and opened his jugular vein. The carcasses were too heavy to move so they returned next morning with seven men, two boats, and a light sledge to collect the meat, heads, and skins.

3.1. *A winter in the Arctic*

The *Germania* lodged in ice for winter in a creek they called Germania Harbour on the south-east corner of Sabine island (Figure 4). The ship was unfitted down to the lower masts and shrouds, leaving the fore topmast as a lofty point for observing air currents and electricity. Everything not required for wintering was taken on land and secured to provide space on deck, which was covered with a heavy tent. Two observatories – astronomical and magnetic – were built of stone on shore near the ship. Rows of ice blocks and rope were erected between them and the ship to help men get to and fro in bad weather and in the dark.[52]

Copeland was one of five men on a sledge expedition led by Koldewey to explore Clavering Island off the north-eastern coast of Greenland.[53] On the second morning, October 28, they set off at 3.00 a.m. in moonlight. As daylight appeared, Copeland was attacked by a polar bear which galloped up to within five paces, then raised itself and struck him down with both fore-paws. Copeland had no time to load his gun but, as the creature caught his clothes, he swung the butt-end of his gun across its snout – and the bear ran away. The party then kept their weapons loaded on the sledge.

In his report of their travels, Koldewey also described the privations: when camping, the party was so closely packed in the tent that the pulling-off of boots could only be accomplished by sitting on one's neighbour. There was always the risk of knocking over the lamp, an uncovered tin dish filled with bear's grease, which twice set fire to the tent. The provision of drinking water by melting snow depended on the limited amount of fuel for the spirit lamp with the result that the men were thirsty most of the time. Provisions were short and by the end consisted mainly of reindeer flesh, 'which caused a dysentery that not even opium could assuage'.[54]

Work on the geodetic survey had stopped in the autumn and the winter was devoted to meteorological, magnetic, and astronomical observations. Copeland reported that the northern lights were very frequent, and that the convergence of the streamers was found to coincide with the direction of the freely suspended magnetic needle.[55] Spectroscopic examination of the auroral light fixed the wavelength of the green line at 1245 of Kirchhoff's scale.[56]

3.2. *Börgen carried off by a polar bear*

After the Sun reappeared in early February the survey stations closer to the ship were definitively selected and marked with either stone cairns or the metal drums in which provisions had been stored. On March 6, however, plans were thrown in disarray when Börgen was seriously injured.

Returning to the ship from the observatory after observing the occultation of a star by the Moon he was attacked by a polar bear, which started to carry him off. Koldewey on the ship heard his cries. The crew went out and fired shots to scare the bear, which dropped Börgen – but then grabbed him again and continued dragging him off. After a few more shots the bear let go again and ran away. Börgen was recovered and taken back to the ship where he was treated by Dr Pansch. The bear had torn his scalp in several places and there were about 20

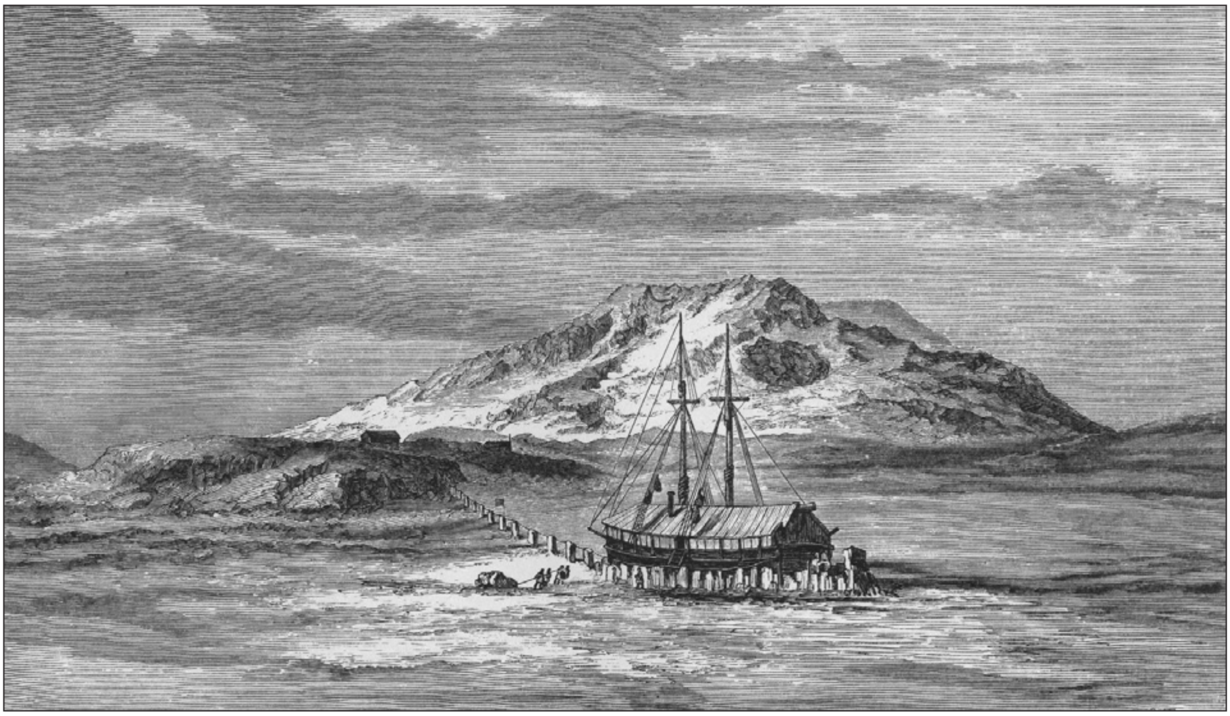


Fig. 4: Copeland's ship Germania lodged in the ice at Sabine Island, north-east Greenland, for the winter of 1869–70. The masts were reduced and a tent of strong sail cloth was erected over the deck. On the shore behind the ship can be seen two small stone buildings, the magnetic and astronomical observatories, connected to the ship by a row of blocks of ice and a rope to guide the observers in the dark. This illustration comes from Captain Koldewey's book 'The German Arctic expedition of 1869–70' (ref. 43).

other wounds, mostly from being dragged along the ice.[57]

In time, his wounds healed but thereafter he had to open and shut one of his eyelids by hand. Years later, Fanny recalled that when Börgen visited Copeland in Dunsink she climbed on his knee and asked him to open and shut his eye with a finger.[58]

3.3. *Resumption of geodetic observations*

Continuing the geodetic work, Copeland had to make field trips without Börgen. During April Copeland made a number of expeditions to expand the network of stations, checking their visibility and optimizing the network of triangles. Angles were measured with a theodolite with 5-inch circles. In the meantime Börgen had recovered and began to resume work.

In early May, the measurement of the 709-metre-long baseline was carried out and on May 14 they were able to start the sledge journey to the north. The plan was to set up the stations on the way there, between which the angles could be measured on the way back. All the angles at sixteen out of seventeen selected stations were measured. The latitude of the north end, on a mountain they called Muschelberg on account of the many fossilized shells they found there, was determined as 75° 11′ 30″.1.[59] The overall length of the arc was thus 39′ 14″.2.

They had planned to go farther north but the season was too far advanced and the sledge kept breaking through the ice, so they hurried back to the ship, which they reached on June 17. A report of the survey, including a detailed map showing the stations and triangles, was written by Börgen.[60]

In July, the ice near the ship began to break up and on July 22 the *Germania* left its winter harbour and set off north. Unfortunately, the way was blocked by pack ice and the crew instead turned south. Their exploration was rewarded by discovery of a large fjord, which they named after Kaiser Franz-Joseph. On August 12 Copeland, Payer, and a young crew member, Peter Ellinger, climbed up the glacier to a peak, now named Payer's peak (6,493 ft, 1,979 m), which remained the highest recorded climb within the Arctic Circle for over 50 years.[61] They saw countless summits around the horizon, of which they named the highest (near 11,000 ft, 3,350 m) Petermann's Peak after the German geographer August Heinrich Petermann (1822–78), the originator of the German Arctic expeditions.[62]

Since the end of July the *Germania's* boiler had become increasingly unreliable so it was decided to return home. The expedition docked in Bremerhaven on September 11, to learn that the Franco-Prussian War had broken out, and that the *Hansa* had been crushed in the ice but the crew saved.[63]

Copeland seems then to have returned to Göttingen and his children, whom he had not seen for more than a year, and set about looking for a position where he could continue astronomy. In due course he obtained one as assistant astronomer at Lord Rosse's observatory at Birr Castle, Ireland. At the same time he must have made or renewed acquaintance with Anna Bertha

Fig. 5: The 72-inch (1.8-m) Leviathan of Parsonstown in c.1885 with Lawrence Parsons, fourth Earl of Rosse, at the eyepiece. Copeland used this for observations of satellites of Uranus, Jupiter and galaxies. The cross-bar used for tracking can be seen about a third of the way down the tube. (National Library of Ireland)

Theodora Benfey (1847–1938), daughter of Theodor Benfey, a distinguished orientalist and professor at Göttingen University, whom he subsequently married.

4. Astronomy at Birr Castle and Dunsink Observatory

In 1871 January Copeland took up his appointment as assistant astronomer at Birr.[64] Over the years, Lord Rosse had employed a series of assistants, and the position became vacant in 1869 when Charles Edward Burton (1846–82) had to leave because of ill health.[65] Given Copeland's mechanical experience, it is likely that the engineering tradition at Birr attracted him as much as the astronomy.[66]

The observatory had become famous for the large telescopes built by the 3rd Earl of Rosse, William Parsons (1800–67), especially the 72-inch (1.8-m) 'Leviathan of Parsonstown'. The latter saw first light in 1845 February and remained the largest telescope in the world for over 70 years. The Leviathan had allowed the discovery of the spiral structure of nebulae, beginning with Parsons' observation of M51 in 1845.[67]

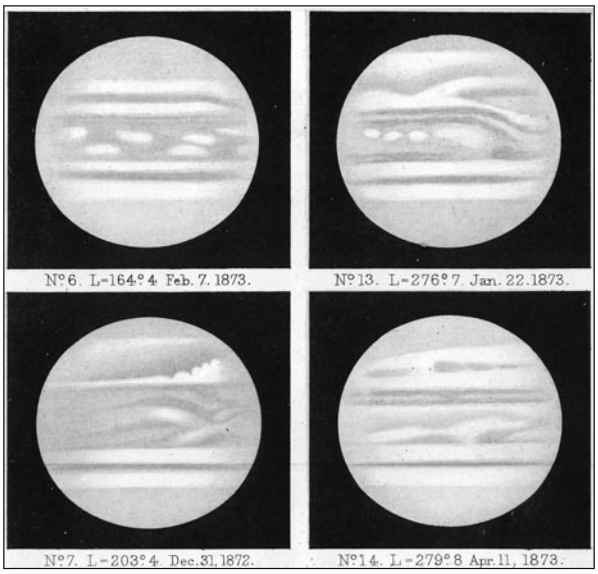
By the time Copeland started at Birr, William Parsons had died and his eldest son Lawrence (1840–1908) had succeeded him both as 4th Earl and in the pursuit of engineering and astronomical excellence. Lawrence Parsons had initiated a programme of measuring the radiant heat from the Moon using the 36-inch (0.9-m) telescope and thermopiles. Copeland's first duties were directed to this programme and his contributions to the observing and reductions were warmly acknowledged in the Earl's report of the results.[68]

In 1871 December Copeland married Theodora Benfey.[69] Their first daughter, Fanny Susannah Copeland (1872–1970), was born at Birr the following year. He received an invitation to join the 1872 Austro-Hungarian Arctic expedition, but being now settled at Birr with a growing family he declined.[70]

4.1. *Observing with the Leviathan*

In 1872 January Copeland began observing the satellites of Uranus, primarily Oberon and Titania, with the Leviathan. The telescope was cumbersome to use. It tilted north–south in altitude between its massive 56-ft-high walls like a transit instrument but, being mounted on a universal joint, could also pan in azimuth between the walls allowing an object to be tracked for about 40 minutes (Figure 5).

Fig. 6: Sketches of Jupiter made by Copeland with the Leviathan around the time of the giant planet's opposition in late 1872 and early 1873. Magnifying powers up to ×650 were used (ref. 72).



In preparation for an observation, the tube was raised to the required elevation and moved to the eastern wall to catch the target at the beginning of its transit. It had a Newtonian focus, with the eyepiece on the west side, and three observing galleries to give the observer access to it depending on the elevation.

Four men were required to assist the observer.[71] One stood at the winch to raise or lower the tube, another at the lower end of the instrument to move it eastward or westward as requested by the astronomer, while a third moved the observer's gallery in or out from the wall to keep the observer conveniently near the eyepiece. The fourth looked after the lamps and attended to minor matters. For tracking, the observer turned a handle near the eyepiece, and the tube moved along a cross-bar with a cog wheel. From the measurements of position angles and separations with the micrometer, Copeland derived orbits for Oberon and Titania and hence estimated the mass of Uranus.

Copeland made 19 sketches of Jupiter around the time of its opposition between 1872 December and 1873 April. From notes of the colours he executed watercolours the next morning which were published as chromolithographs (Figure 6).[72] The observing was facilitated by the application of a clock movement to the telescope, but the limited tracking range precluded study of changes during any one night as the planet rotated. Nevertheless, the observations showed up longer-term changes and allowed re-examination of the rotation period.

However, the principal use of the telescope remained to survey and draw all the brighter nebulae catalogued by the Herschels. There was no systematic search for new nebulae, but in the course of the programme many were discovered and were designated 'nova' in the records. Copeland discovered 35 new nebulae including, in 1874, the group in Leo now known as Copeland's Septet (Table 1).[73]

A feel for the process can be gauged from the record of his observations on 1874 February 9 (Figure 7).[74] Expanding the abbreviations, we have for the first three nebulae:

Table 1

Galaxies discovered by Copeland at Birr

NGC	RA (2000)	Dec	Original
3743	11h 35m 57s	21° 43′ 22″	α
3745	11h 35m 57s	21° 43′ 22″	β
3746	11h 37m 44s	22° 00′ 36″	γ
3748	11h 37m 49s	22° 01′ 33″	δ
3750	11h 37m 52s	21° 58′ 27″	ε
3751	11h 37m 54s	21° 56′ 11″	ζ
3753	11h 37m 54s	21° 58′ 53″	η
3754	11h 37m 55s	21° 59′ 08″	θ
3758	11h 36m 29s	21° 35′ 45″	ι

The coordinates given here are correct, unlike those in the original NGC (see ref 74). Greek letters follow his original notation; galaxies α and ι are not members of the Septet. See the sketch of the group in Figure 7.

> Set for 2464.[75] Found a nebula [ε], preceding Bright, little brighter in the middle, star in Pos. angle 23°.8, distance 109″.3, another [η] preceding Faint, same star Pos. angle 5°.5, distance 71″.7. Third nebula preceding [γ], pretty bright, considerably large, gradually little brighter in the middle, elongated 90°±, same star in Pos. angle 100°.4, Dist 148″.4. The star has a very red star 8.9 mag in Pos. angle 153°.3, Dist. 526″.8 [or 17s.08 following, 470″.6 south. 8.9 mag star = BD +22°2380]. None of the 3 nebulae have Nuclei.

Copeland's galaxies ε, η, and γ are now known as NGC 3750, NGC 3753, and NGC 3746 respectively. Other

1874, Feb. 9. Set for 2464. Found a neb [ε], p B, 1 b M, * in Pos. 23°·8, Dist. 109″·3, another [η] p F, same * Pos. 5°·5, Dist. 71″·7. Third neb p [γ], p B, c L, glbM, E 90°±, same * in Pos. 100°·4, Dist. 148″·4. The * has a very red * 8·9m in Pos. 153°·3, Dist. 526″·8 [or 17s·08 f, 470″·6 s. * 8·9m=B. D. + 22°, 2380]. None of the 3 neb have Nucl.

1874, Mar. 18. Found a neb [ι], pB, S, R, smbM, Nucl. not stellar.

* 8m	Pos. 81°·6	Dist. 161″·2	
* 12m	207·4	63·0	
* 9m from * 8m	303·9	671·0	[or 40s·20 p 374″·5 n]
Neb[α], F, S, R, from * 9m	322·5	78·1	

[* 9m is=B.D.+22°, 2377].

1874, April 5. Group of neb measured from a * 10·11m.

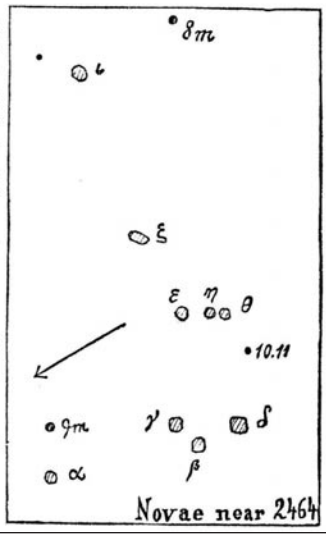


Fig. 7: Copeland's description of the galaxies making up Copeland's Septet as published in The Scientific Transactions of the Royal Dublin Society in 1879 (ref. 74). The sketch accompanying the descriptions is probably by J. L. E. Dreyer. The nebulae labelled α and ι (NGC 3743 and 3758, at bottom left and top left of the diagram) are not members of the Septet.

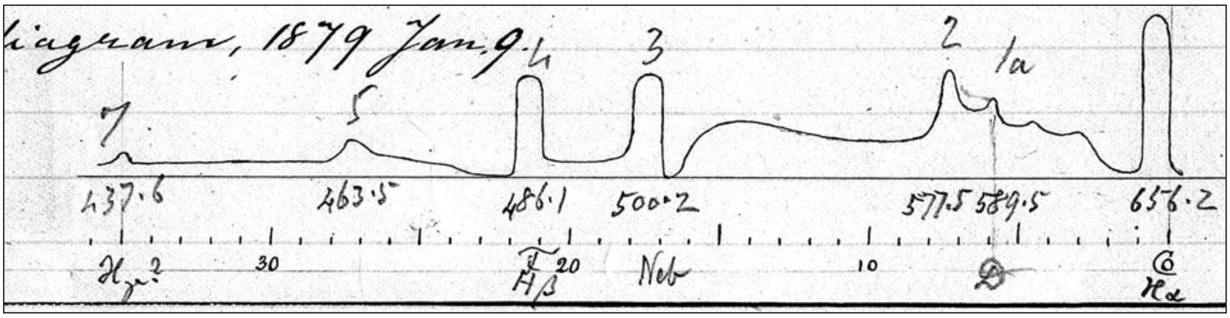


Fig. 8: Emission-line spectrum of Nova Cygni with annotations by Copeland. Wavelengths are in nanometres. The year written at the top, evidently added later, is incorrect; it should be 1877. (From 'Dunecht observations, Schmidt's Nova Cygni', A206 in the ROE Archives)

members of the Septet are NGC 3745, NGC 3748, NGC 3751, and NGC 3754 (his β, δ, ζ, and θ). Making micrometer measurements and notes of faint nebulae was, of course, very different from comparable observations of bright planets because the observer had to retain his dark adaptation, all the while working on a gallery suspended about 30 feet above the ground.

4.2. *Move to Dunsink, and the 1874 transit of Venus*

In the spring of 1874 Copeland moved from Birr to the Dunsink Observatory of Trinity College Dublin where he became Assistant to its director, the German-born astronomer Franz Friedrich Ernst Brünnow (1821–91).[76] The ever-adventurous Copeland was given leave of absence to accompany Lord Lindsay (James Ludovic Lindsay, later Lord Crawford) (1847–1913) on his expedition to observe the transit of Venus in December that year, one of eight teams of observers from Britain.[77] They left for Mauritius on Lindsay's yacht *Venus* on July 9, arriving there on November 2.

On the way they called at the island of Trindade in the South Atlantic, where Copeland and Lindsay collected specimens of birds and plants. Copeland discovered a giant tree fern, now called *Cyathea copelandii*, groves of which are found only in the higher and almost inaccessible parts of that island.[78] On the day of the transit, December 9, Copeland observed with a 6-inch equatorial and double-image micrometer, but the observations were only partly successful owing to cloudy weather.[79]

While Copeland was in Mauritius, his wife returned to Göttingen with Elizabeth, Richard, and Fanny, partly to see her people and partly to be away from Ireland which was then in the throes of Fenian troubles. Copeland returned from Mauritius to take his family back to Ireland but Elizabeth stayed in Göttingen to finish her education. Fanny recalled her first impressions of her father on his return from Mauritius: 'Tall, (six ft and broad shouldered in proportion) and had a flaming red beard'. Old friends called him 'Barbarossa'.[80]

While Copeland was away, the Irish astronomer Robert Stawell Ball (1840–1913) succeeded Brünnow as Director of Dunsink Observatory.[81] Ball, who had been an assistant to Lord Rosse in 1865–67, was favourably impressed by Copeland and later described him as a man of very extensive scientific attainments with a very useful practical knowledge of instruments.[82] Ball reported that, in the course of a walk through a forest in Mauritius, Copeland had found bushes covered with spider cocoons. He had filled an envelope with them and gave Ball a few when he came back from which they furnished the spider wires in the transit circle at Dunsink.

Copeland must have treasured the stock: many years later, when he was Director of the Royal Observatory, Edinburgh, he noted in his Diary for 1894: 'Oct 26. After repeated disappointment with the transit wires, devoted the whole morning to replacing three of them by webs of a Mauritian spider. In the evening it was found that these webs answered most satisfactorily.' [83]

At Dunsink, Copeland observed red stars with the transit circle and on 1876 May 2 Theodora gave birth to their second daughter, Paula Theodora. But Theodora was unhappy in Dunsink, and in the summer of that year they moved to Lord Lindsay's observatory on his estate at Dun Echt, Aberdeenshire, where Copeland took up an appointment as Director in succession to David Gill (1843–1914).[84,85]

5. Copeland at Lord Lindsay's observatory (1876–88)

The private observatory built up from 1872 by Lord Lindsay at Dun Echt was very different from Lord Rosse's at Birr. Instead of large telescopes constructed on the demesne, the equipment at Dun Echt had been acquired by Lord Lindsay, with the aid of David Gill, from the best English and continental instrument-makers.[86] Besides the meridian instruments there were equatorially mounted 6-inch and 15-inch refractors.

Copeland soon employed the latter in a major investigation, tracking the evolution of the spectrum of the bright nova later designated Q Cygni. It was discovered at third magnitude by the German astronomer Johann Friedrich Julius Schmidt (1825–84) in Athens on 1876 November 24, but slowness of communication and poor weather did not allow Copeland to observe it until 1877 January 2. By then the nova had already faded to seventh magnitude, but he and Jacob Gerhard Lohse (1851–1941), another graduate of Göttingen who had joined the observatory in 1877, were able to measure

Table 2

Comets observed by Ralph Copeland and J. Gerhard Lohse at Dun Echt

Comet	Discoverer	Month(s) observed and results
1877b	F. A. T. Winnecke	April–May: spectrum, three emission bands
1877c	Alphonse Borrelly	May: spectrum, bands at different positions
1879d	Johann Palisa	August: positions, elements, ephemeris; September–October, spectrum, comet bands; August–October: positions using micrometer
1880b	J. M. Schäberle	April-May: description, elements, ephemeris for May–November
1880d	Ernst Hartwig	October: spectrum, three emission bands
1880e	Lewis Swift	November: elements
1880f	C. F. Pechüle	December: spectrum, faint, three bands
1881a	Lewis Swift	May: elements
1881 III	John Tebbutt	July–August: usual emission bands, faint fourth band in the blue
1881c IV	J. M. Schäberle	August: three emission bands.
1881f	W. F. Denning	October: elements, ephemeris
1882 I	C. S. Wells	April–June: spectra, sodium D lines as well as comet bands
1882 II 'Great'	W. H. Finlay	September–October: D lines, also E and other prominent iron lines
1884 III	Max Wolf	September: positions
1888e	E. E. Barnard	November: spectrum, weak bands

five bright emission lines with a Vogel spectroscope (Figure 8).[87]

Copeland and Lohse identified two of the five lines with hydrogen (Hα and Hβ), while another, at 502 nm, was found to be close to the brightest line seen in gaseous nebulae, and the remaining two (579 and 464 nm) were identified with emission lines seen in the recently discovered Wolf–Rayet stars.

Further observations at Dun Echt showed the spectrum to be evolving: the hydrogen lines faded and by January 19 the line at 500 nm was the brightest. After February 16 the nova became lost in the twilight. When it was recovered in September, the spectrum showed only the 500-nm line, for which a final wavelength of 500.2 ± 0.4 nm was derived, in excellent agreement with the 500.7-nm nebular line now identified with doubly ionized oxygen [OIII].[88]

This investigation was published in *Copernicus*, a journal established in 1881 and edited by Copeland and the Danish-born astronomer John Louis Emil Dreyer (1852–1926) who succeeded Copeland at Birr and then at Dunsink. Although it included papers by the Dun Echt observers, it was an international journal, publishing a wide variety of contributions, some in French and German. Unfortunately, it was not financially viable, and ceased publication after three years.

Longer-lasting was the series of brief *Dun Echt Circulars*, initiated by Lord Lindsay in 1879 to inform astronomers of the appearance of comets and other temporary phenomena. The mailing list included about 200 recipients.[89] Many Circulars also appeared in the *Astronomical Register*, a journal for amateur astronomers published monthly between 1863 and 1886.

At the same time that the first *Dun Echt Circulars* were issued, Seth Carlo Chandler (1846–1913) and John Ritchie (1853–1939) of the Boston Scientific Society developed a code (the Science Observer Code) for the telegraphic transmission of cometary orbits. To test the usefulness of the code, which was based on the location of words in a dictionary to convey each set of five digits, they arranged with Lord Crawford for the receipt and publication of cable messages containing orbits computed in the United States and vice versa.[90,91]

For example, *Dun Echt Circular* No. 17, issued on 1881 May 9, quoted the elements and ephemeris of Swift's comet received by cable from Boston using the Science Observer Code, followed by new observations from Dun Echt and revised elements and ephemeris derived by Lohse and Copeland.[92] At the meeting of the Astronomische Gesellschaft in 1881 September, Chandler and Ritchie drew attention to the tests between Boston and Dun Echt and Copeland gave a thorough exposition of the code, including examples for communicating cometary elements and ephemerides.[93,94]

5.1. *Cometary observations at Dun Echt*

The observation of comets and determination of their elements was a growing part of the programme at Dun Echt (Table 2). In 1877 April and May Copeland and Lohse observed the spectra of Winnecke's (1877b) and Borrelly's (1877c) comets, each showing three 'bright' bands but at different wavelengths.[95] In 1879, Copeland and Lohse observed the spectrum of Palisa's comet, which showed the comet bands.[96] Earlier, they measured its position and determined the elements of its orbit.[97]

Similarly, they observed and computed elements for two comets in 1880 (1880b Schäberle,[98] and 1880e Swift[99]), and observed three comets in 1881 (1881b, f, and g).[100] They reported the discovery of sodium D emission lines in Comet Wells (1882 I) and the Great Comet of 1882 (1882 II).[101]

The latter was observed in daylight on September 18, just one day after perihelion. The D emission lines were observed to lie just to the red of the corresponding absorption lines from the scattered solar spectrum, indicating a recession velocity of between 37 and 46 mile/s (60–74 km/s). Next in intensity came several lines in the green, each of which also lay just to the red of scattered solar absorption lines, all at the same displacements. These they identified as iron lines, which became controversial,[102] but possible mechanisms for driving some iron lines into emission when a comet is extremely close to the Sun (as was Comet 1882 II when observed by Copeland and Lohse) were demonstrated in 1962 by Greenstein and Arpigny.[103]

In parallel with the Dun Echt observations Copeland set out to coordinate systematic searches for comets, suggesting declination zones to various observers, and making Dun Echt a central station where places of newly discovered comets and nebulae would be measured.[104] Dun Echt may have been geographically isolated but it was closely networked with astronomers in Britain and overseas.

In 1879, Copeland had his first official dealings with the Royal Observatory in Edinburgh. The Astronomer Royal for Scotland, Charles Piazzi Smyth (1819–1900), recorded: 'An announcement from Lord Lindsay that he has been deputed by the Home Secretary to examine the equatorial [telescope, a long-standing bone of contention] and report the cost of completing it for work – will therefore come, with some preliminaries, on [Monday] May 19.'[105]

On May 15 he noted: 'Dr Copeland, Lord Lindsay's chief observer arrived to make the required preliminary examinations', and the following two days 'Dr C hard at work in Dome, with myself and assistants, examining, trying cleaning &c all parts'. This is more friendly than Piazzi Smyth's entry on the commission itself ('They had a long meeting, partly in the Dome, partly in the computing room. I am not present at it or on it, although I receive them within the Obsy …'), suggesting considerable tact and good nature on Copeland's part, given that Piazzi Smyth was at that time mired in quarrels.[106]

5.2. *Travel and observing in the Andes*

Copeland observed his second transit of Venus in 1882 December as chief of a Government expedition to Jamaica which was part of the British contribution to an international campaign; he was assisted in his observations by Captain George Mackinlay of the Royal Artillery.[107,108] Copeland set out from Dun Echt in October, taking the same instrument that he used for the 1874 transit, namely the 6-inch refractor on an equatorial mount. While he was away, Theodora and the children made an extended visit to her family in Göttingen.[109]

After successfully observing the transit, Copeland set off on his own to South America with a view to testing the astronomical capabilities and climate of the elevated situation of Quito, in the Andes mountains of Ecuador. He took with him the 6-inch refractor (but not its equatorial mount, which he considered too heavy for mules), the Vogel spectroscope, and various meteorological instruments. The cost of this expedition was met by Lord Crawford.

His journey took him by sea to the Isthmus of Panama, crossing it, and taking another steamer to Guyaquil, the main port of Ecuador. The political volatility of the region threw up unexpected obstacles that required all his considerable resourcefulness to

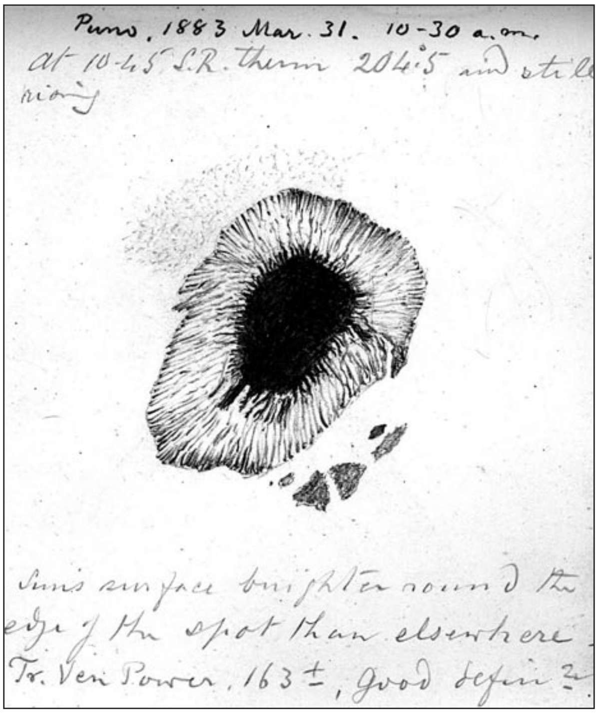


Fig. 9: Sketch from Copeland's pocket notebook of a sunspot observed at Puno on 1883 March 31, with an unsilvered diagonal plane ×163. (ROE Archives: 199, Observations in Puno and Vincocaya)

Table 3

Wolf–Rayet stars discovered by Ralph Copeland in Puno, Peru, giving his designations, modern names, and wavelengths of emission lines where measured

Name of star or coordinates (1883)	Modern name	Line wavelengths (nm)		
γ Argus	γ Velorum	580.9	566.8	464.6
Stone 9168	WR 79	580.9	569.2	465.1
13h 10m 37s, −57° 31′	WR 52	575.3	—	463.3
11h 05m 19s, −60° 21′	WR 42	—	—	—
08h 51m 01s, −47° 08′	WR 14	573	—	463.3
10h 36m 54s, −58° 08′	WR 23	—	—	—

overcome. When he reached Guyaquil on 1883 January 1 the country was in a state of revolution. Forced to change his plans, he continued down the coast by steamer to Lima in neighbouring Peru.

There he was frustrated again by more political conflict: the upper part of the Trans-Andean Railway was closed because of a war between Peru and Chile. He continued further down the coast to Mollendo in southern Peru, the port for Arequipa and Puno on the westerns shore of Lake Titicaca. He was granted a permit to cross the Chilean blockade at Mollendo by the Chilean commander-in-chief. In Lima he had had the good fortune to fall in with the lessee of the Mollendo Railway, Mr John Thorndike, who offered him valuable assistance.

Copeland published an extensive report on his travels in *Copernicus*, reporting detailed meteorological, and astronomical observations.[110] He also published a more descriptive two-part narrative in the *Deutsche Geographische Blätter*.[111] This account begins with his landing in Mollendo on February 2, reporting that the Chilean gunboat enforcing the blockade of the city was at sea, and the English captain of the steamer did not want to waste time waiting for its return, so he allowed passengers with permits to land and continued on his voyage.

The weekly train for the interior left the following morning. Copeland's account in the *Deutsche Geographische Blätter* gives a detailed description of the journey, the terrain, and vegetation as the train climbed from the coast to Arequipa, altitude 7,660 ft (2,335 m).[112] In Arequipa he noted the use of sillar, a volcanic tuff, as the common building material and of stone arches in the construction of house roofs and churches to withstand earthquakes. The Jesuit church had stood for two centuries but showed many cracks. He was in Arequipa at the time of Carnival but was not appreciative of the traditional practice of dousing passers-by with water from eggshells or buckets: 'It's no fun being pelted with eggs filled with all sorts of dyes or even more questionable liquids.'[113]

Copeland was unable to make astronomical observations during his stay in Arequipa because most of his equipment was in a bonded truck which had been shunted off the train en route. But on the recommendation of Mr Thorndike he consulted the mechanical engineers of the railway, who 'transformed a 6-inch lathe into a very fair equatorial mounting by simply reversing the fast head-stock and adapting a cross-axis to the face-plate'.[114]

On February 9 he reached Vincocaya, the highest station (14,360 ft, 4,380 m) on the line, where he stayed the night. The weather was so bad that he left the telescope and heavy equipment there and went on to Puno the following day from where he crossed Lake Titicaca on a steamer and went on to La Paz in Bolivia by stagecoach. The journey, terrain, geology, vegetation, animals, and people are all described with close interest in his report; Copeland was evidently very observant.

The weather in La Paz was no better, so after two weeks he returned to Puno. On the way back across Lake Titicaca he stopped at the island of Coati (or Koati) to examine the ruins of the Temple of the Moon and the nearby stone terraces, which he found particularly impressive.[115] From Puno he continued westwards to Vincocaya where he erected the telescope in the hope of being able to begin observations.[116] But the weather was still bad, with thunderstorms, rain, and snow, so after two weeks he packed up his equipment and went back to Puno, where the weather was reported to be better.

In Puno, he erected his telescope in a corrugated iron hut within the railway station enclosure. By removing the roof of the hut and giving the lathe-bed mounting a suitable inclination on some heavy iron castings (he was now at latitude 16° south), the telescope was readied for observing. To examine the seeing, he observed a number of close double stars, some discovered to be such in the process, measuring separations as small as 0″.8 for β Muscae, ψ Argus (= ψ Velorum), and ε Lupi.[117] He also observed and sketched a spectacular sunspot (Figure 9). To test the clarity of the air, Copeland observed bright stars and Jupiter in daylight.

He had intended to observe the spectrum of the remarkable variable star η Argus (the present-day η Carinae), famous for its eruption in 1843, but had failed to bring a chart with him, having hoped to find one in the library at Quito. He was unable to distinguish it from the other stars in the region by spectroscopic scanning. This was, though, more than compensated for by his sight of the spectrum of γ Argus (now γ Velorum): 'Its intensely bright line in the blue, and the gorgeous group of three bright lines in the yellow and orange, render its spectrum incomparably the most brilliant and striking in the whole heavens.'[118]

The extraordinary beauty of the spectrum inspired him to search for more such stars. In sweeps of the neighbourhood he discovered another five and identified them as Wolf–Rayet stars, i.e. hot, luminous stars

Fig. 10: Copeland with the Cooke spectroscope attached to the 15-inch refractor at the new Royal Observatory Edinburgh in about 1898 after its transfer from Dun Echt. (ROE archives)

with intense stellar winds that are believed to be a late stage in the evolution of O-type stars (Table 3).

In June he returned to Vincocaya where he was able to attach the telescope to the lightweight mounting and clock drive which had been sent out from Dun Echt, and with this he measured the wavelengths of the bright lines. The lines are now known to be from carbon ions (CIV at 580.8, CIII at 569.7, and CIII+IV at 465.0 nm).[119] We can see the accuracy of Copeland's wavelengths for the first two stars in Table 3; he was unable to separate the first two transitions in the other two stars. He observed a fourth, narrower line at 590 nm in γ Argus; this was the D3 line now identified with helium.

Besides the Wolf–Rayet stars, he discovered a number of planetary nebulae and observed and described the spectra of numerous other stars. He also observed the spectrum of lightning during a violent thunderstorm, identifying a number of nitrogen lines. Also in Vincocaya he used the Browning spectroscope that had been sent out from Dun Echt to observe the Sun, hoping to see emission lines from the corona. He detected emission in the C (Hα), F (Hβ), and D3 lines from solar prominences but never from the corona.

After a spell of observing in good weather Copeland left Vincocaya on June 28 for Mollendo, where he boarded a ship for the south. This stopped at Arica in northern Chile. From there he went to Tacna, just across the border in southern Peru, for a week, awaiting the arrival of the northbound steamer. His report includes extensive recording of meteorological data, temperatures, relative humidities, and atmospheric pressures at Puno, Vincocaya, La Paz, and, briefly, at Arequipa, Mollendo, and Tacna.[120]

Regarding the choice of observing stations, he judged that Vincocaya offered no advantage over Puno because of its greater range of temperature and prevalence of dust. He suggested that the summit of one of the islands on Lake Titicaca would offer advantages of more stable temperatures and less dust and concluded that it was possible to observe for nearly nine months of the year. Although La Paz and Arequipa offered more facilities, he considered them hemmed-in by mountains and was concerned about earthquakes in Arequipa. In the event, Harvard College Observatory established its southern station (known as the Boyden station) in Arequipa in 1890 and the Astrophysical Observatory Potsdam chose La Paz in 1926, opting for the locations with the better facilities.

5.3. *Return to Dun Echt*

On the way home, Copeland reached New York at the beginning of August and visited a number of eastern North American and Canadian observatories, surveying their instrumentation, before reaching home on 1883 September 1, nearly a year after his departure.[121]

Back in Dun Echt he continued coordination of comet searching[122] and made sweeps for more objects with remarkable spectra, discovering more planetary nebulae and another Wolf–Rayet star,[123] and continued observing comets and novae.

One reported nova, since given the variable star designation S And and now known to be a supernova, was in the Andromeda nebula. Dun Echt received news of it on 1885 September 1, with a request to investigate.[124] Copeland's observation that night found the spectrum to have little or nothing in common with that of Schmidt's Nova Cygni (see above) in its earlier stages. Together with Lord Crawford and Ludwig Wilhelm Emil Ernst Becker (1860–1947)[125] he accurately measured the position of the nova.[126]

Continued spectroscopy as the supernova faded allowed measurement of three weak emission bands which Copeland associated with bands he later measured in the spectrum of the Mira variable U Orionis, which was initially believed to be a nova.[127] Copeland was cautious of his identification but confident of his wavelengths, and in their review marking the centenary of the eruption G. de Vaucouleurs and H. G. Corwin found them and those of other historical observers to be consistent with those of Type I supernovae.[128]

In 1886–87 Copeland observed the Orion nebula with the new Cooke spectrograph on the 15-inch (Figure 10), leading to his most important discovery, that of helium in the nebula from the D3 line at 587.4 nm.[129] This provided a link between gaseous nebulae, the Sun, and Wolf–Rayet stars (he had observed the D3 line in γ Argus at Vincocaya), showing the widespread presence of helium. On one night he observed what turned out to be another, faint helium line near 448 nm. Encouraged by this discovery, he began a regular spectroscopic survey of the brighter nebulae. This could have yielded valuable results, but he had to set it aside in favour of other work.[130]

Later in 1887 Copeland represented the Royal Astronomical Society at the first of his eclipse expeditions: to Pogoste, near Kineshma, some 335 km (208 miles) north-east of Moscow. He made elaborate preparations to observe the event but on the day of the event, August 19, the weather was so bad that no usable results were obtained.[131]

All this time, Copeland was deeply involved in cataloguing the Dun Echt library, a unique collection of nearly 11,000 astronomical books, pamphlets, and manuscripts, many dating back to the 15th and 16th centuries and of considerable value. In this task he was assisted by his nephew Robert Copeland.[132] He was also responsible for ordering books: for example, in the 12 months following his return from the Andes he wrote 14 letters to booksellers in Britain and the continent, ordering over 150 books.[133] By the time this massive enterprise was completed with the publication of the *Catalogue of the Crawford Library* in 1890, an unexpected turn of events had placed the collection in Copeland's hands.[134]

6. Directorship and transformation of the Royal Observatory Edinburgh

In 1888 Piazzi Smyth resigned as Astronomer Royal for Scotland. The Royal Observatory was in poor condition and a Royal Commission on Scottish Universities recommended its abolition as a national institution. Lord Crawford was outraged at the prospect of Scotland losing its national observatory and offered to donate the instruments and library of his own observatory at Dun Echt to the nation on condition that the Edinburgh establishment thus enriched should be the publicly maintained Royal Observatory on Calton Hill – a donation that was accepted.[135]

In 1888 December Ralph Copeland was appointed Astronomer Royal and Professor of Practical Astronomy in the University of Edinburgh.[136] He took up his post in

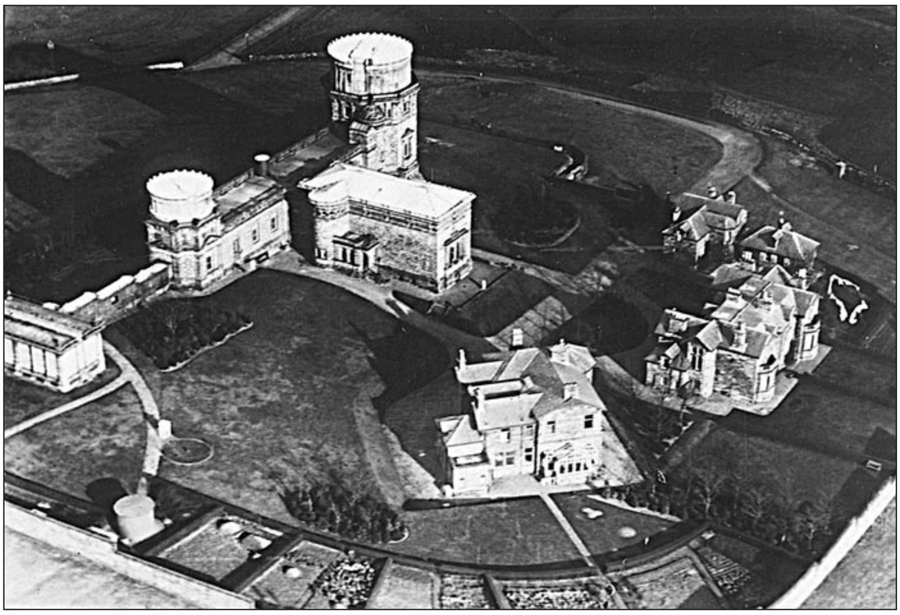


Fig. 11: The Royal Observatory Edinburgh seen from the air in about 1920. The house in the foreground was the Astronomer Royal's residence until 1975 and is now named Copeland House. The turret to the left (west) on the main building holds the 24-inch reflector (from Calton Hill). In the one on the right (east) is the 15-inch refractor from Dun Echt. Far left, reached by a passage, is the Transit House. The turret in the left foreground holds the 12-inch reflector; between it and the Main Building is the meteorological station. (ROE Archives)

early 1889, which came with an official residence in the Astronomer Royal's house in Royal Terrace close to the Royal Observatory. His first task was the selection of a suitable site for the new observatory, away from the smoke of the city centre but close enough to the university to allow him to fulfil his teaching duties. At the same time, the routine work of the existing observatory on Calton Hill, such as provision of the time service, had to be continued.

He recorded his activities in 1889–90 in a Day Book in the Observatory's 'Equatorial Book'.[137] The entries include numerous visits to the hills to the south and west of the city between 1889 February and June, both on his own and accompanied by members of a committee including Lord Crawford, Professor Peter Tait (Natural Philosophy, University of Edinburgh), Lord John McLaren (Court of Session and an amateur astronomer), and Mr John Reid, the Queen's Remembrancer (an officer representing the Crown's interests). Eventually, on June 17, the committee approved the eastern end of Blackford Hill as the most convenient and suitable site.

A few days earlier, Copeland had recorded: 'Fine and calm. City full of smoke, but could see N. Berwick Law from Blackford Hill'.[138] As the site was close to a railway line, its stability against transmission of vibrations when heavy trains were passing was tested and confirmed by observations through a transit instrument brought from Dun Echt and also from reflections in a bowl of mercury.[139,140] Thereafter plans for the buildings could proceed. To guide the design of the new building, Copeland visited several recently built observatories on the Continent.[141]

Interspersed with his activities regarding the site and building for the new observatory, Copeland's Day Book records numerous entries between May and August detailing cleaning and silvering the mirror of the Calton Hill 24-inch reflector. At the beginning of the University's winter session that year he reinstated astronomy lectures after many years of neglect by Piazzi Smyth. In December, he was elected a Fellow of the Royal Society of Edinburgh, and later served as its Vice-President in 1892–96 and 1898–1903.[142]

Copeland's Day Book entries for 1890 report numerous meetings with Lords Crawford and McLaren, Professor Tait, the architect Walter Wood Robertson (1845–1907), and Reginald MacLeod, who succeeded John Reid as the Queen's Remembrancer in 1889, as the plans for the new Observatory were developed. The final plans and estimates were settled in 1890 August.[143]

In 1891 August Copeland read a paper and exhibited a model at the Cardiff meeting of the British Association reporting experiments to replicate the bright streaks on the Moon with a 22-inch plaster model having tiny spherules of glass attached. Like the bright streaks, these were found to be inconspicuous under cross light, but brightest when illuminated from the front.[144]

On 1892 February 1 Copeland received an anonymous postcard alerting him to the appearance of a nova in Auriga. Examination of its spectrum through the 24-inch reflector on Calton Hill showed an emission line spectrum with the C (Hα) line being intense.[145] The next day Lugwig Becker went to Dun Echt to observe the spectrum using the 15-inch refractor and Grubb spectrograph, while Copeland remained in Edinburgh to use the equipment on Calton Hill for a light curve and spectrum using his Vogel spectroscope.[146] He also identified the sender of the postcard as the Scottish amateur astronomer Thomas David Anderson (1853–1932) and persuaded him to write to *Nature* describing the circumstances of his discovery.[147]

Meanwhile, from examination of photographic plates at Harvard, E. C. Pickering found that the nova was invisible up to 1891 December 1 but bright on December 10, reaching maximum near December 18.[148] It became known as Nova Aurigae 1891 and was given the variable-star designation T Aurigae.

During the night of March 7–8 a fire broke out in Copeland's house. He wrote in his Diary:

> March 7 Went to bed at 15 Royal Terrace about 12-30 p.m. – everything in the house at that time appearing to be as usual. Mar 8. About 4-30 a.m. an alarm of fire was given ... The fire must have been burning fiercely for some time, as it had obtained a firm hold of the south-west corner of the house from the basement to the roof – five stories [*sic*] in all. The wooden lining of the roof contributed much to the spread of the fire. By the time that the inmates of the upper part of the house, six in number, had collected in the communicating front rooms of the second floor the smoke had become so suffocatingly dense that it appeared in the highest degree undesirable to rush down the long stone staircase. We therefore decided to descend to the balcony of one of the first-floor windows by the aid of sheets knotted together. … A good many books are more or less disfigured by water, fire and smoke, but happily all the finer parts of the library are absolutely intact.[149]

The Scotsman reported that the Library of valuable scientific literature, at street level in the house, included the Crawford Collection and that the books were removed to the greenhouse at the rear of the building shortly after the outbreak occurred.[150] Fanny, then in Berlin studying music, received a telegram after the fire: 'Fire. No one hurt. All birds dead. Dog saved'.[151]

On March 11 Copeland attended a meeting of the Site and Plans Committee of the new Observatory, again discussing costs. Mr Robertson, the architect, was requested to lessen the requirements by paring as much as possible without interfering with the essential portions of the buildings. Preparations continued: on July 2 Copeland recorded visiting Blackford Hill where a tramline was being constructed up the face of the hill from the railway line for the transport of stone and other heavy building material.[152] Also in July he visited

Figure12: Copeland and his wife Theodora in front of the astronomer's house at Dun Echt in 1888. Standing on the left is their daughter Paula (12) while the children on the right are Theodore (9) and Agnes (6); their oldest daughter Fanny was in Germany continuing her education at the time. The young woman at the back may be Copeland's daughter Elizabeth from his first marriage; her brother Richard was also away. (ROE Archives)

Dublin for the tercentenary celebrations of Trinity College, and then his old places of work at Birr and Dunsink.[153] On July 27 he was in Lancaster to open the Greg Observatory.[154]

For a few days in August, in between visits to Blackford Hill and other duties, Copeland was at Dun Echt again and, with his old colleague Gerhard Lohse, used the 15-inch refractor to observe Nova Aurigae, measuring emission lines at 500.3 and 495.3 nm on August 25 and 26, demonstrating that the nova was now shining as a gas nebula. Under very good conditions on August 28, Copeland observed another line at 580.1 nm, which he identified with that seen in the spectra of Nova Cygni and the Wolf–Rayet stars.[155]

6.1. *Building the new Observatory*

On 1892 October 4 the first stone of the new Observatory was laid on the concrete bedding, apparently without ceremony. Following his visit on October 9 Copeland recorded that the stonework of the East Tower was progressing, a steam crane and two hand cranes had been erected, and that the foundations of the main building were completed.

The need to save costs was relentless. He recorded that on 1893 March 20 the Observatory Plans Committee held a meeting in the office of the Queen's Remembrancer at which the proposed plans of the new domes were discussed. To lessen the cost of the smaller dome, an attempt was to be made to adapt some portions of the Dun Echt dome. On March 29, he and Sir Howard Grubb (from Dublin) went to Dun Echt to examine that dome, but concluded that not much of it could be reused. Copeland was back in Dun Echt in July for the dismounting of the 15-inch refractor prior to its transfer to the new Observatory.[156]

In 1893 August Copeland visited the German Naval Observatory in Hamburg to look at instruments and domes and to see Captain Koldewey, who had recently retired as its Director. Also, in Berlin, he visited Arthur Auwers (1838–1915) to discuss the re-reduction of positional measurements made in 1835–45 by Thomas Henderson (1798–1844), Piazzi Smyth's predecessor, from Calton Hill. He then visited the spectroscopist Hermann Carl Vogel (1841–1907) at Potsdam Observatory, followed by a stay at the Naval Observatory at Wilhelmshaven where his old colleague Carl Börgen was Director.

In 1893 October he resumed teaching – four lectures a week and meeting the class at the Observatory on Friday evenings – and monitoring the building work on Blackford Hill. This pattern continued in 1894 as the new Observatory neared completion. In the summer he travelled around the west of Scotland and the north and east of Ireland to interview people who had

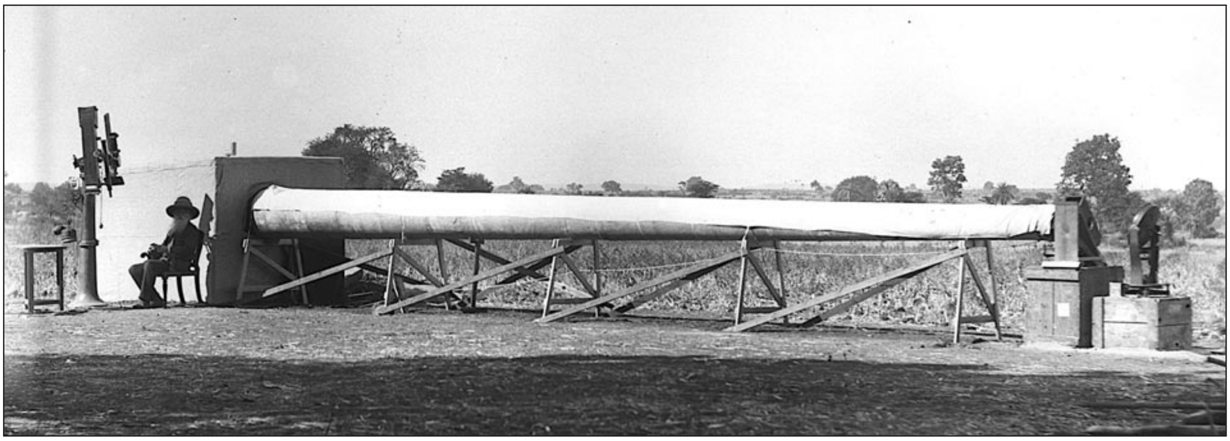


Fig. 13: The 40-foot solar camera with Dallmeyer 4-inch photographic lens at Ghoglee, India, in 1898. Copeland is seated in front of the dark-room containing the focus and is ready to use the telescopes next to him for optical and ultraviolet spectroscopy. (ROE archives)

seen the brilliant meteor on May 19 at 8 p.m. and computed its path.[157]

Since 1852, the Royal Observatory had provided a time service for the city and its port of Leith, signalled by a time ball on the Nelson Monument on Calton Hill that was dropped at a precise time each day. From 1861 this was augmented by a gun fired from Edinburgh Castle, controlled by a cable from Calton Hill.[158]

The continuation of this by the new Observatory must have been questioned because Copeland's Diary for 1895 April 8 records that he called on the Queen's Remembrancer and explained to him the true importance of the time service. He pointed out that the signal was for the use of the Royal Navy and also for merchant shipping, not just for the town. The time gun was supplied with powder by the Treasury and the gun was fired by the military under instructions from the War Office, so that it was a State undertaking in the hands of the Government Astronomer.

He also went to London to meet Lord Crawford, the Under Secretary for Scotland and the Hydrographer to the Admiralty, who all agreed that the time service ought to be continued from the new Observatory. So the Post Office provided wires from Blackford Hill to the Edinburgh General Post Office and Nelson Monument and on November 8 the time-ball dropped and the Castle gun fired for the first time following time signals from Blackford Hill.[159]

Setting up of the new Observatory and installation of the equipment continued during 1895. Copeland moved into the substantial Astronomer Royal's house in the grounds in May.[160] A few months later, Jacob Karl Ernst Halm (1866–1944) from Strasbourg Observatory arrived to take up the position of senior assistant.[161]

The first months of 1896 saw the last major installation: that of the 24-inch reflector transferred from Calton Hill. At last, on 1896 April 7, the new Royal Observatory was formally opened by Lord Balfour of Burleigh, Secretary for Scotland, in front of distinguished guests. Copeland, the architect W. W. Robertson, and Lord Crawford spoke on the history of the observatory, the design of the new building, and the circumstances of the new establishment.[162]

Now that the Royal Observatory was complete and the telescopes installed, one might have expected Copeland to resume his spectroscopic observations undertaken at Dun Echt, such as the survey of brighter nebulae begun after his discovery of helium lines in the Orion nebula. Sadly, as his friend and obituarist Dreyer observed, Copeland's energy and capacity for work had now declined, because the heart disease to which he eventually succumbed had already begun to undermine his strength.[163] His Diary entries ceased during 1896.

6.2. *Eclipse expeditions*

He did, however, undertake three more eclipse expeditions. The first, to Vadsø in northern Norway to observe the total eclipse on 1896 August 8, was supported by a grant from the Royal Society of Edinburgh.[164] On July 18 Copeland sailed from Newcastle accompanied by his son Theodore (1879–1952) as a volunteer, the ROE Second Assistant Andrew James Ramsay (1862–99), and observatory engineer James McPherson.

Their equipment, sent on ahead, included a 40-ft long-focus camera of 4 inches (100 mm) aperture with a moving plate-holder in an improvised dark-room at the focus, the 6-inch (150-mm) Simms telescope with an objective prism for spectroscopy of the chromosphere, another telescope of 1.8 inches (46 mm) aperture with a quartz objective and Iceland-spar prism for ultraviolet spectroscopy, and two more cameras for direct imaging. Unfortunately, the weather was unfavourable at the critical time and no useful results were obtained. On the way back, at the port of Vardø, Copeland had the consolation of welcoming the polar explorer Fridtjof Nansen on his return from his polar expedition of 1893–96.[165]

The following year, Nansen visited Copeland at the Observatory and examined some of Julius Payer's maps of the Arctic.[166] During his expedition, Nansen had found that the northern part of Payer's map of Franz Josef Land was too inaccurate to be of much use. This came as a painful surprise to Copeland who had a high

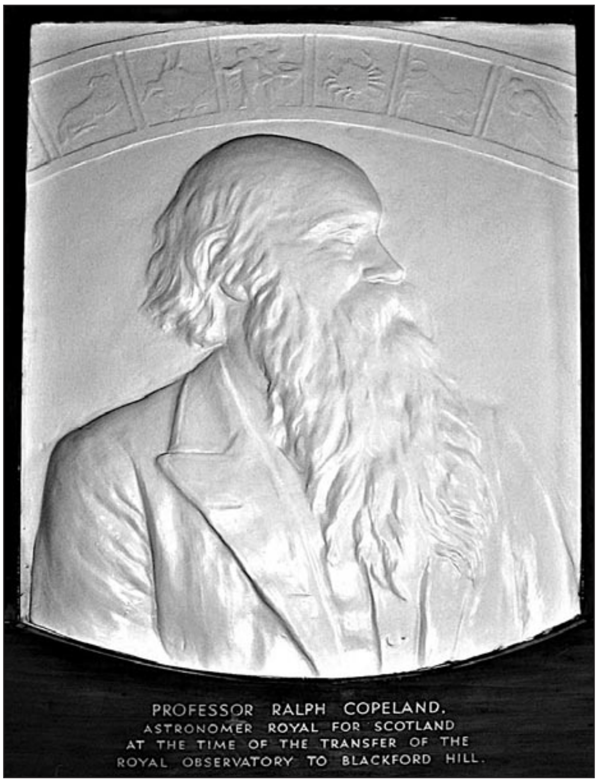


Fig. 14: Mural sculpture of Ralph Copeland in the main entrance lobby of the new Royal Observatory building (Author's photograph)

opinion of Payer dating from their experiences during the Arctic expedition. He therefore borrowed and re-examined Payer's original survey records from the Royal Geographic Society from which he produced an improved map.[167]

At the invitation of the Joint Permanent Eclipse Committee of the Royal Society and Royal Astronomical Society, Copeland took part in an expedition to observe the total solar eclipse of 1898 January 22 from India. The equipment was similar to that he had taken to Vadsø, including the 40-ft long-focus camera for large-scale imaging (Figure 13) and telescopes for optical and ultraviolet spectroscopy. He was again accompanied by the engineer James McPherson. Copeland chose to observe from Ghoglee, 16 miles (26 km) north-west of Nagpur, some distance from other major groups of observers in case one or another was thwarted by bad weather. In the event the weather was good and he obtained useful observations.[168]

Also in 1898 Copeland initiated a major observational programme with the transit circle, the determination of the positions of stars near the ecliptic. This was suggested to him by Sir David Gill to provide a suitable reference system for precise observations of the major planets using the heliometer. Halm began the observing in May, but it was not completed until 1908, after Copeland had died and Halm had left for the Royal Observatory at the Cape.[169]

Copeland next accepted an invitation by the Joint Permanent Eclipse Committee to take part in observing the total solar eclipse of 1900 May 28 from Santa Pola, on the south-east coast of Spain, together with Sir Norman Lockyer and his team. The Admiralty had put HMS *Theseus* at the disposal of the Joint Committee, which conveyed the observers and their equipment from Gibraltar to Santa Pola and whose crew helped with haulage of equipment. Copeland's equipment comprised the 40-ft horizontal camera, operated by the experienced James McPherson in its improvised dark-room, and the Iceland spar and quartz prismatic camera for ultraviolet spectroscopy. Again, the weather was favourable, and good images and spectra were obtained. Copeland's report on this expedition was, like that of the Ghoglee expedition, preliminary and essentially narrative.[170]

Copeland's final investigation, fittingly, used the 15-inch refractor from Dun Echt for spectroscopy of the nova now known as GK Persei, discovered by Thomas Anderson of Edinburgh in the early hours of 1901 February 22. When observed later on February 22 it showed a continuous spectrum, quite unlike that of Anderson's previous discovery, Nova Aurigae. On close inspection Halm noticed weak absorption features, confirmed by Copeland.

The next few nights were overcast. When observed on February 27 the spectrum had changed profoundly to resemble that of Nova Aurigae at its brightest, with strong emission lines. Nearly all the emission lines were very broad, having deep black lines on the blue sides. In his contribution to the Royal Society of Edinburgh, Copeland suggested that the dark lines were from absorption by the same kind of material responsible for the emission spectrum, but of lower temperature and being carried towards us at 800 mile/s (1,300 km/s) relative to the emission-line source.[171] He found it remarkable that this nova should show 'a displacement of nearly the same amount and towards the same side' as Nova Aurigae.

One can speculate that, had Copeland been in his prime, he would have made the jump to the interpretation of the line profiles as arising from a rapidly expanding sphere of hot gas. Unfortunately, he had a severe attack of influenza in the middle of 1901 from which he never fully recovered and it was Halm who interpreted what we now call the P Cygni line profiles.[172,173]

While attempting to recuperate from his illness in Wiesbaden in 1902 May, Copeland suffered an attack of angina pectoris after hurrying to catch a train. The attacks continued and in 1904 he had to relinquish his lecturing and practical work with students to Dr Halm.

Despite his illness, during his last few years Copeland remained mentally active by taking up the study of Persian, and was delighted to be able to read *Omar Khayyam* in the original language.[174] His condition that year was such that his son Theodore, who was an Assistant Commissioner and Sub-Judge at Kohat in the North-West Frontier Province of India, took three months' special leave to visit him.[175]

His health seemed to improve and he was tolerably well in the summer of 1905, but his heart condition worsened and he died on October 27 that year. He was buried in Morningside Cemetery, where he was later joined by his daughters Paula and Agnes in 1910 and 1929, and his wife Theodora in 1938.

7. Ralph Copeland's legacy

Ralph Copeland's gravestone is in Morningside Cemetery but his true memorial is the Royal Observatory on Blackford Hill. He played a key role in the realization of Lord Crawford's benefaction through choice of site, design of buildings, dealings with the Queen's Remembrancer regarding costs, and responsibility for the transfer of equipment and instruments to the new observatory and their installation. At the same time, he reinstated astronomical teaching at the University, including practical work.

Of his own astronomical work, one can point to the discovery of helium in the Orion nebula, the spectroscopic evolution of novae, and spectroscopy of comets – but no new concepts. As remarked by Dreyer, 'his published papers are not as numerous as his friends could have wished, but his anxiety to perfect his results as far as possible, before printing them, of late years frequently led to a paper being laid aside and never published'.[176]

He was certainly an excellent observer, whether of galaxies discovered with the Leviathan (including Copeland's Septet) or accurate wavelengths of emission lines, as well as a resourceful instrumentalist, witness the use of a lathe for an equatorial telescope mount in the Andes. He demonstrated the improved image quality achievable at high altitude and discussed the merits of high-altitude sites for astronomy.

His catalogue of the Dun Echt astronomical library, now the Crawford Collection at the Royal Observatory Edinburgh, is 'one of the most valuable guides to astronomical literature, especially previous to the year 1700'.[177] Finally, Copeland remained an authority on Arctic exploration, being a member of the committee which launched the 1902–04 Scottish Antarctic Expedition in 1894 January.[178]

We can leave the last word with Dreyer, who concluded his RAS obituary of Copeland as follows:

> His character was open, sincere, and generous, he was always anxious to befriend and help anybody whenever he could, and he never shirked any trouble or work to answer inquiries even from people who had no claim on his time. He will be remembered with warm affection by all who had more than a passing acquaintance with him.

Acknowledgements

It is a pleasure to thank Karen Moran, Librarian at the Royal Observatory Edinburgh, for her expert help with the ROE Archive material, and Gillian Wright, Director of the UK Astronomy Technology Centre, for permission to reproduce images from the Archive. My interest in Copeland was sparked by his being listed as a discoverer of Wolf–Rayet stars in the bibliographies compiled by Karel van der Hucht and my exploration of the circumstances of these discoveries for a talk I gave in Karel's honour on the occasion of his retirement.

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26 Dreyer (1906, ref. 1), p. 164.

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30 It might have been his religion: as a Dissenter, he would have been disadvantaged prior to the 1871 Universities Test Act but it is more likely that he was not attracted to, or equipped for, the mathematical syllabus.

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112 Including the large breakfast served at Cachondo (3,250 ft): soup, puchero (traditional stew), fish, beefsteak, coffee, Peruvian wine, and hot pisco, the indigenous liquor.

113 Copeland (1883, ref. 111), p. 110. The original quote in German is: 'Es kein Vergnügen macht, sich mit Eiern bewerfen zu lassen, die mit allerlei Farbstoffen oder noch bedenklicheren Flüssigkeiten gefüllt sind'.

114 Copeland (1884, ref. 110), pp. 194 and 199. His earlier railway engineering experience must have smoothed the path here. The main wheel of the lathe was used as an hour circle: 'it had the awkward number of 63 teeth, but by increasing the hour angle by 1/20th part each tooth of the wheel corresponded to 24 minutes of this augmented time and admitted of easy subdivision'.

115 Copeland (1883, ref. 111), p. 222.

116 Copeland (1884, ref. 110), p. 195.

117 Ibid., p. 200.

118 Ibid., 204–5. Copeland later learned that the Italian astronomer Lorenzo Respighi (1824–89) had first seen this spectrum in 1871. His observing notes giving finding charts and sketches of the spectra are in the ROE Archives: 199, Wooden Box 2, small leather-bound notebook, labelled 'Observations in Puno and Vincocaya'.

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124 Copeland, R., 'On Hartwig's Nova Andromedae', *Monthly Notices of the Royal Astronomical Society*, 47 (1886), 49–61.

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128 de Vaucouleurs, G., and Corwin, H. G., 'S Andromedae 1885: A Centennial Review', *Astrophysical Journal*, 295 (1985), 287–304. These authors also analysed the historical photometry and produced a definitive light curve.

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130 Dreyer (1906, ref. 1), p. 170.

131 Copeland, R., 'The total solar eclipse of 1887, August 19', *Monthly Notices of the Royal Astronomical Society*, 48 (1887), 48–51.

132 Brück (1992, ref. 84), p. 125.

133 *Dun Echt Letter Book 1883–1886*, ROE Archives, 29.190. The same period saw almost as many letters to Thomas Cooke and Son, York, regarding the spectroscope they were building for the observatory.

134 Copeland, Ralph, *Catalogue of the Crawford Library of the Royal Observatory Edinburgh, by authority of Her Majesty's Government*, 1890.

135 Brück (1992, ref. 84), p. 126.

136 *The Morning Post*, 1888 December 18, p. 4, and other newspapers on the same date.

137 *Equatorial Book Vol. 2* (ref. 103); Copeland's 'Day Book' starts on p. 171.

138 North Berwick Law, a volcanic plug about 20 miles (30 km) north-east of Blackford Hill.

139 'Royal Observatory Edinburgh, (Report for 1889)', *Monthly Notices of the Royal Astronomical Society*, 50 (1890), p. 189.

140 Copeland's 'Day Book' in *Equatorial Book Vol. 2*, (ref. 103).

141 Brück (1992, ref. 84), p. 128. These visits are not recorded in the Day Book and may have taken place between appointment and his entering into the post.

142 Waterston, C. D., and Shearer, A. Macmillan, 2006, *Biographical Index of Former Fellows of the Royal Society of Edinburgh 1783–2002*, Part 1, A–J, p. 203.

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150 *The Scotsman*, 1892 March 9, p. 6.

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156 Copeland, R., *Diary* (ref. 83).

157 Dreyer (1906, ref. 1), p. 172.

158 Brück and Brück, op. cit. (ref. 106), 24–25.

159 Copeland, R., *Diary* (ref. 83).

160 Ibid. The Astronomer Royal's house was repurposed for office space in 1975 and from 2014 September 26 named Copeland House. A plaque was unveiled by the Astronomer Royal for Scotland John Brown and Copeland's great-granddaughter Mary Barkworth.

161 Brück (1992, ref. 84), p. 128.

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163 Dreyer (1906, ref. 1), p. 172.

164 Copeland, R., *Diary* (ref. 83).

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173 Halm, J., 'On Professor Seeliger's Theory of Temporary Stars', *Proceedings of the Royal Society of Edinburgh*, 25 (1904), 513–52.

174 Dreyer (1906, ref. 1), p. 174.

175 Copeland, R., letter to Fred Holloway, 1904 November 20, https://www.ericpercival.co.uk/Copeland/RC%20letters/letter9.htm
Fred Holloway was the friend with whom he set up the observatory at Gorton in about 1860.

176 Dreyer (1907, ref. 1), p. 238.

177 Dreyer (1907, ref. 1), p. 236.

178 Copeland, R., *Diary* (ref. 83). His support was commemorated in the name of the magnetic observatory hut built on Laurie Island, South Orkneys, by the Scottish Antarctic Expedition – see Brown, R. N. R., et al., *The voyage of the 'Scotia'; being the record of the voyage of exploration in Antarctic seas* (Blackwood, 1906), p. 108.

179 Dreyer (1906, ref. 1), p. 174.

The author

Peredur Williams is an Emeritus Researcher in the University of Edinburgh Institute for Astronomy, located at the Royal Observatory Edinburgh. After first degrees at the University of Cape Town and a PhD and Fellowship at Cambridge, in 1974 he joined the group at the ROE developing and testing infrared instrumentation. From 1978, he helped commission the UK Infrared Telescope and served UKIRT as a staff astronomer resident in Hilo, Hawaii, in 1979–85. Back at the ROE, he supported operation of UKIRT, then the JCMT and, eventually, the Astronomy Division. Following the restructuring of the ROE, he took a position in the Institute for Astronomy until retirement in 2010. His research has focused on the episodes of dust formation by Wolf–Rayet stars related to their membership of colliding-wind binaries and the discovery of such systems through outbursts in their infrared emission. These systems have long periods, up to decades, and the research continues. His historical interests focus on astronomical spectroscopy.

HD 114762 and the early search for exoplanets

John Harrington

During 1985–88 a small team at Harvard's Oak Ridge Observatory made radial velocity measurements that identified a possible giant exoplanet around the main-sequence star HD 114762, a decade before the first confirmed discovery of such a body. Drawing from interviews with the participants, this paper describes the team's combination of technical expertise and innovative thinking that made the discovery possible, and contrasts it with the scientific mainstream's opposition to the idea of close-in giant exoplanets (now known as hot Jupiters). The legacy of the companion's discovery is also explored, especially its anticipation of higher-resolution instruments that would lead to new discoveries. Finally, the paper discusses the ultra-precise astrometry from the Gaia mission that finally clarified the nature of HD 114762's companion as a red dwarf star rather than the first exoplanet.

1. Introduction

The hunt for planets around other stars (extrasolar planets, or more commonly exoplanets) is a long and sustained one, with purported detections going back as far as the 1850s.[1] Astronomers now generally agree that, after multiple false positives[2,3,4,5] the first real detections of exoplanets finally occurred around a pulsar in 1992 and around the Sun-like star 51 Pegasi three years later.[6,7]

The current consensus on the first exoplanet discoveries, however, overlooks the detection in 1988 of a possible substellar-mass object orbiting about 0.4 au from the 7th-magnitude F-type dwarf star HD 114762 in Coma Berenices.[8,9,10] The discovery team was led by David Winslow Latham (b. 1940) of the Smithsonian Astrophysical Observatory (SAO), who utilized the ageing 1.55-m (61-inch) Wyeth Reflector at Harvard's Oak Ridge Observatory near Boston.[11,12] Latham's involvement in the hunt arose in part from his long-term pursuit of better radial velocity (RV) precision for mapping star motions, but also because of a challenge to him by the Israeli astronomer Tsevi Mazeh (b. 1946) to hunt for a very unlikely type of exoplanet – giants in close orbits around dwarf stars.[13]

HD 114762's companion missed becoming the acclaimed first exoplanet not only because of the uncertainty at the time about its orbital inclination (and thus uncertainty in its mass)[14,15] but also because of the reluctance of other astronomers to accept that giant exoplanets with close-in orbits could exist.[16] That reticence reflected what philosopher of science Thomas Kuhn termed the 'existing paradigm',[17] i.e. an instinctive attachment to the status quo.

The status of HD 114762's companion remained controversial until it was finally resolved with ultra-precise astrometric data from the European Space Agency's Gaia mission in 2022.[18] Those data, when combined with previous radial velocity findings, clearly indicated that the companion's mass was not of planetary scale, but rather that of a red dwarf star.[19]

To understand the early hunt for exoplanets and appreciate the difficulty and significance of discovering HD 114762's companion, one has to know some history of the Oak Ridge facility as well as the background of the astronomers who used it to discover the companion.

2. Oak Ridge Observatory and the Wyeth Reflector

Oak Ridge Observatory, a now-closed facility formerly run by the SAO on behalf of Harvard University, is located not far west of Boston, Massachusetts. The Wyeth Reflector there, named after Harvard benefactor Stuart Wyeth (1862–1929) of the Wyeth pharmaceutical company, was constructed in the early 1930s. It was the successor to Harvard's famous 15-inch (380-mm) f/18 Great Refractor that had been used to discover Saturn's Crepe Ring in 1850 and to take the first daguerreotype image of the star Vega that same year.[20]

Harlow Shapley (1885–1972), who became director of Harvard College Observatory (HCO) in 1921, sought to obtain a large reflector for the observatory. Having previously worked at Mt Wilson Observatory, Shapley was accustomed to having access to its large 60-inch (1.5-m) and 100-inch (2.5-m) reflectors for his work on star clusters.[21]

Fortuitously, a 61-inch (1.55-metre) diameter primary mirror was available, so Shapley pressed ahead with a new observatory on Oak Ridge, some 50 km west of Boston. The Oak Ridge property includes 40 acres atop the 200-metre-high Shrewsbury Ridge, a glacial moraine.[22,23] It was conveniently near Boston, but far enough at the time to escape the city's light pollution.

At its inauguration in 1933, the Wyeth was the fourth-largest telescope in the world.[24] Equipped with an f/5 primary mirror, it packed four times the aperture and (theoretically) sixteen times the light-gathering power of the Great Refractor into a tube only a little longer. Figure 1 shows the telescope in 1998, while Figure 2 shows its drum-like enclosure in 2009.

Despite its relatively large aperture, the Wyeth reflector produced only a modest scientific output from the 1930s to the 1970s, mainly photoelectric photometry.[25,26] One explanation for this dearth of productivity can be found in a 1955 paper in which Harvard College Observatory's deputy director Bart Jan Bok (1906–83) discussed the sky conditions at Oak Ridge.[27] Bok found that the site averaged only 2.9 hours of clear sky each night. Equally depressing, stellar diameters averaged a mediocre 2.5 arcseconds (with a typical range of 1.75 to 3.75 arcseconds); exceptional nights when image diameters fell to 0.75 arcseconds occurred on only one night out of forty.

Oak Ridge, being handy to Boston and Cambridge, was used to instruct generations of Harvard graduate and undergraduate students, but by the early 1970s it was already an ageing facility. Management of Oak Ridge passed to the SAO in 1973, although Harvard continued to own the observatory and have access to it.[28]

3. David Latham, spectroscopy, and stellar velocities

A pivotal moment for Oak Ridge came in the fall of 1963 when David Latham (Figure 3), a young Harvard graduate in astronomy, and his wife moved into a cottage on the observatory grounds.[29] Latham's primary research interest was in the astrophysical characteristics of stars as revealed by their spectral energy distribution (SED), a plot of energy versus wavelength. He needed very accurate SEDs in order to test model stellar atmospheres and the spectra predicted for them. So determined was Latham to measure fundamental stellar attributes that he and a colleague spent portions of six years laboriously compiling an ultra-precise reference SED for the bright star Vega.[30]

Latham liked Oak Ridge but understood its limitations. To obtain really high-quality SEDs for numerous stars he knew that he needed a new telescope at a good site.[31] In 1964 he and fellow graduate student Stephen

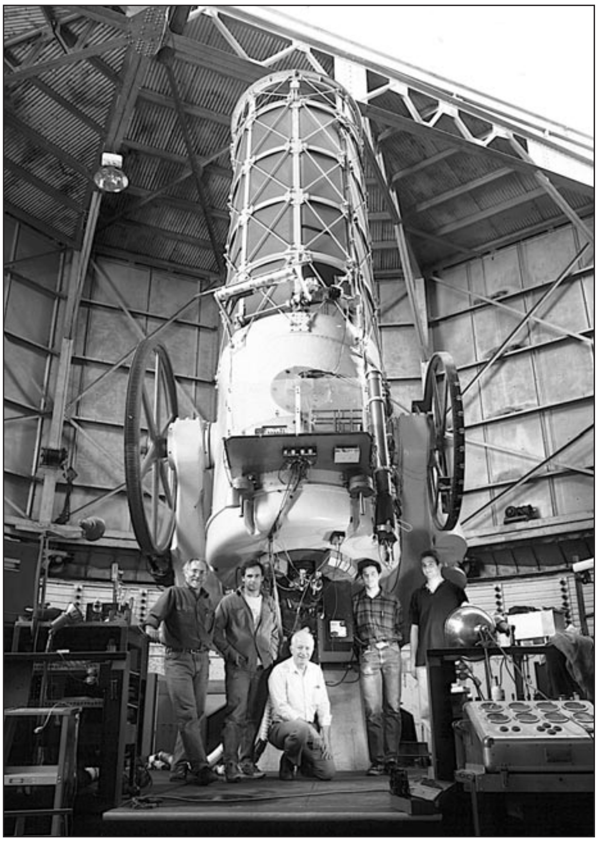

Fig. 1. Harvard's 1.55-m (61-inch) Wyeth Reflector at Oak Ridge Observatory in 1998. From left: Robert Stefanik, Joe Zajac, Costas Papaliolios, Charles Coldwell, Jonathan Wolff. (Paul Horowitz)

Strom (b. 1942) lobbied the SAO Director, Fred Lawrence Whipple (1906–2004), for a new 24-inch (0.6-m) telescope to be sited somewhere in the American southwest. Whipple was instantly supportive of the idea and even insisted that the telescope's aperture be increased to 60 inches (1.5 m).[32]

Mount Hopkins, Arizona, was nominated as the venue for the new facility. Latham spent portions of the next five years helping conduct a site survey, reviewing proposals for telescope design, and building spectroscopic instruments.[33] The new 1.5-m reflector, named the Tillinghast Telescope after Carlton W. Tillinghast Jr. who had been assistant director of the Smithsonian Astrophysical Observatory through the 1960s, began operation in 1969. It enjoyed both generally clear skies and considerable altitude (2,340 metres), characteristics not shared by Oak Ridge.[34]

Latham focused his research on eclipsing binary stars, the masses of which can be determined using Kepler's Third Law since the system's orbital inclination to the Earth must be near zero for the eclipses to occur. Once stellar mass is known, accurate radii and densities can then be calculated on the basis of the mass–luminosity law.[35] Latham especially studied double-line eclipsing binaries, in which the absorption lines alternate between double (when both stars are visible) and single (when one star transits the other).[36]

Fig. 2. The cyclindrical enclosure of the Wyeth Reflector at Oak Ridge Observatory in 2009, four years after its closure. The cornerstone of the building was laid in 1932 by Sir Frank Dyson, then-president of the International Astronomical Union and also Britain's Astronomer Royal, during the IAU's general assembly at Cambridge, Massachusetts. (Wikipedia)

The challenge in observing fainter binaries, whether from Oak Ridge or Mount Hopkins, was that spectrographs substantially dim the incoming stellar light by spreading it out, meaning that a very sensitive detector would be necessary. Fortunately, Latham had a background in instrumentation and had focused much of his early efforts on the then-new technology of photoelectric sensors.[37,38]

3.1. *Enter the Reticon*

Latham was especially intrigued by the Reticon, an early solid-state photoelectric image sensor.[39] Latham's interest arose from the fact that the Reticon promised to boost sensitivity to incoming photons (quantum efficiency) to 10 or even 20 percent,[40] against the miserly few percent typical of film emulsions.[41]

The Reticons would allow him not only to rapidly obtain stellar spectra in large quantities, but also to detect even small wobbles induced by the unseen companions in spectrographic binaries. Measuring such small Doppler shifts in a star's spectral absorption lines would enable him to calculate the star's shifting radial velocity, thereby permitting him to infer the mass of the invisible companion star. But doing so would require him to reach an unprecedented (for the era) precision in radial velocity of about 1 km/s.

In the spring of 1977, Latham and his colleague Marc Davis (b. 1947) began work on a sensitive spectroscopic detector utilizing a Reticon sensor receiving input from a military-type image intensifier device that was in turn fed by a spectrograph.[42] Output from the Reticon sensor was routed to a Data General computer

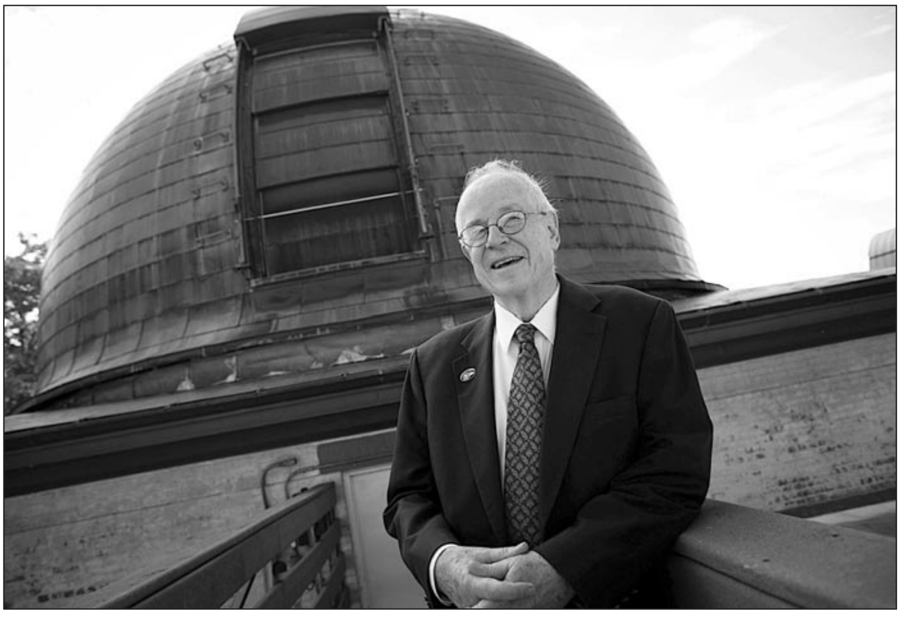

Fig. 3. David Latham pictured in front of the dome of Harvard College Observatory's historic 15-inch Great Refractor. (Stephanie Mitchell/Harvard Staff Photographer)

and a graphics terminal for real-time display of images produced as incoming photons built up.[43]

The resulting system was dubbed the 'Z-machine' (from the redshift symbol *z*), and supported Mount Hopkins' forthcoming redshift survey of galaxies down to magnitude 14.5.[44] Utilizing the Z-Machine, that survey obtained radial velocities for 2,401 galaxies during the early 1980s and ultimately some 25,000 total galactic spectra.[45,46] The result was the famous CfA Redshift Survey, which showed that galaxies are not distributed evenly in space but rather clustered into filaments and around voids.[47]

While building the Tillinghast Reflector Echelle Spectrograph (TRES) for Mount Hopkins in 1979, Latham found sufficient funding to build an identical spectrograph at the Oak Ridge Observatory.[48] He had a backup Reticon sensor at Oak Ridge, where much of the development effort had been conducted. He combined the spectrograph with a military-grade image intensifier and finally the spare Reticon to create a highly sensitive spectral imaging system. Latham dubbed the resulting instrument a 'digital speedometer' since its purpose would be to measure the recession speeds of galaxies.[49]

The Oak Ridge Observatory's greatest significance during the 1970s was probably as a technological testbed for developing new instrumentation (such as the Z-machine) ultimately destined for Mount Hopkins. Latham recalls:

> We parlayed money that was going into the development of the MMT [Multiple Mirror Telescope at Mount Hopkins] into the development of instrumentation. You could justify money for modern instrumentation, but not for a shoelace operation like Oak Ridge. So we developed the technology, we did the testing here [at Oak Ridge], and then we'd take it out to Arizona.[50]

But the area where Latham pushed hardest for SAO funding was in computers and software for processing the radial velocity data. With the Reticons, spectrographs, and computer equipment in place, Latham and the rest of the staff using the Mount Hopkins facility dutifully focused on employing their Z-machine to determine galaxy velocities for the redshift survey, to accuracies of about 25 km/s.[51]

3.2. *Pushing the limits*

Latham also lobbied for observing time to use the more accurate digital speedometer units at both Oak Ridge and Mount Hopkins for his main interest: measuring stellar radial velocities.[52] His goal was to precisely measure the masses and radii of binary stars so as to test various theoretical stellar models. He was thrilled with the Reticon:

> The technology of the photon-counting Reticon applied to stellar spectroscopy opened up all kinds of new possibilities … We could look at the motions in clusters of stars that really hadn't been studied. We could look for binaries in globular clusters. The conventional wisdom in those days was that globular clusters had no binaries … What we ended up showing is the oldest clusters have just as many binaries as the stars in the solar neighbourhood.[53]

Best of all, he could use the two facilities in tandem, employing Mount Hopkins (with its darker, steadier skies) to measure the motions of dimmer stars and Oak Ridge for brighter stars.

Using the digital speedometers with their high-resolution echelle spectrographs, Latham found that he could obtain his desired precision of less than 1 km/s for stellar radial velocities.[54] At the time, Latham's spectrographic system was among the highest-precision radial velocity systems in the world, matched or bettered only by the twin CORAVEL instruments at Haute-Provence Observatory in France and the European Southern Observatory at La Silla in Chile,[55,56] and the system at the Canada-France-Hawaii Telescope on Mauna Kea developed by Bruce Campbell and Gordon Walker.[57] In this latter device a glass cell containing (deadly) hydrogen fluoride gas was inserted ahead of the spectrograph to create several fixed absorption lines to serve as a reference.

One technique that Latham employed to ensure accuracy was to repeatedly observe radial-velocity standard stars, that is, stars determined by the IAU to have unvarying magnitudes and well-established radial velocities, to precisely set the radial velocity zero-point for the Z-machine.[58] He could then be sure that any repeating departure from the zero point meant that a given star was actually wobbling in space due to the gravitational influence of a companion.

4. Tsevi Mazeh and the discovery of HD 114762's companion

In 1984 Tsevi Mazeh (Figure 4) was an associate professor in the School of Physics and Astronomy at Tel Aviv University. He was well-acquainted with the radial velocity effects of companion objects, having five years earlier published his PhD dissertation on the eccentricity induced in a binary star system by a perturbing intruder star.[59]

Mazeh had a novel idea for an observing campaign and needed a system with very high precision to carry it out. He was aware that both Latham and the Swiss astronomer Michel Gustave Édouard Mayor (b. 1942) of the Haute-Provence Observatory in France had built the required equipment for measuring radial velocities.[60] Mazeh sent a message to Mayor in English, not realizing that Mayor was not fully comfortable in the language at that time. Receiving no response, he turned to Latham.[61]

In autumn 1984, while on a visit to the US, Mazeh called Latham to propose a meeting.[62] Mazeh's ensuing pitch was as simple as it was daring: use the digital speedometer at Oak Ridge to hunt for very massive exoplanets on short-period orbits around M-type dwarf

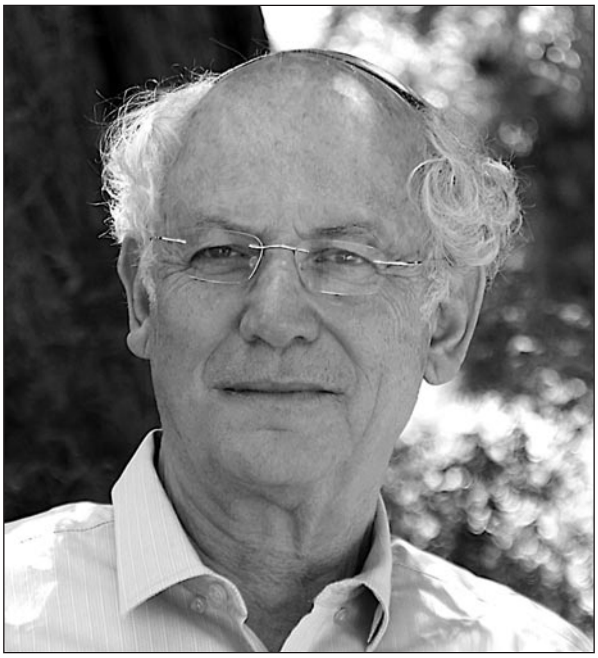

Fig. 4: Tsevi Mazeh , David Latham's collaborator in the discovery of HD 114762's companion. (Israel Institute for Advanced Studies)

stars.[63,64] Any such massive planets, if they existed, would induce a substantial reflex motion (a wobble) in their small host stars as both objects orbited around their common centre of mass (barycentre). That wobble might be detectable by Latham's digital speedometer at Oak Ridge.

Mazeh's proposal ran counter to existing beliefs regarding planetary formation. Planetary scientists did not know how planets much bigger than twice the mass of Jupiter could be formed.[65,66] Furthermore, even if giant exoplanets did exist, they were not expected to be found on close-in orbits.[67] (The concept of planetary migration still lay 20 years in the future.) In any event, the precision of the Oak Ridge digital speedometer of several hundred metres per second was grossly insufficient to find exoplanets.[68,69] Above all, the entire field of exoplanet hunting had a dubious reputation after numerous disproved 'discoveries' over the years.[70,71,72]

4.1. *Challenging a planetary paradigm*

The conventional wisdom regarding exoplanet orbits would later be embodied in a paper by Alan Paul Boss (b. 1951) of the Carnegie Institution for Science who specialized in protoplanetary disks.[73] He and other mainstream researchers believed that giant exoplanets would be found beyond the inner portions of their planetary systems, close to their formation points at or beyond the 'ice line' of their stellar nebulae.[74] Granted, the ice line would be closer-in for dwarf stars, but it was thought that giant exoplanets would still be found at distances not much different from that of Jupiter (i.e. about 4 to 6 au), regardless of the mass of their host star.

Mazeh had anticipated, and carefully prepared for, each of these objections.[75] Perhaps, he argued, giant exoplanets might be found close-in to small, cool dwarf M-type stars after all. If so, the ice line for such stars would be located close in, providing enough supplies of ice and gas to form such giants in situ. Maybe the planet formation theorists were wrong and there could exist exoplanets far more massive than Jupiter. After all, theoretical models had difficulty even accounting for the formation of Jupiter and Saturn.[76] In any event, if such giant, close-in exoplanets did exist around dwarf stars, the stellar wobble they induced would be substantial, and perhaps the Oak Ridge digital speedometer's error bar could be reduced enough through multiple observations of each star to detect that wobble.[77,78]

After two hours of discussion, Latham agreed to give Mazeh's proposal a try.[79] Latham knew that he could probably improve the digital speedometer's accuracy by averaging many observations of the same star. Besides, Latham had the computer equipment and analysis software so that the radial-velocity data could be processed quickly. To ensure accurate results (within the precision range of the digital speedometer), Latham insisted that two nearby standard stars be observed for each observation of a target dwarf.[80,81]

So why did Mazeh not ascribe to the prevailing view that giant planets could not be found within their planetary systems' ice lines? When interviewed by the author in 2019 he squarely blamed astronomers' fixation on the structure of our own Solar System:

> So when they say, 'giant planets must be formed far away and such things cannot exist close to their parent stars,' I ask myself: 'How do they know that?' And they say 'It's based on the theory.' But I knew better, this is based on the single example of the Solar System. I realized that other systems could be very different.[82]

This sceptical approach evidently allowed him to anticipate, or at least be open to, the possibility of a Kuhn-style shift of scientific paradigm for giant planets' orbits.

For his part, why did Latham agree to such a long-shot research proposal? Part of the reason was simply that his work on the digital speedometer and ensuing years of galactic and stellar radial velocity work had equipped him with the right skills and equipment for such a hunt. Perhaps he was attracted to Mazeh's proposal as the ultimate challenge for radial velocity work. Latham later commented: 'All this work to learn how to get orbits for stars and understand the characteristics of stars was a necessary and important apprenticeship for moving into extrasolar planets.' [83]

Soon after his meeting with Mazeh, Latham and the Oak Ridge Observatory's director, Robert Phillip Stefanik, submitted exoplanet investigation proposals requesting substantial time on the Wyeth telescope.[84] The proposal was successful, and in 1985 they began observing three dozen M-type dwarfs recommended by Mazeh, plus pairs of nearby IAU standard stars.[85]

For pretty much every clear night over three years Latham and Stefanik made repeated observations of those stars, using the digital speedometer to search for stellar wobbles. They found that, with repeated observations of a given star, they could reduce their radial-velocity uncertainty to about 600 m/s.[86] (For comparison, Jupiter creates a solar wobble of about 12 m/s.) That precision enabled them to discover two new spectroscopic binary stars among the M-type dwarfs and, surprisingly, several more among the IAU standard stars.[87] What they did not discover, however, were any giant exoplanets in close-in orbits.

4.2. *A wobble in the data*

By early 1988 Latham, Mazeh, and Stefanik knew they had to reach higher radial velocity precision to have any hope of detecting an exoplanet. The obstacles they faced were daunting. The mounting of their sensitive echelle spectrograph to the Wyeth telescope was subject to flexure.[88] The spectrograph was exposed to ambient temperature swings at Oak Ridge, such variation having long been known to affect spectrograph precision.[89] Moreover, their Reticon detector was affected by changes in magnetic field orientation as the Wyeth pointed around the sky.[90]

The team selected a single countermeasure for all three problems: a 13-metre-long strand of low-loss optical fibre that channelled light from the Wyeth telescope to the spectrograph at the front end of the digital speedometer.[91] The use of optical fibre to connect a spectrograph to its parent telescope was a relatively new concept, first suggested by Roger Angel and colleagues in 1977.[92] The optical fibre allowed the spectrograph to be mounted on the Oak Ridge Observatory floor, so that it no longer had to move with the telescope and could now be fitted into a heavily insulated, thermally controlled enclosure that aimed to hold its temperature steady to ±0.1° C. The optical fibre still suffered from imperfect transmission and resulted in a loss of just over a magnitude, but this was a price worth paying to achieve their new goal of 100 m/s precision in radial velocity.

Latham and his colleagues did not have to wait long to detect substantial improvement using the new system. The team obtained new radial velocities for seven IAU standard stars on the first night that the fibre feed was employed (1988 March 28).[93] Working from home three nights later, Latham plotted all the measured radial velocities for the standard star HD 114762 obtained with the old and new systems, but found no obvious drifts or patterns of variation.

Undeterred, he then applied software written by Mazeh to analyse the so-called power spectrum (a measure of which velocities contribute the most to a signal) of the 62 velocities measured with the old, pre-fibre digital speedometer and immediately found a highly significant periodic variation of around 83 days (Figure 5).

Processing the data with another Mazeh-authored software program, Latham quickly produced the preliminary orbital solution shown in Figure 6, indicating an

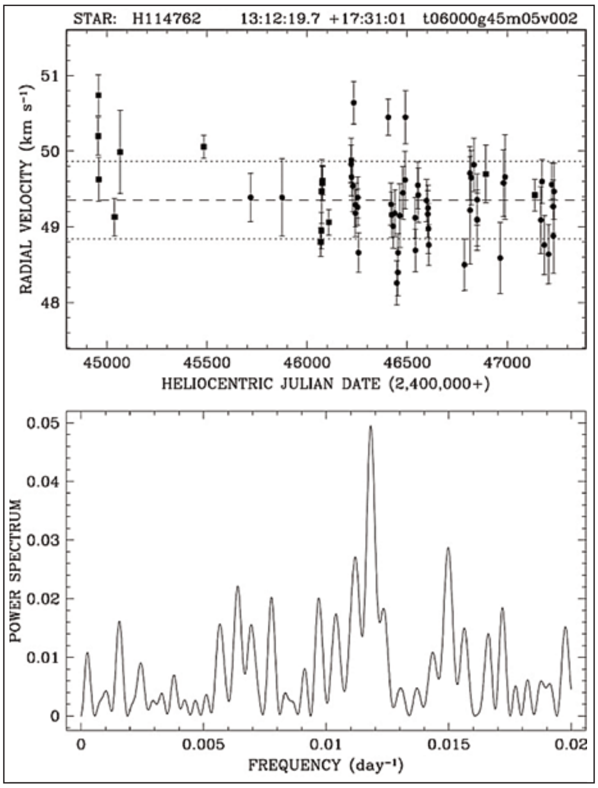

Fig. 5: Initial plot of radial velocity data for HD 114726 versus time (top) and power spectrum analysis (lower) showing a peak frequency indicating an orbital period of around 83 days. The actual period turned out to be about a day longer. (David Latham/Elsevier)

84.2-day orbit. He next called Stefanik, who was working at the Wyeth, to say 'You have to get 114762 tonight'. When queried why, Latham responded 'Because I just reduced the whole data set and it varies'.[94]

After alerting Stefanik, Latham's next priority was to inform his entire observing team, which by then included not only Mazeh and Stefanik but also Michel Mayor in Geneva and Robert McClure in Victoria, British Columbia, both of whom had previously agreed to monitor the same radial velocity standard stars as a check. Latham drafted a lengthy electronic message to the team outlining the data and analytical results for HD 114762 and commented that it would be 'very exciting' if the radial velocity variations were due to a close-in giant planet.[95] He concluded by asking for radial velocity data from his collaborators, in hope of confirming the 84-day period variation. Latham was excited: 'By the time I hit Send for the email, it was well into April Fools' Day, but I was not fooling.' [96]

4.3. *Acclaim and ambiguity*

Latham's team quickly published a paper describing the fibre-fed system in 1988 April.[97] They concluded it by focusing on the singularly large radial velocity anomaly they had observed for HD 114762, noting that it might indicate a spectroscopic binary or even a substellar companion with a mass of only 10 Jupiters, if the orbit were seen exactly edge-on.

Latham realized that he had to obtain many further measurements of HD 114762's radial velocity before he could make a definite conclusion. Initially, the recipients of his e-mail appeal for data had only a very few measurements of HD 114762's radial velocity to contribute. However, about a month later, Michel Mayor suddenly responded with some 30 observations that he had obtained using ESO's CORAVEL spectrograph mounted on the Danish 1.54-metre telescope in Chile.[98,99] This additional data, combined with further observations obtained with the digital speedometers, was sufficient to confirm Latham's tentative orbital solution.[100]

Latham and his team worked throughout 1988 to prepare a definitive paper regarding HD 114762's companion. They knew that any claim of a first possible exoplanet discovery would receive both extensive publicity from the media and close scrutiny from fellow astronomers. Their radial velocity evidence for a companion was reasonably strong, but any conclusion of an exoplanet would be vulnerable to attack on three fronts: no close-in massive planets existed in our Solar System; the eccentricity calculated for the companion's orbit was relatively high at 0.25; and, above all, the orbital inclination of the companion object (and thus its mass) was unknown.[101,102]

With regard to the first two criticisms, the team could certainly argue that the Solar System should not be taken as a template for every other planetary system in the Universe. But the third line of attack – the unknown inclination – was difficult to refute. The problem arose because radial velocity measures only an object's motion towards and away from the observer; side-to-side motion across the line of sight is not detected.

If the orbit of HD 114762's companion happened to be viewed almost face-on, the wobble detected in its host star by Latham's team would signify an object massive enough to be a dwarf star.[103,104] If, on the other hand, the plane of the companion's orbit was almost edge-on to us, the host star's wobble would signify a much less massive object, one small enough to be a brown dwarf or perhaps even a giant exoplanet.[105] Unfortunately, it was impossible to know which was the case.

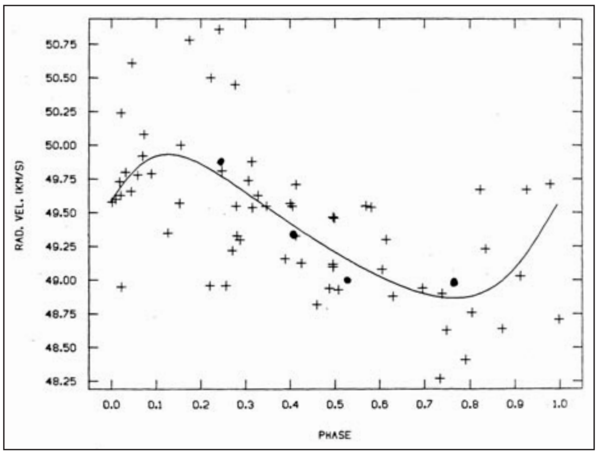

Fig. 6: Plot of Oak Ridge digital speedometer radial velocity data for HD 114762, showing a semi-amplitude of 530 m/s (±90 m/s). Crosses are for old, direct-system measurements while dots are for fibre-optic system data. Preliminary orbital solution shown used only direct system data. (D. Latham, J. Andersen, J. Geary, O. Rodrigues and R. Stefanik. ©The Astronomical Society of the Pacific. Reproduced by permission of IOP Publishing. All rights reserved)

Latham and his colleagues formally announced their discovery in 1988 August at that year's General Assembly of the IAU in Baltimore.[106] Possible exoplanets were a hot topic at that conference, with a Canadian team led by Bruce Campbell and Gordon Walker and an American team led by Ben Zuckerman and Eric Becklin reporting only very tentative exoplanet candidates despite determined searches.[107]

HD 114762 drew much of the publicity and was the subject of a press briefing and ensuing interviews and news articles. Astronomers, predictably, questioned the companion's large minimum mass, its unprecedented close-in orbit, and especially the eccentricity and unknown inclination of its orbit.[108]

Latham's team then spent months collecting additional observations and debating how to write up their discovery. They were sharply divided about how to characterize HD 114762's companion. Mazeh felt that they should be much more definite about a planetary companion; Mayor strongly opposed that view due to the eccentricity of the orbit; and Latham fell somewhere in between.[109]

After months of additional data acquisition, the team published a paper in *Nature* conservatively titled 'The Unseen Companion of HD 114762: A Probable Brown Dwarf'.[110] In the paper's abstract, they recited the uncertainty in the inclination of the companion's orbit, but noted its mass might be as low as 11 Jupiters and therefore it 'may even be a giant planet'. But there was no way to combat the inclination problem, except in the (very unlikely) event that the companion happened to transit in front of its host star from Earth's line of sight.

To check this, a team at McDonald Observatory promptly searched for any dips in HD 114762's flux but found none beyond a detector threshold of 0.01 magnitude.[111] This finding could only constrain the companion's orbital inclination to be less than 89°.

4.3. *Impasse*

The stalemate in determining the nature of HD 114762's companion appeared likely to endure for some time, leaving Latham to ponder his next move. He knew that part of the answer lay in building a much more capable echelle spectrograph, one that was ideally held in a vacuum and thermally more stable than the unit at Oak Ridge. Accordingly, says Latham, 'I wrote a proposal to build on the fibre-fed system here and it never got fully funded. We got started on it, received some seed money, but we gave up. And besides, by then I was associate director and was distracted by all sorts of other things.'[112]

Table 1

Components of the HD 114762 system

Object	Spectral type	Mass (solar masses)	Distance from parent star	Orbital period
HD 114762*	F-type main sequence	0.84	N/A	N/A
HD 114762B**	M-type dwarf	?	134 au	?
HD 114762b***	M-type dwarf	0.29	0.36 au	83.9 days

* SIMBAD astronomical database
** Patience et al. (ref. 115)
*** GAIA Data Release 3

After 1988, Latham and his team made do with repeatedly observing additional radial velocity standard stars and detected another (in the Hyades cluster) that varied with a long period. But the minimum mass for that one indicated the companion must be stellar in nature, so that discovery was just another spectroscopic binary.[113]

Research into HD 114762's companion remained largely quiescent, with only a few exceptions. In 1991, a team from the McDonald Observatory in Texas made extremely high-precision radial velocity observations of HD 114762. These generally confirmed the Latham team's orbital solution for the companion, although they increased the orbital eccentricity to 0.38.[114]

To complicate matters, observations with the 10-m Keck and 3-m Lick Observatory telescopes reported in 2002 revealed that HD 114762 is not a single star but actually a binary, with a stellar-mass companion (HD 114762B) orbiting at only 130 au.[115]

Follow-up observations of HD 114762 with the Lick telescope determined its mass to be around 0.8 solar masses and the amplitude of its wobble to be just over 600 km/s.[116] Photometric measurements taken over 23 years were used to look for any signs of the companion's transit, but none were found. The authors of the Lick survey concluded that 'absolute confirmation of the planetary nature of the companion will likely need to await precision astrometric observations'.

5. The technological legacy of HD 114762's companion

Although the Latham team's discovery of HD 114762's companion is little-known today it is nonetheless significant, both in its own right and for the technological advance it anticipated.

Michel Mayor was a member of the team that discovered HD 114762's companion, but wrote in 2003 that he regarded the companion as a brown dwarf.[117] This he noted was not only due to the uncertainty in the orbital inclination but also because of HD 114762's low metallicity compared to most other stars harbouring exoplanets. Mayor attributed his fascination with substellar companions not to HD 114762's companion, but instead to the stellar radial velocity survey work he had long specialized in.[118,119,120]

Mayor subsequently pursued and obtained funding for what would become ELODIE, a very high-precision fibre-equipped echelle spectrograph designed to hunt for brown dwarfs and exoplanets.[121] ELODIE went one step better than the Oak Ridge spectrograph by being housed in an entirely separate room for tighter temperature control.[122]

Seven years after the discovery of HD 114762's companion, Mayor and his graduate student Didier Patrick Queloz (b.1966) famously used ELODIE and the Haute-Provence Observatory's 1.93-m reflector to make what is usually regarded as the first exoplanet detection around a Sun-like star, 51 Pegasi.[123] That detection required a much tighter radial velocity resolution than that for HD 114762, since the wobble induced in 51 Pegasi by its exoplanetary companion is only about 55 m/s in semiamplitude.[124] Mayor and Queloz shared the 2019 Nobel Prize in Physics for the discovery.[125]

The discovery of HD 114762's companion also helped inspire then-Harvard graduate student David Brian Charbonneau (b. 1974) to search for exoplanets by using the new technique of looking for dips in stellar flux caused by transits.[126] Based on previous radial velocity observations of HD 209458 by Latham's team, Latham suggested to Charbonneau that he monitor it for transits.[127,128] He did so, with the result that HD 209458 b soon became the first exoplanet to be discovered via the transit technique.[129]

6. Gaia resolves the mystery

The key obstacle to understanding the true nature of HD 114762's companion remained, for three decades, the lack of high-precision astrometric data. Such data can provide an accurate estimate of an exoplanet's mass, rather than the minimum mass yielded by the radial velocity technique which, as we have seen, is constrained by the unknown orbital inclination.[130]

The European Space Agency's Gaia mission was launched in late 2013 to compile the most precise 3D catalogue of space objects ever created.[131] Gaia can obtain astrometric measurements to a precision of 5–16

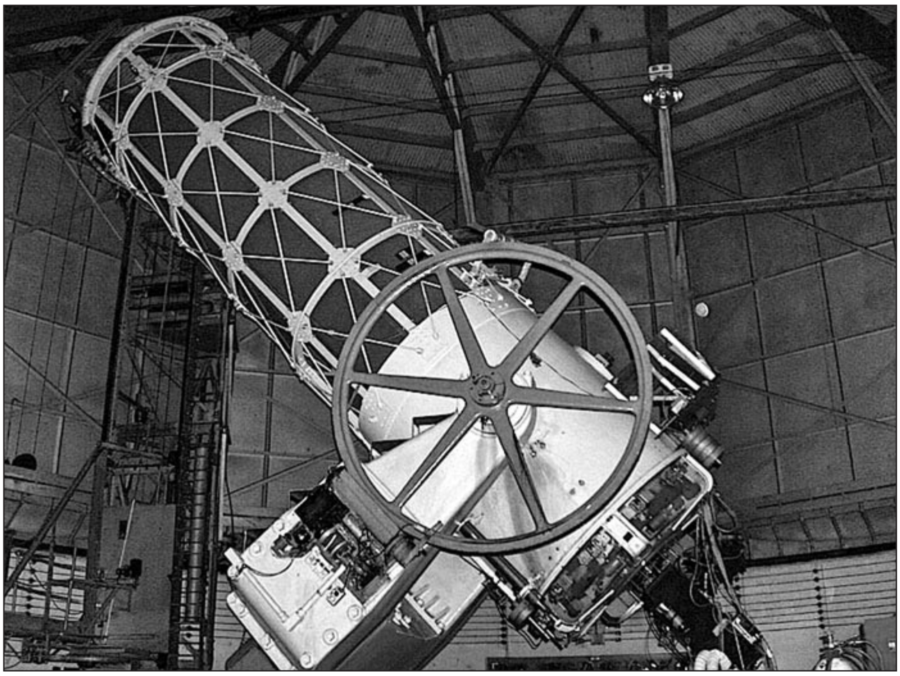

Fig. 7. The Wyeth Reflector in 2004, the year before its closure. (Dave Huestis, Skyscrapers, Inc.)

micro-arcseconds for stars brighter than 12th magnitude. Among those stars is HD 114762. Gaia soon measured its distance (124.5 light years), radial velocity (49.7 km/s), and other parameters with unprecedented precision.[132] What Gaia did not initially provide was a highly precise measure of HD 114762's astrometric wobble, which would reveal its companion's mass and hence resolve whether it was an exoplanet or a dwarf star.[133]

In 2019 a team led by French astronomer Flavien Kiefer introduced a novel technique called GASTON (Gaia Astrometric Noise Simulation to derive Orbit Inclination) that analysed what they termed 'astrometric noise' in Gaia's first data release to estimate the inclination of several companion objects.[134] The central premise of GASTON is that the level of a star's astrometric excess noise measured by Gaia directly correlates with the orbital inclination of its companion, so that excess noise increases as inclination decreases.

Kiefer applied an improved version of the GASTON technique to astrometric data from Gaia's first data release, finding a near face-on inclination of about six degrees for the orbit of HD 114762's companion.[135] That low inclination gave an estimated mass for the companion of around 100 times the mass of Jupiter, far too great for an exoplanet and sufficient to put it into the realm of a small dwarf star. A reanalysis the following year increased the estimated mass to nearly 150 times that of Jupiter.[136]

However, a definitive resolution to the mass of HD 114762's companion awaited Gaia's third data release (DR3) in 2022 June.[137] This included the first astrometric orbital solutions with the sub-milliarcsecond sensitivity necessary to detect planetary-mass objects.

The Gaia DR3 data have confirmed that the HD 114762 system is seen at a very low inclination of only about 2.8°, i.e. nearly face-on from Earth, even smaller than previously thought.[138] As a result, the companion's mass turns out to be about 0.3 that of the Sun, or some 300 times that of Jupiter.[139] HD 114762 b is not a planet after all but an M-type dwarf star (Table 1).

Although this conclusion may be disappointing, according to Mazeh the final answer has not changed the meaning of the original discovery in 1988: it was the smallest stellar companion then detected, pointing the way for future radial velocity research.[140] Latham notes that 'we opened our own eyes and other people's eyes to the idea that there could be planets that we hadn't imagined before.'[141]

7. Coda

Latham and Mazeh both continue as working astronomers, the former still with the Harvard-Smithsonian Center for Astrophysics and the latter at Tel Aviv University. Remarkably for astronomers in their 70s, Latham at the time of writing (spring 2023) serves as Director of Science for NASA's Transiting Exoplanet Survey Satellite (TESS),[142] while Mazeh is an active participant in the Gaia mission.

Although Latham could not develop an advanced radial velocity spectrograph for Oak Ridge, he did later convince the Harvard-Smithsonian Center for Astrophysics to invest in HARPS-N, an ultra-high-precision spectrograph.[143] This can reach a precision of 0.6 m/s and is used to search for terrestrial-sized exoplanets.[144]

Oak Ridge Observatory has not fared as well. After the Latham team's discovery of HD 114762's companion, Oak Ridge gradually declined in importance. Latham and Stefanik continued hunting for spectroscopic binary stars with the observatory's digital speedometer into 2005, but more often they used newer telescopes at Mount Hopkins.[145,146] Undergraduates still visited Oak Ridge in the 1990s for Harvard's basic course in laboratory astrophysics, but soon after, they, too, began going to Mount Hopkins for exposure to observing and instrumentation.[147]

In 2002, a Harvard review panel recommended closure of Oak Ridge, which occurred in 2005.[148] Stefanik says he knew that their days were numbered because 'there was a general sense in the astronomy community that bigger telescopes were coming online and you couldn't support the smaller ones'.[149] Multiple factors went into the decision to close Oak Ridge, especially the combination of relatively poor astronomical seeing and ever-encroaching light pollution. Latham acknowledges the problems: 'We always got ten times more throughput in Arizona than here, primarily because the images were sharper.'[150] The *Boston Globe* evocatively noted in 2005 that light pollution has 'thickened like a cataract over Greater Boston in the last decade'.[151]

As of 2023, the Wyeth reflector and the path-breaking digital speedometer sit abandoned in their weathered observatory.[152] Rust has begun to creep across the telescope's massive tube (Figure 7). The National Air & Space Museum in Washington, D.C., has shown some interest in rescuing the digital speedometer, but as yet nothing has been done to preserve it.[153]

8. Conclusion

This paper has endeavoured to illuminate the early search for exoplanets, the tantalizing discovery of HD 114762's companion, and the repercussions of that discovery. The hunt for the first exoplanets in the 1980s and 1990s was a highly competitive one, with teams from Canada, Europe, and the USA all pushing the available technology to its limits. The team of David Latham, Tsevi Mazeh, and Robert Stefanik demonstrated what a determined and technically imaginative collaboration could achieve, despite limited funding and a relatively small, ageing telescope. Nonetheless, given the limits of their technology, they were fortunate to select and observe a host star which exhibited one of the largest radial velocity fluctuations of any exoplanetary system known even today.

Even though HD 114762's companion did not, ultimately, turn out to be the first exoplanet orbiting a Sun-like star, its discovery had lasting value as a harbinger of future technological advances and discoveries, as the Nobel Prize Committee recognized. In its scientific background paper explaining the basis of the 2019 award to Mayor and Queloz, the Latham team's 1989 paper *The unseen companion of HD 114762: a probable brown dwarf* is among those first cited, quiet testimony to the significance of their search and discovery.[154]

Professional astronomers' resistance to the companion's possible status as an exoplanet was in keeping with the tradition of scientific skepticism. That tendency underlines the difficulty of evaluating novel scientific concepts supported only by ambiguous evidence that is open to interpretation. In any event, mounting evidence suggests that there may be an overlap in mass between large exoplanets and the smallest brown dwarf stars, something that we will learn more about as the Gaia data are mined more deeply. Perhaps the IAU should consider revisiting the intellectual dividing line between planets and stars. That would be a fitting legacy for the discoverers of HD 114762's companion.

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The imagery and science of Mars:
A new look at 160 years of Martian albedo observations

William Sheehan, Joel Hagen, and William K. Hartmann

Major scientific questions about Mars in the late 19th and early 20th centuries involved the well-documented changes in the shape and extent of the dark albedo markings – changes that were at the time interpreted as signs of inundations by seas or the growth of vegetation. More recently, spacecraft missions demonstrated that the changes in light and dark albedo markings were due not to water or life but to dust blown around by seasonal winds. Investigators began to concentrate on the localized geological formations revealed in high-resolution spacecraft images, but the bigger picture of global albedo patterns came to be ignored. Here, we review the history of observations of Martian albedo markings and argue that they can still be scientifically useful, even in the modern era of orbiters and rovers.

1. Mars through the telescope

The surface markings of Mars have fascinated astronomers for more than three centuries, since early telescopes revealed variegated features suggesting the possibility that Mars might resemble the Earth. This perennial fascination led to the creation of an impressive archive of carefully executed drawings by telescopic observers, recording the surface features from opposition to opposition.

Each generation's view of Mars has been different, depending on the observational techniques of the time. While spacecraft studies of Mars have concentrated on ever-smaller physical features down to the level of individual rocks and even sand grains, interest in the classical problem of long-term changes in the global dark and light markings on Mars has decreased. In this paper we argue that the historical archive still contains valuable data for the modern scientific interpretation of the Martian features and their changes.

The usefulness of the historical record has been somewhat limited by differences in observers' telescopes, eyesight, brains, drawing styles, and means of reproduction. However, it seemed to the authors of this paper that valuable information about planet-wide trends in complex Martian phenomena might be revealed by combining spacecraft imagery with historic sketches, maps, and globes. In particular, causes of changes in Martian albedo features identified from orbiter imagery might help explain what earlier observers saw.

2. Creating a database for Mars researchers

In this paper we have tried to present what each generation recorded seeing on Mars. We first collected a large number of historical observations going back to the Dutch astronomer Christiaan Huygens (1629–95) in 1659 and digitally reprocessed them to create a number of maps and globes. A large number, but by no means all, of the historical observations were compiled by the French astronomer Camille Flammarion (1842–1925).[1] This part of our project was almost entirely completed by co-author Hagen. The result was the creation of a virtual museum of Mars: a database of directly comparable formats for telescopic, photographic, and spacecraft observations of Mars over at least two centuries.

Our goal was chiefly to investigate the way dust is distributed by local and global wind patterns, producing albedo changes over decades or even centuries. In addition to creating our virtual museum of historic images we also attempted, somewhat less systematically, to make comparisons with spacecraft-era albedo, topographic, thermal inertia, and geologic maps, as well as maps based on models of circulation and wind patterns. Such wind patterns, of course, vary significantly with latitude, local topographic features, and seasons. We pursued this avenue sufficiently far to show that a great deal of useful research remains to be done by means of such comparisons.

We also wanted to study the way observers' preconceptions about the nature of the planet influenced what

Fig. 1: This chronological graphic contains 112 eyepiece drawings of the Syrtis Major region from 1659 at top left to 1967 at bottom right. Mars is oriented with south at the top and east at left, corresponding to the inverted view in astronomical telescopes. (Joel Hagen)

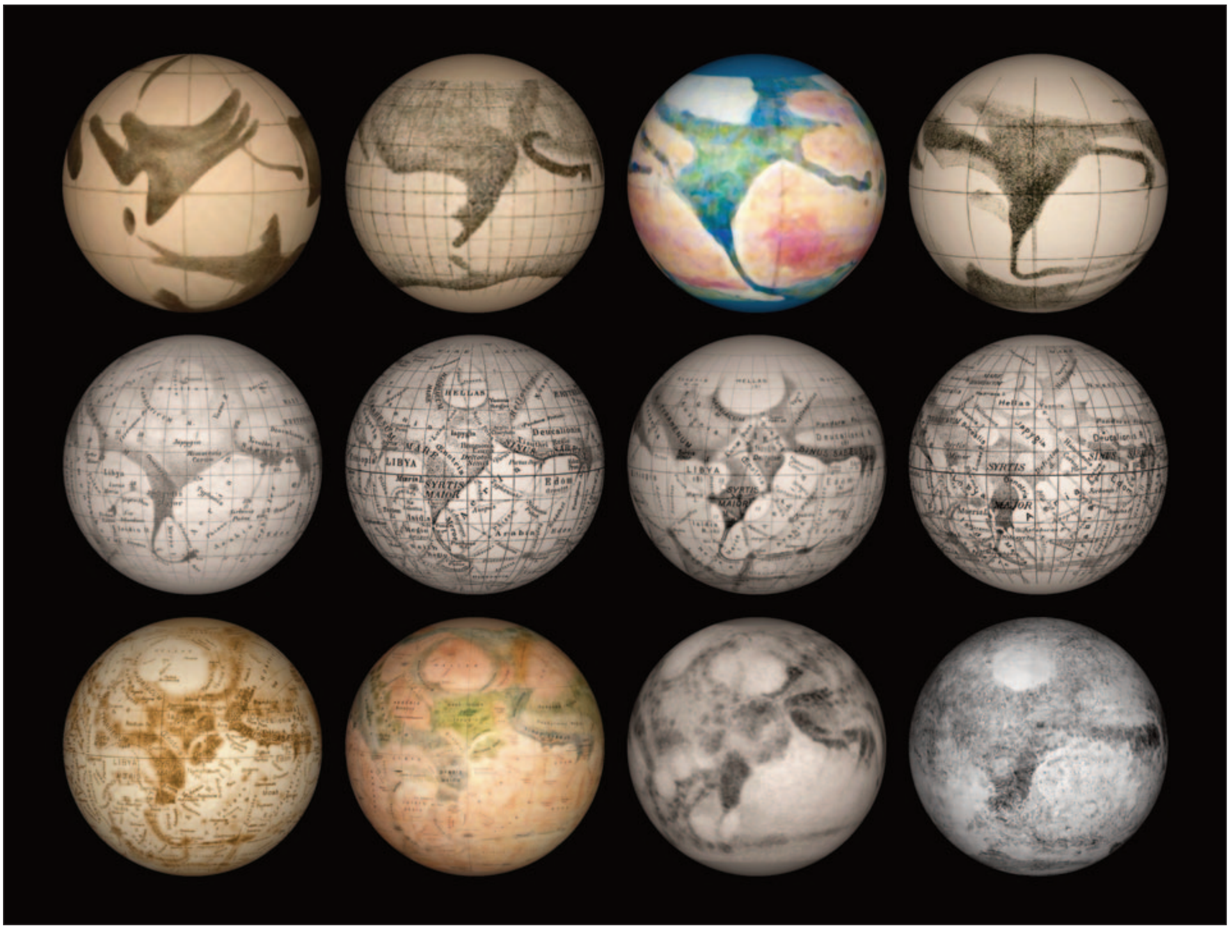


Fig. 2: A series of globes, created to serve as standardized maps and to allow intra-comparison of features as shown by different observers over time. By looking at them chronologically, probable changes in the albedo features are apparent. Note that although many maps were drawn for specific oppositions, some, such as those of Beer and Mädler (1840), Fournier (1913), and Antoniadi (1900, 1930, and 1937) are general maps combining observations from several oppositions. (Joel Hagen)
Top row: 1840 Beer/Mädler, 1864 Kaiser, 1864 Phillips, 1873 Knobel
Middle Row: 1879 Schiaparelli, 1900 Antoniadi, 1903 Antoniadi, 1913 Fournier
Bottom Row: 1930 Antoniadi, 1930 Antoniadi, 1958 Focas, 1971 Mariner 9.

they saw, and to better characterize the way that new data were interpreted and reinterpreted over time. In that sense, the study of Martian markings serves as a valuable example of how scientific research evolves.[2]

For historical comparison, we assembled a collection of 112 eyepiece drawings of the Syrtis Major/Hellas region of Mars from Huygens's 1659 drawing up to 1967 (Figure 1). Although some earlier drawings can be determined to represent the Syrtis Major hemisphere, we included only those with enough recognizable detail to provide meaningful comparisons. All drawings were scaled to a similar diameter and retain their original orientations, based on the inverted view in an astronomical telescope (south at top and west at right) rather than the modern spacecraft convention of north at top and east at the right.

Fifty hand-drawn maps of Mars from 1864 through 1967 were then compared using digital techniques. The original drawings used different projection systems, scales, and orientations of the central meridian. This created significant problems of interpretation. For instance, the large variation in the value of the subsolar latitude caused some observers to report a narrowing of Syrtis Major when in fact it was merely foreshortened towards the north limb. The fact that different projection techniques were used also made intercomparison difficult. A few observers (notably Percival Lowell) attempted to get round this by mapping their observations onto uniform globes, but this was not done consistently.

To compare changes meaningfully over time we have attempted to standardize all the maps using digital tools. The goal was to have all the historical maps at the same scale while using a simple cylindrical projection, which would also match modern maps based on spacecraft imaging. However, albedo changes are often abrupt, and therefore maps made from images limited to very specific dates require an appreciation of changes brought about by major dust storms that might have occurred during each apparition.

All maps were cropped to a full 360° east to west and scaled to a width of 2,000 pixels. The maps were then offset as needed to bring zero degrees latitude and longitude to the centre. A sequence of digital stretching operations brought the latitude markings of the original maps into alignment with the grid of modern Mars maps.

The result is an archive of standardized historical maps that can be more meaningfully compared with one another and with modern instrument-based maps. An advantage of having the maps in simple cylindrical projection is that they can also be wrapped into a sphere to create a digital globe (Figure 2). This makes it possible to recreate and compare any view of Mars seen through the eyepiece by early cartographers. The globe projection also removes distortion inherent in the original map projections, making it easier to perceive features.

3. From Huygens to seas, continents, and canals

The recognition of changes in the Martian features was gradual. At first, progress was frustrated by the intrinsic difficulties of observing Mars.[3] Even at its closest approach to us it remains at least 140 times farther than the Moon, and never subtends an angle more than about 25 seconds of arc at opposition, similar to the apparent diameter of the lunar crater Copernicus. Secondly, the poor quality of telescopes over much of this period made detection of Martian surface details uncertain.

A remarkable sketch by Christiaan Huygens on the evening of 1659 November 28 shows the broad and characteristic wedge of Syrtis Major in easily recognizable form (top left of Figure 1), but that remained the exception for over a century. Even the German astronomer Johann Hieronymus Schroeter (1745–1816) at the end of the 18th century and the Frenchman Honoré Flaugergues (1755–1830) at the beginning of the 19th failed to see the markings well enough to convince themselves that they were seeing permanent features on the surface.[4] The first reliable maps were not drawn up until 1830s by Wilhelm Wolff Beer (1797–1850) and Johann Heinrich von Mädler (1794–1874) in Berlin.

3.1. *Sorting the Martian world into figure and ground*

One of the first things worthy of notice about this early stage of Mars studies is that observers tended to see the surface divided into two parts: dark markings, which make up two-fifths of the area of the planet, and light areas, which make up the remainder. To use terms later introduced by psychologists, the dark markings were seen as the 'figure' and the light areas as the 'ground'. As a result, the dark areas on Mars received most attention, with the light ones being consigned to secondary status as merely the background. This subtle, semantic issue may have affected later interpretations of Mars.

Here we encounter what might be called the psychology of planetary observation. Different observers interpret the planetary markings revealed by their telescopes in their own way – a form of personal equation that complicates intra-observer comparisons.[5] The drawings of early observers differ so much among themselves that in some cases it is difficult even to be sure which face of the planet is in view (Figure 3).

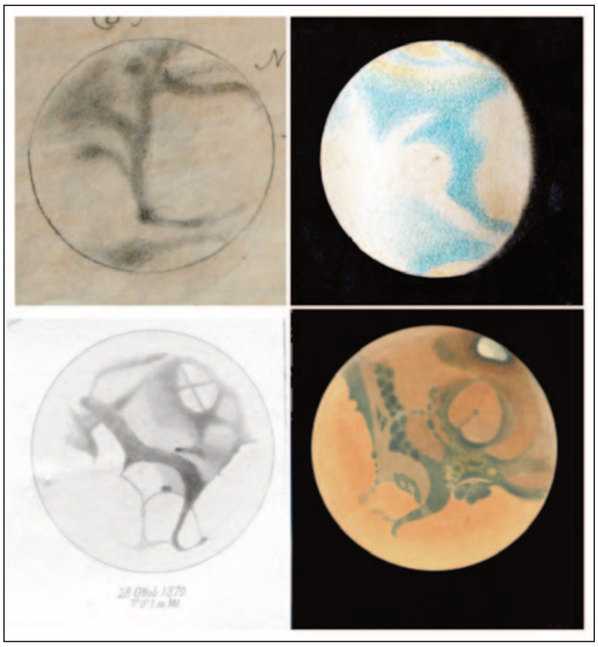


Fig. 3: The 'personal equation' in Mars observations, illustrated. From top left: Dawes 1852 (Syrtis Major very narrow with Nilosyrtis extension prominent); Secchi, 1858 (first coloured drawings of Mars – Syrtis Major narrow and Nilosyrtis prominent and broad); Schiaparelli 1877 (Syrtis Major narrow, Nilosyrtis still prominent but narrow); Antoniadi 1909 (Syrtis Major narrow, Nilosyrtis narrow and truncated).

Although the personal equation would never go away, by the late 1850s and early 1860s all the better observers, including Angelo Secchi (1818–78), J. Norman Lockyer (1836–1920), Frederik Kaiser (1808–72), John Phillips (1800–74), and William Rutter Dawes (1799–1868) had reached a generally high level of agreement in what was being recorded. The 1870s saw a further advance with the work of Étienne Léopold Trouvelot (1827–95), Nathaniel Green (1823–99), Giovanni Schiaparelli (1835–1910), Charles Edward Burton (1846–82), and others.

Schiaparelli, a well-trained professional astronomer at the Brera Observatory in Milan, became the first to attempt to measure the precise positions of Martian features using a micrometer, thus pinning down the main outlines of the surface markings. Schiaparelli's measures were largely adopted by other observers but some, such as Green, continued to rely on estimating positions by eye. Whereas Schiaparelli fixed the position of the prominent bright area Hellas with five measured micrometer positions, Green's position, estimated by dead reckoning rather than measurements, was off by some 8°. These systematic errors should be kept in mind, and need to be corrected when we attempt to compare drawings and charts by different observers.

Green and Schiaparelli both published influential maps based on observations made at the perihelic opposition of 1877 (Figure 4). At a glance, it is evident that they are qualitatively unlike, especially in their depictions of the minor features of the planet. These maps

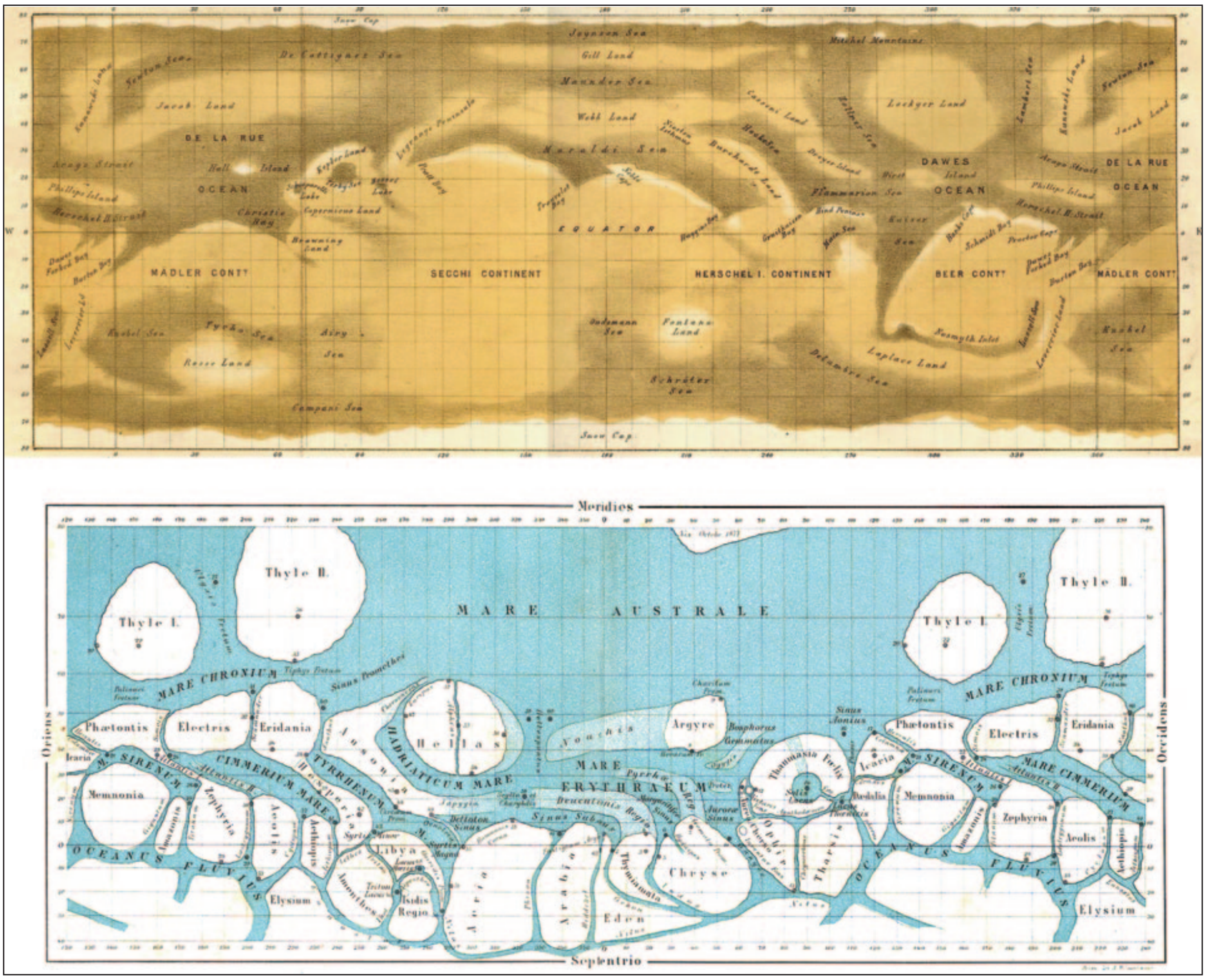
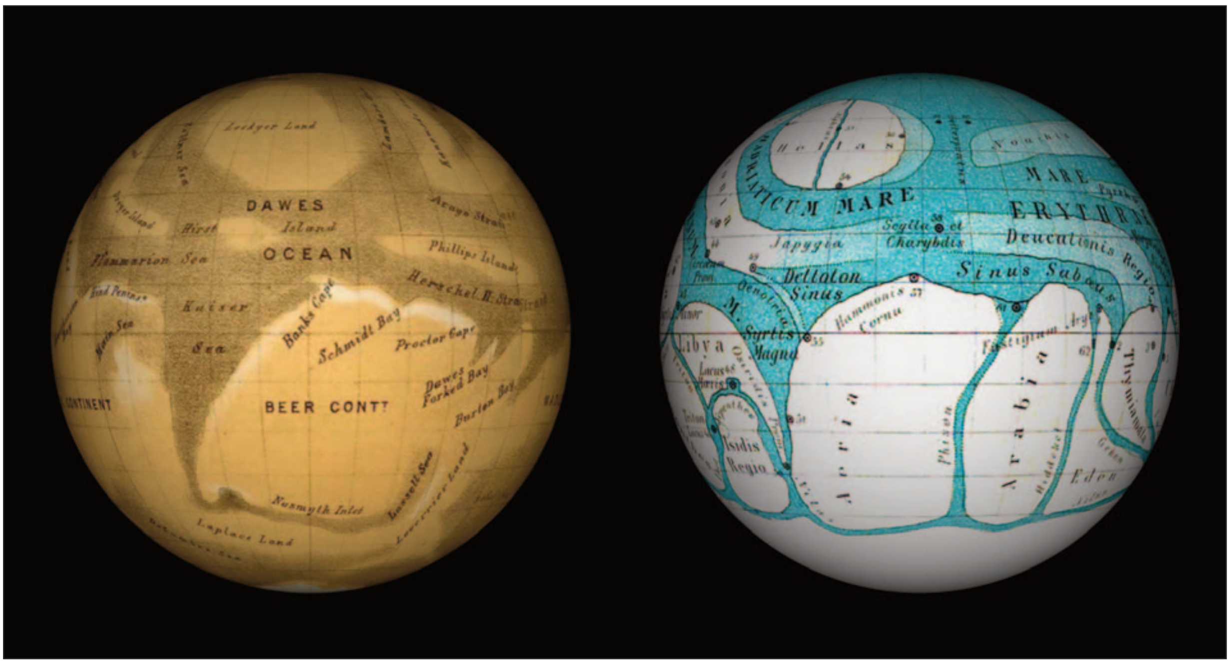


Fig. 4a: Another example of personal equation: Giovanni Schiaparelli's map, in blue, compared to that of Nathaniel Green (top). These maps are shown in the original forms in which they were published, with south at the top, and illustrate the difficulties of comparing them. Green's map incorporated his work from other years, in particular 1873, whereas Schiaparelli's did not. Green's map retained many of Proctor's 1867 English names, but the Schiaparelli map introduces many of the modern names. (William Sheehan)

Fig 4b: Globes constructed from the standardized maps: Green left and Schiaparelli right. (Joel Hagen)



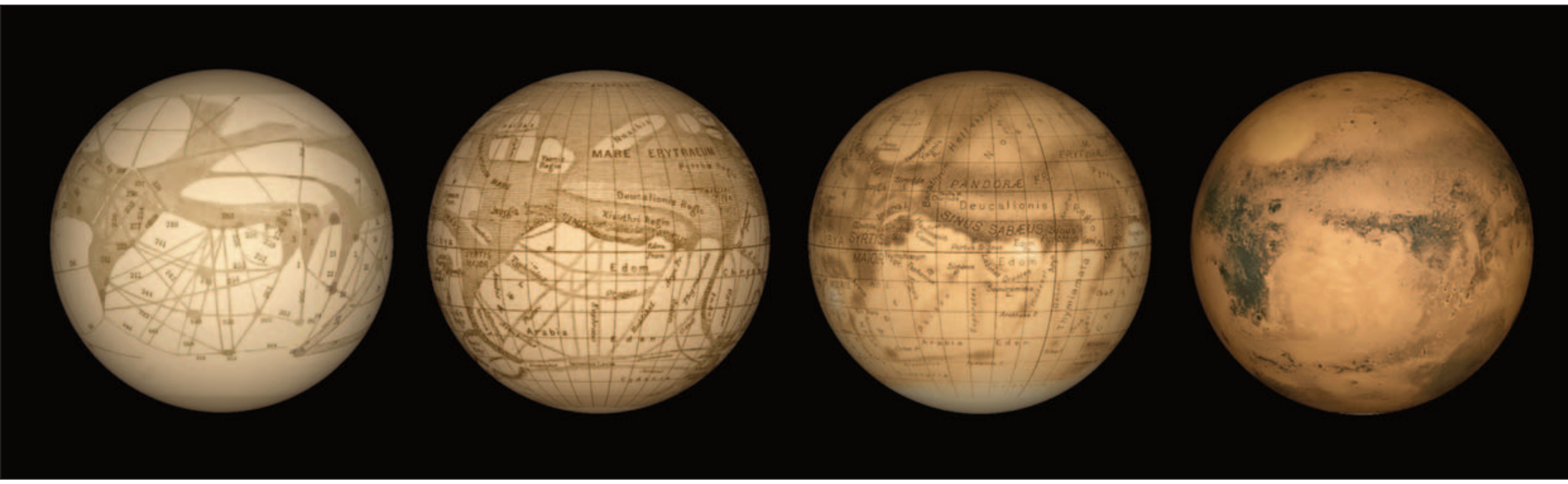


Fig. 5: The canals of Mars. These globes constructed from original maps present views centred on the south-west side of Syrtis Major. From left to right, the globes show the canal system in its most fully developed form (Lowell and Schiaparelli), progressing through the more naturalistic representation of Antoniadi, and finally to the Mars Global Surveyor globe on the right. These globes also show changes in the larger albedo features including in the shape and breadth of Syrtis Major and in the complex of features including the Nilosyrtis and Nepenthes-Thoth at bottom left of the globes. (Joel Hagen)

were made in the early phases of what was to become known as 'canal mania', when the main markings were relatively neglected and instead many observers devoted the lion's share of their effort to delineating – in the literal sense – a network of spindly 'canals' tessellating the 'desert' areas.[6]

During this era attention shifted from the dark areas to the light areas where the canals were most easily detected. Although some of the purported canals do have a basis in real surface features – usually in the form of either broad bands or wispy streaks extending from the sharp endpoints of the larger dark areas – many of the most regular and attenuated of these features, which resemble spider's threads, seem to have been entirely illusory.[7]

4. The canals – a brief digression

As we can see from Figure 5, despite significant differences in drawing style, there is a substantial agreement in the main markings as shown by these observers. However, the extreme narrowness of markings as rendered by Schiaparelli and especially the great champion of the canals, Percival Lowell (1855–1916), needs to be explained.

The most important consideration is that they saw these details only in glimpses, in intervals of good seeing lasting only fractions of a second. Thus, what they registered was a result of the built-in constraints of the eye-brain-hand system under such split-second conditions. They saw that something was there, but they could not determine what that something was.[8]

No one has ever described better the manner of the canals' appearing than Lowell himself. As he wrote in *Mars and Its Canals* (1906):

> When a fairly acute-eyed observer sets himself to scan the telescopic disk of the planet in steady air, he will, after noting the dazzling contour of the white polar cap and the sharp outlines of the blue-green seas, of a sudden be made aware of a vision as of thread stretched somewhere from the blue-green across the orange areas of the disk. Gone as quickly as it came, he will instinctively doubt his own eyesight, and credit to illusion what can so unaccountably disappear. Gaze as hard as he will, no power of his can recall it, when, with the same startling abruptness, the thing stands before his eyes again. Convinced, after three or four such showings, that the vision is real, he will still be left wondering what and where it was.
>
> By persistent watch, however, for the best instants of definition, backed by the knowledge of what he is to see, he will find its comings more frequent, more certain and more detailed. At last some particularly propitious moment will disclose its relation to well-known points and its position be assured.[9]

Psychologists (and propagandists) have discovered that mere repetition makes a fact seem true, regardless of whether it is or not.[10] In Lowell's case, repetition of the fugitive visitations convinced him that the narrow lines glimpsed on the surface of Mars were 'as real as the main markings'. For purposes of this paper, we must regard these questionable details as too uncertain to be relied upon as indications of albedo changes, and so will say relatively little about them in the rest of this paper.

However, some of the more prominent streaks seen on the surface of Mars are important to our story, even though they were often hopelessly and misleadingly caricatured by the likes of Schiaparelli and Lowell. For example, the dark streaky marking Nilosyrtis has appeared at times as a marked extension of the north tip of Syrtis Major, while at other times it has been faint or even invisible. The analysis of changes in such features is important to understanding the nature of Martian atmospheric and surface processes.

5. Early observations of changes in the albedo features

As early as the 1850s, analogies with the Earth played a leading role in the interpretation of the Martian features. The identification of the darker areas (typically perceived as bluish or bluish-green) as seas, and the orange-red areas with continents, was widely accepted. For instance, the sea–land dichotomy was adopted by Schiaparelli on the map he drew, based on his observations in 1877 with the 22-cm (8.7-inch) refractor at the Brera Observatory in Milan. This was despite the fact that, as he himself realized, no specular reflections of the Sun had ever been observed from the dark areas as should have been the case if they were expanses of water.

In 1867 the English astronomer Richard Anthony Proctor (1837–88) had named the purported seas and lands after astronomers, many still living and disproportionately British. Schiaparelli preferred names based on the geography of the ancient Mediterranean and biblical and classical literature. It was a smart move, and his names have served as the basis of the rather romantic nomenclature still in use today. However, he continued to accept the convention of naming them after seas and lands.

Schiaparelli urged that the names be accepted only with caution. He did not intend them to bias the observations in any way, naive as this now seems. Instead, he insisted that mare, terra, island, isthmus, strait, channel, peninsula, cape were meant as a mere convenient shorthand. 'Each of [these],' he said, 'provides a description and notation of what could otherwise be expressed only by means of a lengthy paraphrase, and one, at that, which would need to be repeated each time one spoke about the corresponding subject.' [11] The terms were no more meant to be taken literally than similar terms on the Moon.

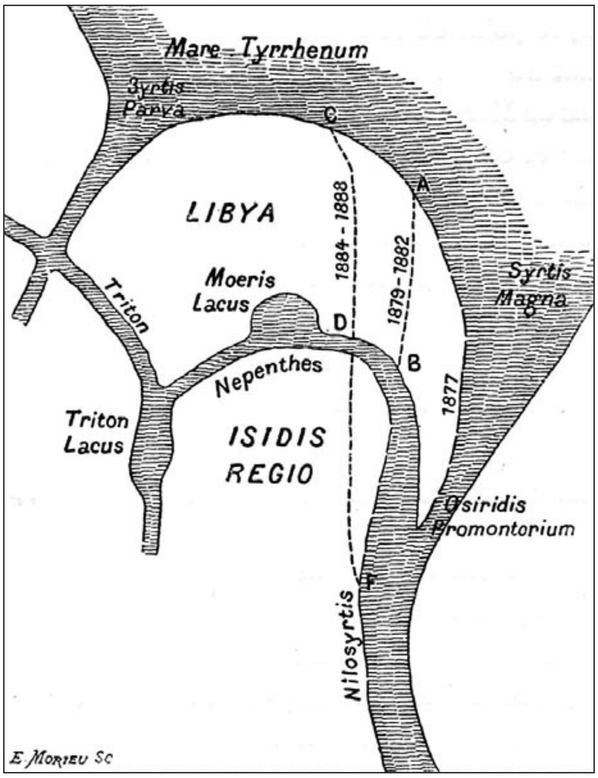


Fig. 6: A diagram by the engraver E. Morieu based on Schiaparelli's observations of 1877, 1879–82, and 1884–88, in which he has indicated by dashed lines and dates the observed changes in the 'shoreline' of Syrtis Major. According to the thinking of the time, it was believed that an area of land had been inundated by the adjacent sea. This is, indeed, a part of the planet where albedo changes have frequently been observed. For instance, the Triton Lacus no longer exists, but has been subsumed within a larger patch to the north (not shown in this diagram) known as Alcyonius. (Camille Flammarion, La Planète Mars, 1892, vol. 1, p. 431)

5.1. *Clouding the issue*

Despite this caveat, Schiaparelli himself asserted in the same work: 'The bright areas on Mars are its continents, and the dark parts its seas.' [12] Furthermore, he deduced that if Mars did have seas, it must also have clouds. From his own observations, he found indications that the markings were affected in significant degree by clouds, 'unstable formations, which cover one or another part of the surface, and make more difficult and time-consuming … the study of the fixed markings of the planet'.[13] In particular, in 1877 he incorrectly explained the lack of anything observationally noteworthy in the Tharsis region – the 'uninteresting hemisphere' of Mars for amateur observers, since it lacks prominent albedo markings – as due to cloud cover.

However, the existence of clouds long remained a rather uncertain proposition. Until the opposition of 1877–78, widespread obscurations had never been observed. Although the first recorded planet-encircling dust storm was recorded between 1877 May and August by the French observer E. L. Trouvelot he was alone in observing that long before opposition, and by the time others such as Green and Schiaparelli got underway the dust had largely cleared. Unfortunately Trouvelot never published his observations; they turned up only in 2009, in the archives of the Paris Observatory library, and so had no influence whatever.[14]

The southern hemisphere summer solstice, which corresponds to the peak dust storm season, occurred on 1877 September 27. By then Schiaparelli's great rival, the British artist and astronomer Nathaniel Green, who had been observing and drawing with a 33-cm (13-inch) telescope between August 19 and September 29 from Madeira, noted on his last night of observations that the eastern border of Thaumasia (a brightish patch south of Solis Lacus) was faint. Schiaparelli recorded a bright streak indenting nearby Protei Regio on September 26, and confirmed it on October 4.

He found that during the period around October 10 'there was a general cloudiness from Noachis to Mare Erythraeum', although it had all cleared away by October 14. We now recognize this as a regional dust storm.[15] These observations were not insignificant, but they hardly constituted the kind of breakthrough that might have occurred had Trouvelot's storm been more widely observed.

The next such event was not recorded until 1909. Whether this was due to a genuine lack of dust storm activity during this period or to oversampling by predominantly northern hemisphere observers of the less-dusty aphelic oppositions is not clear. However, the oppositions of 1892, 1894, 1896, and 1898, at least, were observed for long enough in the southern spring and summer to show that no encircling storms occurred. It may be that this was a less dusty epoch.

Note that even the term 'clouds' as used by these early observers meant only ordinary water-ice clouds, and did not encompass dust clouds or dust storm activity at all. Schiaparelli had written in his first memoir:

> In searching out the cause of the difference of colour [of the different areas on Mars], suffice it to say that if the Earth were seen from a similar distance, it would present much the same appearance as Mars does to us … we can readily accept the supposition that the bright areas on Mars are its continents, and the dark parts are its seas. This probability is further enhanced from the appearance on our chart, where all appears to be disposed in a manner that suggests the expansion of a liquid mass above an uneven surface. Thus all those streaks [canali], which form furrows between the so-called seas and whose ample mouths have the shape of a trumpet, appear as expected if the large dark regions are indeed seas, and the streaks channels of communication between one sea and another.
>
> The remaining parts of the surface of Mars must also be covered with larger or smaller masses of liquid … Could we imagine vapours, clouds, and polar ices above a wholly dry planet? The alternating waxing and waning of the two masses of polar ices presupposes the transport of a great quantity of substance from one hemisphere to the other. Transport on this scale must take place in the form of vapour, but some part must also take place in the form of liquid currents, as happens on the Earth.[16]

Schiaparelli even thought he could explain why the darkest markings on Mars were found in the equatorial regions of the planet. As had been noted by sailors on Earth, the seas nearer the equator (the Mediterranean, for instance) were darker than those in higher latitudes such as the Baltic or North Sea. This, according to the American meteorologist Matthew Fontaine Maury (1806–73), was because of the increased salinity of the near-equatorial areas, due to the greater evaporation caused by more intense solar irradiation.[17] Schiaparelli assumed the same would explain the trend seen on Mars, and took it as support for the hypothesis that Mars was covered with seas and continents like ours. While based on interesting and valid knowledge, this example shows that supposition can be stretched too far on the basis of plausible analogy.

6. Albedo changes provisionally explained

In addition to the bright continents and dark seas there were other areas of intermediate shade which Schiaparelli identified as marshes or lagoons. He cited, for instance, the long peninsula Hesperia separating his two large seas Mare Cimmerium and Mare Tyrrhenum. With the view generally adopted that Mars's dark areas were seas and that it had some sort of meteorology involving a hydrologic cycle, the stage was set for a dramatic announcement at the 1879 opposition.

As interpreted by Schiaparelli, the continental region Libya (the bright area tucked into the notch between the southeastern side of Syrtis Major and the north side of Mare Tyrrhenum) had been inundated by the neighbouring sea (Figure 6). As a result of this change, Syrtis Major appeared distinctly broader than it had in 1877.

The French observer Camille Flammarion (1842–1925) later wrote:

> The extent of the Hourglass Sea [an older name for Syrtis Major] varies. There is no begging the question or evading the fact, though we cannot yet explain it fully. The variation is certain … If the dark patches on Mars represent seas, these increases in extent correspond to flooding, and lead us on

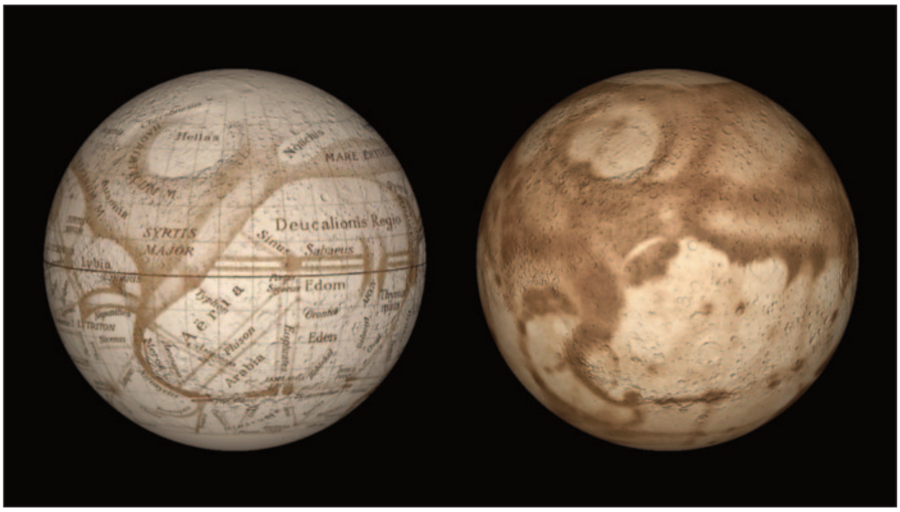


Fig. 7. Topographic relief recorded by the Mars Orbiter Laser Altimeter is combined with an 1890 Schiaparelli map on the left and a 1924 Antoniadi map on the right. Topographic relief provides specific landmarks on the globes, helping to understand what early observers were seeing and recording. Despite their differing styles, in these two maps both Schiaparelli and Antoniadi show remarkable accuracy in depicting albedo boundaries at Hellas, Isidis, and the curve of Nilosyrtis across the northern edge of cratered terrain. (Joel Hagen)

> to the conclusion that the banks – especially the left [east] bank of the Hourglass Sea, along the Flammarion Sea [Lacus Moeris] – are very flat. These floodings, lasting for several months, cannot be due to tides. To avoid these conclusions, we would have to assume that the patches on Mars are not seas. Very difficult![18]

The same change was registered by the Irish astronomer Charles E. Burton, one of the most skilful observers of the period. He is almost forgotten now but deserves to be remembered, if only because he was the first to posit the existence of the yellow clouds (later identified as dust clouds) on Mars.[19]

The apparent 'inundation' of Libya became (with the canali) another cause célèbre of the period. The region was carefully mapped by Schiaparelli at the oppositions of 1882 and 1884, and his results agreed with those of the French astronomers Henri Perrotin (1845–1904) and Louis Thollon (1829–87) using the great 77-cm (30-inch) refractor at Nice (at the time the world's largest). In 1888 Perrotin found that Libya 'clearly visible two years ago … no longer exists today. The nearby sea (if sea it is) has totally inundated it.' [20]

This was hardly an insignificant change; the Martian Libya was about the same area as France. Schiaparelli exclaimed, 'The planet is not a desert of arid rocks. It lives; the development of its life is revealed by a whole system of very complicated transformations, of which some cover areas extreme enough to be visible to the inhabitants of the Earth.' [21]

As we shall see, this area, including the northeast border and northern tip of Syrtis Major and the adjacent part of Isidis Planitia, is notorious for changes, and includes some of the most remarkable ones ever observed on the planet, a result of the interplay of local topography with seasonal winds. The changes, in addition to those at Libya noted by Schiaparelli, include the rise into prominence of the streaky Nilosyrtis off the tip of Syrtis Major between about 1852 and 1920 and the massive development of the Nepenthes-Thoth between 1920 and 1954 which was followed by its almost complete obliteration after the 1956 dust storm (Figure 7).

7. Mars becomes a flat desert world

The idea that the dark areas were seas and the light areas land remained predominant into the 1890s. This was the period when Schiaparelli, Lowell, and others (especially the loyal former employees of Lowell) tended to represent the Martian streaky markings as increasingly narrow lines, leading to the 'canal' controversy which largely preoccupied astronomers concerned with Mars in the late 19th and early 20th centuries.

Other important developments in Martian studies included the discovery in 1892 by the American astronomer Andrew Ellicott Douglass (1867–1962) of 'canals' criss-crossing the dark areas and the demonstration by William Henry Pickering (1858–1938) that light reflected from the 'seas' was not polarized as would have been the case were they really liquid. Combined with the long-established failure to detect specular reflections from the supposedly watery expanses this led to a paradigm shift in which the dark areas were reinterpreted as vast tracts of vegetation (with apparent seasonal changes referred to as a 'wave of colour' or 'wave of darkening') while the bright areas were arid deserts.

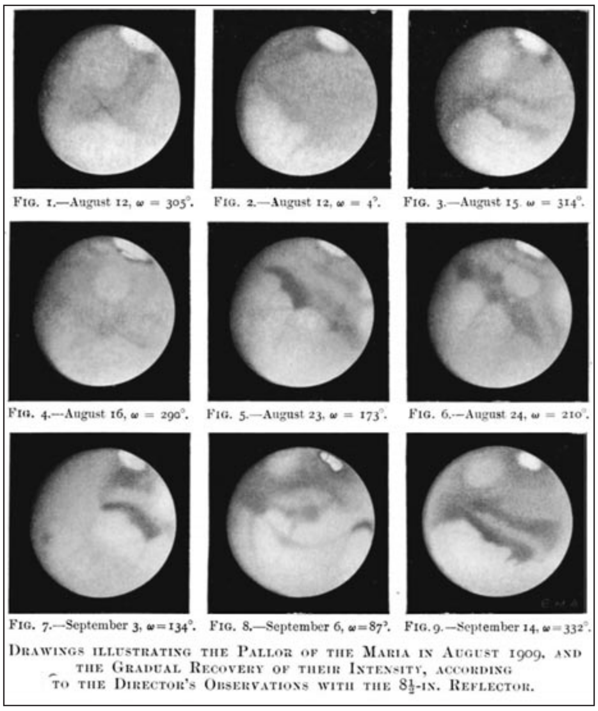


Fig. 8: Antoniadi's drawings made during the planet-encircling dust storm of 1909 recording the gradual clearing of dust from the atmosphere of Mars between August 12, when the planet (except the South Polar Cap) was almost completely hidden and September 14 when the Sinus Sabaeus was returning to its original intensity. (Richard J. McKim and the British Astronomical Association)

At that time Mars was regarded as remarkably flat, with very little relief and scarcely anything resembling an ordinary mountain. It was also now seen as very dry, with little if any liquid water, with the main water mass being captured as ice in the frozen polar caps. For those, like Lowell, who believed the planet to be inhabited, it was conceivable that in order to adapt to such a world they would have constructed a huge system of engineering works: canals.[22] We now know that seasonal changes in colour reported by some observers consisted largely of false surmises based on observational errors related to the use of achromatic refractors and contrast effects.[23]

Yet another dogma of this era held that the atmosphere of Mars was almost always clear, despite the presence of occasional clouds. There were two types of clouds: white and yellow. The yellow clouds sometimes appeared brighter than the desert background, but the fact that the latter were almost the same colour as the continental/desert regions delayed the general recognition of their frequency and importance.

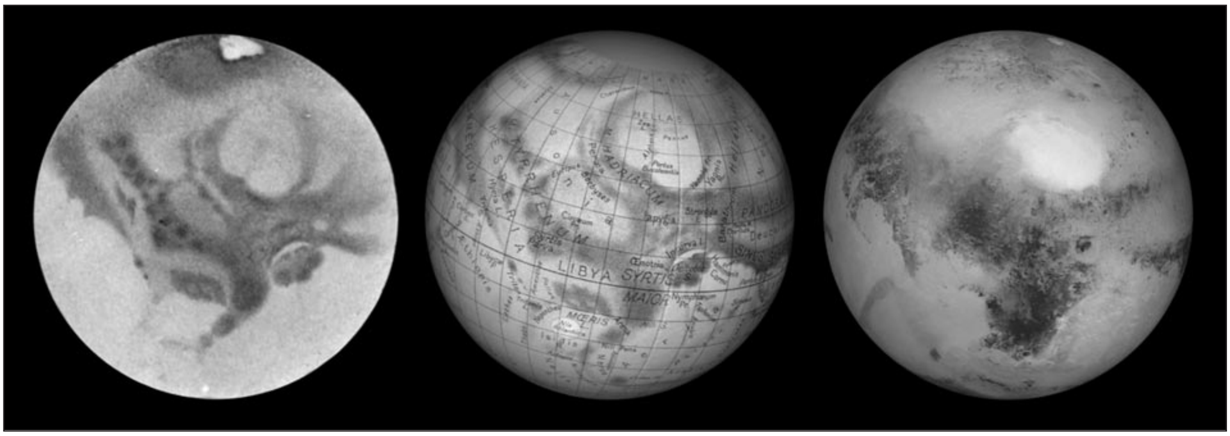


Fig. 9: Antoniadi's famous drawing of Mars, left, as it appeared to him through the eyepiece of the 83-cm (33-inch) refractor at Meudon Observatory near Paris, on 1909 September 20. The middle figure is based on his 1909 map projected on a globe and oriented to the coordinates of his eyepiece drawing, while the one on the right is a globe with the same orientation based on a Viking orbiter map. The differences between the Antoniadi and Viking globes are entirely due to albedo changes over time.

Moreover, even the association of Burton's yellow clouds with suspended dust was not made until 1899, when A. E. Douglass – probably in part based on his experience with dust storms in the Arizona desert – suggested that this was the case in order to explain the yellowish tint he noted along the terminator of the planet. He did not describe dust clouds as such, but Percival Lowell did when he saw a large ochre-orange projection, completely detached from the terminator, on 1903 May 26. Lowell calculated that it was 27 km (17 miles) high and almost 500 km (300 miles) in length, and appeared exactly at the subsolar point.

By the following night it had changed position, from which Lowell calculated that it was moving with a velocity of 26 km/h (16 mile/h), which has since been found to be a typical speed for Martian dust clouds. Despite this, Lowell and his assistants continued to regard such events as exceedingly rare, and to the end of his life continued to believe the skies of Mars were almost perpetually clear. So far do strong beliefs affect observations.

8. The great opposition of 1909

For most observers, though, the great opposition of 1909 (a perihelic one, with greater solar warming) was a decisive step forward in understanding the phenomena of Mars. Lowell was the odd man out. He appears to have refused to recognize the global dust storm that arose before his eyes, and attributed the total lack of detail to bad seeing. The global obscurations simply did not fit with his mindset. Towards the end of 1894 he had considered the fading of albedo features (in reality due to fallout from a regional dust storm) as evidence of the seasonal decay of vegetation, but in 1909 this change was seasonally far too early.

The testimony of many other observers was direct and incontrovertible. The lack of the usual definition of the dark markings was already noted in 1909 June. By August 12 the Greek–French astronomer Eugène Michel Antoniadi (1870–1944), who set up his own 22-cm (8.5-inch) Calver reflector at the observatory of his former employer Camille Flammarion at Juvisy-sur-Orge, found the usual markings either extremely faint or altogether vanished. Antoniadi exclaimed: 'It was nearly impossible to see patches normally as dark as the Mare Tyrrhenum, Syrtis Major and the Sinus Sabaeus! … [T]ruly a unique spectacle.' [24] The planet now appeared to him as a uniform 'citron yellow'. A planet-encircling dust storm was underway, the first to be seen since that observed by Trouvelot in 1877 (Figure 8).

At Yerkes Observatory, photographs taken by Edward Emerson Barnard (1857–1923) with the 1-m (40-inch) refractor showed the markings faint from mid-July until the latter part of September, after which they gradually began to regain their usual intensity. The clearing was timely, and allowed Antoniadi to have an unhindered view of the Martian surface with the 'Grand Lunette', the 83-cm (33-inch) refractor at the Meudon Observatory, when he began to use it on September 20 (Figure 9). It was largely this series of observations that would show that the canals did not exist, at least not in the forms shown by Lowell.[25]

8.1. *Mars as a swirling dust bowl*

At the following opposition, in 1911, Antoniadi again observed at Meudon and found large parts of Mare Erythraeum covered for several weeks with yellowish clouds. Again, in 1924 August, there was local and regional storm activity so that for a period the planet presented a cream colour similar to that of Jupiter.[26] Towards the end of the year the planet was enveloped by a storm. In one of Antoniadi's drawings, made on December 24, only a single dark patch, Nodus Gordii (in the position of the Martian shield volcano Pavonis Mons) is shown. It is the only visible feature on the entire disk.

So long seen as rare events, dust storms – whether seasonal or sporadic – now began to be recognized as a key to the observed changes in large-scale markings of the planet. Antoniadi identified the yellow clouds with fine dust carried aloft by the winds, found them far more common than previously realized, and stated that they occurred with the greatest frequency when Mars was near perihelion. This was only to be expected, since at perihelion the solar heating was 50% greater than at aphelion, producing stronger winds. In Arizona, for example, the initial dust is often picked up by the strong winds in dust devils, which are also seen on Mars. Some dust storms on Mars may also start with localized dust devils, although others may be due to strong regional winds.

All of this, spelled out in Antoniadi's great book *La Planète Mars* in 1930, would stand the test of time. But even Antoniadi continued to accept aspects of Lowell's vision of Mars. Although Antoniadi dismissed most of the canals as complex illusions, he ascribed vivid colours to the dark markings, and followed their apparent changes with the seasons – yet in retrospect it seems likely that these colours were largely the effects of the strong secondary spectrum of the great refractor.[27] About these supposed changes he wrote:

> We have seen that the great extended dark areas of Mars behave as though covered with vegetation, which makes it very probable that one form of life exists there … If … we consider life's marvellous power of adaptation, one of the aims of the Creator of the Universe, we can see that the presence of animals or even human beings on Mars is far from improbable … However, it seems that advanced life must have been confined to the past, when there was more water on Mars than there is now; today we can expect nothing more than vegetation around the vast red wilderness of the planet.[28]

As is typical of advances in science, Antoniadi adopted a kind of hybrid view: on the one hand he disposed of canals in the artificial sense and realized the importance of massive dust storms on the planet; on the other, he was not quite able to give up the belief in vegetation and the wave of darkening.

9. Waving goodbye to the wave of darkening

The seeds had been sown for a new view of Mars that would grow significantly in the next decades. Although the 1909 planet-encircling dust storm was decisive in overthrowing the idea that large-scale obscurations were rare, the notion of Martian vegetation survived virtually uncontested until the great dust storm of 1956. The lattter was the first to occur in the era of Kodachrome colour film, and coincided with the publication of a series of remarkable papers by University of Michigan astronomer Dean Benjamin McLaughlin (1901–65) – whose specialty was stars, not planets – in which he set forth an innovative 'volcanic-aeolian' hypothesis for the Martian features.[29]

McLaughlin took as his starting point a fact that was well known to Mars observers: the dark areas often ended in pointed bays, from which curved streaks (seen

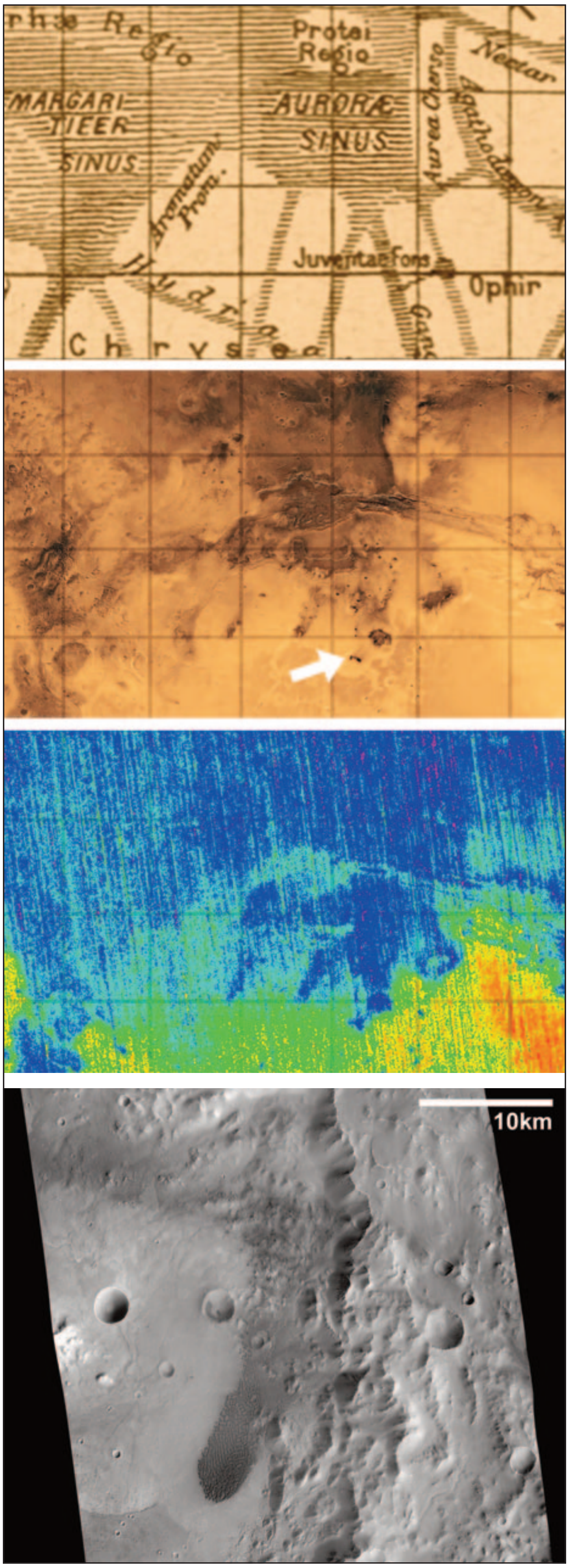


Fig. 10: An inter-comparison of the Xanthe region, site of several prominent classical canals. Top: As shown by Giovanni Schiaparelli based on his observations between 1877 and 1890. Second: A Viking orbiter photomap. Third: A Dust Cover Index map based on measures of spectrally obscuring surface dust. Bottom: A close-up of dark dunes in the crater indicated by the arrow in the Viking image. (Joel Hagen and NASA)

Table 1

Great dust storms on Mars, 1877–2018

Based on data assembled by Richard J. McKim, Mars Section Director of the British Astronomical Association, and published with his permission.

Year	Dates	Time for encirclement (days)	Duration (days)	Ls at start (degrees)	Initiation site	Classification: E = encircling G = global
1877	May 8 to August 6	?	91	184	NW Hellas – E Noachis?	E
1909	Before June 3 to September 20	13?	119	204	Hellas	E
1924	December 9 to mid February 1925	<21	68	311	NW Hellas	E
1956	August 19 to October 31	20	73	249	NE Noachis/Iapigia	E
1971	September 22 to late February 1972	16–17*	161	260	Iapigia/NW Hellas	G
1973	October 13 to 1974 January 11	9	91	300	NW Solis Lacus	E
1975	July 14 to October 21	29	100	270	S Thaumasia	E
1977a	February 15 to mid April	19	60	204	Thumasia Fossae (SW Thaumasia)	E
1977b	May 27 to late October	<24	158	268	Valles Marineris	E
1982	October 14 to late January 1983	?	110	208	Southern mid-latitudes	E
2001	June 26 to December 1	15	159	185	N and NW Hellas	G
2007	June 23 to October 7	15	107	263	NE Noachis	G
2018	May 30 to late September	22	124	184	SE of Niliacus Lacus/ Mare Acidalium	G

* 12 days according to polarimetric data

as canals, often double canals, by many observers) extended in a way that suggested the action in north temperate latitudes of prevailing south-westerly winds. As an example, he pointed to the pointed bays at Sinus Meridiani (also known as Dawes' Forked Bay), from which extended the streaks known in the old days as the canals Hiddekel and Gehon I. Other streaks included the Phison and Euphrates canals that reached out from Sigeus Portus at the middle of Sinus Sabaeus; still another example was Nilosyrtis, which extended from the northern tip of Syrtis Major.

McLaughlin noticed that all these markings were subject to conspicuous nonseasonal changes. Asking himself what the source of this variable dark material might be, he proposed that the most likely explanation was volcanic ash, spewed from still-active volcanoes located at dark spots located in the pointed bays.

Apart possibly from the Mt Wilson astronomer and writer Robert Shirley Richardson (1902–81) this theory did not win many adherents.[30] The chief opposition came from the renowned planetary astronomer Gerard Peter Kuiper (1905–73), then at Yerkes Observatory, whose objections included the fact that active volcanoes would produce large amounts of water vapour, something that was incompatible with the observed paucity of water in the planet's atmosphere.

McLaughlin did not really have a response to this, but the planet-encircling dust storm of 1956 made such a profound impression that even Kuiper changed his mind. Henceforth he distanced himself from the vegetation theory and instead adopted a McLaughlin-like theory in which the ability of winds to move dust around Mars covered lava fields with a thin veneer of dust, with the seasonal removal by wind currents explaining the wave of darkening.[31] For the first time in the history of Mars observations, the concept of changes in markings being due to deposition and removal of dust, in contrast to the hitherto dominant vegetation theory, had now been clearly stated.

This concept was dramatically confirmed in the spacecraft era by Mariner 9, the first orbital Mars mapper. When the spacecraft arrived at the planet in 1971 November it was greeted by the largest dust storm on record, one which covered the entire planet including even the polar caps. Later, after the dust cleared, the role of windblown dust in altering the outlines of many small-scale albedo features was recognized by a number of investigators including, most prominently, Kuiper's former student Carl Sagan (1934–96).

10. Spacecraft views of Martian albedo changes

Mariner 9 was one of five spacecraft aimed at Mars in 1971, of which only three – Mariner 9, and two Soviet orbiters, Mars 2 and Mars 3 – arrived successfully. On arrival, all three had to wait out the dust. The Soviet orbiters had been preprogrammed to take most of their data during the short time near periapse, and although they did return significant data including a total of 60 fairly dust-obscured images, hardly anyone now remembers their contribution. By the time the dust finally settled they had run out of power, while Mariner 9 was still going strong. It became the first space probe able to scan the planet's topography, revealing the enormous shield volcanoes of the Tharsis region plus a vast array of other features including canyons and dry river beds.

For the first time, Mars emerged as a geological wonderland, with numerous phenomena including dune fields, which showed regional-scale movement and accumulation of dust by winds, and numerous examples of lighter- or darker-than-background dust accumulating on the floors of certain craters, which then became the sources of extended streaks of dust blown out of them by prevailing winds. Most of these streaks are too small to be seen from Earth, but the largest may have some connection to some of the historical canals on Mars (Figure 10).

10.1. *Regional and global dust storms*

Since Mariner 9, astronomers have established that large regional dust storms covering continent-sized areas on the planet occur each Martian year, while about once every three Martian years a regional dust storm will develop into a planet-encircling or global one, including the polar caps. Such global dust storms can affect the planet's overall colour and brightness even to the naked eye.

The encircling or global dust storms recorded during the period covered in this paper are listed in Table I. Figure 11 shows the effects of dust storms on albedo features in the periods between the planet-encircling storms of 1909, 1924, 1956, and 1971.

Areas on the planet where local storms tend to form are those where significant variations in atmospheric pressure and temperature exist. These include slopes such as those at the Hellas basin, one of the most common sites for dust storm development, and along the polar cap edges. The season that favours these events is summer, when ground temperatures become warmer than usual, heating the near-surface air. Because southern hemisphere summers occur near perihelion they are particularly active, just as Antoniadi suggested.[32]

10.2. *The devils in the details*

Dust devils, which are common on Mars, are probably a factor in maintaining the Martian atmosphere's perennial haze.[33] The latter not only hid topographical differences and gave rise to the belief the planet was without significant relief but misled astronomers who tried to calculate the thickness of the planet's atmosphere by means of albedo. They overestimated it by an order of magnitude.

On Mars, dust devil activity peaks during the local spring and summer, when the solar insolation is greatest. Among the Martian locations with evidence of dust devil activity identified by Mars Global Surveyor are, in the northern hemisphere, low-lying regions such as Amazonis Planitia and Casius, and, in the southern hemisphere, the large impact basin Argyre Planitia.[34] On the other hand, very little evidence of dust devil activity was found in Chryse, Utopia, or Meridiani.

In the same survey Amazonis Planitia was found to be by far the busiest region for dust devil activity. Casius had the largest number of images with dust devil tracks, although very few dust devils were directly observed. Possibly Casius contains only a thin surface veneer of dust over a darker surface, allowing even small dust devil tracks to be seen; alternatively, net dust deposition rates at Casius may be particularly low, allowing tracks to remain for a long time once formed.

Other features, such as the Nilosyrtis and Nepenthes-Thoth, may resemble Casius, in that a thin surface veneer of dust over a darker surface is likely to explain dramatic and long-lasting changes, as we discuss below in terms of our imagery database.

11. Earth-based and spacecraft observations: an attempt at correlation

As soon as one attempts to correlate details revealed by spacecraft with the broader albedo patterns long observed from Earth, various difficulties arise. The seasonal broadening of the neck of Syrtis Major goes back to Antoniadi, although the change in Libya from 1877 to 1879 mentioned above was noted earlier. Up to 1963 there was seasonal dust activity in the Libya desert

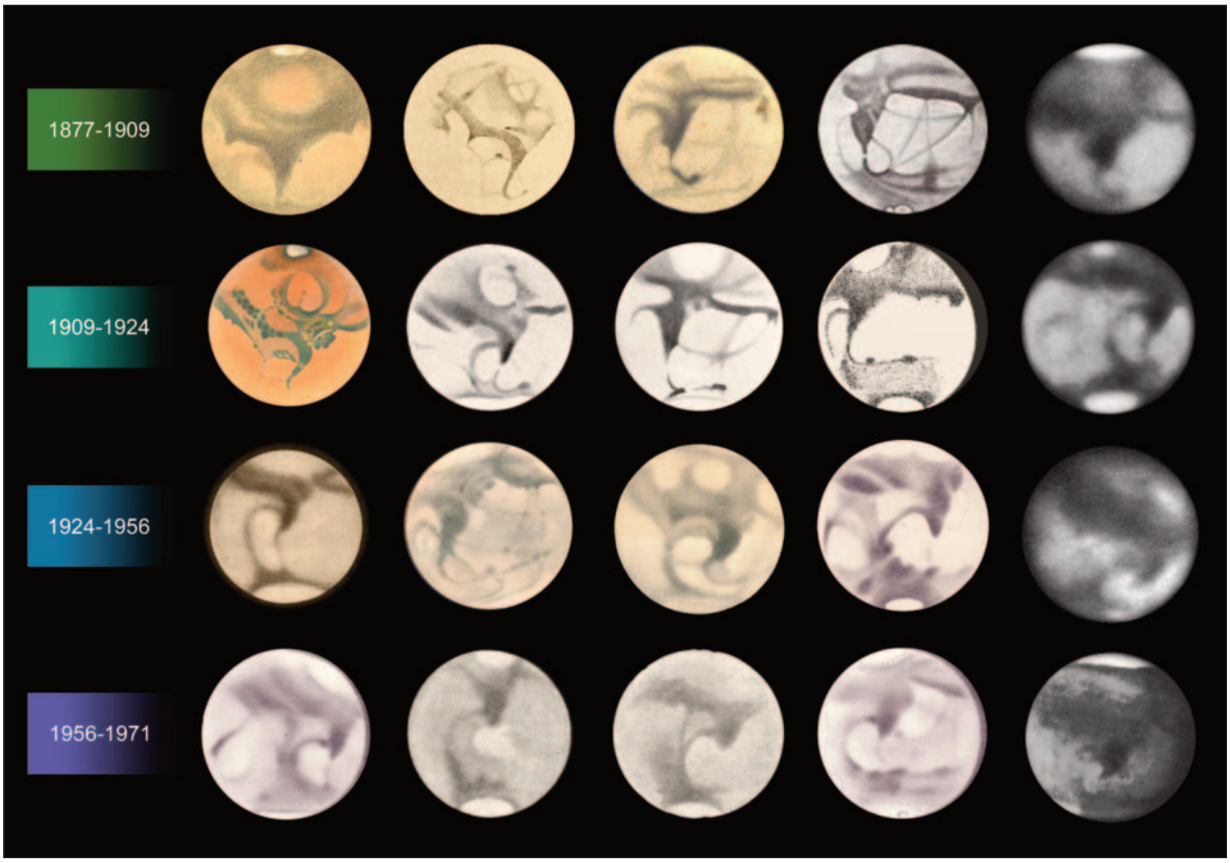


Fig. 11: Mars seen between planet-encircling dust storms. At the end of each row is a photograph from that interval.
1877–1909: 1877 Green, 1879 Schiaparelli, 1881 Boeddicker, 1905 Moreux, 1907 Slipher
1909–1924: 1909 Antoniadi, 1911 Phillips, 1914 Thompson, 1916 Antoniadi, 1916 Slipher
1924–1956: 1931 Schlumberger, 1937 Rudaux, 1937 Rudaux, 1948 Murayama, 1943 Pic du Midi
1956–1971: 1961 Murayama, 1963 Atchison, 1963 Botham, 1967 Murayama, 1969 Mariner 7. (Joel Hagen)

on the east, and this also greatly affected the albedo of the great Nepenthes curve. Based on his long series of photographs of Mars, the American planetary astronomer Earl Carl Slipher (1883–1964) called this the area on Mars that produced the most dust storms. After 1963, though, this activity ceased, and there has been no seasonal broadening of the Syrtis Major for many decades.

A similar statement was also often made about a seasonal broadening and darkening of Pandorae Fretum – in fact, this was cited as some of the strongest evidence of the existence of vegetation on Mars. However, this too is entirely due to sudden regional and/or encircling dust storms beginning in Hellas. (It can also happen when regional or encircling dust activity propagates from the west or northwest.)

More than a third of Mars's surface area was found to have brightened or darkened by at least 10% between the Mariner 9 imaging in 1971–2 and the arrival of the Viking orbiters five years later. Among the features affected was Cerberus, which forms a darkish boundary to the south side of Elysium Planitia. Antoniadi had described it as 'the most beautiful of the irregular streaks on Mars'.[35]

In the interval between Mariner 9 and Viking the boundary of the feature (although not the overall area) changed significantly. The relative darkening of Cerberus with the surrounding bright area gave it a more uniform tone as well as bringing about the disappearance of dark filamentary markings which have subsequently been identified as probable dust devil tracks.[36]

Then, in the late 1980s, Cerberus was noticed to be fading, and has continued to be faint ever since. Possibly the inactivity of the formerly dust-active Libya, and/or the adjacent initiation site of Isidis Planum (Isidis Regio), is the real cause. Up until the early 1960s, the stirring and removal of dust irregularly maintained the darkness of Nepenthes as well as keeping Cerberus dark, but now both regions exhibit the characteristics of high-albedo deserts, where no regular dust removal is taking place.

We now know that changes in the outline and appearance of Martian albedo features can in general be explained by the redistribution and removal of bright material during dust storms.[37] The albedo markings subject to the most dramatic changes appear to be in areas where thinly covered rocky surfaces lie in close proximity to dust sinks.

Specifically, the global dust storm of 2001 blanketed Syrtis Major, stripped dust from the Tharsis region, and injected dust into Solis Planum. Changes in the breadth of Syrtis Major, and a tendency of its boundary to shift eastwards or westwards depending on recent dust storm deposition patterns, provides one of the most striking examples of how changes visible in spacecraft imagery correspond to broad changes in markings visible from Earth. This, incidentally, resolves the old Schiaparelli-era enigma of what was going on at Libya, which is strategically located at the interface between the Syrtis Major plateau and the lower-level Isidis basin.

The dramatic albedo changes that are well-documented in our historical database in places such as Cerberus, Nilosyrtis, and Nepenthes-Thoth show that these processes have taken place for at least the past 170 years, and likely much longer. They also underscore the fact that the changes in albedo features are complex and not fully understandable in terms of any one cause.

A special case that may be important historically involves the fact that when Martian winds interact with large topographic obstructions, typically impact craters, the result is that dust is often deposited in extended linear streaks, sometimes referred to as 'wind tails'. Figure 12 shows a classic example. Most of these are bright and far too small to be seen from Earth, although a subset are dark and typically broader. It seems possible that at least some features mapped by earlier observers as canals (which are often stubby extensions of dark areas) may correspond to such wind tails.

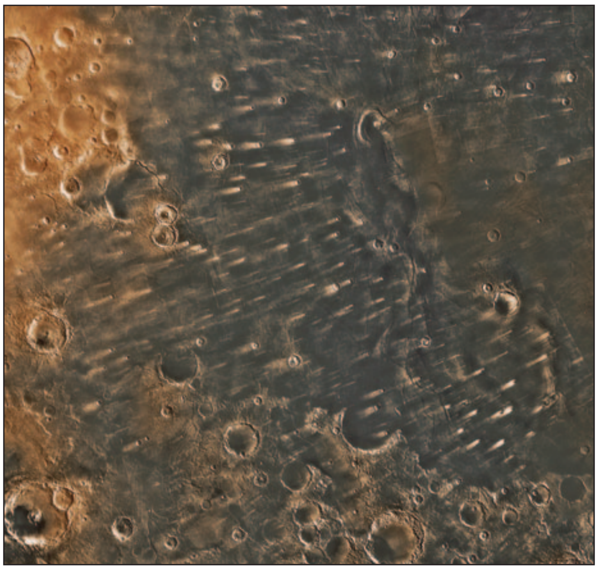


Fig. 12: Light crater tails on the western side of Syrtis Major. This high-resolution Mars Global Surveyor image shows the orientation of the crater tails which corresponds to the time-averaged wind direction. The large Isidis basin depression is just outside the frame on the right. (NASA/JPL/Malin Space Science Systems)

12. Conclusions and future directions

Over the period covered by this paper several major long-term developments in the appearance of the Martian surface features stand out. These include the extreme narrowness of the Syrtis Major in the mid-to-late 19th century and changes in Libya (at the boundary of eastern Syrtis and western Isidis) to which Schiaparelli first called attention in the 1880s. There is also the remarkable prominence of Nilosyrtis in the drawings of Secchi, Dawes, and others in the 1860s, which continued into the early 1900s.

During that period Nilosyrtis was the most prominent of the canals, a striking serpentine feature curving to the east. It began to fade as the Nepenthes-Thoth began its tremendous development as a southward extension of the Casius (an extension of the circumpolar dark area Vastitas Borealis). By 1954 Nepenthes-Thoth had seemingly annexed an area the size of Texas since the previous opposition, but after the Great Dust Storm of 1956 the whole area faded out like a field of vegetation after a killing frost – which was, indeed, what many astronomers of the time believed had actually happened.

Topographic and thermal emission maps from spacecraft help explain the nature of these and other historic observations. The most striking albedo changes occur in intermediate-level terrain between areas of rough topography and higher elevation (like the Syrtis Plateau) and comparatively dusty and relatively flat regions (like Isidis basin). So, for instance, the location of the dark sinuous curve of Nilosyrtis corresponds to the boundary between rougher relief and a smooth northern part of neighbouring Arabia Terra.

Casius, whose southern tip developed into the vast Nepenthes-Thoth extension, is an area where dust devils appear to be commonplace. Although Nepenthes-Thoth has faded, the dark patch of Alcyonius stands as an elevated prominence sticking up out of the dust. The extensive dark rocky surface around Alcyonius was exposed between the 1920s and 1950s and has been thinly overlain by lighter dust since. The Thermal Emission Imaging System (THEMIS) camera on the 2001 Mars Odyssey spacecraft showed this to be an area where dark surface material and bright dust deposits compete to gain the upper hand. Although currently the dust is in the ascendant, the dark surface area will eventually be re-exposed, and Nepenthes-Thoth will rise again to prominence.

In the most general terms, the albedo features of Mars at any given time reflect a range of topographic and mineralogical features covered to a greater or lesser extent in fine bright dust which is distributed and redistributed during local, regional, or global dust storms. The extent to which the dust is spread depends on various factors: whether a storm is local, regional, or global; the direction of prevailing winds where the dust becomes suspended; and the proximity of a given location to the source of the storm.

It is an interesting contradiction that a dust storm at one location may deposit dust, while a later one at the same location may remove it. The changes in albedo features reflect the intermittent covering by thin layers (micron-scale) of bright dust, leading to brightening in a region, followed by subsequent redistribution and removal of dust with re-exposure of dark rocky surfaces. Although the overall redistribution of dust on a planetary scale is from the southern hemisphere to the northern, and the net deposition of dust is into areas such as Tharsis, Elysium, and Isidis, there are many areas such as Hellas and Nepenthes-Thoth which are in relative equilibrium between dust deposition and removal. These areas are alternately hidden or exposed, sometimes on a seasonal basis but at other times over a period of decades.

Attempts to use our database to correlate specific changes with specific storms is a promising area of future research. Observed changes in the albedo markings may reveal the occurrence of unobserved dust storms. This may also help us to determine whether dust-storm activity varies in frequency in different eras.

It seems possible that the period between 1877, when Trouvelot observed the first encircling storm, and 1909 represents a true hiatus in large dust storm activity. On the other hand, the period from 1971 to 1982 (the Mariner 9 and Viking era), when several encircling and one global storm occurred, may have represented a true increase in dust storm activity. There was then another hiatus until 2001, when the most recent upsurge of large dust storm activity began. The factors involved in determining the onset of large dust storms are no doubt complex and may even involve esoteric mechanisms which have only just begun to be understood.[38]

Although visual observations of Mars from the 18th to early 20th centuries have often been dismissed by contemporary scientists, we conclude that useful information can still be drawn from such observations, especially when combined with modern imaging techniques, including by advanced amateurs equipped with CCDs. Comparisons with the early drawings allow us to track the long-term development of Martian features which we now know are not the result of surface water or vegetation but instead are driven by Martian meteorology.

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23 Note that simultaneous contrast causes the eye to perceive blue-green hues in the dark areas strikingly

set off against the ruddy or ocherish bright areas. In addition, the successive episodes of enhancement and fading of markings were described as a wave of darkening rather than a wave of brightening, even though the latter is actually the more apt description.

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Officers and gentlemen:
Military men in the Astronomical Society of London 1820–31

Steven Phillipps

The Royal Astronomical Society was created in 1820 as the Astronomical Society of London, receiving its Royal Charter from William IV eleven years later. Over the course of these formative years one-fifth of the Society's UK members had military backgrounds. This is perhaps unsurprising as many men had been trained in technical affairs in the army or navy over the preceding years – the Society was formed less than six years after Waterloo, and sixteen years after Trafalgar. Veterans of the French and American Revolutionary Wars were also still present. After peace was restored in Europe (the *Pax Britannica*), military vigour was turned to colonial affairs and to exploration. The interests of the Society members changed likewise, many of them venturing into Arctic waters, for example. This paper discusses the careers of the military men who had joined the Society by 1831.

1. Introduction

Despite astronomy's outwardly peaceful status, a large number of the members of the Astronomical Society of London (ASL), which was formed in 1820 and became the Royal Astronomical Society in 1831, had military backgrounds. Part of this was no doubt due to the traditional connections between astronomy and navigation, map making, and exploration.[1] The naval biographer John Marshall (c.1784–1837), for instance, noted in his *Royal Naval Biography* of 1828 that 'we cannot but notice with exultation the number of naval officers who are associated in the meritorious labour of that body the Astronomical Society'.[2]

There were 266 names in the first list of RAS Fellows in 1831 June, as well as 40 Associates.[3] At that point the cumulative total of members since the formation of the ASL, including Associates, had reached 379.[4] Of these members, 66 (one in five) were either naval or army officers and are the subject of the present paper.

Although some were considerably more aristocratic than others, all would, no doubt, have considered themselves to be gentlemen. Some are well-known and have had books written about them; others have biographical notices of some kind; but the remainder have gone largely unreported. Their careers give an interesting perspective on the world around the time the ASL was formed, its lifetime closely matching the reign of King George IV. His successor William IV, 'the Sailor King', who signed the Royal Charter creating the RAS shortly after coming to the throne, appears in the list below (Section 8.2).

2. Founders with military connections

Among the founder members of the Astronomical Society of London on 1820 January 12 was Major (later Major-General) Thomas Frederick Colby (1784–1852), who became a vice-president in 1822.[5,6] The son of another Major Thomas Colby, of the Royal Marines (additionally, four of his uncles were in the army), he passed out at the Royal Military Academy, Woolwich, and was commissioned as second lieutenant in the Royal Engineers when he was 16.

Colby was selected to join the Ordnance Survey by its director William Mudge (Section 3.1) in 1802, despite having lost a hand in a shooting accident, and undertook astronomical and trigonometrical observations. Responsible for the Survey of Ireland, Colby was appointed Mudge's successor as director in 1820 and was elected a Fellow of the Royal Society the same year. He subsequently directed the production of numerous maps of English counties.[7]

Another of the founders of the ASL also had a military connection, but not as a serving officer: the splendidly named Olinthus Gilbert Gregory (1774–1841), who was professor of mathematics at the Royal Military Academy at Woolwich.[8]

3. First intake 1820 February

3.1. *William Mudge*

The first meeting of the ASL took place on 1820 February 8, when several military officers were accepted for membership.[9] One was Colby's superior, Major-General William Mudge (1762–1820). Unfortunately it appears he was also the first deceased member, as he died two months later. William was the son of John Mudge FRS (1721–93), a medical doctor who won the Royal Society's Copley medal for his work on telescope mirrors and was a close friend of the renowned lexicographer Dr Johnson (the younger Mudge's godfather).

William Mudge was commissioned in the Royal Artillery in 1779 and posted to South Carolina. There he joined the forces of the British General Charles Cornwallis just prior to their surrender to George Washington's army at Yorktown, which effectively ended the American Revolutionary War. Back in Britain he was appointed to the Ordnance Trigonometrical Survey in 1791 and became its director in 1798 with offices in the Tower of London.

He became an FRS the same year, publishing a number of papers in their *Philosophical Transactions*.[10] Mudge was later additionally appointed lieutenant-governor of the Royal Military Academy at Woolwich and a member of the Board of Longitude.[11] One of his sons, another William, became a naval officer and ASL member in 1827 (Section 7.8).

3.2. *John Vernon Handfield*

Another army officer with an unfortunately short membership was Lieutenant-Colonel John Vernon Handfield (1777–1821). He was born in Newport, Rhode Island, during the American War of Independence, the son of Colonel Charles Handfield (1752–1831), later the Commissary-General of Stores for Ireland. John Handfield served in Holland and Egypt and on returning to Britain in poor health was by 1804 a First Lieutenant in the Royal Engineers. In 1813 he was promoted to Lieutenant-Colonel.[12]

Handfield was proposed for Fellowship of the Royal Society as 'a Gentleman well versed in the several branches of Mathematics and Natural Philosophy' by his associates Mudge and Rowley (Section 3.3) and the mathematician Charles Hutton.[13] Highly religious, he was on the committee of the Naval and Military Bible Society and taught a Bible class in a Sunday school.[14]

3.3. *John Rowley*

Colonel (eventually Major-General) John Rowley (c.1768–1824) was admitted to the ASL at the same meeting as his Royal Engineers colleague John Handfield (both gave their address as 90 Pall Mall, possibly their London club) and was on the Council in 1822. Rowley trained at Woolwich and was commissioned in the Royal Artillery in 1786. He transferred to the Royal Engineers and accompanied the Earl of Moira's forces sent to assist the counter-revolutionary Vendeans in France in 1793, subsequently serving in Flanders. Elected an FRS in 1809, he became Deputy Inspector-General of Fortifications in 1811.[15] He too had a rather short association with the Society, dying in 1824 December.

3.4. *Sir Robert Lawrence Dundas*

The highest-ranking of the original ASL members was the eventual Lieutenant-General Sir Robert Lawrence Dundas (1780–1844).[16] His father was the second Baronet Dundas (later elevated to Baron Dundas), cousin of the Lieutenant-Colonel Thomas Dundas who negotiated the British surrender at Yorktown noted in Section 3.1. One of his older brothers was Rear-Admiral George Heneage Lawrence Dundas (1778–1834) who became an FRAS in 1831.[17]

Dundas was commissioned Second Lieutenant in 1797, at age 17, and was an engineering officer in the Anglo-Russian invasion of North Holland to oppose the French in 1799 under the 'grand old' Duke of York. He also served in Egypt and was promoted to Lieutenant-Colonel during the Peninsular War of 1808–14, fighting with Wellington's army in several of the major battles against Napoleonic forces, including Santander in 1812 and Toulouse in 1814. He was awarded the Army Gold Medal and Portuguese Order of the Tower and Sword and became a Knight Commander of the Order of the Bath in 1815. Dundas was also a Whig MP on several occasions between 1807 and 1841 and eventually commanded the 59th Regiment of Foot.[18]

3.5. *Sir Thomas Brisbane*

Probably uniquely, there were two meetings of the ASL in 1820 February, the second on the 29th of the month following the adjournment of the first due to the upcoming funeral of George III. This second meeting saw the addition of five more officers to the Society's ranks. The most distinguished was Major-General Sir Thomas (Makdougall) Brisbane (1773–1860) (Figure 1), born into an ancient Scottish family in 1773 (the Makdougall, his wife's maiden name, was added later).[19]

Brisbane was commissioned in 1789 and served in Flanders from 1793. He was next posted to the West Indies and from 1800 commanded the 69th Regiment in Jamaica. Returning to the UK, his observatory at the family seat of Brisbane House, Largs, Ayshire, was reckoned the best in Scotland. He returned to action as a Brigadier-General under Wellington (an old friend) in the Peninsular War in 1812. He was Governor of New South Wales from 1821 to 1825.[20] While there he kept up his astronomical interests, building an observatory at Parramatta, near Sydney, and created another at Makerstoun, near Kelso in Roxburghshire, on his return to Scotland.[21,22]

Brisbane was awarded the ASL's Gold Medal in 1828 and had nine papers in their *Memoirs* or *Monthly Notices*.[23] His major work, *A Catalogue of 7385 Stars, Chiefly in the Southern Hemisphere*, from observations made at Parra-

Fig. 1: Sir Thomas Makdougall Brisbane seen in 1842, engraved by Frederick Bromley from a painting by Robert Frain. In 1835 a catalogue of over 7,000 southern stars was published from observations made at his private observatory in Parramatta, New South Wales. (National Portrait Gallery Australia)

matta, was published in 1835;[24] this was the first southern catalogue since that of Lacaille three quarters of a century earlier. He was president of the Royal Society of Edinburgh from 1832, was created a baronet in 1836, and was a Knight Grand Cross of the Bath.

3.6. *Mark Beaufoy*

Colonel Mark Beaufoy (1764–1827), another of those elected at the second meeting of 1820 February, was born into a wealthy family of vinegar producers in south London. He lived in Switzerland for a time after marrying his cousin Margaretta Beaufoy, and in 1787 became the first Englishman to scale Mont Blanc, calculating its latitude from observations made at the summit.[25] On his return to England in 1789 he settled in Hackney Wick, where he became an officer in the Tower Hamlets Militia, not the regular army.

Fascinated by hydrodynamics from his youth, he helped found the Society for the Improvement of Naval Architecture in 1791 and carried out experiments in Greenland Dock, Rotherhithe, on the resistance of ships' hulls and sails.[26] He became an FRS in 1790 and was an original Council member of the Astronomical Society in 1820. Technically he may no longer have been a Colonel when joining the ASL as he had been removed from his command when court-martialled for 'vexatious and frivolous' disciplining of a subordinate in 1814.

His observatory in Hackney Wick was included in Charles Hutton's 1815 list of notable private observatories in England,[27] although at the end of 1815 he moved to Bushey Heath in Hertfordshire. There he carried out a series of observations of eclipses of Jupiter's satellites for which he was awarded the Astronomical Society's Silver Medal. Beaufoy had four papers in *Memoirs* and his observations also appeared regularly in *Astronomische Nachrichten*.[28,29] After his death his clocks and telescopes were donated to the Astronomical Society by his son George (Section 7.11), who was appointed an Honorary Life Member in return.[30]

3.7. *Alexander Kyd*

Lieutenant-General Alexander Kyd (c.1754–1826) was elected an FRS just a fortnight after joining the Astronomical Society of London. Born in Scotland, the son of Captain James Kyd RN, from 1775 he was in the service of the Honourable East India Company (which in effect had its own private army and navy) as an officer in the Bengal Engineers. He was subsequently responsible for building the docks at Kidderpore, Calcutta (now Kolkata) – the name Kidderpore allegedly deriving from his own – and was later the Surveyor General for Bengal.[31]

He owned three Stradivarius instruments one of which, a cello, became known as the 'General Kyd'. After many generations of owners it eventually came into the hands of the Los Angeles Philharmonic orchestra from whose principal cellist it was stolen in 2004, but fortunately recovered a few days later. It was by then valued at $3.5 million.[32] Kyd also acquired the Mughal jade terrapin now in the British Museum, which was found during engineering excavations in Allahabad.[33]

His son James was a master shipbuilder for the East India Company and, with his brother Robert, joint proprietor of the Kidderpore docks. An older relative was Colonel Robert Kyd, founder of the Botanical Garden in Calcutta which became a major source of tropical plants.[34]

3.8. *James Horsburgh*

Captain James Horsburgh (1762–1836) was from a relatively poor family in Scotland and was first apprenticed on a vessel in the coal trade, which had the misfortune to be captured by the French. When released he made his way to Calcutta and became a first mate. After one of his ships was wrecked due to lack of accurate charts he took up a study of surveying and in due course sent the charts of the China Sea that he had made back to the East India Company in London. He was subsequently given command of his own ship and made further observations on journeys to Bengal and China, in 1810 becoming official hydrographer to the East India Company.[35]

Horsburgh wrote a number of treatises on navigation and made two contributions to the *Philosophical Transactions* of the Royal Society, of which he became a Fellow in 1806.[36] He later had one paper in *MNRAS*.[37]

3.9. *Frederick Marryat*

Captain Frederick Marryat (1792–1848) (Figure 2) was the 'Captain Marryat' who became famous as the author of classic Victorian novels such as *Children of the New Forest* and *Mr Midshipman Easy*. He was at school with Charles Babbage, who later supported his application to the Royal Society in 1819,[38] before joining the navy as a midshipman on HMS *Imperieuse* when he was 14.

He was involved in numerous naval actions and the capture of several Napoleonic ships off the Mediterranean coast of Spain, and used his naval experience in his later books.[39] He also participated in the capture of a number of American ships in the War of 1812. Noted for his bravery in several times rescuing crew mates who had been lost overboard, he later invented a new type of lifeboat and a system of flag signalling.[40]

In 1824 he was senior naval officer in Rangoon (in what was then Burma). Marryat resigned his commission in 1830 to become a full-time writer and edit *The Metropolitan Magazine*. His son Frank followed him as both midshipman and writer, while three of his daughters were also authors: Florence was a well-known novelist and Augusta and Emilia wrote children's books.

4. 1820–21

4.1. *Francis Beaufort*

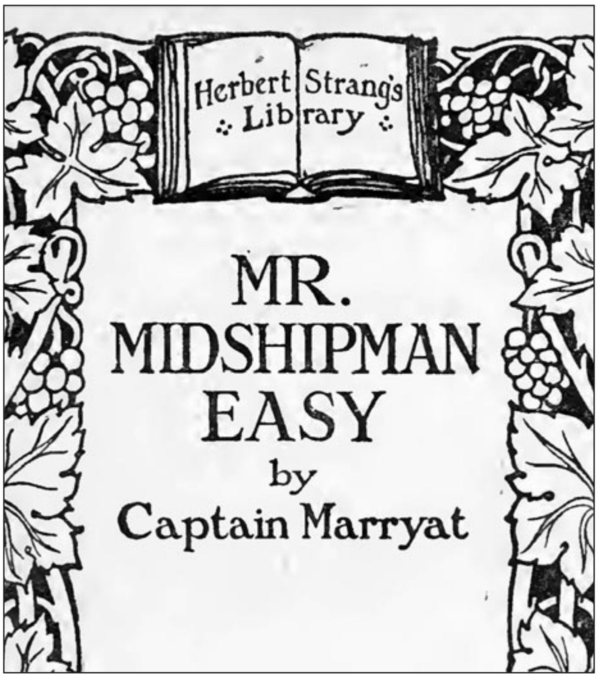
Captain Francis Beaufort (1774–1857) (Figure 3), later Rear-Admiral Sir Francis Beaufort, was proposed as an Astronomical Society member in 1820 April and, in what became the tradition, was elected two months later. He was a vice-president of the Society in 1830.

The son of an Irish clergyman and mapmaker, Beaufort went to sea at an early age in the service of the East India Company, surviving a shipwreck in Indonesia. He then signed up in the Royal Navy in time to serve on the 32-gun frigate *Aquilon* during the fourth Battle of Ushant in 1794, known in naval circles as 'The Glorious First of June'. He was severely wounded in 1800 'gallantly boarding a Spanish polacca of 14 guns and carrying her [off as a prize] from the fortress of Frangarola, near Malaga, where she was moored'.

Promoted to captain in 1810 and serving in places as disparate as India and Rio de la Plata, he was almost killed in an attack by 'fanatic assassins' while mapping the southern shores of Asia Minor. He published *Karamania; or a brief description of the South Coast of Asia Minor, and of the Remains of Antiquity* based on this exploration.[41]

Subsequently Hydrographer to the Admiralty, he is best remembered for devising the Beaufort Scale for wind strength.[42] He retired with the rank of Rear-Admiral and served on the Board of Visitors of the Royal Observatory, Greenwich, also overseeing activities at the Royal Observatory at the Cape of Good Hope.[43] He contributed a paper to *MNRAS* in 1853 on determining the longitude of Tahiti via a partial eclipse of the Sun.[44]

Fig. 2: Captain Frederick Marryat was among those elected at the second meeting of the ASL in 1820 February. Here he is seen in an engraving by Conrad Cook published in 1851, by when he had become a successful author. (British Museum). Below: The title page of Marryat's most famous book, Mr Midshipman Easy (1836).



Herbert Strang's Library

MR. MIDSHIPMAN EASY

by

Captain Marryat

Fig. 3: Captain Francis Beaufort, inventor of the eponymous scale of wind force , in a mezzotint by James Scott published 1857, based on a portrait by Stephen Pearce. (National Portrait Gallery)

4.2. *Basil Hall*

1820 May saw two further naval officers proposed as members of the Society: Captain Basil Hall (1788–1844) and Captain John Wilson. The former was the son of Sir James Hall (1761–1832) of Dunglass, a geologist and president of the Royal Society of Edinburgh.[45]

Joining the Royal Navy at age 14, Hall was commissioned in 1808. In 1812 he joined Vice-Admiral Samuel Hood's flagship *Illustrious* in the East Indies. After accompanying Lord Amherst's embassy to China in 1816 he published his *Account of a Voyage of Discovery to the West Coast of Corea and the Great Loo-Choo Island*.[46] He then commanded the *Conway* in the South American station, carrying out 'experiments with an invariable pendulum' and also communicating observations of a comet seen from Valparaiso to the Royal Society.[47,48]

Before leaving, Hall had offered to make any observations useful to the Astronomical Society; somewhat taking advantage of this offer, the Council responded with four pages of instructions.[49] He later supplied three unrelated contributions to *Monthly Notices*, including an observation of an occultation of Venus.[50] He also travelled widely on his own account, although he ended his days in a mental hospital.[51]

Hall's sister Magdalene had married Colonel Sir William Howe De Lancy, who had the misfortune to be the officer famously killed by a cannonball at Waterloo while talking to Wellington; her second husband was Henry Harvey FRS, an FRAS from 1833, who had served in the East India Company.

4.3. *John Peter Wilson*

Captain John Peter Wilson (1791–1832) was an officer with the East India Company so, as with Kyd and Horsburgh above, perhaps not technically a military man although the East India Company's ships were certainly well-armed. He is recorded as commanding the 75-gun *Cornwall* in 1819–20 on a voyage to China which took almost exactly a year to complete,[52] calling at St Helena on the return leg. He later captained the *Dunira* on the same route. On joining the Astronomical Society he originally gave his address as 'Grove, Epping' but in 1831 he was in Rotherhithe, a centre of East India Company activity.

4.4. *Thomas Blanshard*

There was one further addition before the summer break: Major Thomas Blanshard, often written as Blanchard, (1789–1859), proposed for membership in 1820 June. The son of an East India Company naval captain, he spent most of his career in Bermuda, in charge of the islands' fortifications and other army building work. He was recognized as the inventor of the best pontoon bridge of its day. In 1838, by then a Lieutenant-Colonel, he was made a Companion of the Order of the Bath in Queen Victoria's Coronation Honours.[53] In the 1850s he was responsible for the redevelopment of the Royal Artillery Institute Observatory in Woolwich.[54]

4.5. *John Ross*

Moving on to the Society's next session, Captain John Ross (1777–1856) and Captain Thackray Wetherell were proposed for membership in 1820 November, followed by Captain William Edward Parry the following month.

Ross was born in Scotland and joined the navy as a 'first-class volunteer' (a rating given to 'young gentlemen' training to become officers) when he was aged nine. Later serving in the merchant marine, he was recalled to the navy in 1799 and served as a midshipman during the invasion of North Holland. He further served aboard HMS *Victory* in the Baltic, blockading French-held ports, before it became Nelson's flagship at Trafalgar. He was wounded on several occasions, most severely when bayoneted while boarding a Spanish vessel.

In 1818 Ross was given command of an expedition to the much-sought Northwest Passage from the Atlantic Ocean into the Pacific and sailed around Baffin Island, but failed to press on as he believed mountains (later shown to be a mirage) blocked his route.[55,56] To redeem his reputation, in 1828 he organized a private venture using a steamship as an icebreaker, eventually pushing farther west than any previous Europeans. During this voyage his nephew James Clark Ross (Section 7.12) became the first European to reach the north magnetic pole. Despite losing their ship in the ice, after trekking back towards Baffin Island the expedition were eventually rescued by a whaling boat and returned home in 1832, where Ross senior was knighted.[57]

At the age of 72 he headed one of the expeditions in search of Sir John Franklin (Section 6.1), who had disappeared while in search of the Northwest Passage. While on this voyage Ross was promoted to Rear-Admiral, his naval career eventually totalling some 70 years. He had two contributions in each of *Monthly Notices* and *Memoirs* of the Astronomical Society in the 1820s, including observations of 'the Occultation of the Herschel Planet' from his observatory in Stranraer.[58]

4.6. *Thackray Wetherell*

When elected, Captain Thackray Wetherell (1787–1822) was on a voyage as master of the convict ship *Hebe*, sailing from Falmouth via Rio de Janeiro and Van Diemen's Land (now Tasmania), landing the prisoners at Port Jackson in Sydney Cove in 1821 January. He previously appears several times in papers of the New South Wales Colonial Secretary concerning voyages in 1816 and 1817 to and from England, Batavia (the present-day Jakarta in Indonesia), and India in the *Lord Melville*.[59] (The *Lord Melville* was the renamed HMS *Porpoise*, the infamous Captain Bligh's flagship in New South Wales).

Wetherell was born in Sunderland and was living in Rotherhithe in 1818 but died four years later. The reason for the 'Royal Navy' appellation in the list of members of the Astronomical Society is unclear as both his known commands were merchant vessels.[60]

Fig. 4: Captain John Ross joined the ASL in 1820 November, two years after his return from an expedition in search of the Northwest Passage. Here he is seen in an engraving by Richard Lane published in 1834 from a painting by Benjamin Faulkner. (British Museum)

4.7. *William Edward Parry*

Sir William Edward Parry (1790–1855) (Figure 5) was born in Bath, Somerset, the youngest son of the physician and agriculturalist Caleb Hillier Parry (1755–1822). He joined the Royal Navy's Channel defence fleet as a 'first-class volunteer' when he was 13. He later served at Spitsbergen protecting English whalers and then in North America. He accompanied Captain John Ross (Section 4.5) on his first Arctic expedition in 1818.[61]

Parry, who had thought Ross wrong to turn back when he did, was given command of HMS *Hecla* for a further expedition in 1819. This expedition passed well beyond Baffin Island, reaching longitude 110° west and winning a government prize in so doing. The ship was subsequently iced-in for 10 months but returned to England in 1820 after what was perhaps the single most productive voyage in search of the Northwest Passage. Parry was elected FRS in 1821, as his father had been in 1800.

Parry commanded two similar expeditions in 1821 and 1824 and then made an attempt on the North Pole, starting from the north shore of Spitsbergen and reaching 82° 45′ N, the most northerly latitude attained until 1876. He published journals of his three expeditions, as well as a *Narrative of an Attempt to Reach the North Pole*.[62] Parry was knighted in 1829 and eventually attained the rank of Rear-Admiral.[63] He also served as Commissioner of the Australian Agricultural Company in 1829–34 and as Comptroller of the Royal Navy's new department of steam machinery.[64]

4.8. *Benjamin Blake*

Three more military members were proposed in 1821 March, among them Captain Benjamin Blake (dates unknown) who went on to become an FRS in 1830. His certificate of election for the Royal Society stated that he was a captain in the Honourable East India Company's Army in Bengal and had been employed for 12 years by the Government of India 'surveying large tracts of their territory', including measuring the heights of five peaks in the Himalayas.[65] He also kept meteorological observations in India from at least 1809. His membership listing for the Royal Asiatic Society notes that in 1834 he was in the 47th Regiment Bengal Native Infantry in Cuttac, while his RAS listing the following year gave his address as 'Oriental Club, Hanover Square'.[66,67]

4.9. *Armar Lowry Corry*

Captain Armar Lowry Corry (1793–1855) was a son of the 1st Earl Belmore of Castle Coole, County Fermanagh. He joined the Royal Navy in 1805, serving at the Cape of Good Hope and Buenos Aires and at the bombardment of Copenhagen during the Napoleonic Wars.[68] After captaining a number of vessels in the 1830s–40s and commanding an experimental squadron of steam-driven frigates, he was promoted to Rear-Admiral in 1852 and given command of the Western Squadron and then the Channel Squadron. He was second-in-command of the Baltic Fleet during the Crimean War.

In 1817 he had captained the armed yacht *Osprey* owned by his half-brother, Somerset Lowry-Corry (who sponsored some of the excavations by the Italian archaeologist Giovanni Battista Belzoni), when they visited Egypt.[69] They both inscribed their names as graffiti on a wall of the Temple of Dendur, which is now in the New York Metropolitan Museum.[70]

4.10. *William Henry Smyth*

One of the most famous names from this era was Captain (eventually Admiral) William Henry Smyth (1788–1865). The son of a former officer in the King's Royal Regiment of New York during the Revolutionary War, he enlisted on a West Indiaman at an early age and then served on an East India Company ship that was purchased by the Royal Navy in 1805.[71] In the defence of Cádiz in 1810 during the Peninsular War he was given command of a Spanish gun-boat. He had a further command in the Anglo-Sicilian fleet, being awarded the Order of Saint Ferdinand by the King of the Two Sicilies, and made detailed surveys around Sicily, subsequently expanding this to a survey of the Mediterranean.

He henceforth concentrated on astronomy, building in Bedford 'undoubtably the most complete and practically useful private observatory in existence'.[72] When he moved to Cardiff to supervise the construction of Bute Dock (the Marquess of Bute was also an FRAS), he presented his 5.9-inch telescope to his friend Dr John Lee of Hartwell House, Buckinghamshire; it is now in the Science Museum in London.[73]

Smyth's main interest was in double and multiple star systems, as described in *The Bedford Catalogue* published in 1844, which won him the Gold Medal of the RAS.[74] As RAS President at the time, he was responsible for their official response to the controversy surrounding the discovery of Neptune.[75] He had nine contributions in *Monthly Notices* or *Memoirs* including his observations of Comet Halley in 1835.[76] He was vice-president of the Royal Society and a member of many other scientific societies in the UK and overseas. He was also on the Board of Visitors of the Royal Observatory at Greenwich. His wife Anne was also a noted observer.

Their second son, Sir Charles Piazzi Smyth (named after Giuseppe Piazzi, discoverer of Ceres, whom his father had met in Sicily), became Astronomer Royal for Scotland.[77] Their oldest son, Sir Warington Wilkinson Smyth, became a professor of mineralogy, while the youngest son, General Sir Henry Augustus Smyth, continued the military line. Their eldest daughter, Henrietta, married the Rev. Baden Powell, the Savilian Professor of Geometry at Oxford (and FRAS), and was the mother of Lord Baden-Powell, founder of the Scouting movement.

Fig. 5: Captain William Edward Parry was elected to the ASL in 1820 December, the month after his fellow Arctic explorer John Ross. This engraving of him from 1821 is by James Thomson after a portrait by Samuel Drummond. (National Portrait Gallery)

4.11. *George Young*

Lieutenant George Young (1797–1848) of the Royal Navy, proposed in 1821 May, was the son of Sir Samuel Young (1776–1826) of Formosa Place near Maidenhead, a senior official of the Madras Civil Service (and also an early member of the Astronomical Society, having been proposed in 1821 January). In 1826 he succeeded his father as Captain Sir George Young, the second baronet. His mother Emily was a member of the Baring banking family (see also Section 8.11).

George Young joined the navy in 1811, being involved in the attack on Leghorn (Livorno) in 1813. He had a succession of further postings on the Brazilian, Mediterranean, and Home stations, serving on the 100-gun HMS *Queen Charlotte* at the bombardment of Algiers, aimed at forcing the Dey of Algiers to free European Christian slaves. He was subsequently on *Royal Sovereign* under Captain E. W. C. R. Owen (Section 5.3). After being promoted to lieutenant in 1818, he was mostly employed in the West Indies.[78] His grandfather, Admiral Sir George Young (1732–1810), had fought with General James Wolfe at Quebec in 1759, and his younger brother Horatio Beauman Young (1806–79) also became an admiral.

5. 1821–22

5.1. *Alexis Greig*

A whole set of military members was proposed at the start of the next session of the ASL in 1821 November, for election two months later. Perhaps the most unlikely-sounding was His Excellency Alexis Greig (1775–1845), Vice-Admiral of the Imperial Russian Navy in Odessa, who was otherwise known in Russia as Alexei Samuilovich Greig. He was born in Kronstadt, a naval base near St Petersburg, where his father, Admiral Samuel Greig (1735–88), from a well-known Scottish family, was Governor.

He started his career at sea in the Royal Navy, returning to Russia to take part in operations against the French in 1798 and opposed the Ottoman navy in the Russo-Turkish War of 1806–12. He was placed in command of the blockade of Danzig (the modern Gdańsk) during the War of the Sixth Coalition in 1813–14 and was commander of the Black Sea Fleet and governor of Sevastopol from 1816 to 1833.[79]

Greig became a member of the State Council of Imperial Russia under Czar Nicholas I and was placed in charge of the construction of Pulkovo Observatory. His brother Samuil, the Russian consul in London, was the first husband of mathematician and honorary RAS Fellow Mary Somerville,[80] while his son, another Samuil, was a general in the Imperial Russian Army fighting against the British-French alliance in the Crimean War.

5.2. *Francis Alexander Delap Halliday*

Captain Francis Alexander Delap Halliday (1773–1830) was the son of Major John Delap Halliday and nephew of Major Wilbraham Tollemache, the sixth Lord Dysart. Born in Ham House, Surrey, he joined the Royal Navy in 1788 at age 15 and was promoted to Lieutenant in 1801, serving aboard the frigate HMS *Iphegenia* until she was destroyed in the Egyptian campaign. He also served in the Channel and Baltic Fleets, subsequently captaining the *St Christopher* in the West Indies, where they captured the *Exchange* in 1808.

The *London Gazette* announced that ‘Notice is hereby given to the officers and company … who were actually on board at the capture … that a distribution of a sum remitted on account of the proceeds of the said prize will be made on Tuesday next’.[81] For ‘first class’ officers (presumably the commander) this amounted to £239 10s 8½d, while a sixth-class ordinary seaman made £7 5s 7¾d, a decent sum at the time. This posting also enabled him to visit the family estates in Antigua. Halliday’s last command, the brig *Ferret*, was wrecked on the Northumberland coast (through no fault of his) in 1812.

His elder brothers were Vice-Admiral John Richard Delap Tollemache (formerly Halliday) and William Augustus Halliday, briefly an army captain. Four of his sons joined the navy and one the army.[82]

Fig. 6: Edward William Campbell Rich Owen. In 1806 he attacked Boulogne using Congreve rockets and later became commander of George III’s Royal Yacht. He joined the ASL in 1821 November. Here he is portrayed in 1849 by Henry Pickersgill in admiral’s full dress uniform. (Royal Museums Greenwich)

5.3. *Edward William Campbell Rich Owen*

Admiral Sir Edward William Campbell Rich Owen (1771–1849) (Figure 6) was born on Campobello, an island in Nova Scotia owned by his father, Captain William Owen (1737–1778). He followed his father into the navy at 15 and after promotion to lieutenant in 1793 served at the blockade of Cádiz. From 1802 he had a succession of commands, notably the HMS *Immortalité* which was prominent in actions off the French coast. In 1806 he made an attack on Boulogne using Congreve rockets.

Serving everywhere from the North Sea to the Great Lakes, Owen became commander of George III’s Royal Yacht in 1816, the same year that he was knighted. In 1821 he was appointed a colonel of Royal Marines and from 1823 he became, successively, Commander-in-Chief West Indies, Surveyor-General of the Ordnance, and Commander-in-Chief East India Station.[83] Promoted to Vice-Admiral in 1837 he became Commander-in-Chief of the Mediterranean Fleet in 1841. He was also briefly MP for Sandwich, Kent, in 1826–29.

5.4. *William Fitzwilliam Owen*
Captain William Fitzwilliam Owen (1774–1857) was the younger half-brother of Sir Edward Owen (Section 5.3), both joining the Astronomical Society at the same time, in 1821 November.[84] Born illegitimate in Manchester, he became a midshipman in 1788 at age 13 and in 1794 served on HMS *Culloden* in the battle with the French at the Fourth Battle of Ushant (the so-called 'Glorious First of June').

Making lieutenant for a second time in 1797, despite an earlier court-martial, in the Spithead Mutiny of that year he was held in irons by the mutineers who considered him 'too hard', even for those days. He had a command in the East Indies from 1803 and explored the Maldive Islands before his ship was captured by the French in 1808.

After his release he surveyed the Great Lakes with Henry Wolsey Bayfield (Section 7.7) and later surveyed the entire east African coast.[85] As part of the British effort to suppress the slave trade in East Africa, and apparently against the wishes of his superiors, Owen declared a short-lived Protectorate over Mombasa in 1824.[86] A committed abolitionist, he was sent to establish an international court on the island of Fernando Po off the west coast of Africa to prosecute captured slave traders but was again removed by the Admiralty because of his excessive zeal.

Owen had one contribution in *Monthly Notices*, on the construction of optical instruments, which he presented to the Society in 1833.[87] He eventually retired as Vice-Admiral and settled in New Brunswick, having inherited Campobello Island from his father.[88] Owen was elected an Associate Fellow of the American Academy of Arts and Sciences in 1844.

5.5. *William Henry Shirreff*
Captain (eventually Vice-Admiral) William Henry Shirreff (1785–1847) joined the Royal Navy as a 'first-class volunteer' when he was 11. He served on the frigate *Stag* under Captain Robert Winthrop (Section 8.4) protecting British shipping from French privateers until they were wrecked in a violent storm at Vigo Bay in north-western Spain. In 1805 his ship captured a Spanish privateer, of which he was given command, but he in turn was captured by the French and imprisoned on the island of Guadeloupe in the Caribbean.

By 1812 Shirreff was commanding a frigate in North America and he later spent four years patrolling the South American coast, serving as senior officer in the Pacific Ocean, protecting British interests and supporting local movements for independence from Spain.[89]

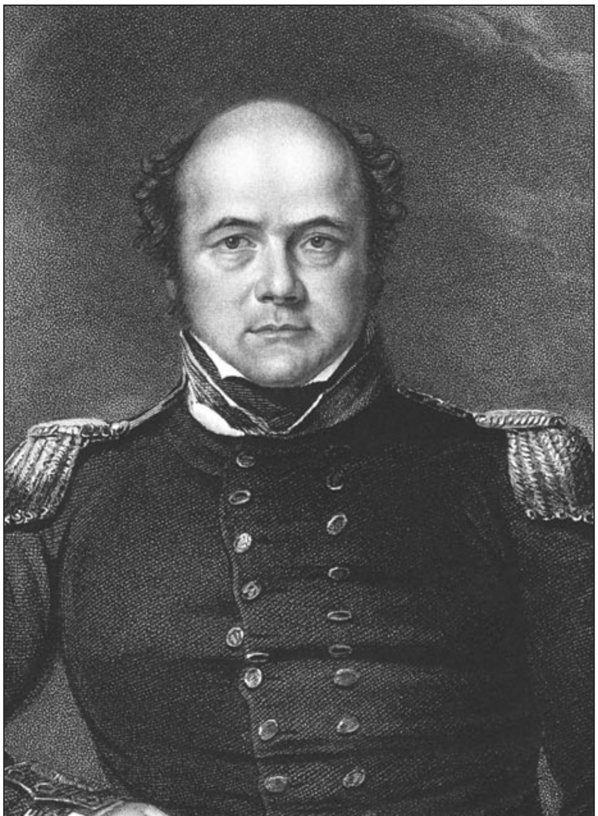
Back in England in 1821, and having joined the ASL, he built himself an observatory with a 5-ft telescope.[90] In 1830 he was captain of the flagship HMS *Warspite* at Rio de Janeiro and he was later Captain of the Port at Gibraltar (where he again constructed an observatory, in this case for providing accurate time to shipping) and finally Admiral-Superintendent of Portsmouth dockyard. His daughters Maria (who married the nephew of former Prime Minister Earl Grey) and Emily were prime movers for public day-schools for girls and the setting up of the Women's Education Union.[91]

6. 1823–25

6.1. *John Franklin*
After this rush of members, only twelve military men signed up in the next three years. First, elected in 1823 January, was Captain John Franklin (1786–1847), subsequently Rear-Admiral Sir John Franklin (Figure 7).[92] A native of Lincolnshire, he first went to sea on a merchant ship when he was 12 and joined the Royal Navy in 1800, seeing action in the Battle of Copenhagen as part of Nelson's squadron. He also fought at Trafalgar, in HMS *Bellerophon*. In between he had taken part in the first circumnavigation of New Holland, serving under Matthew Flinders who subsequently renamed it Australia, and in 1819 he was sent to survey the north coast of Canada.[93,94]

Franklin was again in Canada in 1825, sailing west from Great Bear Lake in a joint mission with Captain Frederick William Beechey (Section 6.5) who, it was planned, would meet up with him after sailing in the opposite direction, from the Bering Strait.[95] On his

Fig. 7: Captain John Franklin became a member of the ASL in 1823 January. He is seen here in an 1830 engraving by John Thomson from a portrait by William Derby. He died in 1847 on his expedition to complete the charting of the Northwest Passage. (National Portrait Gallery Australia)



return Franklin was knighted and from 1837 to 1843 was Lieutenant Governor of Van Diemen's Land (now Tasmania).

His final, legendary, expedition was to take the specially built ships *Terror* and *Erebus* in search of the Northwest Passage.[96] Setting sail in 1845 May, they were last seen by other Europeans in July. The ships became icebound in 1846 September. Later explorers learned from local Inuit that the survivors had attempted to walk across King William Island to safety but had succumbed to the conditions. Franklin, who had died prior to the remnant of the expedition led by Captain Francis Crozier of the *Terror* (Section 7.9) abandoning the ships, was posthumously promoted Admiral. The wrecks of the two vessels were finally discovered in 2014 and 2016.[97]

6.2. *George Everest*

Another famous name joined in 1823 March, Captain (later Lieutenant-Colonel) George Everest (1790–1866).[98] Everest joined the East India Company in 1806 and was commissioned in the Bengal Artillery. After carrying out survey work in Java he became chief assistant on the Great Trigonometric Survey in 1818 and in 1823 took over as its superintendent. Despite a long period suffering from the effects of malaria, he was largely responsible for surveying a meridian arc from the southernmost point of India up to Nepal, a task which took 25 years.[99] He published seven contributions on surveying in the *Monthly Notices* or *Memoirs*.[100]

Everest was Surveyor General of India in 1830–43 and after returning to England he was promoted colonel in 1854. The Royal Geographical Society named Peak XV, which had then recently been identified as the highest in the Himalayas, in his honour in 1865, despite Everest's own objections, including that it was difficult to pronounce for Hindi speakers.[101]

6.3. *Hugh Scott*

Captain Hugh Scott (1777–1852) joined the ASL in 1823 April. He was the son of Walter Scott, Laird of Raeburn, the uncle of Sir Walter Scott the novelist. Hugh Scott was in the marine service of the East India Company and in 1811 obtained letters of marque (essentially a licence for privateering) for the *Ceres*, sailing several times between the UK and China via St Helena.[102] He served afloat with the East India Company until 1822, commanding the East Indiaman *Charles Grant*. He subsequently gave his address as Butterley Hall, Derbyshire, the residence of his father-in-law, the canal engineer William Jessop. This building is now the headquarters of the Derbyshire Constabulary.

6.4. *John Molesworth*

Commander John Molesworth (1789–1858) joined the Society in 1823 November. He was the younger brother of the 7th Viscount Molesworth of Swords, in the County of Dublin. (Another brother was in the Royal Artillery and his cousin, the 6th Viscount, had been a Major-General).

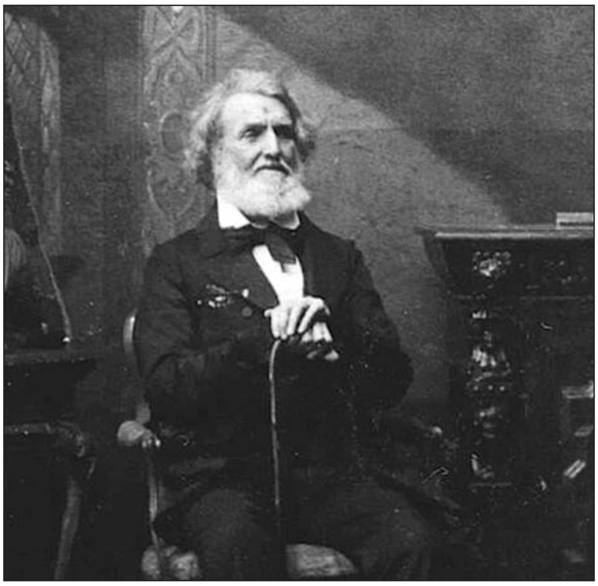


Fig. 8: George Everest, Surveyor General of India, photographed in 1862 by Camille Silvy. (National Portrait Gallery)

Molesworth went to sea in 1800, serving as a midshipman on the flagship *Canopus* during the Battle of San Domingo in 1806 and in an expedition against Constantinople (Istanbul) the following year. He had numerous further postings in the Mediterranean, serving onshore after the capture of forts on the Gulf of Spezia and the surrender of Genoa in 1814. He was promoted to commander in 1821 and retired in 1829.[103]

6.5. *Frederick William Beechey*

Captain Frederick William Beechey (1796–1856) was the next military member of the Society, elected in 1824 June. Son of the artist Sir William Beechey, he joined the Royal Navy aged ten. He served in an action off Madagascar in 1811 which ended the Mauritius Campaign, and in the unsuccessful attack on New Orleans in 1815.[104] He sailed with John Franklin to Greenland and was second in command on Edward Parry's expedition to the Arctic in HMS *Hecla* in 1819 (see Section 4.7).

In 1821–22 he surveyed North Africa under Captain W. H. Smyth (Section 4.10), accompanied by his older brother, the explorer and antiquarian Henry William Beechey, after which he was elected FRS in 1824. He was next sent in HMS *Blossom* to the Bering Strait to attempt to link up with Parry and Franklin sailing the opposite way along the northern coastline of Canada. On the way he discovered numerous Pacific islands (also visiting Pitcairn where he met the descendants of the *Bounty* mutineers), subsequently publishing a *Narrative of a Voyage to the Pacific and Beering's Strait*.[105] From 1835 to 1847 he carried out coastal surveys in South America and the British Isles, the latter including tidal surveys.

Later superintendent of the Marine Department of the Board of Trade, he was promoted to Rear-Admiral in 1854 (another brother, Richard, was also an admiral) and was also president of the Royal Geographical Society in 1855–56. He had one communication in *Monthly Notices* on determining longitudes and two in *Philosophical Transactions* on tides.[106]

6.6. *Peter Lecount*

Lieutenant Peter Lecount (1794–1852) joined the Royal Navy in 1809, serving as a midshipman at the Siege of Cádiz the following year and losing an eye in the capture of a privateer.[107] After serving on a succession of vessels in home and American waters, he retired as a lieutenant in 1827 and became a civil engineer.[108] He had a particular interest in railways, working with Robert Stephenson, and wrote *The History of the Railway connecting London and Birmingham*.[109] He had already written papers for the Board of Longitude on chronometers and celestial navigation between 1820 and 1823.

Lecount joined the Society in 1825 January while still a midshipman – apparently a unique occurrence at the time – and had three papers in *Monthly Notices* in 1829–30, being particularly interested in observing eclipses of Jupiter's satellites while at sea.[110]

6.7. *Henry Foster*

Lieutenant (later Captain) Henry Foster (1796–1831), the son of a Lancashire clergyman, joined the navy in 1812, originally as a Royal Marine. Between 1817 and 1819 he 'visited the Columbia River with the commissioners to establish the boundary line between Great Britain and the United States'. He assisted Basil Hall (Section 4.2) in his pendulum experiments and was part of the British Naval Scientific Expedition to the Arctic in 1823, during which he assisted the soldier-astronomer Captain Edward Sabine (1788–1883). (Sabine, later Major-General Sir Edward, had been an FRS since 1818 but for some reason did not join the RAS until 1839).[111]

Foster subsequently joined Captain Edward Parry's Northwest Passage and North Polar expeditions (Section 4.7), carrying out astronomical and geomagnetic observations. He was elected a Fellow of the Royal Society in 1824 and of the Astronomical Society in 1825 January, winning the former's Copley medal in 1827 for his magnetic and other observations made during the Arctic expedition.

From 1828 to 1831, by now commander of HMS *Chanticleer*, he led the British Naval Expedition to the South Atlantic, touching upon Antarctica, carrying out further gravity measurements with a pendulum.[111] Unfortunately, while continuing his experiments in Central America on the return journey, he was drowned in the River Chagres in Panama after falling from a large canoe used to reach otherwise inaccessible places.[113] He published two contributions in *Philosophical Transactions* and four in *Monthly Notices* and *Memoirs*, including two published posthumously on observations of the comet of 1830.[114]

6.8. *John Anthony Hodgson*

Captain John Anthony Hodgson (1777–1848) was also elected a member in 1825 January. He entered the military service of the East India Company in 1799 and the following year became a lieutenant in the Native Infantry. Hodgson developed an interest in science and was selected for a survey to determine the positions and heights of Himalayan mountains.[115] At one point he was caught in an avalanche while observing eclipses of Jupiter's moons, a subject on which he made several submissions to the *Memoirs*, among a total of seven communications to the Astronomical Society.[116] He later observed the 1822 transit of Mercury from Calcutta.[117] Hodgson was Surveyor-General for India in 1821–23 and 1826–29. In 1845, with a rank of Major-General, and also as a Colonel in the Bengal Native Infantry, he was appointed to the command of the district of Rohilkhand in Uttar Pradesh, dying there three years later.

6.9. *Frederick Fitzgerald de Roos*

(John) Frederick Fitzgerald de Roos (1804–61) was the son of Lord Henry Fitzgerald, a retired Lieutenant-Colonel from the American wars, and Baroness Charlotte de Roos, one of whose ancestors signed Magna Carta. He joined the Royal Navy in 1818, was promoted lieutenant in 1825, and was posted to Halifax, Nova Scotia. He subsequently published a *Personal Narrative of Travels in the United States and Canada*, his somewhat disparaging views incurring the wrath of Americans.[118, 119] Promoted to Captain in 1835, he retired as a Rear-Admiral in 1857.

de Roos was elected to the Astronomical Society in 1825 and the Royal Society in 1831 but appears to have ended his RAS membership after 1840. He also wrote a book on European lighthouses.[120] His surname was later written de Ros or Fitzgerald-de Ros. Two of his brothers were senior Army officers. His uncle, Lord Edward Fitzgerald, a British veteran of the American Wars, had later been an associate of Tom Paine and a leading figure in the Irish insurrectionary movement, and was fatally shot while resisting arrest in 1798.

6.10. *William D'Urban*

Descended from 'a very ancient and noble family', Captain William D'Urban (c.1771–1837) had rapidly earned promotion to navy lieutenant in 1790 through assisting Admiral John Elliot with lunar observations at sea. He was involved in the capture of Cape Town in the French Revolutionary War and later served in the Mediterranean and Adriatic, often in a diplomatic capacity, including negotiations with the Grand Master and Knights of Malta.[121]

In 1804, having inveigled his way into a Spanish troop convoy heading for Minorca 'he captured [it] with the assistance of Nelson's look-out ships'. He was with the Anglo-Russian forces in Naples and the Adriatic the following year. Another of those elected to the Astronomical Society in 1825, he was also a Doctor of Civil Law. He was promoted Rear-Admiral just before his death in 1837.

6.11. *George Wright*
Lieutenant-Colonel George Wright (1779–1856) was born in Edinburgh, the son of a surgeon, and commissioned in the Royal Engineers in 1797 during the Peninsular Wars.[122] He was included in the list of Astronomical Society members as of 1825 June,[123] but he must have had a short-lived association with the Society as he is not in the list for 1831, perhaps because he had returned to Edinburgh.[124] He was promoted to Major-General in 1837 January.[125] His son Edward William Carlile Wright (1815–1871) also rose to the rank of colonel.

6.12. *Charles Ramsay Drinkwater*
Captain Charles Ramsay Drinkwater (1802–84), from 1837 known as Drinkwater Bethune, was elected to the Society in 1825 June. The son of Lieutenant-Colonel John Drinkwater, a friend of Horatio Nelson who served during the Siege of Gibraltar, he joined the Royal Navy in 1815, being in the force that conveyed Napoleon to exile in St Helena. He had commands in Australasia and the Far East in the 1830s and 40s, and was made a Companion of the Bath for his services during the First Opium War with China. He also served as Assistant Hydrographer to the Admiralty from 1846.[126]

He had two contributions in *Monthly Notices*, a note on a method of determining longitude from a lunar occultation (as Drinkwater), read at the same 1827 June meeting as Colonel Hodgson's above, and an observation of a comet (as Bethune).[127,128] In 1851 he became the Laird of Balfour (inheriting via his mother) and was promoted to Admiral in 1866.

One of his sons was a naval captain and another an army lieutenant-general. His brother John, a lawyer and later a member of the Supreme Council of India, was counsel for Sir James South, the president of the Astronomical Society in 1829–31, in his famous dispute with telescope makers Troughton & Simms in the 1830s.

7. 1825–28

7.1. *William Samuel Stratford*
Additions of military types to the Astronomical Society membership increased again in the latter part of the 1820s, a further 15 joining up to the summer recess in 1828. First, in 1825 November, was Lieutenant William Samuel Stratford (1789–1853) who became Secretary of the Society from 1826 to 1831. He joined the Royal Navy, serving as a midshipman in the Mediterranean and in the defeat of a Turkish squadron in the Dardanelles, and was also involved in the attack on Copenhagen.[129] He was commissioned as lieutenant in 1815.

Stratford was a Council member and vice-president of the RAS. A highly able mathematician, he was particularly involved when the Admiralty asked for RAS input on the state of the *Nautical Almanac* in 1831, becoming Superintendent of the Nautical Almanac Office for the next 22 years. He had already been responsible for new tables of aberration and won the Astronomical Society's Silver Medal in 1827 for his work with Francis Baily in compiling the Society's catalogue of 2,881 stars.[130] He also contributed comet ephemerides.[131] His proposers for fellowship of the Royal Society in 1832 included Astronomical Society founders Francis Baily, John Herschel, and Thomas Colby.[132]

7.2. *Thomas Graves*
Captain Thomas Graves (1802–56) became a member of the Society in 1826 January. After studying at the Royal Naval College at Portsmouth he joined the Royal Navy at age 15, on HMS *Bulwark* captained by his father, of the same name. He served in Newfoundland and South America, subsequently joining Captain W. H. Smyth (Section 4.10) as a midshipman on surveying operations in the Mediterranean and then taking part in surveying the Strait of Magellan, the same expedition as Captain Pringle Stokes (Section 7.5).

Graves spent ten years surveying the Greek islands in command of HMS *Beacon*, also investigating local antiquities and becoming a keen naturalist.[133] He was subsequently Marine Magistrate and Superintendent of the Ports of Malta. He died of a stab wound inflicted by a Maltese sailor who was aggrieved that Graves had ordered his boat to be hauled-up for a fortnight for having overcharged a passenger.

7.3 *Henry Norquoy*
Captain Henry Norquoy (dates unknown) joined the Society at the same time as Thomas Graves (Section 7.2). Norquoy had sailed with the East India Company since 1800 and was third officer on the *Comet* in 1803 when she ran into five French ships of the line north of Madeira and was captured, although the crew were soon liberated.[134] By 1825 he was master of the *Shannon*, sailing from Singapore and Batavia via St Helena. He is also noted as having taken part in surveying operations.

7.4 *John George Graham*
Captain John George Graham (c.1791–1854) became a member of the ASL in 1826 April. He was the son of Dr Robert Graham of Stirling (who later changed his surname to Moir of Leckie on inheriting the Leckie estate) and grandson of Charles Stewart of Ardshiel who led the Stewart clan at Prestonpans and Culloden. His first naval posting was on HMS *Victory* in 1809 and he received his commission in 1815. He served on a string of vessels, suffering shipwreck in the Bay of Bengal in 1820 when on the *Carron*. His first command was the *Icarus* in Jamaica from 1823.[135]

Just before his death in 1854 when on the retired list, he was promoted to retired Rear Admiral.[136] He earlier gave his address as Touch House, Stirling, the ancestral home of the Seton family; the family histories were probably intertwined as Prince Charles Edward Stuart stayed both at Touch and the nearby Leckie House during the Jacobites' march on Edinburgh prior to the Battle of Prestonpans in 1745.[137]

7.5. *Pringle Stokes*

Captain Pringle Stokes (1793–1828) was elected to the Society in 1826 January.[138] He joined the Royal Navy as a midshipman when he was twelve and was a lieutenant on the *Owen Glendower* on a lengthy voyage around South America and then in the suppression of the West African slave trade, taking command temporarily after the death of its captain in 1823.

In 1826 Stokes took HMS *Beagle* to chart the coast between Montevideo and Tierra del Fuego and around the Strait of Magellan.[139] Suffering from stress and depression, Stokes shot himself in 1828 August, Robert Fitzroy taking over the command after the *Beagle* returned to Montevideo (Section 8.13).[140] Stokes' handwritten journal of the voyage sold for £92,500 at Sotheby's in 2009.

7.6. *Henry Shrapnel*

The rest of 1826 saw only one new military figure joining the Society.[141] Lieutenant-General Henry Shrapnel (1761–1842) of the Royal Artillery (commissioned as second lieutenant in 1779) became famous for inventing the shell named after him when he was only 23. Following service in Flanders with the Duke of York against the French Republican Army in the 1790s he was promoted to Major in 1803 and Lieutenant-Colonel a year later. Shrapnel continued working at the Royal Arsenal at Woolwich making further improvements to munitions. He became Colonel-Commandant of the Royal Artillery in 1827.[142]

7.7. *Henry Wolsey Bayfield*

Captain (eventually Admiral) Henry Wolsey Bayfield (1795–1885) joined the ASL in 1827 May. Born in Hull, he entered the Royal Navy as a first-class volunteer just before his eleventh birthday, serving in several battles off the Spanish coast. He was posted to Canada in 1814, towards the end of the second American war. From 1816, when he worked with Captain W. F. Owen (Section 5.4), Bayfield spent the next 40 years surveying the coasts, lakes, and rivers of Canada including lakes Ontario, Huron, and Erie, the St Lawrence River, and the Labrador coast.[143]

Bayfield joined the Society while temporarily in the UK producing charts for the Admiralty from this work. He published numerous works including *Sailing Instructions for the Gulf and River of St. Lawrence* and was a regular contributor to the Geological Society of London and to the *Nautical Magazine*.[144]

Bayfield was an active observer of lunar occultations and eclipses of Jupiter's satellites, reporting in *Monthly Notices* on work carried out at his residence on Prince Edward Island.[145] He also observed the 1832 transit of Mercury from Quebec.[146] In retirement he was promoted to Admiral in 1867, and prior to his death at the age of 90 he was the longest-surviving RAS member.[147] He was also a noted artist as was his wife Fanny Amelia, daughter of Captain Charles Wright of the Royal Engineers, whom he married in 1838.

7.8. *William Mudge*

Commander William Mudge (1796–1837), the son of Major-General William Mudge (Section 3.1), joined the ASL in 1827 May. He became a lieutenant in the Royal Navy in 1815 and was employed on the survey of the east African coast under Captain W. F. Owen (Section 5.4).[148] Mudge later carried out mapping of the Irish coastline producing various charts, and while there supplied an account of a prehistoric village, excavated in a bog in Donegal, to the Society of Antiquaries.[149] He died in 1837 while on his posting to Ireland and was buried with full military honours.

7.9. *Francis Rawdon Moira Crozier*

Lieutenant (later Captain) Francis Rawdon Moira Crozier (1796–c.1848) was another to join in 1827. Born in County Down, Ireland, he had entered the Royal Navy in 1810 and on an early voyage in the Pacific was another to encounter the last surviving mutineers from the *Bounty* on Pitcairn Island. In 1824 he was appointed master's mate of the *Fury* under Edward Parry (Section 4.7), undertaking three expeditions to the Arctic and learning to speak Inuktitut.[150]

Crozier was appointed to command of the *Terror* in 1839 and accompanied Sir James Ross (Section 7.12) on his voyage to the Antarctic Ocean. In 1843 he was elected FRS for his work on magnetic observations. In 1845 he was reappointed to the *Terror* as second-in-command of Captain John Franklin's doomed expedition in search of the Northwest Passage (Section 6.1). The expedition was officially accepted as lost by the Admiralty (and RAS) in 1854.

Their last written record, signed by Crozier, noting Franklin's death in 1847 and the abandonment of the ships in 1848, was found by later searchers.[151] Legend has it that Crozier was the last survivor. As well as a number of Arctic and Antarctic features, a lunar crater is named after him.

7.10. *George Fisher*

Technically, the Reverend George Fisher (1794–1873), elected in 1827 June and a future vice-president of the Society, was in the Royal Navy, although as a chaplain. He had already been on one Arctic voyage while a student at Cambridge and was selected as astronomer and chaplain on Captain Edward Parry's expedition of 1821–23 in search of the Northwest Passage; during this voyage he made extensive observations on atmospheric refraction at low temperatures. Fisher's final post before retiring from the navy in 1833 was as chaplain on HMS *Victory*.

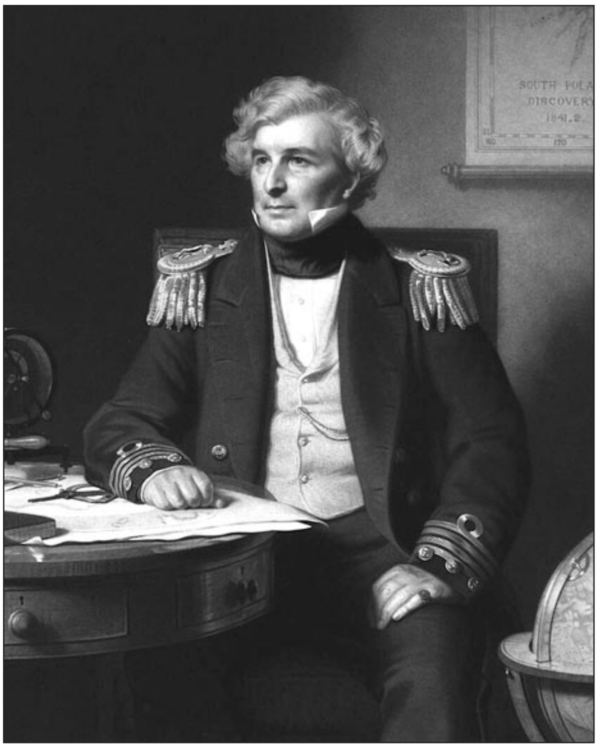
He had been an FRS since 1825, making contributions to the *Philosophical Transactions*, and became headmaster of Greenwich Hospital School and later its Principal.[152, 153] He had an observatory built there and sent observations of the 1860 solar eclipse to *Monthly Notices*, one of four submissions to the RAS journals between 1833 and 1861.[154, 155] Fisher also wrote textbooks on algebra and geometry and was the first educator to devise a numerical scale method for measuring student attainment.[156]

7.11 *George Beaufoy*

Lieutenant Commander George Beaufoy (1796–1864), incorrectly entered as Beaufort in the 1831 fellows list, was elected an honorary member of the Society in 1828 January. The son of Colonel Mark Beaufoy (Section 3.6), he entered the Royal Navy in 1810 as a first-class volunteer on the 74-gun *Elizabeth*, and over the next few years saw service around the world as a midshipman. On being appointed Lieutenant in 1821 he was posted to Halifax, Nova Scotia, and continued in the service until 1851, subsequently taking over the family vinegar business.[157]

Beaufoy was given the honorary membership for donating the instruments from his father's observatory to the ASL.[158] He also communicated his own observations to the Society.[159] His son Mark Hanbury Beaufoy, later a Liberal MP for Kennington, won the F.A. Cup playing for Old Etonians in 1879.[160]

Fig. 9: James Clark Ross reached the north magnetic pole in 1831 and later led a search for the vanished explorer John Franklin. He is seen here in a mezzotint by Alexander Scott, based on an 1850 portrait by Stephen Pearce. (National Portrait Gallery)



7.12. *James Clark Ross*

Captain Sir James Clark Ross (1800–62) (Figure 9) joined the ASL in 1828 March. He was the nephew of Sir John Ross (Section 4.5) and, after joining the Royal Navy in 1812, accompanied him on his Arctic expedition in 1818.[161] He was also on four Arctic voyages with Edward Parry (Section 4.7) between 1819 and 1827. The young Ross participated in his uncle's 1828 expedition in search of the Northwest Passage and led the small party that first reached the North Magnetic Pole.

In the 1830s Ross participated in the British Magnetic Survey with Edward Sabine. He then commanded his own expedition charting the coast of Antarctica in HMS *Erebus* from 1839 to 1843, his friend Captain F. R. M. Crozier (Section 7.9) accompanying him in HMS *Terror*.[162] In the process he discovered the Ross Sea. Ross was knighted in 1844 and was elected FRS in 1848, providing the Royal Society journals with a number of contributions.[163]

Also in 1848, he was sent on one of the many searches for the Franklin expedition (which had itself sailed in *Erebus* and *Terror*) and eventually reached the rank of Rear-Admiral of the Red.[164] As well as geographical features, a crater on the Moon and a species of seal are named after him.

7.13. *Edward Nicholas Kendall*

Also joining in 1828 March was Lieutenant Edward Nicholas ('Ned') Kendall (1800–45), the son of a naval captain of the same name from a distinguished Cornish family. Educated at the Royal Naval College, Portsmouth, he entered the Royal Navy in 1814. Surviving a shipwreck on the Cape Verde Islands in 1819, most of his work was as a surveyor, frequently crossing paths with others mentioned in this paper.[165]

In 1824, he joined Edward Parry's third Arctic expedition as assistant surveyor on HMS *Griper* and the following year sailed with John Franklin to Great Bear Lake. He later married one of Franklin's nieces. Kendall was then part of Henry Foster's expedition to southern waters making pendulum observations (Section 6.7) and in 1830 was successor to Thomas Boteler (Section 7.14) on *Hecla*, the same ship which had been used by Parry in the Arctic, in the survey of West Africa. He was later sent to make a clandestine survey of the boundary between the USA and New Brunswick.

Leaving government employ, he worked for the New Brunswick and Nova Scotia Land Company and the West India Mail Steam Navigation Company, and at the time of his early death in 1845 was superintendent of the Peninsular and Oriental Steam Packet Company in Southampton.[166]

7.14. *Thomas Boteler*

Commander Thomas Boteler (c.1797–1829) was elected in 1828 May but unfortunately died the following year at the age of 32. He was surveying the west coast of Africa in HMS *Hecla* when 'he fell a sacrifice to the

Fig. 10: Duke of Clarence (the future King William IV) in a mezzotint by Henry Dawe, from a portrait by Charles Jagger. The Duke joined the ALS in 1828 and signed its royal charter three years later after becoming king. (National Portrait Gallery)

noxious climate', i.e. yellow fever, which had already claimed the lives of most of his crew.[167]

He had gone to sea in 1810 and, after being commissioned as lieutenant, spent five years surveying around Africa from Tenerife to Madagascar under W. F. Owen (Section 5.4). He wrote his own *Narrative of a voyage of discovery to Africa and Arabia*, which was published posthumously.[168] Boteler had reached the rank of commander in 1826. Two of his brothers were also commanders in the Royal Navy and another was a lieutenant-colonel in the Royal Engineers.

7.15. *Frederick Page*

Frederick Page (1769–1834) was also elected in 1828 May. Although not an army officer as such, he was the Lieutenant-Colonel commanding a local battalion connected to the Royal Berkshire Militia from 1809 and was thereafter generally referred to as Colonel Page. Born in Newbury, Berkshire, he was a local landowner and barrister and a social commentator on the Poor Laws.[169]

A Deputy Lieutenant for Berkshire, when the so-called 'Swing' riots by agricultural workers protesting against mechanization broke out there in 1830, he wrote to the Home Secretary describing a 'chase thro' the country [by mounted yeomanry and regular troops] in pursuit of those who had participated' – some of whom were transported to Botany Bay – and, by the standards of landowners of the day, was generally sympathetic to the agricultural workers' cause.[170]

Page was a member of the Institution of Civil Engineers, particularly interested in canal navigation, and his widow presented the Institution with 'all such parts of his library and collections as relate to the objects of the profession'.[171]

8. 1828–31

8.1. *Henry Dundas Trotter*

The final years of the Astronomical Society of London saw thirteen military men elected. Captain (later Rear-Admiral) Henry Dundas Trotter (1802–59) was elected in 1828 December. Born in Edinburgh, he joined the Royal Navy in 1818. He was first sent to the East Indies followed by operations against pirates in the Persian Gulf. He was later the senior officer for operations off the west coast of Africa, capturing a Spanish schooner which had attacked American shipping.

Trotter led the Niger expedition of 1841 on the new iron steamer HMS *Albert* with orders to negotiate commercial treaties with local rulers, particularly with regard to suppressing slavery. The mission had to be abandoned due to a high mortality rate among the crews and Trotter himself had to turn down other senior posts due to the effects of fever contracted there.[172] He was, though, commodore at the Cape of Good Hope during the Crimean War.[173]

8.2. *Duke of Clarence*

The Society received a signal honour in 1828 when William Henry, Duke of Clarence (1765–1837) (Figure 10), the Lord High Admiral and brother of George IV, became the 301st name in the Society's list of members and associates. He had served in the Royal Navy in his youth, joining as a plain midshipman at the age of 13, and was at the Battle of St Vincent in 1780.[174] According to a royal biographer, he was perfectly at home with his shipmates, being arrested with them after a drunken brawl in Gibraltar.[175]

He served in New York in the American Revolutionary War and was the target of a plan, agreed by George Washington, to have him kidnapped. He was a captain by 1786 and was promoted to rear-admiral in command of HMS *Valiant* in 1789, leaving active service the following year; he became Lord High Admiral in 1827.

He acceded to the throne as William IV ('the sailor king') in 1830 on the death of his brother and it was he who signed the Society's Royal Charter the following year, subsequently becoming Patron. His brother Prince Augustus Frederick (1773–1843), the Duke of Sussex, was also an FRAS (elected 1828 June) and later President of the Royal Society.

8.3. *George Cockburn*

The highest-ranking serving officer in our list, elected in 1829 May, was Admiral of the Fleet Sir George Cockburn (1772–1853) (Figure 11). He was a captain's servant aged nine, properly going to sea in 1786 and being appointed lieutenant on the flagship *Victory* off

Toulon in 1793. He also served under the then Captain Nelson and was present at the battle against the Spanish fleet at St Vincent in the French Revolutionary War. Cockburn had commands in the Mediterranean until the peace in 1802 and later served around the world during the Napoleonic Wars.

In 1812, by now a rear-admiral, he proceeded to Bermuda to blockade American ports and the following year proposed the joint army and naval assault on the City of Washington (now D.C.). Reputedly, Cockburn wanted to raze the whole city in revenge for American attacks on Canada,[176] but the army commander settled for burning the Presidential Mansion (now the White House), Capitol, and other government buildings. Cockburn later conveyed Napoleon to St Helena and briefly became governor of the island. In 1832 he was commander-in-chief of the North America and West India Station. He was a member of parliament for Portsmouth, several times a junior Lord of the Admiralty, First Naval Lord (now First Sea Lord) from 1841 to 1846, and inherited the family baronetcy in 1852.[177]

Fig. 11: George Cockburn poses imperiously with Washington in flames behind him. Mezzotint by Charles Turner from a portrait by John James Halls, 1819. (Library of Congress)

8.4. *Robert Winthrop*

Joining the same month as Cockburn, Rear-Admiral Robert Winthrop (1764–1832) was born in New London, Connecticut, into a family of colonial administrators. His uncle, attached to the British forces in New York, secured him a place in the Royal Navy when he was 17. Winthrop was aboard Admiral George Rodney's flagship *Formidable* during the British victory over the French at the Battle of Dominica, considered the Royal Navy's greatest success in the American Revolutionary War.

He obtained command of HMS *Undaunted*, but this was wrecked off Jamaica in 1796. He was then involved in the fighting in French-controlled Holland, his men 'cutting out' (i.e. capturing by boarding) a number of vessels 'notwithstanding they were much annoyed by the fire from the enemy's batteries and gun-boats'.[178]

He subsequently took possession of the squadron of the Batavian Navy anchored off Texel when it surrendered without firing a shot in 1799.[179] He had numerous commands during the Napoleonic wars and was promoted to Vice-Admiral of the Blue in 1830. Winthrop's two sons were Royal Navy commanders and a nephew became a Vice-Admiral.

8.5. *Henry Raper*

Lieutenant Henry Raper (c.1799–1859) was elected to the ASL in 1829 November. He had joined the Royal Navy in 1811, serving under his father, the Admiral of the same name.[180] In 1815 he was on the *Alceste* which conveyed the Earl of Amherst on an embassy to China but was wrecked in Indonesia on the return journey. In 1822 he served under W. H. Smyth (Section 4.10) in the Mediterranean 'with exceptional opportunities for the scientific study of navigation, nautical astronomy and surveying' and was promoted to lieutenant in 1823.

He retired on half pay soon afterwards but was appointed by the Admiralty to their committee on improving methods for the determination of the tonnage of ships. In 1840 he published *The Practice of Navigation and Nautical Astronomy*, which was adopted by the Admiralty for use aboard their ships and won him the Gold Medal of the Royal Geographical Society.[181] He was a council member and secretary of the RAS for many years and made five contributions to their journals, mostly concerning transit observations.[182]

8.6. *Richard Owen*

Commander (subsequently Rear-Admiral) Richard Owen (1796–1863) joined the ASL in 1830 January. Born in County Wexford, Ireland, the son of a clergyman, he had been in the Royal Navy since 1811 and was commissioned lieutenant in 1821 while attached to a surveying vessel in the West Indies. He spent five years in a survey of African coasts with the unrelated W. F. Owen (Section 5.4) where, in addition to the ravages of fever, they also became involved in the first Ashanti War in 1826.[183]

He next carried out work for the Ordnance Survey before a final posting, from 1829 to 1837, back in the West Indies, communicating with the Astronomer Royal John Pond regarding suitable chronometers.[184] He sent observations of Halley's comet to the RAS in 1836.[185]

8.7. *Thomas Drummond*

The last to sign in before the summer recess in 1830 was Lieutenant Thomas Drummond (1797–1840), elected in May. After Military College in Woolwich he joined the Royal Engineers, subsequently being recruited to a trigonometric survey of the Highlands. He moved on to the Ordnance Survey of Ireland, where he utilized the 'Drummond Light', his adaptation of the 'limelight' used for illuminating indoor venues, which he reported to the Royal Society could be seen from a distance of 66¼ miles.[186]

A Whig supporter, he was then placed in charge of the Boundary Commission ahead of the Reform Bill (or Representation of the People Act) of 1832. In 1832 he was appointed private secretary to the Chancellor of the Exchequer, in which role he helped the Society obtain its apartments in Somerset House. He was appointed Under-Secretary for Ireland in 1835 but died in 1840.

8.8. *Alexander Bridport Becher*

While the finishing touches were being made to the Society's Royal Charter, the 1830–31 session began still under the name the ASL. Two new members were elected before the end of the year, Commander Alexander Bridport Becher (1796–1876) in November, and Captain John Betham in December. Becher, son of another Captain Alexander Becher and grandson of Commander John Becher, had started his naval career as a midshipman in 1812.[187]

In 1817 he was employed in the survey of the Canadian lakes under Commodore E. W. C. R. Owen (Section 5.3) and his younger half-brother Captain W. F. Owen (Section 5.4). He also spent time on other survey work with Captain Basil Hall (Section 4.2) on the *Conway* and was promoted to lieutenant in 1822.

Thereafter employed in the Admiralty Hydrographic Office, Becher corresponded regularly with Astronomer Royal John Pond concerning the supply of chronometers and acted as secretary to the Board of Visitors at the Royal Observatory, supplying one contribution to *Monthly Notices* on the design of an artificial horizon that could be attached to a sextant.[188] In addition, he was the editor of the *Nautical Magazine* for 40 years and wrote numerous books on winds and currents such as *Navigation of the Pacific Ocean*.[189] Becher was advanced to retired Rear-Admiral just prior to his death in 1876.[190]

8.9. *John Betham*

John Betham (1787–1834) was a captain in the East India Service in the Bombay Marine (later the Indian Navy) from 1808. He corresponded with the Poet Laureate Robert Southey, a friend of his sister Matilda, who was also a poet and a painter, sending papers to Southey in 1813 which stated 'that our navy officers behave with great insolence to the Company's marine, – & that there is a hearty contempt on one side – which is returned very naturally, & somewhat more properly, with as hearty a hatred on the other'.[191]

Southey dissuaded him from making this public as it was 'one of those things upon which the least that is said the better' but Betham did later publish the *Trial of Captain John Betham* in 1829, which detailed his dismissal from the service after an argument with Sir Charles Malcolm over the quality of the biscuits his ship was provided with.[192] Despite these travails, according to his RAS obituary he was 'an officer of spirit and talent' who 'displayed much discretion in the arduous duties of boat-master, coroner and police magistrate' in Madras.

8.10. *Thomas Henry Shadwell Clerke*

The New Year of 1831 saw the election of two military men, Major T. H. S. Clerke and Lieutenant Alexander Baring, plus two others proposed, Commanders Henry Downes and Robert Fitzroy.

Thomas Henry Shadwell Clerke (1792–1849), born in County Cork, entered the army as an ensign in 1805 and was made a lieutenant in the 5th Regiment of Foot two years later. He fought in a number of engagements in the Peninsular Wars until losing a leg at Redinha in 1811. At the conclusion of the war he was appointed a captain of the Staff Depot.[193]

He was the original editor of the *United Service Journal* and was involved with the United Service Institute. Created a Knight of the Royal Guelphic Order by William IV in 1831, he was also a Fellow of the Royal Geographical and Geological Societies[194] and an FRS (1833). His brothers were Major-General St John Augustus Clerke, Colonel of the 75th Foot, and Major William Clerke of the 77th Foot.

8.11. *Alexander Baring*

Lieutenant Alexander Baring (1810–32) was a member of the well-known banking family, son of the extraordinarily wealthy landowner and politician of the same name (subsequently the 1st Baron Ashburton) who had arranged the Louisiana Purchase funded by the bank. (According to the 19th-century French statesman the Duc de Richelieu there were then 'six main powers in Europe: Britain, France, Austria-Hungary, Russia, Prussia, and Baring Brothers').[195] Baring gave his address as Bath House, Piccadilly, the new London residence of the family, when he joined the Society. However, a year later he died on board the HMS *Alfred* off Napoli di Romania (i.e. Nafplio, then capital of newly independent Greece) when still only 21 years old.[196]

8.12. *Henry Downes*

Commander Henry Downes (1791–1852) joined the Royal Navy as a first-class volunteer in 1805 and was in action at the reduction of the Dutch island of Curaçao in the Caribbean two years later. He also served in the Baltic and was shipwrecked in Ceylon (Sri Lanka) in 1811.[197]

Attaining the rank of Lieutenant in 1813, he was engaged off the African coast in suppression of the slave trade, the force capturing and freeing the slaves from no less than 21 Spanish and Brazilian slave ships. Six of these came as a direct result of the exploits of Downes and his crew on the unfortunately named small tender *Black Joke*.[198] Particularly noted was his capture of the much larger and more heavily armed Spanish brig *El Almirante*, and as a result of 'this very dashing exploit' he was advanced to commander in 1829.

Back in England he was much involved in the formation of the Royal United Services Institute and became its honorary director. He was also one of the instigators of a rather unsuccessful naval Christian mission in the Loo Choo Islands (now the Ryukyu islands, Japan).

8.13. *Robert FitzRoy*

Last of the early military Astronomical Society members, but undoubtedly the most important in the history of science, was Commander Robert FitzRoy (1805–65) (Figure 12).[199] He was the son of General Lord Charles FitzRoy, a direct descendent of King Charles II, while his mother was related to Foreign Secretary Viscount Castlereagh. Winner of the mathematics prize at the Royal Naval College, Portsmouth, he joined the Royal Navy in 1819, when he was 14, and became the first midshipman to qualify as lieutenant 'with full numbers', i.e. a mark of 100%. In 1828 he was appointed flag-lieutenant to the commander-in-chief of the South American Station, on HMS *Ganges*. After the demise of Pringle Stokes (Section 7.5) he took temporary command of HMS *Beagle*, which was undertaking a hydrographic survey of Tierra del Fuego.[200]

Fig. 12: Robert FitzRoy commanded Charles Darwin's voyage on the Beagle but dissociated himself from the theory of evolution that resulted from it. Albumen print by London Stereoscopic & Photographic Company, 1860s. (National Portrait Gallery)

In 1831, with the help of Francis Beaufort, the Hydrographer to the Admiralty (Section 4.1), he fitted out the *Beagle* for another survey voyage and Beaufort suggested Charles Darwin as a suitable scientific 'gentleman companion'. Their world-changing journey via South America, the Galapagos Islands, and Australasia took nearly five years. FitzRoy's work won him the Gold Medal of the Royal Geographical Society.[201,202,203] He was appointed governor of New Zealand but his even-handed treatment of Maori land rights, against those of colonists, led to his replacement.

Elected FRS in 1851, he began a new career as a meteorologist for the Board of Trade, working on ways to predict future weather events, and is credited with the first use of the term 'weather forecast'.[204] His one *Monthly Notices* contribution was on meteorological observations.[205]

After *Origin of Species* was published, the highly religious FitzRoy apparently felt guilt for his part in Darwin's development of what he saw as an irreligious theory and sided with Bishop Samuel Wilberforce in opposing the theory of evolution. He was advanced to Vice-Admiral on the reserve list in 1863 but committed suicide by cutting his own throat two years later.

9. Later years

At the eleventh annual meeting of the Astronomical Society of London in 1831 February it had been announced that

> the first topic of congratulation which the Council have to offer, is the change of style and name. The intimate connexion which exists between the objects of our association, and the honour and safety of the British Navy, has not escaped the attention of His Majesty. The countenance shewn to us by the Duke of Clarence, as Lord High Admiral, has been continued and confirmed by William the Fourth: and we are now assembled as the *Royal Astronomical Society*, with the Sovereign as our *Patron*.

The Royal Charter was signed on March 7 and the first meeting under the new title took place on March 11.

Perhaps following the example of the new king, further army and navy personnel continued to join the Society. Indeed, the 1840 list of Fellows included no fewer than 71 military gentlemen.[206] This was up from 56 in 1831 and represented a peak representation by the officers and gentlemen. By the late 1850s the numbers were back down to around 50 again, out of a total of 384 Fellows.[207]

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Georges Lemaître: Great savant and absent-minded professor

Simon A. Mitton

This research note gives a translation and commentary of an interview with Françine Quinet (1923–2021), a former student of Georges Lemaître (1894–1966), conducted in 2020 June for a Belgian television station. The interview adds detail and colour to the story of Lemaître's enthusiasm for using electromechanical calculators in applied mathematics and theoretical physics.

1. An oral history witness report of Georges Lemaître's teaching style

Following the publication of my paper on Georges Lemaître and Big Bang cosmology in Issue 14 of *The Antiquarian Astronomer*,[1] a colleague drew my attention to an oral history interview of one of Lemaître's former pupils that had been published by Radio Télévision Belge in 2020 June. The interview marked the fifty-fourth anniversary of Lemaître's death.

In this paper I present a translation of the interview together with my contextual comments. My intention is that such recollections be preserved and made generally accessible. Although this witness report does not add to our considerable knowledge of Lemaître's research in cosmology and physics, it does give us a glimpse of his teaching style and his lasting impact on students.

2. Lemaître and Louvain 1940–44

Lemaître's second period of the experience of war has been comprehensively described by Dominique Lambert, a distinguished professor of philosophy at the University of Namur, Belgium, and a great expert on the life and works of Lemaître.[2] This section draws on Lambert's text to give a bare-bones outline of the challenges Lemaître faced at Louvain during the war years.

At the outbreak of World War II Belgium was a neutral state. On 1940 May 10 Nazi Germany launched its blitzkrieg of Belgium, the Netherlands, and Luxembourg to clear the ground for the invasion of France. Three days later the British army withdrew its defences in Belgium, retreating to France. A huge number of refugees encumbered by baggage carts and meagre food supplies also headed west. On May 16 the university library at Louvain went up in flames with the loss of a million items.[3]

Lemaître rushed to Charleroi, arriving on May 13 to take charge of evacuating his extended family and their servants' families to the presumed safety of France. Their race against time began on May 15. At the border only Canon Lemaître, having priority as a decorated World War I veteran, and nine of his immediate family were granted entry, the press of refugees from Belgium being so great that the authorities refused his friends and neighbours.

Lemaître had hoped the ten of them could get to Boulogne and take a boat to England but that was not to be. By May 22 German tanks had breached the front at Sedan and encircled not only the French and Belgian armies but also the British Expeditionary Force in full flight for the Dunkirk beaches. Lemaître's group, entangled by the chaos, had to abandon their trek north on May 27 when halted by a German motorcyclist. Their food was running out, and for three weeks they were reliant for their bread on the generosity of the locals.

On June 18 they took the road back to Belgium, and by the end of the month Lemaître was back in Louvain, where the university reopened to students and faculty on July 8. Classes commenced one month late, at the start of November.

Life in Louvain had become depressingly difficult because of the destruction of housing and supply infrastructure. Lambert records in a footnote an oral communication on 1998 June 25 with a former student, Émilie Fraipont, an Ursuline nun, who lauded the canon for his lively ability to anticipate students' needs.[4] His apartment door openly invited students in mathematics and physics; they were free to come and go as they pleased, fortified by mugs of hot chocolate.

Lemaître's academic contacts were rather limited. He participated in scientific meetings at the Royal Academy of Belgium and the Royal Belgian Society for astronomy, meteorology, and geophysics, but he was no longer pioneering cosmological research. His research field concerned the motion of charged particles in the geomagnetic field, and he lectured on orbital problems in advanced classical mechanics.

In 1941 October Françine Quinet, an 18-year-old resident of Thuin, a small market town to the south of

Fig. 1: A group photograph dated 1942 May 26 of Abbé Georges Lemaître with his colleagues and students. Françine Quinet is sitting at right in the front row. The location is the Collége des Prémontrés of Université catholique de Louvain, dating from 1571, when it was established as a college of theology for the training of canons for the Abbey. It became incorporated with the university in 1755. The building is currently allocated to the department of biology and the faculty of science. (UC Louvain, Archives Georges Lemaître, BE A4006 FG LEM-1421).

Charleroi, commenced her degree in mathematics at the Université catholique de Louvain (UCL), some 90 km from her place of birth (Figure 1). She was one of a dozen mathematics undergraduates admitted that year. Lemaître had been professor of physics at Louvain since 1931, and his teaching responsibilities focused on mathematical physics. The text that follows is a translation of Françine Quinet's words as recorded during the interview, conducted when she was 96, less than a year before her death.[5]

3. Françine Quinet recalls Lemaître's classes at Louvain

He lectured to us on mechanics, astronomy, and relativity. He sometimes told us about his Big Bang. He explained to us that the Universe started from an atom that had split up; it was very clear. We, his students, wondered if he was right, or if he was wrong. It was the beginning of his theory, and he was strongly criticized in its first years. But later the opposite was true, wasn't it?

3.1. *A great scientist but a poor teacher*

The students respected the scientist; but on the other hand, the teacher had his head in the clouds. Look, he was a great scientist, but a poor teacher! He did not prepare his lectures, and when he entered the auditorium, he asked us: 'What did I tell you about, the last time?' We answered him and he said: 'Okay, so today I'm going to talk to you about this and that' according to his mood, and away he went.

During a proof, he would say: 'It is easy to go from this equation to that equation: you only need to apply this theorem.'

'But we never studied this theorem,' we students would interject. 'Haven't you? Well, I'm going to explain it right now!'

And he slipped in that theory in the middle of his proof. As for us, we were by now completely lost! As he played that trick on us several times before, we had to get together and share our notes:

'Did you note this?'

'Oh no, I don't have that!'

'Look here's what I remembered, let me give you that!'

And so on.

3.2. *The dreaded exams*

Lemaître's examinations were also feared, not for their difficulty but for his forgetfulness. During one exam, he asked me a question (I forget what it was about). I thought about it over and over, but it didn't mean anything to me. What to do? So, I asked him: 'Professor, I think you never talked about this!' 'No?' he exclaimed. 'No, that's right, I always came to your class. I would have remembered that I assure you!' 'Go and get your notes,' he asked. So, I left the exam room to get my bag, and I handed him my notes. He leafed through them, informing me that they were well kept. He admitted that he must never have touched on this subject. So, he quizzed me about something else, and the exam lasted two hours. My friends were worried because the exam usually lasted half an hour. But I did well, he gave me 19/20.

3.3. *Afterwards, he would treat us to a beer!*

A great savant, and very approachable, we students greatly admired him, despite him being an absent-minded professor. Unlike the other university professors at that time, he did not mind being interrupted by students during his classes, and he chatted with them in the corridors. Georges Lemaître regularly rounded up his students for practical astronomical work, in the evening and at night.

I am sure that it actually was for his own experiments! Our astronomical calculations had to be correct. So he split us into two groups: one group worked using his calculator (it was a huge machine, rare at the time).[6] The other group worked with logarithms. At the end, we compared our calculations, and if there was the slightest difference, he swapped us around then made us start all over again. But then he would treat us to a beer!

3.4. *Lemaître's discussions with Einstein*

We students were aware and proud to meet a leading scientist with prestigious scientific friendships. He told us that he had discussions with Einstein. He was delighted with that. And we were happy for him because we had such great respect for him.

With her mathematics diploma in hand and the war over, Françine Quinet worked at Charleroi before returning to the Athénée Royal de Thuin school, where she taught for 40 years.

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2 Lambert, Dominique, *Un Atome d'Univers: la vie et l'oeuvre de Georges Lemaître* (Éditions Lessius et Éditions Racine, 2000) 215–232. A revised edition in English was published in 2016. There is an e-book available through the internet, ISBN 9788378860501, useful as an aid but best consulted in parallel with the French original.

3 The Université catholique de Louvain (UCL) Library has experienced a dramatic history. Established in the early 15th century its treasure house of rare books and manuscripts was lost to the French after the Revolution. The Great Hall of the old library was gutted in 1914 then rebuilt with American support. On 1940 May 16 British-German exchanges of artillery fire ignited a great conflagration that destroyed the building. (Source: *The Brussels Times*, 2018 December 14.) The Georges Lemaître Archives are housed in the new library at Louvain-la-Neuve.

4 Lambert, op. cit. (ref. 3), p. 218, note 8.

5 The transcript reproduced here is a translation of the oral history interview that was conducted at Françine Quinet's home by Christine Borowiak, a broadcast journalist with the French-language station Radio Télévision Belge. It was first published by RTBF www.rtbf.be/info on 2020 June 19 at 14:06 UTC. The translator was Agnès Aubert of Cambridge, who has preserved the register, vocabulary, and moods of the verbs as voiced by Madame Quinet.

6 Lemaître had several Mercedes Euklid model 29 mechanical calculators (Figure 2). These German-made devices were hand-driven and had a full numerical keyboard rather than sliders for entering numbers. Division was fully automatic. Lemaître developed a rational iteration method for solving differential equations with Mercedes calculators. Françine Quinet remembers such solutions being carried out by the undergraduates.

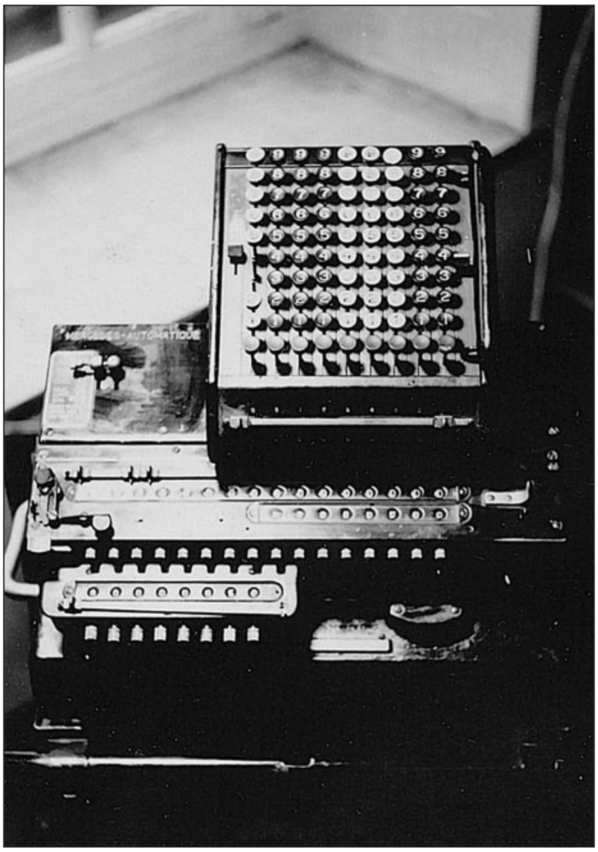

Fig. 2: A Mercedes electromechanical calculator used by Lemaître 1933–1958. He became a notable pioneer in the employment of machine calculation for the analysis of differential equations. This model could store seven numbers in memory; multiplication and division were automatic. From 1945 Lemaître became adept at programming in machine language. (UC Louvain, Archives Georges Lemaître, BE A4006 FG LEM-1270).

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Simon Mitton is a Life Fellow of St Edmund's College, Cambridge, where Lemaître resided for ten months in 1923–1924 while carrying out research in cosmology under the tutelage of Sir Arthur Eddington. Mitton's biographical research has focused on Lemaître, Fred Hoyle, George Gamow, and Ralph Alpher, but his other works include *Vera Rubin, A life* (jointly with Jacqueline Mitton) and *From Crust to Core, a chronicle of deep carbon science*, a major academic monograph on the discovery of long-term deep carbon cycle in Earth's interior. His most recent paper is *A Short History of Panspermia*.

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