The Antiquarian Astronomer

Journal of the Society for the History of Astronomy

Issue 11 **June 2017**

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On the cover:

A sundial for seafarers

The British government's Longitude Act of 1714 set off a scramble for a giddy prize: not just the financial reward of up to £20,000 (the equivalent of millions today) but the honour of becoming the first person to crack a problem of immense practical and commercial significance that had baffled all generations before, namely finding longitude at sea. In reality the method of lunar distances, in which a navigator measured the angle between the Moon and a reference star or the Sun, was always the front runner because it relied on the predictable and unvarying motions of the heavens, even though the calculations involved to turn these observations into an accurate position were onerous.

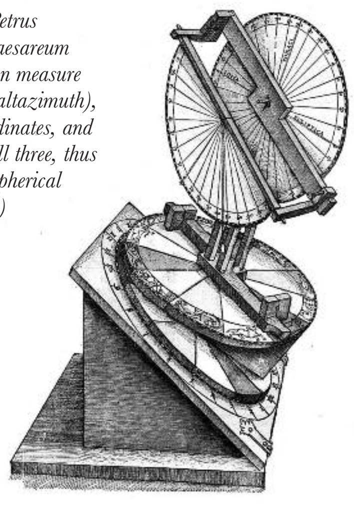
There was understandable scepticism over the leading rival scheme to produce a mechanical timepiece that would work accurately in all weathers on a heaving ship. Although in the end John Harrison succeeded brilliantly, chronometers remained expensive and hard to come by for many years, and the lunar distance method was still used on some ships until the end of the 19th century. A third idea, due to the Irish inventor Christopher Irwin, was also briefly in contention: a gimballed chair to provide a stable base from which to observe the motions of Jupiter's satellites, using them as a form of clock. This was declared unworkable after trials at sea because of the relatively high magnifications needed to see the satellites.

Apart from these scientifically plausible approaches, the lure of the Longitude Prize brought forth many weird and wonderful schemes. Some proposals seemed the fantasies of madmen, while the difficulty of obtaining a hearing from the Board of Longitude might have driven other inventors over the brink. The final plate of William Hogarth's *Rake's Progress* shows the interior of the Bedlam madhouse with an inmate sketching methods of finding longitude on a wall.

One hopeful contender for the prize that has hitherto escaped almost all attention was an intriguing portable sundial invented in the 1730s by one William Ross of Worcestershire, illustrated on the cover. Catchily dubbed the Rossipher, it owed more than a little to the medieval instrument known as a torquetum (*below*), a kind of analogue computer for measuring and converting celestial coordinates. The Rossipher, its inventor thought, would simplify many of the observations and calculations necessary for finding longitude from anywhere on Earth.

Unlike many other longitude projectors (as they were called) Ross was not mad, simply misguided. Its principles were correct, but in practice the device was far too crude to produce the accuracy necessary to earn any reward from the Board of Longitude. In this issue, David Bryden rescues the unheralded Rossipher from obscurity, and muses on its possible influence on scientific instrument making in the 18th century.

COVER: Rossipher Mechanical Equinoctial Dial, Inv. 39529. © Museum of the History of Science, University of Oxford.



A torquetum illustrated in Petrus Apianus's Astronomicum Caesareum of 1540. The instrument can measure positions in horizontal (i.e. altazimuth), equatorial, and ecliptic coordinates, and allow conversions between all three, thus simplifying calculations in spherical trigonometry. (BnF Gallica.)

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ISSN 1740–3677

From the Editor

Williamina Paton Fleming, an expatriate Scot, became a leading member of the group of female computers at Harvard College Observatory in the late 19th and early 20th centuries. The observatory's director, Edward C. Pickering, recognized the merits of women in performing the routine and repetitive tasks of cataloguing stars and classifying their spectra; also, he was able to hire more of them because they were paid less than men. Over her three decades in the observatory Fleming rose to become supervisor of the group of women computers who included such pioneers of stellar classification as Annie Cannon, Henrietta Leavitt, and Antonia Maury. In this issue, Paul Haley takes a detailed look at the career of Williamina Fleming and her contribution to the immense output of Harvard College Observatory, the forerunner of the Big Data sky surveys of today.

Human computers of another kind, in this case all men, are Carolyn Kennett's subject as she explains how it was that many of the intricate calculations for *The Nautical Almanac* in the late 18th and early 19th centuries came to be done not at Greenwich but in an obscure corner of Cornwall. The purpose of *The Nautical Almanac* was to help sailors find longitude at sea by the method of lunar distances, but many hopeful inventors proposed alternative schemes, all of varying degrees of impracticality. In this issue David Bryden examines one such scheme and its inventor, William Ross, who devised a portable sundial he named the Rossipher, now preserved at the Museum of the History of Science in Oxford and featured on our cover.

On page 33, Stephen Holmes and Charles Fitzgerald-Lombard recount the sad tale of another little-known instrument, which at the time of its construction in 1860 was one of the largest telescopes in the world: a 15-inch (0.38-m) refractor at Downside Abbey, Somerset, built by an eccentric London optician, Thomas Slater. Unfortunately, the observatory in which it was housed burned down a few years after its construction. How different might the history of English astronomy have been had it survived to produce useful work?

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 http://adsabs.harvard.edu/bib_abs.html 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 2000 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.

Williamina Fleming and the Harvard College Observatory

Paul A. Haley

Scottish-born astronomer Williamina Paton Stevens Fleming (1857–1911) worked closely for three decades with the Director of Harvard College Observatory (HCO), Edward Charles Pickering (1846–1919). Fleming performed a pivotal role in the Henry Draper Memorial project on stellar spectra and led the Harvard team of female computers, serving as the observatory's Curator of Astronomical Photographs between 1899 and 1911. This paper reviews her contribution to the growth of HCO and her leadership of Pickering's women assistants using archived correspondence, journals, annual reports, and contemporary accounts. Her mentoring role is examined particularly in regard to Annie Jump Cannon (1863–1941) who succeeded her at Harvard and further developed the Harvard spectral classification system. A new assessment of the contribution made by Fleming to the success of Pickering and the HCO is discussed.

1. From Dundee, Scotland, to Cambridge, Massachusetts

Williamina Paton Stevens was born in Dundee, Scotland, on 1857 May 15, the fifth child (of ten) of Robert Stevens (1826–64) and Mary Walker (1832–1910). She had seven brothers and two sisters but infant mortality claimed four of the boys.[1] Her father was a craftsman and early pioneer of photography in Dundee.

An accident with a railway delivery wagon early in 1864 when she was only six years old seriously crushed her left ankle. Doctors advised amputation at the knee but her father insisted they should try to save her leg. He did not live to see the results of his advice as he died in March that year.[2] For several years Mina (as she was usually called) needed a steel-reinforced leather boot for support.

At the age of 10 Mina was diagnosed with a heart weakness and spent a year in Woodside, a children's hospital. During this time she learned the value of appreciating small gifts and resolved to be kind towards children in similar difficult circumstances.[3]

She became a student teacher at age 14, thereby avoiding employment at the jute mills and marmalade factories in the city.[4] By the time of her marriage in 1877 May to James Orr Fleming (1841–1900), a widower from Paisley with a career in merchant banking, her older brother Robert was planning his emigration to America. He was followed in due course by most members of the Stevens family; only her married older sister Mary would remain in Scotland.

Mina's marriage seemingly came under strain after the traumatic loss of a first son. In 1878 December she boarded a steamer to Boston, Massachusetts, following in her brother's footsteps. A month later she conceived for the second time and was three months pregnant by the time of Robert's April wedding in Cambridge.[5] Although the record is not clear, it seems that her husband left her, went to live in New York, and remarried.

Around this time Mina worked as a housemaid for Edward and Lizzie Pickering and part-time at HCO. She then returned to the family home in Dundee where her son was born on 1879 October 6. She named him Edward Charles Pickering Fleming.[6] Mina remained in Dundee for 18 months before sailing again to Boston in 1881 April, leaving her son in the care of her mother; it would be over six years before they would follow her.

Edward Charles Pickering (1846–1919) came from a distinguished New England family based in Boston. During his twenties he developed the first instructional laboratory in physics at the Massachusetts Institute of Technology (MIT). In 1870 he was experimenting with sound telegraphy and accompanied Joseph Winlock (1826–75), the third director of HCO, to Spain for the December solar eclipse.

In 1874 Pickering married Lizzie Wadsworth Sparks (1849–1906), the daughter of historian and former Harvard University President Jared Sparks (1789–1866); they had no children. Winlock died in 1875 June and Edward Pickering was appointed the fourth director of HCO in 1877 February at a salary of $3400 (equivalent to about £61,000 today).[7,8]

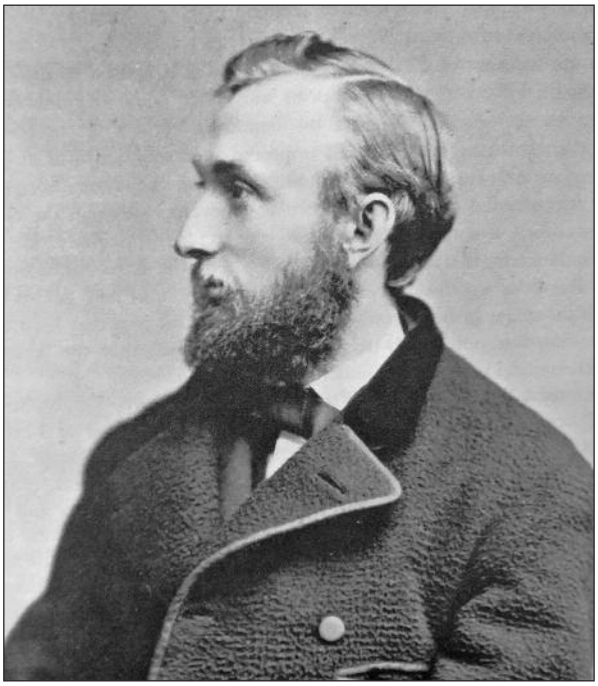
 

Fig. 1: Williamina Fleming, seen here around 1895 when she would have been aged 38, became the leading female astronomer at Harvard College Observatory (HCO) in the late 19th and early 20th centuries. Edward Pickering, seen here around 1880 when he would have been aged 34, was the fourth Director of HCO from 1877 to 1919. (Institute of Astronomy, University of Cambridge)

2. Harvard College Observatory in 1877

Harvard College Observatory was established in 1839. In 1845 it moved to a new site and two years later mounted a 0.38-m refractor by Merz and Mahler (a twin of the one in Pulkowa Observatory) in the Sears Tower, courtesy of the citizens of Boston who raised \$25,730 (*c.* £460,000 today).[9]

The initial director of HCO, William Cranch Bond (1789–1859), facilitated the first daguerreotype image of a star (Vega) in 1850. Seven years later, using collodion plates and an improved driving clock, his son George Phillips Bond (1825–65), later to become the second HCO director, made a photographic study of Mizar and Alcor. He reflected: 'On some lofty mountain and in a purer atmosphere we might, with the same telescope, include the 8th magnitude ... measure the relative magnitudes of the stars ... distances and angles of position of double stars ... as exact as the best micrometrical work.'[10]

Winlock succeeded the Bonds but did not continue with stellar photography. Instead, American interest in astrophotography was taken up by Lewis Morris Rutherford (1816–92) and Henry Draper (1837–82). The work of the latter became inextricably linked with HCO after the arrival of Edward Pickering as its fourth director.

2.1. *Harvard astronomers*

When Pickering took up his post in 1877 February there were four astronomers under his direction. Arthur Searle (1837–1920) had begun in 1868 and was temporary director after Winlock. William Augustus Rogers (1832–98) started in 1870. Leonard Waldo (1853–1929) and Joseph F. McCormack (1854–80) were also assistants. By 1880 Pickering had recruited Winslow Upton (1853–1914), Oliver Clinton Wendell (1845–1912), and John Rayner Edmands (1850–1910).

Observatory income consisted of \$175,000 from endowments and \$14,000 from sale of a time service (*c.* £3.4 million total today). At this time a copyist or computing assistant could be hired for \$500 per year or 25 cents per hour (*c.* £9000/year today).[11]

HCO policy had changed in 1875 to admit women staff and three were appointed to assist Rogers; these included his wife and also the eldest daughter of the deceased director, Anna Winlock (1857–1904), who was an excellent mathematician. A fourth computer for Rogers began in 1879: Selina Cranch Bond (1831–1920), the daughter of the first director of HCO, who would give loyal service for 27 years.

2.2. *Instruments and observing programmes*

To accompany the 0.38-m equatorial Winlock ordered a 0.20-m meridian circle from Troughton & Simms which was installed in 1870. The 'great refractor' was essentially a visual instrument occupied in photometric observations of the newly discovered Martian moons and the satellites of Jupiter and Saturn. HCO had responsibility for helping revise F. W. Argelander's *Bonner Durchmusterung*.[12] This involved measuring positions with the meridian circle for all stars to 9th magnitude in one northern zone (50–55°) which was the primary responsibility of Rogers and his team of computers.

Table 1: Female assistants at Harvard College Observatory 1875–1911

No.	Name	Dates	Yrs.	Notes
1	Mrs R. T. Rogers	1875–98	23	Wife of William A. Rogers
2	Miss Rhoda G. Saunders	1875–88	12	
3	Miss Anna Winlock	1875–1903	28	(1857–1904) Mathematician. Daughter of Joseph Winlock
4	Miss Selina Cranch Bond	1879–1906	27	(1831–1920) Daughter of W. C. Bond and sister of G. P. Bond
5	Miss Nettie A. Farrar	1881–86	5	Married and moved to Texas
6	Mrs Williamina P. Fleming	1881–1911	30	(1857–1911) Named her son Edward Charles Pickering Fleming
7	Miss Louisa Winlock	1886–1915	29	(1860–1916) Daughter of Joseph Winlock, sister of Anna
8	Miss R. W. Gifford	1886–88	2	Brother assisted Willard P. Gerrish
9	Miss Louisa D.Wells	1887–1933	46	'Tiny and vehement' [CPG]
10	Miss Annie E. Masters	1887–89	2	Former teacher and book-keeper
11	Miss Jennie T. Rugg	1887–89	2	
12	Miss Nellie C. Storin	1887–96	9	
13	Miss Antonia Maury	1888–1933	Part time	(1866–1952) Niece of Henry Draper. BA Vassar, 1887. 'A dreamer … denouncing injustice' [CPG]
14	Miss Florence Cushman	1888–1937	49	(1860–1940) 'A dignified galleon of a woman' [CPG]
15	Miss Mabel C. Stevens	1888–1906	18	Took Radcliffe entrance exam, but insufficient finances
16	Miss Edith F. Gill	1889–?	31+	Sister Mabel joined three years later. 'Hover in the background' [CPG]
17	Miss Lillian L. Hodgdon	1889–1939	50	'Voluble strutting hen' [CPG]
18	Miss Evelyn F. Leland	1889–1925	36	(c.1870–1930)
19	Mrs Imogen Willis Eddy	1889–1904	15	(?–1904) Died in fall from elevator. Two years' work for B. A. Gould
20	Miss Amy Jackson McKay	1891–1907	16	(?–1907) Died after 6-month illness
21	Miss Harriet I. Stevens	1891–1910	19	
22	Miss Mabel A. Gill	1892–?	28+	Sister of Edith. 'Quiet … always busy' [CPG]
23	Miss E. Gertrude Wolfe	1893–99	6	Retired with eyesight problem
24	Miss Ida E. Woods	1893–?	27+	'A stickler for protocol … a sense of being slightly superior' [CPG]
25	Miss Annie Jump Cannon	1896–1940	47	(1863–1941) BA Wellesley 1878, MA 1907
26	Miss S. J. Hall	1897–1900	3	Became Mrs Bonesteele in 1898
27	Miss Sarah E. Breslin	1898–1912	14	
28	Miss Darsie C. Bard	1899–1900	1	
29	Miss Maude E. Harriman	1900–05	5	
30	Miss Marion F. Michaelis	1900–06	6	
31	Miss Henrietta Swan Leavitt	1902–21	19	(1868–1921) Volunteer in 1895. BA Radcliffe, 1892
32	Mrs Johanna C. S. Mackie	1903–20	17	(1860–1943) Mina's sister
33	Miss Katherine Searle	1904–12	8	Related to Arthur Searle. BA Radcliffe, 1901
34	Miss Ida May Stevens	1904–09	5	(1882–?) Mina and Johanna's niece. Became Mrs Garret in 1907
35	Miss Grace R. Brooks	1906–20	14	
36	Miss Alta M. Carpenter	1906–20	14	
37	Miss Mollie E. O'Reilly	1906–18	12	Became Mrs Sloan in 1918
38	Miss Arville D. Walker	1906–?	14+	'Billy'
39	Miss Mary E. Howe	1907–09	2	
40	Miss Margaret Harwood	1907–12	5	(1885–1979) 6 months/year. BA Radcliffe, 1907. Became first director of Maria Mitchell Observatory in 1912
41	Miss Ruth C. Waterbury	1907–10	3	
42	Miss Marion C. Whyte	1911–13	2	

This table omits women who spent < 1 year at HCO, e.g. Mary Wagner (1893 September–December).

[CPG] = Cecilia Payne-Gaposchkin (1900–1979) who began working at HCO in 1927. Quotes about some female computers are from her autobiography, published by CUP in 1984.

In Pickering's first *Annual Report* (1877) an appendix describes the work of other American observatories with the conclusion that work on photometry was unexplored territory and the resolution 'to determine the brightness of all the heavenly bodies, so that all may be compared with a single standard.'[13] Local instrument makers Alvan Clark & Sons were recruited by Pickering to construct a 40-mm f/20 meridian photometer. During 1878 over a dozen photometer designs were tested on the 0.38-m equatorial by Pickering, Searle, and Upton, while Rogers was completing his observations of some 8000 zone stars with the meridian circle.

2.3. *Pickering's early success*
To keep HCO telescopes fully employed Pickering initiated a public subscription funding scheme to raise \$5000 a year (*c.* £90,000 a year today) for 5 years.[14] At this stage he estimated the total value of HCO to be around \$300,000 (*c.* £5.4 million today).[15]

During 1879 various maintenance tasks were completed including repairs to the large dome shutters and decoration of the East Computing Room for the female assistants.[16] A survey of planetary nebulae using a double-image micrometer and direct-vision spectroscope with the 0.38-m refractor was accompanied by a visual survey of spectra with a 0.10-m refractor to identify stars with bright lines.[17]

Observations of 4260 stars with the 40-mm meridian photometer occupied Pickering for typically four hours on clear nights using a polarization method visually to compare two stars. The *Harvard Photometry* catalogue (HP) containing the results of these observations would be published in 1884 (Harvard *Annals* vol. XIV), earning him his first RAS Gold Medal two years later.[18]

3. The sixth female assistant at HCO

Four female computers were fully occupied by Rogers on reduction of his zone observations. In 1881 first Nettie Farrar and then Mina Fleming began at HCO.[19] Their initial work involved copying and computing tasks for Volume XIII of the Harvard *Annals* and publication of Winlock's micrometric measures with the 0.38-m refractor.

Ladies were not allowed to use the telescopes at night, but a daytime opportunity arose in 1882 December when the transit of Venus was observed through thin cloud. It was likely that the lady computers were invited to view the transit through at least one of the six telescopes in operation while the male observers were busy recording contact times.[20]

Farrar and Fleming had started working on the first part of Volume XIV of the *Annals*, supplying copy for the *Harvard Photometry* catalogue to the printers regularly throughout 1883. Edmands assumed responsibility for the HCO Library at this time and would have supported them.

During 1884 Mina moved on to Part II of Volume XIV which included a literature review from old catalogues, going back to Ptolemy and Herschel; this work included discussion of sources of error, which would have given her a better understanding of the nature and requirements of astronomical research. Pickering was clearly pleased with the speed and accuracy of her work on the *Annals*.

3.1. *The influence of Henry and Anna Draper*
In 1867 Henry Draper, a physician and professor of chemistry, married Mary Anna Palmer (1839–1914). In 1874 she inherited significant wealth from her father's real-estate business. For 15 years the Drapers collaborated on observations, photography, and laboratory work. In 1872 they succeeded in capturing the spectrum of Vega showing four absorption lines through a 0.70-m reflecting telescope with a quartz prism and wet plates.[21]

By 1880 the Drapers were using dry plates for their photographic work with a 0.28-m Clark refractor, and in 1881 March recorded an image of the Orion Nebula. However, in 1882 November Henry Draper died from double pleurisy.[22]

Five days before his early demise the Drapers hosted a dinner party at their New York mansion for 40 leading scientists and friends. Pickering used the opportunity to encourage Draper to publish his work on stellar spectra, offering the services of HCO to assist in their measurement and reduction. This offer was repeated in 1883 January by letter to his widow.[23]

Mrs Draper visited HCO in February, bringing with her 21 plates containing tiny stellar spectra 6 mm long. These were measured by Pickering who then presented the results to the American Academy of Arts and Sciences in April.[24]

3.2. *Early experiments on stellar photography*
In 1882 Pickering secured \$500 funding (*c.* £9000 today) for a method to estimate the brightness of stars using stellar photography.[25] His younger brother, William Henry Pickering (1858–1938) from MIT, began photographic tests with a 0.17-m f/5 portrait lens in December that year; 462 stars to 9th magnitude were recorded but the star images proved large and distorted.

Improved results using a 50-mm f/3.5 Voigtländer lens in a driven 30-minute exposure revealed stars of 8th magnitude in a region 15° square. These Harvard experiments began just a month after David Gill (1843–1914) and Edward Haggar Allis (1849–1911) succeeded in imaging comet C/1882 R1 with a 63-mm f/4.5 doublet lens in driven exposures of 30 to 140 minutes.[26]

3.3. *Pickering in Europe in 1883*
After six years' work at HCO Edward and Lizzie Pickering sailed to Europe in the summer of 1883 for their first vacation. Pickering visited many of the main European observatories, delivered a key presentation to the RAS in London, and examined catalogues produced by Sir William Herschel (1738–1822).[27]

It seems probable that his extensive tour of European observatories was partly intended to review equipment and techniques in each country and partly to gauge the strength of the competition.[28] At the June RAS meeting Pickering, newly appointed as a Foreign Associate, presented a seminal paper: *On the determination of the light and colour of the Stars by Photography*.[29]

In this, many key aspects of the future Harvard approach were outlined: comparing modern photometric catalogues with historical records; imaging large fields on a single plate; capturing three types of image (star dots, trails, and spectra) in a time-efficient manner; preparing a series of photographic maps of the whole heavens to identify new stars; and investigating the colour of stars using plate sensitivity. Responding to a question from the Astronomer Royal, William Christie (1845–1922), Pickering showed a photograph of stellar spectra but chose not to reveal further details.[30]

4. Funding developments and 'some plan of cooperation'

Securing new sources of funding was now essential for HCO. The 5-year subscription fund had ended and declining interest rates were undermining endowment returns. During 1884 five male assistants were made redundant, effectively ending the visual study of spectra.

Pickering and Wendell began testing a new 100-mm meridian photometer which would extend the work of the first Harvard Photometry. In spring of 1885 a second series of stellar photography tests began using a 60-mm 30° objective prism. With this, 100 spectra were imaged on a single plate to 8th magnitude in a 1-hour exposure.[31]

Following the death of her husband, Anna Palmer Draper initially planned to hire two assistants to continue their spectral work at the Hastings Observatory, New York. Pickering suggested several possible recruits but inwardly hoped that HCO at Cambridge might continue in some way the Drapers' pioneering approach.

In 1885 May Pickering explained his plans for 'a somewhat extensive piece of work in stellar photography ... I wish to ask if you would not like to enter upon some plan of cooperation by which Dr. Draper's name should be associated with the work ... maps of the heavens from which the position, brightness variability and (indirectly) the colour of the stars could be determined'.[32] Agreement in 1886 February on a joint venture heralded a major new direction for HCO for decades to come and created an unexpected opportunity for the sixth female assistant at Harvard, Mina Fleming.[33]

4.1. *The 0.20-m Bache astrograph*

By 1885 June Pickering had secured a $300 grant from the Rumford Fund and $2000 from the Bache Fund (total *c.* £41,000 today) to extend his photographic investigations. A Voigtländer doublet (Petzval) lens of 0.20 m aperture was refigured by the Clarks to produce an f/5.6 astrograph and was mounted equatorially (Fig. 2).

The brass lens cell was fixed in a steel tube mounted in trunnions on a large fork with a clockwork drive. It was erected in a transit shed with a 0.60-m slit allowing plates to be taken for up to 40 minutes across the meridian. The plate scale of 1° per 2 cm gave coverage of 12° in declination and 10° in right ascension. This scale matched exactly the *Bonner Durchmusterung* (BD) charts; when enlarged three times they matched the scale of 1 arc-minute per millimetre used by Peters and Chacornac for their ecliptic charts.[34]

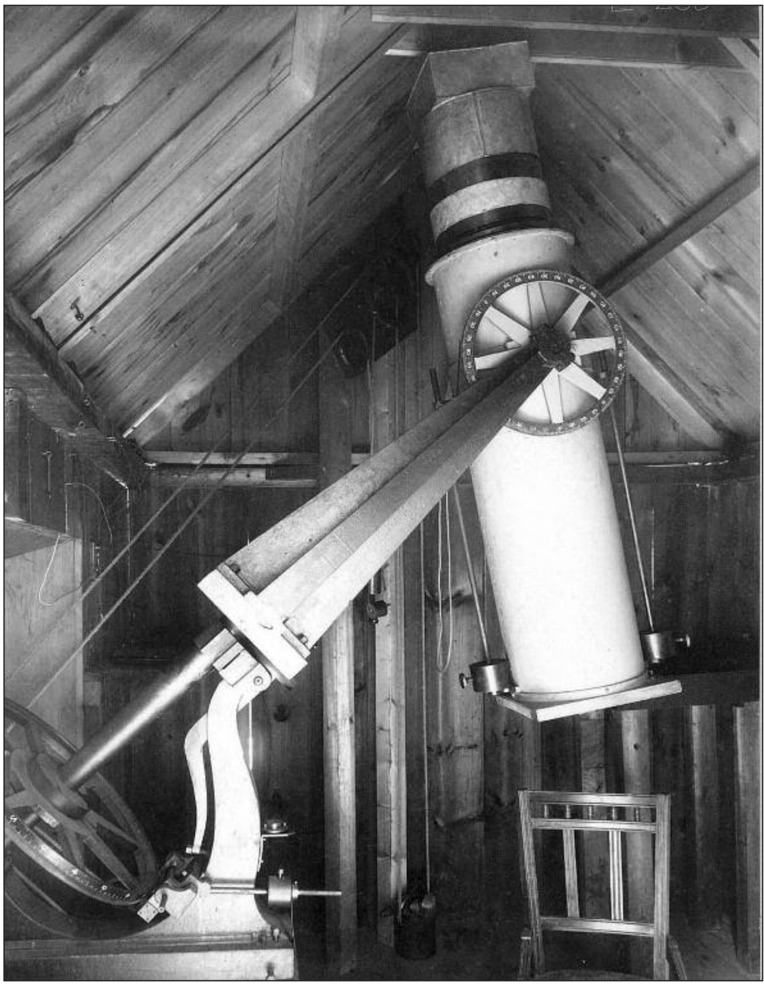


Fig. 2: The 0.20-m f/5.6 Bache astrograph was first used at Cambridge in 1885. After three years it was moved to Colorado for site testing and then Chosica in Peru, before being installed at Arequipa in 1890. (UAV 630.271, (8), E230, Harvard University Archives)

Pickering devised three types of work: star trails; driven exposures for charts; and spectral study. Experiments showed that 30-minute star trails reached 14th magnitude near the pole but only 8th magnitude at the celestial equator.

Photographic magnitudes were determined for 117 stars within 1° of the pole by Nettie Farrar; only 38 stars were listed in the BD for this region. The nebulosity around Maia in the Pleiades, detected by the Henry brothers in Paris in mid-November, was subsequently found on a plate taken a fortnight earlier in Cambridge. An investigation of the spectra of members of the Pleiades began in 1886 January.[35]

Pickering calculated that the Bache astrograph could produce 2000 plates annually, if operated for ten hours per night and four nights per week. He further reasoned that with two such astrographs in different hemispheres, and utilizing only the central 5° square region of each plate, mapping the whole sky in a single year would be possible with 1600 plates.[36]

With the imminent arrival of support from Mrs Draper it was now possible for him to believe he could chart the heavens with a veritable army of instruments: photometer, astrograph, and spectroscope. However the data generated by these surveys would be unprecedented and a team of computers would be essential.

4.2. *The Henry Draper Memorial (HDM)*

Anna Palmer Draper agreed to support a photographic study of stellar spectra at HCO as a memorial to her husband. Initially this involved a $1000 gift and $200 per month (*c.* £18,000 and *c.* £3600 a month today).[37]

Willard Peabody Gerrish (1866–1937) was recruited in 1886 February to begin taking plates.[38] A cottage was later refurbished as a darkroom, with the three-times enlarged copies transferred to the HCO computing rooms and mounted for daylight illumination. Stars were identified by comparison with the *Bonn Atlas*, and stellar spectral lines were compared with the solar spectrum.

Mrs Draper donated her 0.28-m f/14 Clark refractor with corrector lens for photographic use in 1886. A year later this was followed by the other Draper instruments, a 0.38-m mirror and a 0.70-m f/5 reflector. New mountings were constructed by George Bassett Clark (1827–91) and they were mounted in two wooden observatories with 6-m domes where they were used for taking photographic spectra of bright and faint stars respectively.

The mean dispersion achieved with HCO instruments varied from 300 Å/mm for the Bache astrograph fitted with a 13° prism to 45 Å/mm with a 15° prism on the Clark refractor; the addition of three similar prisms increased the dispersion to 11 Å/mm for first- and second-magnitude stars.[39] The Bache astrograph produced spectra 1 mm wide by introducing a driving clock error of 12 seconds in either a 5-minute or 1-hour exposure for 6th- or 8th-magnitude stars respectively.[40]

The primary aim of the HDM project was to produce a catalogue of spectra of bright stars of the entire sky visible from Cambridge north of −24° declination. On each plate three or four exposures of 5 minutes were taken of areas 10° square; typically 40 spectra of 6–12 mm length and 1 mm width could be classified, except in the case of red stars which appeared fainter. By 1887 March Pickering was able to report that 308 plates had been measured and 11,287 spectra identified; 99 plates exposed for 1 hour revealed 2974 spectra. In all 15,729 spectra were obtained with the Bache astrograph in the first nine months.[41]

4.3. *A new challenge for Mina Fleming*

In 1886 October Pickering informed Mrs Draper of the successful mounting of the 0.28-m Clark refractor and the expenditure to date on the Draper Memorial Fund.[42] At this stage 137 Bache plates of 5 minutes exposure and 87 of 60 minutes exposure had been taken. One hundred and ninety plates had been measured and 6769 spectra recorded; about 3000 stars had been identified and their names entered opposite each.

Pickering explained: 'Mr. Gerrish attends to the photographic work and receives $50/month ... Miss Farrar measures the photographic plates at 30 cents/hour. Miss Winlock copies and computes at 25 cents/hour.'[43] Louisa Winlock had become the seventh female computer at HCO, joining her sister on the staff; later she was joined by Miss R. W. Gifford whose brother supported Gerrish during each clear night. Mrs Draper was effectively now funding an increasing number of HCO assistants for the HDM catalogue.

At the end of the year Pickering informed her: 'Miss Farrar who has measured all the plates until recently, is about to get married ... she is now instructing Mrs. Fleming who has assisted me, and who will I think take her place satisfactorily.'[44]

In practice Mina had already shown an aptitude for examining the Bache plates. Earlier in the year she had made the important discovery of two Wolf–Rayet (WR) stars after noticing bright lines in a couple of faint spectra on a plate taken of the Cygnus region.[45] At this time there were 13 known WR stars of which three had been found visually by Pickering five years earlier. Mina's discovery was reported in *Nature* in 1886 September.[46]

At the end of 1886 Mina became responsible for the examination, physical care, classification, and indexing of thousands of glass plates. For the next 25 years she made herself indispensable to the success of HCO and gained an international reputation for her astronomical work.

5. Expansion of HCO

Having struggled to find sufficient funding for many years Edward Pickering gained control of two new bequests in 1887. One of these, the $230,000 Boyden Fund (over £4 million today), was for the establishment of an astronomical observatory on a mountain peak.[47] The 0.33-m f/14 Boyden refractor made by the Clarks included a reversible crown lens to enable both visual and photographic work. The other, the $300,000 Paine legacy (*c.* £5.4 million today), covered the Paine Professorship of Practical Astronomy chair that was held by Pickering and also routine HCO expenses.[48] Mrs Draper had also increased her contribution fourfold to $10,000 per annum (*c.* £180,000 today) for the Henry Draper Memorial.

Optimistically Pickering also advertised in 1888 November for a $50,000 (*c.* £900,000 today) donation to construct a much larger photographic telescope. His plan for a 0.60-m f/5.5 instrument with a 4-element objective capable of reaching 16th magnitude became a reality 5 years later.

Additional staffing expanded the productivity of HCO. In 1887 William Pickering transferred from MIT to lead the new Boyden Department. Edward Skinner

King (1861–1931) graduated from Hamilton College, New York, and joined the HCO team; he soon began supervising the photographic work at Cambridge. The third new astronomer was Solon Irving Bailey (1854–1931) who would play a major role in establishing the Boyden Station in the southern hemisphere. Four women computers were also recruited by Pickering in 1887. Of these, Louisa Wells worked at HCO for 46 years.

5.1. *The search for a mountain site*

In 1876 Edward Pickering supported the formation of the Appalachian Mountain Club. Both his brother William and John Edmands shared this adventurous spirit and an 1887 summer expedition by them all to 4300-m Pike's Peak in Colorado was organized. Site-testing included meteorological surveys together with assessment of the atmospheric seeing and transparency, for which a 0.30-m refractor was used.

A second exploratory trip the following year included both the Bache astrograph and the Boyden refractor. More sites in Colorado were tested together with California where they photographed the solar eclipse in 1889 January. The group then split up. William Pickering took the Boyden refractor to Mount Wilson while Solon Bailey and his family travelled much farther south to Peru and Chile on a two-year expedition with the Bache astrograph.

A mountain site at 2027 m was selected north of Chosica, Peru. In four months 1200 plates were taken with the Bache astrograph, extending the photographic and spectral surveys to the south celestial pole. While his brother Marshall completed the photographic work, Solon Bailey used Pickering's 100-mm meridian photometer to make 26,000 measures of the brightness of 6700 southern stars.

During the cloudy months of 1889 September and October the brothers investigated other potential sites, eventually deciding that one near Arequipa offered the best opportunities for the southern hemisphere Boyden Station. Arequipa was a small town surrounded by desert near the extinct volcano El Misti; the site was at 2457 m elevation and latitude 16° 24′ south.[49] The Boyden Station in Peru would operate for 36 years and be of immediate use to Pickering for the Harvard photographic map of the heavens.

5.2. *The Carte du Ciel*

Development of the Carte du Ciel, including the contributions of David Gill at the Cape of Good Hope and Amédée Ernest Barthélemy Mouchez (1821–92) at Paris Observatory, has previously been described by the author.[50] Edward Pickering did not take up the invitation from the French Academy of Sciences to attend the first International Astrophotographic Congress held in 1887 April at which the Carte du Ciel project was discussed.[51] But he did offer several recommendations based on the experience at HCO, and he offered to help with the photometric results.

In choosing not to attend the Paris Congress Pickering neatly avoided the vast majority of pitfalls that subsequently undermined the Carte du Ciel project. His decision was justified by the absence of direct government funding to American observatories; the Harvard Corporation were already managing several large bequests for astrophotography and Pickering was planning to upgrade to a 0.60-m f/5.5 instrument.

He would not have known that the Government of the French Republic had already chosen to commission the 0.33-m f/10 astrograph design for the Carte du Ciel which would effectively limit the photographic fields to 2° square, whereas he preferred a 5° field. However he would have suspected that Gill would push for observatories to produce a catalogue and not just a chart of the heavens, as was indeed the case.[52]

By this time HCO had the largest team of computers in the world and Pickering intended to keep them focused on measurements for photometry and spectroscopy, enabling the history of the heavens to be captured. Distractions like the Astrophotographic Catalogue were simply not relevant.

So as Pickering began his Colorado expedition he knew the Carte du Ciel would not involve HCO and he was free to keep to his planned investigations, no doubt a huge relief. Meanwhile back in Cambridge Mina's long wait was nearing an end: in 1887 September a boy of nearly 8 years of age crossed the Atlantic with his grandmother to join his mother in Massachusetts.[53]

6. The many roles of Mina Fleming

Mina was aged 29 and had worked at HCO for nearly six years when she took responsibility for the Draper Memorial Catalogue.[54] Initially she reviewed the existing methods of spectral classification for her analysis of the Bache plates. Pickering valued her efficiency in preparing HCO publications and chose to significantly consolidate her role in this respect.

Pickering was keen to promote HCO as a clearing-house for observational data and expansion of the number of women computers was essential to handle the increasing number of plates. Mina assumed responsibility for recruiting the majority of suitable candidates from 1888 onwards, achieving an impressive team of loyal workers many of whom would remain at HCO for decades.

Training, monitoring and planning their work schedules became a routine task. She devised a Form of Records to explain the format and expectations of clerical work required for the record-books; accuracy, speed, and legibility were essential requirements. In practice all female assistants now reported to Mina who ensured that the correct etiquette, efficiency, and discipline were maintained.

Analysis of the glass plates enabled women computers to become observers without needing to work at

Fig. 3: Women computers often worked in pairs. Here, Mabel Stevens records nebula positions in Orion measured by Mina Fleming (right). Each plate was laid on a frame tilted at 45°, and light reflected through it by a horizontal mirror. Each portion of the plate was studied with a magnifying glass, and the coordinates of objects measured by a T-square. (W289693_1, Harvard University Archives)

night in an observatory. All employees were given one month vacation per year; August was usually the least productive month due to high humidity in the summer. The women's working environment included 'two, light, pleasant rooms ... convenient writing-tables, shelves of notebooks, astronomical catalogues and reports, with their walls hung with star maps and portraits of noted astronomers ... magnifying glasses, frames for holding the plates ... [nearby] wooden boxes containing the brittle though perishable glass plates.'[55] A musical, the Observatory Pinafore, written by Winslow Upton in 1879, provides an alternative earlier (male) insight into HCO culture and expectations.[56]

Pickering had no deputy to share his workload and increasingly relied on Mina to act in a secretarial role for correspondence; this would extend to his discussions with HCO astronomers whose work also needed to be published in the *Annals*. As the number of Bache plates rapidly increased Mina developed an efficient storage and retrieval system.

In time she would prepare papers for astronomical conferences, support HCO workshops, and develop a strong mentoring approach for her successors. Despite all of these roles demanding attention Mina maintained her ability to discover a whole host of significant astronomical objects, from variable stars to gaseous nebula, from novae to Wolf–Rayet stars, and from near-Earth asteroids to stars with peculiar spectra.

6.1. *Spectral classification at Harvard*

At the Collegio Romano observatory, Angelo Secchi (1818–78) had used a 0.16-m flint glass objective prism of 12° refracting angle with the 0.24-m Merz refractor to conduct his 15-year visual study of the spectra of 4000 bright stars. By 1868 his classification scheme included four classes: Type I included white and blue stars of the Sirius type with hydrogen absorption lines; Type II stars were slightly coloured with a solar-type spectrum; Type III were orange to red stars of the Betelgeuse type showing banded spectra, including many long-period variables; Type IV were red stars with absorption bands separated by bright spaces, the carbon stars.[57]

Pickering had adopted the objective prism instrument at HCO so it was natural that he should further develop Secchi's system. Type V stars were announced in 1891 and included WR spectra with bright lines and planetary nebulae. Type VI stars followed in 1908, with absorption bands accompanying shorter blue wavelengths.[58]

Mina was assigned several tasks. These involved:

1. Classifying and describing 28,266 spectra, representing 10,351 stars to 7th magnitude north of declination −25°, photographed on 633 Bache plates each measuring 20 × 25 cm;
2. Estimating the photographic stellar magnitudes by measurement of the photographic density around 432 nm using a shaded glass wedge;

3. Recording the shortest-wavelength hydrogen line visible, estimating the strength of the calcium absorption line, and the presence or absence in the spectrograms of the F line (Hβ) at the long-wavelength cutoff;
4. Identifying the coordinates of each spectrum using a stand and also by overlaying the plate on the *Durchmusterung*, followed by calculating the star's position for epoch 1900;
5. Applying corrections for declination, plate sensitivity, transparency of atmosphere, and driving clock irregularities, using the *Harvard Photometry* catalogue as a reference.

Each plate included up to four regions 10° square with any given star recorded on at least four photographs. Plates were placed on a stand and illuminated with natural light reflected by a mirror (Fig. 3). As the work progressed, Mina enlarged the four Secchi spectral types into 13 groups, adding group O for WR stars with bright lines, P for planetary nebulae, and Q for those not classified by A to P.[59]

6.2. *New colleagues and more discoveries*

Fortunately Mina was able to enlist the support of many additional colleagues for numerical computations and clerical work, notably Louisa Winlock, Louisa Wells, Florence Cushman, Mabel Stevens, Edith Gill, Lillian Hodgdon, Evelyn Leland, and Imogen Eddy.[60] Pickering approved of Mina recruiting her team but reserved the right to add his own personnel.

His excellent links with nearby women's colleges resulted in three famous recruits. Antonia Caetano Maury (1866–1952) was trained by Maria Mitchell (1818–89) at Vassar College and graduated in 1887; Annie Jump Cannon (1863–1941) was trained by Sarah Frances Whiting (1846–1927) at Wellesley College and graduated in 1884; and Henrietta Swan Leavitt (1868–1921) graduated from Radcliffe College in 1892.[61]

Maury, the niece of Henry Draper, was appointed as the 13th female computer in 1888 June. Her task was to study in detail the spectra of bright northern stars imaged by the 0.28-m Draper refractor. Spectrograms from this instrument were capable of enlargement to 60×10 cm and for Sirius revealed over 500 faint lines.

In 1887 March a plate taken of ζ Ursae Majoris had shown a doubling of the calcium K line. By 1889 January this periodic doubling had been investigated by Maury; Pickering announced the discovery of Mizar as the first spectroscopic binary the following November. Maury then found a similar pattern in β Aurigae spectra, but although credited by Pickering she felt her work deserved greater recognition.[62]

She devised a more complex spectral classification system of 22 groups with Roman numerals and a/b/c categories. Her detailed study of the width and sharpness of spectral lines slowed the work significantly and delegating tasks to other assistants proved impossible.[63] Between 1891–93 she left HCO for a teaching post and a further absence in 1895 involved a trip to Europe; final publication in HCO *Annals* XXVIII came in 1897, some nine years after Maury started.[64]

Between 1888 and 1890 an impressive series of discoveries flowed from HCO, with Mina Fleming central to most of them. Plate B2312 involved a 90-minute exposure with the Bache astrograph, taken in 1888 February by William Pickering. Careful inspection by Mina noted 'a semicircular indentation 5′ in diameter 30′ south of Zeta [Orionis]' – she had discovered the now-famous Horsehead Nebula (Fig. 6).[65]

Fig. 4: Examples of stellar spectra, from the First Annual Report of the Henry Draper Memorial, published in 1887 March: (1) 4-mm Draper spectrum of Vega, 5-minute exposure with a 50-mm f/3.5 Voigtländer lens and 30° prism in 1882; (2) 9-mm Harvard spectrum of Mizar and Alcor, 5-minute exposure with 0.20-m f/5.6 Bache astrograph, showing the typical scale of images examined by Mina Fleming; (3) 50-mm spectrum of Vega, taken in 59 minutes with 0.28-m Clark refractor with 2 prisms in 1886 November; Antonia Maury had responsibility for investigating the spectra of the bright northern stars; (4) 80-mm spectrum of Pollux, 50-minute exposure with 0.28-m Clark refractor using four prisms in 1887 January.

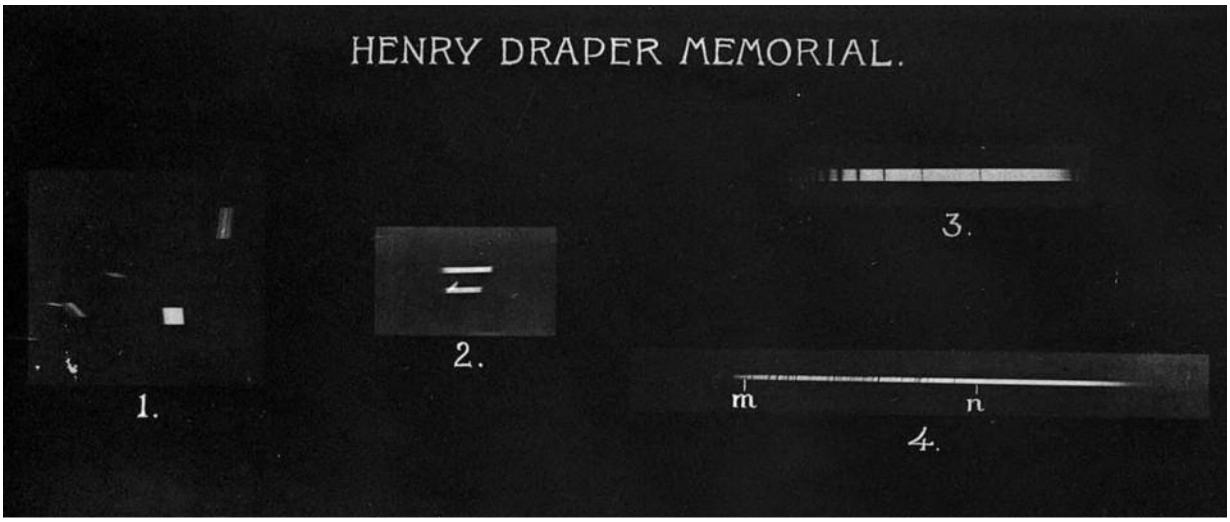


Fig. 5: Mrs Draper funded the Henry Draper Memorial project. This 1891 group includes Mina (standing, right) showing her some plate journals. The other female assistants pictured are, from left, Florence Cushman, Imogen Eddy (seated), Louisa Winlock, and Mabel Stevens. The cramped conditions in which the women worked became apparent to Mrs Draper during her visit. (W289692_1)

Pickering was keen to estimate the number of nebulae that might be discovered photographically. As a trial, he selected the region around the Orion Nebula from RA 5h 10m to 5h 50m and declination −10° to +5°. Mina's careful scrutiny of this area, 0.4% of the whole sky, resulted in a table containing 27 nebulae. Based on this investigation Pickering estimated that 4000 to 5000 nebulae might be discovered using 400 plates.[66]

Plates 2185 and 642 were used as standards in a lengthy investigation into the photographic determination of the brightness of stars.[67] In addition to star trails of the Hyades, Mina also examined 1000 stars to 15th magnitude within 1° of the north celestial pole. For this, ten series of plates photographed between 1885 August and 1888 March by the Bache astrograph, the 0.28-m Draper refractor, and the 0.33-m Boyden refractor were investigated, with 20 stars chosen as standards.

A study of stars in and around the Pleiades involved eight plates taken between 1885 November and 1888 February. For this work Mina collaborated with William Pickering and Edward King in a review of the excellent images photographed by the Henry brothers and the earlier astrometric study by Charles Wolf (1827–1918) at Paris Observatory.[68] Bright equatorial star trails also formed a significant element of this study. Star magnitudes from the *Harvard Photometry* were compared with intensity values from photographic images. Pickering postponed his final conclusions until after photometric values for fainter stars became available; this work would later be completed by Henrietta Leavitt.[69]

In the second half of 1889 Bache plates from Chosica, Peru, began arriving at HCO. Mrs Draper had commissioned a replacement astrograph for Cambridge: the 0.20-m f/6.2 Draper astrograph was mounted on a German equatorial and equipped with a 5° objective prism enabling spectra of 10th-magnitude stars to be photographed.[70]

Mina scrutinized the incoming Bache and Draper astrograph plates, intent on spotting more stars with bright line spectra. Seven WR stars were found in 1889, including several near the Carina Nebula; five more followed in 1890, by which time Mina had discovered half of all known Wolf–Rayet stars.

Her keen eyesight also facilitated the discovery of variable stars. In 1889 September S Centauri was found as a 6th-magnitude star missing from catalogues. Pickering encouraged her to report findings in both the *Sidereal Messenger* and *Astronomische Nachrichten*; a series of papers announcing new variable stars in different constellations along with lists of stars having peculiar spectra began in 1890. However it would be the publication of *The Draper Catalogue of Stellar Spectra* in 1890 that would forever establish her name among the greatest of women astronomers.[71]

7. HCO in the early 1890s

The first 15 years of Edward Pickering's leadership of HCO were dominated by his carefully planned strategy of expansion made possible by a series of successful grant applications, bequests, and collaborations. He had elevated Harvard to the highest levels globally by securing a southern hemisphere observatory at Arequipa equipped with quality Clark instruments.

Whole-sky surveys for photometry, photography, and spectroscopy were beginning to reveal the secrets of the stars. New technology had been exploited to enable the history of the heavens to be investigated. Through the generosity of his main benefactor the Henry Draper Memorial had facilitated expansion of his team of assistants, the female half being ably led by Mina Fleming. Inevitably the continued success of HCO would be dependent on Pickering maintaining an efficient and focused team; unfortunately, his younger brother had other plans.

7.1. *A Problem in Peru*

William Pickering left for Arequipa in 1891 January on HCO's second Peru expedition. Solon Bailey's group departed in May, by which time William had already cabled his brother to send more funds. The demands grew more frequent as William overspent on land acquisition and house building.

By August the 0.33-m Boyden refractor had been erected near the Bache astrograph under superb conditions of seeing and transparency. To the increasing dismay of the HCO director the number of glass plates arriving from Arequipa reduced; it became apparent that William was mainly using the Boyden refractor as

Fig. 6. Discovery plate B2312 for the Horsehead Nebula, seen at left below the bright star Zeta Orionis (Alnitak) in Orion's Belt. It is probably the best-known object discovered by Williamina Fleming, but she is not usually credited with it. This plate is a 90-minute exposure with the Bache astrograph in 1888 February. (DASCH sample image)

a visual instrument for his planetary and lunar observations.

In 1891 October he received a directive from his older brother to begin the photographic programme. By 1892 June Edward Pickering had to inform him that he was to be recalled and would be replaced by Bailey; reluctantly Edward agreed to allow William to remain in Peru for the 1893 April solar eclipse.

William opted to use his remaining time observing the close Mars opposition of 1892 August. Further consternation in Cambridge arose when he then began cabling the New York Herald with a series of speculative ideas about Martian topography. In 1893 February Bailey's family group returned to Arequipa for a five-year term; HCO would at last have an efficiently operating southern hemisphere station.

7.2. *The Harvard Plate Store*

Storage of 30,000 glass plates in the West Wing of HCO had given its director many challenges. The wooden construction of the main building was a continual reminder to Pickering of the devastating fire of 1764 which had destroyed part of the original observatory. Completion of a new fireproof three-storey brick building in 1893 March was therefore highly welcome.

Eight tons of glass plates were transferred using a rope and pulley system during a five-hour operation.[72] Mina Fleming was now responsible for a facility costing $15,000 (*c.*£270,000 today). In 1902 a brick extension would be added to facilitate further storage.[73] During her lifetime the Harvard collection would grow in size to 200,000 plates.[74]

The relatively cramped working conditions for the women assistants had been apparent to Mrs Draper during her 1891 visit to HCO (Fig. 5). The key difficulty of retrieving speedily and safely a series of glass plates spanning nearly a decade would be significantly improved by the Plate Store.

In addition to her initial inspection of all incoming plates Mina often needed to trace back earlier examples for given regions of the sky. This had become a routine job for suspected long-period variable stars whose spectra often showed brighter hydrogen lines near maximum; she would select adjacent stars as comparison stars, determine their approximate positions, and then hunt for the suspect variable on older plates.[75]

Inquiries were also arising from other astronomers. In 1892 September HCO received a request from Edward Singleton Holden (1846–1914), director of Lick Observatory, for confirmation of a new variable star in Aries; Mina soon found the star recorded on nine plates dating back to 1890 October.[76] Pickering's dream of capturing the history of the heavens was becoming a reality.

At the beginning of 1892 astronomers across the world were excited by the discovery of a bright new star in the winter sky by the Scottish amateur astronomer Thomas David Anderson (1853–1932). Nova Aurigae 1891 was the first to be studied by the spectrograph and Pickering reported HCO observations a fortnight after its announcement. Mina had examined Harvard plates from 1885 November, finding the first recorded image of it at 5th magnitude on a plate taken on 1891 December 10.[77]

Spectra of the nova were photographed at Cambridge by both the 0.28-m Draper refractor and the 0.20-m Draper astrograph, with the latter recording low-dispersion spectra as the star faded. The possibility of finding fainter novae in other constellations within the HCO plate store would now be actively pursued at Cambridge.

During Antonia Maury's two-year absence the analysis of high-resolution spectrograms was another area tackled. Mina investigated first-magnitude stars, measuring their intensity at 20 different wavelengths; Pickering reported the findings in 1891 October.[78] In his 1891 *Annual Report* Pickering noted: 'An interesting discovery was made by Mrs. Fleming, that the bright lines in the spectrum of β Lyrae change their position in a manner somewhat like the doubling of the dark lines in β Aurigae.'[79]

7.3. *The Chicago Columbian Exposition in 1893*

In the autumn of 1888 Mina met solar astronomer George Ellery Hale (1868–1938) who had begun working as a volunteer assistant at HCO while completing his MIT undergraduate studies. Hale tested a model spectroheliograph at Harvard and investigated the solar spectrum using a 0.30-m horizontal telescope; in 1890 improved instruments at Kenwood Astrophysical Observatory, Hale's private observatory in Chicago, facilitated his study of calcium in the spectra of prominences. Pickering supported Hale's early career in several ways. Through their liaison Hale gained respect for the tremendous discoveries being made by the Harvard women assistants, and became a lifelong friend of Mina Fleming.

In 1891 Hale visited astronomers across Europe to seek support for a new journal, *Astronomy and Astrophysics*, which ran to three volumes prior to the launch of *The Astrophysical Journal*.[80] Mina had begun writing papers under her own name in 1890 and was keen to send reports to Hale from her series on stars having peculiar spectra. In addition to her work on Nova Aurigae, details of her latest discoveries of WR stars appeared regularly during 1892; by this time she had discovered 24 of the 37 known Wolf–Rayet stars.[81]

Hale used the pages of *AstAp* to promote the World Congress on Astronomy and Astrophysics to be held during the Columbian Exposition in Chicago in 1893 August.[82] HCO was naturally expected to play a major role, and Mina was delegated two main tasks: preparation of an exhibition of 250 photographs from the Harvard Plate Store, and production of a paper on the role played by women computers at Harvard.[83]

Although unable to attend the Chicago conference herself, this opportunity launched Mina into the world of international astronomy, enabling her to build valuable networks and guaranteeing her inclusion at similar gatherings for nearly two decades.

Her paper *A Field for Woman's Work in Astronomy* provides a valuable insight into her thoughts about her adopted country, the support she had received, and the work of her team:

> The United States of America is a large country, with a large-hearted and liberal-minded people. Here they have made room for comers from all other countries, have welcomed them and have given a fair open field and equal advantages in pursuing their labors or studies, as the case may be. There is no other country in the world in which women, not as individuals, but as a class, have advanced so rapidly as in America, and there is no other country in which they enjoy the same unlimited freedom of action which affords them the opportunity to find their own level. In their studies they encounter very little narrow-mindedness or jealousy in their brother students or fellow workers in the same field of research, but in general they are treated with the greatest courtesy, encouragement and assistance being graciously accorded.
>
> Labour honestly, conscientiously and steadily and recognition and success must crown your efforts in the end.
>
> The measurements of about 40,000 stars are now being made by Miss Eva F. Leland. She is also engaged in the measurements of the brightness of the stars in clusters. Miss Louisa D. Wells and Miss Mabel C. Stevens have shown great skill and accuracy in making the identification of stars shown in the photographs, with those contained in existing catalogues ... micrometric measurements of the lines in the photographic spectra of the bright stars have been made by Miss Florence Cushman.
>
> While we cannot maintain that in everything woman is man's equal, yet in many things her patience, perseverance and method make her his superior. Therefore, let us hope that in astronomy, which now affords a large field for woman's work and skill, she may, as has been the case in several other sciences, at least prove herself his equal.[84]

Fig. 7a: Harvard College Observatory in 1887, looking southeast from the cottage used as a darkroom. In the foreground are: 0.32-m and 0.25-m photographic telescopes in the leftmost dome; the 0.20-m Bache astrograph in transit shed; 0.70-m f/5 reflector in the middle dome; 0.38-m reflector mounted in open; 0.28-m f/14 Clark photographic refractor in third dome, at right. From First Annual Report of the Henry Draper Memorial project, published in 1877.

One of the highlights of the Congress was the opening of the exhibit of the mounting for the Yerkes 1.0-m telescope, which had been erected in the huge Manufacturers and Liberal Arts Building, with accompanying talks by Hale, Clark, and Warner. Also attending the Congress was Dorothea Klumpke (1861–1942), an American working at the Paris Observatory, who delivered a paper on photographic charting of the sky.[85] At this time Dorothea was leading the Micrometer Service in Paris with a team of four female assistants. It is unfortunate that the two astronomers were unable to meet as they had much in common.

8. New stars and new challenges

In 1893 October Pickering announced Mina's discovery of a 7th-magnitude nova in the southern constellation of Norma, now known as IL Nor.[86] She had been examining spectra on a Bache plate taken that July in Arequipa and noticed the similarity of the bright hydrogen lines with those of Nova Aurigae 1892. Earlier plates to 14th magnitude showed nothing at this position.

Responding to a query from Jacobus Cornelius Kapteyn (1851–1922) over the exact position of the new star Pickering explained: 'Its exact position cannot readily be found at present since it appears only on a spectrum plate. Estimates by means of squares 1-mm on a side gave the position for 1875 ... a measure with the dividing engine gave a position.' [87]

Encouraged by her success Mina resolved to use this spectral approach to seek more novae. In 1895 she was to be rewarded by three discoveries, one of which proved to be beyond the Milky Way (see Section 8.2).

8.1. *The 0.60-m Bruce photographic telescope*
Pickering's 1888 November request for $50,000 for a photographic instrument with three times the aperture of the Bache and Draper astrographs took five years to come to fruition. In 1889 June Catherine Wolfe Bruce (1816–1900) agreed to fund the 0.60-m f/5.7 instrument, which became known as the Bruce telescope. Its four-element objective using glass from Mantois in Paris was figured by the Clarks with two 0.60-m objective prisms. The design enabled fields 5° square to be photographed at a scale of 1 arc-minute per mm; at this scale, 1600 plates would cover the whole sky.

In 1893 November the astrograph was assembled in Cambridge for trials and in 1896 April Bailey had it operational in Arequipa. Pickering decided not to compete with the international Carte du Ciel and elected instead to use it for special investigations. Mina began receiving the large Bruce plates from Peru in 1896 September. By the end of 1899 over 4000 Bruce plates had been added to the Plate Store, some recording 400,000 stars to 16th magnitude.[88]

8.2. *HCO Circulars*
As discoveries rapidly increased, Pickering launched the Harvard *Circulars* in 1895 October. In addition to her editorial responsibilities for the Observatory's *Annals* Mina now took over production of these important new publications.[89]

Circular 1 announced the discovery of her second nova, now known as RS Car, which had appeared in Carina in 1895 April. A Bache plate of 60 minutes exposure taken in Arequipa had captured its spectrum, which was similar to those of Nova Aurigae and Nova Normae. Mina identified the bright lines by Greek letters for the first time: 'The hydrogen lines Hβ, Hγ, Hδ, Hε, and Hζ are bright, and the last four of these are accompanied by dark lines of slightly shorter wavelength.' [90] Further investigation showed evidence of spectral change as the nova faded.

Circular 4 in 1895 December announced two more nova discoveries, in Centaurus and Perseus.[91] In 1934

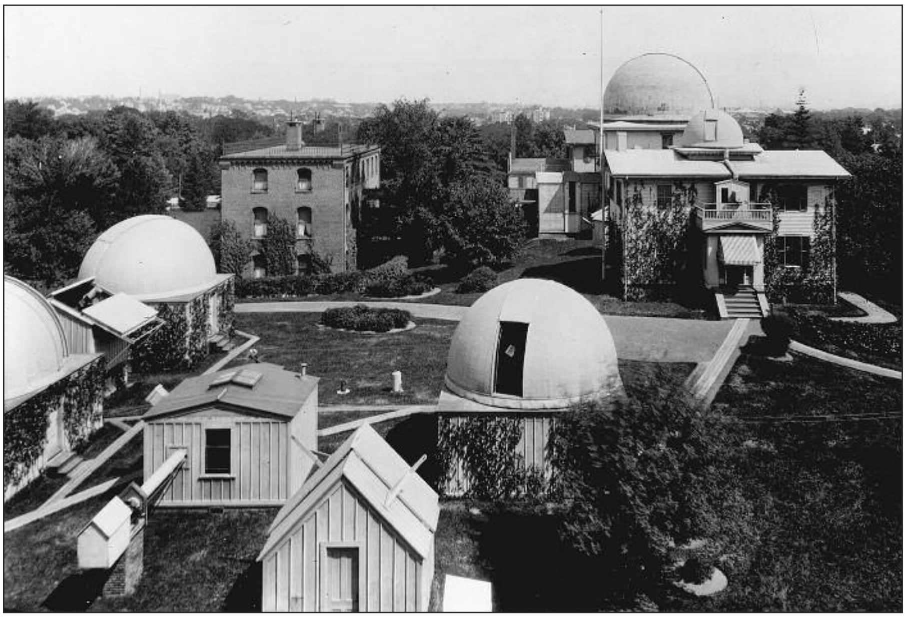


Fig. 7b: Harvard College Observatory c.1899 looking east. The Plate Store is in the three-storey brick building in the background at left; the 0.20-m Draper astrograph is in the runoff shed between the two domes at left; the 0.30-m horizontal photometer in left foreground was used by Hale for his first spectroheliograph. The large dome on the main building housed the 0.38-m 'great refractor' installed in 1847 which was for 20 years the largest telescope in the United States.
(From 1915JRASC..9..203C)

the object in Centaurus was reclassified as SN 1895B. Located 25″ from the nucleus of NGC 5253 it was the third extragalactic supernova discovered.[92]

Circular 6 three months later listed 14 new variable stars of long period discovered by Mina who was now adept at spotting the bright hydrogen lines characteristically seen near maximum; she was also highly methodical in comparing spectral information on older plates.[94] To share her workload she delegated some variable star work to Eve Leland and Louisa Wells. Their first joint results appeared in *Circular 7* in 1896 June.[94]

Mina's series titled *Stars having Peculiar Spectra* had become a regular HCO feature and *Circular 9* listed her continuation for mainly Type IV stars together with a gaseous nebula.[95] In discussing her WR discoveries of 1894 she had begun distinguishing between these two groups: 'The photographic spectra of faint gaseous nebulae and stars of the fifth type closely resemble each other and can only be distinguished by the wavelength of the principal bright line. In gaseous nebulae this line (5007) is of greater wavelength than Hβ while in stars of the fifth type the line (4688) is of shorter wavelength.' [96]

In *Circular 11* the third spectroscopic binary discovered by HCO was announced. Solon Bailey had reviewed 52 plates of the star μ^1 Scorpii to calculate a period of 35 hours from the doubling of spectral lines. Mina Fleming would have found this frustrating as she had previously checked three earlier plates and noted 'lines double' on two of them; unfortunately pressure of work meant they were then overlooked.[97] However her disappointment proved brief as in the same monthof 1896 August the twenty-fifth female assistant was appointed at HCO – a woman destined to become Mina's protégée.

8.3. *Mentoring opportunities*

Pickering had kept a watchful eye on potential college recruits to complement the skills of his staff. In the case of Henry Draper's niece Antonia Maury he had also felt an obligation to the Draper family but became disappointed with her progress and absences.

Maury returned from Europe in 1895 December to begin her third period at Cambridge. This time her work focused on annotations for *Annals* volume XXVIII, Part I, *Spectra of Bright Stars Photographed with the 11-inch Draper Telescope as part of the Henry Draper Memorial*, published in 1897. Maury investigated the spectra of 681 bright stars north of declination −30°; these were usually 60-minute exposures using up to four objective prisms which gave an 80-mm spectrum between Hε 3970 and Hβ 4861.[98,99] Her study enabled her to develop a new spectral classification system.[100]

Henrietta Swan Leavitt had graduated in 1892 from the Society for the Collegiate Instruction for Women, later renamed Radcliffe College. After taking additional astronomy courses she travelled abroad but unfortunately lost her hearing. She began volunteering at HCO in 1895. Initially she was involved in extending Mina's 1885 project on the photographic brightness of circumpolar stars. She then moved on to the photometry of variable stars, but a family crisis delayed her starting on payroll until 1902.

Annie Jump Cannon graduated from Wellesley College in 1884 where she was taught by physicist Sarah Whiting, who had close links with HCO. After her mother's death in 1894 Miss Cannon returned to Wellesley as an assistant to Whiting and enrolled in astronomy courses at Radcliffe. In 1907 she completed her MA degree at Wellesley.

Annie Cannon had a hearing disadvantage but was determined to accomplish something important with her life. Mina Fleming, who was six years older but had already achieved a highly successful career in astronomy, was an ideal role model.

Cannon began as a volunteer in 1896 February and unusually was allowed to observe variable stars in the evenings. In July she finished her Wellesley post and became a permanent HCO assistant.[101] *Circular 12* issued a few months later highlighted the existence of an unknown series of lines noted by Mina in the spectrum of the extremely hot star ζ Puppis. In *Circular 16* it was announced that Cannon had discovered the same lines in the spectrum of 29 CMa.[102] They are now known to be due to ionized helium.

Fleming and Cannon struck up a close collaboration that brought a major advance to HCO spectral classification. Pickering found it easy to decide who should investigate the spectra of bright southern stars for the HDM.[103] Mina would now consolidate her mentoring role of Annie Cannon; she was training her successor.

9. Conferences, and a near-Earth asteroid

As Edward Pickering drafted the fiftieth HCO *Annual Report* at the end of 1895 he could reflect on many successes. His dream of managing observatories in both hemispheres and cultivating an excellent staff of committed astronomers was realized. He had used the 100-mm meridian photometer on 115 nights, making 73,448 measures; on one night he observed 322 stars during a six-hour period, using the same technique that he had developed in 1882.[104]

Over the next 15 years he would average 130 evenings per year, including work with a new 0.30-m instrument, and make his one-millionth photometric setting in 1903 May.[105] This dedication meant that he began most days in the late morning; Mina's secretarial role ensuring the post and other matters demanding his scrutiny were already prepared.

The Yerkes Observatory dedication ceremony in 1897 October gave Hale the opportunity to convene the first American Conference of Astronomers and Astrophysicists, to which the HCO director and his wife were invited as special guests. Pickering delivered a summary of variable star work at Cambridge over the previous 5 years, explaining that 'the spectra of a large part of this class of [long period] variables are of the third type, and when near maximum the hydrogen lines are bright.'[106] Pickering praised Mina's discoveries of 80 variables; these included 26 in 1895 and 30 in 1896 which she had published in the *Astrophysical Journal* and HCO *Circulars* respectively.[107] At the conclusion of the conference Hale announced that the next venue would be at Cambridge in 1898.

Mina was also now being acknowledged as co-author of some Harvard *Annals*. In Volume XXVI, Part II, *Miscellaneous Investigations of the Henry Draper Memorial*, she is credited as 'M. Fleming, Assistant'.[108] Her classification of a thousand stars across seven open clusters utilized plates from both the Bache and Draper astrographs. For the Pleiades she investigated 91 stars finding 65% class A, while in contrast a similar number of stars in Praesepe had only 31% class A.[109]

9.1. *Second Conference of Astronomers and Astrophysicists*

The second annual conference of astronomers and astrophysicists was held at HCO in 1898 August, attended by 92 delegates including 17 women.[110] Mina played a leading role in organizing events.

Among the 24 papers presented was Mina's contribution on *Stars of the fifth type in the Magellanic Clouds*.[111] Pickering presented her paper and in conclusion added: 'Mrs Fleming had omitted to mention that of the 79 stars nearly all had been discovered by herself, whereupon Mrs Fleming was compelled by a spontaneous burst of applause to come forward and supplement the paper by responding to questions elicited by it.'[112] Mina's discovery of six WR stars in the Large Magellanic Cloud had been announced in *Circular 19* in 1897 September from an examination of plates taken by the 0.60-m Bruce astrograph.[113]

The third conference, held at Yerkes Observatory in 1899 September, was also the inaugural meeting of the newly constituted Astronomical and Astrophysical Society of America (A&ASA); this organization was eventually to grow into the American Astronomical Society. Simon Newcomb (1835–1909) was elected President and Pickering delivered a paper on the *Revised Harvard Photometry*. Annual meetings continued at venues in New York, Washington (twice), St Louis, and Philadelphia, with Pickering in regular attendance. Mina's role within America's leading society began in 1905 when Pickering was elected President.

9.2. *The hunt for Eros*

One week before the Cambridge conference Carl Gustav Witt (1866–1946), director of the Urania Observatory in Berlin, discovered an indistinct 0.4-mm line on a 2-hour exposure; he soon realized it was a fast-moving asteroid near aphelion.[114] Asteroid 433, later to be named Eros, had a strange elliptical orbit which would bring it closer to Earth than any similar object except the Moon.

Circular 34 described Wendell's photometric measurements of the asteroid made through the 0.38-m refractor plus Mina's analysis of its photographic brightness on plates taken by the 0.20-m Draper astrograph; both of them found the minor planet to be 12th magnitude.[115]

In November HCO received a request to find Witt's object within its Plate Store, as earlier positions would enable its orbit to be more accurately determined. To aid the search, Seth Carlo Chandler (1846–1913) produced an approximate ephemeris but with a large degree of uncertainty. Mina eventually examined over 1300 square degrees on plates from three astrographs, representing 3% of the entire heavens.

Twenty-one plates were found and labeled with the asteroid and comparison stars used to locate its position.[116] *Circular 36* in 1898 December described her work as 'especially laborious and fatiguing to the eyes'.[117] It involved superposing two plates of the same region taken with the same instrument and checking for a single faint image. Success with plates taken in 1896 April and June enabled Chandler to improve the ephemeris, from which Mina located plates for 1893–4.[118] Mina's reward for this mammoth task was to be taken off HCO payroll in 1899 and be made an employee of Harvard Corporation under a new title; her astronomical career was now officially approved.[119]

10. Curator of Astronomical Photographs

As the 19th century drew to a close Mina's discoveries continued steadily. A new remarkable object was announced in 1897 November: a Bache spectrum plate taken in June in Arequipa had included the spectrum of a bright meteor, with six bright lines measured by Mina.[120]

Pickering decided to make a special effort to obtain meteor trails and spectra during the annual November Leonid shower. HCO *Circulars 31*, *35*, and *40* describe the methods adopted. Observers were stationed both at both Cambridge and 20 km south at the Blue Hill Meteorological Observatory.

In the first year 91 and 47 meteors were recorded respectively.[121] The following year, 1898, 800 meteors

Fig. 8. Mina Fleming in the enlarged Harvard Plate Store. She was responsible for the Store from 1893 until her death in 1911. During this time the number of glass plates increased to 200,000 enabling the 'history of the heavens' to be investigated for the first time. (UAV 630.271 (388) Harvard University Archives)

were recorded at Cambridge by 30 observers. Five photographic doublets covered the region within 30° of the radiant. Parallax measures were obtained using a second station to the north but no spectra were obtained.[122]

Pickering then sanctioned two wide-angle cameras for Cambridge and Blue Hill to regularly patrol the heavens. Three plates were to be taken every night with the aim of determining the altitude, radiant point, velocity, and spectrum of one-third of all bright meteors visible.[123]

Circular 21 included the observation that β Lupi might be a spectroscopic binary; Mina was keen to add such an object to her portfolio, but further photographs proved inconclusive.[124] In *Circular 24* she was on safer ground, providing details of recent variable star discoveries, including those made by her assistants Louisa Wells and Eve Leland. It was now common practice at HCO to photograph many of these stars monthly and combine results with up to 100 library plates to deduce any light curves.[125]

Pickering was also keen to discover short-period variables photographically. Using a Cooke anastigmatic 26-mm f/13 astrograph with a 20 × 30-cm plate, eight 10-minute exposures were obtained over a 7-hour period for a region 33° square. This method was designed to discover any variable star with a period shorter than 14 hours, as both a maxima and minima would be recorded; Pickering estimated that the entire sky could be covered in just 40 plates to 9th magnitude and that amplitudes of 0.5 magnitude would be measurable.[126]

Mina's series of papers under the name *Stars having Peculiar Spectra* continued for the Draper Memorial project in 1898 June. In the November issue of *ApJ* she explained further her classification of the spectra of long-period variables, for which around 100 new examples with bright hydrogen lines had been found.[128]

In 1899 March, after a three-year gap, she found her fifth and brightest nova, in Sagittarius, now known as V1059 Sagittarii. *Circular 42* announced details of the new star which had been photographed in Arequipa in 1898 March at magnitude 4.7.[129] Pickering duly noted that of the 15 novae discovered in the last four centuries Mina had discovered one-third of them. Her tally increased to six in 1900 July with 7th-magnitude Nova Aquilae (V606 Aql), discovered from the existence of seven bright lines on plates taken the previous year.[130]

A 1900 spring visit to Europe by Edward and Lizzie Pickering included the Paris Exposition, for which Mina prepared some 400 plates from the Harvard Plate Store.[131] Later that year Pickering was awarded his second Gold Medal from the RAS 'for his researches on variable stars and his work in astronomical photography'. In his address on making the presentation, RAS President Edward Ball Knobel (1841–1930) noted 'the important part of the work undertaken by lady assistants, one of whom – Mrs. Fleming – is entitled to our gratitude, as from her minute and accurate examination of the photographs she has been able to announce some of the most interesting discoveries in variable stars and stars with peculiar spectra that have been recorded.' [132]

10.1. *Mina's 1900 Journal*

A revealing insight into Mina's thoughts aged 42 is provided by the Harvard University 'Chest of 1900' time-capsule project. At this time her son was 20 and Annie Cannon was lodging with the pair at 273 Upland Road, Cambridge.[133]

> March 1, 1900: In the Astrophotographic building of the Observatory 12 women including myself are engaged in the care of the photographs; identification, examination and measurement of them; reduction of these measurements and preparation of results for the printer ... My home life is necessarily different from that of other officers of the University since all housekeeping cares rest on me ... My son Edward, now a junior in the Mass. Inst. of Technology, knows little or nothing of the value of money and, therefore, has the idea but that everything should be forthcoming on demand. The first part of this morning at the Observatory was devoted to the revision of Miss Cannon's work on the classification of the bright southern stars, which is now in preparation for the printer ... several pages of the remarks on the individual stars were read, criticized, corrected or questioned.
>
> March 3: Another full day at the Observatory from 9[a.m.] to 6 [p.m.]. Part of the morning I spent with Miss Cannon, discussing the remarks on her classification, and explaining the reasons why we had changed one thing and questioned another ... Looking after the numerous pieces of routine work which have to be kept progressing, searching for confirmation of objects discovered elsewhere, attending to scientific correspondence, getting material in form for publication, etc., has consumed so much of my time during the past few years that little is left for the particular investigations in which I am especially interested. The Director, however, says that my time employed in the above work is of more value to the Observatory so I have delegated my measures of variables, etc., to Miss Leland and Miss Breslin.
>
> March 4 [Sunday]: This is my day of rest and retirement so far as Observatory work is concerned.
>
> March 5: If one could only go on and on with original work looking for new stars, variables, classifying spectra and studying their peculiarities and changes life would be a most beautiful dream ... I am more than contented to have such excellent opportunities for work in so many directions, and proud to be considered of any assistance to such a thoroughly capable scientific man as our Director.
>
> March 12: I had some conversation with the Director regarding women's salaries. He seems to think that no work is too much or too hard for me. But let me raise the question of salary and I am immediately told that I receive an excellent salary as women's salaries stand. Sometimes I feel tempted to give up and let him try some one else, or some of the men, in order to have him find out what he is getting for $1500 a year from me, compared with $2500 from some of the other assistants. Does he ever think that I have a home to keep and a family to take care of as well as the men?

At this time Mina was receiving weekly physiotherapy for her right arm. Repetitive strain injury affected some female assistants and the continuous retrieval of glass plates for scrutiny involved significant physical labour.

Fig. 9: HCO staff aboard C. S. Minia in 1900 May, en route for the solar eclipse in Georgia. Front row, from left: Louisa Wells, Mabel Gill, Mina Fleming (holding Gill's hand), Mabel Stevens, Evelyn Leland. Middle row: Captain William De Carteret, Edward Fleming (Mina's son), Edith Gill, Florence Cushman (partly obscured behind Mina), Imogen Eddy, and Ida Woods. Back row: unknown man and ship's officer, probably James Adams. The Minia, a cable repair ship, found unwanted fame 12 years later when she was one of the vessels chartered to recover bodies from the Titanic disaster. (UAV 630.271 (173), Harvard University Archives)

Mina's journal reflections on her salary warrant further scrutiny. Lafortune has reviewed HCO payroll records, which had been subject to an 80-year blackout.[134] This analysis reveals Mina was on payroll from 1881 and received an increase in salary to $83 per month ($1000 a year, *c.*£18,000 today) between 1891 and 1896 November. Between 1896 December and 1898 October she received $125 per month ($1500 a year, *c.*£27,000 today); after this time she was paid by Harvard Corporation.

Her first pay rise coincided with the publication of two volumes of the *Annals* for the *Draper Catalogue*; curiously it began two years after she took responsibility for recruiting female assistants (in 1888) so presumably she was serving a probationary period to prove her management skills.

The more significant increase in 1896 December, which continued until at least 1900 April according to her journal, followed her successful organization of the Harvard conference of astronomers and astrophysicists and significant contributions to the HCO *Circulars*; it coincided with her new position as Curator of Astronomical Photographs. Until 1911 Solon Bailey received $1000 per year, so Mina's reference to 'other (male) assistants' probably related to Wendell and Searle who both served long careers at HCO.

10.2. *A trip to Georgia*

Edward Pickering returned to Cambridge just before two expeditions departed to view the total solar eclipse of 1900 May from Georgia. The official party was led by William Pickering who hoped to find an intra-Mercurial planet.[135] The HCO staff excursion (Fig. 9) accompanied small groups from MIT and Blue Hill Observatory who chose Washington, Georgia, for their location.

For Mina and her son this was an opportunity to view a solar eclipse near solar minimum. Totality lasted 90 seconds with equatorial streamers observed to 3.5 solar diameters. A 75-mm f/15 camera was used by the MIT observers. Just prior to the eclipse Mrs Draper decided also to view the eclipse and persuaded Edward and Lizzie Pickering to accompany her as guests. Before their departure from Georgia the whole group enjoyed 'afternoon teas and a farewell barbecue'.[136]

11. Mina Fleming and Annie Cannon

By 1901 there were 45 volumes of HCO *Annals* completed, of which Mina had worked on 39. Volume XXVIII, Part II, was *Spectra of Bright Southern Stars* by Annie Cannon and included her classification of 1122 stars from analysis of 5961 plates photographed at Arequipa with the Boyden telescope. The 0.33-m refractor was used with up to three objective prisms, producing measurable spectra from Hε to Hβ of up to 74 mm in 60-minute exposures.

Cannon used a 50-mm eyepiece to examine each plate and modified the spectral classification first developed by Fleming for the Draper Catalogue.[137] The higher dispersion allowed her to introduce decimal subdivisions for spectral types; she also reordered some letters, which would later result in the famous O, B, A, F, G, K, M, R, N, S sequence.

From Mina's 1900 Journal it is clear that Annie Cannon was lodging with her. Whether this arrangement began when Cannon started at HCO in 1896 is unknown; however it is probable since Cannon regularly observed variable stars from HCO in the evenings and Mina lived close to the Observatory. The author has transcribed Cannon's diary for 1905 and found that she was living at 52 Concord Avenue between June and October.[138]

Mina's Journal makes it clear that the two women occasionally worked together at home in the evenings on HCO matters. Hence it seems probable that some of the credit for Cannon's later success on spectral classification can be traced to the role of her mentor during the first 15 years of her career at HCO.

11.1. *The discoveries continue*

Circular 54 issued in 1901 January detailed another batch of variable stars, 53 of them discovered by Mina.[139] Among them was a star with a range of 0.8 magnitude and a period of just over half a day; this we now know as RR Lyrae.[140] Mina's 1901 summer *Circular* summarized her latest group of *Stars having Peculiar Spectra* in which a large number of gaseous nebulae and Type V stars were listed.[141]

The year 1902 was celebrated as the 25th anniversary of Pickering's directorship. An anonymous gift of $20,000 (*c.*£360,000 today) was partly used for the Plate Store extension. In May discovery of a new Algol variable in Cygnus was announced, found by Mina while searching for an image of Comet Brooks; some 400 plates were inspected to construct a light curve with a period of 31.3 days, the longest of any then known.[142] It is now known as UZ Cygni.

In August Miss Leavitt returned to HCO, becoming the thirty-first female assistant. She was assigned to study variable stars on the Bruce plates from Arequipa. Her work on Cepheid variables within the Large and Small Magellanic Clouds would later be internationally acclaimed.

Annie Cannon had begun collating variable stars in 1900 September and a summary of her work was published in the Harvard *Annals* in 1903 as *A Provisional Catalogue of Variable Stars*.[143] This volume listed 1227 stars, of which HCO staff had discovered 694; Bailey was credited with 509 variables within globular clusters while Fleming's total was 166.

In 1903 March the English astronomer Herbert Hall Turner (1861–1930) discovered a possible nova in Gemini. *Circular 70* described the follow-up investigation by Mina and Eve Leland; they found it had been magnitude 5 at brightest and its spectrum revealed six bright lines.[144]

Pickering's 1903 *Annual Report* noted: 'Owing to the pressure of other work during the daytime Mrs. Fleming has not been able for some time to continue the classification of the spectra for the Southern Draper Catalogue. Suitable arrangements have accordingly been made so that she is now doing this work at her home in the evening. In this way she has classified the spectra and measured the light of 3,506 stars. These stars are all south of declination −60°.' [145]

The HCO Plate Store had passed the 150,000 mark by 1903. Pickering explained: 'On the average, photographs are included of every portion of the sky, taken on about two hundred nights, from 1889 to the present time, and showing stars as faint as the eleventh magnitude. A nearly continuous history of the sky, such as does not exist elsewhere, is thus furnished.' [146]

A Carnegie Institution grant of $2500 (*c.* £45,000 today) had improved HCO's capacity to mine this mass of plates. Mina had successfully appointed her sister, Mrs Johanna Crighton Stevens Mackie (1860–1943), and she was soon joined by their niece, Ida May Stevens, whom Mina had nurtured as she grew up in Cambridge.[147] These two additions to Mina's team proved to be replacements for Anna Winlock and Imogen Eddy, who both died in 1904 after 28 and 15 years service respectively to Harvard College Observatory.

In 1904 March Mina noted the variable star RS Ophiuchi as a potential nova based on its spectrum of the third type with bright hydrogen lines and two more bright lines similar to γ Velorum.[148] This star, typically of 11th magnitude, was found to have brightened to at least magnitude 7.7 in 1898 June. In 1905 May Pickering approved its reclassification from a variable star to 'Nova Ophiuchi, No. 3'.[149,150]

11.2. *Pickering's presidency of the A&ASA*

In 1905 September Mina discovered her eighth nova, and her second in Aquila.[151] But it was events at the end of December that proved more important. At the seventh meeting of the Astronomical and Astrophysical Society of America, held at Columbia University, New York, Edward Pickering was elected the second President, a role in which he continued until 1919. For Mina Fleming and Annie Cannon it proved an opportunity to attend an evening reception at the Madison Avenue home of Mrs Draper. They also presented papers on *Peculiar Spectra* and *Variable star light-curves*.[152] It is unclear how much additional work Mina was delegated following Pickering's election.

In 1906 May Mina received international recognition when she was made an Honorary Member of the Royal Astronomical Society, only the fifth woman to receive this accolade.[153] Praise by her homeland was undoubtedly pleasing but Mina was probably more humbled by being appointed an Honorary Fellow of Wellesley College that same year; although not a graduate, Mina supported the philosophy of this leading women's college, which had supplied Harvard College Observatory with such an excellent trainee in Annie Cannon.[154]

The same year proved busy for recruitment. Continuing low pay might have influenced some experienced computers to resign, but Mina replaced them with four new ladies who would all give excellent service: Grace Brooks, Alta Carpenter, Mollie O'Reilly, and Arville Walker, all of whom started at Harvard in 1906.

Mina's *Circulars* included her usual batch of *Stars having Peculiar Spectra* and variables, including another Algol-type.[155] She had now discovered 50 (of the 63 known) Wolf–Rayet stars. While examining plate A6911, a 4-hour exposure taken by the 0.60-m Bruce astrograph, Mina identified a large triangular wisp of nebulosity near the star 52 Cygni. Today this is known as 'Pickering's Triangle' or, more accurately, 'Fleming's Triangular Wisp', part of the Veil Nebula supernova remnant.[156]

In 1906 August Lizzie Pickering, Edward's wife of 34 years, died after a long illness,[157] but he carried on with his usual energy. Early the following year in *Circular 123* Pickering summarized the type of requests they dealt with, neatly explaining the varied roles of Mina and her team: 'For instance, evidence of the previous existence of a new star; of a star now missing; the position of an asteroid; the magnitude at minimum of a faint variable; early position of a faint star suspected of proper motion.'[158]

A serious fire in 1907 March threatened to consume the director's residence. While Pickering tackled a burning sofa, Mina used her extinguisher on the flames licking a large casement window and ceiling cornice. Together with other members of the HCO fire-fighting team the situation was under control by the time the city brigade arrived.[159]

In 1907 October Mina tabulated a list of red stars in the vicinity of Nova Velorum, which had been discovered the previous year by Henrietta Leavitt.[160] At this time Miss Leavitt was contributing to Mina's previous project on developing a standard North Polar Sequence, while Annie Cannon focused on identifying variables among the two million stars imaged on the Harvard Map of the Sky.[161] Three more female assistants were appointed, including Margaret Harwood (1885–1979) who worked at HCO for six months a year for five years.[162]

Publication of HCO *Annals* XLVII Part I, *A Photographic Study of Variable Stars*, proved a major milestone for Mina in 1907.[163] This volume contained sequences of comparison stars for each of 222 variables discovered by her or under her direction on the Henry Draper Memorial plates. Most of these variables were identified from their Type III spectra, displaying bright hydrogen lines.[164] Another milestone, this one personal rather than professional, was that she became an American citizen in September that year.[165]

11.3. *The Bruce Medal*

In 1908 Edward Pickering was awarded the Bruce Medal of the Astronomical Society of the Pacific for his work on photometry, spectroscopy, and photography; he was the seventh recipient since 1898. Pickering had proposed Mina for the award in 1900, adding the following year: 'I cannot do better than repeat my recommendation of last year that "in view of the important part taken by women in American Astronomy, and since the Bruce Medal was established by a woman [Catherine Wolfe Bruce, who also funded the Harvard astrograph], I recommend the woman who has made the most important astronomical discoveries, Mrs. W. Fleming."'

In 1905 he strengthened his nomination: 'Mrs. W. P. Fleming, for her discoveries and continuing researches in stellar spectroscopy, extending over the last 24 years. She has discovered nearly all of the Novae, stars of the 5th light and stars having hydrogen lines bright which have been found during the last 20 years. See also her work published in Harvard *Annals* 26, 27, 50, in Harvard *Circulars* ... and publishing and editing many other volumes.' [166] Pickering's nominations were to no avail and it would not be until 1982 that a female astronomer, Margaret Burbidge, finally received this international honour.

Advances in printing technology significantly reduced production times of the *Annals* after 1907. As Pickering explained to David Gill: 'We have just introduced a monotype, a machine by which one typewriter can do the job of four compositors. The energies of the entire Observatory are being exhausted in keeping this monster supplied with copy.' [167]

Volume L of the *Annals*, published in 1908, was the *Revised Harvard Photometry*, a major catalogue of positions, photometric magnitudes, and spectra for 9110 stars to magnitude 6.5, the forerunner of the *Bright Star Catalogue*.[168] Pickering noted in the Preface that Mrs Fleming 'has devoted a large part of her time to the supervision of the preparation for publication of the present Volume'.

Her other main publication of 1908 was *Circular 145* in which she proposed a sixth type of stellar spectra, listing 51 examples of stars showing dark absorption bands.[169] This suggestion had previously been presented at the ninth meeting of the A&ASA held in August at Lake Erie, Ohio, which Mina attended with Pickering.[170]

At the tenth meeting of the A&ASA a year later at Yerkes Observatory, HCO representation included the impressive line-up of Fleming, Leavitt, and Cannon who delivered papers on meteor spectra, standard photographic magnitudes, and variable stars respectively.[171] Mina continued her August trip westwards to visit her son in Salt Lake City, where he was now working as a metallurgist, and they journeyed together to Los Angeles.[172]

12. New theories of stellar evolution

In 1909 September Henry Norris Russell (1877–1957) contacted Pickering about his hypothesis for two types of red stars. In 1908 July Ejnar Hertzsprung (1873–1967) had made a similar distinction between nearby red dwarf stars and more distant giant stars. He regretted the omission of Maury's 'c' characteristic from Volume L of the Harvard *Annals*; his combined work with Russell would result in a new theory of stellar evolution, including the H–R Diagram, in 1913.[173] Mina's initial contribution to this debate appeared in *Circular 149* in 1909 March. A two-hour Bache exposure of a region in Sagittarius had revealed a large number of red stars with peculiar spectra, while a shorter exposure of 69 minutes recorded very few red stars.

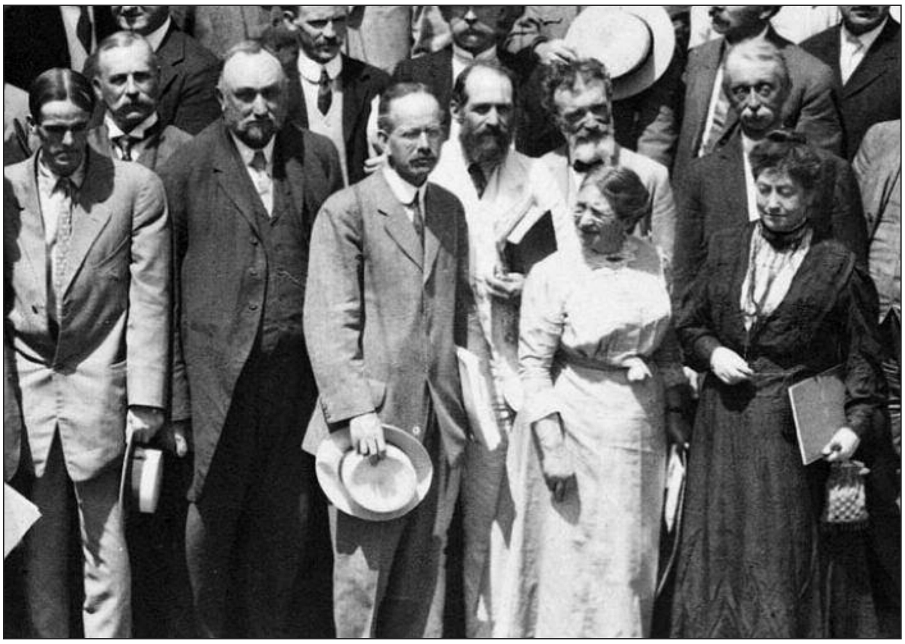


Fig 10: The 1910 meeting of the International Union for Cooperation in Solar Research, better known as the Solar Union, was held at Mount Wilson. Among the attendees were, in the front row, Walter S. Adams, Edward C. Pickering, George E. Hale, Mrs Elise Kapteyn, and Williamina Fleming, with Jacobus Kapteyn behind Mina. (Kapteyn Astronomical Institute)

12.1. *The first white dwarf: 40 Eridani B*

In 1910 Mina made an important observation regarding the triple star Omicron² Eridani, more usually known as 40 Eridani. She classified the spectral types of the three components as K, A, and G, raising an intriguing puzzle: how could the ninth-magnitude companion to a fourth-magnitude primary have a spectral type, A, associated with some of the hottest stars known? Pickering commented sagely: 'It is just such discrepancies which lead to the increase of our knowledge.' [174]

At that time Russell was visiting HCO prior to the 1910 August meeting of the A&ASA in Cambridge. His work on the parallax of nearby stars had extended to noting their spectral type from the Harvard plates. Russell doubted the reliability of Mina's 'discrepancy' but included it in his graph of spectral types plotted against absolute magnitudes. Hertzsprung also agreed with Russell that faint white stars were unlikely.

The breakthrough came at the end of 1914 when Walter Sydney Adams (1876–1956) succeeded, after a two-year campaign with the 1.5-m reflector at Mount Wilson, in obtaining a spectrum for Sirius B, which he classified as A0. This agreed with Mina's result and showed there were at least two small, dense, hot stars. A third example was found at Mount Wilson in 1917 by Adriaan van Maanen (1884–1946).[175] Such stars are now known as white dwarfs, the exposed cores of stars such as the Sun that have lost their outer layers.

12.2. *The 1910 meetings of astronomers*

Planning for the eleventh meeting of the A&ASA at HCO in 1910 August occupied many months. The three-day conference involved five sessions, 48 papers, and over 100 delegates, 15 of them female (Fig 10). Excursions to the Whitin Observatory at Wellesley College and the Blue Hill Meteorological Observatory were organized as well as to the astronomical laboratory at Harvard University. Immediately afterwards most astronomers departed from Boston for the long journey to Pasadena to attend the fourth meeting of the International Union for Cooperation in Solar Research, also known more simply as the Solar Union or ISU, on August 31–September 2.[176]

This meeting was held at Mount Wilson Observatory where Hale had established the 1.5-m reflector and two solar towers. Eighty delegates attended, including 37 from Europe; in all 13 countries and 50 different observatories were represented, making the event the largest ever gathering of astronomers in the world. For Williamina Fleming the meeting marked the pinnacle of her acceptance on the world astronomical stage. The journey from Boston to Pasadena occupied eight days with visits to Niagara Falls, Chicago, the Lowell Observatory in Flagstaff, and two days at the Grand Canyon before a crossing of the Mojave Desert to reach their destination.[177]

At Pasadena delegates viewed the laboratories and workshops including Hale's spectroheliograph design for the 45-m Tower Telescope and the 2.5-m glass blank for the Hooker Telescope. An afternoon garden party at the Hales' home at Hermosa Vista proved an enjoyable distraction from concerns over the following day's ascent of Mount Wilson. An average gradient of 1:10 up dusty, narrow tracks occupied eight hours, with most delegates opting for mule-drawn carriages.

Mount Wilson hotel accommodated half of the delegates with the remainder under canvas for four nights. Pickering and Fleming were the HCO delegates, the director being housed in a cottage while Mina enjoyed meeting six female assistants from Mount Wilson's staff. At the end of proceedings most delegates travelled north to visit Lick Observatory. Mina opted to make her second journey to Salt Lake City to visit her son Edward; it would prove to be their last meeting.

Three outcomes of the Solar Union meeting impacted directly on HCO. First, delegates agreed to expand the remit of the Union to include stellar spectra. Second, Pickering secured global agreement on his plan for Standard Photographic Magnitudes. And third, the Harvard system of spectral classification, fundamentally the six classes designated B, A, F, G, K and M, received widespread approval. Pickering had now received the necessary global endorsement for his lifetime's work.[178]

Three years later, in 1913 April at Bonn, the fifth Solar Union meeting universally adopted the Harvard spectral classification system; Pickering and Annie Cannon attended this meeting. Nine years later, in 1922 May at Rome, the newly created IAU formally approved the Harvard system.

12.3. *Final months*

Shortly after the Solar Union meeting, while still with her son in Salt Lake City, Mina learnt of the death of her mother in Cambridge.[179] This necessitated her immediate return to the north-east, but by the time Pickering returned in mid-September HCO routines were back to normal. One of his first tasks was to confirm Mina's latest two discoveries.

Nova Sagittarii No. 2 was her ninth nova, discovered from its faint spectrum on a Bache plate taken in March at magnitude 7.8.[180] Nova Arae was her tenth nova, discovered in a similar way on an April plate at magnitude 6.0.[181] Pickering proudly announced the ongoing success of his team: 'Of the 16 new stars found during the last 25 years, 13 have been found at this Observatory, one by Miss A. J. Cannon, two by Miss H. S. Leavitt from photographic charts and 10 by Mrs. Fleming from the Draper Memorial photographs.'

Discussions at the final session of the Solar Union meeting had resulted in formation of a committee to recommend a stellar spectral classification system. Written responses were invited from leading astronomers, with 28 received from 17 different observatories, the majority backing the Draper system.[182]

In November Pickering voiced his expectation that stellar evolution theories would soon be forthcoming and that the proven Draper system could support these. Antonia Maury conveyed a similar wish for an evolutionary scheme with retention of the observations of line width and sharpness visible in high-dispersion spectrograms.

In 1911 January Mina expressed the hope that new technology might improve the definition of fainter spectra. At this stage she had divided class M into four subclasses with one of these further divided into eleven groups. By February Annie Cannon had studied 4300 photographic spectra. Her response promoted the O, B, A, F, G, K, M system with decimal subdivisions, but also included the need to incorporate results from slit spectrographs as well as objective prisms.[183]

Pickering was now 64 years old and actively seeking to delegate some of his responsibilities to Solon Bailey, whom he hoped would soon succeed him as director of HCO. Bailey had led the HCO expedition to South Africa in 1909, finding an excellent observing site near Bloemfontein which would eventually become the southern hemisphere replacement for Arequipa in 1927. However Pickering was struggling to raise sufficient finance at this time and having to dismiss some male assistants; interest rates had fallen and even Mrs Draper had to halve her monthly contributions to $400 per month (*c.*£7200 today) after 20 years of generous support.

Mina concentrated on the completion of *Annals* Volume LVI which included eight sections relating to stellar spectra. Part VI was her main focus, *Stars having Peculiar Spectra*.[184] Published in 1912, it effectively summarized in 60 pages her work for the Henry Draper Memorial over nearly three decades. Her final *Circular* appeared four months after her death from pneumonia in Boston Hospital on 1911 May 21. Typically it covered more *Stars having Peculiar Spectra* and discoveries of variable stars.[185]

13. Tributes to Mina Fleming

In his 1911 *Annual Report* Edward Pickering marked the passing of his close colleague:

> The Observatory has suffered a severe loss by the death, on May 21, 1911, of Williamina Paton Fleming, Curator of Astronomical Photographs. She was an Honorary Member of the Royal Astronomical Society, an Honorary Fellow of Wellesley College, and last winter received the gold medal of the Mexican Society of Sciences. Mrs. Fleming's record as a discoverer of new stars, of stars of the fifth type, and of other objects having peculiar spectra, was unequalled. Her gifts as an administrative officer, especially in the preparation of the Annals, although seriously interfering with her scientific work, were of the greatest value to the Observatory.[186]

Pickering believed Mina's chief gifts were executive and administrative. As he recalled: 'A gift of order is much different from a gift of administration. The former helps the latter. Mrs. Fleming had both. She was very methodical and possessed an extraordinary memory, which was especially manifest in her preparation of the observatory records.' [187]

Her obituary in the *Monthly Notices* of the RAS by Herbert Hall Turner noted: 'Within the last year or two more than one serious operation had been necessary ... It would be unjust not to remember that she left her heavy daily labours at the observatory to undertake on her return home those household cares of which a man usually expects to be relieved. She was fully equal to the double task.' Turner had great admiration for Mina Fleming, especially her work on variable stars: 'Many astronomers are deservedly proud to have discovered one variable, and content to leave the arrangements for its observation to others: the discovery of 222, and the care for their future on this scale, is an achievement bordering on the marvellous.' [188]

Annie Cannon produced the most detailed obituary, which included this tribute:

> Gifted with great keenness of vision and a clear and logical mind … she never doubted the validity of the photographic evidence. Her industry was combined with great courage and independence ... her power of grasping facts quickly and clearly was useful in final readings and corrections of [*Annals*] copy and proof ... her great natural vitality and courageous spirit had sustained her through trying illnesses ... Mrs. Fleming was possessed of an extremely magnetic personality and an attractive countenance, enlivened by remarkably bright eyes [very dark brown] ... fond of people and excitement, there was no more enthusiastic spectator in the stadium for the football games, no more ardent champion of the Harvard eleven ... she was never too tired to welcome her friends at her home or at the observatory ... her cheery greeting with its charming Scotch accent, will long be remembered by even the most casual visitors to the Harvard College Observatory.[189]

Local media in Cambridge recorded: 'No other woman astronomer has so brilliant a line of achievements to her record ... she seemed to read the heavens as an open book ... editing more than 20 quarto volumes of astronomical publications ... the intricate maze of computations which could keep more than a dozen women computers steadily busy.' [190]

Grace Thompson described Mina as 'the most efficient woman investigator ... manifesting a very genius for the task of organisation'.[191] Always heeding the advice and approval of the director, 'her discerning scientific judgement suggested many of the most important and interesting investigations undertaken, and then aided in planning and carrying them out with an unerring precision.' [192] Mina's creative tastes were also reviewed:

> She might have supported herself by needlework, millinery, dressmaking ... she delighted in doing

bits of sewing ... Mrs. Fleming's dolls always sold readily, those in full Highland costume being especially popular ... a Christmas tree for the children of families connected with the observatory work of Arequipa Station in Peru ... everyone helped enthusiastically ... Mrs. Fleming insisted they should be astronomical dolls ... Vega, Castor, Pollux ... quite an astronomical sensation when Mrs. Fleming introduced a big, handsome Algol, and as its dark companion a miniature black Dinah.

Additional features of Mina's personality were listed as 'very quiet, very earnest, very sincere, quick to sympathise, altogether magnetic ... none could have been more reticent of personal credit ... her own part in researches she unconsciously left inconspicuous ... she regarded her work as a high privilege. But she gave unstinted praise to her assistants.'

13.1. *Stars having Peculiar Spectra – Annals 56, Part 6*

Mina's main two instruments had been the 0.20-m Bache and Draper astrographs, each producing nearly 40,000 plates of size 20 × 25 cm covering 10°-square regions of sky. Additional photographs of spectra involved an objective prism and slight alteration to the telescope drive rate; Mina also reviewed all plates from the 0.60-m Bruce astrograph. Only small dispersions were achieved, between 2 mm and 7 mm typically for the smaller instruments. However these tiny barcodes were often all that Mina needed to trace the history of the heavens for a variety of objects, including:

1. New Stars. Ten of nineteen identified from their spectra, with novae differing from long-period variables by having a bright Hε hydrogen line, and occasionally a bright K calcium line.
2. Gaseous Nebulae. Spectrum P – typically showing continuous spectra with bright lines, including 59 discoveries by Mina.
3. Type V. Spectrum O – the most striking spectra with most light concentrated in two bright bands, one in the blue and the other in the yellow. After 13 visual discoveries of Wolf–Rayet stars between 1867 and 1884 the HDM plates took over, with 94 discoveries listed.[193]
4. Stars having bright hydrogen lines. Type I stars with typically a bright Hβ line.
5. Spectroscopic Binaries, including Pickering's discovery of ζ Ursae Majoris (Mizar) and Maury's discovery of β Aurigae, both in 1889. Mina tabulated those brighter examples of Class A showing alternate single and double lines, including her own two discoveries of β Lupi in 1897 and ζ Centauri in 1899.
6. Variable Stars. Lists for Algol type, β Lyrae type, short and long-period variables tabulated; Mina credited herself with the discovery of four Algol-type variables between 1902 and 1910, one β Lyrae type in 1904 (RV Ophiuchi), and four short-period variables between 1901 and 1907 (including RR Lyrae in 1901).

13.2. *Her final catalogue*

Mina's final catalogue, not quite completed before she died, was published in Harvard *Annals* 71, Part II, in 1917 under the title *Spectra and Photographic Magnitudes of Stars in Standard Regions*. In 1884 Pickering had designated 48 regions of the sky for which a uniform system of standard magnitudes might be developed, using both photometric and photographic measures. In 1911 Mina completed her measures of 1434 stars between second and eleventh magnitudes, identifying between 12 and 60 stars per region for use in future investigations. This catalogue was subsequently extended to 19th magnitude by Annie Cannon.[194]

13.3. *DASCH*

A year after Mina's death Pickering reflected: 'The greatest need is provision for a number of computers to utilize the vast amount of material contained in the Harvard collection of photographs. It may be compared to a library of 200,000 volumes with only a dozen readers.'[195]

One hundred years later the Digital Access to a Sky Century @ Harvard (DASCH) project was underway using a custom-built high-speed scanner to digitize over 500,000 glass plates held by HCO.[196] At the time of writing (2017 February) 151,786 plates had been scanned and the plan for Time Domain Astronomy (TDA) was nearing a reality. Scanning *c.*400 plates per day would enable all the Plate Store to be digitized by 2018.

In 2016 January the Cambridge city water main below the Observatory ruptured, flooding a basement to a depth of one metre and requiring 62,000 plates to be rescued and frozen; an 18-month operation to thaw and photograph each plate prior to removing its paper sleeve and gently cleaning the photographic emulsion is planned.[197, 198]

Conclusion

More detailed biographies of female astronomers are needed. Williamina Fleming was an educated young woman when she first arrived in the United States in her brother's footsteps. Her marriage had proved unsuccessful and dreams of a fresh start might have been thwarted by a second pregnancy. Fortunately her new employer was willing to support some of her needs and keep open the opportunity of a permanent position. Mina proved herself an immensely valuable asset and quickly established herself as a leading astronomer in America.

Opportunities provided by advances in photography and spectroscopy coincided with the support, encouragement, and financial backing of Mrs Draper. The Henry Draper Memorial became the central pillar for the growth of Harvard College Observatory; its director skilfully assembling instruments, observers, and programmes for whole-sky surveys. The unprecedented amount of data arriving necessitated a corps of female assistants, mostly appointed and motivated by Mina. The Harvard Plate Store quickly became the world's central repository for the photographic history of the heavens. In her detection of Eros Mina proved she could find the proverbial needle in the haystack.

Her discoveries – 1 supernova, 9 novae, 59 gaseous nebulae, the Horsehead Nebula, 2 spectroscopic binaries, 75 Wolf–Rayet stars, and 310 variable stars – secured her place in any astronomical hall of fame. But it was her unstinting loyalty, dedication, and outstanding effort that ensured HCO delivered its director's aspirations. Harvard Corporation never acceded to Pickering's requests for an assistant director; they did not need to, as Mina fulfilled this role admirably during the second half of her three decades at Cambridge.

By the time of the 1910 Solar Union meeting at Mount Wilson she ranked among the world's leading astronomers; in more enlightened times she would have received the Bruce Medal for her achievements. Today, with the exciting developments of the DASCH project, it is perhaps not too late to celebrate her life and pioneering achievements.

Acknowledgements

The need for this research was realized during the author's work on the Gill-100 project (see *The Antiquarian Astronomer*, 10, 2016 June, pp. 13–37) which investigated decisions taken during and prior to the 1887 Astrophotographic Congress in Paris. An additional query on the role of Harvard College Observatory from Ian Glass initiated action during the first half of 2016.

I am particularly grateful to Mark Hurn, Piet van der Kruit, Keith Lafortune, Robin Carlaw, Robin McElheny, and other reference staff at Harvard University Archives, all of whom have provided encouragement, access to archives, or responded to various queries. I also acknowledge the important help of works by Lyle Gifford Boyd, Tom Fine, Dorrit Hoffleit, Stefan Hughes, Bessie Zaban Jones, Pamela Etter Mack, Cecilia Payne-Gaposchkin, Howard Plotkin, Dava Sobel, and Grace Agnes Thompson. Dava Sobel's book The Glass Universe appeared in the final stages of preparation of this paper; the author wishes to thank her for sharing examples of her on-site research at Harvard University Archives.

The research presented here made extensive use of the Hathi Trust Digital Library; Harvard University Archives; Smithsonian/NASA Astrophysics Data System; and various sources retrieved online through Google Books and JSTOR Digital Library. I would also like to thank my wife Ann who has contributed significantly to the many discussions about Mina Fleming's life during the past year.

References and notes

1. Hughes, Stefan, *Catchers of the Light* (eBook, 2012), Vol. 8, pp. 686–703, hereafter Hughes (2012), includes a genealogy of the Stevens family. Hughes records only one son for Mina, but see Note 5.
2. Robert Stevens owned a large carving and gilding business which involved picture framing and work in goldleaf. He pioneered the daguerreotype photographic process in Dundee; he died 1864 March 19. Mary Stevens joined most of her children in America in 1887.
3. Mina recounted her ankle injury in 1906 to 9-year-old Margaret Carnegie (1897–1990), daughter of Andrew and Louise Carnegie, the Scottish industrialist and philanthropist who were living in New York. Margaret had also suffered a serious ankle injury and was delighted to receive occasional educational gifts, jewellery, and small presents. See 'Miscellaneous Correspondence of W. Fleming' at Harvard University Archives. HUG 1396.
4. Thompson, Grace Agnes, 'Williamina Paton Fleming', *New England Magazine*, 48 (1912), 458–67, hereafter Thompson (1912). Mina instructed for five years in Broughty Ferry, a burgh adjoining Dundee.
5. Williamina Fleming married on 1877 May 26 at the United Presbyterian Church in Dundee. It is unknown if James Fleming accompanied his wife to Boston. It is usually suggested that he abandoned her when she became pregnant for the second time. By coincidence, at the time of their 1879 April wedding Robert and Anne Stevens were also expecting an October child. Writing to Louise Whitfield Carnegie (1857–1946) in 1905 Mina explained: 'Of my own two boys, only one lived to grow up.' Carnegie folder (Box 3), Pickering correspondence (UAV.630.17.5). The author is grateful to Dava Sobel for providing a transcription of this letter.
   See also: Sobel, Dava, *The Glass Universe: How the ladies of the Harvard Observatory took the Measure of the Stars*, (Viking, 2016), p. 117, hereafter Sobel (2016). This modern appraisal of the work of the women at HCO is a welcome addition to the history of astronomy.
6. Mina's decision to include the full name of her employer on her son's birth certificate has been interpreted by some as implying Pickering was the father. The author has found no evidence to support this notion and considers it more likely that as the support of the Pickering family had proved immensely significant she had wished to honour his name.
7. The author has used a currency conversion of £1 = $5 for this paper, with the assumption that costs have risen by a factor of 90 since the 1880s.
8. Useful biographies are: Bailey, Solon I., 'Biographical Memoir of Edward Charles Pickering 1846–1919', National Academy of Sciences (1932); Tenn, Joseph S., 'Edward C. Pickering: the Seventh Bruce Medallist', *Mercury*, Jan/Feb 1991, pp. 27–30); and Plotkin, Howard, 'Edward Charles Pickering', *Journal for the History of Astronomy*, 1990JHA..21..47P.
9. Tom Fine's website 'Harvard College Observatory History in Images' showcases his research of early archive illustrations for HCO. Another useful source is Schmidt, Richard E., 'The Tuttles of Harvard College Observatory: 1850–62', 2012AntAs..6..74S.
10. Letter from G. P. Bond to W. Mitchell written 1857 July 6, 1890PASP..2..300.

11. Mack, Pamela Etter, ‘Women in Astronomy in the US: 1875–1920’, BA thesis Harvard University (1977). Compared with domestic service or factory work, women considered astronomy jobs as highly desirable, due to good working conditions, companionship and reasonable duties. In 1875 room and board cost $6/week so a $500/year salary provided a ‘minimum wage’. Teaching posts typically paid $900/year but were scarce. Male assistants at Harvard, engaged in night observing or mechanical work, received $800/year in 1887.

12. Friedrich Wilhelm Argelander (1799–1875) was the German astronomer responsible for the Bonner Durchmusterung, published 1852–9. At the Astronomische Gesellschaft meeting in Leipzig in 1865 a proposal to revise this star catalogue led to over a dozen observatories collaborating.

13. 1877 HCO *Annual Report*, 1877 November 26. After this date all Annual Reports were issued in the autumn of the year in question, usually in September.

14. 1877 HCO *Annual Report*. The last subscription had been in 1868 for the meridian circle. Pickering reasoned the scientific output of HCO could be doubled with an income of $6000 ($3500 for 5 assistants, $1000 for salary increase, $1000 for apparatus and books, $1000 for publications). A $2000 gift from Miss Harris helped. The cost of each volume of the HCO *Annals* was $2000 (*c.*£36,000 today).

15. 1878 HCO *Annual Report*.

16. 1879 *Annual Report*. Refurbishment of the East Computing Room included repainting and papering prior to carpet-laying in 1880. It coincided with Mina’s initial period at HCO, when she was assisting with bookkeeping and accounting work part-time. Pickering was keen to develop his group of female assistants and sought Mina’s advice on making their working conditions as pleasant as possible. She did not start on HCO payroll until 1881 and it is probable that Edward and Lizzie Pickering covered some of her expenses in the intervening period, especially her passage twice across the Atlantic.

17. Hoffleit, Dorrit, ‘The evolution of the Henry Draper Memorial’, *Vistas in Astronomy*, 34 (1991), 109–10, hereafter Hoffleit (1991).

18. Pickering’s first RAS Gold Medal. Pickering’s first survey was completed by 1881 August after which a 100-mm f/15 meridian photometer was constructed to extend the work to 9th magnitude.

19. Mina Fleming returned alone to Boston in 1881 April on a steamer from Glasgow. Edward Fleming remained in the care of his grandmother Mary Stevens (née Walker) for the next six years. It is possible that Pickering supported this arrangement financially as preferable to having a young child with his name in Cambridge. The situation became impossible to continue by 1887 September.

20. ‘Venus Transit at HCO’, *Proc Am Acad*, 18 (1883), 15–40.

21. The Drapers toured Europe in 1879, making visits to Huggins and Common and a presentation to the RAS on 1879 June 13.

22. Barker, George F., ‘Memoir of Henry Draper. 1837–1882’, National Academy of Sciences (1888).

23. *Jones, Bessie Zaban, and Boyd, Lyle Gifford, The Harvard College Observatory. The First Four Directorships, 1839–1919*, (Harvard University Press, 1971), hereafter Jones & Boyd (1971).

24. Pickering, Edward Charles, ‘Researches upon the Photography of Planetary and Stellar Spectra. By the late Henry Draper. Results of Measurements by Professor E. C. Pickering’, *Proc Am Acad of Arts and Sciences* xix 146, pp. 231–61; includes two plates showing the Drapers’ observatory and telescopes at Hastings, New York.

25. Rumford Fund of American Academy grant.

26. Haley, Paul A., ‘Entente céleste: David Gill, Ernest Mouchez, and the Cape and Paris Observatories 1878–92’, *The Antiquarian Astronomer*, 10 (2016), p. 19, hereafter Haley (2016).

27. 1883 HCO *Annual Report* dated 1883 December 19. Pickering visited observatories at Greenwich, Oxford, Cambridge, Paris, Brussels, Bonn, Strasbourg, Berne, Geneva, Milan, Vienna, Berlin, and Potsdam, together with the private observatories of Huggins, Common, and Ranyard.

28. ‘Astronomical Photography’, *The Observatory*, 6 (1883), p. 149.

29. ‘1883 June 8 meeting of the Royal Astronomical Society’, *The Observatory*, 6 (1883), 199–206.

30. During his European tour the Collegio Romano observatory in Rome was not visited; Angelo Secchi (1818-78) had died 5 years before Pickering’s trip. Secchi had used a 160-mm flint objective prism of 12° refracting angle with the 240-mm Merz refractor in a visual study of the spectra of bright stars. Pickering planned to adopt a similar approach but using a short-focus astrograph to secure wider fields and sensitive dry plates to record the spectra of fainter stars. This innovative plan was kept secret as he first needed to secure funding.

31. Pickering, E. C., ‘Stellar Photography’, *Memoirs of the American Academy of Arts and Sciences*, 11 Pt IV (1886).

32. Letter from Pickering to Mrs Draper, 1885 May 17, quoted in Jones & Boyd (1971), p. 227.

33. Boyd, Lyle G., ‘Mrs Henry Draper and the Harvard College Observatory: 1883–1887’, *Harvard Library Bulletin*, 17 (1969), p. 75, hereafter Boyd (1969); includes a review of key correspondence with Pickering.

34. Haley (2016) p. 15 and pp. 21–22. Jean Chacornac (1823–73) visually mapped stars to 13th magnitude along half the ecliptic; Paul Pierre Henry (1848–1905) and Prosper-Mathieu Henry (1849–1903) were continuing this project in Paris. Each ecliptic chart covered 5° square and typically contained 1500 stars. Visual mapping became impractical when the Milky Way regions were attempted. The Henry brothers constructed a 0.16-m f/13 astrograph in autumn 1884 and then a 0.33-m f/10 instrument to match the Chacornac charts; this latter instrument was adopted by the French Government for the Carte du Ciel project in 1886 April. Christian Henry Frederick Peters (1813?–90) worked to a similar scale with each chart averaging 3000 stars to 14th magnitude. It is probable that Pickering discussed the astrograph approach with the Henry brothers, or more probably the director of Paris Observatory Ernest Mouchez (1821–92), during his summer visit of 1883.

35. Pickering, E. C., *An investigation in Stellar Photography*, Am. Acad. Memoir (1886), presented 1886 March 10.

36. Between 1885 and 1923 the 0.20-m Bache astrograph took 53,754 plates, averaging >1400 plates per year; Pickering’s plan was ambitious and achieved an amazing output. 1891AnHar..26..1P, Table 1, gives a complete catalogue of dates and exposures. The first Bache

plate, taken on 1885 August 4, was a 48-minute exposure of the north celestial pole.

37. Mrs Draper supported HCO financially for 28 years, contributing $387,000 (*c.*£7 million today) together with major instruments.

38. Gerrish graduated from MIT in 1887 but had begun working in 1885 at the nearby Blue Hill Meteorological Observatory under director Abbot Lawrence Rotch (1861–1912). His mechanical skills proved useful at HCO where he devised several engineering solutions to improve the efficiency of the instruments; the Gerrish polar telescope is one such example.

39. Hearnshaw, John B., *Astronomical Spectrographs and their History*, (Cambridge, 2009), pp. 143–5. The four large prisms were made by splitting thick glass plates diagonally. They were fitted as drawers within a square brass box which weighed over 45 kg and was fixed in front of the 0.28-m objective; changing the number of prisms must have required a significant rebalancing of the telescope.

40. Barker, George F., 'On the Henry Draper Memorial Photographs of Stellar Spectra', Am Phil Soc presentation, 1887 April 1.

41. Pickering, Edward C., *Henry Draper Memorial. First Annual Report* (John Wilson, 1887), p. 8.

42. Letter from Pickering to Mrs Draper 1886 October 13; Boyd (1969), 93–4.

43. This letter suggests that Gerrish and Farrar were effectively on 'equal pay' at this time (*c.*£10,800 today). Gerrish would have received a pay rise after his graduation from MIT in 1887.

44. Mack, Pamela Etter, *Women in Astronomy in the United States 1875–1920* (Harvard University, 1977), p. 65. Letter from Pickering to Mrs Draper 1886 December 31, quoted in Boyd (1969) p. 95. Nettie Farrar married Charles Harris of California and they moved to Texas.

45. Today these are known as WR 139 and WR 133. Charles Wolf and George Rayet discovered three in Cygnus in 1867; Respighi found one in 1871; Pickering three in 1880/1; and Ralph Copeland six in 1883–4, all by visual means.

46. Pickering, Edward C., 'Draper Memorial photographs of stellar spectra exhibiting bright lines', *Nature*, 34 (1886), p. 440.

47. The engineer Uriah Atherton Boyden (1804–79) had died eight years earlier. Pickering first contacted the trustees of his estate in 1882. HCO gained control of the fund in 1887 February; this facilitated an immediate grant of $20,000 and an annual income of $11,000 (*c.*£360,000 and *c.*£200,000/year respectively today).

48. The attorney Robert Treat Paine (1731–1814) was an amateur astronomer and loyal supporter of Harvard College.

49. Fleming, Williamina, 'Harvard College Observatory Astronomical Expedition to Peru', *PASP*, 4 (1892), 58–62.

50. Haley (2016) p. 26 section 9.4, 'Pickering's alternative plan', summarizes the Harvard approach; see footnote 90 on p. 36 for the 1903 Harvard 'map of the sky'.

51 Winterhalter, Albert G., 'The International Astrophotographic Congress and a visit to certain European observatories and other institutions', Washington Observations for 1885 (Washington US Naval Observatory, 1891) 55–8, hereafter Winterhalter (1891). This useful summary provides an independent version of events at the Paris Congress in chronological order. This occupies the first 74 pages of the 350-page report which continues with a series of observatory visits, including UK.

52. Letter from Gill to Pickering, 1891 April 8. Jones & Boyd (1971), p. 210.

53. Hughes (2012) p. 689 describes how on 1887 September 10 young Edward Fleming boarded the Montreal Ocean Steamship *SS Prussian* at Glasgow docks bound for Boston. He was accompanied by his grandmother Mary Stevens (50) and cousins Andrew (11) and Joanna Stevens (11); none ever returned to Scotland.

54. Edward and Lizzie Pickering enjoyed a successful marriage of 34 years but had no children. It is possible that they supported Mina and her son's education in some way. This hypothesis explains how, despite her modest salary, Mina was able to send her son to MIT and pay for extra private tuition at the same time as supporting her mother and running a home. Jones & Boyd (1971) p. 394 hints at this possibility when describing Mina's 'strong personal attachment' to Pickering. By 1906 Mina's accommodation was also supporting her younger brother Charles James Stevens (1863–1920) and his two sons, Charles (12) and Malcolm (10), their mother having died in 1904 November. At this time she also had two dogs, a Boston terrier and a beagle hound.
Pickering's 1919 Will & Codicil included no provision for Edward Fleming; the author is grateful to Robin Carlaw (Harvard University Archives) for supplying a copy of these documents.

55. Reed, Helen Leah, 'Women's Work at the Harvard Observatory', *New England Magazine*, 12 ii (April 1892), p. 167.

56. Jones & Boyd (1971) pp. 189–93. The Observatory Pinafore was written in 1879 August but not performed until 1929. One reason was the early death of Joseph McCormack in 1880, from typhoid, which left HCO staff disinclined to stage a musical parody of H.M.S. Pinafore. It can be accessed online at: http://hea-www.harvard.edu/~jcm/html/play.html. It includes the notion of Mina teaching HCO staff a Highland polka, had she not returned to her native land.

57. McCarthy, Martin F., 'Fr. Secchi and Stellar Spectra', *Popular Astronomy*, 58 iv (1950), 153–68.

58. Pickering E. C., 'A Fifth Type of Stellar Spectra', *Astronomische Nachrichten* 127 i (1891). Fleming prepared most of this paper.
Fleming, Williamina, 'A Sixth Type of Stellar Spectra', Harvard *Circular 145*, 1908 December 1.

59. Hoffleit (1991) pp. 120–3. See also: Hoffleit, Dorrit, 'Pioneering Women in the Spectral classification of Stars', *Phys. Perspect.*, 4 (2002), 370–98 which includes a section on Mina pp. 371–81. At this time (1886–91) the idea of stellar temperature being linked to spectra had not been proposed.

60. Misses R. W. Gifford, Annie Masters, Jennie Rugg, and Nellie Storin also worked at HCO at this time, but due to marriage mostly for only two years. The job of assistant required 'knowledge of ordinary arithmetic and legible handwriting'; it was mainly clerical, tedious and repetitive but nevertheless viewed as respectable work for an American woman at the end of the 19th century.

61. The arrival of three graduate women at HCO might have undermined the role of Mina Fleming. In practice only Maury's arrival seems to have caused a problem. This may well have arisen from her lowly pay of

25c per hour but probably resulted from her preference to speculate about the evolution of stars, which Pickering found difficult to restrain.

62. Maury calculated the orbits and periods of revolution for the first two spectroscopic binaries; this involved analysis of plates taken across 70 nights at HCO in 1889.

63. Cecilia Payne-Gaposchkin, recalling Maury as an older woman when she periodically returned to HCO, described her as 'sensitive, imaginative, affectionate ... a rejected sort of person'. She was very talkative and undoubtedly found the routine atmosphere of HCO taxing.

64. *The Spectra of Bright Stars* involved analysis of 4800 photographs of 681 bright northern stars; Annie Cannon's work (Part II of Vol. 28) appeared three years later, for 1122 bright southern stars. Mina edited both volumes.

65. Barnard 33/IC 434. The compiler of the first *Index Catalogue*, J. L. E. Dreyer (1852–1926), omitted Fleming's name; research by Stephen Waldee and Martha Hazen, 1990PASP..102.1337W.

66. 1890AnHar..18..113P, Vol. XVIII. No. VI, 113–17.

67. 1890AnHar..119P, Vol. XVIII. No. VII, 119–214.

68. Haley (2016), p. 14.

69. Mina's work built on Nettie Farrar's initial survey of 117 polar stars, illustrating how Pickering planned many projects in cycles expecting to add further results as the technology improved and his assistants developed their skills. Leavitt and Fleming would both later extend this work.

70. Spectra of the Draper astrograph were one-third the length of the Bache ones; importantly, red stars could now be investigated. The Wolsingham Observatory Circulars, by Rev. T. H. E. C. Espin (1858–1934), for 1887–1900 were received at HCO; his visual study of variable stars, red stars, and remarkable spectra were often included by Mina in her references.

71. 1890AnHar..27..1P 'The Draper Catalogue of Stellar Spectra'. Mina's 1890 papers included: 1890AN..123_383P, 'Spectra of δ and μ Centauri' dated January 16; 1890AN..124_175P, 'New Variable in Caelum' dated February 26; 1890AN..124_271P, 'New Variable Star in Cygnus' dated April 16; 1890AN..125_155P, 'Stars having Peculiar Spectra' dated July 1; 1890AN..125_361P, 'New Variable Star in Scorpius' dated July 31; 1890AN..125_363, 'Stars having Peculiar Spectra' dated September 8; 1890AN..125_365, 'New Variable Star in Sagittarius' dated September 12; and 1890AN..126_117P, 'Stars having Peculiar Spectra including new Variables in Triangulum and Hydra' dated October 21. 1891AnHar..26..1P 'Preparation and Discussion of the Draper Catalogue Part 1'. Despite carrying out the bulk of the classification and supervising the entire production of the catalogue Mina was not listed as co-author of either volume. Instead Pickering credits her work on page xxiv of the Introduction.

72. 1893 March 2 transfer at rate of 6000 plates per hour. Each box contained one hundred 20 × 30-cm plates. The building measured 18 × 9 m with three storeys including a basement. A room for examination and discussion was included.

73. 1892 HCO *Annual Report*. $9200 donations, about two-thirds the cost raised; 1896 HCO *Annual Report* confirms cost of $15,000; 1904 HCO *Annual Report* $20,000 anonymous gift used partly for 9-m square three-storey extension.

74. 1893PASP..55..220 …'The Bruce Photographic Telescope' pp. 221–2 includes a description of the second-floor storage room for the plates: 'Two large cabinets run through the centre of the room, and are divided into compartments, each capable of holding 100 plates. There are 120 of these compartments, so that each cabinet will hold 12,000 plates. One is devoted to the photographs taken at Cambridge and the other to those taken in Peru. The plates taken by the new [Bruce] instrument will be larger, so that a cabinet with larger compartments has also been prepared, which will hold the result of about a year's work.'

75. 1890AN..125..361P 'New Variable Star in Scorpius', 1890 July 31.

76. 1892AN..131..61 'A New Variable Star in Aries', 1892 September 9.

77. 1892AN..129..112 'Ueber den neuen Stern in Auriga', 1892 February 15.

78. 1891AN..128..377P 'Distribution of Energy in Stellar Spectra', 1891 October 31.

79. 1891 HCO *Annual Report* pp. 175–6. Including this discovery might have prompted Maury to return to HCO as she regarded β Lyrae as 'her work'.

80. *The Sidereal Messenger* (10 volumes) preceded *Astronomy and Astrophysics* (3 volumes) which in turn was succeeded by *The Astrophysical Journal* from 1895. Hale and James Edward Keeler (1857–1900) collaborated with Pickering. When *ApJ* launched Hale overcame a funding deficit by contacting Pickering. A $1000 cheque (*c.*£18,000 today) duly arrived from Miss Bruce; this enabled better-quality illustrations to be used. HCO supported Hale's endeavours by supplying regular papers and discovery announcements. *The Sidereal Messenger* and *AstAp* can be searched using the Hathi Trust Digital Library.

81. 1892AstAp..11..418 'Stars having Peculiar Spectra', 1892 April 14; see also 1892AstAp..11..765, October 10; and 1892AstAp..11..945, 1892 November 10.

82. The World's Columbian Exposition celebrated the 400th anniversary of Columbus. Hale was the main organizer and was supported by astronomer George Washington Hough (1836–1909). Hale promoted the emerging science of astrophysics by including presentations on spectrum analysis, astronomical photography, and stellar photometry.

83. It is likely that Mina also prepared some of Pickering's paper 'The Constitution of the Stars' which appeared just before the Congress in 1893AstAp..12..718. Hale had invited Pickering to present his paper but testing of the new Bruce telescope was underway at Cambridge and the Director sent his brother William instead; Mrs Draper also attended the Exposition and would have seen the enlarged photographs taken during her visit to HCO two years earlier – see Fig 12. See also Sobel (2016), pp. 54–5.

84. 1893AstAp..12..683 'A Field for Woman's Work in Astronomy', 1893 August 4.
Brück, M. T., 'Lady Computers at Greenwich in the early 1890s', *QJRAS*, 36 (1995), 83–95, provides a UK perspective for the short-lived (1890–5) experiment of employing female assistants at this time.
See also: Reed, Helen Leah, 'Women's work at the Harvard Observatory', *New England Magazine*, 6 (1992), 165–76. This paper includes an image of Mina in her earlier years at HCO.

85. Ogilvie, Marilyn Bailey, *Women in Science: Antiquity through the 19th Century*, (MIT, 1986), p. 153.

See also Haley (2016), pp. 29–32.
Dorothea Klumpke (Klumpke-Roberts after 1901) had begun working for Ernest Mouchez in 1887 and supported him significantly during the last five years of his life, especially after his deafness became acute.

86. 1893AN..134..59P 'Entdeckung eines neuen Sterns im Sterbilde Norma', 1893 October 29, gives details of Pickering's telegram to Kiel. 1893AN..134..101P 'A New Star in Norma', 1893 November 9, gives more details of Mina's discovery of her first nova – the first nova detected by spectral photography.

87. 1893AN..134..181 'The New Star in Norma', 1893 November 28. Pickering describes the two methods Mina used for measuring the position of images.

88. The Bruce plates measured 35 × 43 cm.

89. *Cambridge Chronicle*, Vol. L, no. 17, p. 2, 'Something about women astronomers employed at Harvard Observatory', (1895 April 27). At this time Mina was living in Frost Street, Cambridge, but planning a new residence to be built in Huron Avenue, near Brendon Street, a 'stone's throw' from HCO.

90. HarCi001, 1895 October 30. Mina's second nova.

91. HarCi004, 1895 December 20.

92. Caldwell, N., and Phillips, M. M., 'Star formation in NGC 5253', 1989ApJ..338..789C, includes the Harvard discovery plate taken in 1895 July. The first extragalactic supernova discovery was by Hartwig 10 years earlier: SN 1885A (S Andromeda); the second was by Wolf, 1895A (VW Vir) in NGC 4424.

93. HarCi006, 1896 March 10. Mina was checking between 24 and 66 plates for each variable star.

94. HarCi007, 1896 June 5. HCO were also now confirming variable star discoveries made by astronomers across the world.

95. HarCi009, 1896 July 9.

96. 1894AN..137..71, 1894 November 21.

97. HarCi011, 1896 August 31.

98. 1897AnHar..28..1M, *Spectra of Bright Stars*. Maury studied 4800 plates for this HDM investigation which began in 1888. The report is 128 pages long, including supplementary notes relating to the discoveries of the spectrum of helium.

99. While Maury was examining spectra up to 80 mm long Fleming continued to work with the 0.20-m Bache and Draper astrographs with spectra between 2 and 6 mm length, produced by objective prisms of refracting angle 5° and 13° respectively.

100. http://ocp.hul.harvard.edu/ww/fleming.html links to Mina's 1900 Journal. At this time she was editing Miss Cannon's work and noted: 'This takes more time and concentration of thought than any manuscript I have worked on since we put Miss Maury's volume (XXVIII Pt. I) through the printer's hands'.

101. Annie Cannon began on payroll in 1897 September. Lafortune, Keith, 'Women at the Harvard College Observatory, 1877–1919: Women's Work, The New Sociality of Astronomy and Scientific Labour' unpublished MA thesis, University of Notre Dame, 2001; hereafter Lafortune (2001).
I am grateful to Keith Lafortune for a copy of his thesis. It examines three points of view: 1. women's work in the sciences; 2. more collaborative industrial approach; 3. a cultural study of women in the workplace at HCO. For Annie Cannon he includes a letter from Pickering, dated 1896 January 15: 'Spend as much time at the Observatory as you wish ... I have spoken to Miss Leavitt ... one or more telescopes will also be available for the observation of variable stars which you wish to make.'

102. HarCi016, 'The Spectrum of ζ Puppis', 1897 January 12.

103. In 1898 June Pickering recommended Annie Cannon for a Radcliffe degree. She had worked five hours a day on HCO research for a year, observing 1–3 hours with the west equatorial on 63 evenings (365 observations of variables) and continued the work of Miss Maury, examining 1400 photos of ~400 stars to classify their spectra.

104. 1895 HCO *Annual Report* (the 50th). Pickering's three-month trip to Europe was probably a vacation; he did not attend RAS meetings in April, May, or June, possibly due to the criticism received from RAS President Andrew Ainslie Common (1841–1903).

105. 1903 HCO *Annual Report*. On 1903 May 23 Pickering completed his one millionth photometric setting (39,796 with 50-mm, 643,308 with 100-mm, and 316,896 with 300-mm meridian photometers). He regularly shipped the 100-mm instrument to Peru for Solon Bailey to complete surveys below –30° declination. Usually Pickering worked from 7 pm to 11 pm. Visual photometry to an accuracy of 0.1 magnitude was superseded by advances in photographic emulsions after 1912.

106. 1895ApJ..1..27P, 1894 December 14. Pickering used this paper for his talk but updated the number of variables discovered by Mrs Fleming to 80; she had also confirmed a similar number suspected by other observers. Vogel classification subscripts were now in regular use for spectra.

107. 1895ApJ..1..411F, 1895 April 9, 'Eleven new variable stars'; 1895ApJ..2..198F, 1895 July 5, 'Seven new variable stars'; 1895ApJ..2..354F, 1895 November 19, 'Eight new variable stars in Cetus, Vela, Centaurus, Lupus, Scorpio, Aquila and Pegasus'; HarCi006, 1896 March 10, '[14] new variable stars'; HarCi007, 1896 June 5, 'Ten new variable stars'; HarCi010 'Six new variable stars', 1896 August 13.

108. 1897AnHar..26..193, *Miscellaneous Investigations of the Henry Draper Memorial*. Mina's investigation, 'The Spectra of Stars in Clusters', is Chapter XIV, pp. 260–86.

109. Hoffleit (1991), p. 125. Mina investigated 975 star spectra in seven open clusters: Pleiades, Praesepe, Carina, NGC 3523, Coma, NGC 6405, and NGC 6475.

110. Eleven female assistants attended including Imogen Eddy, Mina Fleming, Edith Gill, Lillian Hodgdon, Eve Leland, Antonia Maury, Mabel Stevens, Anna Winlock, Louisa Winlock, Gertrude Wolfe, and Ida Woods.

111. Fleming, M., 'Stars of the fifth type in the Magellanic Clouds', in Proceedings of the Second Conference of Astronomers and Astrophysicists, *ApJ* 8 (1898), p. 232.

112. 1898ApJ…8_193. The youngest delegate was 18-year-old MIT student Edward Fleming, Mina's son, who would become a naturalized American in 1904 January, three years before his mother.
Donaghe, Harriet Richardson, 1898PA..6..481D, 'Photographic Flashes from Harvard Observatory', p. 483 is the source for Pickering's quote.

113. HarCi019, 1897 September 28. Some of these stars were also claimed by Stewart at Arequipa. Two later Bruce plates revealed 15 more in the LMC and one in the SMC.

114. 1898AN…147..141R, Entdeckung eines neuen Planeten 1898 DQ. French astronomer Auguste Honoré Charlois (1864–1910) at Nice Observatory photographed Eros on the same evening but did not announce the discovery until after Witt.

115. HarCi034, Witt's Planet DQ, 1898 September 30. Both Wendell and Fleming were working on Eros by September 6; the photographic brightness was less than the photometric brightness, so nearly 13th magnitude.

116. Falese, J., and Sliski, D., 'Asteroid 433 Eros, Part 1', http://altbibi.io/gazette/asteroid-433-eros-part-1/ 2013 October 17. Illustrates four labelled images of Eros on HCO plates.

117. HarCi036, Witt's Planet (433) DQ, 1898 December 26.

118. HarCi037, Additional observations of Eros (433), 1899 January 16, describes Mina's continuing work, although she is not mentioned in the text. Instead Pickering used the opportunity to explain how the small 2° fields of the astrographs at Greenwich and Oxford were undermining their attempts to photograph Eros; Pickering was skilled at finding ways to praise the search capabilities of his doublet-lens astrographs.

119. HarCi051, Positions of Eros (433) in 1893, 1894 and 1896, 1900 June 7. It must have been a relief for Mina to delegate further study on Eros to her assistants; Eve Leland, Anna Winlock, and Ida Woods completed further measurements and reductions.

120. HarCi020, 'Spectrum of a Meteor', 1897 November 8.

121. HarCi031, 'The November Meteors', 1898 May 30.

122. HarCi035, 'The November Meteors in 1898, 1898 November 19'.

123. HarCi040, 'Photographing Meteors', 1899 February 20.

124. HarCi021, 'A New Spectroscopic Binary', 1898 January 1.

125. HarCi024, 'New Variable Stars', 1898 January 31.

126. HarCi029, 'Variable Stars of Short Period', 1898 May 21.

127. HarCi032, 'Stars having Peculiar Spectra', 1898 June 21. Annie Cannon's investigation of Stars resembling ζ Puppis is in the same *Circular*.

128. ApJ1898..8..233F, 'Classification of the Spectra of Variable Stars of Long Period'.

129. HarCi042, 'A New Star in Sagittarius', 1899 March 14. Mina's fifth nova discovery – a nice way to celebrate her new role as Curator of Astronomical Photographs.

130. 1900ApJ..12..52P, 'A New Star in Aquila', 1900 July. See also HarCi056 'Anderson's New Star in Perseus', 1901 February 27; the final paragraph gives spectrum details observed by Mina.

131. This was Pickering's fourth trip to Europe. He first crossed the Atlantic in 1870 for the total solar eclipse in Spain, then in 1883 for a vacation and tour of observatories, and another three-month vacation in 1895. On this fourth trip he left his wife to represent him at Paris while he returned to HCO. One possible reason was the Georgia solar eclipse on May 28 to which a number of staff travelled south to observe. The Exposition Universelle of 1900 was a world's fair in Paris from April to November and was visited by *c.*50 million people; it included the 1.25-m refractor, which was never completed.

132. 1900MNRAS..61..293.

133. http://oasis.lib.harvard.edu/oasis/deliver/~hua09003 The Chest of 1900 includes eight document boxes and eleven envelopes of photographs to mark the end of the 19th and beginning of the 20th century. The wooden chest was sealed until 1960 and re-examined in 1999; it covers the month of 1900 March/April. Lafortune (2001) includes a quote from an undated draft letter from Mina to Louise Carnegie: 'Please do not place too high a value on my work. I have only done the best I could with what was given to me and I do often feel that someone else with my opportunities might have done better' but the draft statement is crossed out. Papers of Williamina Fleming Misc. Correspondence HUG 1396.

134. Lafortune (2001), Appendix 2.

135. 1900ApJ..12..84P, 'Harvard Observatory Expedition'. No glass plates were secured due to the instrument being knocked at the critical moment.

136. MIT *Technology Review*, vol. II, no. 3 (1900), 'The Georgia Solar Eclipse'.
See also Sobel (2016), p. 98. Another member of the HCO group was Annie Cannon. For Mrs Draper this was her second solar eclipse – she had spent the 1878 eclipse inside a tent, calling out time signals to her husband's group outside.

137. 1901AnHar..28..129C. Cannon chose not to use Maury's scheme of 22 classes for bright northern spectra.

138. Concord Avenue marks the southern boundary of HCO. Cannon's diaries for 1894, 1905, 1907–11, and later years can be accessed via Harvard University Library. HUGFP 125.2 Box 1.

139. HarCi054, 'Sixty-four New Variable Stars', 1901 January 24.

140. RR Lyrae was discovered by Fleming in 1900; earlier examples of this class included U Lep and S Ara, together with cluster variables found by Solon Bailey.

141. HarCi060, 'Objects Having Peculiar Spectra', 1901 July 6.

142. HarCi065, 'A New Algol Variable +43° 4101', 1902 May 6. The star was at maximum brightness of mag. 8.9 on 388 plates; 19 plates showed it at mag. 9.3 or fainter. Pickering was delighted that the HCO Plate Store, which now covered 14 years, could reveal such discoveries.

143. 1903AnHar..48..91P, 'A Provisional Catalogue of Variable Stars'. In 1880 about 200 variable stars were known.

144. HarCi070, 'Nova Geminorum Before its Discovery', 1903 April 3.

145. 1903 HCO *Annual Report*, p. 253. In a letter to Mrs Draper, Pickering described the 'suitable arrangements' for Mina to work on the Southern Draper Catalogue at home in the evenings: 'a measuring apparatus has been made for her and a recorder provided'. Sobel (2016), p. 108.

146. HarCi084, 'Carnegie Grant of 1903', 1904 August 24. The HCO Plate Store was growing at ~10,000 plates per year.

147. Ida May Stevens was the 34th female assistant at HCO. She was born in Cambridge in 1882, the second child and only daughter of Robert Stevens and Anne Emerson. At this time she was the youngest female employee. In 1907 she married and became Mrs Garret; she left HCO in 1909 after five years. Her Aunt Johanna completed 17 years at HCO; she was

awarded a gold medal by the AAVSO for discovering the first nova in Lyra.

148. HarCi076, 'Stars Having Peculiar Spectra', 1904 March 21.

149. HarCi099, 'A Probable New Star, RS Ophiuchi', 1905 May 15. Annie Cannon deduced the light curve.

150. RS Ophiuchi is now classified as a recurrent nova, and consists of a red giant and a white dwarf in close orbit. Eruptions occur about every 20 years, typically reaching 5th magnitude; at other times the star remains at 12th magnitude.

151. HarCi106, 'H1175 Nova Aquilae, No. 2. 185604', 1905 September 23.

152. They would have visited the laboratory dedicated to the memories of the pioneering work of Henry Draper and John Draper.

153. The four other women astronomers were: Caroline Herschel (1750–1848), Margaret Lindsay Murray Huggins (1848–1915), Mary Somerville (1780–1872), and Agnes Mary Clerke (1842–1907); Anne Sheepshanks (1789–1876) was also honoured for her gifts to astronomy.

154. *Wellesley College News*, Vol. 5, No. 34, p. 1, 1906 July 11. Mina was appointed Honorary Fellow in the Department of Astronomy at Wellesley College.

155. HarCi111, 'Stars Having Peculiar Spectra. 13 new Variable Stars', 1906 February 16; HarCi117 183390, 'A new Algol Variable. –30° 16169. H 1236', 1906 May 20.

156. 1906HarCi111, 'Spectra of Known Variables', 1906 February 16, p. 3. Also see Astronomy Picture of the Day (APOD) 2015 September 17.

157. Mrs Lizzie Wadsworth Pickering (1849–1906) was the daughter of Jared Sparks, the President of Harvard College 1849–53. She supervised the grounds of HCO and was an expert on floriculture, with floral displays rivalling the botanic gardens. She introduced university teas for college students and was patroness of Harvard plays and a Cambridge society leading hostess. She was buried in Mount Auburn Cemetery, Cambridge. See also Sobel (2016), p. 119.

158. HarCi123, 'Photographs of Faint Stars', 1907 January 19. HCO specialized in information for any star to 13th magnitude covering a period of 20 years.

159. Mina recounted her fire-fighting experience to young Margaret Carnegie, explaining their monthly drills and system of telephone rings used to pinpoint the location of any fire on the HCO site. HUG 1396.

160. HarCi124, 'Stars Having Peculiar Spectra. 18 new Variable Stars', 1907 January 26; HarCi131 'Group of Red Stars near Nova Velorum', 1907 October 3; HarCi132 'Stars having Peculiar Spectra. 15 New Variable Stars', 1907 October 15.

161. Henrietta Leavitt continued the NCP work until 1921, identifying 46 stars from 4th to 21st magnitude using almost 300 plates taken with apertures from 13 mm to 1.5 m.

162. Margaret Harwood became director of the Maria Mitchell Observatory in 1916 and supported the development of Harvard Astronomical Fellowships for Women with the help of Pickering.

163. 1907AnHar..47..1F, 'A Photographic Study of Variable Stars'; 113 pages of Mina's research.

164. Eve Leland, Louisa Wells, Sarah Breslin, Mabel Gill, and Mabel Stevens assisted Mina with the identification and computation of the comparison stars.

165. Mina's American citizenship is dated 1907 September 7. Sobel (2016), p. 127.

166 Tenn, Joseph S., 'A Brief History of the Bruce Medal of the A.S.P.', *Mercury*, 15 iv (1986), 103–11.

167. Letter from Pickering to Gill, 1907 March 27, Royal Geographical Society with The Institute of British Geographers, The Gill Collection (DOG/125). This source consists of four boxes with 34 files and 1000 letters consisting mainly of correspondence from astronomers to David Gill. They are designated DOG/1–DOG/192 and have been transcribed by the author.

168. 1908AnHar..50..1P, 'Revised Harvard Photometry – observed with the 2-inch and 4-inch Meridian Photometers'. Mina acknowledged the assistance of Florence Cushman, Mabel Gill, Amy McKay, and Mabel Stevens from her team.

169. HarCi145, 'A Sixth Type of Stellar Spectra', 1908 December 1. See also Hoffleit (1991), p. 139, for a discussion of Class R stars.

170. 1908ApJ..28..250, 'Astronomical and Astrophysical Society' includes Mina as the only female presenter. An account of the meeting is in JRASC..2..255–60 (1908) but does not include Mina at the event.

171. 1909PA..17..463–4 and 1909PA..17..588. Mina's paper was 'A Photographic Spectrum of a Meteor'.

172. *The Salt Lake Tribune*, Utah, 1909 August 22, p. 20, mentions this was Mina's first trip to the far west. Her son Edward was then a chemist in charge of a laboratory at Garfield.

173. Hertzsprung's *Zur Strahlung der Sterne* was published in 1905 on stellar magnitudes and luminosities. Maury's work was duly acknowledged in 1922 by the IAU when they modified Cannon's scheme to include the prefix 'c' for stars with narrow sharp lines.

174. Holberg, Jay B., *Sirius: Brightest Diamond in the Night Sky*, (Springer, 2007), 114–17. Russell published his recollection of Mina's involvement in 1944.

175. 40 Eridani is a triple-star system 16.5 light years away, first observed by William Herschel in 1783. The primary is magnitude 4.4 and of spectral class K1 (an orange dwarf). The 9th-magnitude companion B is the most easily observed white dwarf for amateur astronomers. An 11th-magnitude component C is a red dwarf in orbit around the white dwarf. For *Star Trek* fans there is an interesting link between Mina Fleming and Mr Spock: the planet Vulcan was reputedly located within the 40 Eridani system!

176. The Solar Union had been started by Hale in St Louis in 1904 September, meeting again in Oxford in 1905 September and Meudon in 1907 May. It was a forerunner of the International Astronomical Union.

177. Plotkin, Howard, Edward Charles Pickering's Diary of a Trip to Pasadena to Attend Meeting of Solar Union, August 1910. This fascinating account by Pickering provides a real insight into both the journey and organization of this major conference. Curiously Mina (the only other HCO delegate) is not mentioned once.

178. 1910JRASC..4..356C, 'The Mount Wilson Conference of the Solar Union' by C. A. Chant, pp. 356–72, and 1910PASP..22..169W, 'The Fourth Conference of the International Union for Co-operation in Solar Research' by H. C. Wilson, pp. 169–79, provide complementary summaries of this event.

179. Mary Walker (1832–1910) died September 6; at this time Mina and Edward were in Salt Lake City.

180. *Harvard Bulletin* 426, 1910 October 1.

181. *Harvard Bulletin* 427, 1910 October 13.

182. 1911ApJ..33..260, 'Correspondence concerning the classification of stellar spectra', pp. 260–300. A fascinating account of the views of astronomers across the world; the adoption of 'absolute magnitude' and its link to the luminosity of stars had been introduced by Kapteyn in 1902, but would not be ratified until 1922. See also: Hughes, David W., 2006JAHH..9..173H, 'The Introduction of Absolute Magnitude (1902–22)'.

183. 1915JRASC..9..203C, 'The Henry Draper Memorial' by Annie J. Cannon gives a useful summary. Cannon succeeded Fleming as Curator but remained on HCO payroll until 1938. During 1911–15 she completed classifications of stars to 8th magnitude for the new HD catalogue. These were published 1918–24 and covered 225,300 stars. Cannon then extended her work to fainter magnitudes up to 1936 (she was then aged 73); she died 1941 April 13.

184. 1912AnHar..56…165F, 'Stars having Peculiar Spectra', pp. 165–226 with two plates.

185. Mina was living at 52 Concord Avenue, Cambridge, in 1911. Her autopsy showed blood poisoning in kidneys and spleen, so recovery from pneumonia was unlikely.

186. 1911 HCO *Annual Report*.

187. Thompson (1912). See also Pickering, E., *Harvard Graduates' Magazine*, vol. 20 (1911), 49–51. Pickering's eulogy for Mina can be accessed through the Hathi Digital Trust Library.

188. 1912MNRAS..72..261.

189. 1911ApJ..34..1, 'Williamina Paton Fleming'.

190. *Cambridge Tribune*, 1911 May 27. Interment was at Mount Auburn Cemetery, Cambridge. Founded in 1831 it was the first large-scale landscaped burial ground set in tranquil surroundings. The final resting place of Edward Pickering and his wife is located nearby. Lafortune (2001), p. 145, states that Pickering is in lot #3401 and Fleming, a short distance away towards Harvard Square, in lot #6188.
Cambridge Chronicle, 1911 May 27. Mina died on Sunday afternoon at New England Hospital. Her funeral was held Tuesday afternoon at her home, 52 Concord Avenue, with Rev. Joel Hastings Metcalf (1866–1925); the Harvard quartet played three hymns. Her son was working in Chile at the time; he died in 1951.
Metcalf was a skilled optician who made a 0.40-m f/5.25 doublet and a 0.25-m f/4.9 triplet photographic lens for HCO. The former instrument was installed in 1910 and used curved 20 × 30-cm plates. The Metcalf triplet anastigmat was used at both Arequipa and Bloemfontein; its design doubled the field of good definition (to 8° square) achieved by the Bache astrograph.

191. Thompson (1912).

192. This statement supports the author's opinion that the success of HCO was not solely built on the leadership of Pickering but benefited significantly from Mina's input behind the scenes.
Paul Kohlmiller has presented an interesting case study: 'Annie Jump Cannon – the most important woman in the History of Astronomy' (2006) [www.ephemeris.sjaa.net/0612/Cannon.pdf]. However he underestimates the role of her mentor of 15 years and his criteria focus more heavily on her later years, a time when many of the uncertainties of stellar evolution had been resolved. Certainly Cannon became proficient at the rapid classification of stellar spectra, but a quote by Cecilia Payne-Gaposchkin given by Kohlmiller (from Greenstein, 1993) is instructive: '[Cannon] had amazing visual recall, but it was not based on reasoning. She did not think about the spectra as she classified them ... she simply recognised them.'

193. Hucht, Karel A. van der, 'The VIIth catalogue of galactic Wolf–Rayet stars', *New Astronomy Reviews*, 45 (2001), 135–232 gives a total of 227 galactic WR stars. Mina's 1912 catalogue was the second such catalogue; the first was due to William Wallace Campbell (1862–1938) in 1884 containing 55 stars, 12 of which have since been deleted. Mina listed 94 discoveries of Type V stars (Spectrum O), including 21 within the LMC and 1 in the SMC. Hucht lists 53 discoveries by Mina within the Milky Way. Adding the 22 she found in the LMC and SMC gives Mina a total of 75 WR stars. Among these is the eclipsing binary WR 22 (HD 92740), one of the most massive stars known (>70 solar masses), which she discovered in 1889.

194. 1917AnHar..71..27F, 'Spectra and Photographic Magnitudes of Stars in Standard Regions'. See also Hoffleit (1991), 140–1.

195. 1912 HCO *Annual Report*, Miscellaneous section.

196. http://dasch.rc.fas.harvard.edu/project.php The Plate Store covers the period 1885–1992. See also Sobel (2016), 264–6.

197. Carlisle, Camille M., 'Flood Threatens Photographic Plates', *Sky & Telescope*, 2016 March 8.
Some 12% of the HCO Plate Store was affected by the flooding. Insurance cover fortunately facilitated a new (faster) scanner and the DASCH project is back on track. In due course this will allow all of the HCO plates that Mina Fleming and her team of computers investigated to be accessed online. In addition a team of volunteers are busy transcribing the individual research journals of the female assistants.

198. 'DASCH data release 5 (DR5) now available; update on Flood Recovery', American Astronomical Society, 2016 August 9.

The author

Paul A. Haley was born in 1956 and has lived near Hereford, England, with his wife Ann for the past 26 years. Following a 20-year secondary teaching career he spent eight years delivering astronomy heritage projects across Europe, as director of both The Share Initiative and Space Today UK. Paul is a regular contributor to both the SHA *Bulletin* and *The Antiquarian Astronomer*. Future work will include a new biography of Sir David Gill together with further work on the Wolf–Rayet discoveries of Mina Fleming; design and production of stained-glass panels to commemorate different aspects of the history of astronomy; and further development of Birch Hill Observatory. Paul's other interests include Pyrenean Mountain dogs and mountaineering.

The Great Observatory at Downside 1859–67

Stephen P. Holmes and Charles Fitzgerald-Lombard

Had it not been for an unattended heating furnace and an unexpected wind, the history of English astronomy in the late 19th century might have been quite different. As it was, these two chance events combined to cause a fire which destroyed an observatory housing what was at the time one of the largest refracting telescopes in the world. The fact that both the telescope and the observatory are now almost entirely forgotten is probably due to their seemingly unlikely location – the grounds of Downside Abbey, a Benedictine monastery between Bath and Wells in Somerset. This paper seeks to rescue the Great Observatory from obscurity by detailing the reasons why it was built at Downside in the first place; its design and construction; its brief operational life; and finally its sad demise. A few speculations are then entered into regarding what the observatory might have achieved had it survived.

1. A little background

To understand why Downside Abbey was not, in fact, as unlikely a location for a major astronomical observatory as might be thought it is necessary to go back several centuries, assisted by information gleaned from a very full history of the Abbey and school, *Downside*, written by the Benedictine monk and historian Henry Norbert Birt (1861–1919).[1]

Late in the 16th century, the reforming zeal of Elizabeth I meant that Catholic priests who continued their training and ministry in England risked capture, torture, and death. Schools were thus established on the near-continent where priests could be trained in safety to fill up the rapidly dwindling ranks of the old clergy. These schools were often located in religious houses, widely separated from one another, and so a desire arose to found a new centre into which these scattered communities could be gathered.

1.1. *St Gregory's College is established*

In the case of the Benedictine Order this was finally achieved in 1606 when a monastery dedicated to St Gregory was founded in the French town of Douai, into which they moved in 1611. Douai was chosen because of its pre-existing English College of the secular clergy and also because it was a university town already popular with English recusants. Other houses were established in Dieulouard, Lorraine; St Malo, Brittany; and Paris.

It was not only priests who suffered as a result of the Reformation, as it became almost impossible for Catholic children to obtain a decent education in England. Those families who could afford it were able to send their children to the continental English schools which, although they had originally been established for the training of priests, were now being opened up to lay persons also.

It was natural for the tutors at these schools to be drawn from the religious community, not just for theological reasons but also because monks were themselves among the best-educated people around at the time. The Benedictine Order in particular was at the forefront of this development, as it had a long tradition of service to the community and a flexibility of organization which enabled it to restructure itself to meet changing needs.

As soon as the English monks were solidly established in Douai, their reputation for learning was recognized and they were called upon to provide professors of philosophy for Marchienne College in that town, and to occupy Chairs in the University. English parents naturally desired to entrust their sons (for it would only have been the sons in those days) to the training of the English monks and so there was a ready demand for their services.

Beginning very soon after the foundation of Douai, and firmly established by 1625, a predominantly lay school thus developed. This continued to prosper during the 17th and 18th centuries, expanding its buildings and number of students, but everything was brought to a crashing halt by the upheaval of the French Revolution in the late 1780s.

1.2. *Return to England and the move to Downside*
Many English students managed to escape back to their home country before the fortunes of war swung against the Revolutionary forces, who were forced to fall back to a defensive position in Douai town. This resulted in the community being forcibly evacuated in dreadful circumstances, after which the church and other buildings were ransacked and plundered to such an extent that after their eventual release from virtual captivity it was impossible for the monks to return to their former activities. Given also the considerable antagonism for the English which had developed after the Revolutionary Wars, it was clear that Douai could no longer be relied upon to afford a home.

Fortunately, the religious climate in England was now very much more tolerant than it had been two centuries earlier, and so permission was sought for both the monks and the lay people still with them to escape the disturbed state of France by travelling across the Channel. After a number of refusals, permission was finally granted early in 1792 when 92 individuals drawn from several religious communities in Douai and St Omer bade farewell to France, crossed the Channel in an American vessel, and made landfall at Dover on March 2.

The deprivations of captivity had reduced the numbers at St Gregory's to such an extent that barely a dozen were left by the time of the return to England. They were initially supported by Sir Edward Smythe (1758–1811), a former pupil, at his family seat of Acton Burnell in Shropshire, where he put aside a portion of the park (and later a wing of his house) so that a school for boys might be opened. This grew slowly, and a chapel was added, but a combination of financial constraints and hopes of an eventual return to Douai hampered its development.

Fate intervened again in 1811 however, when Sir Edward died. His son required all the accommodation at Acton Burnell for his young family and the dowager Lady Smythe, and so another move became necessary. After considering a number of locations, an area of land close to the city of Bath was purchased. Hence in 1814 a new Benedictine house was established at Downside, together with a school whose reputation for educational excellence dated back many decades.

2. Later developments

All thoughts of a return to Douai eventually faded and the buildings at Downside, both religious and secular, were steadily added to over the next forty years. A serious downturn in fortunes in the 1830s caused by the opening in nearby Bath of Prior Park College, a competitor Catholic school offering a new and modern curriculum, was soon overcome so that by mid-century both the monastic community and the school were well established.

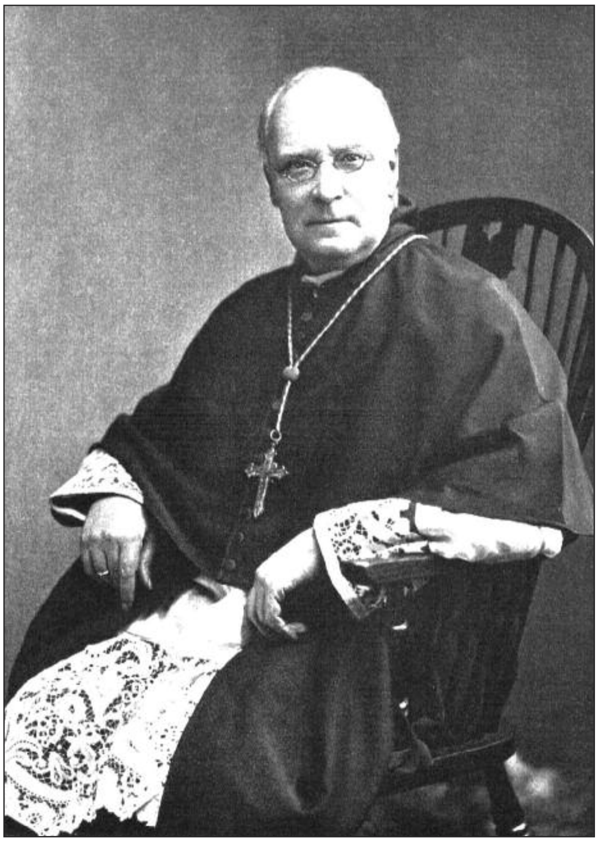


Fig. 1: Dom Benedict Snow. Educated at Downside from 1851–55 and ordained in 1865, he was librarian from 1866–68 and also curator of the observatory before leaving to become a parish priest. Snow was made Provincial of York and titular Abbot of Glastonbury in 1888 and died at East Dulwich. © Downside Abbey Archives.

Indeed, in 1854 Downside opened a major extension to its school, designed by the well-known Catholic architect Charles Francis Hansom (1817–88) of Clifton, Bristol. A comprehensive syllabus was now being taught, including modern and ancient languages, history, geography, mathematics, religion and, importantly for later developments, science.

This latter subject evidently included some aspects of astronomy. Terence Benedict Snow (1838–1905), curator of the short-lived observatory and later to become titular Abbot of Glastonbury, records in his 1903 book *Sketches of Old Downside* that 'Star-gazing at Downside has had its fluctuations. The Great Bear, the Polar Star, Orion's Belt, at times attracted flattering attentions, at others they twinkled on neglected and unnoticed; an erratic comet with its appendages would revive flagging interest, or Saturn's ring, or Jupiter's moons, or Venus chasing the setting sun over Cox's shrubberies. On these occasions a brass telescope was brought out, secured on a small table, and surrounded by a knot of boys awaiting their turn'.[2]

2.1. *Early astronomical interest*
How or why this fascination with astronomy was being fostered is unclear. The Benedictine writer Hubert van Zeller (1905–84), who resided at Downside Abbey, tells us in his 1954 book *Downside By and Large* that during the academic revival of the 1840s 'ornamental science' was added to the curriculum.[3] The development of this subject was strongly encouraged by contacts with London University, while the Great Exhibition of 1851, where large telescopes were displayed and the first national weather forecasts were posted, spurred a wider interest in all things scientific, particularly astronomy and meteorology. Abbot Snow tells us that at Downside, 'The complete set of meteorological instruments, the records of which were sent to Greenwich, furnished another instruction to scientific knowledge'.[4] The 1854 extension added a chemical laboratory and study-room, and students were being taught in the quaintly named philosophical-instrument room.[5]

Whatever the reason, the next development was a major one because as early as 1854 news arrived at Downside of the purchase in London of a 15-inch (0.38-m) object-glass, one of the largest in the world at the time. This rumour was later confirmed by the news that 'a building worthy of the glass' was in contemplation.[6]

Many aspects of the project raise puzzling questions, and these have been only partially resolved through recent research in the Downside archives. In particular, despite the fact that money must have been in short supply after the recent building extensions, here we have the community not only purchasing (Snow's word) perhaps the largest telescope in England but then apparently commissioning the same Charles Hansom who had been involved with the building extension to design a substantial observatory, transit room, library, and museum – the whole exceeding 2000 square feet (186 square metres) on two floor levels – generously appointed and decorated and with no obvious attempt at economy.

The only substantive clue arises from an entry in the archives which reveal that the (Latin) minutes of a Prior's Council meeting dated *Tertio Idus Iulii MDCCCLIX* [1859 July 13] record permission for the expenditure on the building of an observatory of *circiter £600* from the *peculium* [endowment] of Dom Benet Tidmarsh (1818–1902) who, being a councillor himself, had presumably presented the proposal.[7] In fact he had been cellarer (i.e. bursar) until 1854 and hence must already have worked with Hansom on the earlier building. It could be, therefore, that Norbert Birt was referring to Tidmarsh when he alludes to 'an enthusiast in astronomical research' in his description of the observatory.[8]

2.2. *Competition spurs determination*
Whether just the strong support of one individual, however influential, would have been enough to force through this expensive project is open to question. A critical factor that might have swung the argument is one that is well-known today – competition. The negative effect of another school opening nearby has already been mentioned, and there was more generally a lively rivalry between the various Catholic boarding schools and competition for pupils, especially from the leading Catholic families on whose benefactions they depended.

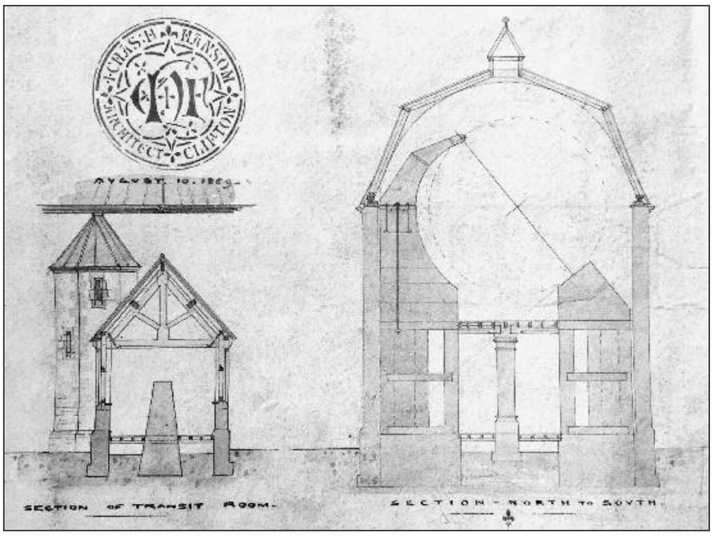
The Downside observatory might thus have been seen as a prestige project designed not only to attract more scholars to the school but also to support the independent academic life of the monastery itself. This had become increasingly important for many houses during the 19th century, when Catholics did not have access to English universities, and had developed entirely separately from the secondary schools attached to them.

An observatory would be particularly attractive as it would build upon the interests seemingly already active in the community. It would also be indicative of a scientific, and thus modern, outlook and serve as a counter to those facilities being set up by the Jesuit community who, historically, had an even greater interest in education and, latterly, science than the Benedictines. Indeed, the observatory they established at Stonyhurst College, Lancashire, in the late 1830s may well have provided a model for Downside.

The eminent Italian astronomer Angelo Secchi (1818–78), of the Jesuit Collegio di Romano Observatory in Rome, had stayed at Stonyhurst in 1848, in retreat from revolutionary troubles in Italy, and Stonyhurst's astronomical leanings, particularly in solar observation, apparently stemmed from his time there.[9] Around this time the Stonyhurst Observatory had acquired a 4-inch (100-mm) refractor, which was then upgraded to an 8-inch (200-mm) in 1867, and again to a 15-inch (380-mm) by Grubb in 1894.[10]

It is also recorded that 'throughout the 19th century improvements were being made to the buildings … The Stonyhurst Observatory was particularly well equipped

Fig. 2: Charles Hansom's final design for the Downside Observatory shows a north–south cross-section of the transit and equatorial rooms, with the astronomical library beneath. It bears the architect's stamp and is dated August 10 1859. © Downside Abbey Archives.



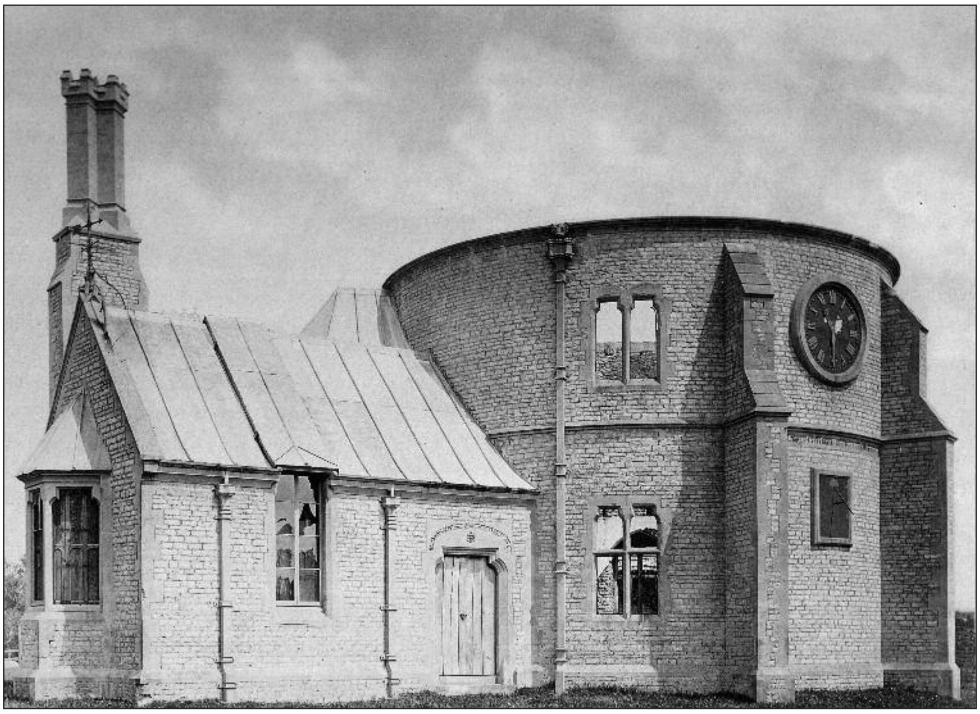


Fig. 3: The gutted shell of the Observatory building as it appeared in 1871, possibly taken by Monsignor Lord William Joseph Petre (1847–93), who was educated at Stonyhurst and Downside. He taught at Downside from 1874–77, where he endowed a library in 1876, a cloister, and a swimming pool.
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and between 1865–83 functioned as one of the Board of Trade's meteorological stations'.[11] These developments would not have passed unnoticed at Downside, possibly providing the extra impetus for the development of its own observatory.

However it was instituted, the dream of Downside becoming (to quote Snow) 'a centre of astronomical life' with 'visions of astronomical triumphs … and a halo of scientific glory'[12] was taken seriously, as is shown by the two sets of attractive coloured plans from the office of Charles Hansom, still in the Downside archives (Fig. 2).

Proof that this ambitious scheme was in fact executed is evidenced not only by Snow's narrative but also by a fine photograph of the fire-gutted, but otherwise upstanding, shell of this great observatory (Fig. 3). Nevertheless, the fact that the date of the architect's plans was some five years later than the news of the purchase of the object-glass does lead one to speculate what schemes, if any, might have developed in the meantime.

3. The 'Master Builder' arrives

While Hansom was the architect for the project, the site manager and, it would seem, designer of the scientific equipment within the Observatory was one 'Mr. Slater of London', from whom the object-glass had been purchased; we shall have more to say about him later. His arrival on site was clearly a dramatic event, for Snow tells us that

> In due course Mr. Slater, the maker of the glass, appeared, a short, square-built man, clad in a rusty black frock-coat, with an iron-grey grisly beard, florid cheeks, wandering eye and iron-grey hair encased in a black velvet smoking-cap. He was regarded with the deference paid to a magician with weird powers, especially on hearing that he had traversed the hilly road from Bath on a tricycle made by himself, and worked by a small steam-engine under the seat, at a cost of threepennyworth of spirits of wine for the journey. This combination of genius and economy fully established, in our youthful minds, his competency for any scientific undertaking.[13]

Spirits of wine is what would now be called methylated spirit, but whether Mr Slater actually had a meths-powered three-wheeler at this early, but not impossible, date is not entirely clear. Snow maintains the mystical tone of Slater's arrival in his next passage:

> On a bright playday the magician came, with an attendant spirit carrying a tripod, which when extended and erected supported, not a cauldron, but a theodolite. We thronged round the unwonted sight, and were warned to keep a respectful distance, from no danger to ourselves but rather to the instrument.
>
> The tripod flitted from place to place, mysterious wands were planted here and there, cabalistic characters were marked on the turf, and when the magician vanished we felt that the scientific era had really commenced.[14]

While the flowery phraseology is clearly deliberately overstated, it does capture something of the wonder attached to scientific endeavours in this era. Recall that Faraday's experiments with electromagnetism had been performed just 20 years before, and that chemistry was still imbued with more than a whiff of alchemy in the mind of the general public.

4. The Observatory building

Hansom's revised plan, bearing the date August 10 1859, simplified the earlier plan for a transit room but, if anything, elaborated the planned equatorial room, which was to be the principal workspace. The photograph of the shell, dated 1871, confirms the execution of this plan in every visible detail (Fig. 3).

A fine building, very much in Hansom's idiom, the Great Observatory was perched on the highest point of Mogg Hill and must have made a striking impression on those who ventured thus far from the main school and monastery (Fig. 4). Snow, though, was unimpressed:

> The building was not artistic; it was a temple of science, not of art. Even on a bright day, with the blue sky and a belt of dark trees behind, the picture did not satisfy the eye. A circular wall of white lias, thirty feet in diameter and thirty feet high, with buttresses and semi-Gothic windows surmounted by a large, glistening zinc dome of no approved shape, crowned by a cap in no known architectural fashion, was not a pleasing object … A small rectangular transit-room jutting up against it on the west destroyed its symmetry, and suggested a scientific washhouse.[15]

There speaks an architectural snob, one feels. To top everything off, both literally and descriptively, Snow tells us about the observatory roof:

> To gain access to every part of the heavens required ingenuity in the construction of the large, heavy roof. On the top of the wall and round the ninety feet of its circumference rested a thick iron plate, containing a large groove; at the bottom of the roof was a similar groove in a thick iron casting, furnished on the inner side with upwards of a thousand teeth; between the two grooves were placed cannon-balls, on which the roof rested and revolved. At intervals in the side of the wall were fixed capstan-looking wheels that worked rods with cogs fitting into the teeth of the roof plate, and on turning a capstan the roof slowly revolved; a couple of shutters turned back on hinges and left an open slit of six feet.[16]

Fig. 4: Pen-and-ink sketch of Downside Abbey and grounds from the archive collection of Dom Alphonsus Morrall (1825–1911), Prior of Downside 1866–68. The observatory building is shown at upper centre. The plan is undated, but is thought to have been drawn up in 1866, the year before the observatory was destroyed.
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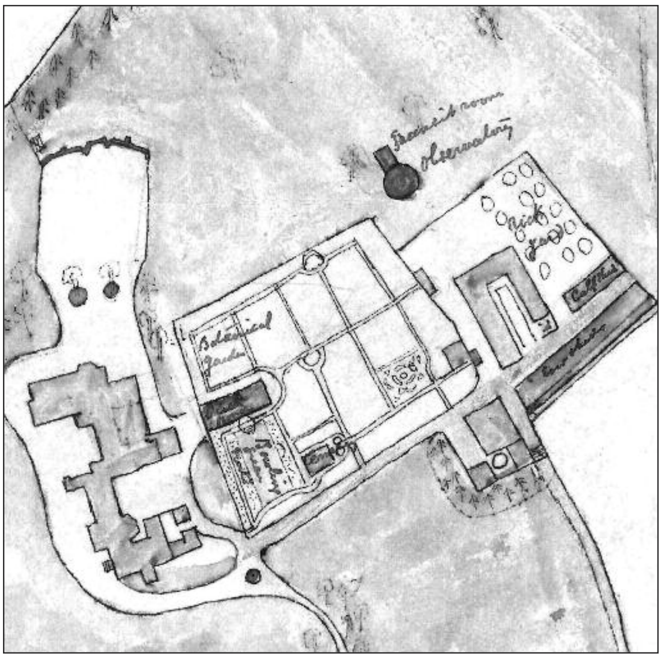

Cannon-balls were readily available in the mid-to-late 19th century, as artillery began to change over from ball to shell ammunition and also as surplus from conflicts such as the Crimean War and the American Civil War, and so the use of these mass-produced but accurately made spheres as bearings for observatory roofs was very common. In all other respects, the mechanism for causing the dome of the roof to revolve which Snow describes is almost exactly the same as in more modern large observatories.

4.1. *The equatorial and transit rooms, and the museum*

If the outside aspect was not to Snow's liking, he at least conceded that the inside was appropriate to its function:

> The interior was arranged solely with a view to scientific work. The circular building was divided into two compartments, the lower of which, some fifteen feet in height, was necessary in order to raise the telescope. The upper, the equatorial-room, reached by a spiral stone staircase, formed a spacious hall of noble dimensions, thirty feet in diameter, the walls fifteen feet high, and the apex of the dome some forty feet from the floor.[17]

Snow gives us an equally precise description of the transit room:

> In comparison with the equatorial, the transit room jutting out below was quite modest in size and appointments. Rectangular in form, it had casement windows in the north and south walls and a sloping zinc roof with two shutters. When these were drawn back, and the windows opened, it left a clear space from sill to sill six feet in breadth. The telescope, four and a half inches in diameter, rested on two small piers, and had an accurately fixed motion due north and south to catch the stars in the middle of their course and mark the time of the passage of the meridian. A transit-circle, clock, and the usual instruments completed the furniture.[18]

That last reference to the clock is of particular interest since it refers to the salvaged regulator timepiece still operative in the monastery. Having escaped the ravages of the fire, it was reconstructed some time in the early 1890s by Father Edward Stutter (1842–1922), a keen amateur astronomer, and taken by him to Acton

Burnell, where the Benedictines had initially been located after their flight from France and still had a presence. It there actuated the chronograph in the small observatory he had built, containing a 150-mm equatorial and a 75-mm transit instrument.[19] After Father Stutter's death the timepiece was stored for many years in a box at Downside until, in the late 1950s, it was restored by Dom Augustine James (1883–1970).

In the space below the equatorial room was found a home for the College Museum. We are told that 'Glass cases lined the walls and stood in the centre of the floor, and in these were stored fifty years' accumulation of collections and curios. Every phase of museum acquisitiveness was more or less represented … The whole was in good order, and formed the nucleus of a capital museum'.[20] The decision to display these items in such close proximity to the telescope would, as we shall see, have dire consequences some years later.

5. The object-glass

Before moving on to describe the construction of the telescope itself, it is appropriate to consider the wondrous object-glass. As mentioned above, both van Zeller and Snow tell us that it was obtained from a Mr Slater of London but give no further details. It is virtually certain, however, that this was Thomas Slater (1817–89), one of the most ambitious optical technicians of the 1840s and with a fairly high opinion of his own talents.[21]

He was certainly eager to experiment with the possibility of producing very large object-glasses, and is perhaps best known for the largely unsuccessful 24-inch (0.61-m) Craig telescope erected on Wandsworth Common in 1852 but disused by 1854 and dismantled just two years later.[22] A very comprehensive account of all aspects of the history of this telescope may be found at the website *The Craig Telescope, The Story of London's Lost Leviathan*.[23] On the page devoted to Thomas Slater it is stated that 'At his address in London [Somers Place, Euston] he had workshops and even a well equipped observatory housing his own skilfully made 14.78-inch (37.54-cm) aperture refractor through which he was to observe Donati's Comet [in 1858]'.[24]

It would seem that the object-glass of Slater's own telescope was the twin of the one he had supplied to Downside. But how did he come to be in possession of such a large refractor? In his account of the Downside lens Norbert Birt describes it as 'a wonderful telescopic object-glass, the "sister" of which was secured for the Government Observatory at Cape Town'.[25]

However, a search of the website of the Royal Observatory, Cape of Good Hope, the formal name of the 'Government Observatory' and now part of the South African Astronomical Observatory, yielded no mention of a telescope or lens of 15 inches aperture.[26] An inquiry to the SAAO confirmed that no such lens was in their possession at this early date – indeed, they had no telescope larger than 7 inches (0.18 m) until around the 1890s.[27]

Whether Birt's suggestion is something of a myth, or whether the Royal Observatory had got wind of the failure of the Craig telescope and thus cancelled their order, we may never know. All that can be said is that a 15-inch refractor would be a very large instrument to be in the hands of an amateur observer in the 1850s and so the possibility that its lens was originally made for some other purpose is quite strong.

5.1. *Comparison with other large refractors*

Which brings us to the other statement made about the object-glass, namely that it was 'one of the largest in the world'. A list of the largest telescopes of the 19th century in Wikipedia tells us that there was no refractor of greater than 10 inches (0.25 m) aperture until 1843 and that apart from the Craig telescope there were only two examples of 15 inches or greater right up until the 1870s and 80s.[28]

The earlier of these two, the 15-inch refractor at Harvard College Observatory, was the largest in the USA from 1847 until the 18.5-inch (0.47-m) at the Dearborn Observatory, Chicago, took its crown in 1865, becoming the largest in the world in the process. This list is not quite complete as it stands though, as the Pulkovo Observatory in St Petersburg, Russia, had a 15-inch refractor in 1839, whose lens was the twin of that at Harvard. Also missing is the 13.5-inch (0.34-m) Grubb refractor constructed at Markree Observatory, Ireland, in 1834.

The Pulkovo, Harvard, and Markree instruments, and several of those in the Wikipedia list, are mentioned in Henry C. King's book *The History of the Telescope*[29] but no reference includes the Downside instrument, or that used personally by Thomas Slater, so there could be other omissions. However, it does seem reasonable to conclude that the Downside refractor was indeed one of the largest in the world at the time of its construction, and (again excluding the Craig telescope) certainly larger than any which would be constructed in the UK and Europe until the 1880s.

We are told by Abbot Snow that the object-glass 'comprised two plane convex lenses riveted together'.[30] van Zeller says 'welded', so it must be assumed that they are both referring to some sort of support frame rather than the lenses themselves. This form of construction is entirely plausible, being similar to that used for the Craig telescope.[31]

It is noted that 'Sir James South, Mr. Delarue, and other astronomers of note had examined it, and pronounced it to be an excellent glass'.[32] Sir James South (1785–1867) was a founder and later President of the Astronomical Society, and a noted amateur observer in the 1820s and 30s.[33] Warren De La Rue (1815–89) was a pioneer of astrophotography of the Moon and Sun, and also produced one of the world's first electric light bulbs.[34] The approval of these great men undoubtedly helped Slater's reputation.

6. The telescope and its mount

While the description of the telescope itself given by Abbot Snow is somewhat sketchy, he does provide a very comprehensive description of its mount:

> A massive pier on the north rose up through the floor from the rock below to a height of fifty feet from the ground, and was surmounted by an iron girder which, like a giant hand, clutched a huge beam that rested diagonally on a similar smaller pier on the south; to prevent vibration, these piers were built free from the wall and floor, and stood solid and independent. Attached to the beam was a large iron cradle, on which rocked or slept the tube of the telescope. With a focal length of twenty feet and a diameter of eighteen inches, the huge wooden tube looked unmanageable; but being evenly balanced by a large fly-wheel on the side of the beam opposite to the cradle, a slight touch easily set it in motion: the cradle moved on the beam and the beam itself, which formed the polar axis, revolved between the piers, thus producing the double motion, and enabled the telescope to be moved to any part of the heavens except due north.[35]

From this description we can tell that the mount was almost certainly of the English cross-axis type, in which both ends of the polar axis are supported on pillars.[36] This makes the mount very rigid, but is suitable only for a permanent installation because of its bulk and the impossibility of changing the angle of the polar axis by any significant amount, this being basically determined by the relative heights of the pillars. No image of the Downside telescope is known to exist, but its general appearance must have closely resembled George Bishop's 7-inch (180-mm) of 1836 at his observatory in Regent's Park (Fig. 5).

6.1. *Ancillary equipment*

Snow then moves on to the ancillary equipment, mentioning that 'eight Huyghenian eye-pieces, ranging from 75 to 2,000 powers, magnified to that extent the image formed in the focus of the object-glass' before describing the forerunner of the electric motor drives later attached to equatorial mounts: 'The weight-clock was an ingenious application of clock-work to put the telescope in motion at the same rate as the star, so that after it was attached there was no need of touching the tube; weights were added or taken off according as the star was hasty or sluggish in its movement.'[37]

Weight-clocks were not clocks in the horological sense of the word, as they were not intended to tell the time but merely to rotate the polar axis in order to track objects as they moved across the sky. Their central component was a drum mounted on a shaft, around which were wound multiple turns of a cord, from which hung the weight. The tendency of the drum to spin around when the weight descended under the influence of gravity was controlled by a regulator mechanism driven off a gear-wheel attached to the drum. The polar axis slow-motion control was then attached to the shaft of the drum.

Unfortunately, Abbot Snow's description of the Downside mechanism is insufficient to tell us which

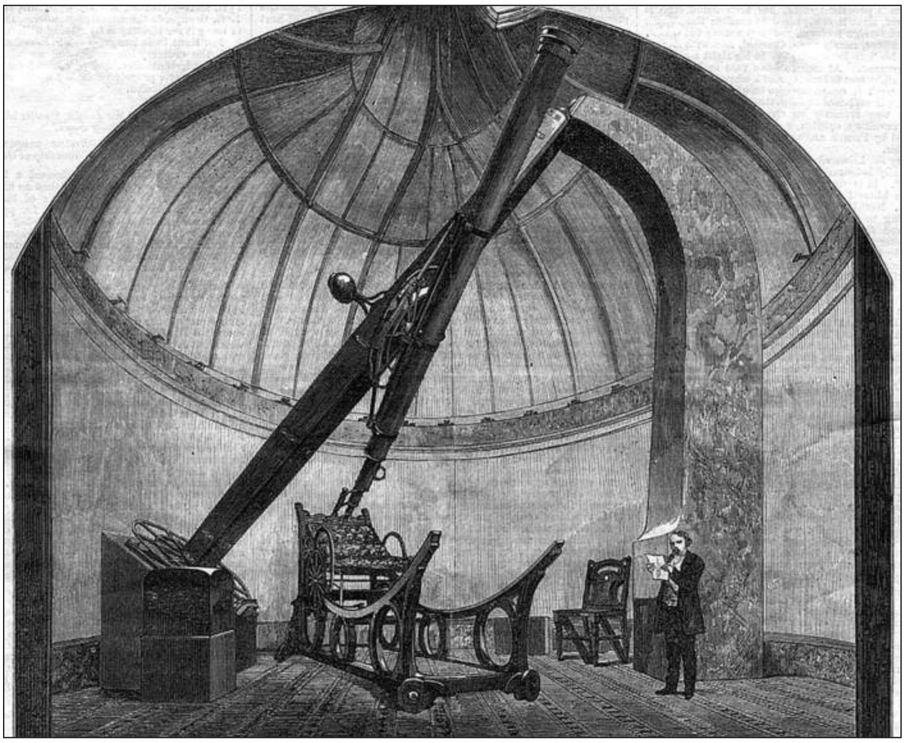

Fig. 5: The Downside telescope would probably have looked like a larger version of the 7-inch (180-mm) refractor made by George Dollond in 1836 for the private observatory of George Bishop (1785–1861). Like the Downside telescope, this was supported on an English mounting. Bishop's telescope was originally housed at the South Villa of Regent's Park, London, but is shown here in a drawing from the Illustrated London News after its move to Twickenham where it was re-erected by his son on the north bank of the river Thames.

type of regulator was used. The earliest practical drives used the constant circling motion of a conical pendulum,[38,39] before being largely superseded by those regulated by a fly-ball governor similar to those used on steam engines.[40] However, neither of these types of regulator would normally be adjusted by 'adding or removing weights' as Snow states, but rather by moving the pendulum bob or fly-balls along the arm upon which they are mounted.

Conversely, while it would be possible to use a swinging pendulum plus lever-escapement (as in a true clock), which could indeed be adjusted by adding or removing weights, there is no historical evidence in the literature or from surviving telescopes from the period that this type of regulation was ever used – mainly because the action of the escapement would tend to introduce an undesirable intermittent motion into the drive. Regulation by true clocks did find favour in the mid-20th century, but using balance-spring escapements rather than pendulums.[41]

One cannot discount the possibility that the drive on the Downside telescope was regulated by a purely frictional device and adjusted by altering the driving weight,[42] or was perhaps even one of Slater's own devising, but it is unfortunately not possible to draw any firm conclusions.

7. Using the telescope

A major problem with large telescopes (and particularly those of great length, as almost all were in the 19th century) is actually getting your eye to the eyepiece, which can be almost anywhere within the observatory dome. Snow tells us how it was done at Downside: 'To reach the telescope in every position two wooden stages, fifteen feet high, were provided within the room, and these had a double motion on iron rails – one round the room from pier to pier, the other to and fro on the framework to bring the eye to the telescope; seats were arranged in tiers and some loose cushions ministered to the comfort of the head and other members'.[43]

Making an observation was therefore not a straightforward matter. Indeed, Snow tells us that the preparation for a peep at a star was an elaborate process:

> Having secured a fine night and lit the gas, you seized a capstan and heaved away hand over hand, and slowly moved the heavy roof, creaking and grunting, until the slit was on a line with the star; a touch at a rope made the roof politely doff its cap, and a tug at two others opened the upper and lower shutters, and discovered your night's hunting-ground in the sky; you next mounted the stage and adjusted it sidewards and forwards into position, took your seat, and smoothly and easily swung round the great tube within your grasp.[44]

Opening the roof, pointing the telescope in about the right direction, and gaining your seat were, however, just the initial obstacles to be overcome before you could actually see anything. Snow continues:

> Surrounding the eye-piece was a bewildering array of appliances worthy of a high-pressure steam-engine; one handle moved a ten-feet lever that clamped the telescope at the centre, another similar one gave it a slow motion, a third attached it to the weight-clock. Near these were the focussing apparatus, the circles for declination and right ascension with their verniers, a gas-jet to illuminate the verniers and micrometer wires, and, lastly, a little baby telescope called the "finder".
>
> Having coaxed the infant to find your star, you clamped the whole concern, attached the weight-clock, adjusted the focus, became satisfied that all the instrumental trappings were in order, and calmly composed your eye for whatever intelligence the star had to convey, the celestial colloquy being suspended now and again to heave away at a capstan to keep the roof-opening in proper relations with the telescope.[45]

8. Observations at Downside

Although the Great Observatory was successfully completed in early 1860, all was not well. Hubert van Zeller tells us bluntly: 'Admitted by the astronomical world as being one of the finest in the country, the Downside Observatory possessed this one defect: it did not work.'[46]

Abbot Snow confirms this assessment: 'Apart from the meteorological observations, the scientific work of the observatory never assumed any definite form, mainly on account of the imperfect adjustment of the object-glass. After fixing all the machinery, minute, careful, and patient observations with delicate manipulation were necessary in order to adjust the position of the two lenses so as to give clear definition to the celestial objects.'[47]

van Zeller continues: 'Mr. Slater was sent for, and reluctantly came. Swiftly and dexterously he adjusted the instrument for a view of nearer objects (the moon and so on) and then, very hurriedly, went away again. This was repeated several times: Mr. Slater bouncing rhythmically up the drive on his steam tricycle, adjusting the gauge of his telescope to ever nearer and nearer ranges, instructing the students to wait patiently for a break in the clouds, and off again over the hills before dawn.'[48]

8.1. *Early hopes unrealized*

The authorities delicately hinted that Slater had lost interest in the project as soon as he had received payment. He retorted that he was 'at any time at their service if the authorities would only sweep the sky of its clouds, for which he did not supply a scientific broom'.[49] The correspondence threatened to become strained, with Slater only rarely responding to appeals to attend to his creation and then giving up altogether. As van Zeller put it: 'The tassel on his velvet cap no longer rose and fell in those automotive rides along the lanes of Somerset.' [50]

It should not be thought, however, that the telescope was a total failure. It simply fell short of the level of perfection that had been expected of it, thereby demoting it to an 'educational' instrument rather than one capable of serious astronomical use. Abbot Snow gives us a vivid account of observations made of the Moon and planets:

> On a warm, clear night the instrument had a fascination of its own … The nearer moon and planets created more enchantment, especially the jagged edges of the crescent moon … the light from the earth dimly outlined the mountains and valleys in the shade … At other times a bright speck would appear at some distance from one of the [crescent] horns; it was a mountain peak at sunrise … Saturn was a beautiful object … Jupiter and its moons in a frequent state of occultation, Mars and Venus shone on the field with great brilliancy.[51]

Observations were also made of the Sun using (possibly unwisely) 'a series of darkened glasses adjusted to its brightness' and, more surprisingly, 'an ingenious eyepiece invented by Mr. Dawes'.[52] A Dawes eyepiece is not the sort of item one would expect an amateur observatory to possess. Made by the eminent makers Thomas Cooke & Son of York, such an eyepiece is a rather large cylindrical affair approximately 75 mm in diameter which can be focused independently of the telescope with its own rack-and-pinion mechanism.[53]

Unwanted heat is absorbed first by a ring of solid ivory, and afterwards by a disk of ceramic material with a central perforation. The Sun's light then reaches an aperture wheel which contains ten bored holes ranging from 9/32 to 1/130 of an inch (7 mm to 0.2 mm); these serve to restrict the field of view. A second wheel is placed behind the first and this holds six single lenses of increasing power. A third and final wheel holds seven 'London Smoke' glasses of varying intensity that reduce the brightness of the image. This eyepiece thus conveniently serves three functions: alteration of field diameter, magnification, and absorption or dispersion of unwanted heat and light.

8.2. *A remarkable observation*

Snow then again shows his delight in whimsy by telling us that

> The only discovery on record made with the telescope excited considerable local interest. A stout astronomical aspirant for the first time fixed his attention on the jagged edge of the moon; after gazing intently for some moments he declared that he saw "biffins" in the moon. "Biffins" was a local name appropriated to dried Normandy pippins floating in a luscious fluid, a dish that graced the College board at its superior festivities; a fancied resemblance between these and the craters on the moon led to the discovery, which speedily spread through the whole establishment.[54]

Whether this startling discovery was reported in the learned journals of the time is not recorded.

9. The demise

Snow begins his description of the ultimate fate of the Great Observatory by saying: 'The expectations of scientific work, or of credit to the College from the possession of such a magnificent instrument, were doomed to disappointment, for the whole structure was reduced to ruins in a few hours.' [55] He then relishes every detail of the disaster which took place on the morning of Sunday 1867 January 20, first setting the scene:

> The building was warmed by hot air; a furnace sunk outside the east end of the observatory heated a flue under the floors of the museum and transit-room, iron gratings admitting the hot air into the building. One frosty night the attendant, finding the fire dull, left the dampers open; a fresh east wind sprang up during the night, and the furnace, being taxed to its utmost capacity, overheated the cement lining of the flue and set fire to the joists of the floor.[56]

Matters then progressed very rapidly:

> On that Sunday morning the meteorological observations were taken at nine o'clock, and nothing amiss was noticed; at ten o'clock the alarm was given of fire in the museum. On arriving at the spot it became evident that the building was doomed, for it was impossible to enter the museum or the equatorial-room … The flames first burst through the windows, crackling and angry at being confined, and as they licked up the roof and found vent the molten zinc trickled down the eaves. Before long the supports of the roof were eaten away, and then came the great crash, the lull, and the roar of the conquering flames soaring up jubilant. By the end of high mass all that was consumable had perished, and the fire smouldered on among the debris till late in the afternoon … The large object-glass was found in the debris, shattered into fragments, some of which showed evident signs of fusion.[57]

Although the local fire-brigade were called, their efforts were in vain:

> Without loss of time the fire-engine was hauled to the spot, but the hose when screwed together proved to be too short by some yards to reach the nearest pond. The men at once rolled a large tub on to the scene, broke the ice (a foot thick), and carried the water in buckets to the tub into which the hose was inserted … It was bitterly cold, with a dull leaden sky and a strong wind … the clothes of the amateur firemen were covered with ice, and some thoughtful soul provided hot beer for the men who worked at the engine and the buckets.[58]

9.1. *A disaster waiting to happen*

With the exact knowledge provided by hindsight, Abbot Snow added a final comment: 'If the contents of the building had been designedly arranged to accelerate a fire, it could not have been better prepared: the light dry wood of the museum cases and the stuffed birds quickly spread the flames, which, eating rapidly through the floor of the equatorial-room, caught the light framework of the wooden stages, which took them direct to the roof.' [59] No risk assessments in those days, unfortunately.

Reports of the fire are very few and far between. Indeed, apart from the local records, only one was found, in the snappily titled *County Observer and Monmouth Central Advertiser* (also syndicated to the *Abergavenney and Raglan Herald*, the *Usk and Pontypool Messenger*, and the *Chepstow Argus*). In a section headed Epitome of News, among articles relating to 'The Trafalgar-square Lions' and 'Death from the Bite of a Centipede', we are told that

> On Sunday the observatory connected with St. Gregory's College, Downside, near Bath, was totally destroyed by fire. It originated apparently in the heating apparatus, which kindled the joists of the ground floor; the flames, which caught some stuffed birds and other natural history specimens in the museum kept in the lower room, were rapidly communicated to the equatorial room above, in which was a magnificent refracting telescope of 15 inches diameter and 20 feet focal length.
>
> The observing stages formed capital fuel for the fire, and in less than an hour the whole was one mass of flame, leaving no possibility of rescuing anything. The loss of the glass and astronomical plant attached to the telescope is the more unfortunate, as the observatory had only just been placed in full working order. The loss to the college of the antiquities, curiosities, and natural history collections in the museum cannot be estimated, for they contained many unique and invaluable specimens and were the result of 50 years' accumulation. [60]

Thus perished the observatory and its contents; its subsequent fate was ignominious. The north support pier survived the flames with, in Abbot Snow's words, 'its iron girder like a giant spectre-finger held up in warning', but the danger that it might fall meant it was soon removed.

While the relatively undamaged transit room remained in service for many years as a Clerk of Works office for the early phases of the building of the nearby abbey church, the shell of the main structure was demolished and its stone cannibalized for use in current building projects. Ironically, the semi-gothic windows of one of these bore a striking resemblance to those of Charles Hansom's observatory.

Summing up the situation in his 1903 book *Sketches of Old Downside* Abbot Snow observed with great sadness:

> The loss to the College cannot be estimated, for it is not represented by money value only; it provided an opportunity, seldom within reach of a college, of organising a thorough system of observations that would command the attention of the scientific world through the magnitude of the glass.
>
> In simultaneous observations of any astronomical event the results from the Downside glass would have always been sought for; it would have been a training in science for the whole establishment, since interest in, and hence knowledge of, the work could not fail to be diffused as a part of the "esprit de corps"; and the observatory provided an unrivalled source of attraction and pleasure to strangers and visitors, for no-one could look through the glass at the more prominent celestial objects without taking away impressions that would never be forgotten.[61]

Norbert Birt adds: 'Fate, however, relegated such daydreams to the lumber-room of "might-have-beens".' [62]

van Zeller, though, indulges in a dramatic flight of fancy: 'If this were an Ibsen play instead of serious history, Mr. Slater would be brought back for the closing scene: the Master Scientist, unable to keep away from the creature of his invention which has betrayed him, and returning in secret on the eve of an astral manifestation, fires the building and himself perishes in the burning – leaving behind him among the trees by the cinder-path a now silent steam-driven tricycle which typifies the neglect of a lesser success in the glare and glamour of a greater failure.' [63]

10. Final thoughts

Over and above the undoubted educational value that having a large telescope available for use by the school pupils would have bestowed, what contribution to astronomy in general might the Downside refractor have been able to make, had it survived? Any assessment is of course compromised by a lack of detailed knowledge of the quality of the instrument. There are no observing diaries to consult and, even if they had been compiled, they would most likely have been destroyed in the fire. All we have to go on are Abbot Snow's disparaging comments in the early part of his narrative and his more emotive description of observations of the Moon and planets later on.

In particular, he states: 'Saturn was a beautiful object, the great power of the glass developing the divisions in the ring and its shadow on the body of the planet; the appearance of the ring when quite perpendicular to the body was a test of the excellence of the glass',[64] which perhaps indicates that things were not as bad as originally stated. The reference to the rings being 'perpendicular to the body' is entirely accurate, as the Earth was then undergoing one of its periodic passages through the ring plane. It must have made quite an impression on a young student for him to have remembered it when writing his book 40 years later.

10.1. *Potential astronomical studies*

Large telescopes at that time often undertook photometric and astrometric work, primarily for the preparation of star charts and measuring the orbits of double stars. Astrophotography did not begin until the 1880s so brightness was estimated by eye and position-measuring was done using a micrometer at the eyepiece. However, such activities would have required a planned, long-term programme of meticulous measurements by dedicated observers, which is unlikely to have fitted in with the constraints of a religious and educational community.

Turning to the planets, the observatory was built too late to have made any of the easier discoveries, and too early to have benefited from the improvements in technique necessary to produce lenses large enough to observe fainter objects.

For example, Phobos and Deimos, the moons of Mars, were not seen until 1877; Amalthea, a fifth moon for Jupiter (after the easily visible Galilean quartet) was not found until 1892; Saturn's moon Hyperion was discovered in 1848, but the next one (Phoebe) was not found until 1899; Uranus' moons Ariel and Umbriel were seen in 1851 but Miranda had to wait until 1948; and Neptune's largest moon Triton was found in 1846 but the next (Nereid) was not discovered until 1949.

The long-suspected innermost ring of Saturn, called the Crêpe Ring because of its tenuous nature, was finally confirmed in 1850 and was also seen with the Craig telescope in 1852. Any planetary observations would have been restricted to recording surface markings, a field which quickly began to develop in the mid-19th century. Detailed observations of the markings on Mars and the belts of Jupiter would easily have been made with a 15-inch refractor.

Finally, there are temporary phenomena, comets being the classic example. We know that Thomas Slater observed Donati's Comet with his own 15-inch telescope in 1858, making drawings which were published in the *Illustrated London News* and can now be found online.[65] Other Great Comets would have been obvious targets for observation from Downside.

Equally unpredictable would have been asteroids, a steady stream of which were discovered in the second half of the 19th century with smaller telescopes than that at Downside; eleven had been discovered with the 7-inch (180-mm) refractor at George Bishop's observatory in Regent's Park in 1847–54.[66] Discoveries were somewhat fortuitous, requiring observers to have good charts of star fields and hence notice an interloper. Regular observation would give the best chance of spotting something, but occasional observations might have struck lucky.

It seems reasonable to conclude, therefore, that given a number of sufficiently interested observers among the religious and educational communities at Downside, a programme of essentially ad hoc observations of planets and comets could have made a significant contribution to the work being carried out elsewhere by a relatively small number of astronomers, mostly amateurs. The destruction of the observatory should thus rightly be regarded as a grievous loss to the astronomical community in the UK. In this year of the 150th anniversary of the fire we can only pose that age-old question: 'What if?'.

Acknowledgements

The authors would like to thank Mike Frost, Director of the Historical Section of the British Astronomical Association, for his support and suggestion that *The Antiquarian Astronomer* would be an appropriate place to publish this paper. Thanks are also due to Simon Johnson and Steven Parsons of the Downside Archives for their help in locating archive material and photographic images; to Greg Smye-Rumsby for his permission to quote from the Craig Telescope website; to Kevin Johnson of the SHA for advice on telescope drives; and to Ian Glass, Associate Research Astronomer at the SAAO, for his response to the question about the 15-inch object-glass allegedly procured for the Royal Observatory, Cape of Good Hope.

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Steve Holmes BSc (Hons), CEng, CPhys, is a Member of the British Astronomical Association and a Fellow of the British Interplanetary Society. He has been interested in things celestial ever since he can remember, having learnt his way around the sky using *I-Spy The Sky* and *The Observer's Book of Astronomy*. An early project during his teenage years was a determination of the orbital periods of Jupiter's Galilean moons from drawings made using a small refractor (which he still has) but the increasing ease with which professional-quality observations can now be made with relatively inexpensive equipment has moved his interest on to theoretical studies.

Charles Fitzgerald-Lombard OSB, MPhil, is a Benedictine monk, having been Abbot of Downside from 1990 to 1998, and also parish priest of St Edmund's Parish, Bungay, Suffolk. His association with Downside led him to investigate the history of the Great Observatory, which resulted in him writing an article for *The Raven*, the year-book of Downside School. Having asked his co-author on the present project to proof-read the text of the article, the pair then collaborated on this paper.

An 18th-century astronomical hub in west Cornwall

Carolyn Kennett

From 1775 to 1809 the village of St Hilary in Cornwall was the home to the head comparer of *The Nautical Almanac*, Malachy Hitchins (1741–1809). Hitchins was responsible for supervising and checking the complex calculations made by a team of human computers. He not only employed local men as computers but also instructed them in mathematics and astronomy. These men would go on to have valuable scientific careers. Hitchins's influence as a tutor and enabler has long been overlooked. This paper looks at his life and the long-standing effect it had on the English scientific community.

1. Introduction

In the late 18th century an astronomical hub sprang up in an unlikely location: five miles from the town of Penzance in Cornwall. Scientific work of national and international importance was being undertaken not in a university or a city, but in the far southwest of England in and around a small village called St Hilary Churchtown.

St Hilary lies half a mile off an old ridgeway, once the main arterial link to London before the A30 superseded it. The village nestles down a quiet back lane, a couple of miles from Mount's Bay. There is today a collection of about dozen houses, an old school house (now a heritage centre), and the 13th-century parish church. All the buildings are constructed from large granite blocks, typical of the style and materials used in the area in that period. Many have commanding views across open countryside towards St Ives Bay and the north coast of Cornwall.

What is an idyllic and peaceful location today would have been very different during the late 1700s. This was once a bustling area of tin and copper mines with a population of 996 people in 1801, a population which was expanding rapidly due to the mining opportunities.[1]

In 1775 the position of vicar of St Hilary became available and was offered to 34-year-old Malachy Hitchins, a Cornishman from just outside Redruth. It would be Hitchins who transformed this location into a centre of employment for the astronomical community.

2. Early life of Malachy Hitchins

Malachy Hitchins was born in 1741 at Little Trevince in Gwennap, a village about three miles southeast of Redruth, Cornwall, and was baptized on May 18 that same year. His father was Thomas Hitchins (1697–1746), a local miner, and his mother, Grace Martyn (1698–?), was the sister of Thomas Martyn, a local cartographer.[2]

Malachy was the youngest of a fairly large family, with six brothers and two sisters. Although his schooling in these early years was probably only basic, his uncle Thomas Martyn, who had produced in 1748 a very accurate map of Cornwall, would have been on hand to play a part in his education. By an early age he was expected to follow other members of his family and go into the mines at Gwennap.

Work in the mines is described in the memoirs of the Reverend Henry Martyn (1781–1812), a relative on his mother's side of the family, who noted a trend for self-education: 'The miners, it appears, are in the habit of working and resting alternately every four hours; and these seasons of relaxation from manual labour, they frequently devote to the improvement of their minds.' [3]

Malachy's cousin John Martyn worked alongside him in the mine and used the down-time similarly to improve his mathematics. John's mathematics never improved to the same extent as Malachy's, although a knowledge of basic arithmetic enabled him to gain a position in Truro as a merchant's clerk.[4]

2.1. *Survey of Devon*

Malachy did not spend long as a miner. Most probably due to his family connections as well as his mathematical ability he was offered a job assisting the mathematician Benjamin Donn (1729–98) on surveying for a map of the county of Devon.[5]

Working with Donn would have given Malachy hands-on experience in the surveying techniques of the time. During this period Malachy seems to have moved to Devon, as records show him residing in Bideford in 1762.[6] The ensuing map of Devon was published in

1765, although Malachy's contribution is not credited on it.

Unfortunately the survey was far inferior to that of the prior one of Cornwall completed by Malachy's uncle, Thomas Martyn. Perhaps it was Donn's abilities rather than Malachy's inexperience that was to blame, for Donn was known as a drinker. It is said that one night he was found staggering homewards claiming that he was directing his course by the light of the planet Jupiter.[7] Whatever the case, it did not harm Malachy's career – he was later employed by the Bishop of Exeter, Fredrick Keppel (1728–77), to survey the manor of Cargol in the parish of Newlyn, Cornwall.[8]

2.2. *Mathematics and the Devon Fireball*

While working on the survey of Devon, Malachy had begun answering mathematical questions submitted by readers of *The Ladies' Diary*.[9] But it was his description of a large fireball published in *The Gentleman's Magazine* in 1762, when he was aged 21, that showed the beginnings of his astronomical interest:

> Bideford, December 21
>
> Happening to be walking on Sunday the 5th instant, about 8 h 50 m *Post Merid.* I instantly saw the streets so illuminated as could not be equalled by a meridian Sun. I immediately cast my eyes upwards, and to my very great surprize [sic] saw a luminous body, or flaming meteor, equal in magnitude to the Moon, falling in the direction under specified. This meteor, when it first appeared to me, was in a right-line with the bright star in *Hircus* [i.e. Capella]; that is, E. by N. altitude 57 degrees, which I imagine was near the place of its commencement; since the sudden blazing which it occasioned, must instantaneously attract an amazed eye. It performed its descent gradually, so as to fall about 10 degrees in 4 or 5 seconds; leaving behind it a long tail, or seeming liquid flame, which subtended from one extreme to the other, an angle of about 10 degrees; that part of the tail next to the body seemed to blaze like the meteor itself, but the other extreme turned blue and smoky, bearing the form in the figure [below].
>
> 
>
> The body diminished, or burnt out by degrees to support the tail, the extremity of which continued to vanish into smoke, till the whole body was dissolved, which happened to be in a line with the bright star in Orion's right shoulder [Betelgeuse], altitude about 23 deg. and azimuth E.S.E.½E, from whence the direction of its path is known. The tail continued to burn bright for about a minute afterwards, and the fire seemed to vanish last of all at that end where it first had its being; but the serpentine form remained for 5 or 6 minutes, tho' only as a bright cloud. The atmosphere, at the beginning of this extraordinary phænomenon, was very clear, and inclinable to freeze; but after the body's dissolution, a thick smoke descended from its path to the horizon; which disappeared in about a quarter of an hour.
>
> This meteor, which was, I believe, by far the greatest observed for forty years past, must have kindled very near the Earth's surface, otherwise the blazing would not be great enough to dazzle the strongest eye.[10]

What he describes is certainly an exceptionally bright fireball, with a trail lasting five or six minutes, distorted by high-altitude winds. His report contains accurate altitudes and azimuths befitting his background as a surveyor and reveals an accurate knowledge of the positions of bright stars.

There was also a report of the same meteor from Lulworth Castle in Dorset, 120 miles away, which closely matches his own description.[11] These two reports are the only ones known for this brilliant fireball, whereas previous fireballs in 1719 March and 1758 November were widely seen.[12] Perhaps the night of the 1762 event was cloudy elsewhere. Malachy's suggestion that it was the largest known fireball for 40 years seems to be nothing more than the attempt of a young man to impress the reader.

2.3. *Higher education and marriage*

While awaiting the publication of the map of Devon by Donn, Malachy matriculated at Exeter College, Oxford, in 1763, where he continued his correspondence with the magazines of the day. For example, on 1763 October 10 he wrote from Exeter College to *The London Magazine* with his calculations of the start, middle, and end of a partial eclipse of the Moon that was due the following March.[13]

On 1764 January 10, soon after joining Exeter College, he married Joanna Hawkin (1739–1815) at the village of Buckland Brewer in Devon, a few miles from Bideford.[14] They were to have four sons and a daughter (see Section 7.1).

Evidently Joanna was better-off than Malachy, for he reported to his biographer Richard Polwhele (1760–1838) that his wife paid his college fees. Even so, he left the college to work on *The Nautical Almanac* before finishing his degree and did not graduate as BA until 1781 February 27. In 1785 Malachy was incorporated into St John's College, Cambridge, where he graduated with his MA in the same year.

During his time at Exeter College in Oxford, Malachy undertook two positions as a curate. The first was held briefly in 1765 at Norton Fitzwarren in Somerset. He was ordained a priest in September that same year.[15] The second curacy was much longer, from 1766 to 1771, at Merton in Devon, relatively local to his wife's family in Shebbear. His wife resided at Merton in the cottage which came with the job and a number of his children were born there.

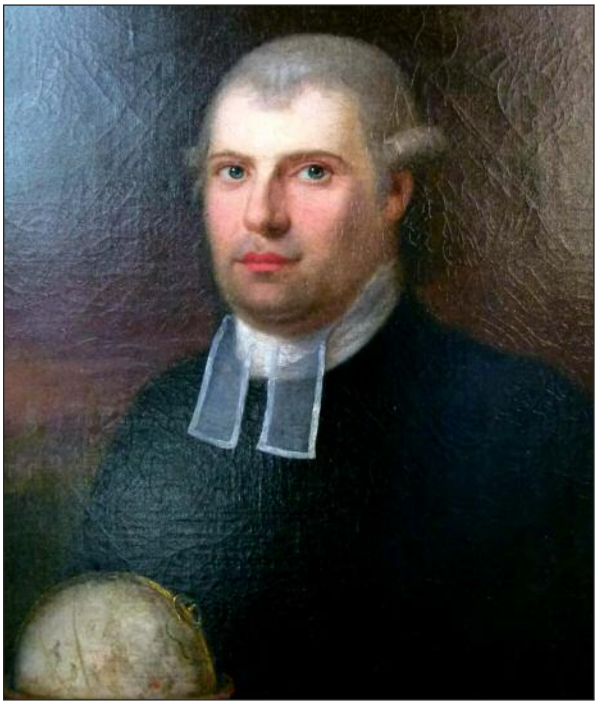


Fig. 1: Malachy Hitchins (1741–1809) seen in an oil painting by the Cornish portrait painter John Opie. (Private collection.)

3. Malachy Hitchins at Greenwich

While at Oxford, Malachy had made a favourable impression on Thomas Hornsby, the Savilian Professor of Astronomy.[16] Hornsby sat on the Board of Longitude and regularly met Nevil Maskelyne, the Astronomer Royal, at board meetings. Hornsby recommended Hitchins as a computer for *The Nautical Almanac*. He was appointed by Maskelyne at the end of 1767 and took up the post in 1768.[17] It was a relationship that would last a lifetime.

3.1. *The Nautical Almanac*

The Nautical Almanac and Astronomical Ephemeris, to give the publication its full title, was first issued in 1766 for the year 1767.[18] Its aim was to simplify the complex calculations needed for determining longitude at sea by the lunar distance method.

Previously, the calculation of longitude at sea had been virtually impossible. Parliament pushed through a longitude act in 1714, offering a prize of £20,000 to anyone who could find a way of calculating longitude at sea to within half a degree. By 1767 the solution to the longitude problem had not been found, although a number of ideas were close and had already received part-payments. These included John Harrison's chronometers as well as the lunar method as devised by Tobias Mayer which involved measuring the angular distance between the Moon and certain reference stars.

Nevile Maskelyne was particularly keen on the lunar method, as he had himself tested it successfully on a voyage to Barbados in 1763–4, but he knew that the calculations involved were too difficult and time-consuming for normal seafarers. He hoped to make the method more practical by having many of the calculations completed in advance and published in book form. That book was *The Nautical Almanac*. It included tables of the daily position of the Moon at noon and midnight, along with its angular separation from the Sun and bright navigation stars at three-hourly intervals (Figs. 2 and 3).[19,20]

The job of making these calculations fell to a number of computers employed by Maskelyne. To calculate each entry, the computer had to look up as many as twelve figures in various tables and then perform up to fourteen arithmetic operations. As many as 1365 entries were needed for each month's tables in *The Nautical Almanac*. The volume of work was immense, tedious, and open to human error.[21]

Maskelyne employed two computers to make each set of calculations independently, following the detailed instructions he had issued, and he would then check the results in person. Malachy must have impressed Maskelyne in his accuracy as a computer because in 1769, after one year in the job, he was promoted to the role of a comparer, in which he would cross-check the work of two other computers. By 1778 he had taken on Maskleyne's role as the main comparer, a role which he retained until his death in 1809.[22]

3.2. *Assistant to the Astronomer Royal*

A transit of Venus was due to occur in 1769 which, it was hoped, would enable astronomers to measure the distance between the Earth and the Sun with far greater accuracy than had previously been possible. To make the most of the opportunity, astronomers were being sent around the world to observe the transit, in one of the most important scientific ventures of the eighteenth century.

By the time Hitchins started work on *The Nautical Almanac* in 1768, preparations for the transit were well underway. William Bayly (1737/8–1810), the existing assistant to Maskelyne, had been selected to travel to North Cape in Norway to observe the transit. This left Maskelyne without help at Greenwich, so he turned to Malachy as a temporary stand-in.

Why did Maskelyne choose Hitchins to replace Bayly? It seems that Malachy by now had advanced his studies under Hornsby at Oxford and knew more than just mathematics. Maskelyne described Malachy as 'a gentleman well acquainted with astronomy and astronomical calculations, who has made and examined many belonging to the Nautical Almanac, and has been so obliging as to come here and assist me in making astronomical observations, during the absence of my assistant'.[23]

As Bayly readied to leave Greenwich, Hitchins moved into the Royal Observatory to take over his role for nearly four months. From 1769 April 24 until August 10 Hitchins assisted Maskelyne in the Observatory's

P R E F A C E.

THE Commiffioners of Longitude, in purfuance of the Powers vefted in them by a late Act of Parliament, prefent the Publick with the NAUTICAL ALMANAC and ASTRONOMICAL EPHEMERIS for the Year 1767, to be continued annually; a Work which muft greatly contribute to the Improvement of Aftronomy, Geography, and Navigation. This EPHEMERIS contains every Thing effential to general Ufe that is to be found in any Ephemeris hitherto publifhed, with many other ufeful and interefting Particulars never yet offered to the Publick in any Work of this Kind. The Tables of the Moon had been brought by the late Profeffor MAYER of Gottingen to a fufficient

Fig. 2: Nevile Maskelyne's preface to the first edition of The Nautical Almanac, published in 1766 for the year 1767. Malachy Hitchins joined the staff two years later, in 1768.

JANUARY 1767. [9]

Diftances of ☽'s Center from Stars, and from ☉ eaft of her.

Days.	Stars Names.	Noon. ° ′ ″	3 Hours. ° ′ ″	6 Hours. ° ′ ″	9 Hours. ° ′ ″
1					
2	α Pegafi.	46. 41. 15	44. 57. 51	43. 14. 53	41. 32. 32
3		33. 15. 35	31. 40. 16	30. 6. 42	28. 35. 2
4	α Arietis.	57. 55. 16	56. 6. 21	54. 17. 44	52. 29. 25
5		43. 32. 47	41. 46. 31	40. 0. 36	38. 15. 1
6	Aldeba-	62. 4. 49	60. 22. 21	58. 40. 17	56. 58. 37
7	ran.	48. 36. 32	46. 57. 27	45. 18. 47	43. 40. 35
8		35. 37. 28	34. 2. 38	32. 28. 29	30. 55. 5
9		23. 22. 20	21. 55. 18	20. 30. 0	19. 7. 3
10	Pollux.	51. 3. 14	49. 27. 59	47. 52. 57	46. 18. 9
11		38. 27. 43	36. 54. 20	35. 21. 12	33. 48. 17
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]

Fig. 3: Part of the tables for January in the first Nautical Almanac, giving the Moon's distance from certain prominent stars at three-hourly intervals for navigators using the lunar-distance method.

routine work of observing meridian transits of stars and planets with the 8-ft transit instrument originally installed by James Bradley.[24] Hitchins also observed the transit of Venus from Greenwich on June 3.

3.3. *Transit and eclipse*

Seven people gathered at the observatory to observe the all-important transit on the evening of 1769 June 3. The evening was described by Maskelyne as clear and very serene 'which afforded as favourable an observation of the transit here as could well be expected, considering that the Sun was only 7° 3′ high at the external, and 4° 33′ at the internal contact'.

Malachy was placed in the eastern summer house with a reflector of 6 feet focal length magnifying 90 times, alongside Reverend William Hirst, a veteran of the 1761 transit, who observed with a 2-foot reflector that magnified 55 times.[25] Hirst had brought with him Henry Vansittart (1732–70), the former governor of Bengal, who had agreed to take timings. Hirst has left a good description of the happenings that evening in the

Fig. 4: Timings of the transit of Venus as observed at Greenwich on the evening of 1769 June 3 by Nevil Maskelyne, Malachy Hitchins, and five others. The timings of the first and second contacts differ by almost a minute between the observers. (Philosophical Transactions of the Royal Society)

	External contact. h ′ ″	Regular circumferences in contact. h ′ ″	Thread of light compleated, or the internal contact. h ′ ″	Telefcope made ufe of.	Magnifying power.
N. Mafkelyne	7 10 58	7 28 31	7 29 23	2 feet reflector.	140
M. Hitchins	7 10 54	7 28 47	7 28 57	6 f. reflector.	90
W. Hirft	7 11 11	— — —	7 29 18	2 f. reflector.	55
J. Horfley	7 10 44	7 28 15	7 29 28	10 f. achromatic.	50
S. Dunn	7 10 37	7 29 2[illegible]	7 29 48	3½ f. achromatic.	140
P. Dollond	7 11 19	— — —	7 29 20	3½ f. achromatic.	150
E. Nairne	7 11 30	— — —	7 29 20	2 f. reflector.	120

eastern summer house, with him shouting out to Vansittart as the planet touched the limb so the time could be read off Halley's sidereal clock.[26]

Unfortunately the results were less accurate than hoped as it was difficult to time the exact moment when Venus reached the edge of the Sun. Hirst and Hitchins recorded times of first contact that differed by 17 seconds (Fig. 4). Similar discrepancies occurred at second contact, as Venus moved fully on to the face of the Sun. This was a result of what later came to be known as the black drop effect, clearly visible in the diagram published by Hirst.[27]

Maskelyne summed up the general disappointment in his report published by the Royal Society: 'The differences between the different observations seem pretty considerable, and greater than I expected, considering that all the telescopes may be reckoned pretty nearly equal, excepting the 6 feet reflector, which is much superior to them all; and to its greater excellence and distinctness I principally attribute the difference of 26″ by which Mr. Hitchins saw the internal contact before me; as I can depend on his observations.'[28]

Malachy continued observing stars into the early hours with the transit instrument, and was still there the following morning to join Maskleyne and others in observing a partial eclipse of the Sun.[29] In Cornwall John Bradley, nephew of the former Astronomer Royal James Bradley, was simultaneously timing the transit and eclipse to establish the longitude difference between the Lizard Point and Greenwich.[30]

Hitchins continued as Maskelyne's assistant at Greenwich until the return of Bayly on August 3. The two assistants worked alongside each other for another week, until August 10, when Malachy's final observation is dated.[31] After this spell as a practical astronomer, Hitchins went back to his home in Merton and resumed his work on *The Nautical Almanac*.

4. Return to Cornwall

Malachy was soon to move on from Merton. After a period from 1772 to 1775 as vicar in Hennock, about eight miles southwest of Exeter, he returned to Cornwall. In 1775 the Bishop of Exeter, Frederick Keppel (the same man who had previously employed Malachy as a surveyor), offered him the position of parish vicar at St Hilary. He moved with his family into the vicarage there in November 1775. In 1785 he also became vicar of the parish of Gwinear. He retained both livings until his death, mixing his parish duties with those of his work on *The Nautical Almanac*.[32]

4.1. *Work as a comparer*

As mentioned above, the calculations for the *Almanac* were divided between pairs of computers to help guard against error. All computations were duplicated, apart from those of the Moon's position in which one of the pair would calculate the Moon's position at noon each day for a given month, while the other would calculate the midnight position. Results were sent to the comparer to be checked for accuracy and then collated for printing. All communications were by post, and queries from the comparer to the computers regarding discrepancies could go unanswered for weeks or even months. Records show that Hitchins was writing to each computer several times a month.[33]

Not all the computers were honest, as Hitchins discovered in 1770. Joseph Keech and Reuben Robbins lived near each other in London and had decided to cut down the work involved by sharing results. Hitchins, though, realized that their results were too similar to have been done independently. They were summarily dismissed, and asked to pay Hitchins compensation for his time in redoing their work.[34] It was at this point that Maskelyne decided that they should employ computers who lived at different locations, so cheating could be eradicated. Hence a computer hub forming in Cornwall seems all the more remarkable, although this did not arise until later (see Section 5) and care was taken to ensure that close neighbours were assigned calculations for different months.

4.2. *A change of schedule*

As the efficiency of the computing system improved, the calculations were being published ever-further in advance, at first for three years and eventually for ten years. In 1793 the Board of Longitude began to consider suspending calculations beyond 1804, to allow improvements in the solar and lunar tables to be incorporated in future computations. Scientifically this made sense, but for the computers and comparers it was a threat to their livelihoods.

Malachy presented his case to the Board of Longitude in 1793: 'Having been employed for twenty-six years past by the Hon. Board of Longitude in computing and revising the Nautical Almanac … he is sorry to find that he is now suddenly and unexpectedly to lose his appointment for seven or eight years to come, and perhaps for ever.' He noted that he had 'discharged some private pupils for whose education he was liberally paid, and refused others that were offered him, that he might give his whole time to the computation of the ephemeris'.[35]

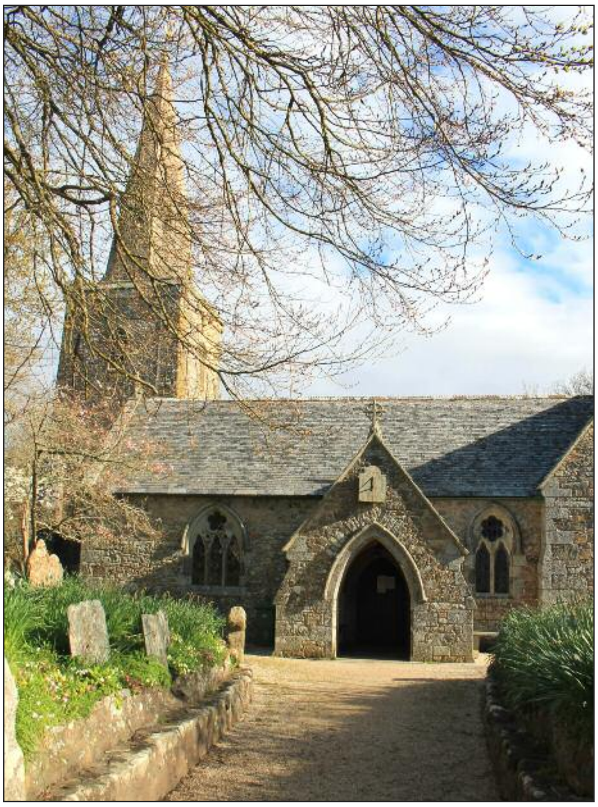


Fig. 5: The Church at St Hilary. Only the 13th-century tower remains from Hitchins's time. A fire destroyed the main structure in 1853 and a new church was built to replace it. (Carolyn Kennett)

In the end, the Board decided to suspend computations for five years and to employ the computers on other work in the meantime. After this hiatus, publication of *The Nautical Almanac* was resumed for five years ahead, with the improved accuracy that had been hoped for.[36]

4.3. *Chronometer work*

Adding to the astronomical activities in west Cornwall, Malachy's family was also involved in testing the expensive and sought-after chronometers. After John Harrison's invention of the chronometer, a number of watchmakers were employed by the Board of Longitude to make copies and develop the design. An initial number of these replicas were made by the London watchmaker Larcum Kendall (1719–90).

Fig. 6 is a receipt showing that Malachy's 16-year-old son William was paid not only to look after one of these valuable replicas but keep it wound up and calculate its errors.[37] The receipt states that it was Kendall's first watch, K1; this had broken down on an earlier voyage and been returned to the maker for repair. The watch was in the care of the young Hitchins between 1786 November and 1787 April before travelling with the First Fleet out to Australia in 1787 May. On board it was kept under the watchful eye of William Dawes (1762–1836)[38] and would not return to the UK until 1792. This priceless timepiece is now housed at the National Maritime Museum in Greenwich.

5. Computers in Cornwall

Twenty-nine years after finding cheating by computers in London, Malachy was able to persuade Maskelyne to let him assemble a group of local men to participate in the work. This considerably speeded up communications between him and the computers.

5.1. *The James family*

Among the first people Malachy would have met when he moved into St Hilary were the James family, who were a large and longstanding family in the parish. It was a member of this family, Nicholas James, who was first of the locals to be taken on by Malachy as a computer on *The Nautical Almanac*. He was recruited at short notice in 1799 to replace another computer appointed by Maskelyne, Francis Simmonds from Hampshire, who had proved to be not good enough. James worked on the *Almanac* until 1828, becoming one of the longest-serving and most trusted of the computers.[39, 40]

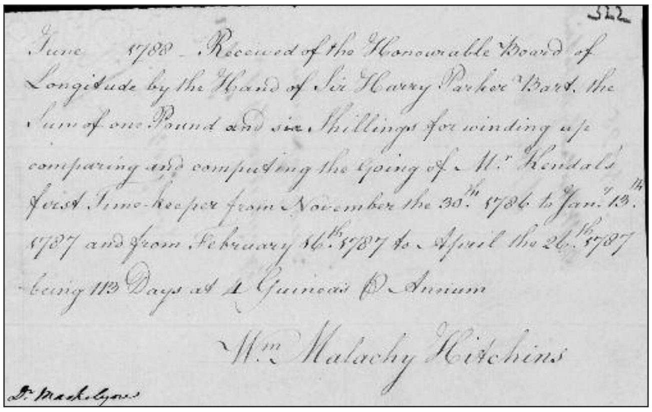
Born in 1773, Nicholas James was only a toddler when Malachy moved to the parish. By 1799, when he was 26, he was listed as a schoolmaster on the village census. The original school house, between the vicarage and the parish church, was rebuilt in the 1860s, but the original site and footprint was used so the modern building probably looks very similar (Fig. 7). The most likely original setup was a stables on the ground floor with a vestry and schoolroom upstairs.

James married on 1800 November 11 and went on to have numerous children, one of whom he named after Malachy.[41] This propitiously named child continued the mathematical tradition by taking on the role of head clerk at the large mining company works in Hayle. Nicholas James died on 1844 January 31, still living in St Hilary, and was buried at the parish church.

5.2. *The Dunkin family*

William Dunkin was born in either St Erth or St Hilary in 1781 and attended Penzance Grammar School along with a young Humphrey Davy, where the two formed a friendship over a common interest in science. He had also become friends with a former pupil from Penzance Grammar, Davies Giddy, who lived in neighbouring St Erth (see Section 5.6).[42]

As was the Cornish tradition William was expected to work as a miner but instead he spent evenings in the library at the Giddy family home. In an attempt to put Dunkin's mathematical talents to best use, Davies Giddy


322

June 1788 – Received of the Honourable Board of Longitude by the Hand of Sir Harry Parker Bart. the Sum of one Pound and six Shillings for winding up comparing and computing the Going of Mr Kendals first Time-keeper from November the 30th 1786 to Jany 13. 14 1787 and from February 16th 1787 to April the 26th 1787 being 113 Days at 4 Guineas ℘ Annum

Wm Malachy Hitchins

Dr Maskelyne

Fig. 6: A receipt signed by Malachy's son William acknowledges payment of £1 6s 'for winding up comparing and computing the Going of Mr. Kendal's first Time-keeper' from 1786 November 30 to 1787 January 13 and 1787 February 16 to 1787 April 24. (Cambridge University Digital Library, Papers of the Board of Longitude, RGO 14/17 p. 322r)

introduced him to Hitchins and suggested he work as a computer.[43] As a result, in 1804 William Dunkin started work on *The Nautical Almanac*.

Around this time Hitchins suffered from bouts of gout and would take to his bed for periods of rest and recuperation.[44] It seems in later years that William Dunkin acted as a general assistant to Hitchins at the vicarage in St Hilary. When Hitchins died in 1809 Dunkin temporarily took over his role of comparer until an official successor was appointed, who was Thomas Brown of Tideswell, Derbyshire. Dunkin continued to reside in St Hilary until 1814 when he moved to Truro.

The era of computing at home came to an end in 1832 when an official Nautical Almanac Office was set up in London. William Dunkin was the only one of the existing computers who moved to London to join the permanent staff there.[45]

Dunkin's two sons Edwin and Richard both later joined the Royal Observatory. Edwin rose to become the Chief Assistant to the Astronomer Royal, William H. M. Christie. Edwin became a Fellow of the Royal

Fig. 7: The Old School House at St Hilary Churchtown, seen in 2016. (Carolyn Kennett)

Society in 1876, President of the Royal Astronomical Society in 1884, and President of the Royal Institution of Cornwall in 1890.

5.3. *Richard Martyn*

Richard Martyn (*c*.1790–1850) was not yet 20 when he was taken on as a computer in 1809 to replace John Pascoe, a Devon surveyor who had resigned his role the previous year. Martyn lived in St Mabyn, about three miles east of Wadebridge in Cornwall. He was Hitchins's nephew and still new in the role when Hitchins died. His initial workings lacked the accuracy required for the job as his training had been cut short on Hitchins's death. But he was fortunate to have both William Dunkin and Nicholas James to help.[46] His work improved and Martyn continued as a paid computer for several more years.

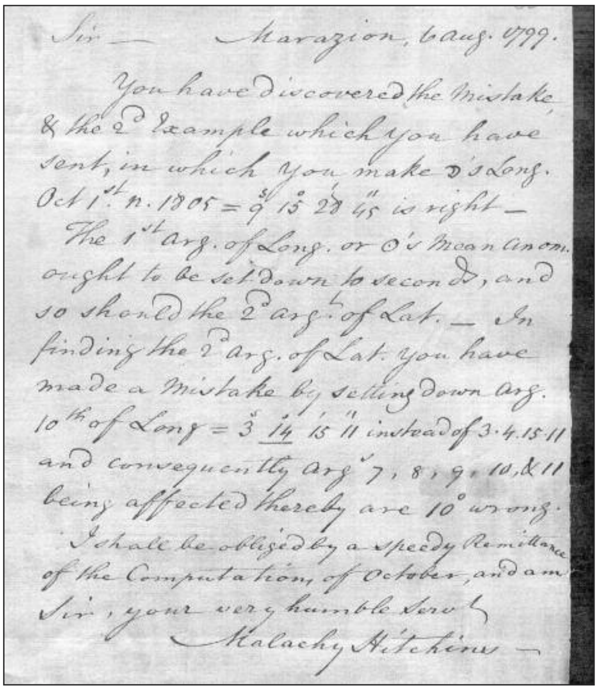
5.4. *John Hellins*

John Hellins (*c*.1749–1827) worked on *The Nautical Almanac* under the careful watch of Hitchins while he was a teacher at a small school at Bishop's Tawton in Devon. He had an interest in science and mathematics but was self-taught, having come from a poor family of labourers. He had a chance introduction with Hitchins, who recognized his exceptional abilities.[47] Hitchins introduced Hellins to Maskelyne from which he gained not only a position of computer but also briefly became Maskelyne's assistant at Greenwich in 1773. Although Hellins never resided at St Hilary, he did become curate at Constantine in Cornwall for 1779–83. He was made a Fellow of the Royal Society in 1796 and was awarded its Copley Medal in 1799 for his work on computing planetary perturbations.

5.5. *Other protégés farther afield*

Hitchins was also in communication with a number of other young astronomers, giving advice about astronomical techniques and calculations. One of these was Joshua Moore (dates unknown), an astronomer who emigrated to America in 1793 after being Maskelyne's assistant at Greenwich for a short time in 1787–8. It seems that during his time at Greenwich he was working more on calculations than observations, as there are no records of him observing when he was there. What is known is that he moved to Cambridge where he worked on *The Nautical Almanac* until the 1790s and communicated with Malachy about mathematical techniques.

Other letters from Hitchins that still exist are those he sent to a young John Crosley (1762–1817).[48] Crosley was one of Maskelyne's assistants from 1789 to 1792 and again in 1798, and he also worked briefly on *The Nautical Almanac*. In 1799 and 1800 Malachy wrote to Crosley outlining mistakes he had made in his calculations, along with advice to ensure that such mistakes did not occur again (Fig. 8). Crosley was a talented mathematician who was later to become president of the London Mathematical Society which met in Spitalfields, London; no doubt the mentoring he received from Malachy helped develop his abilities.



Sir — Marazion, 6 Aug. 1799.
You have discovered the Mistake & the 2d Example which you have sent, in which you make ☽'s Long. Oct 1st n. 1805 = 9s 15° 28' 45" is right — The 1st Arg. of Long. or ☉'s Mean Anom. ought to be set down to seconds, and so should the 2d Arg. of Lat. — In finding the 2d Arg. of Lat. you have made a Mistake by setting down Arg. 10th of Long = 3s 14° 15' 11" instead of 3.4.15.11 and consequently Arg. 7, 8, 9, 10, & 11 being affected thereby are 10° wrong. I shall be obliged by a speedy Remittance of the Computation, of October, and am Sir, your very humble Servt
Malachy Hitchins —

Fig. 8: Letter from Malachy Hitchins to John Crosley datelined 'Marazion 6 Aug. 1799' tells him 'You have discovered the mistake', goes on to point out another mistake, and ends by asking for 'a speedy remittance of the computations of October'. (British Library)

5.6. *The Giddy family*

Among other scientific friendships Hitchins struck up in Cornwall was with the Giddy family from the neighbouring parish of St Erth, about three miles north of St Hilary. Edward Giddy was curate of the church, and his son, Davies, was born in the village in 1767. Davies Giddy was educated at Penzance Grammar School, and this education was extended under the careful watch of Malachy, who took the young man under his wing as a private student.[49]

Davies did not become a computer on *The Nautical Almanac*, but was destined for greater things. In 1784 Malachy recommended the 17-year-old to the Mathematical Academy in Bristol of Benjamin Donn, the same man Malachy had worked for on the production of the map of Devon.[50] When he married, Davies Giddy changed his name to Davies Gilbert (the maiden name of his wife, the agronomist Mary Ann Gilbert) and it was under this name that he became president of the Royal Society from 1827 to 1830.

6. Other scientific endeavours

Part of Malachy's role as a vicar was to keep the parish records and census. He did this, as with everything, to an exceptionally high standard. Unusually, he also peppered the accounts with the occasional scientific note, such as the following which appeared on Saturday 1796 August 20 in the marriage register: 'At 20 mins past 2 o clock P.M. a slight shock of an earthquake was felt at St Hilary, which lasted about 2 or 3 seconds being in the middle space of a rumbling noise which attended it, and which lasted 6 or 7 seconds. The motion was from east to west. The air was still. The thermometer at 70.' [51]

By 1801 he had returned to his mining roots as part of a group of local men keen on exploiting the existence of silver in Herland copper mine in Gwinear. He outlined the discovery of silver ore in the mine in the *Philosophical Transactions* of the Royal Society.[52] Unfortunately, the mine did not produce enough silver to cover the cost of extracting it and the mining activity halted at a very early stage.

Finally Malachy used his influence to have a discovery of three Roman urns in west Cornwall presented at the Society of Antiquaries. A short account of the discoveries that he sent to Sir Joseph Banks was read at the Society of Antiquaries twice, on 1802 March 11 and March 18.[53] The urns, discovered in three different locations in 1779, 1789, and 1793, all contained coins and were of great interest due to their location far west of previously known Roman settlements. Malachy suggested that the Romans could have used various locations such as Chûn Castle, an Iron Age hill fort, as military stations.[54]

It is also worth mentioning Samuel Vince, Plumian Professor of Astronomy at Cambridge, who in his 1797 book *A Complete System of Astronomy* credits Hitchins as having produced and supplied for publication a table for calculating lunar occultations. Vince in his book describes Hitchins as 'a gentleman well conversant in the theory and practice of astronomy, who had the goodness to communicate it to me, with permission to publish it'.[55] Following this is an explanation and then an example of how to calculate the time of the occultation of Aldebaran at Greenwich on 1795 January 2.

7. Family matters

Malachy Hitchins married Joanna (or Johanna) Hawkin on 1764 January 10 at Buckland Brewer in Devon. She had been born in Shebbear, Devon, in 1739 and was a member of the well-off Fortescue family of that area. This put her in a position to pay for Malachy's college fees.[56] Their first child, Richard Hawkin Hitchins, was born in late 1764 in Bideford. Another four children would follow, three while they resided in Merton[57] and the final one in St Hilary. Joanna was buried in the church grounds at St Hilary on 1815 July 18.

7.1. *Children of Malachy and Joanna Hitchins*

Richard Hawkin Hitchins, their first child, was baptized on 1764 October 21 in Bideford. He was to follow his father to Exeter College, Oxford, where he gained his MA in 1789 and BD in 1799.[58] He became vicar at Baverstock in Wiltshire in 1804 July. A sale after his death in 1827 included a valuable library consisting of over 2000 volumes.[59]

Thomas Martyn Hitchins was baptized on 1766 May 20 in Merton. In 1782 he worked as the Reversionary Patentee for the diocese of Exeter, before attending Exeter College, Oxford, in 1785–8. He became curate at Stoke, a suburb of Plymouth, in 1797–9 and then minister of St John the Baptist Chapel of Ease, Devonport (1799–1830). He married Emma Granville on 1799 March 28 at St Hilary. The Grenville family resided in Marazion, Cornwall. Emma's sister Lydia was to have a well-documented love affair with Henry Martyn, a missionary with the East India company and Thomas's cousin. Thomas died in 1830.

Josepha Hitchins, Malachy's only daughter, was born 1768 June 2 in Merton. She married William Millett (1762–1821) on 1800 March 1 at St Hilary and lived at Gurlyn in the parish of St Erth.

William Malachy Hitchins was born on 1770 August 19 in Merton but spent most of his formative years at St Hilary. At the age of 16 he travelled to Greenwich, where he worked as an assistant to Nevile Maskelyne, the Astronomer Royal, between 1787 February 10 and June 23. He followed a number of assistants who had left in rapid succession. Although still very young, he would have got the job through his father's working relationship with Maskelyne.

Another possible reason for his employment is that Kendall's watch had been residing at St Hilary since 1786 November, so perhaps it made its return journey to London with William. There is a break in the payments for managing the watch between 1787 January 13 and February 16 during which time it could have been transferred to London. Payments then resumed until April 26, so this second period of measurements must have been made while William was at Greenwich.

After four and a half months working with Maskelyne, William returned to Cornwall where he became a solicitor in Marazion. He died the age of 32 in 1802.

Their final child, Fortescue Hitchins, was born at St Hilary on 1784 February 22. Fortescue followed his brother William into law and also became a solicitor in St Ives. He was also an author and poet. His compilation *The Sea Shore, with Other Poems* (1810) had a list of subscribers that included Maskelyne and Sir Joseph Banks.[60] Fortescue died in Marazion on 1814 April 1, aged 30. His material on the history of Cornwall was edited and published after his death by Samuel Drew.[61]

7.2. *Death of Malachy Hitchins*

Malachy Hitchins died in St Hilary on 1809 March 28.[62] He was buried within the church at St Hilary but unfortunately the grave is no longer marked. *The Complete Parochial History of Cornwall*, vol. 2, 1868, contains the only known record of the location:

> The Rev. Malachi Hitchens [sic] and his wife were interred in the church, in one grave, near the west

window of the north aisle. Their two sons, Malachi and Fortescue, were interred in the chancel; a plain stone bearing the name of Malachi only, covered their grave.[63]

A fire destroyed the church on Good Friday 1853, but reports in the local newspaper suggest that Malachy's grave survived the inferno:

> With the mass of fire and debris on the floor a vault fell in, and being in an angle under the windows a quantity of snow was thrown into it to extinguish the fire ... The walled graves of the Rev. Malachi Hitchens and family are not fallen as first thought, being covered with stone. Our elder parishioners cherish a lively recollection of the former Pastor.[64]

A new church was built on the site of the original. A raised floor was laid so the graves were not disturbed. Malachy's grave is to be found in its original position, about a foot and a half below the current chancel floor.

8. Legacy of Malachy Hitchins

Malachy Hitchins will primarily be remembered for his painstaking work which established the national and international reputation of *The Nautical Almanac* for accuracy and reliability. He proved very difficult to replace, as the Astronomer Royal Maskelyne acknowledged:

> Since the death of the late Mr. Hitchins, the able and faithful comparer of the Nautical Almanac ... I have found it necessary to bestow an extraordinary degree of attention, in directing the operation of the computers and comparers of the Nautical Almanac – As no person immediately occurred to fill the place of Mr. Hitchins.' [65]

His successor, Rev. Thomas Brown (1755–1836), vicar of Tideswell in Derbyshire and brother-in-law of William Lax, a member of the Board of Longitude, was not regarded as of the same standard.

I like to think that Malachy's high standards were in part driven by the need to produce an accessible solution to the problem of finding longitude at sea, very likely having seen the impact on local families of loss of life among seafarers. *The Nautical Almanac* was deliberately priced by Maskelyne to be afforable to sailors, whereas a chronometer was beyond their means. *The Nautical Almanac* is still in production today, but the calculations are now done by non-human computers.[66]

Hitchins should be acknowledged for a large and long-lasting influence on a number of local people, introducing them into the field of science and astronomy. Most famously this includes the Giddy and Dunkin families. His influence stretches far beyond the small region of St Hilary into the lives of many budding and hopeful jobbing astronomers who looked to him for help and personal advancement. His efforts enabled this small and remote corner of England to become central to the advancement and sharing of astronomical knowledge and techniques in the late 18th century.

I will leave the last words to an obituary which was published in the *Weekly Entertainer* (a popular west country magazine) and quoted in Charles Gilbert's *Historical Survey of the County of Cornwall*:

> To all who knew him as a man, a clergyman, or an author, he is the subject of pleasure and of sorrow; of pleasure from the recollection of integrity, Christian simplicity and genuine benevolence – his pastoral assiduity and sincerity – his genius and learning; of sorrow, from the sad consideration that all his good qualities and virtues and talents are now no more, and can hardly be replaced. [67]

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William Ross and a misguided means of finding longitude

David J. Bryden

The Longitude Act of 1714 offered prize money for methods of finding longitude 'practicable and useful at sea'. Promising proposals could be funded by the Longitude Commissioners with up to £2000 for development and trials. William Ross (1701–?) of Hanley Castle, Worcestershire, was one such aspirant. With his portable universal sundial – the so-called *Rossipher* – or his fixed garden sundials, Ross claimed to undertake observations and provide solutions to many problems in astronomy without recourse to complex calculations. His sundial designs, together with his belief in their application for finding longitude at sea, are here placed in the context of local and national scientific activities of the time. Ross understood the basic mathematics of astronomy, but lost touch with advancing observational techniques and related computational methods. Like many land-bound projectors, he had a misplaced belief in the value of his approach and craved acknowledgment by the establishment, decrying the fact that his proposals were largely ignored.

1. William Ross of Hanley Castle

William Ross was a shadowy figure about whom little has previously been known.[1] Research by the current author has established that he was the second son of Richard and Elizabeth Ross, baptized at St Mary's Church, Hanley Castle, Worcestershire, in 1701 December, and serving as church warden 1734–38.[2] His father died when he was only six. Presumably Elizabeth Ross managed the land-holding until her sons grew up.[3]

As a Hanley Castle Freeholder, William appears in the 1741 Worcestershire parliamentary poll book.[4] On 1745 June 1 he was licensed as yeoman and a bachelor 'aged about forty one' to marry Mary Hart, spinster, also of Hanley Castle, 'aged about 35 years'. The licence provided for marriage at either Hanley Castle, Welland, or the chapel at Bransford; it was presumably solemnized at the latter.[5] Ross possibly lived in London towards the end of his life, but did not relinquish his connections with Hanley Castle.

A glebe terrier (i.e. an inventory of land holdings from which the rents go to the local church) of 1761 notes him owning several adjacent parcels of land, all held by tenants.[6] Ross had sufficient income to travel to London and stay there in 1735, and again in 1759 and in the 1760s, if not at other times. He could afford to commission the printing of books and make representations to those in the establishment who he thought would be interested in his discoveries. Neither the place nor date of his death has been established.

1.1. *The publications of William Ross*

Two books by William Ross are known, both published in London 'for the author'. First of these was *The New Astronomer*, elaborated by the subtitle: *Or, Astronomy made easy by such instruments that readily shew by observation the stars, or planets places either in the equator or ecliptick, or of Luna in her own proper orb, in any part of the world; they also take the latitude, find the variation of the needle, and a true hour of the day. Likewise they are instruments as ready and useful in surveying, as any hitherto in use*.

Five hundred copies of this 100-page book, with many woodcut text diagrams and three folding engraved plates, were printed in 1735 October by the London printer William Boyer.[7] It was listed at 2s 6d by the London bookseller J. Roberts in 1736 December.[8] Unsold copies were reissued in 1760, expanded with a 32-page supplement described as 'A further addition to the New Astronomer. To the Right Honourable The Lords Commissioners for the Discovery of the Longitude, A Complete Meridian, Is humbly dedicated by their Lordships Most humble, and most obedient, Subject and Servant, 1760. W. Ross.'

The *Further Addition* does not appear in the ledgers of the original printer, so it is likely that Ross commissioned another London printer to do the work. Only nine existing copies of *The New Astronomer* are known to me, four with the supplement.

His second book appeared in 1765, known from a single 49-page copy, bearing the title-cum-description *A Complete Longitude is here mathematically and instrumentally set forth, by tables and propositions, such that are founded on principles that are entirely new; and are composed for clock or watch, in a sexagenary way suitable to his garden dial*. It is attributed to 'the author, N.A.', meaning that it was written by the same person as *The New Astronomer*.

Ross was strangely reticent in proclaiming authorship of his publications. The title page of *The New Astronomer* says only that it is 'By W.R.', although the plates are signed with his name. In contrast, the supplementary opening page of the sheets that were added to the reissue names the author as W. Ross, while his 'To the Reader' is signed with the initials 'N.A.', i.e. the author of *The New Astronomer*. When advertising the reissue Ross failed to give his name, nor did he indicate where copies could be purchased.[9] In a subsequent advertisement he again designated himself simply 'N.A.' [10] This pseudonym reappears on the title page of *A Complete Longitude* of 1765, although the dedication carries his name.

Fig. 1: The Rossipher, the portable universal sundial invented by William Ross. Its base is 270 mm diameter and made of wood, probably walnut. The instrument itself is about half a metre high. (University of Oxford, Museum of the History of Science.)

Ross had *The New Astronomer* printed in London because the capital had specialists to make the woodcut diagrams found throughout the text. As to the engraved plates, if Ross did not cut them, then he insisted that his own drawings were slavishly copied, because the overall style differs from London technical illustration of the period. In Worcester he would have had little choice of printer, and there is no evidence that the city had a rolling press to print the plates.[11]

No advertisements for Ross's books have been located in Worcester newspapers around the period of their publication. What was printed and published in 18th-century Worcester was primarily aimed at a local market. An analysis of book advertising in the Worcester press for the period 1713 to 1741 records only 57 separate titles, of which just six were books on applied science.[12] So far as the local booksellers were concerned, Ross's publications would have been unlikely to find buyers.

It is clear from Ross's comments in *The New Astronomer* and the *Further Addition* that some copies of these books were destined for those whose support and recognition he was soliciting. In contrast, *A Complete Longitude* was an integral part of the package for pupils responding to his offer of tuition advertised in London in 1766. Copies might have been restricted to those who paid for and attended the course in which his garden dial, or the portable version of it, was central to his novel method of finding longitude.

1.2. *The Rossipher, a portable universal sundial*

In 1966 the English science historian Eva Taylor first linked William Ross with an unusual instrument known as the Rossipher that is preserved in the Museum of the History of Science in Oxford (Fig.1).[13] The Museum describes the Rossipher as combining the features of the medieval torquetum and the equinoctial ring dial.

Its combination of base plate, adjustable equatorial plate, and ecliptic plate, with an adjustable vertical circle, allows the instrument to be used at any given latitude to follow the movements of any celestial object (the Sun, Moon, star, or a planet) with a single motion. It enables conversions between altazimuth, equatorial, and ecliptic coordinates which would otherwise require mathematically demanding calculation.[14] It is made of brass on a wooden base and stands just over half a metre high, depending on how it is configured.

The altitude circle is engraved: '*Wm. Rofs* Inventor | of this his Rofsipher | INST^MT | 1731' (Fig. 2). However, we can be reasonably sure that 1731 was not the true date of manufacture. Ross did not use the term Rossipher in *The New Astronomer* of 1735, so the instrument at Oxford was mostly likely made after that book was published. The Oxford instrument must have been made before 1752, because the ecliptic scale is calibrated for the Julian calendar rather than the Gregorian one which was not adopted in Britain until 1752. The style and execution are consistent with London

Fig. 2: Inscription on the altitude circle of the Rossipher, attributing it to Wm. Ross and with the date 1731, although the true date of manufacture was probably some years later. The circle is 205 mm in diameter. (David Bryden, reproduced by permission of Museum of the History of Science, University of Oxford.)

work with a date of 1740 ±10 years, which is about as close as we can get to dating it.

The instrument bears no maker's signature. This is not surprising, as it was a specially commissioned piece, and the wording prominently engraved on the altitude semicircle was stipulated by Ross. However, there are good reasons for supposing that the manufacturer was the London instrument maker Jonathan Sisson (1690–1747).

For one thing, the Rossipher has strong design similarities with the 'New Theodolite' designed and made by Sisson, published in 1725, and more particularly with his 'latest improved Theodolite' that appeared in 1737.[15] In particular, the geared rack-and-pinion motion of the base circle, the azimuth circle, and the altitude semicircle is something that Sisson introduced in 1725. This feature was sometimes used by other London instrument makers, notably by Thomas Heath (*fl.*1720–53) in his 'new improved theodolite' of 1731, but the racked altitude circle in Heath's design is inverted.[16] What's more, it seems possible that making the Rossipher might have stimulated Sisson's own design ideas, as we shall see at the end.

The engraving on the Oxford instrument has stylistic differences in the layout and weight of hand on separate parts. One obvious difference is in the marking of half-way points between lettered or numbered parts of the scale. The degree scale and 32 lettered points of the compass on the base plate have no sub-markers (Fig. 3); the altitude scale uses a grouping of three arrowheads, as does the declination scale on the sighting mechanism (Fig. 4); the equatorial hour scale and calendar circle use a fleur-de-lis (Fig. 5); while the upper hour and ecliptic scale use a single arrow (Fig. 6). This latter scale and the sighting mechanism are in a distinctly lighter hand than the others.

The evidence of workshop practice is fragmentary, but some London makers sub-contracted the lettering and figuring of scales once they had been divided, while larger workshops had in-house specialists to do such work. If Ross was a customer willing to pay a premium for early delivery, the maker (presumably Sisson) might well have had the lettering and the division done by more than one of his journeymen, perhaps even sub-contracting to other workshops.

In setting the lowest circle with its internal compass into a wooden base the maker has saved commissioning a bespoke brass casting from a foundry, something that he might be unlikely to use again. This is a factor against attributing the piece to Heath's workshop, which made standing universal sundials using heavy brass castings for the base, whereas the Sisson business apparently did not. The curved supports that hold the assembly above the compass box are squat and make reading the compass quite difficult. This is evidently a design compromise, as greater height would have lifted the centre of gravity and made the instrument less stable. Overall,

Fig. 3: Base plate of the Rossipher, divided by 10° subdivided to 1°, with 32 compass points. The compass box and the whole mounting are rotated using a pinion working on a hidden rack.(David Bryden, reproduced by permission of Museum of the History of Science, University of Oxford.)

Fig. 4: The vernier read-out on the altitude semicircle, allowing latitudes to be set to the nearest 5 seconds. Note the use of the three arrowheads to mark the 5° interval, and the rack-work on the edge of the circle. (David Bryden, reproduced by permission of Museum of the History of Science, University of Oxford.)

although bespoke, the piece looks as if it has been put together utilizing stock castings and parts wherever possible.

Whoever made it, and in which year, the Rossipher provides conclusive evidence that William Ross was no desk-bound designer. He was keen to demonstrate the instrument's multitudinous applications whenever and wherever he had the opportunity, as we shall see.

Fig. 5: Equatorial scale of the Rossipher. A fleur-de-lis marks the 30′ (half hour?) points and there is a decorative wheat-ear border. Note the knurled-head turnscrew. The rack work is cut on the inside of the hour ring, and hidden by the inner circle of months – this revolves when the pinion is turned via the knurled-head screw. Equivalent times for Boston, Damascus, Fort St George [Madras, India], Pekin, Xalisco [Mexico], and New Severn [Hudson Bay, Canada], can be read on the equatorial hour scale. (David Bryden, reproduced by permission of Museum of the History of Science, University of Oxford.)

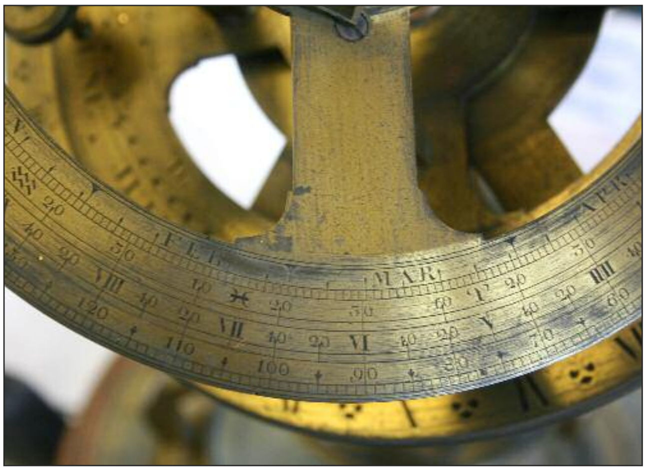


Fig. 6: Ecliptic scale of the Rossipher. A single arrowhead marks 5° intervals. Note that the first point of Aries is at March 9½ indicating that the dial was made for the Julian calendar. Hence the instrument must date from before 1752, the year the Gregorian calendar was introduced into England. (David Bryden, reproduced by permission of Museum of the History of Science, University of Oxford.)

2. William Ross and the Royal Society

The archives of the Royal Society provide the earliest evidence of William Ross's scientific activities. On 1732 March 9 members heard a paper 'Description of a Dial invented by Mr Wm Ross of Hanly [sic] Castle in the County of Worcester'. Into the records the clerk copied the description sent by Ross.[17] The drawings sent with the account were pasted into the volume. They are signed, and dated 1731/2 (Figs. 7 and 8). Although Ross acknowledged that his contribution had been 'courteously received', that appears to have been the sole encouragement from the scientific establishment.

He sent the Society a copy of *The New Astronomer* after publication in 1735, describing his dial in its expanded forms, together with worked examples of how it should be used. There is no record of what the Society made of it. Their archives preserve a manuscript sent in 1736 June, endorsed 'Mr. Wm. Ross Ephemeris for June 1736 … not read nor to be enter'd.'[18] This does not indicate lack of interest – a tabulated ephemeris was unsuitable for reading at a meeting.

The final evidence of Ross's interaction with the Royal Society is a letter he wrote from Hanley Castle, dated 1744 September 28. It opens with the phraseology of one who feels he has been ignored but who does not wish to appear pressing: 'I fearing that my last have miscarried, occasions me to write to you in the same words'. He refers to his 1732 contribution and to *The New Astronomer* of 1735: 'I have much improved my first Instrument'.[19] Reading between the lines, we can deduce that Ross is angling for an invitation to submit an expanded treatise to be read and considered for publication in the Society's *Philosophical Transactions*.

Unfortunately for Ross, his 1732 account was written just as interest in dialling was on the wane. Around the time he made his first approach to the Royal Society others were submitting papers relating to dialling. In 1731 March Richard Graham (1693–1749) had read to the Society his 'Description and use of an improv'd equinoctial dial for shewing the hour by the Sun or any of the Stars, with great exactness',[20] followed in December by 'Description and use of an instrument for taking the latitude of a place at any time of the day'.[21]

Graham's second dialling paper was published in the *Philosophical Transactions*, but after that the Royal Society's published proceedings contained no articles related to sundials or their application for another 30 years, when James Ferguson (1710–76) published 'A new method of constructing sundials, for any given latitude without the assistance of dialling scales or logarithmic calculations'.[22] That was the final paper dealing with sundials to appear in that august journal. Given the declining interest in dialling, it is not surprising that the Society was unresponsive to Ross's *New Astronomer* in 1735, the ephemeris he sent the following year, or to his letter of 1744.

Although dialling had lost its status as a leading-edge science, the subject was taught for its own sake and as an introduction to practical astronomy. Dialling proficiency remained a sign of mastery of the three-dimensional geometry of solar astronomy. Throughout the Hanoverian era sundial design remained a matter of considerable interest, if only because until the spread of the electric telegraph in the early Victorian period the sundial remained the readiest means of setting domestic clocks and watches.

Ross was not alone in proposing design variants. In 1746 *The Gentleman's Magazine* published drawings of a 'new-invented Universal Dial' which the Northampton Philosophical Society had commissioned for their use. That monthly publication, only tangentially interested in scientific matters, published three further sundial designs over the next forty years, in addition to reprinting Ferguson's article on sundial design from the *Philosophical Transactions of the Royal Society*.[23]

3. Ross and the Commissioners of Longitude

Isolated from the scientific mainstream in rural Worcestershire, Ross felt he was being cold-shouldered by the scientific establishment, his efforts ignored, and his ideas stolen. In 1760 the resentment surfaced:

> I Long ago had printed the following Schemes and their Uses; but foreseeing that Disadvantages might arise from so rash an Attempt, I made it my utmost Endeavour to find on what Basis any Oppositions might be founded; I diligently apply'd my self for Security to the Hon[ble] the R.S. of London in 1731; what I then offer'd was courteously receiv'd, and desired I would proceed; and to the Right Hon[ble] the L—ds of the Adm—ty in 1732, and to several whom I thought it might concern, and might be in their Power to prevent any Oppressions, suddenly I was repulsed with Loss; and as I then did imagine it to be for some private Ends, I publish'd in 1735 a small Pamphlet, and apply'd to such as I had entirely serv'd, for Security; and still I found some private Ends were more prevailing, and myself to undergo an Oppression, a Wrong, a design'd Project, and an Heathenish Prosecution of Body and Soul, which could only tend to the utmost Extent of Ruin and Destruction.[24]

Ross dedicated the 1760 supplement of his book to 'the Lords Commissioners for the discovery of the Longitude'. The 1714 Act gave the Commissioners limited operational guidance. A Commissioner receiving an application responded as he thought fit, drawing in other members and taking external advice only if he considered the proposal promising, and where resources were required from the Admiralty for development costs or sea-trials. Such was the ad hoc nature of the Commissioners' activities that 1737 marks their first recorded formal meeting. Ross in 1732 would have found it difficult to navigate the administrative morass, particularly from outside London.

From the late 1750s reports in the press of the sea-trials of Christopher Irwin's marine chair and John Harrison's chronometer ensured wide awareness of the potential financial reward for solving the longitude problem. The publicity created pressure on the Commissioners to be seen to evaluate proffered designs, and forced the pace of the formalization of the Board of Longitude. By the late 1750s it had become easier to get a hearing from the nascent Board, but the academic astronomers, led by the Astronomer Royal and the Professors of Astronomy at Oxford and Cambridge, did not suffer gladly those they considered fools.

After 1760 the Board continued to deal with Harrison's case and Tobias Mayer's lunar tables, but concluded that Irwin's chair was of no value. It also dealt with various other proposals sent by hopeful inventors. Ross felt frustrated by the difficulty of getting a hearing: 'In Pursuit of redress in London, in 1760 … I had wrote and printed several letters and petitions in all Obedience to the Right Hon[ble] the L—ds appointed; and to several, desiring they would promote my Intentions'.

Specifically he had written to 'L—d Mac – s—d' [George Parker (*c.*1697–1764), Second Earl of Macclesfield and President of the Royal Society], and 'L—d A-s-n' [the circumnavigator George Anson (1697–1762), subsequently First Baron Anson, at that time First Lord of the Admiralty]. In 1759 June Ross had inserted advertisements in the London press, although withholding his name:

> IT is with humble Submission and Obedience and to fulfil their Majesties most gracious Requests; to the Right Honourable the Commissioners appointed, I come now to offer and prove my long proposed methods of a perfect Meridian, at this Season of the Year, when they may be fairly proved by Truth and by Day-Light; I can represent more than 100,000 different Planes of Horizons by Instrument, and from it determine for what Place: I can ascertain Hours, alter the Latitude more than one Degree, more or less than the true Latitude and it will shew that it is a perfect Meridian, and the Variation of the Needle to a Truth: In the perfect Meridian, I conceive that the Poles, the Observer, and Moon, (that they, their Verticals and Perpendiculars) are all in a right Line; so let there be ever so many Observations taken in one Day (in such sort) and at as many different Places, then will their differences of Meridians be in Proportion one with another, without an Equation, with certainty. At certain Hours, I can alter the Latitude to two degrees more or less than the true Latitude, and will not alter the Hour any single Minute of Time. All this I can confirm and prove by Mathematical Problems, suitable for such Latitudes that I represent, and such that are mostly

> thousands of Miles from this Kingdom. I further perceive by the several alteration of Latitude at certain Hours, that these will greatly give P[illegible] for the Ship's Motion, where the Naked eye is capable of discerning without Levels of any sort is near the balance; besides the durations are too long, as one Quarter of an Hour or more, that there is Time and Times may be repeated to prove their Truth in Observation.
>
> N.B. The Author proposes this Day, and Tomorrow giving his attendance at the Saracen's Head, Friday-street, Cheapside, where he will shew some Particulars what he has asserted, and if the Day permits, in some Measure make Proof of the same, in order, to find the Neglected of this that has been so long and oft tendered for fair Play.[25]

Given the short notice, one wonders whether anyone came to Ross's demonstration, and quite why he withheld his name. Few competent astronomers or navigators would be drawn to an exposition by an anonymous author making claims that bore little relation to contemporary practice.

Many others besides Ross had found it difficult to ensure a hearing from the Commissioners of Longitude and turned to alternative outlets. In 1736 one projector had his longitude proposal published at length in *The Gentleman's Magazine* and as late as 1760 another addressed the Commissioners of Longitude through the same channel, while in 1759 an inventor was offering to sell his ideas to the highest bidder.[26]

Ross was by now firmly committed to the belief that his small analogue instrument could sight the Sun, Moon, or stars with sufficient precision to provide accurate indications of time, latitude, and longitude. He was also convinced that his design had been unacknowledged and stolen.

In the late spring of 1762 in an advertisement headed 'The New Astronomer' Ross, identifying himself as 'N.A.', made further strong claims for the validity of his approach and again vented his ire on the establishment:

> These Extents of Longitude (in Degrees) long ago, might have been made Public, but dreading, that if they were directed to the Ambitious, such that will promote Shipwreck to be an annual Property to themselves, they will not regard it: if to the more covetous, that will think all they can take off other People's Properties their lawful Gain; it will be no Purpose; therefore the Author has delayed these Works for many Years, and now publishes them to be examined by the skilful, and to know whether the Sea-Clock would have given that true Point of Compass, *already mentioned* in the *New Astronomer*, which was wanting to the Association, the Dolphin, the Dodington or Bideford, where there w[as] Sea Room.[27]

In 1763 February the members of the Board of Longitude agreed on further sea trials and funding for Harrison's chronometer, as well as an additional sea trial, without further funding, of Irwin's marine chair. They postponed a decision on an award to the widow of Tobias Mayer for his lunar tables, and invited the Royal Society to examine a machine for finding longitude which had been the subject of a presentation to them by the mechanic to the King of Denmark. They also postponed considering a scheme sent in by an inventor who failed to attend to explain his proposals. One other hopeful supplicant appeared with an instrument; the minutes tersely record that it was judged 'to be of no kind of utility'.

Letters were tabled from six persons who had submitted proposals to find longitude. Among them was one 'From Wm. Ross, dated the 3d Feby 1763, by instrumental and other methods', but no further detail of the contents were given.[28] There was also a statement of future policy, designed to deter time wasters: all applicants would be told 'they must obtain Certificates from persons of known Skill & judgement that their schemes have been tried & have been found to answer what they propose by them; or that there is a very great probability that they will do so upon Experiment, before this Board can take any notice of them'. No Ross correspondence survives in the Board's papers, and his name does not reappear in their minutes.[29]

Although largely occupied with the final stages of evaluating Harrison's chronometer, the Board continued to consider new supplicants. At its meeting of 1766 April the Board asked the Astronomer Royal to report back on proposals for discovering the longitude sent in by five named persons, but Ross was not among them.[30] Nevertheless just five days before that meeting took place Ross advertised in the London press, promoting his own solution to the problem of finding longitude and scorning the successful trials of Harrison's chronometer:

> LONGITUDE taught after a new and correct method, and with an entire new apparatus now before the Board of Longitude, and submitted to the opinion of the Regius Professor of Astronomy, by W. ROSS. This Complete Longitude is now printed, and will be communicated by the author, who has made it his study for upwards of forty years, on such terms as he shall agree for with his pupils. The operations are performed by the points of the heavens, which are ever and invariably the same; and demonstrated mathematically and instrumentally by draughts and by figures, and clearly proves the errors of watches and watchmakers, whose machines, if credited, would prove the heavens to be in a state of confusion. Those methods of the inventor, when explained by himself, will also serve as a sufficient check to those who prefer silence before speaking the truth, when required, with a view, it is supposed, to convert the author's labour and contrivance to their own profit and emolument. In fine [sic], the Complete Longi-

tude is now printed, and offered thus to the public, to prove the certainty of the principles therein advanced, which so many have spent their time and exhausted their learning to controvert. Watches are like common animals, only made useful by the care and correction of their makers or masters. The author may be heard of at the Burying-ground in St. Mary le Bon.[31]

A Complete Longitude continued Ross's application of his sundial designs of *The New Astronomer* but with special reference to what he called his 'Garden Dial'. The grandiose 'sexagenary way' of the title page alludes to minutes of time having a base of sixty to the hour. The book gave examples of how to add and subtract in that base, an indication of the relative innumeracy of the students he was expecting. His rambling and simplistic books indicate that, like many other longitude projectors, Ross was out of touch with what the scientific establishment considered to be preferred solutions. Those with experience of shipboard navigation knew he was no judge of what was effective, practical, and accurate in a technically demanding area of applied science.

Possibly he got as far as having a meeting with the Astronomer Royal, or other members of the Board, in connection with his 1763 submission, for he terminates a long letter published in a London newspaper in 1765 October with the paragraph:

It is to answer the reflections of the learned I write, as when they say what trade are you, what have you to do with the longitude? When we by our Globes and Right Ascent can answer all you speak of. Quere[sic], with submission, why not I, when so many years they have imitated my works as their own property, can't we reasonably think them to be such that had rather a thousand perish; and say, there is enough left behind to inherit their Income, tho' the cries of the distressed have so oft called for help, and the Parliament have so long requested it of the skilful![32]

So far as it went, his *New Astronomer* of 1735 was an adequate exposition of what could be achieved with the universal sundial that he had designed, although it contained nothing that could not be found in other dialling texts of the period. However, his own understanding of the nature and form of the astronomical problem to be solved did not progress. He certainly failed to appreciate that the 1763 publication of *The British Mariner's Guide* made finding longitude at sea by the method of lunar distances a realistic proposition.[33]

When the *Guide*'s author, Nevil Maskelyne, was appointed Astronomer Royal in 1765 (and *ex officio* a Longitude Commissioner), the die was cast. The Commissioners of Longitude paid for computation, printing, and annual publication of *The Nautical Almanac and Astronomical Ephemeris*. Occasional supplements explained new methods of computing latitude and longitude. For active practitioners of the subject, the age of scientific navigation had arrived. Navigation textbooks led the way in making the method of lunar distances accessible to mathematically competent navigators.[34] By the last decade of the 18th century, even the less mathematically demanding navigation texts were including treatments of lunars.[35,36] Rudimentary solutions like Ross's could no longer compete.

4. The sundials of William Ross

The context in which Ross first operated is illustrated by an advertisement printed in a Worcester newspaper over four decades later. In this, an artist and engraver named James Ross (1746–1821), no relation to William, advertised his skills, which included making 'horizontal sun Dials for Gentlemens' Gardens, elegantly engraven on Brass (skilfully calculated to shew every Minute distinctly, together with the Sun's Place &c. by Mr. James Beresford, Teacher of the Mathematicks in Bewdley.) Those Gentlemen who are desirous of having a Thing so usefully ornamental, may depend on having one carefully executed to any Size and truly calculated for any Latitude, on the shortest Notice'.[37]

James Ross trained in Worcester under Robert Hancock and had initially engraved for the Worcester Porcelain Company. He was brought up at Ribblesford, near Bewdley, and commissioned Beresford to design bespoke sundials for the local gentry as useful garden ornaments.[38] Forty years earlier William Ross had supplied a similar market with dials that would otherwise have to be ordered from London workshops.

If William Ross had local competition it could have come from the Irish-born surveyor and teacher of mathematics John Dougharty (1677–1755), who had left Bewdley for Worcester by 1711.[39] Dougharty's textbook, published in London in 1748, included the application of trigonometry to 'several important and curious problems in astronomy, navigation and dialling'.[40] He put sundials in the gardens of properties he developed in Worcester at Holywell Hill and Diglis, claiming credit for the one installed at Hartlebury Castle.[41]

Presumably William Ross attended the long-established grammar school at Hanley Castle. His *New Astronomer* of 1735 indicates that his mathematical skills were more advanced than would be taught in the conventional school curriculum of the time. Did he interact with John Dougharty? In addition, had he met the Swiss-born polymath Nicolas Facio or Fatio (1664–1753), an associate of Isaac Newton, who retired to Worcester about 1720 and continued to take part in the quest for finding longitude at sea?[42] As to Ross's interest in dialling, perhaps it was stimulated by a near neighbour, the painter Charles Ponty (dates unknown) of Hanley Swan, who in 1716 included in his repertoire the ability to paint 'any sort of dials with proper ornaments'.[43]

The sundial described by William Ross in his 1732 paper that was read at the Royal Society is an equatorial. The principle was long known. Ross's design for

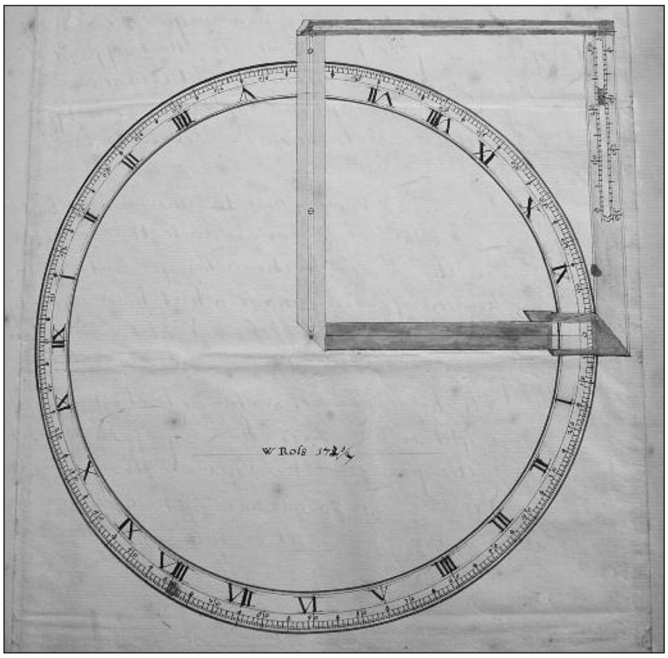


Fig. 7: The dial plate and sighting mechanism of Ross's dial of 1732. The dial plate is drawn in plan, while the sighting mechanism is drawn with distorted perspective so as to show the operational parts. The shaded portion is in the same plane as the dial plate, but the whole forms a square set perpendicular to it. Compare with Instrument No. I of Fig. 9. (David Bryden, courtesy the Royal Society; Archives RBO/17/6)

mounting and setting the pin-hole gnomon, and using it as a sighting device when making observations of stars (Fig. 7), is unusual, but the principle behind it was not.[44] The drawing for the mounting (Fig. 8) is not discussed in his text, but it includes features that had been integral to the portable universal equatorial sundial for well over a century. Craftsmen in London, Dieppe, Paris, Augsburg, Nuremburg, Munich, and Vienna had long been making and selling such dials.[45]

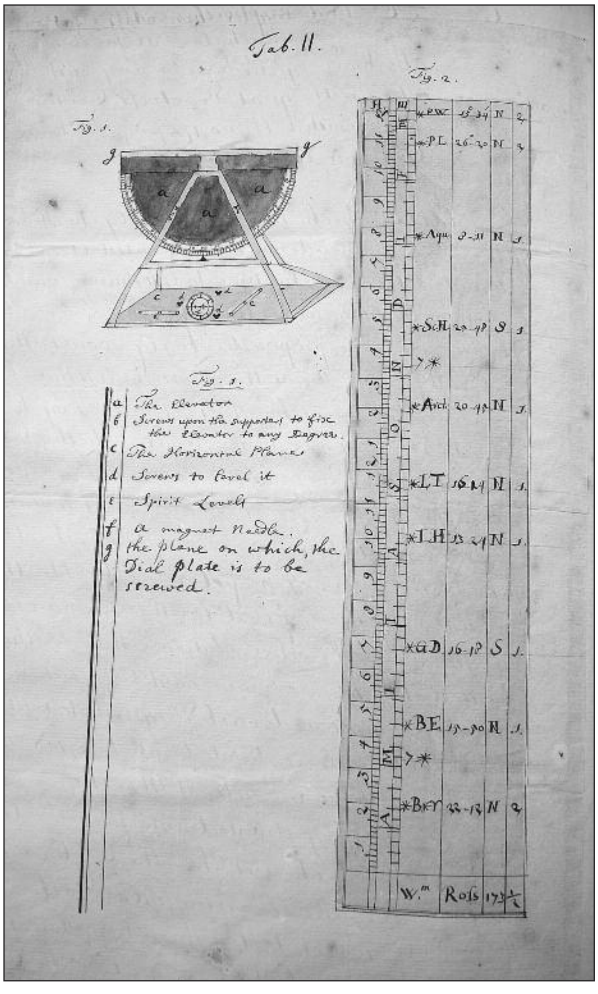
Ross's design applied his instrument to telling the time at night by observations of the stars. A user could sight any one of ten selected bright stars and then by a simple operation with a pair of dividers read off the time from the calibrated ruler (Fig. 8). Neither idea nor application was novel. Horary quadrants made in 1623 to the design published by the English mathematician and astronomer Edmund Gunter (1581–1626) typically included a table of five stars for undertaking a similar exercise, with a planispheric nocturnal on the back; in principle this allowed time to be measured at night provided some part of the sky was visible.[46]

Later in the 17th century the universal quadrants designed by the English mathematician and surveyor William Leybourn (1626–1716) had scales engraved upon them intended to be used in a manner similar to that described by Ross.[47] Hence Ross's design contained nothing that was inherently original. It was a variation on known dialling themes, but one that the Royal Society considered sufficiently interesting to read at a weekly meeting.

4.1. *Finding longitude*

In *The New Astronomer* of 1735 Ross expanded on the account he had sent to the Royal Society three years earlier. His preface opens with an encomium to the lay reader in praise of geometry and its application to the useful arts, especially navigation: 'the Glory, Beauty, Bulwark, Wall and Wealth of Great Britain' as he put it. He continues: 'My chief design in printing the following treatise is to acquaint the world with such instrument that the inventor believes may be of good service in several parts of the mathematicks, and particularly in finding the Longitude by sea or Land with great readiness and exactness.'[48] The emphasis on finding longitude was the driving force behind the book's publication, and it remained at the core of the 1760 *Further Addition* and of his *Complete Longitude* of 1765.

Fig. 8: The mounting and the calibrated ruler. The scales on the ruler are headed H (hours) and M (months), with each month identified by an initial letter from April at the bottom to March at the top. Star names are given in the accompanying text as PW = Pegasus's Wing; PL = Pegasus' Leg; Aqu = Aquila; ScH = Scorpion's Heart; Arct = Arcturus; LT = Lion's Tail; LH = Lion's Heart; GD = Great Dog; BE = Bull's Eye; B♈ = Bright Star of Aries. The fourth and fifth columns give the star's declination N[orth] or S[outh] and the sixth the magnitude. (David Bryden, courtesy the Royal Society; Archives RBO/17/6)*



Ross's belief that he had designed an instrument with some novel mechanical features which could be used for finding longitude was not totally misplaced. He knew that observations of the eclipses of Jupiter's satellites could be used, but that this required the use of telescopes that were too long to be used effectively aboard ship. He dismissed the use of a timepiece, on the spurious grounds that the length of a seconds pendulum varies with latitude – which is true, but irrelevant as pendulum clocks were no longer seriously considered for use at sea. In the event it was the spring watch and the subsequent development of the marine chronometer that provided the most generally practical solution.

Ross knew too that a prerequisite for computing longitude by measuring the angular separation between the Moon and the Sun or a star – the lunar distance method – was a reliable ephemeris of lunar motions. Yet, being inexperienced in practical astronomy, he failed to appreciate that his instrument of 250 mm diameter with pin-hole sights would give only approximate measurements of angular distance, of no use for serious position-finding.

His 'easy longitude' would attract the novice through mathematical simplicity and, like the exposition in his *A Complete Longitude* of 1765, allow the barely numerate amateur to get latitude and longitude figures by simple arithmetic using observation made with one of Ross's garden dials. But it was totally irrelevant to the new breed of scientific navigators who demanded far greater precision.

His worked examples give measurements to one second of arc, yet his instrument is only subdivided to one degree, and at best could be read to the nearest 15 seconds. In practice, the error in measuring angular distances using pin-hole sights set a few inches apart was likely to be of the order of at least a degree. His trigonometry was basic; he did not appreciate that an error of one second of arc in measuring a lunar distance leads to an error of half a degree in computed longitude.[49]

Ross failed to realize that his 1735 text had been left behind by advancing theory and practice. The theory of longitude by lunar distances was being actively worked on in Europe. The national observatories at Paris (1667) and Greenwich (1675) were established primarily to make radically better measurements of the position of the stars and the movements of the Moon and planets, so allowing the mathematically competent mariner to make a meaningful calculation of longitude. At the same time, theoreticians were making corrections for factors such as atmospheric refraction and lunar parallax. For ship-board use the Hadley reflecting quadrant was displaced by the more accurate sextant.[50]

The anti-establishment fulminations in the first half of *A Further Addition* of 1760 will not have assisted his case for a hearing, while the text that follows demonstrates that he had become out of touch. When Ross needed contemporary data he did not seek out the

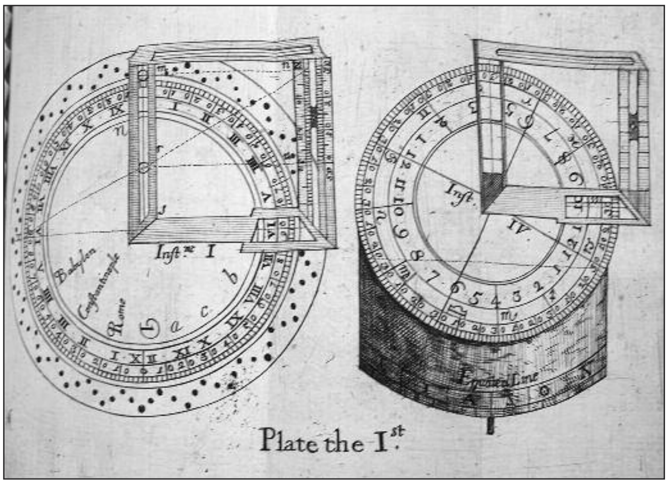


Fig. 9 (above left): Instrument I. This is essentially the same drawing of the sundial plate and sighting mechanism as Ross sent to the Royal Society in 1732. Babylon, Constantinople, and Rome are marked on the dial plate, enabling the time at those locations to be given with respect to the local time read from the dial. Compare with the different selection of locations marked on the surviving Rossipher in Figure 5. In his book A Complete Longitude, Ross provides a table of 60 locations east and west of London and explains how to find the local time using his dial.

Fig 9 (above right): Instrument IV. Mounted on a base that is set at 23° 30′ above the horizon, this represents the plane of the ecliptic. With this device local latitude can be observed.

(David Bryden, courtesy the Royal Society; Library R61378 & R61338)

recently published observations based on John Flamsteed's painstaking work at the Greenwich Observatory, but an anonymous almanac maker publishing under the name of the long-dead astrologer John Gadbury.[51] No wonder the Board of Longitude refused to engage with him.

4.2. *Dial making*

Ross claimed a local reputation as a diallist among his immediate neighbours. He wrote to the Secretary of the Royal Society in 1744 to announce that he had

> so much improved my first instrument by means of a Double Index's, and compacted it suitable for a Gentlem^{ns} Garden. I have imploy'd some leisurely Hours in serving some few Gentl^{mn} with them. I Strike the Letters with Punches, but they will not hold to strike rightly on Brass, therefore I strike them on Pewter, or such like Metall, which bears all sorts of we[a]ther exceeding well; some make use of Oak Posts for Pillars and couler them, some have them of the Yew tree wood, which will stand a Great many years; One I have fix'd on a Pillar made of the Bath stone, which is the best of all: The size that I have made are about 7½ Inches Diameter with Brass Index's'.[52]

By 1760 Ross seems to have solved the technical problem of calibrating on brass. The supplement to *The New Astronomer* notes: 'Dials of this sort may be had at very *reasonable Prices*, that will answer these Purposes, they may be had either in *Pewter*, or *Brass*; the *Pewter* will continue many Years, *barring Accidents*.' In an advertisement that year he wrote: 'There is another Sort of Instrument, that may be as a fixed Dial in a Garden, whose Uses Night and Day are nearly the same, for most Propositions; therefore will be good for Instructions. It may with Ease made suitable for any declining Wall, and moveable to and from any Sash Window.'[53] By this date Ross was often in London, and had ready access to workmen skilled at engraving brass. His own garden dials were no doubt used for 'many Years', but I have been unable to locate any surviving examples.

5. The Instruments of *The New Astronomer*, 1735

The New Astronomer describes and explains the uses of seven instruments, illustrating them on three plates (Figs. 9, 10, and 11). The opening pages of *A Further Addition* of 1760 make clear that Ross felt that these designs had been plagiarized:

> I found my past Works pyrated and marketed from One to Another, as their own properties, and so had been for several years past … In some Cases I find they greatly diminish my true ROSSIPHER Instrument, using but a Part of it, such that is suitable to guide the Telescope aright in Observation … They continue their further Favours, and call it a Portable Observatory, an Equatorial Instrument, an Azimuth Instrument, an Equal Altitude Instrument, a Transit Instrument, a Theodolite, a Quadrant, and a Level; not only these, but I fairly pronounce my true ROSSIPHER Instrument to be such that will set to more than 100 000 different Horizons, and all are accountable.[54]

The unnamed target of these allegations was James Short (1710–68), an Edinburgh-born craftsman who moved to London in the late 1730s, specializing in making mirrors for reflecting telescopes. In 1749 Short's paper 'The description and uses of an equatorial telescope' was read at the Royal Society, and later published in their *Philosophical Transactions*.[55] Ross possibly saw the version reprinted by the popular lecturer Benjamin Martin (1704–82).[56]

Short wrote: 'In order to have the other Uses of this Instrument, you must make the Equatorial Plates become parallel to the Horizontal Plates; and then this Instrument becomes an Equal Altitude Instrument, a Transit Instrument, a Theodolite, a Quadrant, an Azimuth Instrument, and a Level.' Excluded from the reprinted version was Short's introduction, in which he explained: 'I do not pretend to anything new in the Combination of these Circles, of which this instrument consists, the same Combination having been made before me, by way of a Dial; but I believe the putting of so large a telescope upon this Machinery and applying it to the uses I have done, is somewhat new.'

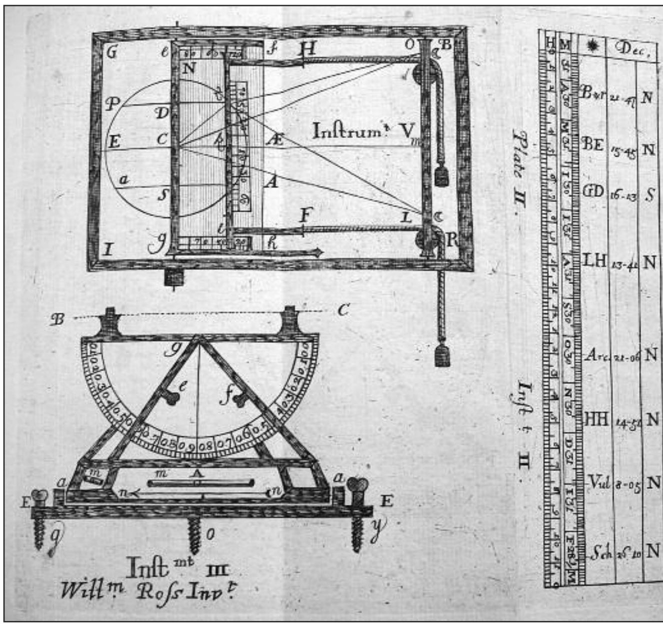


Fig. 10 (right of diagram): Instrument II. The calibrated ruler used to give the time at night from observation of one of the seven bright stars listed on the scale. In his submission to the Royal Society Ross identified each of the stars by name, but in the printed text he presumed his readers knew the shortened names. In the illustration he has reversed the order (top to bottom) and offered a slightly different and smaller selection of stars. His figures for declinations have been adjusted; there is no column for stellar magnitude. The scales on the ruler are headed H for hours and M for months, with each month identified by an initial letter. Star names are: B ♈ = Bright Star of Aries; BE = Bull's Eye; GD = Great Dog; LH = Lion's Heart; Arc = Arcturus; HH = Head of Hercules; Vul = Vultur (i.e. Altair); Sch = Scheat. The fourth column gives the declination N[orth] or S[outh].*

Fig. 10 (bottom of diagram): Instrument III. 'A pedestal, by which the first instrument may be made portable and universal'. Compared with the drawing sent to the Royal Society, there is a significantly larger compass needle. The text discusses how to use the dial to find the magnetic variation, a topic ignored in the 1732 submission. There is greater clarity over the placing of the bubble levels, m, which must be set at right angles, so that the pedestal can be levelled using the screws g, o, and y; these screws are more clearly delineated, and better placed than those on the 1732 drawing. The altitude semicircle mounting is set on a central bearing allowing it to rotate on the base plate. The bearing is not shown in the drawing, but is indicated in the text.

Fig. 10 (top of diagram): Instrument V. This is an analogue device. In essence it is an adjustable form of the woodcut diagram (Fig. II on page 16 in New Astronomer) for finding lunar ascension and declination. Instead of undertaking a trigonometrical calculation, measurements could be made directly from the instrument. It would be useful as an illustrative teaching device. Set within an oblong frame, GBIR, are three axes: NS, fixed, represents the axis of the Earth; OL represents the axis of the Moon – this axis can slide within the frame. The third axis slides within the sub-frame, efhg, and represents the apparent lunar axis. This axis slides over a scale and has to be set and fixed at the local latitude. The proportions of the drawing are misleading – it is drawn with a height:breadth ratio of about 2:3. Ross's description on p. 32 of his book indicates that it should be about 1:30. (David Bryden, courtesy the Royal Society; Library R61378 & R61338)

Indeed, as early as 1742 one of his reflectors had been mounted on a universal equatorial made by Jonathan Sisson, in essence constructed of two of the latter's theodolites, one mounted above the other.[57] In *The New Astronomer* Ross wrote that his instrument could be fitted with 'telescopes or reflecting glasses at the discretion of the artist', but gave no positive advantages of doing so.[58]

Ross might have been aware that prior to the publication of Short's universal equatorial the 1746 catalogue of another London mathematical instrument maker, George Adams (*c*.1709–73), advertised a 'double instrument' described as having

> two chief parts connected together, having four several motions, all moved by rack work. 1. A circular motion to shew all horizontal angles. 2. A semicircular vertical motion. 3. A circular equinoctial motion, or for any place at right angles to the vertical. 4. A motion through a double sextant, at right angles to the third, that has a refracting telescope fixed to it. By this instrument, all angles, either horizontal, or of elevation or depression, the azimuth and altitude of any star, the meridian and latitude of the place, with the hour of day or night, are directly given; also the right ascension and declination of the moon, a planet, comet or any star, at one observation.[59]

There is no doubt that Instrument VI described and illustrated by Ross in 1735 could be used for the purposes listed by Adams, and similarly for those described by Short. Indeed there might be some substance to Ross's claim that others had pirated his design.

The evidence appeared decades later. In 1793 Sir George Shuckburgh (1751–1804) provided the Royal Society with an account of the equatorial refractor made for him by Jesse Ramsden (1735–1800) and recently installed in his private observatory in Warwickshire. Shuckburgh prefaced this account with a survey of equatorial mountings, from antiquity to the present. He opened the 18th-century history with the Short universal equatorial, noting successive improvements in that design published by Edward Nairne (1726–1806), Peter Dollond (1730–1820), and Ramsden.[60] An anonymous reviewer of the article, presumably drawing on handed-down trade memories, criticized this section of the historical overview:

> When he comes to the invention of the modern instrument, and attributes it solely to Mr. Short, we find it necessary to put in a claim for a man of considerable merit, whose name ought, in this instance, to have the precedence. The equatorial instrument, which passes under the name of Mr. James Short, was the invention of the very ingenious Jonathan Sisson. The first was made for Archibald Lord Islay, afterwards Duke of Argyle … Jeremiah Sisson, son of the former ... applied endless screws to give motion to the different circles; but, in point of accuracy, this construction

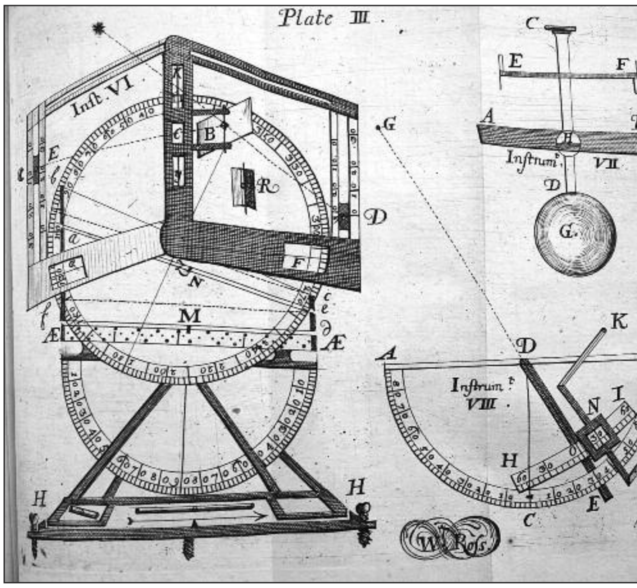


Fig. 11 (left of diagram): Instrument VI. This illustration breaks the rules of perspective drawing so as to better show all the relevant parts. The sighting mechanism is turned to show the 'double index', mounted on the ecliptic circle divided into 360°. The 'double index' was an improvement Ross mentioned in his 1744 letter to the Royal Society. In addition to the pin-hole gnomons at E and D there is an additional one at B. The effect of the hinge is to make the viewing slot adjustable in size; with the addition of a hair line stretched between K and y on the axis, this is intended to allow finer setting of the sliding pin-hole gnomon, resulting in a more precise reading of declination. The ecliptic circle is set at 23½° to the equatorial dial plate, AE, which is here shown in side elevation, and is set at right angles to the altitude semicircle. Overall the instrument is a form of portable universal equatorial, with the whole set on a central axis mounted on the base-plate. Again that axis is not shown on the drawing.

Fig. 11 (top right of diagram): Instrument VII. A device intended to keep instruments such as this dial steady on board a ship. CD is a rod hinged through the deck, AB, on what appears to be a universal ball joint at H, with a heavy counterweight G below. At this date, the ball joint effect would have been achieved by using gimbals. The instrument would be set on the stand at C, and in principle would remain still. Pendulous counterweights were tried before and after Ross as a means of counteracting the inevitable movement of instruments when used on ships. They were particularly favoured by designers with limited ship-board experience.

Fig. 11 (bottom right of diagram): Instrument VIII. 'An instrument that will take an observation to seconds of a degree', provided that the instrument had a radius of one yard (0.93 m). In the Further Addition Ross notes that a 'Long Radius Instrument' could be used for making accurate lunar distance observations, but he reserved further elucidation 'for another place'. What he does not cover is the major problem of constructing, dividing, mounting, or operating such a large instrument, let alone using one at sea. Even in a small instrument, performance depends on mechanical build quality, the accuracy of the dividing of the main scales, and of the read-out. The larger the instrument, the more significant becomes the first factor, and in particular there is a problem of flexure of the different elements of the mounting. Ross mentions that a telescope could be mounted on Instrument VI, but does not indicate that it would be advantageous to do so. (David Bryden, courtesy the Royal Society; Library R61378 & R61338) was much inferior to the wheel and pinion of Jonathan Sisson.[61]

There is physical evidence that Sisson had made a portable equatorial stand in 1742, seven years before Short published his design. As we saw in Section 1.2, the Rossipher preserved in the Museum of the History of Science at Oxford could well have been a product of Sisson's workshop. Was it making this instrument that put the idea into Sisson's head? If so, William Ross could have had a previously unheralded influence on scientific instrument design.

Conclusion

The surviving Rossipher openly proclaims William Ross as its designer, yet he remains an enigmatic figure. His books do not overtly name him as author. His 1759 public demonstration advertisement fails to give his name. His 1760 announcement of the reissue of his book is similarly silent, while his 1762 advertisement hides his identity behind the initials 'N.A'. An advertisement of 1766 is the last record of his activities.

Here was a provincial longitude projector whose ambition soared beyond a local reputation for designing and making sundials for gentlemen's gardens, and whose longitude quest was betrayed by a failure to grasp the complexities of the rapidly advancing science of navigation. The evidence suggests that the lure of a longitude award warped his judgement and led him to overvalue the performance of his Rossipher, leading to a lifetime of frustration and bitterness.

He had designed and commissioned a complex sundial that could be used to do far more than merely tell solar time. It could make a variety of measurements from which latitude, longitude, and magnetic variation could be ascertained. He presumed that such an instrument entitled him to join the longitude quest. He was ignored by the scientific establishment because he failed to appreciate that scientific navigation required the use of finely divided instruments, reading to minutes of arc, and adapted for use at sea, the whole married to advanced mathematics to compute precise results. A small-radius instrument with open sights had some value in teaching general principles, but it was not a credible contender for a longitude prize.

There were many others like Ross. With the benefit of hindsight the proprietor of a nautical academy in London, John Hamilton Moore (1738–1807), later commented: 'The Reward held out by Government for the determining of the Longitude has induced many to attempt it, especially in the mechanical Line, and … many of them have been visionary, whimsical Men, totally unacquainted with the Difficulties attending such a Discovery'.[62]

When Ross was making his case an anonymous contributor to a London newspaper in 1764 analysed contemporary press coverage of aspirants to the longitude prize. The Board of Longitude had, the writer said, been 'amused with *specious projects* and pretences (for the sake of the *premium*, more than the honour of discovery)'. Ill-informed, land-bound 'longitude schemers' were taken to task in verse. The opening stanza provides the flavour of a scathing analysis:

> ABOUT this Longitude, when all this doubt
> It is (*they say*) and yet 'tis not found out!
> Mechanic *Schemers* buzz about the Board,
> In hope they may some further aid afford!
> Some, with strange notions, run from truth away,
> And others, by as vain, are led astray.[63]

Acknowledgements

Malcolm Fare of Hanley Castle alerted me to Ross's appearance in the 1741 Worcestershire Poll Book and to the 1761 Hanley Castle vicarage terrier, as well as publicizing my search for surviving Ross garden dials in the parish magazine. Stephen Johnston of the Museum of the History of Science at Oxford facilitated my examination of the Rossipher, and drew attention to the variety of engraving styles. Stephen Price kindly copied for me the report on the Dougharty dial at Hartlebury Castle.

References and notes

1. Taylor, E. G. R., *The Mathematical Practitioners of Hanoverian England* (Cambridge 1966), identifies Ross as from London, and possibly a teacher of mathematics. Wilson, J., *Biographical Index of British Sundial Makers from the seventh century to 1920* (Crowthorne, for the British Sundial Society, 2007), cites Taylor but describes Ross as an Edinburgh teacher of mathematics, born 1715.
2. Hanley Castle Parish Registers: Worcestershire Archive and Archaeology Service: Mic X 985.66. The marriage of Richard Ross to Elizabeth Saunders, both of Hanley Castle, 1696 January 16 (NS); their first child, Edward, baptized 1698 April 7; a daughter, Frances, baptized 1704 January 16. William Ross's name appears as churchwarden at the end of the list of baptisms for 1734, 1735, 1737, and 1738.
3. Hanley Castle Parish Registers: WAAS: Mic X 985.66. Richard Ross, 'Yeoman', buried 1707 December 12; Elizabeth Ross, 'widow', buried 1729 March 28.
4. Worcestershire Poll Book for 1741: WAAS: BA3762/8, Vol III p. 14.
5. Worcester Diocese Marriage Licence records: WAAS, BA2030. The licence was valid for three months. No Ross/Hart marriage is recorded at Hanley Castle or Welland in 1745 or 1746, hence the presumption that the marriage took place at Bransford, although there are no extant registers from Bransford to confirm this.
6. 'A True and perfect Terrier ... of all the Lands, Tythes and Profits belonging to the vicarage of Hanley Castle 1 Jan 1761'. WAAS: BA 2358/5/41.
7. Maslen, K., and Lancaster, J., *The Bowyer Ledgers*

(London, The Bibliographical Society, 1991), p. 174.

8. *Gentleman's Magazine*, 6 (1736), p. 751; *London Magazine*, 5 (1736), p. 704.
9. *Gazetteer and London Daily Advertiser* no. 9846, 1760 October 31.
10. *St James's Chronicle or the British Evening Post* no. 178, 1762 April 29–May 1.
11. Cooper, M., *The Worcester Book Trade in the Eighteenth Century*, Occasional Paper Number 8, (Worcestershire Historical Society, Worcester, 1997), *passim*. Freshwater, P. B. (ed.), *Working Papers for an historical directory of the West Midlands book trade, no. 1, to 1779*, (Birmingham Bibliographical Society, 1975) records no engravers in Worcester at this time. As late as 1759, when Richard Turner (1720–91), 'Professor of Mathematicks and Philosopher in Worcester', advertised for subscribers to his perpetual calendar in *Berrow's Worcester Journal* (1759 June 14 and 1759 August 2) he noted that the original was to be sent to London for engraving.
12. Cooper (1997), p. 38 and Appendix B.
13. Taylor (1966), p. 189. MHSO Inventory Number 39529. Founding gift of Lewis Evans, 1922, no other provenance. The MHS description is as follows: 'Turned wooden base with 3 levelling screws, magnetic compass and azimuth adjustment by rack and pinion; three curved supports to platform for latitude semicircle with rack motion, equinoctial circle, with racked adjustment for ecliptic circle with pivoted sighting arm and index.'
14. Hudson, G. M., 'Torquetum', in Bud, R., and Warner, D. J. (eds), *Instruments of Science: an historical encyclopedia* (New York and London 1998), 623–6; see also North, J. D., *The Ambassadors' Secret: Holbein and the world of the Renaissance* (London 2002), 108–11. For the early history of the universal ring dial see Maddison, F. R., 'Medieval scientific instruments and the development of navigational instruments in the XVth and XVIth centuries', *Agrupamento de Estudos de Cartographia Antiga,* 30 (Coimbra 1969), 43–46.
15. Wyld, S., *The Practical Surveyor or the art of land measuring made easy ... from observations made with the New Theodolite* (London for J. Hooke [bookseller] and J. Sisson, mathematical instrument maker, 1725) – see frontispiece. Gardiner, W., *Practical Surveying Improved, ... wherein are shewn the construction, uses and excellency of Mr. Sisson's latest improved theodolite* (London for Jonathan Sisson mathematical instrument maker and [A.] Bettesworth and [C.] Hitch [booksellers], 1737) – see frontispiece. There are examples of the 1737 design in several collections: National Museum of American History, Washington 328868; Science Museum 1921-588; National Maritime Museum NAV1451.
16. Hammond, J., *The Practical Surveyor* (London, for Thomas Heath, mathematical instrument maker, 1725) – see frontispiece. For an example by Heath see Christie's Sale 8278 *Scientific and Engineering Works of Art* (London 2000 April 13), lot 47; see also an example in the National Museum of American History 309596, unsigned; and another, signed by Cole, Science Museum 1927-1923.
17. Archives Royal Society RBO/17/6 endorsed: 'Read March 9, 1731/2'. Ross's original submission is preserved at ARS: Cl.P/3ii/33 and is endorsed 'March 9, 1731 Copied'.
18. ARS: Cl.P/8ii/60.
19. ARS: MM/20/19.
20. ARS: RBO/17/7; see also Cl.P/3ii/34.
21. ARS: RBO/16/32; see also Cl.P/8ii/32.
22. *Philosophical Transactions of the Royal Society*, 38 (1735), 450–7; 57(ii) (1768), 389–93.
23. *Gent Mag*, 16 (1746), 477–8; see also 24 (1754), 17; 39 (1769), 287–8; 57 (1787), 49; 39 (1769), 143–4.
24. Ross (1760), pp. 1–2.
25. Ross (1760), pp. 4 and 6, cites *Daily Advertiser* 1759 June 4, and 'Gazetteer for his H–n—s's Birth Day in 1759'. The quoted text is from *Gazetteer and New Daily Advertiser* no. 5503, 1759 June 4.
26. *Gent Mag*, 7 (1736), 67–72; *Gent Mag*, 30 (1760), 261–2; *London Gazette* no. 9891, 1759 April 28.
27. *St James's Chronicle or the British Evening Post* no. 178, 1762 April 29–May 1. HMS *Association* was Sir Cloudesley Shovell's flagship, wrecked off the Scilly Isles in 1707; EIC *Doddington* was wrecked in 1755 with treasure destined for Clive of India; HMS *Bideford* was wrecked in 1761. Why Ross cited 24-gun frigate HMS *Dolphin* is unclear; she was in the ill-fated fleet of Admiral John Byng at the battle of Minorca (1756), but subsequently undertook two circumnavigations (1764–6 and 1766–8), assisting opening up the Pacific to British exploration and trade.
28. Cambridge University Library: RGO 14/5 'Minutes of the Board of Longitude' for 1763 February 26.
29. There was a William Ross in contact with the Board in 1806, but he was a printer and publisher from Philadelphia, born New York *c.*1746, died 1829 – see the biographical note in *Journal of the House of Representatives of The United States: John Adams Administration 1797–1801*, 2 (2nd session 1797–8) in the collected reprint series (Wilmington 1977), p. v.
30. CUL: RGO 14/5, 1766 April 26.
31. *Gazetteer and New Daily Advertiser* no. 11578, 1766 April 21.
32. *Public Ledger* no. 1816, 1765 October 30.
33. Maskelyne, N., *The British Mariner's Guide: containing, complete and easy instructions for the discovery of the longitude at sea and land...* (London 1763).
34. Robertson, J., *The Elements of Navigation* 2nd edn. (London 1764). Waddington, R., *A practical method of finding the Longitude* (London 1763); and Waddington, R., *A Supplement to the treatise for finding the longitude* (1765).
35. MacKay, A., *The theory and practice of finding the Longitude at sea or land* (London 1793), p. 64 *et seq*.
36. Wess, J., 'Navigation and Mathematics: A match made in the heavens?', in Dunn, R., and Higgitt, R., (eds), *Navigational Enterprises in Europe and its Empires* (Basingstoke 2016), 201–22.
37. *Berrow's Worcester Journal*, 1775 February 16 and 23.
38. Penney, C., http://thehurdlibrary.tumblr.com/post/78766503059/who-was-james-ross. On Beresford see Millburn, J. R., *Wheelwright of the Heavens: The Life and Work of James Ferguson FRS* (London 1988), p. 183.

39. Smith, B. S., 'The Dougharty family of Worcester, estate surveyors and mapmakers, 1700–1760', *Transactions of the Worcestershire Archaeological Society*, 3rd series, 15 (1996), p. 254.

40. Dougharty, J., *Mathematical Digests* (London 1748), 381–454.

41. Smith (1996), pp. 253, 254. Dougharty (1748), p. 383, for horizontal dials of the sort 'commonly set upon a pedestal in a Garden'. Early in his career Dougharty had advertised that he was able to supply 'all sorts of Mathematical Instruments, for Navigation, Dyalling &c at very reasonable rates' – *Worcester Post Man* 536, 1719 September 25–October 2. Price, S., and Walker, P., 'The Sundial at Hartlebury Castle', (unpublished report for the Friends of Hartlebury Castle, 2012).

42. Facio, N., 'Of the quantity of the errors arising in the determination of the latitude and longitude from the neglect of the refraction of light in the Moon's atmosphere', *Gent Mag*, 8 (1738), 185–7, dated Worcester 1738 March 29. His publications included *Navigation Improv'd; being chiefly the method for finding the latitude at sea as well as by land* (London 1728). Green, V., *The history and antiquities of the city and suburbs of Worcester* 2 (London 1796), p. 93, includes Facio as an eminent Worcester man, settling in the city 'about the year 1720'.

43. *Worcester Post Boy*, 1716 June 15–22.

44. The universal equatorial ring dial designed by mathematician William Oughtred predates by several decades its first publication in *Mathematical Recreations* (London 1653). It was widely made by London instrument makers – see Bryden, D. J., *Sundials and Related Instruments: The Whipple Museum of the History of Science, Catalogue 6* (Cambridge 1988), item 220 *et seq*.

45. See, for example, Bryden, D. J., *Sundials and Related Instruments: The Whipple Museum of the History of Science, Catalogue 6* (Cambridge 1988), items 176–219; also Cowham, M., *A Dial in Your Poke* (Cambridge 2004), 101–12.

46. Gunter, E., *The description and use of the sector* (London 1623), p. 188 et seq. For surviving examples see Bryden, D. J., *Sundials and Related Instruments: The Whipple Museum of the History of Science, Catalogue 6* (Cambridge 1988), items 279–88; also Cowham, M., *A study of the Quadrant* (Cambridge 2014), 24–29.

47. Leybourn, W., *Panorganon, or a universal instrument* (London 1672). Leybourn, W., *Cursus Mathematicus* (London 1690), 716. See also Cowham (2004), 35–40.

48. Ross (1735), p. v.

49. Howse, H. D., 'The Lunar-Distance method of measuring longitude' in Andrews, W. J. H. (ed.), *The Quest for Longitude* (Cambridge Mass., 1996), p. 158.

50. Ibid., 150–61.

51. Job Gadbury took over publication of John Gadbury's almanacs after the latter died in 1704; Job died 1715. See Capp, B., *Astrology and the popular press: English Almanacs 1500–1800* (London 1979), 307–8. The Gadbury *Ephemeris or a diary astronomical, astrological, meteorological for the year...* appeared annually until at least 1760.

52. ARS: MM20/19. In the context of Ross's use of pewter, note that the co-signatory of his Marriage Allegation and Bond (see Ref. 5) was a Worcester tin-plate worker.

53. Ross (1760), p. 13. *Gazetteer and London Daily Advertiser* no. 9846, 1760 October 31.

54. Ross (1760), pp. 2–4.

55. *Phil Trans R. Soc.*, 46 (1752), 241–6.

56. *A Supplement to the Philosophia Britannica, Appendix II*, (London 1759), 74–80.

57. For the Short/Sisson instrument see Bryden, D. J., *James Short and his telescopes*, (Edinburgh 1968), 21–22.

58. Ross (1735), p. 12; compare Ross (1760), p. 4.

59. 'A catalogue of mathematical, philosophical and optical instruments as made and sold by George Adams', in Adams, G., *Micrographia Illustrata*, (London 1746), p. 260.

60. Shuckburgh, G., 'An account of the equatorial instrument', *Phil Trans R. Soc.*, 83 (1793), 67–73.

61. *The British Critic*, 2 (1793), p. 188. Archibald Campbell (1682–1761), Whig politician, was created Lord Islay in 1706 and succeeded his brother as 3rd Duke of Argyll in 1743.

62. Moore, J. H., *The Practical Navigator and seaman's new daily assistant*, (London: 9th edition, 1791), p. 228. The book was first published 1772 but the comment was first inserted in the 9th edition.

63. *Lloyd's Evening Post* no. 1136, 1764 October 19–22.

The author

David Bryden worked for nearly four decades in various national and university museums including the National Museums of Scotland, the Whipple Museum of the History of Science, and the Science Museum. After taking a first degree in engineering at Leicester in 1964 he spent a year at Oxford on a course in the History and Philosophy of Science. His PhD from the University of Cambridge was awarded in 1993 on the basis of publications on early scientific instruments and the British instrument trade. He continues to research and publish on patents and the British instrument trade 1720–1840. His sole current formal appointment is as Flag Master of Pershore Abbey. He is a Fellow of the Society of Antiquaries.

Errata

On page 9 of *The Antiquarian Astronomer* Issue 7, March 2013 ('James Stuart and the Rochdale Pioneers' by Philip A. J. Barnard), in the second column, second full paragraph, 'Josephine' should read 'Laura'.

On page 49 of *The Antiquarian Astronomer* Issue 8, June 2016 ('David Gill: clock maker to global astronomer' by Paul A. Haley) the dates for John Hartnup should read 1806–85.