Stars And Storms

The Life and Work of John Isaac Plummer, Victorian Astronomer and Meteorologist

Dr. J. M. Appleton

John Isaac Plummer in a photograph thought to have been taken around 1900, while he was employed at Hong Kong Observatory. (Courtesy of Richard Bellamy-Brown.)

In memory of Ken Goward, FRAS (1952 – 2009),
an inspiration to those who study the history of Astronomy.

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Foreword By Richard Bellamy-Brown

I have to confess to being both touched and honoured by being asked to contribute to James' biography of my great-grandfather, John Isaac Plummer. When I first began researching my family history, it never occurred to me that it might end here. I had been researching for some while when I decided it would be good to add photographs of family members to their profiles. When I got to my great-grandfather's photograph, something, I know not what, prompted me to look him up on the Internet. It was here that I came across the OASI web site with its request for a photo of the great man: the rest, as they say, is history. I contacted the then chairman of OASI, Ken Goward, and provided him with a copy of the only photo I possess of John on his own.

In December 2004, Ken invited me to Orwell Park and we spent a fascinating day in what had been my great-grandfather's workplace. I was amazed and delighted that so much interest was being shown in his life and achievements and thrilled to be invited to become an honorary member of OASI.

Obviously, almost eighty-five years after his death, we know little about what John was like as a person. Photographs of him show what would appear to be a stern man, but from what my father and my aunt told me about him, he was far from that, in complete contrast to their grandmother who was somewhat severe. They both remembered him very affectionately as a kind and, at times, mischievous, man. My aunt remembered him as a great family man who always had time for his grandchildren, who all used to look forward to visits to see him at his home in Leatherhead. My father used to speak with awe of his physical strength. He was by all accounts an accomplished pianist and one of his party tricks, when my father was about six years old, was to make a bridge with his fingers on the piano keyboard and then have my father sit on his forearm. This he would do without causing his grandfather's wrist or fingers to collapse; possibly the result of the physical work involved in the day-to-day running of an observatory!

21 April 2009

Foreword By Dr. Allan Chapman MA, D.Phil., D. Univ., FRAS

When we speak today about "professional" and "amateur" astronomers, we often forget that in Victorian times, the designations meant exactly the opposite of what they mean today. For with the exception of a tiny handful of men, including the Astronomer Royal and the Professional Directors of half a dozen University Observatories around the British Isles, the term "professional astronomer" in Britain invariably meant not a high-level researcher, so much as a scientific employee doing fairly routine work. For in 1874, when the 29-year-old John Isaac Plummer began working at the private observatory-mansion of Colonel George Tomline at Orwell Park, Suffolk, "Grand Amateurs" ruled high-level British astronomy.

For as a result of political and social circumstances in Victorian Britain, very little public money was spent on pure scientific research of any kind. Money, rather, was left in taxpayers' pockets with the intention that private initiatives would provide the intellectual and cultural, as they had already provided the industrial and economic, driving forces of the nation. So along with the founding of art galleries, theatres, colleges, concert halls and chapels, pure scientific research was expected to come from public-spirited initiatives within the private sector. And these initiatives came thick and fast, with astro- and solar physics, binary star and planetary observation, deep-space cosmology, and the new big telescope technologies, and optical engineering, developing beyond recognition between 1800 and 1900. Some "Grand Amateurs", such as Lord Rosse, Sir John Herschel, and William Lassell, did their own hands-on research, entirely on their own or else assisted by a salaried "professional", and went on to make incredible discoveries. Colonel Tomline, like some other Grand Amateur patrons, while seriously interested in science, did not seem to have been active as an observer, though he did like being shown the heavens, and having them shown to his house guests at Orwell Park. Rather, Colonel Tomline, as a wealthy landed gentleman and patron of culture, saw it as his duty to advance science by paying someone else to use the splendid 10-inch refracting telescope and other instruments which he provided, and publish research on his behalf.

George Tomline, therefore, was a Grand Amateur, and John Isaac Plummer was his employee professional astronomer.

But as Dr. Appleton makes very clear in *Stars and Storms*, being a professional astronomer could be a precarious and unprotected occupation. For example, there was no job security, and while Plummer seems to have been allowed a free hand in his researches at Orwell Park, he was dismissed in 1889 when the Colonel died. Indeed, by the beginning of 1890 he was faced with the urgent need to find not only a new job, but also a new home for his family, as the Plummers lived at *Orwell Dene*, a tied house on the Orwell estate. What is more, Plummer's sacking had nothing to do with any failure regarding his duties, but came about quite simply because the new régime at Orwell Park was not interested in astronomy, and felt no obligation to maintain an astronomer. And this was despite the fact that Plummer had been granted an honorary MA degree from Durham University, and was an active and highly respected FRAS with published research to his name!

John Plummer came from a social background similar to that of many other professional or employed astronomers in Victorian Britain. Not from a poor background by any means, but from a modest lower-middle-class one, for his parents were respectable grocers and shop-keepers who even had a servant to wait on them, as John and his family in turn would have one to wait on them. Like John Plummer, most professional astronomers would have entered into their careers at around 15 or 16 years old, often after receiving a good schooling up to that age, at a local Grammar or small private school. With a good basic knowledge of mathematics and geometry, some Latin and Greek, and perhaps a smattering of German – the international scientific language of the day – they would be taken on as a "computer", or apprentice calculator, at the Cambridge or Greenwich Observatories. If the young men showed an aptitude for practical astronomy, they would be trained in the use of the big instruments, to take Right Ascensions, Declinations, time transits, or measure binary stars or comets through a large equatorial with a micrometer. And if they failed to obtain one of the coveted "established" Assistantships at Greenwich, with life-long tenure, a month's annual holiday, and a pension at 65, they looked elsewhere.

And this is how John Plummer worked successively at the Cambridge, Greenwich, Glasgow and Durham Observatories, before becoming Colonel Tomline's "kept astronomer" at Orwell Park in 1874.

Yet we can see how galling it must have been for highly-intelligent, dedicated and hard-working young men to work for employers where they may have been referred to as "kept", as Plummer was. On the other hand, in that visibly hierarchic age, it would have been understood that such an appellation came with any kind of employee job. After all, solicitors "kept" clerks, physicians "kept" their own dispensing apothecaries, and beneficed clergy "kept" a curate or two. And as mentioned above, the Plummer family, father and son, in their respective generations, "kept" a servant to wait on them.

The social divide, for a young man from Plummer's background, was well and truly crossed if he had been fortunate enough to apply for, and win, a University scholarship. Such a training would open up potential access to the learned professions. Alternatively, he could cross it by making a fortune in business or industry. Either way, he would rank undisputedly as a gentleman. Yet in a letter to the Admiralty in 1879, the Astronomer Royal, Sir George Airy, referred to "J. Plummer Esq": a clear indication of gentlemanly social placing, for Airy tended to designate lesser mortals as plain "Mr."

Indeed, with his MA (Dunelm) and FRAS, it is likely that John Plummer regarded himself as one of astronomy's leaders, rather than one of its servants, and one can understand the frustration that he must have felt upon losing his losing his job at Orwell Park, to be obliged to leave England to work under the famously prickly Dr. Doberck at the Government Observatory in Hong Kong.

But if it is easy to recognise the *Stars* in Plummer's life, from where do the *Storms* come? Laying aside whatever personality clashes may have occurred, most serious Victorian observatories had two sets of functions: astronomical, then meteorological and geomagnetic. Since the Royal Observatory, Greenwich, set up its Magnetic and Meteorological Department in 1838, a network of private and public observatories had burgeoned across Great Britain, the Empire, Europe and the U.S.A. They collected vast sums of data in the hope of uncovering the complex laws that lay behind both global and regional meteorology – in the hope that mathematically reliable weather predictions could be made – and likewise for the Earth's complex magnetic field. Both had a direct bearing upon safety at sea, and were of obvious significance to Great Britain, and the other Imperial and commercial powers of the age.

Meteorological and geomagnetic work, however, was generally regarded as intellectually inferior in content to that of astronomy, at least for those people who were routinely employed to collect the data. It still seemed, at that early state in the development of both sciences, that geomagnetism and meteorology lacked any kind of mathematical or theoretical underpinning, and the mountains of data collected continued to elude any coherent scheme of interpretation. A magnetic or meteorological scientist seemed shackled to routine observation, and knew he would never discover a comet, or asteroid, or a nova that would send his name across the world. On the other hand, magnetic instruments sometimes went wild when a storm broke out in the atmosphere of the Sun!

But the China seas were notorious for their Typhoon storms, and his pamphlet *The Origin of Typhoons* (1910) not only shows Plummer to have been a scientific meteorologist, but also tells us something of the rôle that storms played in his career.

James Appleton has produced a splendid scholarly yet accessible study of the life and work of John Isaac Plummer, and has given us an insight into the career, achievements and inevitable frustrations of a leading member of that Victorian community of men – the employed professional astronomers.

Allan Chapman.
Wadham College, Oxford.
21st April 2009.

Preface

In 1848, Colonel George Tomline purchased Orwell Park Mansion in the village of Nacton, near Ipswich, Suffolk. He was keenly interested in the sciences and, in the early 1870s, during an extensive re-modelling of the mansion, arranged for the construction of an astronomical observatory on the east wing of the building. His observatory boasted many unique architectural features and was equipped with a fine 258 mm equatorially mounted refracting telescope; it was one of the most extravagant astronomical facilities in private ownership in the country. On the recommendation of the Astronomer Royal, Sir George Biddell Airy, Tomline engaged John Isaac Plummer to operate his observatory. Plummer began work at Orwell Park in June 1874; his tenure marked the heyday of the observatory and there is little doubt that, at least in his early years there, he enjoyed using the facility and appreciated the intellectual stimulation associated with describing his work to Tomline's house guests, many of whom were important scientists, politicians and dignitaries. Tomline died in 1889; his heir terminated Plummer's employment and Orwell Park Observatory then lay little used for many years.

Nowadays, Orwell Park Educational Trust owns Orwell Park Mansion. The Trust licenses use of the observatory to the Orwell Astronomical Society, Ipswich (OASI), which operates the facility for the benefit of its members and opens it by arrangement to visitors and to the public to encourage public interest in and understanding of Astronomy.

Plummer's work at Orwell Park Observatory forms a fascinating counterpoint to the activities there nowadays of OASI. The archives of the Society record the efforts of members to research his life and work. First to undertake serious research were Mike Barriskill and Charles Radley, who, in 1978, searched the archives of the Royal Astronomical Society and identified Plummer as Tomline's professional astronomer. Roy Gooding built upon this information in the mid-1980s, compiling a broad overview of Plummer's life and key aspects of his work in the UK. In the late 1990s, Ken Goward began another fruitful line of enquiry and, through Professor P. Kevin MacKeown and other contacts in China, uncovered much about Plummer's professional career after he moved to Hong Kong. Richard Bellamy-Brown, Plummer's great-grandson, on learning of Ken's research, kindly provided photographs and information about the family history. In 2006-11, I searched the archives of the Royal Observatory, Greenwich, Glasgow Observatory and Durham Observatory, together with online newspaper archives, for material on Plummer's time in the UK and Bermuda (the latter while in charge of a government expedition to observe the transit of Venus of 1882). Subsequently, as ever more newspapers made archive material available online, another search in 2023 unearthed considerable additional insight into Plummer's activities in Durham. Research over such an extended period, with many lines of enquiry, has uncovered much material and it has proved possible as a result to compile a reasonably full account of the main aspects of his life and work. His career was interesting and varied and I have tried to illustrate its key aspects.

Throughout his career, Plummer published, in the professional literature, 74 papers and one textbook on astronomy, five papers and a pamphlet on meteorology and a short contribution on natural history. He also contributed 18 articles and letters to newspapers and a magazine, and wrote a weekly newspaper summary of the weather at Durham. I have undertaken a detailed appraisal of his publications and, where possible, have re-analysed his observational data to check his conclusions. In some cases, it has proved possible to correct errors in the original work!

Despite his significant publication record, few scientists referenced his work and histories of the period barely mention him. This work is his only known biography; I hope that it goes some way towards filling the gap in the historical record.

Unfortunately, throughout many of the almost 135 years since Tomline died and Plummer ceased his work at Orwell Park, the fabric of the observatory has suffered from neglect and has deteriorated badly. Major, expensive restoration work is long overdue. OASI and Orwell Park Educational Trust are exploring potential sources of funding to enable restoration work to be undertaken. I hope that Plummer's biography, through publicising the life and work of the only professional astronomer employed at Orwell Park Observatory, can support the fund-raising effort.

JMA, 31 October 2023

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- Judith Cook unearthed many historical records.
- Greig Tulloch expertly translated publications by W. Döllen and E. Weiss.
- OASI member Jennie Wood persuaded relatives to search the surroundings of Gibbs Hill Lighthouse, Bermuda, for evidence of Plummer's 1882 expedition to observe the transit of Venus.
- OASI member Bill Barton, FRAS researched aspects of Plummer's life and work.
- OASI members Mike Whybray, Dr. Paul Whiting, FRAS and Tina Hammond reviewed the text and suggested numerous improvements.

This research has made use of NASA's Astrophysics Data System (ADS).

Contents

1 Introduction

John Isaac Plummer began his astronomical career in September 1860 at Cambridge Observatory as a *computer* (a junior employee responsible for analysis or *reduction* of observational data). He quickly ascended the astronomical career ladder of the time, moving to the Royal Observatory, Greenwich (ROG) in January 1864 and to Glasgow Observatory in February 1865. During the early years of his career, he learnt the fundamental techniques of astronomy of the era.

In November 1867, he moved to Durham Observatory. Initially, he was nominally under the direction of Professor Temple Chevallier, founder of the observatory, but in practice was free to define his own programme of work and undertook a diverse range of investigations. In 1871, Chevallier's retirement precipitated considerable uncertainty about the future of the observatory; in response, Plummer drastically reduced the amount of observing that he undertook and instead devoted time and energy to finding a new position, writing to the county press and publishing in the field of meteorology as well as astronomy, likely to make his name visible to potential employers.

The tactic worked and, in June 1874, on the recommendation of the Astronomer Royal, Sir George Biddell Airy, Colonel George Tomline engaged Plummer to operate his private observatory at Orwell Park, near Nacton in Suffolk. Plummer must have approached his new position with great anticipation! The remuneration was handsome, there was the prospect of considerable intellectual stimulation through meeting Tomline's many learned visitors and house guests, and the equatorial telescope at the facility, excellent by the standard of the era, was far superior to those with which he had struggled at Durham. Again, he had the freedom to define his own lines of research. He worked at Orwell Park for 16 years, at first undertaking a wide variety of astronomical investigations. Unfortunately, after a few years, some of the initial promise of the position proved illusory; in consequence, he restricted the range of his astronomical work and concentrated for the second half of his time at Orwell Park almost exclusively on determining the positions of comets.

Tomline died in 1889 and his heir eventually terminated Plummer's employment. In late 1890, he moved to Ipswich, where he began an increasingly urgent search for new employment. He contacted the Astronomer Royal, a position by this time occupied by William Christie (who succeeded Airy in 1881). Fortunately, Christie recommended him for the post of Chief Assistant at Hong Kong Observatory, a position that he took up in May 1891.

At Hong Kong, he worked under the famously prickly Dr. William Doberck. Although the primary business of the observatory was to provide a time service and undertake meteorological and magnetic observations, Doberck was an accomplished astronomer and undertook many studies of the heavens. Plummer contributed to all aspects of the work of the observatory but, unfortunately, his first years there must have been far from pleasant professionally, as he endured a stormy relationship with Doberck. He retired from Hong Kong in 1911 and returned to the UK, spending his final years in comfort in Oxshott, Surrey, where he died in 1925.

Plummer was active in the scientific literature of the era. He published 74 papers and a textbook on astronomy, five papers and a pamphlet on meteorology and a short contribution on natural history. He read papers at meetings of the Royal Astronomical Society (RAS) and of the Royal Meteorological Society (RMS), debated with scientists in the learned press of the day, and wrote in local newspapers about astronomical and meteorological matters for the benefit of the lay person. Despite his publication record, few scientists referenced his work and historians of the period have largely overlooked his contribution to science. Indeed, his story is a poignant one, with more than a hint of unfulfilled potential. Although his publications reveal work that was variable in quality, with attention to detail that was occasionally lacking, this was undoubtedly attributable in part to the difficulties that he confronted at Orwell Park and Hong Kong. Had he spent 16 years working in an observatory with better facilities than Orwell Park, in the company of fellow astronomers with whom he could discuss, shape and review his projects, and 20 further years in a more congenial working environment than Hong Kong, he might have achieved much more than he did.

The remainder of this document is structured as follows. Section 2 provides a summary, in chronological sequence, of Plummer's life and work. Section 3 is a commentary on his publications. We know very little about some aspects of his life and section 4 provides a list of suggested areas for further research. The appendices provide supporting material describing in detail aspects of his life and work; they add depth to the narrative of sections 2 and 3.

Appendices 1-16 assess in detail his publications. Appendix 1 considers his textbook, comparing the state of knowledge of the time with the theories and understanding of modern astronomy. Appendices 2-15 each examine a specific strand of his astronomical work and provide a modern perspective; the organisation is thematic, rather than chronological, in contrast to section 2. In examining his publications, where possible I have re-analysed the observational data to check the reduction and conclusions and to correct errors in the original work. Appendix 16 provides an appraisal of his meteorological publications.

Appendices 17-20 provide further insight into his life and activities. Appendix 17 summarises his efforts to keep Durham Cathedral Clock running to time. Appendix 18 recounts reports in the press of his activities (and includes transcripts of two of his three obituaries). Appendix 19 summarises his relationship with Ipswich Science Gossip Society/Ipswich Scientific Society, gleaned from the minute books of the Society. Appendix 20 reproduces his statement for the vacancy of Chief Assistant at Hong Kong.

Appendices 21-23 address technical matters. Appendix 21 details Doberck's approach to calibrating the Hong Kong transit telescope prior to its use, principally by Plummer, in taking measurements for the determination of the latitude of the Colony. Much of Plummer's astronomical work was associated with positional astronomy, for which he used *micrometer* eyepieces to estimate the angular distance between celestial objects; appendix 22 provides a brief overview of the types of micrometer eyepiece that he reported using. Appendix 23 provides details concerning the interpretation of his observing reports and their comparison with predictions made using modern astronomical ephemerides.

Appendices 24 and 25 tell of his relatives. Appendix 24 provides brief biographical details of two close relatives who enjoyed distinguished astronomical careers and appendix 25 details the visit by his great-grandson, Richard Bellamy-Brown, to Orwell Park Observatory in 2004.

Appendix 26 details observations by Dolman, Plummer's predecessor at Durham Observatory.

2 Life And Work

2.1 Early Years

We know little about the early years of John Isaac Plummer; the established facts are as follows. He was born on 05 February 1845 to parents John and Catherine, the third of four children. His place of birth was Garden Row, St. Pauls, Deptford. A map by Edward Stanford (1862), an acclaimed cartographer of the era, shows Garden Row as a short street just north of New Cross, Deptford, forming part of the southern boundary of a large market garden, from which, presumably, the name derived. In modern times, the area was redeveloped as Batavia Mews, SE14, and Garden Row is no more.

Plummer grew up with older sisters Mary and Elizabeth, and younger brother William Edward. His father was a grocer, earning enough to keep the family in reasonable comfort, employing a general servant who lived in the family home. The 1851 census indicated that the family had moved to 78 High Street, Deptford. The address still exists; it is an unremarkable three-story end-terrace on the corner with Frankham Street, with the ground floor nowadays fitted out as a shop (figure 1).

Figure 1. 78 High Street, Deptford. (James Appleton, 2013.)

At age 15, at Cambridge Observatory, Plummer began his career in astronomy. To do so, he must have benefitted from a good elementary education. Perhaps he was inspired in his choice of career by the sight of the domes of the ROG, easily visible only a few kilometres to the east of Deptford.

Whatever the events that led Plummer to pursue a career in astronomy, the heavens clearly exerted a powerful lure on the family. William followed in his footsteps, starting a career in astronomy at the ROG in 1864 or early 1865. A generation later, William's son Henry took up his first astronomical post at Oxford University Observatory, beginning a career in the science that was to be by far the most distinguished of the three.

2.2 Cambridge

Professor James Challis (1803-82) was Director of Cambridge Observatory 1836-61 (see figure 2.) Although the observatory was generally well equipped, by the late 1850s, a rather inefficient system for determining the positions of stars, involving two telescopes rather than the more usual transit circle, together with a shortage of funds to pay computers to perform data reduction, had resulted in a considerable backlog of observations in need of analysis and publication. In 1859, the Sheepshanks Benefaction, created in honour of Richard Sheepshanks (1794-1855), had transformed the finances of the observatory. To take advantage of the increased funding and to clear the backlog of observational data awaiting reduction, Challis halted routine observations, hired computers and concentrated the efforts of his two assistants and the new computers on addressing the backlog (which, by 1865, was finally processed and published).

Plummer was one of the computers hired to tackle the backlog of data reduction. Challis appointed him in September 1860, paying for his services from the Sheepshanks Benefaction. The 1861 census listed him as lodging at Cambridge Observatory[1] with the profession of *astronomical clerk*. Professor John

[1] He lived at the observatory together with Challis, his wife and daughter, Arthur Bowden (also an astronomical clerk), two general servants and a cook.

Adams[2] (1863) in his 1862-63 report to the Cambridge Observatory Syndicate, described him as a *computer* working on volume XX of the *Cambridge Observations* and assisting with observations. Hutchins (2008) lists his salary in 1860 as £48 *per annum*.

Figure 2. Cambridge Observatory. (Society for the History of Astronomy, 2012.)

Plummer's main duty at Cambridge Observatory was to perform astronomical computations. In 1863, he undertook transit observations and used the Cambridge Mural Circle to estimate stellar north polar distances (NPDs; angular distances from the north celestial pole). He appears to have undertaken the observations competently, for Andrew Graham[3] (1872), First Assistant at Cambridge Observatory, writing later to Adams noted: *He seems to be a good transit observer… The NPDs which result from his observations are satisfactory… Mr. Todd says he has a good eye for detecting faint objects.*

The *Cambridge Chronicle And University Journal* (1864) and Adams (1864), in his 1863-64 report to the Cambridge Observatory Syndicate, noted that Plummer left the observatory in December 1863.

2.3 Greenwich

On leaving Cambridge, Plummer returned to Deptford, moving to 13 Surrey Terrace, Counter Hill, New Cross[4]. From there he wrote to Airy requesting employment at the ROG (figure 3). At the time Airy was staying at his country retreat in Church Lane, Playford, near Ipswich and Edward Stone[5], Chief Assistant at the ROG, was in charge. Correspondence between the two concerning the request reveals that Airy had little regard for Plummer, although the reasons for this are not clear. Relevant passages in the correspondence, from early 1864, are as follows:

> Airy (1864a), 01 January: *I suppose that you will communicate with Mr. J. Plummer… and let him understand all about duties of computers. {I doubt whether he will do for us.}*
>
> Stone (1864a), 02 January: *I have written to Mr. Plummer to call at the Observatory on Tuesday next. I shall be able to judge better about him after an interview.*

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[2] John Couch Adams (1819-92) was appointed Director of Cambridge Observatory in 1861 after Challis resigned due to poor health brought on by overwork.

[3] Andrew Graham (1815-1908) worked at Markree Observatory, County Sligo, where, in 1848, he discovered the asteroid (9) Metis, and later at Cambridge Observatory. After he left Markree, following a lengthy period of inactivity at the observatory, William Doberck, who shortly assumes a major role in our story, succeeded him.

[4] Attempts to locate the premises have failed. Stanford's (1862) map shows Surrey Terrace just off what is now Lewisham Way, but houses in the area appear to have been renumbered since Plummer's era. (NB: The 1860s Surrey Terrace is some kilometres distant from the modern-day street of the same name!)

[5] Edward James Stone (1831-1897) appears several times in what follows. In 1860, he was appointed chief assistant at the RGO. In 1868, he was elected FRS and, in 1870, appointed Her Majesty's Astronomer at the Cape of Good Hope. In 1878, following the death of the Radcliff Observer at Oxford, he was appointed to the post. He served as President of the RAS 1882-84.

Airy (1864b), 04 January: *The principal thing which I fear in Mr. Plummer is insubordination, and upon this the most precise information ought to be given to him, that he will be placed under the command of an assistant as Mr. Dunkin*[6] *or Mr. Lynn*[7]. *State this in writing (with particulars of hours etc) and copy your statement.*

Stone (1864b), 05 January: *Mr. Plummer called this morning and I gave him a paper, in accordance with your instructions, in which I insisted strongly on the necessity of punctuality and subordination: he stated that he was quite prepared to accept the conditions contained in the paper and I therefore feel myself justified in engaging him…*

Plummer started work at the ROG on 11 January 1864. His move between the observatories was a path well-trodden by computers of the period. Hollis (1925), in a history of the assistant astronomers at the ROG, wrote of the junior computers: *several of them served for a term at the Cambridge University Observatory, which in those years might have been looked on as an annex to Greenwich, so much were the personnel intermingled.*

Figure 3. The Royal Observatory Greenwich. (John Wainwright, 2013.)

In December 1864, Stone (1864c) compiled for Airy a list of the monthly salaries of the supernumerary computers. The lowest was £3-0-0 and the highest £5-0-0; Plummer's salary was towards the bottom of the range at £3-10-0. Stone recommended that salaries in 1865 for all staff be unchanged from those for 1864.

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[6] Edwin Dunkin (1821-98) also appears several times below. He began work at the RGO in 1838 as a computer but Airy soon recognised his abilities and made him a permanent member of the observatory staff in 1845. He went on to become Chief Assistant when Airy retired. He was author of many scientific papers and popular articles on astronomy and was elected FRS in 1876 and President of the RAS in 1884.

[7] William Thynne Lynn (1835-1911) worked as an assistant at the RGO 1856-80.

It is possible that Plummer's employment at the ROG overlapped with that of his brother, William, who started there in 1864 or early 1865; however this has not been established definitively at the time of writing.

Plummer stayed at the ROG for a little over a year and, in early 1865, left to take up employment at Glasgow Observatory (figure 4).

2.4 Glasgow

The papers of Airy in the ROG archive together with material from Hutchins (2008) and reports in the local press enable the compilation of a good description of the circumstances of Plummer's move to Glasgow.

In 1860, Glasgow University appointed Professor Robert Grant (1814-92) to the conjoined posts of Professor of Practical Astronomy and Astronomical Observer. Grant's main duties were to undertake astronomical observations, to deliver an annual course of lectures and to provide a time signal for Glasgow, the neighbouring towns and the shipyards on the Clyde.

In the early years of Grant's tenure, he was much concerned with improving the equipment and facilities at the observatory. When he took up the professorship, the main instrument was a 150 mm meridian circle by Ertel of Munich. Although he was very pleased with it[8], he wanted an equatorial telescope to enable studies of a more diverse nature. After a very effective public appeal, which raised £1400 primarily by donations from a dozen or so wealthy citizens of Glasgow, he purchased equipment from the estate of the late Sir William Keith Murray of Ochtertyre, Perth and Kinross, including a 230 mm equatorially mounted refractor which, at the time, was the largest equatorial instrument in Scotland. Grant arranged for the Ochtertyre refractor to be installed at Glasgow Observatory and was subsequently the main speaker at an inauguration ceremony on 30 April 1863.

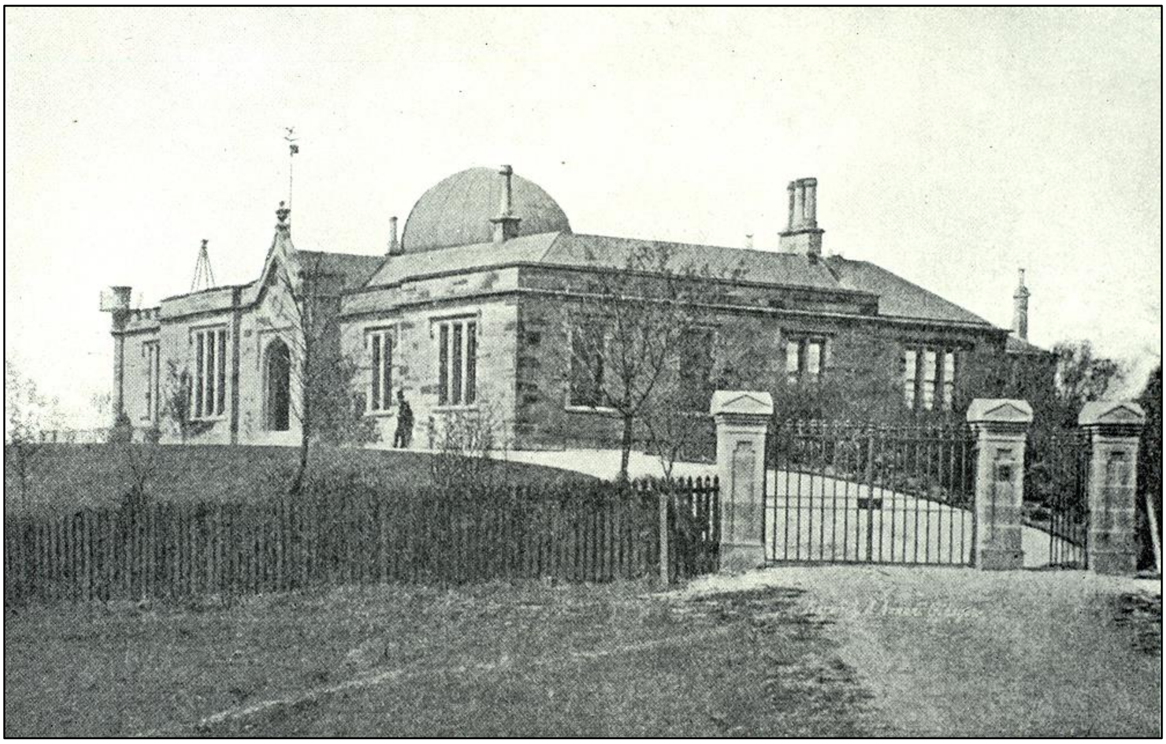

Figure 4. Glasgow Observatory, Dowanhill, c. 1850. (University of Glasgow, 2023.)

[8] Not all astronomers shared Grant's opinion. Many years later, William Doberck (1898a), whose role in Plummer's work is described in section 2.7, in a passing reference described the Glasgow meridian circle as *very old and defective*.

Grant's speech was widely reported (*The Astronomical Register*, 1863; *The Glasgow Daily Herald*, 1863; *The Morning Journal*, 1863) and contained a section lamenting the lack of financial provision for assistants to operate the observatory. His words were prophetic as he subsequently found it indeed impossible to work all the instruments in addition to discharging his lecturing duties and negotiating the provision of a time service. He employed one assistant, whom he paid out of his salary (which amounted to £50 *per annum* from the Treasury and a further £220 *per annum* from the University (Barclay, 1863)). However, to handle the workload he needed a second and so, on 28 November 1863, Grant (1863a) wrote to Airy asking him to recommend an assistant. The two men subsequently met, after which Grant (1863b) provided further details of the post in writing. The ideal assistant would be:

> *some person possessing the advantage of having been trained at the Royal Observatory. He would require to take part in the observations with the Meridian Circle and the Equatorial, and in the computations necessary in the reduction of the observations. Occasionally also in the absence of the other assistant he would be asked to attend to the Meteorological Observations which are taken morning and evening.*
>
> *The salary which I am prepared to offer a young man possessing the requisite qualifications is one hundred pounds a year.*

Airy persuaded one of the Greenwich computers, Mondeford Reginald "Augustus" Dolman, to take up the post at Glasgow. Grant (1864), writing to Airy on 08 February, noted how pleased he was with the new assistant: *Mr. Dolman, since he commenced his duties as Assistant here, has given me great satisfaction. He is most attentive and zealous and executes his work in the most unexceptional manner.*

Grant's annual reports to the Senate of Glasgow University (*The Glasgow Daily Herald*, 1864; *The Glasgow Daily Herald*, 1865; *The Glasgow Daily Herald*, 1866a; *The Glasgow Daily Herald*, 1867) list the objects of study at the observatory as follows:

- With the transit circle – stars listed in the *Nautical Almanac* for the purposes of regulating the observatory clocks; and stars in the British Association Catalogue (BAC), in the magnitude range 5 – 8, to determine their positions. The latter work formed the basis of the Glasgow Star Catalogue, published in 1889 (see below).
- With the Ochtertyre refractor – minor planets, comets, double stars and, occasionally, planets. Grant's hopes to use the refractor also for observation of the Sun, planets and *occasional phenomena*, including eclipses and occultations of stars by the Moon appear not to have been realised.

In addition, meteorological observations were recorded every morning and evening. Negotiating arrangements for the provision of a time service to Glasgow and the surrounding areas likely occupied much of Grant's time too, although not that of his assistants.

In the annual report for 1864, Grant commented that Dolman's conduct since he joined *justified the favourable accounts which had been previously received respecting him* and that he worked alongside a junior assistant, Mr. A. McGregor. Grant also expressed great satisfaction with the Ochtertyre equatorial, praising its *exquisite definition and stability of mounting*.

Unfortunately, although evidently pleased with the equipment at the observatory and the work being undertaken there, Grant had not succeeded in making permanent arrangements for financing Dolman's post and, at the end of January 1865, the Treasury refused a request from the University to provide funding. Perhaps feeling that his post lacked permanence and enticed by the prospect of a significant step up the astronomical career ladder of the time, Dolman left Glasgow to take up the position of *Observer to the University of Durham*.

Grant published Dolman's (1865a) observations around the date that the latter left Glasgow. They consisted of positional estimates, made with bar and ring micrometers, of the asteroids (7) Iris, (22) Calliope, (29) Amphitrite, (44) Nysa and (52) Europa, spanning the period 12 March to 21 November 1864.

Once Grant knew that Dolman was preparing to leave, on 17 January 1865, he wrote (Grant, 1865a) to Airy with news of the imminent departure and expressed the intent to offer the post to another former Greenwich computer, Charles Talmage (1840-86), then working at the private observatory of Joseph Barclay at Twickenham. Talmage did not accept the opportunity. However, news of the vacancy spread, and, on 02 February 1865, Grant (1865b) again wrote to Airy indicating that Plummer had approached him offering his services and providing impressive testimonials from his time at Cambridge Observatory:

> *I have received a letter from Mr. J. Plummer, one of the supernumeraries at the Royal Observatory, containing an offer of his services as Assistant at this Observatory in the room of Mr. Dolman. Mr. Plummer has forwarded along with his letter excellent testimonials from Prof. Challis and Professor Adams; and if the step which he has taken is not inconsistent with any engagement which he may have formed with you, I should feel disposed to accept his services, presuming of course that he has given the same satisfaction at the Royal Observatory as he had previously given at Cambridge.*

Airy (1865) replied to Grant the next day, with a summary of Plummer's duties at Greenwich and an appraisal of his abilities. It appears that, in the year that Plummer spent at the ROG, the quality of his work convinced Airy to revise his opinion of him.

> *We think very highly of J. I. Plummer, and are sorry that he thinks of leaving us: although, in accordance with my established policy, we will do everything possible to help him to a better position than that which he has here.*
>
> *His work here has been principally that of a Computer, in which employment his work has been orderly and accurate. But he has also been employed as occasional Astronomical Observer, and has done very well in that character. At present, his certificate for observing with the Altazimuth has been duly signed and only awaits my sanction.*
>
> *He is very quiet and perfectly well behaved, regular in conduct.*
>
> *I do not think that he is actually as good a mathematician as Mr. Dolman: though I believe that he is sound, and is able to master anything required, in a short time.*

On 07 February 1865, Grant (1865c) wrote to Airy to tell him that he had offered the post to Plummer who, he hoped, would be able to start work in mid-February. The position represented a considerable step up the professional career ladder for Plummer, and he grasped the opportunity. In what must have been for Grant a very welcome development, in April 1866, the Glasgow University Senate approved an annual subsidy of £100 to him for all purposes, at last placing the post on a sound financial basis.

Plummer's astronomical notebooks from Glasgow no longer survive. However, the local press and the scientific literature of the period reveal some of the projects in which he was involved. Grant first mentioned his work in a paper in the *Monthly Notices of the Royal Astronomical Society* (*MNRAS*) describing work to establish the longitude of the observatory using the telegraph, a technique called *galvanic signalling* (see Grant, 1865d; *The Glasgow Daily Herald*, 1866b). For the project, Grant collaborated with Airy at Greenwich to obtain access to telegraph circuits linking the two observatories and arranged for observers at both to time transits of 28 specified stars. When the cross hair of a transit instrument bisected a star, the observer pressed a button that recorded, at the two locations, the time of the transit. Straightforward analysis of the data subsequently enabled Grant to estimate the difference in local sidereal time between the two observatories and from that the difference in their longitude. Unfortunately, the Glasgow weather was not favourable[9] and, despite attempting observations from 28 April to 26 May 1865, the observers were able to time transits for analysis on only four nights. Notwithstanding the paucity of observations, Grant's final estimate of the longitude of Glasgow Observatory was within a few seconds of arc of the modern figure. Plummer undertook the observations at Glasgow.

While at Glasgow, Plummer (1867) published only one paper, which was, in fact, his first publication. It appeared in *MNRAS* and described observations of the Leonid meteor shower of 13-14 November 1866. The paper was unremarkable, reporting observations of individual bright meteors and an estimate of the position of the radiant of the meteor shower. Appendix 6 provides further details.

Much later, in a lengthy contribution to a newspaper, Plummer (1887a) referred to his work at Glasgow with Professor J. D. Everett (1831-1904), Assistant to the Professor of Mathematics. The two used an apparatus consisting of a metal ball supported vertically by a steel spring, in a position of unstable

[9] In earlier correspondence with Airy concerning the establishment of Glasgow Observatory, Grant (1862) commented tellingly: *This is such a horrid climate…*

equilibrium, to estimate the distortion caused by the Moon in the Earth's crust. Appendix 18.3 provides further details.

During the period 1860–81, Grant's main effort was on astrometric observations and he finally published his results in 1883 as the *Glasgow Star Catalogue of 6415 Stars for the Epoch 1870* (Grant, 1883). The introduction to the *Catalogue* did not credit Plummer as a contributor; however, it is likely that he estimated the positions of some of the stars and contributed to the associated data reduction as, in a later publication, Grant (1885) referred to the support of his assistants in the work. Plummer retained a long-term interest in the *Catalogue* as, five years after its publication, Grant (1888), introducing a revised version, referred to errata which Plummer had identified in the original.

Plummer stayed at Glasgow Observatory for rather more than two and a half years and, in November 1867, took up the post of *Observer to the University of Durham*, following once again in the footsteps of Dolman.

2.5 Durham

The Rev. Dr. Temple Chevallier[10] (1793-1873) founded Durham Observatory (figure 5). He funded the facility by a national appeal that, by 1840, had raised almost £1200, enabling him to purchase most of the instruments belonging to the Rev. Thomas J. Hussey, a well-known amateur living in Kent, and install them in the newly constructed observatory. In 1841, the University created Chevallier Professor of Mathematics and Astronomy and, in 1842, he became Director of the observatory.

Figure 5. Durham Observatory. (James Appleton, 2010.)

However, he enjoyed many interests and responsibilities in addition to those associated with astronomy and, as a result, took little active involvement in work of the observatory. Indeed, Rochester (1980) noted, in a history of astronomy at Durham: *...sporadic observations were made but little of note*

[10] Chevallier was a polymath clergyman making important contributions to astronomy and divinity.

appeared in the astronomical journals for several years until Plummer observed the transit of Mercury on 1868 November 4 and a fine display of the Aurorae Borealis on 1869 April 2.

Rochester's judgement is unjustifiably harsh[11] as regards Dolman, who continued at Durham the observational work that he began at Glasgow, achieving a respectable publication record. Dolman's (1865b) first paper published from Durham contained positional estimates of five asteroids, all of which had been known for several years. In the mid-1860s, every few months or so saw the discovery of a new asteroid, and three of the discoveries appear to have piqued the interest of personnel at Durham. Thus, asteroids (84) Klio[12] and (85) Io were discovered in August and September 1865 respectively; Chevallier (1865) wrote to the *Durham County Advertiser*[13] advising that the two bodies were under observation at Durham, and that Dolman had computed an orbit for Klio. Dolman (1865c, 1865d, 1865e, 1865f, 1866) reported in *Astronomische Nachrichten* observations of the bodies during late-1865 to early-1866. His observations included computation of an ephemeris for Io. In mid-June 1866, (88) Thisbe was discovered; Dolman (1867a) reported observations of the object beginning some seven weeks after discovery.

On 09 February 1866, Chevallier (1866) reported observation of an aurora and an auroral arch that he and Dolman had observed (possibly separately) two days previously. He described its appearance at various times during the evening as *white and very steady*, *pulsating* and *fully formed and very brilliant.* Later in the year, Dolman (1867b) reported observations of Comet I 1867 (38/P Stephan-Oterma) beginning less than a week after its discovery. Appendix 26 provides more details on Dolman's observations at Durham.

Dolman also made meteorological observations, publishing the results weekly in *The Advertiser*. His first such report appeared on 10 February 1865. Of the 133 weeks to his last published report, on 23 August 1867, only 11 were missing. His meteorological reports span his entire time at Durham, unlike his astronomical reports, which ceased a year earlier.

Richard Carrington (1855), Durham Observer 1849-52, described the astronomical equipment at the observatory: the main instruments were a 165 mm Fraunhofer equatorial, a 125 mm Rosse equatorial, an 85 mm transit refractor and a sidereal clock by Hardy. Although the Hardy clock *did its part most satisfactorily*, the other instruments were far from ideal. The Rosse equatorial was inferior to the Fraunhofer and, unfortunately, the latter was not entirely satisfactory: it had no clock drive, was fitted with small setting circles and was mounted in an insufficiently rigid manner on a stone pillar rising through the centre of the observatory, with the result that it suffered from *the tendency to unchecked vibration from a breath of wind, or any other source of disturbance.* As Hutchins (2008) put it: *…the instruments were adequate for opportune observations of comets and asteroids, but inadequate for any longer-term programme.* It may be that the poor quality of the instruments together with lack of support by Chevallier led to Dolman becoming disillusioned and demotivated, explaining the lack of published astronomical results after those produced during a burst of initial enthusiasm. His surviving observing notes at the observatory are sparse and scruffy, exhibiting nothing of the *attentive and zealous* approach that Grant commented upon less than four years earlier, and suggest a serious lack of motivation.

The absence of published observations after August 1866 perhaps suggests an early stage of a journey that had a very unfortunate end indeed. A year after his last publication in the scientific literature, during the night of 23-24 August 1867, at the observatory, Dolman committed suicide by hanging. *The Advertiser* (1867a) reported the tragedy, and subsequent inquest. Evidence adduced pointed to mental unsoundness in the maternal line and indicated that he suffered occasional fits of depression. He had entertained two visitors to the observatory late on the evening of 23 August, showing them through the telescope Jupiter and a double star, and they had noticed nothing unusual about his state of mind. Chevallier described him as v*ery intelligent and very attentive* and noted that he had just completed a *very carefully prepared statement of observations of Jupiter* and that the two were to dine together on

[11] It seems that Rochester's search in the astronomical journals was none too thorough, and it may be that he simply missed Dolman's seven papers in *Astronomische Nachrichten* reporting observations made at Durham.

[12] On discovery known as Clio.

[13] Hereafter referred to for brevity simply as *The Advertiser.*

the evening of 24 August. The jury found that Dolman hanged himself while in an unsound state of mind.

Following Dolman's suicide, the weekly reporting of meteorological summaries in *The Advertiser* ceased for two weeks, and then restarted on 13 September, but without attribution. Although meteorological readings could be recorded and published in an expedient manner without need of an *Observer*, the same was not, of course, true of astronomical observations and Chevallier must have felt the need to fill the vacant post. No records have been found describing in detail how the successor to Dolman was selected; whatever the process, by early November 1867, Plummer was incumbent. Some eight years later, *The Advertiser* (1874a) reported, in text likely to have been provided by Plummer himself, then on the point of leaving the post, that *He was brought to Durham by the late Professor Chevallier, who entertained a high opinion of him as an astronomer…* One can only speculate about his feelings on taking up the post given the antecedents of the vacancy.

Plummer's first entry in the astronomical log at Durham is an observation of the transit of κ Piscium on 02 November 1867 (Plummer, 1874a). The meteorological record (Durham Observatory MSS, 1871) for the following day contains an entry, started in an unknown hand and finished in that of Plummer, the transition marked by a capital letter mid-sentence: *On and After this date the observations are taken by Mr. Plummer*. Several weeks later, *The Advertiser* (1867b) reported confirmation, at a Convocation of the University, of his appointment.

Plummer's salary at Durham was £80 *per annum* (Hutchins, 2008) and he benefitted from accommodation on the ground floor of the observatory (Fowler, 1904). By the time he started, additional instruments were available at the observatory in addition to those listed by Carrington, including a second sidereal clock, by Webster, and a Browning star spectroscope.

As a matter of practicality and courtesy, Chevallier must have welcomed Plummer to Durham and helped to install him in his new role. Indeed, Plummer's record in the archive of the observatory (Plummer, 1874a) of transit observations indicates that one evening shortly after he started, Chevallier accompanied him and adjusted the sidereal clock: *Nov 6 23h 30m. Prof. C. stopped Hardy for about 1 min and turned the pendulum screw through 1 div*. No subsequent records suggest that Chevallier actively participated in Plummer's work and it seems that, after providing initial assistance, he once more directed his energies elsewhere.

Documents in the observatory archive illustrate the fresh vigour and energy that Plummer brought to the role. Initially, Plummer's observing notes were much more orderly, detailed and extensive than Dolman's, indicating a more rigorous and sophisticated approach. For example, he made it one of his first tasks to investigate the accuracy of some of the instruments and, finding much in need of attention, to re-calibrate them. His notes (Plummer, 1870a) of transit observations for early November 1867, referring to the micrometer eyepiece of the transit instrument, record: *The Equatorial Intervals used are those formed by Mr. Carrington in 1852. These seem to be very much in error*. During the period 08 November 1867 – 10 March 1868 he calculated a new series of equatorial intervals and re-calibrated the bar micrometer and ring micrometer. In a flush of initial enthusiasm, he even estimated a very small correction factor, for use in determining the positions of asteroids, to account for the *want of perpendicularity of the bars* of the bar micrometer (Plummer, 1870b), and used it in reducing his observations of the bodies. (The correction turned out to be an indulgence of no material significance and he discontinued its use after January 1868.)

He pursued the following studies:

i. **Aurorae**. On 19 October 1868, he observed a *bright and conspicuous* auroral arch from the observatory. He described the phenomenon in *The Advertiser* (Plummer, 1868a) and, in anticipation of further appearances of auroral arches, appealed to the public for observing reports. He observed further aurorae on 02 April and 13 May of the following year, this time subjecting them to scientific scrutiny and publishing his conclusions in the astronomical literature. A further aurora on 05 February 1874 was widely seen throughout the British Isles and Plummer, who had observed it from Durham, corresponded in the scientific literature with another observer, Captain S. P. Oliver, about the nature of the phenomenon. See appendix 8 for details.

ii. **Lunar occultations.** A lunar occultation occurs when the Moon passes between the observer and a star. Occultations were important to Victorian scientists because they fixed the position of the Moon relative to the stars at a given instant and therefore could be used to check theories of the lunar orbit. Within days of starting at Durham Observatory, Plummer began a programme of observation of lunar occultations. He publicised, via the pages of *MNRAS*, an approximate method developed by Chevallier for transforming occultation predictions from one location to another, and corresponded about the use by observers elsewhere of occultation predictions calculated for the ROG. Astronomers of the era occasionally reported that a star about to be occulted would appear to be *projected upon* or *hang upon* or *be attached to* the limb of the Moon for several seconds before disappearing. (Occasionally they reported the analogous phenomenon at reappearance events.) Plummer reported one certain instance and one suspected instance of *projection*. He proposed an explanation for the phenomenon and discussed it in the pages of *MNRAS* and *The Advertiser*. See appendix 2.2 for details.

iii. **Transit of Mercury, 05 November 1868.** A transit of Mercury occurs when the planet passes between the Earth and the Sun and it is visible in silhouette against the solar disk. Plummer observed the transit of 1868 and used a micrometer eyepiece to estimate the position of Mercury relative to the Sun. See appendix 3 for details.

iv. **Apparent diameter of Venus and the effect of irradiation.** *Irradiation* (Sidgwick, 1979) is a phenomenon whereby a bright object, e.g. a planet or the lunar limb, tends to encroach upon a dark background to an extent that is proportional to the difference in intensity. It is a physiological effect caused by the spreading of excitation from the retinal area stimulated by the brighter object. As a result, a planetary disk can appear larger in the eyepiece than it does photographically. Plummer began a programme of observations in 1868 to estimate the apparent diameter of Venus and the effect of irradiation. He obtained results that were unsatisfactory so suspended the work without publication. Five years later, he undertook a new set of observations, this time analysing the data and publishing conclusions (Plummer, 1873a, 1873b). In the same year, he also published recommendations on how to estimate the diameter of Venus during the forthcoming transit of the planet in 1874. (See appendix 4 for details.)

v. **Comets.** He observed five comets, publishing estimates of positions and occasional notes on their appearance. His estimates were intended for the benefit of astronomers computing orbital parameters of the bodies. See appendix 5 for details.

vi. **Asteroids.** He observed and published estimates of position of 39 asteroids. These results too were intended for use in computing orbital parameters. See appendix 7 for details.

vii. **Spectroscopy.** A spectroscope is an optical instrument for producing the spectrum of a source of light, that is, a measure of intensity as a function of wavelength. The spectrum of a luminous body can reveal much about its composition and chemistry; for example, the spectrum of a typical star comprises a continuous background with numerous dark absorption lines, each associated with the presence of a particular element in a diffuse gaseous atmosphere surrounding the surface. In early 1869, Plummer observed the spectra of the Sun and nine other stars, identifying the most prominent absorption lines in each. Shortly after completing the work, he witnessed two bright aurorae and seized the opportunity to undertake an innovative comparison of their spectra with those of Betelgeuse, Aldebaran and the Sun (Plummer, 1869a). He also observed the spectrum of Winnecke's Comet (C/1868 L1). At the time, spectroscopy was a new science, and his work attracted the attention of William Huggins, one of the pioneers of the field. Five years later, Plummer (1874b) reported observing the spectrum of Henry's Comet (C/1873 Q2) and sending an observing report to M. Le Verrier, Director of the Paris Observatory. See appendix 10 for details.

viii. **Meteorology.** Plummer was responsible for meteorological observations, comprising daily readings, taken at 10.00am and 10.00pm, of the barometer, dry, wet, max and min thermometers, wind direction, velocity, average velocity, and rainfall. He published weekly meteorological summaries in *The Advertiser*, the first on 22 November 1867 and the last on 15 May 1874, during that time missing 31 weeks[14].

Weather records at the observatory extended back to 1850; however, there was a discontinuity in the temperature record in 1859 associated with the movement of the thermometers to a new location. To make the data more widely useful, he undertook temperature measurements at both the

[14] This figure excludes the year 1871 for which it has not yet been possible to obtain copies of *The Advertiser*.

old and new locations to estimate the effect of the move and presented his results in a paper read to the RMS (Plummer, 1873c, 1873d).

The weather observations were largely unexceptional. However, 1872 turned out to be extraordinarily wet and, in November of the year and the following January, *The Advertiser* published Plummer's (1872a, 1873e) comparisons of the rainfall with the average. Over the whole year, the excess rainfall amounted to a staggering 59.1 cm above the average (1850-71) of 64.0 cm. The previous record for annual rainfall was in 1852, when there had fallen a mere 80.1 cm.

Of course, the stormy weather to which the north-east can be subject also featured in the meteorological reports. *The Advertiser* (1869a) reported a violent gale on 13 February 1869 which caused *considerable damage to property*, although fortunately, no loss of life. The storm damaged the anemometer at the observatory, which recorded a velocity of 90kph at 10.00pm on 13 November and broke before the next scheduled reading at 10.00am the following day; it remained out of service for almost a month, the next published reading being at 10.00pm on 12 March. On 06 November 1872, another gale caused loss of life and much destruction and again broke the anemometer (Plummer, 1872b), the instrument coming back into service approximately one month later (Plummer, 1872c). (In his annual report to the RMS for 1873, Plummer (1874c) mentioned that the anemometer was repaired at the beginning of the year, and noted that *it is of rather too slender a construction to withstand the gales which occasionally sweep over the Observatory*.)

Plummer's (1874c) annual report to the RAS for 1873 noted that *The meteorological work has been somewhat increased by the observer taking part in the scheme for synchronous observations of weather over the whole of the northern hemisphere, which has been suggested by American meteorologists, and which commenced at Durham on January 1, 1874*. Further investigations are required to establish precisely what this involved. In any case, the times of readings quoted in the weekly meteorological summaries remained unchanged, 10.00am and 10.00pm.

See appendix 16 for details for Plummer's meteorological work at Durham.

ix. **Regulation of Durham cathedral clock.** Plummer's duties included regulation of the cathedral clock. His records survive for the period May 1869 – May 1870 (Plummer, 1871a) and indicate that the task was fraught, as the rate of the clock varied frequently and significantly, likely due to changing atmospheric pressure and humidity. He was able to maintain clock time for the citizenry typically to within a few tens of seconds of astronomical time. See appendix 17 for details.

In 1871, Chevallier suffered a stroke and retired from his Chair, after which the University changed the Professorship of Mathematics and Astronomy to the Professorship of Mathematics. Inevitably, the change precipitated a period of uncertainty and instability at the observatory. Matters were compounded during 1872 when the Warden of the University, William Charles Lake (1817-97), intimated his intention to close the observatory and abolish the post of *Observer* and advised Plummer to obtain another situation *at as early a date as possible*.

In June 1872, Plummer wrote to Airy indicating that he had heard of plans to increase the staff at the ROG and asking to be considered for an assistant astronomer's post, should one become available. He was anxious not to suffer financial loss from the move, writing: *I beg to offer myself for that vacancy should the emolument be not less than I am at present in receipt of…* The First Assistant at the ROG, William Christie[15], replied, stating that no decision had been made to recruit staff. Nonetheless, later in the year, a post of Junior Assistant was indeed created, and, in December 1872, Plummer (1872d) wrote again to Airy explaining that he had been unable to apply for the vacancy as the Post Office had delivered a packet late (it presumably contained information concerning the post) and in any case he was nearly three years too old. He enquired whether there could be a relaxation in the upper age limit for vacancies!

Summarising the year 1872 in a rather subdued annual report to the RAS, Plummer (1873f) stated: *During the past year the scheme of observations that has been hitherto pursued has been greatly interfered with by the unsettled state of government of the Durham University…* He went on to indicate that he found the Fraunhofer equatorial inadequate for the ongoing programme of observation of

[15] William Henry Mahoney Christie (1845-1922) later assumes a major role in Plummer's story. Educated at Trinity College, Cambridge, he was appointed Chief Assistant at the ROG in 1870 and Astronomer Royal (replacing Airy) in 1881. He retired in 1910.

asteroids; he proposed to discontinue observations of the bodies and instead deploy the limited resources of the observatory on other projects: *...but the necessity for a large instrument to perform this work* [observation of asteroids] *satisfactorily is yearly becoming greater. Finding the equatoreal*[16] *more and more inadequate for the work, it appears that the time is now come to discontinue the attempt, and to leave this branch of astronomy to the care of the Continental observatories which have so perseveringly followed it. It is not without regret that this statement is made, but it is hoped that the resources of the Observatory may be more usefully employed in other directions. Comets, when discovered, will be observed with the equatoreal, and a few planets will be occasionally followed beyond the limits of the Berlin ephemerides when such observation is likely to advance our knowledge of their orbits…* In his annual report to the RAS for 1873, Plummer (1874b) confirmed that observation of asteroids had indeed been discontinued.

In the event, the University did not abolish the post of Observer and Plummer remained at Durham. However, events during 1871-72 were profoundly unsettling and many of his observing records become sporadic or peter out altogether during this period (Plummer, 1871a, 1871b, 1871c, 1872e, 1873g, 1873h, 1873i; Durham Observatory MSS, 1878). Although Plummer (1874a) continued to record transit observations, his notes become noticeably less neat and orderly, and he ceased applying corrections for collimation, level and azimuth errors, rendering the results useless; clearly, he no longer valued the work.

Plummer (1868b) published his first astronomical paper at Durham in 1868, concerning the transit of Mercury, and subsequently maintained a respectable presence in the scientific literature. Spurred on by the knowledge that his post at Durham was no longer secure and that he might need to find another, possibly at short notice, after 1872 he increased the number of his publications, likely to make his name known to potential employers. In 1873 and 1874, although he recorded few observations, he published considerably more than on average in previous years at Durham and his output included a textbook and his first papers on meteorology. Table 1 lists the number of his publications (excluding the weekly meteorological summary in *The Advertiser*) each year at Durham, showing the effect clearly.

Publications	**1868**	**1869**	**1870**	**1871**	**1872**	**1873**	**1874**
Articles / letters in scientific journals	2	5	1	2	1	8	5
Reports / letters in newspapers	1				2	5	
Textbook						1	

Table 1. Number of publications at Durham.

While at Durham, his publications in the astronomical literature amounted to 11 papers in *MNRAS*, nine in *Astronomische Nachrichten*, one letter to *Nature* and a textbook; and his meteorological publications to three contributions to the *Quarterly Journal of the Royal Meteorological Society*. He also contributed eight letters to *The Advertiser*; they covered astronomical matters (the aurora of 19 October 1868, meteors, a possible lunar atmosphere, comets, and the solar partial eclipse of 26 May 1873), the amount of rainfall in the city, and a plea for improved lightning protection at Durham Cathedral.

The local press mentioned Plummer several times, giving his textbook a very favourable review, advertising lectures that he gave on *Time* and *Physics* and reporting his presence at social events, mingling with the great and the good of the city. Appendix 18.1 provides further details.

By the time Plummer published his textbook, he likely considered himself an accomplished astronomer, ready for a senior position at a major observatory. He was knowledgeable about many aspects of contemporary astronomy, had initiated innovative investigations of his own design, taught classes on physics, and published a textbook and papers in the scientific literature. Given the uncertainty over his post, he was alert to potential opportunities. Fortunately, one presented itself and, in early 1874, he left

[16] Modern spelling is *equatorial*.

Durham to take up the post of Colonel Tomline's astronomer at Orwell Park. *The Advertiser* (1874a) reported[17] the move, describing the new role as *very lucrative*.

His last entry in the Durham Observatory archive was in the daily meteorological record for 25 February 1874; his successor, Gabriel Alphonsus Goldney (another former computer at Greenwich who trod the path to Durham), completed the entry for the following day.

At a Convocation on 05 May 1874, reported three days later in *The Advertiser* (1874b), the University awarded Plummer an honorary MA in recognition of his daily meteorological and astronomical work and of his original observations with a spectroscope of the aurora borealis and Comet Henry.

2.6 Orwell Park

Colonel George Tomline[18] was born in 1813 at Riby Grove Estate, near Grimsby, Lincolnshire. He was educated at Eton, where William Gladstone was among his classmates. He inherited enormous wealth from both parents but, despite thus being a highly eligible bachelor, never married (the gossip of the day hinted at his being let down in love) and instead expended his energies in civil and governmental affairs and in science. In 1848, he purchased Orwell Park Mansion[19], overlooking the River Orwell at Nacton, Suffolk. Finding the property not ideally suited to his needs, in the early 1870s, he had the house remodelled and added a large extension, including an astronomical observatory and self-contained state apartments for the use of his many house guests.

Tomline's colossal wealth enabled him to demand the best for his observatory. He appointed John Macvicar Anderson (1835-1915), later president of the Royal Institution of British Architects (RIBA) architect, and Wilfrid Airy (1836-1925), son of the Astronomer Royal, engineer responsible for astronomical instrumentation. Design and construction of the observatory constituted an unique architectural challenge, described by Airy (1874), Anderson (1875) and *Building News And Engineering Journal* (1874).

Tomline specified that his observatory be integral to the mansion. This was highly unusual at the time; it was customary for a wealthy Victorian to site the facility at some distance from his house, atop a low hill or rise in the land, to rest undisturbed by the routines of daily life and to command a clear view of the horizon. In order to hold the telescope clear of the mists that can rise from the nearby River Orwell and provide views unobstructed by the chimneys of the mansion, Airy specified that the floor of the observing room at Orwell Park be 16 m above ground level, thus establishing the height of the observatory tower and its essential form as a five-story edifice. Figure 6, redrawn from Anderson (1875), shows key features of the facility, and figures 7 and 8 are photographs of respectively the observatory tower and the rear of the mansion, showing the observatory dominating the eastern end of the building.

Airy dedicated the top floor to astronomical purposes and, on the lower floors, enabled Anderson to design highly desirable additional facilities for the enjoyment of Tomline and his guests. The basement and ground floor housed a Turkish bath suite (at the time, a fashionable and desirable facility in a country mansion): the steam room was in the basement and the tepid and cool rooms occupied the ground floor. The first floor comprised a muniment room (for the storage of papers and other valuables) and the second floor a *belvedere* giving access to balconies from which to admire the lands surrounding the mansion. The third floor housed the equatorial room, and, off it, a small transit chamber. The observatory was of an Italianate style, in keeping with the remainder of the mansion.

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[17] The report contains a summary, likely furnished by Plummer himself, of his achievements at Durham. Intriguingly, it mentions his popular lectures on "Spectrum Analysis" delivered in the Divinity Room, Durham. No other record has been found in the local press of Plummer lecturing on the subject, and the reference may be to his evening classes in Physics, which may have contained an element of spectral analysis.

[18] Despite his title, Tomline was not a military man. *Colonel* was an honorific courtesy of the Royal North Lincolnshire Militia, in which he was Lieutenant Colonel.

[19] An earlier owner of the property was the famous naval figure Admiral Edward Vernon.

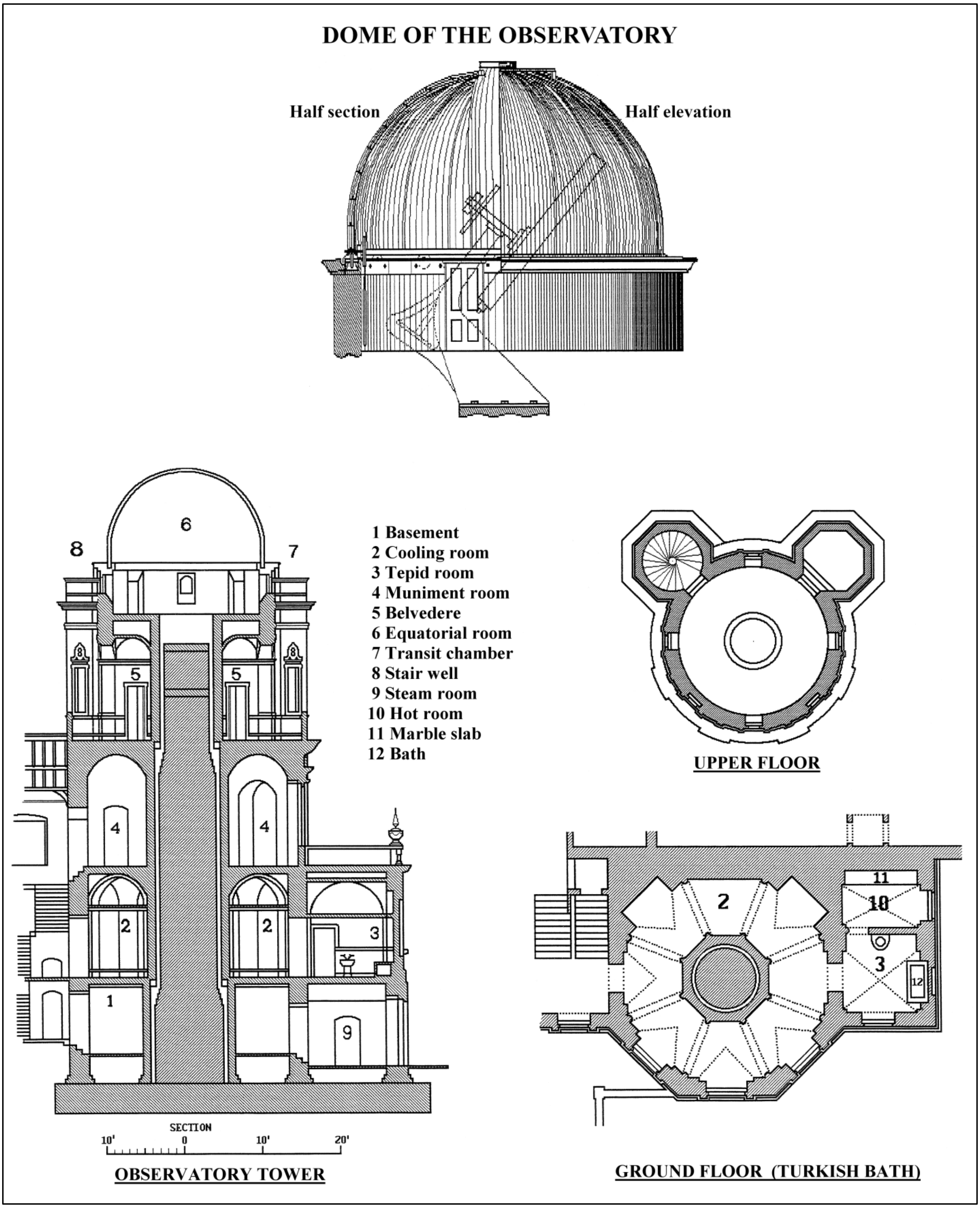

Figure 6. The main features of Orwell Park Observatory, redrawn from Anderson (1875).

Figure 7. Orwell Park Observatory. (James Appleton, 2010.)

Figure 8. The rear of Orwell Park Mansion, with the observatory on the eastern end of the building. (James Appleton, 2010.)

The observatory was constructed to a high specification. Access to the equatorial room is via a spiral staircase leading to a full-size door in the wall, rather than the much cheaper option, adopted in many contemporary observatories, of a trapdoor in the floor. The dome is lined on the inside with tongue-and-groove mahogany planks, each individually shaped. Originally, the inside wall of the equatorial room was similarly clad, but the mahogany there was at some date removed (likely because of its resale value) and the wall nowadays has a plaster finish. Bricks, window panes, doorframes and doors are all curved to match the circular profile of the tower. Warm air flues from the boiler of the Turkish bath suite heated the equatorial room; this kept the instruments free from damp but meant that it was necessary to open the shutter of the dome for an hour or so to allow the air temperature to stabilise before using the telescope. Architecturally, the belvedere is especially impressive: it flaunts high vaulted ceilings, large masonry scrolls separating the balconies and superlative views over the surrounding land. Some years after commissioning the observatory, Tomline had a hydraulic lift installed to provide effortless access to all floors. The building is unique amongst Victorian astronomical observatories, many of which, like Durham Observatory, were comparatively utilitarian.

The observatory houses two Troughton & Simms refractors: a 258 mm f15.1 equatorially mounted telescope (figure 9) and a 75 mm transit instrument (figure 39). The equatorial refractor was, in its era, a fine instrument. The object glass is an achromatic doublet, ground by the German optical company Merz as, at the time, the maximum diameter of lens that English companies could manufacture satisfactorily was about 150 mm. Airy checked its performance prior to having it mounted in the telescope tube at Orwell Park. He first installed it in a temporary telescope tube fixed to the 325 mm *Great Equatorial* at the ROG and observers compared the performance of the two instruments, particularly in observations of bright double stars.

The mount of the instrument is of an innovative design permitting easy operation and providing unobstructed views of the entire hemisphere of the sky. It was fabricated as a single, massive casting; lifting it into position in the equatorial room must have presented a significant engineering challenge. It is fixed to a York stone slab set at the top of a brick-and-mortar pillar that extends from the foundations to just below the floor level of the equatorial room. (Airy specified the use of mortar rather than cement, as the former expands and contracts less with changes in temperature.) A cylindrical brick wall runs the height of the building and encases the pillar; thus, apart from a shared foundation, the pillar is independent of the rest of the edifice, the arrangement minimising the transfer of vibration from the living space of the mansion to the telescope. The mount and tube of the equatorial refractor cost £1345-12-8 and the object glass a further £333-6-8 (Orwell Park Estate, 1895). The transit telescope is of the type used by ROG expeditions to observe the transit of Venus in 1874 (Plummer, 1876a): its small aperture limits its capabilities. In addition to the telescopes, the other vital piece of equipment at the observatory was its chronometer, by Dent; unfortunately, it disappeared after Tomline died. The equipment was installed in the observatory around the beginning of 1874.

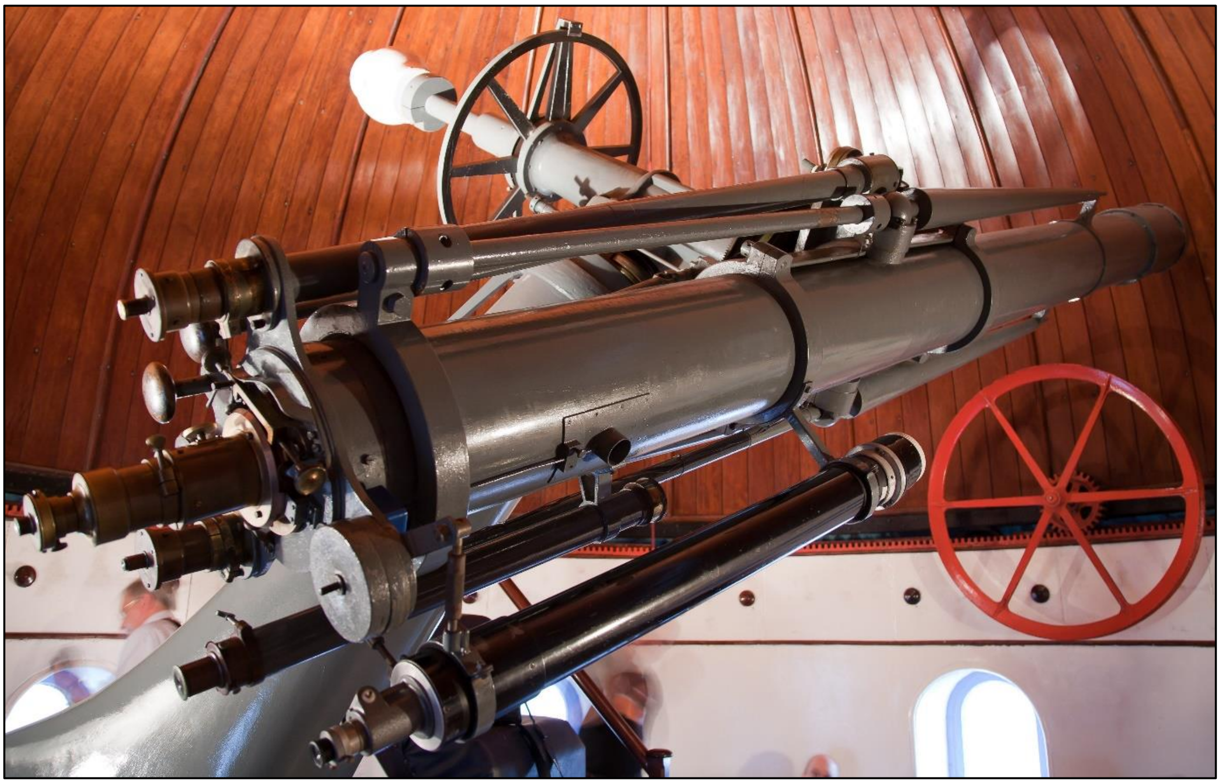

Figure 9. The Orwell Park equatorial refractor. (Ken Stacey, 2010.)

In late 1873 or early 1874, his fine private observatory nearly complete, Tomline began the search for a professional astronomer to operate it. A letter from Albert Marth (1874), Durham Observer 1856-63, to Professor Adams, full of astronomical news and opinions, indicates that Tomline approached the Astronomer Royal for a recommendation and the latter proposed Plummer.

Tomline did not stint on the terms of employment of his professional astronomer, providing remuneration of £300 *per annum* plus a tied house (Marth, 1874). The salary was approximately half that of a typical director of a university observatory or professor of astronomy (Hutchins, 2008) and Plummer was, therefore, comfortably off (*c.f.* his salary of £80 *per annum* at Durham Observatory) and able to afford a domestic servant who lived with the family (*EADT*[20], 1878a). The tied house, which still stands, is named *Orwell Dene* after the land upon which it was built. It is situated on Levington Road, Nacton, a short walk from the observatory across the valley in front of Orwell Park Mansion, and offers a magnificent view of the latter.

The post at Orwell Park represented a wonderful opportunity too in aspects other than purely financial. Plummer would have looked forward to use of the powerful equatorial refractor; benefitting from a large aperture, clock drive, massive, rigid mounting, and large setting circles, it was greatly superior to the telescopes at Durham. He had been promised spectroscopic instruments, enabling him to continue the innovative work that he had begun in the field. And he would have sensed a different *zeitgeist*: whereas Durham Observatory had been constructed to a restricted budget, Orwell Park Observatory was designed and built without regard to cost and flaunted its expensive features. He could look forward to the stimulation of meeting Tomline's numerous house guests, many of whom were scientists or holders of important public office, and discussing with them his work. Although, at the time, East Anglia was a relatively isolated region of the UK, he could keep in touch with mainstream developments in astronomy via the Cambridge Observatory library, which Professor Adams placed at his disposal (Plummer, 1875a) and via correspondence with other astronomers.

Plummer commenced work at Orwell Park Observatory in June 1874. In his first publications from there (Plummer, 1874d, 1875b), he described the instruments at the observatory:

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[20] For brevity, the *East Anglian Daily Times* is referred to herein as the *EADT*.

During the past year this Observatory has been fully equipped, and for the most part is now in working order[21]*. The principal instrument is an equatoreally mounted refractor of large aperture, furnished with all the appliances necessary to render it in every respect a really useful instrument. The object-glass by Messrs Merz, of Munich, is of 10 inches aperture. Its definition is excellent, the beauty and regularity of the diffraction rings around the stars' images being the best possible proof of the excellence of its figure. The form of mounting renders this instrument one of the most easily worked of its size yet erected…*

The Observatory is provided with a small transit instrument and an excellent clock by Dent…

Colonel Tomline's Observatory will be furnished with spectroscopic appliances before the next apparition of the Zodiacal Light [February-March 1875]...

He went on to define the anticipated main field of work at the observatory: *it has been determined to employ this fine instrument chiefly for the observation of comets, both periodical and occasional…* It is not known why Tomline chose this as the chief business of his observatory. However, Plummer likely influenced his choice as, when he started work for the Colonel, he had already gained experience in cometary observing and believed that the bodies played an important part in the formation of the solar system (see appendix 14).

Plummer's observing notebooks from Orwell Park no longer survive, but the scientific press of the period indicates the work that he undertook there. No doubt in order to confirm his status as a professional astronomer in charge of an observatory, he applied to join the RAS and, on 11 February 1876, was elected a Fellow. Prior to this date, he arranged for colleagues, already Fellows, to communicate his work to the Society; once elected, he contributed papers under his own name. He published (in *MNRAS* and other journals) on the following subjects: comets, aurorae, the zodiacal light, stars with uncertain proper motions, meteors, Venus, photometry of the lunar eclipse of 1877, the transit of Mercury of 1878, lunar occultations and determination of the longitude of the observatory. His main work was, as anticipated, the observation of comets, and he published reports of observations or attempted observations of 45 of the bodies. The appendices provide further details of his published observations.

There is no record of Plummer undertaking meteorological work at Orwell Park; however, while there he published in *Nature* two brief contributions to debates on meteorological questions. In 1875, he responded (Plummer, 1875c) to an article criticising the quality of data published by the Meteorological Office. Two years later, he published a short letter (Plummer, 1877a) on the cause of the apparent increase in temperature at the ROG during the third quarter of the 19th century. (Appendix 16 provides details.)

The first local reference to Plummer is in the minute book of the Ipswich Science Gossip Society[22], one of several local societies that, at the time, took an interest in matters astronomical. The Society organised an excursion from Ipswich to Orwell Park on 11 July 1874. Twenty-six members attended: they were shown the grounds and Tomline's art collection and were introduced to Plummer, who took them over the Observatory. The visit marked the start of a long association between Plummer and the Society – appendix 19 provides details.

Plummer's position as a privately employed astronomer undoubtedly conferred upon him a unique status in the locality, and thus he features in reports in the local and regional press, providing insight into his activities and personal circumstances (see appendix 18). The uniqueness of Orwell Park Observatory aroused interest locally, and over the years, he must have played host to many visiting groups[23]. He was chosen foreman of a coroner's jury in 1877 and received an invitation to mingle with the great and the good of the region in celebrations marking the opening of a new lock at Ipswich docks in 1881. He was associated with local schools, contributed to entertainments held in school buildings

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[21] In fact, Plummer (1876a) later indicated that the observatory became operational in 1875.

[22] The Society formed in 1869 and, in 1875, changed its name to the Ipswich Scientific Society. In 1924, it amalgamated with the Ipswich & District Field Club to form the Ipswich & District Natural History Society.

[23] Indeed, strong interest in visiting the observatory continues to the present day!

and officiated at prizegivings. He was a benefactor of Ipswich Museum, and a golfer. He engaged too in correspondence in the press. He wrote letters about astronomical events and news, encouraging the adoption of Greenwich time rather than local time (Ipswich was one of the last towns in the UK to adopt the former) and concerning the change of the calendar from Old Style to New Style in 1751-52 and the apparent effect on the seasons. His more substantial contributions include a dialogue of an incendiary nature with John Hampden, a fervent believer in a flat Earth, and lengthy correspondence about the possible influence of the Moon on the occurrence of earthquakes (a matter still the subject nowadays of active research and conflicting views in the scientific literature).

Although Tomline expended a huge amount of money to build and equip one of the finest private observatories in the land and to retain the services of a professional astronomer, he did not take an active interest in the work there. Plummer made no mention in his publications of Tomline engaging in the work of the observatory. Some of Tomline's obituaries mention his interest in astronomy, but none suggest that he was an active observer. For example, his obituary in the *EADT* (1889) stated simply that *his love and knowledge of astronomy were very great; and his observatory at Nacton (well and widely known in astronomical circles) was anything but a folly*. In the same edition of the paper, personal reminiscences by *one who knew him well* mentioned that *with astronomers, I have heard him apparently holding his own*. His obituary in *The Lincolnshire Chronicle* (1889) explained his interest: *he "kept an astronomer" because he conscientiously believed it to be his duty to employ his money in every direction which human activity demanded recognition and the cooperation of men of wealth*. His obituary in *The Ipswich Journal* (1889a) did not mention astronomy at all. It seems that Tomline was content to maintain Plummer essentially as an ornament, a *tame astronomer* brought out to impress aristocratic house guests with his command of a fashionable science that was rapidly advancing in Victorian times. Tomline likely regarded him merely as a servant, albeit one with highly specialised skills, and was content to let him pursue astronomical work without interference while he expended his considerable energy on his many interests in state and commercial affairs.

In 1878, Stone (by then Her Majesty's Astronomer at the Cape of Good Hope) accepted the post of Radcliffe Observer at Oxford. On hearing the news, in December 1878, Plummer (1878a) wrote a speculative application to Airy for the vacant post at the Cape. Airy (1878a) replied the next day in a curt note, explaining that the Board of the Admiralty would be responsible for making the appointment. There were three other applicants: William Christie, David Gill and Alexander Freeman. In January 1879, Airy (1879) wrote to the Secretary of the Admiralty with his appraisal of each of the candidates. Of Plummer, he wrote: *J. I. Plummer Esq., formerly Supernumerary Computer at the Greenwich Observatory, and now in charge of the private observatory of Colonel Tomline at Orwell Park near Ipswich, has managed his little observatory creditably; but I do not think that he possesses the command of usual astronomical science or the familiarity with the* [text unclear] *subjects which would place him in the same rank with the other candidates.* David Gill was appointed, and Plummer remained at Orwell Park.

Tomline gave permission for Plummer to participate in the work of the ROG to observe the transit of Venus on 06 December 1882 (Plummer, 1882a). He was appointed to lead the team sent to make observations from Bermuda, and the expedition took him away from Orwell Park for over two months. He observed with Lieutenant Charles Burnaby Neate, RN (1846-1916), a veteran of the previous transit of Venus, in 1874, and the pair were assisted by Sergeant Dobing, RAM. After several weeks of training at the Radcliffe Observatory, Oxford, during summer 1882, Plummer entered Bermuda on 23 October 1882 with Dobing, and Neate two weeks later. They established an observing station at the foot of Gibbs Hill Lighthouse on the south coast of the island. Both observers used 150 mm equatorially mounted refractors. Although their observations of both ingress and egress of the transit were hampered by cloud, their results were nevertheless generally of good quality compared to those of the generality of observations reported to the ROG.

Neate left Bermuda the day after the transit. Plummer stayed on for a few days to auction surplus equipment and departed the island for New York (where he mailed his observing report to the ROG) on 21 December 1882. The second leg of his journey home, from New York to Liverpool, turned out to be surprisingly eventful and was much covered in both local and national press. He took passage on the Inman Line steamship *City of Brussels,* under Captain Land, departing on 28 December 1882. The first four days' sailing were calm, but then a *terrible gale came on.* The ship nevertheless reached Queenstown (Blackpool) safely, set down the mail then departed for Liverpool. On reaching the mouth of the River Mersey at approximately 06:00 on 07 January, Captain Land encountered a fog so dense that it was impossible to see more than a few metres ahead; he decided to lay to, in the hope that the fog would clear, posted lookouts and ordered that the fog whistle be sounded. Unfortunately, despite his precautions, after some 40 minutes, the ship was rammed by the *Kirby Hall* of Glasgow, the collision punching a hole of approximate dimensions 2.5 x 1 m in the starboard bow. Captain Land immediately gave the order to abandon ship and the passengers and crew took to the lifeboats, Land himself being last to leave. According to a report in *The Ipswich Journal* (1883), Plummer displayed a cavalier attitude towards his personal safety, being one of the last passengers off the vessel as he was *engaged in procuring some of the contents of his cash box*. The inrush of water was so rapid that the ship sank within 20 minutes. When muster was taken, it was found that fatalities amounted to two passengers and eight members of crew. Although Plummer survived the collision, he lost all his instruments and luggage and finally arrived home to Nacton the next day. Later, he gave a lecture at Harwich on the transit of Venus[24]: he must have recounted a tale that was unexpectedly and unwantedly exciting! (See appendix 4.4 for further details of the expedition and observations.)

The expedition to Bermuda marked a profound change in Plummer's astronomical work. During his initial years at Orwell Park, he pursued a wide range of astronomical studies, continuing the diverse range of interests that he had developed at Durham. However, on return from Bermuda, for the remainder of his time with Tomline, he concentrated almost exclusively on comets and all but abandoned other subjects of observation. By this time, it had become apparent that the initial promise of Orwell Park had not fully materialised and the narrowing of his field of work reflected, perhaps, a pervasive disenchantment. It is possible to identify some of the likely contributory factors. Although in his first publication from Orwell Park, he looked forward to the use of *spectroscopic appliances* promised by Tomline, he did not mention the equipment in subsequent observing reports and it appears, therefore, that Tomline reneged on his promise. In 1875, the latest copy of the *Greenwich Observations* that he could readily access was dated 1864 – not indicative of easy access to a well-stocked library. Indeed, his access to Cambridge Observatory library appears to have ceased after two years (Plummer, 1878b, 1880a). In addition, he experienced considerable operational difficulty with the transit telescope: initially, he found a periodicity in the errors of the instrument and four years later wrote that it was not suitable for the observation of comparison stars for estimating the positions of comets (Plummer, 1878b, 1882a). As positional astronomy constituted by far the largest part of his work at Orwell Park, the difficulties with the instrument must have been especially frustrating. Tomline was very well connected, because of which Plummer was introduced to a wide variety of erudite and eminent visitors. However, the intellectual stimulation that they provided may have only partly overcome the sense of isolation associated with life in East Anglia. Plummer was geographically remote from the mainstream of astronomical activity and his separation from other observers must have compounded the operational difficulties that he confronted. Inevitably, the difficulties restricted both the volume and quality of work that he was able to undertake; indeed, he referred to this in his later application for the post of Chief Assistant at Hong Kong Observatory (see appendix 20).

Tomline appeared to enjoy almost rude health until, around the beginning of 1889, he became hemiplegic. Perhaps recognising that the end was near, and knowing that his nominated heir, Captain Ernest Pretyman, was not interested in astronomy, he took steps to close Orwell Park Observatory, advising Plummer to seek another appointment without delay. Plummer (1889a) wrote to Christie who, by this time had been appointed Astronomer Royal, requesting assistance in finding a post and asking to be considered for any vacancy that might arise at the ROG.

In late summer 1889, Tomline entered a coma, in which he lingered for five days, decease occurring on 25 August. Plummer (1890a), in his last annual report to the RAS from Orwell Park, detailed his astronomical work in 1889 and concluded, poignantly, with news of Tomline's death and the imminent closure of the observatory.

Correspondence between the Rev. Edmund Ledger, MA (1841-1913) and Christie provides additional insight into events following Tomline's decease. Ledger was Professor of Astronomy at Gresham

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[24] Tomline's obituary in the *EADT* (1889) indicated that he set out with Plummer to travel to Harwich for the lecture but the two became separated when changing trains at Manningtree. In a flash of ready humour, he subsequently threatened an acquaintance that, if Plummer did not arrive at the venue in time, he would arrange for *some Harwich Venus to give us an address on the Transit of an Astronomer*!

College and Rector of Barham, north-west of Ipswich, and owned a property in nearby Claydon. At a meeting of Ipswich Scientific Society in 1889 (see appendix 19), he presented a talk at the conclusion of which Plummer proposed the vote of thanks; it is likely that Ledger knew both Tomline and Plummer. Ledger (1890) indicated that Tomline had granted Plummer a year's notice to leave his employment, a period which Pretyman subsequently extended. He also indicated that Pretyman was anxious to sell the equatorial refractor shortly after he inherited it! In reply, Christie (1890a) indicated that although he felt *very sorry for Mr. Plummer*, he did not know of anything that he could do to assist him. In this, he seriously underestimated both his own influence over the course of events and Plummer's determination!

By early 1890, Plummer was still resident at *Orwell Dene* and, although his employment as a professional astronomer had ceased, he was left with an accumulated backlog of cometary observations that he was anxious to reduce and publish. In February 1890, Plummer (1890b) wrote once more to Christie, this time asking for support with an application that he had made to the Government Grant Committee of the Royal Society for a grant of £150 to complete the work. The backlog amounted to 91 observations of eight comets, and he expected to be able to use the Orwell Park Refractor for a further four months to make additional observations. An unnamed official subsequently replied (ROG Archives, 1890) to the effect that, as Christie was a member of the Committee, it would be improper for him to take any specific action in support of the application. Eventually, the Civil Service gave the matter due attention and the Chairman of Board B of the Committee, Professor G. Carey Foster, supervised assessment of the application. He obtained an evaluation by "AD" (full name not stated) of the value of the work confirming that it would be desirable to reduce and publish the observations, noting that three of the comets concerned, Barnard's (C/1889 G1), Swift-Gehrels' (64P) and Borrelly's (C/1889 X1), had not been extensively studied. AD estimated that reduction of a complete cometary observation comprising, for example, six comparisons of position with two stars required approximately four hours labour, and proposed payment of £20 to cover reduction of approximately 100 observations (equivalent to a rate of 1/- per hour.) He suggested payment of an equal sum to cover time spent at the eyepiece and generously rounded up the total amount to £50. Foster (1890) advised Christie of AD's suggestion. Christie (1890b) concurred, and recommended payment of a grant of £50.

Plummer made his final cometary observation from Orwell Park Observatory on 24 May 1890. He then left *Orwell Dene* and moved to eight Constitution Hill[25], Ipswich, the move likely marking the end of his employment by Pretyman. By this time, he was clearly most anxious to obtain a new position. Not having received a response from Christie to his letter of January 1889, he wrote again (Plummer, 1890c), renewing his interest in any vacancies and offering his services on a freelance basis to undertake reduction of astronomical data for the ROG. This time, Christie (1890c) did reply, a few days later, but in a thoroughly non-committal way.

While living in Ipswich, in August 1890, Plummer (1890d) wrote to the editor of *The Ipswich Journal* publicising the BAA, which was in the process of forming; he went on to become a founder member of the Association, and was included in the BAA list of members for 31 December 1890.

In November 1890, Plummer (1890e) published his final report on cometary observations. (As he had continued making observations while the Royal Society considered his application for funding, the final report addressed a slightly different set of observations to that which he had promised in his request for a grant.) While living in Ipswich, he also submitted two brief contributions to *Nature*, one concerning natural history[26] (Plummer, 1890f) and one astronomy (Plummer, 1890g). His last known engagement in the town was on 03 December 1890 when he presented a talk entitled *Stars* to Ipswich Scientific Society.

During his time at Orwell Park Observatory and subsequently at Ipswich, he published 27 papers and short communications in *MNRAS*, 12 in *Astronomische Nachrichten*, six in *The Observatory*, nine in

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[25] Constitution Hill was subject to piecemeal development. At some time during 1910-11, properties there were renumbered, because of which number eight is nowadays number 43.

[26] The publication, a letter in *Nature*, was Plummer's only contribution to the scientific literature outside the fields of astronomy and meteorology. He wrote in response to a communication from the Duke of Argyll, assuring him that the araucaria tree grew cones containing fertile seeds.

Nature, one in *Popular Science Review* and one in *Science For All*. All the publications dealt with astronomical or meteorological matters except for one communication in *Nature*.

2.7 Hong Kong

In 1883, Dr. William Doberck (1852-1941) was appointed first Director of Hong Kong Observatory (figure 10), remaining in post until he retired in 1907. In his first annual report, Doberck (1885) detailed the founding of the observatory and described the building itself and the instrumentation within it. See also Starbuck (1951), Dyson (1983) and MacKeown (2007, 2011) for details of the establishment of the observatory and the work undertaken there; much of the below is based on MacKeown's publications.

The main roles of the observatory were to provide a time service for the Colony, undertake geomagnetic and meteorological monitoring and issue typhoon warnings. Its only official astronomical role was in connection with the provision of the time service, for which a small transit instrument and associated equipment were provided. However, Doberck was a skilled astronomer. He had worked at Markree Observatory in County Sligo from 1874-82, publishing almost 100 astronomical papers while there, and was keen to advance astronomy at Hong Kong. Accordingly, in the mid-1880s, he had a 150 mm equatorial refractor installed. In a paper in 1902, he admitted (Doberck, 1902a) that, although the drive mechanism of the equatorial worked well, the instrument itself was not a good one, being *upwards of eighty years of age, and nearly past use*. Nevertheless, he put it to much use.

Figure 10. Hong Kong Observatory, photographed in 1913. (World Meteorological Organization, 2023.)

Shortly after Doberck took up his post at Hong Kong, he instituted a system to provide a warning of impending typhoons: a signal was displayed for the benefit of ships in the harbour and a "typhoon gun" was fired to warn the populace at large (Sham, 1983). At the time, the science of weather forecasting was not well developed, and Doberck, unfortunately, compounded the difficulties inherent in the task by eschewing the opportunity to cooperate with other meteorological observatories in the region to share information and empirical data. Partly as a result, several storms for which the observatory did not issue a warning struck the Colony. A particularly savage un-forecast storm struck on 15 October 1889; it caused the Governor great dissatisfaction as he had noted signs of its approach earlier in the day. After the event, there was much criticism in the local press of the observatory and of Doberck, and *The China Mail* called on the Governor to convene an enquiry: *...it would not be a bad thing if the Governor appointed a small commission to enquire into the whole matter. His Excellency may have some diffidence in stirring up this affair as Dr. Doberck's appointment was made by the Colonial Office, but the question of storm warnings is of such importance to the Colony that he ought not to hesitate to make a strict investigation.* There was further criticism of Doberck in a debate in the Hong Kong Legislative Council in December 1889 and, bowing to public pressure, in January 1890, the Governor appointed a six-man commission to examine the workings of the observatory. The commission was charged with investigating specific failures associated with the lack of a warning for the storm of 15 October, wider matters concerning the provision of storm warnings in general and the overall operation of the observatory.

Against local expectations, the commission's report (which was laid before the Legislative Council but not formally published) was not particularly critical of Doberck. Instead, it noted (Doberck, 1891a) that *The annual cost of the upkeep of the Observatory was originally estimated at ten thousand dollars, but only seven thousand dollars has been spent. An Observatory is essentially one of those Institutions on which, if thoroughly good results are to be obtained, a considerable sum of money must be spent.* It went on to recommend expansion of activities at the observatory, improvements to infrastructure and to the system for signalling storm warnings, and the appointment of an increased staff of assistants, including three from Europe, at least one of whom should be capable of taking charge of the observatory in the absence of the Director. The Acting Governor accepted the recommendations of the commission, forwarded the report to the Colonial Office, where it also found favour, and made provision to appoint a Chief Assistant and an Assistant Meteorologist.

Christie's papers in the ROG archive provide a fascinating insight into the appointment of a Chief Assistant. On 05 December 1890, Doberck (1890a) wrote to Christie recommending for the role Mr. C. E. Engelenburg of Utrecht, stating that he had assisted in a magnetic survey of South America and an investigation of tides and that he was *eminently suitable*. Four days later, Doberck (1890b) provided a formal specification for the vacancy containing the following conditions:

- Salary $HK 2160 *per annum*, including an accommodation allowance of $HK 300. (The $HK was worth around 3s 4d at the time, making the salary was worth approximately £360 *per annum*.)
- Salary reduced to 50% on leave. Leave to be granted without special grounds after six years' service and before that only in cases of *serious indisposition or of urgent private affairs*.
- Pensionable as in the Colonial Office list.
- Free passage for the successful applicant and his family to Hong Kong, repayable if the candidate left the post within three years for reasons other than ill health.
- The successful applicant to live in British Kowloon.
- Qualifications the *Same as regards an Assistant Astronomer in the British Isles*.

Meanwhile, on 08 December 1890, Plummer (1890h) wrote to Christie stating that Dr. Ralph Copeland[27] at Dunecht Observatory had informed him of the vacancy at Hong Kong. He requested details of the post and asked for Christie's opinion about whether it would be suitable for him, and whether he knew of any other appropriate vacancies. Christie (1890d) replied on 10 December, forwarding brief details of the post (he had not yet received the full specification) and Plummer (1890i) responded on 12 December confirming his interest, albeit unenthusiastically, writing: *In the present dearth of astronomical appointments I may be prepared to accept one which I might otherwise regard as scarcely satisfactory*. On 08 January 1891, Plummer (1891a) wrote again to Christie, his letter betraying signs of desperation, enquiring whether there had been any progress: *As having been idle now nine months it is imperative that I should find employment very shortly… I sincerely hope that you will endeavour to befriend me in this matter.* Christie (1891a) replied the next day stating that he had not

[27] Ralph Copeland (1837-1905) led the RGO observing team that observed the transit of Venus from Jamaica in 1882. He and Plummer likely became acquainted during preparations at the Radcliffe Observatory prior to the journey to the West Indies. He later became third Astronomer Royal for Scotland.

heard from the Colonial Office and advising Plummer to forward a statement of his age, previous employment and the work that he had undertaken at Orwell Park Observatory. On 10 January, Plummer (1891b) forwarded a statement[28] (reproduced in appendix 20). On 13 January 1891, H. W. Just (1891a), an official at the Colonial Office, wrote to Christie to advise that he would shortly receive a formal request for a recommendation for the post of Chief Assistant. As Doberck had a reputation as a very prickly individual, Just went on to advise Christie that *care will have to be taken not to send out anyone of an uneven or irritable temper, as the astronomer at Hong Kong, Dr. Doberck, has the reputation of being somewhat difficult to get on with in that respect.*

During his time at Orwell Park, Plummer had met many of Tomline's influential visitors and he now appealed to some of them to support his application. MacKeown (2011) references letters from the Marquess of Bristol and Lord Colville of Culross (amongst others) to Lord Knutsford, Secretary of State for the Colonies, in support of Plummer's application. The Marquess recalled how he had met Plummer while *…staying with the late Col. Tomline who kept a "tame" astronomer about the place… he seemed a very respectable, pleasant man…anxious to do anything for a living* and went on to request that he be offered employment: *I should be glad if I heard in the future that he could keep to his congenial pursuits at Hong Kong.* Lord Colville first wrote to the Secretary of State to request an appointment for Plummer in Jamaica and, when this turned out to be not within the latter's gift, wrote again (Colville, 1891), on 17 January 1891, asking once more for assistance in finding an opportunity, stating that Tomline had held *a great opinion* of his astronomer and that he was *quite at the top of his profession – and, when with Tomline, the Greenwich authorities used to borrow him*. He also advised Plummer to write again to Christie to confirm his interest in the post; Plummer (1891c) did so on 20 January, using some obsequious phrases: *…I shall not fail to do my utmost to justify any recommendation you can make in my favour… I am glad to learn that the selection of someone to fill the post has been left to you...* On the same day, Just (1891b) wrote again to Christie, bringing to his attention the letters received from the Marquess of Bristol and Lord Colville. Christie (1891b) replied on 21 January stating that he intended to recommend Plummer for the post: *It does not seem likely that a better candidate than J. I. Plummer would offer himself for the post of Chief Assistant at Hong Kong Observatory and I propose to recommend him for the appointment… As far as I have had an opportunity of judging, I should say that he is not of an uneven or irritable temper… and as Mr. Plummer seems such a good man for the post I should think it would not be necessary to advertise for applications.*

Also on 21 January, an official (ROG Archives, 1891) wrote to Christie on behalf of the Secretary of State, enclosing Doberck's specification for the post and requesting a recommendation. Christie (1891c) replied as follows, formally recommending Plummer: *I would recommend Mr. John Isaac Plummer, MA, FRAS. He is a gentleman well qualified for the appointment. From what I know of Mr. Plummer's work for many years past at the late Colonel G. Tomline's Observatory at Ipswich and also at Durham Observatory, I consider that it is not likely that a more suitable candidate could be found for the post and there would therefore be no occasion in the present instance to advertise for candidates for the vacancy which Dr. Doberck appears to have already made sufficiently known.* The Colonial Office duly offered the post to Plummer. He accepted the offer and, on 30 January 1891, wrote (Plummer, 1891d) to Christie to thank him: *I can have no doubt that I owe this entirely to your advocacy of my claims.* On 02 February, he travelled to London and met with Christie at the ROG to thank him in person.

Christie spent little time and effort on the selection of a Chief Assistant. He did not advertise the post, and recommended Plummer with minimal scrutiny of his overall ability, no evidence of a comparison of his credentials with those of Engelenburg (or of anyone else), and in opposition to the wishes of Doberck. Of course, he knew of Plummer's work through his publications in the astronomical literature, and the two had been in contact in 1872 concerning the assistant astronomer's vacancy at the ROG, likely in 1881-83 in connection with the transit of Venus and again since 1889 when Tomline became ill. In late 1889 and early 1890, the correspondence between the two was considerably more voluminous than that concerning Engelenburg. Christie may have thought that he knew Plummer and this, together with the letters of support from the aristocracy, may have led him to conclude that Plummer was a "safe" candidate.

[28] Plummer was clearly eager to impress and wrote the statement on high-quality parchment!

Plummer auctioned his furniture and household belongings at his home in Ipswich in February 1891 (advertised in *The Ipswich Journal*, 1891a, 1891b) and shortly thereafter he and his family travelled to Hong Kong aboard the *Glenorchy*, a steamship of the *Glen Line*, departing London on 17 March 1891. He took up the post of Chief Assistant at Hong Kong Observatory, reporting to Doberck, on 01 May 1891. (Starbuck (1951) notes that Plummer was the first expatriate addition to the staff.) *The Observatory* (1891) and the *Ipswich Journal* (1891c) noted the appointment. Doberck (1891a), in his annual report for 1890, finalised in 1891 after Plummer started at the observatory, welcomed the new arrival, noting that he was *so favourably known from his observations of comets*. At the observatory, Plummer worked alongside Frederick Figg, another British ex-patriot, who held the position of First Assistant, Miss Anna Doberck (William's sister), and a variety of local and foreign junior assistants. In the hierarchy of the institution, Plummer was second only to Doberck.

The annual reports of the observatory during Plummer's time there, initially compiled by Doberck (1891a, 1892, 1893, 1894a, 1895a, 1896a, 1897a, 1898a, 1899a, 1900a, 1901, 1902b, 1903, 1904, 1905a, 1906a, 1907a) and later by Figg (1908, 1909, 1910, 1911, 1912), provide the official record of the work undertaken. They indicate that Plummer's duties were to maintain the time service for the Colony by making astronomical observations of transits and by attending to clocks, the chronograph and the time ball, to make magnetic observations, to copy meteorological records from ships' logs and to assist in the collation of data thereby obtained. Formally, the role of the observatory included astronomical observing only as required for the maintenance of a time service. Doberck considered two of his major astronomical projects to fall within this remit and accordingly detailed them in his annual reports. However, he also undertook, in a somewhat clandestine manner, many other astronomical projects, frequently relying on Plummer to assist with the data reduction. Wisely, he omitted to publicise in the Colony the unofficial astronomical work, to avoid antagonising the government and populace, both of which considered the science of forecasting storms a matter of much greater importance (MacKeown, 2011). Despite Plummer's numerous astronomical duties at Hong Kong, both official and unofficial, he published no astronomical work while there and appeared to feel that his role no longer justified payment of a subscription to the RAS; as a result, in 1894, the Society struck him from its list of Fellows.

In 1895, Doberck (1895b) described the equipment associated with maintenance of the time service. The primary sidereal clock, installed when the observatory was commissioned, was constructed by Dent, described by its maker as *being of the very finest possible construction*. In practice, however, it did not keep perfect time, sometimes gaining or losing at a rate of a second or more per year and, to provide a means of checking it, in August 1891 Doberck obtained a second clock, by Brock. Initially the Brock appeared to be less stable than the Dent; in particular, it ran slightly faster after its regular Monday morning winding than before. Its errors were undoubtedly associated with its poor condition upon arrival in Hong Kong: Doberck noted that *the works were very rusty when unpacked and the pivots had to be polished. This was because it had not been oiled before packing…* Fortunately, after a year or so at the observatory, it appeared to settle down and Doberck (1893) concluded that it performed similarly to the Dent: *it appears that one goes just as well as the other and equal weight is therefore given to them...* Both clocks were used to set the time of another clock that triggered the daily release of the time ball.

The observers at Hong Kong kept the clocks running to time by synchronising them with the apparent daily motion of the stars. For this, they used a 75 mm transit telescope, constructed by Troughton & Simms in 1883, and a Grubb chronograph, obtained in early 1892. The transit telescope was mounted in a room just off the main observatory building. The graticule eyepiece of the instrument was equipped with seven fixed wires and one movable wire; it possessed the useful feature (the benefit of which is explained below) that it could be rotated around the optical axis with the degree of rotation indicated on a scale. The chronograph consisted of a drum, around which was wrapped a sheet of paper, rotating at constant speed. A carriage moved a marker pen along the length of the drum so that, as the latter rotated, the pen traced a spiral on the paper. An electrical impulse could be applied to the pen to cause it to write a "blip" to mark a specific event. The Dent clock was fitted with electrical contacts arranged to cause the pen of the chronograph to write a periodic time mark on the paper. The observer at the eyepiece of the transit telescope pressed a button to record when each wire bisected the star under observation, causing another mark to be written. Subsequent analysis of the marks enabled determination of the time of the transit.

During Plummer's time at Hong Kong Observatory, the staff took over 26,000 transits. Because of Plummer's astronomical background, Doberck assigned him primary responsibility for observations to maintain the time service, and the observatory annual reports indicate that, in a typical year, he took approximately 500 transits for this purpose. Most other transits were associated with the creation of the *Hong Kong Star Catalogue* (see below) and were taken by a variety of staff (including Plummer). Doberck (1899a) noted that, in taking transits, he and Plummer had the same personal equation to within *a couple of hundredths of a second*.

In 1896, Doberck began a major astronomical project to determine the latitude of the observatory. Fourteen years earlier, Colonel Henry Palmer[29], RE, had been first to estimate the latitude of the site where the observatory was later built, arriving at a figure of 22° 18' 12.2". He had used Talcott's method, employing a six-centimetre transit telescope borrowed from the commander of a US survey ship visiting the region. Talcott's method relies on the use of a micrometer eyepiece to measure, on the meridian, the difference in zenith distances of stars of a pair, culminating at approximately the same time, one north and one south of the zenith. To obtain a robust estimate, the observer must average measurements over several pairs of stars. Although Doberck did not express any lack of confidence in Palmer's figure, he used Talcott's method to make a new estimate, publishing the results at length in his 1897 annual report (1898a), which described how he spared no effort to ensure that the work was as rigorous and comprehensive as possible. His first task was to prepare a catalogue of suitable pairs of stars, listing their positions for the date of observation. He based the new catalogue on the frame of reference defined by Auwers' (1879) *Fundamental Catalogue* and, to populate it, extracted positional information on 204 stars from 12 donor catalogues, transforming the data as necessary. In his annual report for 1896, Doberck (1897a) was most charitable towards Plummer's contribution to the work: *For the determination of the latitude of the Colony and of the changes to which it may be subject, a catalogue of upwards of 200 Hong Kong zenith stars based upon the latest and best observation made in a number of European observatories was constructed. In such work, Mr. Plummer's assiduity and scrupulous accuracy in astronomical calculations do excellent service.* Having thus highlighted the excellent quality of work being undertaken at the observatory in preparation for use of the transit instrument, Doberck requested the government to provide a larger transit instrument, which would be used *for the local time-service, for determinations of geographical positions in the Far East, and for many other important purposes*. Unsurprisingly, the Colonial Office was not swayed by the request, and he was forced to persevere with the original equipment.

He then turned his attention to optimising the transit instrument for the task. He removed the seven fixed wires from the graticule eyepiece, leaving only the movable wire. Throughout the work to determine the latitude of the observatory, the instrument was also in use to take transits for maintaining the time service. When measuring zenith distances for Talcott's method, the observer positioned the eyepiece with the wire horizontal and, when taking transits to determine local time, rotated it so that the wire was vertical. When taking a transit, the observer recorded on the chronograph several bisections of the star by the wire, advancing the latter for each one by 10 revolutions of the micrometer screw, instead of using multiple fixed wires. Doberck maintained that *The time is moreover determined as accurately in this way as by fixed wires.*

Key to the reduction of observational data generated by Talcott's method were accurate knowledge of the amount by which a turn of the micrometer screw moved the wire of the eyepiece and the deviation from horizontal of the transit instrument. Doberck took great care to estimate these quantities accurately; appendix 21 provides details.

During 28 September 1896 – 28 December 1897, Doberck made 381 observations of the zenith distances of stars and Plummer made 1485. Nutation affects estimates of latitude made by astrometric methods, meaning that the value determined in this way varies with time by a small amount. Doberck undertook a comprehensive data reduction to estimate the latitude and its variation with time; his final estimates (1898a) were respectively 22° 18' 13.242" ±0.016" and an expression comprising four time-dependent trigonometric terms, the largest of amplitude 0.160". He compared his estimates with work

[29] Henry Spencer Palmer (1838-93) was a surveyor, astronomer and engineer. In 1881, he submitted to the Governor of Hong Kong a proposal to build an observatory (MacKeown, 2011).

by Seth Chandler[30] (but did not provide a specific reference), finding a maximum discrepancy less than 0.5" in magnitude. He also undertook an in-depth error analysis and derived an estimate of the constant of aberration (the maximum amount by which a star's apparent position deviates from its true position due to the Earth's motion in its orbit) which agreed to three significant figures with the modern value (Ridpath, 1989), 20.5".

Doberck's approach to the determination of the latitude of the observatory was hugely indulgent and extraordinarily precise. In the words of MacKeown (2011), it was *largely an exercise in accurate astronomical analysis*. His final estimate was 1" N of the value obtained by Palmer, corresponding to a circumferential displacement of approximately 31 m. The error term of his estimate was equivalent to a discrepancy of only ±50 cm! His estimate was accepted and, from 1910 onwards, the annual reports of the Hong Kong Observatory detailed the coordinates of the building on the front page, specifying the latitude as 22° 18' 13.2". Plummer's opinion of the project can only be imagined: the sophistication and rigour of the method and the effort put into calibrating the transit instrument and analysing the observational data were worlds apart from his work with the Orwell Park transit instrument.

Doberck's (1899a) second major official astronomical project was the creation of a catalogue of the RA of some 2000 stars *so distributed that when the sky clears for only a couple of minutes a satisfactory determination of the time can be obtained.* He expected to base the catalogue on the analysis of 20,000 transits, which he anticipated would require five years to observe. He renewed the request made to the Government two years previously to provide a large, fixed transit instrument, in order to speed the work. His justification this time listed an even wider range of uses than before: in addition to the customary purposes of the determination of time, longitude, geodetic bearings, latitude, RA and declination, he proposed somewhat improbably also to use it to observe earthquakes, to run a level across the harbour, and to contribute to survey work. To bolster his arguments he pointed out that lesser centres of shipping than Hong Kong, such as Madras (Chennai) and Perth, enjoyed the use of fixed transit circles, whereas he had available only a semi-portable instrument. Alas, once more, the Government was deaf to his request, and he perforce continued to use the Troughton and Simms instrument. During 1898-1904, he and Plummer took 19,888 transits with the instrument; during 1899, the peak year of observations for the catalogue, they took 4890.

Doberck (1905b) eventually completed the data reduction and published the *Hong Kong Star Catalogue*. In his annual report (1905a) for 1904, he described it as *very accurate* and noted that it provided more dense coverage of the heavens than had been originally envisaged, its stars being *so distributed as to afford a star every minute for determining the time...* In the introduction, he praised Plummer's contribution to the work: *Mr. J. I. Plummer took about 7000 transits. I took about 9000. Mr. Plummer attended to the chronograph, and the reductions from apparent to mean places, and reduction to 1900.0. During the first six months I reduced the observations. Next year they were reduced under my supervision. During the remainder of the time Mr. Plummer reduced them. The calculations were not done in duplicate, but Mr. Plummer's skill is well known and the smallness of the probable errors*[31] *prove that the work was accurately done. I attended to the construction of the catalogue and the determination of proper motions.*

Doberck described in his annual reports the projects to determine the latitude of the observatory and to create the *Catalogue*. He also pursued, in a rather more surreptitious manner, numerous other astronomical projects, publishing his results in the astronomical literature and not troubling the readers of his annual reports with mention of them. His primary area of interest was double stars and he made numerous observations of them at Hong Kong and while on leave in Columbus, Ohio, in 1897 and in Copenhagen in 1900 and again in 1903. In the astronomical literature, Doberck credited Plummer with orbital calculations in support of double star observations as follows: α Centauri (1896b); γ Virginis (1896c); η Coronae Borealis (1896d); μ^2 Bootis (1897b); ζ Herculis (1897c); γ Leonis (1897d); Castor (1898b); Σ228 and OΣ400 (1898c); ζ Cancri, ω Leonis, H I 39 (1906b); ξ Scorpii, Σ 2173, Σ 3121, μ^2 Herculis (1907b); and α Centauri (again) (1907c). He pursued diverse other astronomical projects too,

[30] Seth Chandler (1846-1913) discovered a small periodic motion, nowadays referred to as the *Chandler Wobble*, with a periodicity of 433 days, of the Earth as it spins on its axis (American Geophysical Union, 2000).

[31] The term probable error (PE) referred to 0.67 times the standard deviation of the distribution. For a normal distribution, 50% of the observations lie within ±1 PE of the mean.

mentioning Plummer's contribution as follows: transits of the Moon (1895c); proper motions of some southern stars (1899b); observations of the zodiacal light (1899c) and stellar magnitudes (1900b). In the latter publication, he was most complementary towards the contributions of both Plummer and Figg: *I was ably assisted by Mr. J. I. Plummer and Mr. F. G. Figg……My thanks are due to Mr. J. I. Plummer, and to Mr. F. G. Figg for the willingness with which they have assisted me in carrying out this investigation. The former gentleman has devoted much time to calculations in connection with this work.*

Although Plummer had no prior experience of magnetic observations, at Hong Kong they constituted an important part of his duties. He initially made magnetic observations under the supervision of Figg but the annual reports show that, from 1894 onwards, he was trusted to make observations unsupervised, with Figg performing the data reduction. During 1898-1903, when he was busy with observations and data reduction for the *Hong Kong Star Catalogue*, Doberck spared him the chore of magnetic observations and Figg took sole responsibility for the work.

One of the main tasks of staff at the observatory was to establish mean weather patterns in the region. In 1892, Doberck (1893) commenced an ambitious project to determine the mean weather for each month of the year for every degree of longitude and latitude, initially within the area from 104°E (the longitude of Singapore) to 180° E and from 0° N to 45° N. Two years later, (1895a), he extended the southerly latitude limit to 9° S, making a total of 3996 degree squares. His aim was to provide sufficient data to enable *masters of vessels to know before-hand the weather that may be expected on voyages and to select the most favourable routes during the different months of the year*. He sent staff from the observatory to visit ships in the harbour to copy data from weather logs. Unfortunately, this soon became a significant chore and he complained that the staff were *all so closely engaged in the Observatory, that no more than one of us at a time can be spared for visiting ships in the harbour, and he can devote only half his hours of duty to work afloat*. He therefore instead invited ships' masters and owners to forward logbooks to the observatory where staff copied relevant data. (From 1908, ships could use wireless telegraphy to communicate weather observations to the observatory.) As an inducement, he noted that shipping lines providing the most information on weather patterns along their routes would receive in return the most trustworthy weather information! Doberck's (1894a) annual report for 1893 indicates that Plummer contributed to the project; however, it was Anna who undertook the bulk of the work. The project developed into a monumental task and, by the time Plummer retired from the observatory, Anna had amassed over 400,000 weather observations which she was busy analysing.

The senior staff at Hong Kong Observatory being so few, when one was on leave the others had to embrace extra duties. Thus, during Figg's absence in 1904, Plummer took charge of weather forecasting and storm warnings (Doberck, 1905a). Similarly, when Plummer took leave of absence from 08 March 1905 – 23 February 1906[32], Figg took charge of transit and magnetic observations (Doberck, 1906a). (The records of the BAA[33] indicate that Plummer moved, within Kowloon, from Stanmore House to Bay View, shortly before taking his leave of absence; it is not known whether the two events are, in some way, connected.)

Although Doberck was very complementary in the published literature towards Plummer's astronomical work there was, at least initially, an enormous amount of friction between the two (MacKeown, 2004, 2011). Indeed, their combative working relationship must have dominated Plummer's experience at Hong Kong. Several factors may have contributed towards their mutual antagonism all, no doubt, amplified by Doberck's prickly personality. Plummer was eight years older than Doberck and, on joining the observatory, may have felt that the move marked a demotion in his status as an astronomer: whereas previously he had been accustomed to communicating observations directly to prestigious

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[32] There is evidence that Plummer returned to England during this lengthy leave of absence. The *Hong Kong Daily Press* (1905) lists *J T Plummer* as departing the Colony on 09 March 1905 "per *Empress of Japan* for Vancouver &c.", and (1906) *Messrs J F Plummer* arriving "per *Delta* from London". The route from Hong Kong to Vancouver then by Canadian Pacific Railway to Halifax and thence across the Atlantic was the quickest route to London at the time, all travel being with the Canadian Pacific company (an integrated transport system!) Although the initials do not match Plummer's "J I", this may simply represent errors in transcription.

[33] Researched by Bill Barton, FRAS.

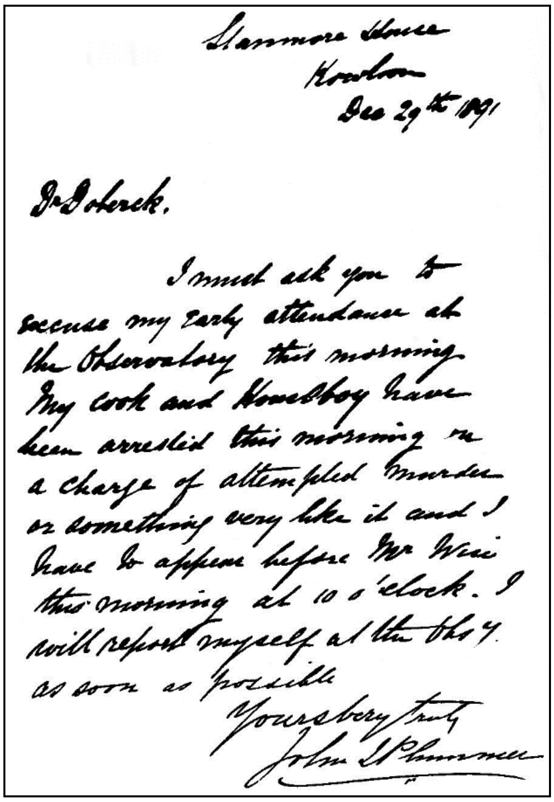
journals such as *MNRAS* and *Astronomische Nachrichten*, at Hong Kong some of his duties were menial. Although he had published four papers on meteorology, reading one of them to the RMS, he lacked any substantive background in the subject, yet it constituted the main role of the observatory. He lacked, too, a background in magnetic measurements. Further, he was not Doberck's preferred candidate for the vacancy. Although Plummer was the senior assistant at the observatory, Doberck (1892) regarded Figg as considerably more effective, writing of him: *He teaches all the other assistants and does any work which is too difficult for them*.

Less than three months after Plummer arrived in Hong Kong, he declined in a memo a dinner invitation from Doberck, writing that he preferred instead to stay at home with his family. A memo that he wrote to Doberck shortly thereafter, on 06 October 1891, further makes plain the divide between the two: *...in connection with cleaning the time ball apparatus… is a disgustingly dirty job even for a Chinese Coolie and in consequence I must decline to undertake the cleaning myself. Indeed I am surprised that you should have asked me to do such work … you ask me to undertake the testing of currents which is work I am unfamiliar with, as you are perfectly aware…*

Later in October 1891, a Colonial Office minute recorded that *it was evident that Dr. Doberck did not hit it off with Mr. Plummer* and, towards the end of the month, the Colonial Secretary wrote to Doberck urging him to repair the relationship: *...I am to inform you that His Excellency trusts that you, as Head of the Department in which you are both working, will find the means of placing your relations with Mr. Plummer on a sounder footing…* Doberck (1891b), no doubt irritated by the intervention of the Colonial Secretary, wrote on 04 November 1891 to Christie seeking to justify his antagonism towards the new arrival: *Mr. Plummer has turned out to be a most incompetent man, no friend of science in general and a particular enemy of this observatory. He has been very troublesome and his conduct has been ungentlemanly. Were it not that he was selected by yourself and so warmly received by me, the consequences might have been deplorable.*

Plummer's family life too experienced some turmoil around this time. A memo which he wrote to Doberck on 29 December 1891 (figure 11) conveys some of the insecurity that he must have felt regarding his new position together with a sense for the strange events that could befall an ex-patriot in Hong Kong. The text reads: *I must ask you to excuse my early attendance at the Observatory this morning. My cook and houseboy have been arrested this morning on a charge of attempted murder or something very like it and I have to appear before Mr. Wise this morning at 10 o'clock. I will present myself at the Obsy as soon as possible.* Newspaper reports of the hearing before Mr. Wise make entertaining reading (see appendix 18.6).

Doberck had applied for a lengthy leave of absence from the observatory just before Plummer's arrival in 1891 but withdrew the application when the incompatibility between the two became apparent. In 1894, he once more prepared to go on extended leave and drew up a detailed roster of duties for the staff while he was away. It contained some very restrictive clauses and made Figg rather than Plummer responsible for the observatory during his absence. He arranged for Plummer and Figg to sign the roster and then sent details to the Governor for endorsement. The Governor declined in uncompromising terms to accept the arrangements: *...the Officer Administering the Government declines to sign the document forwarded... or any document of a like nature. In the event of your being granted leave of absence at any future time the officer who may be appointed to act as your* locum tenens *will be responsible for the proper conduct of the department during your absence.*



Stanmore House
Kowloon
Dec 29th 1891

Dr Doberck,

I must ask you to excuse my early attendance at the Observatory this morning. My cook and Houseboy have been arrested this morning on a charge of attempted murder or something very like it and I have to appear before Mr Wise this morning at 10 o'clock. I will report myself at the Obsy. as soon as possible

Yours very truly
John I Plummer

Figure 11. Memo to Doberck. (Plummer, 1891.)

Doberck (1894b) then petitioned the Governor to accept his proposal, writing, on 06 May 1894, a catalogue of complaints against Plummer: *Mr. Plummer was selected according to my own suggestion for his fitness as an assistant astronomer. I expected that an officer so selected would easily learn meteorological and magnetic work but I was disappointed in Mr. Plummer… He has no knowledge of weather forecasting and storm warnings…he has no knowledge of electricity or the testing of the electric apparatus connected with the time ball. Mr. Plummer has no knowledge of official routine…nor of supervision of the scientific staff, nor of official correspondence. Mr. Plummer is not on good terms with the staff of this Observatory…*

Doberck's claim that he suggested Plummer for the role of Chief Assistant does not align with the archival record. In any case, the Governor, advised by the Colonial Office to use his discretion, confirmed Plummer in the post of Acting Director. However, Doberck refused him access to the correspondence file of the observatory, perhaps because it contained some particularly unflattering comments about him, for example, the above letter of 06 May 1894 and, in a letter to the Colonial Secretary: *…the Governor thinks that Mr. Plummer ... is the proper person to act for me, although I declare him to be unfitted for such duty.*

Doberck went on leave at the end of May 1894, intending to be away for about a year. On leave in England, where he married, in September 1894 he received in the mail a reprimand from the Colonial Office. Plummer had complained to the Governor about the non-availability of the correspondence file, the Governor passed the complaint to the Colonial Office and, treating the matter seriously, the civil servants there demanded an explanation. In what is for Doberck an unusually obsequious letter, he offered reasons for his behaviour and promised not to repeat the misdemeanour. He then curtailed his leave and returned to Hong Kong. Arriving in the Colony on 27 December 1894, he went straight to the observatory but the next day was docked to half pay as though he were still on leave and asked to explain his behaviour: *What right had you to extract promises from an officer appointed by His Excellency to act during your absence? Were you not informed … that His Excellency had disapproved of the arrangement proposed by you, and that the officer appointed to act would be responsible for the proper conduct of the department?*

In reply, he pointed out, with some exaggeration, the disastrous condition in which he found his beloved observatory on his return, all, he claimed, due to the incompetence of Plummer. He was kept on half pay but the Governor convened a committee of two officials to investigate his complaints against Plummer. The men of the committee, the Captain Superintendent of Police and the Treasurer, spent a day at the observatory interviewing Doberck, Plummer and Figg and wrote a report, which was not made public. They looked into Doberck's allegations against Plummer, who, to take one example, responded to the accusation that *the wires* [of the telescope] *had been allowed to get into such a state as to render fine observations impossible*, with the reasonable remark that *during the cool season it is impossible to find* [spider's threads]*... He has been looking for good spider's threads for some months to replace them with.* The Committee members, clearly oblivious to the clandestine astronomy undertaken by Doberck, much of which involved Plummer, gave as their opinion that the principal cause of friction between the two men was *the discontinuance of the astronomical observations which Dr. Doberck considers so important and of such value to the shipping*. They largely agreed with Doberck's accusations against Plummer, observed that *it appears… somewhat fortunate that Dr. Doberck should have curtailed his leave* and forwarded his request that his salary be restored, being *unaware of the reason which has led to his being thus punished*. The report largely supported Doberck's opinion that Plummer was unfit to manage the observatory and, on all future occasions when he was absent, notwithstanding Plummer's protestations, Figg was appointed Acting Director.

Touching in his annual report for 1894 very delicately on events at the observatory during his absence, Doberck (1895a) singled out Figg's work for special praise: *The way Mr. Figg discharged these duties, which are of considerable importance to shipping, during my absence, is deserving of the highest praise, and calls, I respectfully submit, for some reward from the Government*. Of course, there was no such encomium for Plummer.

In fact, Plummer appeared to nurse a long-running grudge over the enquiry and, when Doberck went on leave for five months during summer-autumn 1897, wrote to the Governor appealing for a private interview about the matter: *…but as I have never heard anything as to the results of that enquiry I can only assume that the charges then so suddenly sprung upon me were considered frivolous, or were rebutted…* The Governor denied the request. As a last resort, Plummer appealed to the Secretary of State for the Colonies, only to be told that such matters were entirely at the discretion of the Governor. In a possible oblique retort, Doberck (1898a), in his annual report for 1897, noted: *During my absence on leave during the summer and autumn Mr. F. G. Figg acted for me, and I found everything in good order on my return.* The contrast with the situation that he confronted on return to the observatory after leave three years earlier would have been obvious to all concerned.

The archive does not reveal any further tension between the two men subsequent to 1897 and, in view of Doberck's complementary remarks about Plummer's astronomical work in the published literature, it seems that they eventually must have learned at least to tolerate one another.

The circumstances of Doberck's departure from Hong Kong Observatory are uncertain (MacKeown, 2011). On the morning of 18 September 1906, the most destructive storm of modern times to strike the Colony bore down with great speed and, in the course of a passage of less than three hours, caused thousands of fatalities and enormous loss to shipping. The storm was localised and the observatory was unable to give a warning significantly in advance of its arrival. A subsequent enquiry exonerated both the observatory and Doberck. However, the incident, coming after a career full of antagonism towards the government, may have been the final straw and caused the Governor to encourage his early departure. Whatever the reasons, in May 1907, Doberck went on leave, retiring on a pension in September of the year, at age 55. His retirement was at the earliest age at which he could collect full retirement benefits.

On Doberck's departure, Figg was promoted Director. There was the inevitable review and reassignment of the duties of staff and, with one exception, Plummer was assigned exclusively to meteorological duties and undertook no more astronomy. In 1908 and 1909, he contributed to mapping the tracks of typhoons (Figg, 1909, 1910). The work formed the basis for a public lecture that he gave in the Colony in 1910, shortly before retiring, on the causes and evolution of the phenomenon. Later in the year, Plummer (1910) elaborated the lecture into a pamphlet entitled *The Origin of Typhoons*. Unfortunately, it appeared to lack official endorsement by Figg on behalf of the observatory and was badly out of line with meteorological thinking of the time. (See appendix 16.4.) The pamphlet was Plummer's only known publication while at Hong Kong.

The only known astronomical work at the observatory following Figg's promotion was in 1910. On 20 April of the year, Halley's Comet made its perihelion passage, *en route* to transiting the Sun on 19 May.

Figg (1911), in his annual report for the year, noted that the comet had been visible to the naked eye from Hong Kong between 17 April and 25 June and, in the middle of May, *had presented a most brilliant spectacle*. He reported an attempt, using a camera attached to the equatorial telescope, to photograph the comet in transit. Although the sky was partially cloudy, the observers made four exposures in the hour before the transit and nine exposures during the transit. The developed plates showed an image of the Sun of diameter 25 mm, with some detail of the solar disk but no trace of the comet. Figg did not name the observers contributing to the work but, given Plummer's extensive experience of observing comets, he was likely involved in the endeavour. The report marks the final trace in the historical record of astronomical activities to which Plummer may have contributed.

2.8 Retirement

On 10 January 1911, Plummer left Hong Kong Observatory to begin four months leave. From 10 May, he drew an alimentary allowance of HK$1080 that was converted to a pension on 17 August (MacKeown, 2011). While on leave, he returned to England and the 1911 census, taken on the night of 02 April, recorded him as a guest at the Embankment Hotel, Bedfordshire. After a short stay in Bedford, he moved to *The Red House* in Oakshade Road, Oxshott, where he lived with his daughter, Euphemia, and her family. The property still stands: it is a substantial dwelling (nowadays configured as three flats) indicating financial comfort in his final years.

By a twist of fate, Plummer in his retirement lived not far from Doberck who, on leaving Hong Kong, established a private observatory, named *Kowloon*, equipped with a 150 mm refractor, at his new home at Sutton. Given the history of the two men's working relationship, it is unlikely that they saw anything of one another in their later years.

Plummer died at *The Red House* on 06 February 1925, aged 80 years and one day. His death certificate records the cause of death as *diabetes mellitus and heart failure*. It mistakenly accords him a status that he undoubtedly would have relished, recording his profession as *Astronomer Royal for Hong Kong (retired)*.

2.9 Family

While based at Durham, on 24 November 1869, Plummer married Marion Meikle Forsyth, a housekeeper living in Glasgow. The wedding took place in Glasgow. Plummer was timely in his nuptials as, until academic year 1866-67, Durham University required that the Observer to the University be unmarried (Rochester, 1980).

Census records from 1881 together with information provided by Richard Bellamy-Brown, Plummer's great-grandson, indicate that Plummer's immediate family was as follows:

- John Isaac Plummer, born 1845 at St. Pauls, Deptford.
- Marion Meikle Plummer, née Forsyth (wife), born 1847 in Scotland.
- Marion Maud Edith (daughter), known as "Maudie", born 1871 in Durham.
- Euphemia Beatrice Mary (daughter), known as "Bee", born 1877 in Nacton.
- John Archibald Temple (son), known as "Archie", born 1878 in Nacton.

The *EADT* (1876a) records the birth of a daughter in Nacton on 23 July 1876; alas, she did not survive to be counted in the census five years later.

Figures 12 and 13, kindly provided by Richard, show Plummer and some of his family. Figure 12, believed to have been taken around 1900 (i.e. at approximately the same date as the photograph on the front cover), shows Plummer, wife Marion and, in the back row, daughters Marion and Euphemia and person unknown (middle). Figure 13, taken in June 1912 in Bedford, shows Plummer and his grandchildren Edith Marguerite, Arthur Edward and Eric Francis.

The family's stay in Hong Kong was tinged with considerable sadness: Plummer's wife died in Kowloon on 14 October 1900 (*The China Mail*, 1900) and Maudie in 1910.

Figure 14, compiled by OASI member Bill Barton, FRAS, presents Plummer's family tree.

Figure 12. **Plummer, wife Marion and (back row, L-R) daughter Marion, person unknown and daughter Euphemia. (Courtesy of Richard Bellamy-Brown.)**

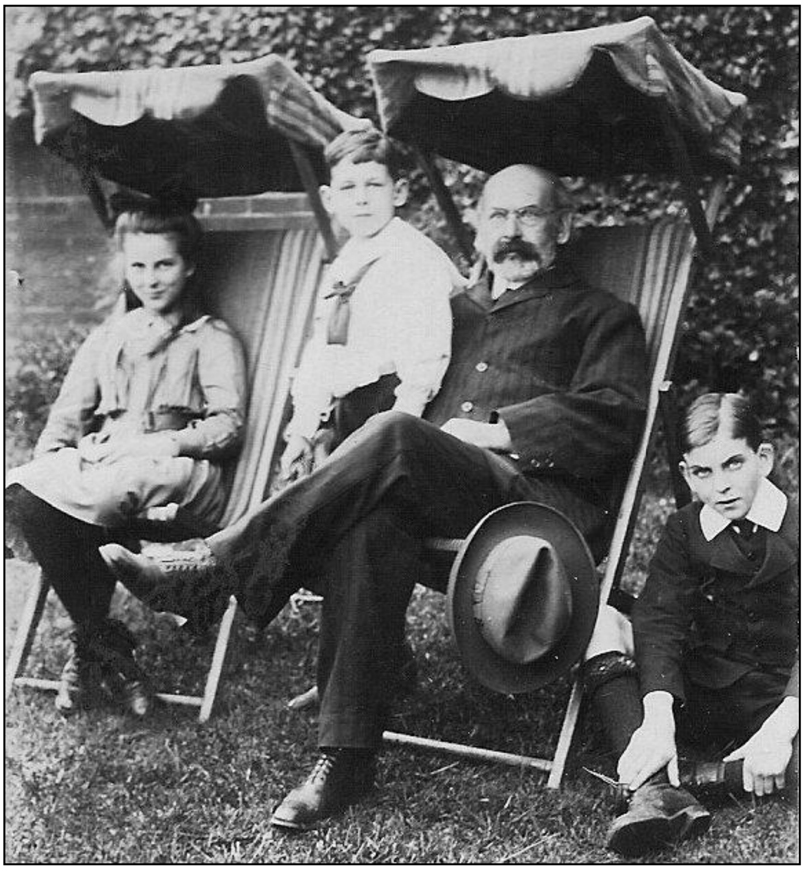


Figure 13. **Plummer and grandchildren (L-R) Edith Marguerite, Arthur Edward and Eric Francis. (Courtesy of Richard Bellamy-Brown.)**

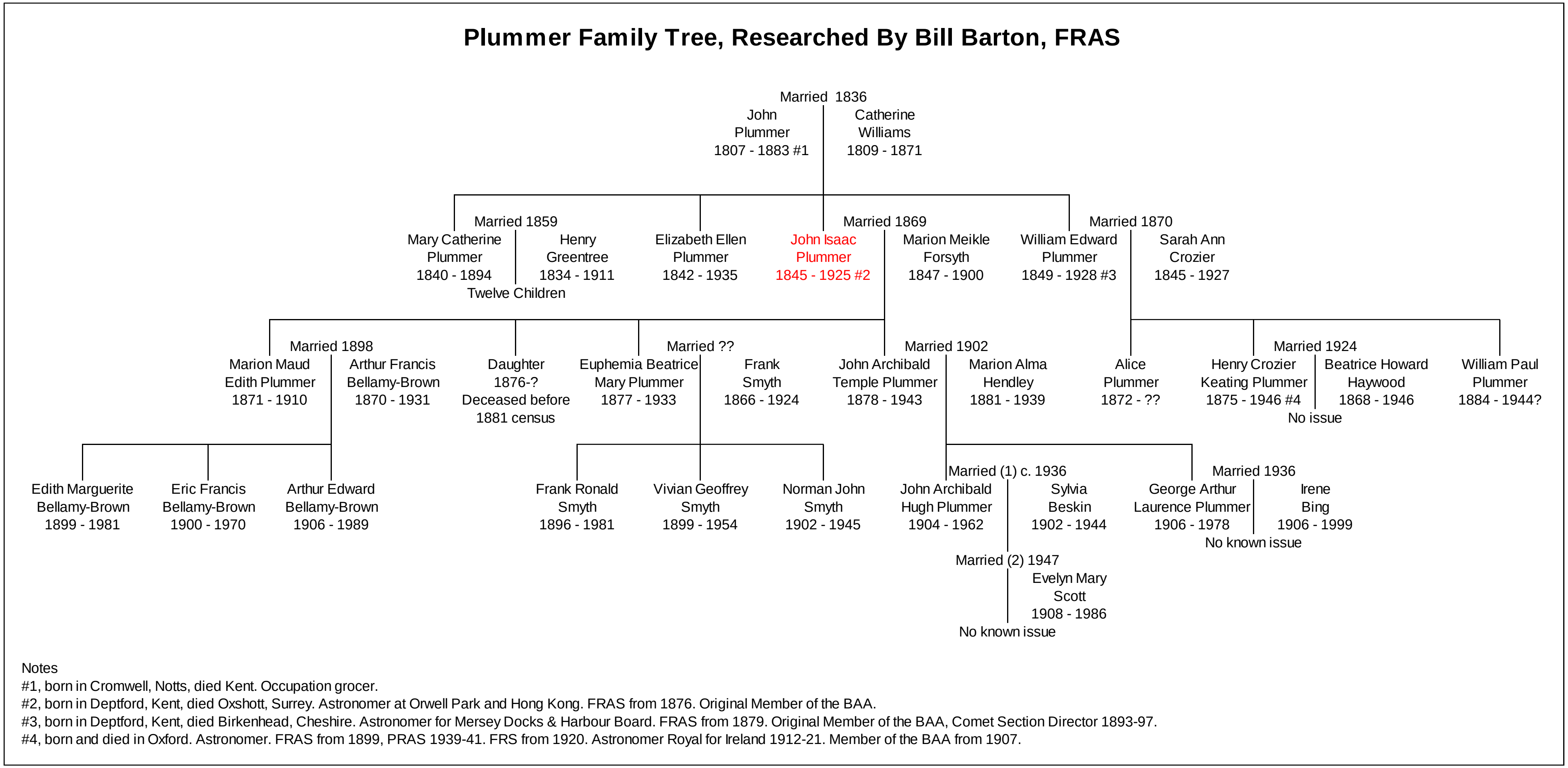


Figure 14. Family tree.

3 Commentary On Published Work

Plummer's published work illuminates his abilities, strengths and weaknesses as meteorologist and astronomer. He was capable of writing clearly and concisely (a style exemplified by his textbook) indicating a capacity for logical, structured thought and a care for clarity of expression. However, in terms of technical content, several of his publications exhibit significant difficulties. Although he must have received a good general schooling in the sciences to enable him to pursue his chosen career, he received no formal specialist training and this left gaps in his knowledge, in particular his understanding of physical principles, which were sometimes manifest in his publications. Much of his work as an astronomer was concerned with the reduction of observational data, and in this too there are some serious problems. Close examination of his data reduction unfortunately reveals work of variable quality, with occasional numerical errors, inaccurate approximations, and rather muddled explanations of the analysis performed. Of course, he worked in an era without the computational aids taken for granted nowadays and undertook all data reduction by hand, without an assistant; however, the presence of mistakes indicates inadequate checking of calculations.

This section provides a commentary on his meteorological and astronomical publications and identifies those that exhibited particular problems. It is not intended to detract from the huge amount of excellent work that he undertook, rather to provide a rounded view of his abilities.

3.1 Meteorology

Plummer's (1873c, 1873d) first meteorological publication dealt with the recording and comparison of temperatures at Durham and made no reference to physical principles. He was somewhat uncritical in drawing inferences from his analysis and did not adequately investigate whether the data fully supported his conclusions (a tendency that became apparent again several times in later work), but otherwise the material was unremarkable.

His next three meteorological publications, his annual report to the RMS for 1873 (1874c), a contribution on subjective effects in the recording of meteorological data (1875c), and a proposed explanation for the recorded rise of temperature at the ROG (1877a), were also unexceptional.

His sixth and final meteorological publication (1910), a pamphlet entitled *The Origin of Typhoons*, was much different. In it, he attempted to explain the mechanisms responsible for creating the destructive storms that wreaked such havoc upon Hong Kong. Unfortunately, his explanation betrayed a lack of understanding of meteorological principles and was at variance with mainstream thinking of the day. MacKeown (2011) describes the work as *scientifically eccentric*, noting that it appeared to lack official endorsement from the Director of Hong Kong Observatory, may have engendered institutional embarrassment over its contents, and exerted a conspicuous lack of impact on scientific thinking of the time.

Appendix 16 provides a detailed analysis of his meteorological publications.

3.2 Astronomy

The majority of Plummer's astronomical publications, particularly those dealing with straightforward observations, describing the standard theories of the day, or providing relatively straightforward analyses of data, were comparable with the publications of his contemporaries. Although some of his hypotheses and ideas appear speculative to modern readers, they were generally not out of step with the thinking of the era. However, unfortunately, some of his publications propose explanations uncritically and without adequate investigation. Worse, in a few instances, his astronomical publications are not consistent one with another and it seems that, in preparing his reports, he did not always consult earlier related publications or observing notes. In other cases, especially when struggling to propose explanations for poorly understood (at the time) phenomena, he did not appear to feel bound to maintain consistency with earlier publications.

On beginning work at Orwell Park Observatory, Plummer (1875b) stated that the primary aim of the facility was to be the observation of comets. He was very successful in this aim, publishing observations of 45 comets while at the observatory and attempting to observe a further three. However, in other areas of astronomy he appears not to have had a clear programme of activity or set of goals and, as a result, started several lines of enquiry that he did not bring to a satisfactory conclusion. The main difficulties with his astronomical publications are summarised below.

1. *Projection on the limb* during lunar occultations

On 28 March 1868, he observed the occultation of γ Tauri, describing the star in his observing notes as *attached to the lunar limb* for five seconds before disappearance. His published report (Plummer, 1869b) was faithful to the description in his notes. One and a half years later, on 24 September 1869, he suspected that Aldebaran appeared attached to the limb preceding occultation disappearance, but did not publish a report of the observation until four years later (Plummer, 1873k).

In the 1873 paper, he made reference to his observation of projection in 1868 but provided a considerably different account to that published in 1869 (and referred to the star erroneously as ζ Tauri). He went on to describe other reports of projection by various observers. He reviewed the main explanations proposed for the phenomenon and outlined a refinement of an earlier theory, based upon a supposed lunar atmosphere, most dense around the limb, which refracted the light of the star immediately prior to occultation. He explored his theory by examining reports of projection in the published literature, but came to no definite conclusion. Unfortunately, his explanation of projection was at odds with his textbook (Plummer, 1873j), in which he made no mention of reports of projection and adduced as evidence to demonstrate that the Moon was *destitute of any sensible atmosphere*, the observation of occultations, in which, he stated, stars disappeared with *astonishing suddenness* behind the limb.

Three years later, on 04 February 1876, in a public lecture in Ipswich, he again espoused the belief that the Moon was airless and presented evidence supporting the absence of an atmosphere. He did not attempt to reconcile the differing views that he had expressed on the question of a lunar atmosphere. Appendix 2.4 provides further details.

2. Transits of Mercury

Plummer observed the transit of Mercury of 05 November 1868 from Durham Observatory and that of 06 May 1878 from Orwell Park Observatory. To observers in the UK, the 1868 transit began before the Sun rose and only the last hour and a half of the event was visible. In 1878, the opposite situation prevailed and, from the UK, only the ingress phase of the transit was visible before sunset. In his report of the 1878 transit, he noted (Plummer, 1878c) that, at 2nd contact, the limb of Mercury appeared to disengage more rapidly from the solar limb than anticipated. He claimed to remember the same effect during the 1868 transit – clearly a mistaken recollection. It appears that in preparing his observing report in 1878, he did not consult records of the 1868 event.

He observed the transit of 1878 using the equatorial refractor at Orwell Park, with a slightly tinted glass, under weather conditions that were *unfavourable.* He reported that, despite the basic equipment and poor weather, his wife observed the silhouette of Mercury against the solar corona 2m 14s before 1st contact and he observed it one minute later. His wife was not known to be an observer (he did not mention her in any other of his observing reports) yet for her to have observed the silhouette of Mercury as reported would have required her to possess exceptional eyesight and be skilled in observing. Only two other reports have been found in the astronomical literature of the silhouette of Mercury being visible off the solar disk in 1878; both observers used more sophisticated equipment than Plummer and one enjoyed much more favourable weather conditions. It is simply not credible that the Plummers made the observations claimed. Appendix 3 provides further details.

3. Apparent diameter of Venus and the effect of irradiation

Plummer maintained an interest in Venus while at Durham and subsequently for the first few years at Orwell Park. He expended much effort on estimating the apparent diameter of the planet and the effect of irradiation. In March - June 1868, Plummer (1873a) measured the apparent diameter of Venus and obtained an estimate of irradiation very much larger than that of the Rev. Robert Main[34] (1856), who had derived a figure from a very large number of observations made at the ROG during an 11-year period. In consequence, Plummer did not publish the work and, five years later, made new observations with *greater care and precaution*, publishing his results (Plummer, 1873b) in August of

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[34] The Rev. Robert Main (1808-78) served for 25 years as First Assistant at the RGO before becoming Director of Radcliffe Observatory.

the year. He analysed the data to estimate the irradiation and concluded that the ambient temperature had no systematic effect on the results. He also presented anecdotal evidence that irradiation depended on atmospheric transparency, but in doing so, gave a biased presentation of the records of meteorological conditions from his observing notebook and did not report fully the exception cases. It is not clear why he did not attempt a more rigorous investigation, for example by estimating the transparency of the atmosphere on a quantitative basis and developing a regression model to estimate how well it predicted the degree of irradiation. In his analysis of the observing data for 1868 and 1873, he assumed that the degree of irradiation was independent of the distance between Earth and Venus. In fact, the data indicates a very marked dependency, and it is unclear why he overlooked this.

In 1877, Plummer (1877b) published an analysis of observations of an apparent close passage of Venus to the star λ Geminorum on 18 August 1876. Although poor sky conditions hampered the work, he nevertheless analysed the data to illustrate the variability of the irradiation of Venus over short timescales. Unfortunately, in performing the data reduction, a simple numerical mistake rendered all the estimates slightly biased. Fortunately, the analysis still captured approximately the variation of irradiation during the observing session and, as this was the main thrust of the work, the conclusions remain valid.

In the three papers, Plummer provided the following estimates of the irradiation of Venus:

Plummer, 1873a	Unsatisfactorily large value which prevented publication of results.
Plummer, 1873b	Point estimate: -0.546". Suspicion that atmospheric transparency affected irradiation.
Plummer, 1877b	Variation within a range of 2.5" during a period of two hours, determined by the brightness of the sky and amount of cloud cover.

He did not bring to a satisfactory conclusion his studies of the irradiation of Venus, nor provide a reconciliation of his differing estimates. Appendix 4.2 provides further details.

4. Brightness of Venus

In 1876, Plummer (1876b) constructed a simple photometer and used it to estimate the magnitude of Venus and its brightness, at maximum, relative to that of the mean full moon. Unfortunately, his data reduction was badly flawed. His tabulation of the raw observational data revealed a very significant random variation that propagated through the subsequent analysis. He compounded this difficulty by several errors in data reduction: inconsistent corrections for atmospheric extinction; confusion over readings from the photometer; and excessive numerical approximation. Unfortunately, the problems with the analysis were so extensive that his conclusions are invalid. Appendix 4.3 provides further details.

5. Palisa's Comet (C/1879 Q1)

Plummer observed the comet during the period 10 September – 15 October 1879 and published his findings in two reports (Plummer, 1880b, 1882b). In the first, he commented on a variation in the brightness of the comet's nucleus near perihelion, expressing confidence that the variation was real as sky conditions at the time of his observations were *most satisfactory*. However, in the second, on the contrary he noted that moonlight, haze and the low altitude of the object had hampered observation around the time of perihelion! In fact, it appears that the change in brightness *was* real as at least one other observer reported it. Appendix 5 provides further details.

6. Accuracy of star catalogues

In 1876, Plummer (1876c) reported preliminary findings of an extensive study that he had commenced to investigate the accuracy of stellar proper motions listed in the British Association Catalogue (BAC) of stars. Unfortunately, his methodology was not without difficulties and some of his calculations appear incorrect. He claimed boldly to have uncovered evidence that some proper motions were variable in both magnitude and direction. His annual report to the RAS for 1876 (1877c) indicated that he had identified 196 stars in the BAC with aberrant proper motions and had observed them on the meridian. Two years later, in his annual report to the RAS for 1878 (1879a), he anticipated obtaining *interesting results bearing on proper motion*. Unfortunately, although he clearly undertook much work, both observational and computational, on stellar proper motions, he did not present evidence of their variability (or of other aberrant behaviour) and was unable to derive corrected proper motion estimates for those that he believed to be invalid. Other astronomers do not appear to have responded to his claims. The work, therefore, must be viewed as incomplete. Appendix 11 provides further details.

7. Orwell Park Observatory transit instrument

Plummer made literally thousands of measurements with the Orwell Park transit telescope but, unfortunately, experienced considerable difficulties in so doing. In keeping with the standard practice of the era, he estimated the errors of alignment of the instrument before each use. In 1878, he reported (Plummer 1878b, 1878d) a cyclic variation, of amplitude *circa* 10", in both azimuth and altitude errors. He believed that the cause was heat radiated from the pillar supporting the equatorial refractor but offered no evidence to support this conclusion. He made no mention even of considering alternative explanations and appeared to be unaware of a meeting of RIBA on 16 November 1874 at which Wilfrid Airy, responsible for instrumentation at the observatory, described how the transit telescope was supported by large wrought-iron beams that could expand and contract due to variations in temperature, slightly altering the alignment of the instrument.

Plummer used the transit instrument to estimate the longitude of the observatory and published (Plummer, 1879a) a final estimate over 30" east of the value adopted by the Ordnance Survey. Such a large discrepancy could have affected the accuracy of data reductions. He was aware of the issue and undertook further work to refine the estimate but did not arrive at a conclusion that warranted publication. In his annual report to the RAS for 1881, Plummer (1882a) concluded, for reasons unspecified, that the transit instrument was unsuitable for demanding astrometric work; this indictment inevitably casts a long shadow over the accuracy of all the positional astronomy that he undertook at Orwell Park. Appendix 13 provides further details.

8. Formation of planetary systems

In the late nineteenth century, paleontological evidence began to amass suggesting that the age of the Earth, and hence the Sun, was at least many millions of years. Astronomers and physicists struggled to explain processes that could create a star and then maintain its energy output for such an extended period. Plummer (1875d) published a review of the scientific debate and proposed that comets could provide a mechanism to transport mass into a nebula, creating centres of high density that could grow to form stars, and subsequently to bring in material to replace that lost through combustion. The explanation relied on comets having appreciable mass and on nebulae being relatively close to the Earth. Yet only two years previously, in his textbook, he had stated exactly the opposite. He did not attempt to reconcile, or even to acknowledge, the seeming contradiction. Appendix 14.1 provides further details.

9. New nomenclature for stars and asteroids

Plummer(1876d) proposed a new nomenclature for stars and asteroids. Although his scheme was logical, inevitably other astronomers ignored it. He could not have anticipated a different outcome! Appendix 15.1 provides further details.

4 Suggested Further Work

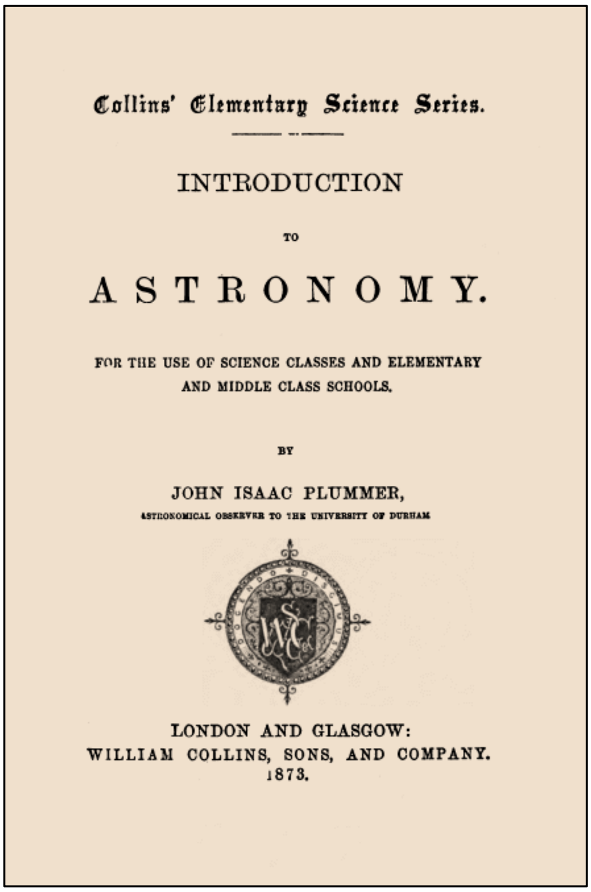
Although we now know much about Plummer's life and work, avenues remain for further research. Unanswered questions and potential lines of further investigation are as follows.

1. The observatories at which Plummer worked are associated with differing amounts of surviving documentation. No original documents remain from Orwell Park Observatory. The archives of Glasgow and Durham Observatories are relatively compact and were searched thoroughly, for material directly associated with Plummer, in 2011 and 2010 respectively. Professor MacKeown undertook comprehensive research in the archive of Hong Kong Observatory. As a result, there is little likelihood of uncovering new, relevant, material at Glasgow, Durham or Hong Kong. However, the archives of Cambridge Observatory and the ROG are extensive and, although they were searched in 2008 and 2010, the searches were not exhaustive: it is possible that additional pertinent documents await discovery by someone with the patience to undertake a thorough exploration.
2. Although the archives of many local papers are now accessible online, only limited material from the *EADT* is available in this way. The opportunity awaits for someone with great patience to undertake a manual search of the paper's archives during the period of Plummer's residence in East Anglia.
3. Investigate the addresses occupied by Plummer in his early years in Deptford. What information is available in local archives and public records regarding ownership of the properties?
4. In the 19th century, Durham University provided the Observer with accommodation on the ground floor of the observatory (Fowler, 1904). Documents in the Durham Observatory archive refer, from 1949 onwards, to *Observer's Cottage*, still in existence, to the SE of the observatory at a distance of approximately 40 m. When was *Observer's Cottage* built, who occupied it, over what period, and when did it become the preferred accommodation for the Durham Observer? In addition, early Ordnance Survey maps (First Edition, 1897, 1919 and 1939 editions) indicate the existence of a small building, no longer present, located approximately midway between Observer's Cottage and the observatory: was this building an early incarnation of Observer's Cottage? If not, what was its purpose?
5. Refurbish the Orwell Park Observatory transit telescope, put it to use once more and search for evidence of the difficulties that Plummer experienced. Does the instrument still suffer from periodic errors? Is it fit for use as a meridional instrument for determining the longitude and for demanding astrometric work? Examine the profile of its errors and investigate whether the radiation of heat from the masonry pillar supporting the equatorial refractor can explain the empirical data.
6. Compare the position and proper motion data of stars in the BAC, Greenwich 1864 and Armagh star catalogues with those in modern reference catalogues. Search for evidence of the irregular proper motions that Plummer thought he had detected. Investigate the validity of the methodology that Plummer adopted to search for discrepancies between the Greenwich and Armagh star catalogues.
7. Research the scheme referred to in Plummer's (1874b) annual report to the RAS for 1873, proposed by American meteorologists, to make synchronous observations of weather over the whole of the northern hemisphere. What impact did it have on the workload at Durham following its adoption there on 01 January 1874.

APPENDICES

A1 Textbook

In 1873, Plummer (1873j) published a textbook entitled *Introduction to Astronomy*. Figure 15 shows the title page of the work. The publisher was William Collins, Sons & Company, Limited of London and Glasgow. The subtitle, *For the Use of Science Classes and Elementary and Middle Class Schools*, indicated the target market of the work. In the preface, he expanded on his aim and the intended readership, arguing that astronomy was not taught in the UK to the same extent as on the Continent and in America, and that this was in part due to the lack of suitable inexpensive schoolbooks, a situation which he intended to remedy. He set out lofty goals, aiming to *imbue the youthful mind with a love for science in its true aspect* and hoping that the text would *lead some to seek for deeper knowledge in other more advanced works*.



Collins' Elementary Science Series.

INTRODUCTION

TO

ASTRONOMY.

FOR THE USE OF SCIENCE CLASSES AND ELEMENTARY AND MIDDLE CLASS SCHOOLS.

BY

JOHN ISAAC PLUMMER,

ASTRONOMICAL OBSERVER TO THE UNIVERSITY OF DURHAM

LONDON AND GLASGOW:
WILLIAM COLLINS, SONS, AND COMPANY.
1873.

Figure 15. Title page of textbook. (From Plummer, 1873.)

Naturally, the book reflected the state of knowledge of the era. Astronomers then had little understanding of the workings of the universe and Plummer perforce emphasised the description of objects and phenomena rather than explaining the causal mechanisms at work. For example, he provided a good observational description of the Sun but could not explain its energy output and longevity; in contrast, modern astronomical textbooks, even at an introductory level, generally describe the nuclear reactions that power the Sun and explain how they maintain its energy output over billions of years. A notable exception was the emphasis that he placed on the universal law of gravitation, the application of which astronomers had developed to a high degree, and which he used to explain the motions of double stars and bodies in the solar system.

Astronomers of the era had poor knowledge too of the large-scale features and structure of the universe. Although they understood the solar system to be located within a vast lenticular system of stars forming the Milky Way galaxy, they were unaware that many of the nebulae visible in their telescopes were, in fact, similar galaxies at distances of tens of millions of light years. Although a few astronomers speculated that some nebulae might lie outside the Milky Way, the consensus was that the bulk of the universe was contained within it. Because of the paucity of knowledge about the universe at large, the majority of the textbook dealt with the solar system, and only some one and a half chapters covered deep space. Unfortunately, knowledge even of the solar system was very sparse compared with modern understanding. Plummer's contemporaries knew it to comprise the Sun, eight major planets and their brighter moons, 125 asteroids (with more discoveries anticipated), comets and meteor streams, and understood its scale with good accuracy. But they knew almost nothing of the composition or characteristics of the bodies themselves (indeed what knowledge they thought they possessed turned out ultimately to be largely wrong) or of the role that mechanisms such as gravitational resonances, magnetic fields and the solar wind play in shaping its overall structure. The discovery of Pluto lay almost 60 years in the future and the Oort cloud and Kuiper belt objects were unsuspected.

The textbook lacks the colour prints that adorn modern works on astronomy. Photography at the time was still a young technology and colour photography had not been invented. However, Plummer clearly shared the Victorian love of geometrical figures and his descriptions make considerable use of them. Reinforcing the target readership of the textbook, he provided a comprehensive set of questions at the end of each chapter to enable the student to test and reinforce his knowledge.

The remainder of this appendix summarises the main themes of the textbook and compares the ideas of the time with modern thinking. Note that the grouping of material below differs from that in the textbook in order to make for a concise exposition. Where quantitative estimates of Plummer's era are compared with modern values, unless stated to the contrary, the latter are taken from Seidelmann (ed.) (1992) and Ridpath (1989).

A1.1 Form And Dimensions Of The Earth

Chapter one provided a description of the form and dimensions of the Earth. Various observations (e.g. of ships sailing towards the horizon, or of the altitude of the Sun during a rapid, high-altitude ascent in a balloon) provided evidence that the Earth was approximately spherical. Triangulation could accurately determine the form of the Earth as an oblate spheroid with the following dimensions (after Airy & Bessel): equatorial diameter 12,755.02 km, polar diameter 12,712.36 km. The corresponding modern values are respectively 12,756.272 km and 12,713.504 km.

Foucault's pendulum and the apparent daily rotation of the night sky showed that the Earth rotated once each day on its axis. The planet's rotation and its form as an oblate spheroid jointly resulted in the net strength of its attractive force being slightly less at the equator than at the poles, an effect that accurate weighing scales and pendulum clocks could measure. The oblateness of the Earth represented the equilibrium figure for the rotating planet.

Solar heating of the atmosphere in the tropical zones caused the air there to expand and ascend, and this, combined with the Earth's rotation on its axis, created the trade winds. He attributed cyclones to *unusual heating of some portion of land or water from local causes* resulting in the formation of a partial vacuum, into which blew rotatory winds. Little did he know, as he drafted the text, that some two decades later he would be employed at Hong Kong Observatory studying the phenomenon in detail! The final part of chapter one dealt with atmospheric refraction and twilight.

A1.2 Position And Time

Chapter two covered the definition and measurement of position and time (two fundamental aspects of observational astronomy). Plummer began with a description of the usual celestial coordinate systems: horizon (altitude, azimuth), equatorial (Right Ascension or RA, declination) and ecliptic (ecliptic latitude, ecliptic longitude), weaving a description of the Sun's apparent motion and of the seasons throughout his description of equatorial coordinates.

The chronometer and transit telescope were the primary tools of the era for determining the RA of celestial objects. Several errors could affect the accuracy of observations made with the instruments and he maintained that *it is the duty of the practical astronomer to find out these errors and make allowance for their effects*. (Again, he could not have foreseen how prescient were his remarks and the problems, later in the decade, that errors associated with the transit telescope at Orwell Park were to cause him.) The mural circle was used to measure the declination of celestial objects. Whereas the transit telescope and mural circle were constrained to make observations on the meridian, astronomers used an altazimuth or equatorially mounted instrument to observe bodies elsewhere in the heavens.

He described the principles of operation of the refracting telescope and the Newtonian reflector. The first astronomical telescopes were simple refractors with single-element objectives that introduced significant chromatic aberration, and it was not until the mid-18th century that the invention of the dual-element achromatic doublet objective remedied the situation. Plummer was of the opinion that, although achromatic refractors offered the finest optical quality, reflecting telescopes, being easier to manufacture with large apertures, also had a valuable role in observational astronomy.

He concluded chapter two with a description of time in astronomy and an explanation of how inappropriate assumptions about the length of the tropical year resulted in a discrepancy between the calendar and the seasons which had forced Pope Gregory to abandon the Julian calendar in favour of the Gregorian, adopted in England in 1751-52. The Julian calendar was still in use in Russia.

A1.3 Planetary Motions

Chapters three and eight addressed gravity and how it governed the motions of the planets. Plummer began with a description of the apparent motions of the bodies and how, in ancient times, these were explained by the Ptolomaic system of epicycles and deferents. The work of Copernicus, Brahé and Kepler eventually overturned the Ptolomaic system and ushered in essentially the explanation of planetary motions that we accept today. He described Kepler's laws of planetary motion in detail but did not explain how they were a consequence of Newton's law of gravitation. (The latter is more fundamental, but to have explained fully the relationship between the two would have required mathematics beyond the scope of the text.)

He articulated Newton's law of gravitation in its full generality as *every particle of matter in the universe attracts every other particle, with a force varying directly as the mass of the attracting particle and inversely as the square of the distance between them*. However, he restricted discussion of the effect of gravity essentially to double stars and the solar system: in his era, astronomers had not grasped its effect in determining the large-scale structure of the cosmos. The gravity of the Moon and Sun determined the fundamental characteristics of the ocean tides on Earth, which accordingly were highest when the bodies were in syzygy. Gravitational perturbations by the Sun and Moon were jointly responsible for the nutation of the Earth's axis, and perturbations by the Sun were responsible for the main periodicities in the lunar orbit. Mutual gravitational perturbations between planets could induce significant changes in their lines of nodes, lines of apsides and inclinations; small changes in their eccentricities and inclinations; and no material changes in their major axes. He concluded that the solar system was dynamically stable, that the orbits of the planets were not jeopardised by mutual gravitational interactions and that even if the Sun's gravity were somehow to alter in strength, the planets would simply adjust their orbital radii to compensate. In modern times, astronomers have undertaken numerical simulations investigating the evolution and dynamical stability of planetary orbits over periods of billions of years (e.g. Peterson, 1993), in broad terms confirming Plummer's conclusion.

A1.4 Scale Of The Solar System

Plummer described estimation of the scale of the solar system in chapter three. The mean distance between the centres of the Earth and the Sun, defined as the Astronomical Unit (AU), is of fundamental importance to astronomy because it defines the scale of the entire solar system via Kepler's third law ($P^2 \propto a^3$, where P and a are respectively the orbital period of a planet and its semi-major axis). Astronomers customarily express the AU in terms of the solar parallax, defined as the angle subtended by the equatorial radius of the Earth at a distance of exactly one AU. (Trigonometry relates the two expressions.) Unfortunately, attempts to measure the distance of the Sun directly, via the apparent shift in its position when seen from two widely separated observatories, had proven unreliable because its heat greatly disturbed the atmosphere making impossible the precise measurement of small angles close to the solar disk. Astronomers therefore had tried to estimate its distance indirectly by measuring the angle between the centres of the Sun and the Moon when the latter was at dichotomy; the application of trigonometry then produced an estimate of the distance of the Sun in units of the lunar distance. The latter, in turn, could be determined accurately by measurement of the apparent displacement of the Moon against the background of fixed stars when viewed from two widely separated observatories. Unfortunately, this method too proved unsatisfactory because features on the lunar surface prevented determination of the exact instant of dichotomy.

Astronomers had therefore turned to other techniques, such as observations of transits of Venus, to estimate the solar parallax. Transits of Venus occur in pairs; the last to occur before Plummer's era were in 1761 and 1769. Johann Encke[35] had undertaken a comprehensive analysis of the 1769 observations and computed the value 8.5776"[36] for the solar parallax (corresponding mean Earth-Sun distance 153,359,400 km). Although Encke's estimate became widely accepted, by the early 1870s, evidence began to amass that it was too small. For example, Edward Stone (1863) published an estimate of 8.932" based on observations made at the ROG and at Williamstown, Victoria, Australia, of Mars near opposition in 1862. The well-known *black drop* effect associated with the transit perhaps had caused uncertainty in 1769 in timings of the instants when Venus appeared to touch the Sun's limb, resulting in an under-estimate of the solar parallax. Embracing the general suspicion of the previously accepted value, Plummer adopted in his textbook the figure 8.94", equating to a mean Earth-Sun distance 147,142,700 km. He shared the general hope and expectation that the forthcoming transits on 09 December 1874 and 06 December 1882 would provide an opportunity to derive a more accurate value. Modern values are 8.794144" and 149,597,870.66 km.

He explained Bode's Law (a chance numerical relationship between the semi-major axes of the major planets) and went on to describe a scale representation, expounded by Sir John Herschel[37], of the solar system. Herschel's model represented the Sun by a globe of diameter 0.6 m and the planets by objects varying in size from a grain of mustard seed representing Mercury, to a moderate sized orange representing Jupiter, in orbits with a diameter up to 4 km for that of Neptune.

When making precise measurements of the positions of a body in the solar system, it was necessary, due to the velocity of the Earth in its orbit, to take account of the aberration of light due to the motion of the observer, and to allow for light travel time from the body under study to the observer.

A1.5 The Sun

Chapter four described the Sun, quoting its diameter as 1,372,260 km, close to the modern value of 1,392,000 km. The chapter gave an extensive comparison of the bulk, gravity, mass and density of the Earth and the Sun. To telescopic observers, sunspots are often the most prominent feature of the solar disk; through close observation, astronomers had deduced that they were depressions in the visible surface and, by tracking their daily motion, estimated the rotation period of the Sun and the position of the solar axis. Surprisingly, Plummer made no mention of differential rotation, whereby the Sun rotates faster at the equator than at the poles. He described Heinrich Schwabe's[38] *recent discovery* of the 11-year periodicity in the frequency of sunspots but noted that attempts to demonstrate a corresponding periodicity in terrestrial meteorological phenomena had not succeeded.

In Plummer's era, astronomers did not know of the solar wind or coronal mass ejections, both of which can influence events on Earth. However, there was evidence of a link between the two bodies: *…an observation which was made by two observers in 1859[39]. A bright mass of the photosphere was seen projected over the black nucleus of a spot, and, after moving with rapidity, disappeared. Simultaneously there was a great disturbance in the direction of the magnetic needle, and a magnetic*

[35] Johann Franz Encke (1791-1865) was Director of Berlin Observatory and Professor of Astronomy at the University of Berlin. He studied the orbits of comets and asteroids. Comet Encke (2P), the Encke Gap in Saturn's rings, a lunar crater and an asteroid are named after him.

[36] Quoted in truncated form by Plummer in the preface to the book as 8.577".

[37] Sir John Herschel (1792-1871), son of William Herschel (discoverer of Uranus), was a scientist and inventor.

[38] Heinrich Schwabe (1789-1875) recorded sunspots every clear day in the 17 years up to 1843 in a search for a transit of the supposed planet Vulcan, orbiting closer to the Sun than Mercury. He failed to find Vulcan but instead discovered the periodicity in sunspot numbers.

[39] One of the observers was Richard Carrington, who had left Durham Observatory and established a private observatory at Redhill, Surrey.

storm of great violence prevailed for some time afterwards, accompanied by a vivid display of aurora borealis.

During a total solar eclipse, the Moon obscures the bright glare of the solar disk, enabling astronomers to study prominences on the limb and the much fainter corona (the extremely tenuous, hot, outer atmosphere of the Sun). Figure 16 (from the frontispiece of the textbook) is a drawing of the total solar eclipse of 07 August 1869, illustrating the features.

Figure 16. Solar eclipse, 07 August 1869. (From Plummer, 1873.)

Astronomers believed the Sun to consist of an opaque, solid body, visible as the umbra (nucleus) of sunspots, surrounded by six atmospheric strata, in the following order outwards:

1. A dense, non-luminous, cloudy layer visible as the penumbra of sunspots. This layer strongly reflected the light of the next layer outwards.
2. A highly luminous photosphere, which produced the heat and light of the Sun.
3. A highly heated region of luminous metallic gases, the existence of which had been revealed by the recently-developed science of spectroscopy.
4. The chromosphere, comprising a very hot, tenuous gas, within which prominences sometimes occurred.
5. The self-luminous and reflective inner corona.
6. The much broader, non-luminous, outer corona or halo.

Unfortunately, although this model provided a coherent framework within which to fit the observed phenomena, the lack of understanding of solar physics of the era resulted in it being inaccurate.

Plummer concluded his description of the Sun by conveying an impression of its immense scale. The Earth received only one part in 2.4×10^9 of the solar output, but even such a tiny proportion was sufficient to melt in a year a hypothetical layer of ice 35 m thick covering the entire planet. His figures lie comfortably within 10% of modern estimates (using figures for the density of ice and its enthalpy of fusion from Wikipedia (2023a, 2023b)). Astronomers of the era had no explanation for the source of such prodigious energy and could only assume that the Sun "burned" through the mechanism of everyday combustion. If this were the case, in order to sustain the solar output for long enough to enable geological processes to shape the Earth, a mechanism was required to transport fresh material to the Sun to replace that lost through combustion. Plummer believed that meteors could provide such a mechanism and calculated that a layer of meteoric material of average depth 7.3 m over the entire surface of the Sun would need to arrive each year to maintain the solar output (see appendix 14.2). The existence of the zodiacal light, indicating the presence of a tenuous mass of material surrounding the Sun, provided evidence to support the theory, but he noted that it was far from universally accepted, writing that the problem was one *upon which even speculation fails, and the question must remain to be solved in the future*. Nowadays, scientists explain the energy production of the Sun in terms of nuclear physics: the core of the Sun acts as a giant fusion reactor, with hydrogen atoms under extremes of heat and pressure combining to form helium, with an attendant release of energy.

A1.6 The Earth And Moon

Plummer addressed the Earth, the Moon and their orbital motion in chapters three and five. He described the Earth's movement in its orbit and how it caused the seasons; techniques for determining latitude and longitude; and approaches for estimating the density of the planet. Techniques for the latter, all fundamentally relying on a comparison of the gravity of the Earth with that of a known mass of material, gave an average density of 5.67 times that of water, very close to the modern figure 5.515 g/cm^3.

He gave a comprehensive account of the orbit, dimensions, libration and phases of the Moon. Astronomers making joint observations at widely spaced observatories (for example the ROG and Her Majesty's Observatory at the Cape of Good Hope) had been able to make direct estimates of the lunar parallax against the background of fixed stars. This facilitated calculation of the average distance between the centres of the bodies as 384,393 km; the modern value is 384,400 km. Although observers had found no evidence of polar compression of the Moon, there were suspicions that it was slightly egg-shaped, with the smaller end directed towards the Earth, as this was the shape that gravity would have caused it to adopt had its material been at one time plastic. He believed that all planetary satellites kept the same face turned towards the parent body (just like the Moon). He noted *That our satellite is destitute of any sensible atmosphere is shown by a variety of facts…* The evidence was largely observational, obtained via telescopic study of the Moon: the absence of twilight upon the borders of the darkened hemisphere; the sharpness of shadows on the surface; the lack of a bright line due to atmospheric refraction around the lunar limb during a solar eclipse; and the sudden disappearance of stars when occulted. However, his confidence in the absence of a lunar atmosphere vanished later in 1873 when he proposed, in the pages of *MNRAS*, a new theory to explain the supposed phenomenon of *projection upon the limb* during lunar occultations. His theory assumed that an atmosphere, of sufficient density to refract starlight, surrounded the Moon. See appendix 2.4.

He believed that lunar craters were volcanic in origin as their shapes were similar to those of terrestrial volcanoes. In fact, for very many years, astronomers debated whether volcanism or the impact of bodies arriving from space was the primary cause of craters; nowadays the scientific consensus is that impacts are the primary cause (see e.g. Beatty, Petersen and Chaikin, 1999).

Finally, in his coverage of the Earth and the Moon he gave a comprehensive account of solar and lunar eclipses.

A1.7 The Planets And Asteroids

Plummer described the planets and asteroids in chapters four, five and six. For each planet he provided key orbital and physical data and described the known characteristics. Table 2 compares his data for the planets (converted to SI units) with modern values. The data is generally in fair agreement. Shading indicates the main exceptions, where the difference exceeds 10% (an arbitrary threshold), as follows:

- Densities of Mercury and Mars. If a satellite orbits a planet, it is possible to estimate the mass and hence the density of the parent body from measurements of the orbit of the satellite. Mercury has no satellite and, when Plummer wrote his textbook, the satellites of Mars had not been discovered[40], so astronomers were forced to estimate the densities of the two planets from perturbations that they imposed on passing comets, a technique which did not produce accurate estimates.
- Densities of Uranus and Neptune. Inaccuracies here may be ascribed to general difficulties in his era of observing such distant bodies.
- Equatorial diameter of Mars. With the exception of Neptune, planetary diameters were generally known accurately in Plummer's era. The discrepancy in the case of Mars is unexpected and may be a misprint, an intended value of 4220 miles (6791 km) perhaps being printed in error as 4920 miles (7918 km).

[40] Asaph Hall, observing at the US Naval Observatory, discovered Phobos and Deimos in 1877.

- Equatorial diameter of Neptune. The planet is distant, difficult to observe from the Earth and presents such a minute disk (never larger than 2.3") that astronomers in Plummer's era were unable to estimate its equatorial diameter accurately.
- Axial rotation periods for Mercury, Venus, Uranus and Neptune. Mercury lacks pronounced surface features, and dense atmospheres, exhibiting only subtle features, shroud the other three planets; as a result, astronomers had not been able to estimate their rotation periods accurately.
- Orbital eccentricity of Neptune. When Plummer wrote, Neptune had been known for less than 30 years (it was discovered on 23 September 1846) and had progressed through only a small portion of its orbital path; therefore astronomers did not know its orbital parameters with the precision enjoyed today.

Planet	Data	Mean Density (g/cm^3)	Equatorial Diameter (km)	Sidereal Period of Axial Rotation (d h m s. R = retrograde.)	Mean Orbital Radius (10^6 km)	Sidereal Period (days / years)	Orbital Eccent-ricity
Mercury	P	7.27	4,765	24h 5m 30s	56.958	87.969d	0.206
	M	5.43	4,879	58d 15h 30m 32s	57.909	87.969d	0.206
Venus	P	5.36	12,088	23h 21m 23s	106.432	224.701d	0.007
	M	5.24	12,104	243d 0h 14m 24s (R)	108.209	224.701d	0.007
Earth	P	5.67	12,755	23h 56m 4.09s	147.142	365.256d	0.017
	M	5.515	12,756	23h 56m 4.10s	149.598	365.256d	0.017
Mars	P	2.82	7,918	1d 0h 37m 22.735s	224.201	687d	0.093
	M	3.94	6,794	1d 0h 37m 22.663s	227.939	686.980d	0.093
Jupiter	P	1.32	142,250	9h 55m 21.3s	765.554	11.862y	0.048
	M	1.33	142,984	9h 55m 29.9s	778.298	11.862y	0.049
Saturn	P	0.756	115,717	10h 29m	1403.564	29.457y	0.059
	M	0.70	120,536	10h 30m 0s	1429.394	29.457y	0.056
Uranus	P	0.990	53,145	-	2822.548	84.014y	0.047
	M	1.300	51,118	15h 36m 0s (R)	2875.039	84.010y	0.046
Neptune	P	0.848	61,445	-	4419.661	164.5y	0.008
	M	1.76	49,528	18h 25m 55s	4504.450	164.793y	0.009

Table 2. Planetary data from Plummer and modern sources. (P=Plummer, M=modern.)

Only three planets (Mars, Jupiter and Saturn) show consistent evidence of features in modest telescopes, and he provided an illustration of each. Planetary photography was not well developed at the time, so his illustrations were sketches, reproduced in figure 17. The sketches show considerable detail and appear to present an idealised representation of what an observer would expect to see at the eyepiece of a large telescope. He did not attribute them to anyone.

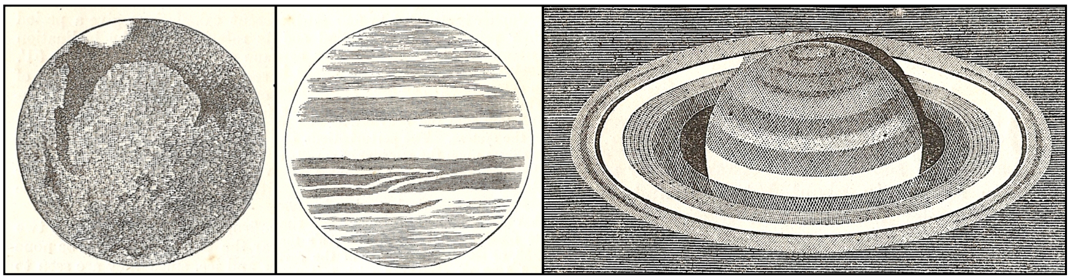


Figure 17. Mars, Jupiter & Saturn. (From Plummer, 1873.)

Astronomers of the era had minimal knowledge of the physical constitution and composition of the planets (other than Earth) and he required little more than a page to describe contemporary knowledge of each. His descriptions appear wildly fanciful to modern readers.

Mercury

He wrote: *…very little is known of its physical constitution. Its lustre is most brilliant, and effectually hides its features; but it is believed to possess a dense cloudy atmosphere…* Observers had reported discerning the tops of mountains protruding through the supposed atmosphere, from which they had estimated the rotation period. Unfortunately, the difficulties of observing the planet, which never strays far from the Sun in the sky, meant that the estimates were unreliable: in fact, Mercury possesses no appreciable atmosphere and its rotation period is very different from the early estimates. It was not until 1964 that astronomers used radar to determine reliably the rotation period and establish that it is locked in a 3:2 resonance with the orbital period. Plummer noted that Mercury undergoes transits across the solar disk and explained as an effect of irradiation the black drop effect, often visible around the times of internal contact of a transit.

Venus

The most noticeable feature of the planet is its brilliance, and Plummer reported observing it at noon and seeing it cast a shadow at night. As in the case of Mercury, astronomers thought that they had detected mountains protruding through a dense atmosphere and had used them to estimate the rotation period. Again, unfortunately, the observations were badly flawed and it was not until the modern era of radar mapping that astronomers were able to obtain accurate estimates of the rotation period.

Mars

Plummer wrote before the discovery of the two moons of Mars and therefore stated that it had none. From consideration of Mars' distance from the Sun, he knew that the intensity of solar radiation incident on the planet was only 43% that on the Earth. Despite this, the polar caps were not greater, in relation to the size of the planet, than those of the Earth and they fluctuated in size in a similar fashion. He concluded that Mars must enjoy a temperate climate similar to that of the Earth and either be covered by a very dense atmosphere or be composed of material that retained solar heat very effectively. He noted that *permanent markings and conspicuous diversity of colour upon the disc of the planet clearly indicate the existence of continents and seas; but, curiously enough, the larger portion of the surface would appear to be land.* He attributed the red glow of Mars to the soil of its land masses which, he thought, was probably similar to red sandstone on Earth.

Modern astronomers present a radically different description of Mars. The temperature on the surface is known to be much lower than on Earth (the average daytime temperature is approximately -50°C) and the surface is known to be devoid of water (although it may be present underground).

Asteroids

Astronomers in Plummer's era had identified and calculated orbits for 125 asteroids. He gave the approximate limits of the asteroid belt as defined by the orbits of Flora and Camilla, orbiting the Sun at the following mean distances respectively: 323,127,000 km and 523,856,000 km. An early theory to explain the formation of the asteroids, namely that they were the remnants of a large planet which had exploded or suffered a collision, was largely discredited. The then current theory was that a large ring (similar to the rings of Saturn) had existed between the orbits of Mars and Jupiter, but had somehow lost structural integrity and disintegrated. Nowadays, more than 1.3 million asteroids have been identified (IAU Minor Planet Centre, 2023) and the realm of the bodies has expanded, with many found in the outer solar system. Astronomers believe asteroids to be the remnants of partially formed planets; in the case of main belt asteroids, planetary formation having been disrupted by gravitational perturbations due to Jupiter.

Jupiter

Plummer wrote: *Jupiter is certainly surrounded by a dense cloudy atmosphere, capable of strongly reflecting the solar light. The dark belts are, in all probability, rifts or fissures in the clouds, exposing the surface and caused by violent permanent winds, more or less resembling our own sub-tropical trade winds.* He believed that the small round dark spots occasionally visible on Jupiter might be the peaks of mountains protruding through the atmosphere and the small round bright spots also occasionally visible might be vapours associated with mountain tops. He was quite wrong! Jupiter is a "gas giant", composed primarily of gaseous hydrogen and helium surrounding a core of metallic hydrogen, and the spots are circulatory patterns in the atmosphere.

He did not mention the Great Red Spot; although astronomers observed it intermittently from at least *circa* 1700, it was as late as 1879, when it was very well defined and surrounded by white clouds, that they began to pay it sustained attention.

He devoted four pages to a description of the motions of the Galilean satellites and how, in 1676, Rømer used them to demonstrate the finite velocity of light. Although astronomers generally credit Galileo Galilei with discovering the satellites, Simon Marius, who claimed to have observed them before Galileo, suggested the names Io, Europa, Ganymede and Callisto. Galileo disputed the claim and accused him of plagiarism. For many years, therefore, astronomers referred to the satellites simply as Jupiter I, II, III and IV to avoid crediting a possible plagiarist with their discovery. Plummer adopted this convention. It was as late as 1975 that the scientific community officially accepted the names suggested by Marius (Beebe, 1997).

Saturn

Plummer's description of Saturn concentrated on the planet's rings. Astronomers had identified three rings (denoted A, B and C) and he quoted their thickness as *certainly not more than 250 miles* [400 km]*, and in all probability very much less*. He acknowledged that the rings could not be solid, as internal stresses would result in them shattering; he inclined toward the view that they were composed of myriad small solid bodies each in an independent orbit around the planet. Nowadays, astronomers recognise seven main rings (A-G) and a huge number of individual narrow ringlets and believe the ring system to be only several tens of metres thick (Beatty, Petersen and Chaikin, 1999). Probing by radar has confirmed that the rings are comprised of myriad small bodies orbiting the planet.

He stated that the rings revolved around a point some 725 km distant from the centre of the globe of Saturn. Historically, observers differed greatly over whether the rings revolved around the centre of the globe or were offset from it. Modern textbooks generally consider the rings to be centred on the globe, e.g. see Moore and Hunt (1983).

Astronomers had discovered eight moons orbiting Saturn, but Plummer admitted that they knew *very little* about them. As of the early 21st century, the count of moons has risen to over 60, but many are very small bodies, only a few kilometres in diameter (NASA Jet Propulsion Laboratory, 2023).

Uranus and Neptune

Both planets are so remote from the Sun that astronomers of Plummer's era knew little about either. He noted that Uranus was accompanied by four faint satellites and that *Neptune possesses one minute satellite, and possibly another*[41]. Modern tallies of satellites are Uranus 27 and Neptune 14 (NASA Jet Propulsion Laboratory, 2023).

A1.8 Comets

Chapter seven was devoted to comets. The unexpected appearance of a comet was, to people of ancient times, a matter of great awe, because of which the historical record was replete with reports of sightings. In Plummer's era, comets were more observed telescopically than by the naked eye.

Most comets presented the general appearance of a central condensation or nucleus surrounded by a larger and more diffuse coma, usually with a tail of greater or lesser extent pointing away from the Sun. The tail was usually the most prominent feature of a bright comet. When approaching the Sun, a comet appeared to emit material to form the tail; as it subsequently receded following perihelion, it appeared to re-absorb the material as the tail shrank. The only attractive force active over celestial distances was gravity, yet it was known to exert only a relatively weak force on bodies of low mass and Plummer therefore found the observed behaviour impossible to explain, writing: *it further seems almost inconceivable that the matter thus emitted can be collected again by the feeble attraction of a comet*. Astronomers suspected that the Sun had an effect on the morphology of comets and in particular of their tails. For example, the great comets in 1680 and 1843 (C/1680 V1, Kirch's Comet and C/1843 D1 respectively) exhibited enormous tails, thought somehow to be connected with their

[41] In fact, it was not until 1949 that G. P. Kuiper discovered Nereid, the second moon of Neptune.

very close perihelion passages to the Sun. Further, short-period comets generally appeared less bright at each succeeding perihelion passage. However, Plummer could offer no coherent explanation for the apparent influence of the Sun on a comet. Nowadays, scientists explain the appearance of a comet in terms of solar heating associated with the perihelion passage causing the outgassing of dust and gas from the nucleus. After the nucleus has ejected sufficient material, a visible tail can form, its characteristic shape caused by the interaction of its constituent particles with the solar wind. As the comet recedes from the Sun, solar heating declines, the outgassing of material reduces and the tail shrinks and finally disappears. A comet loses some of its mass on each perihelion passage, thus a short period comet that has completed many orbital revolutions is likely to be faint and of relatively low mass, all the volatile material in the nucleus having evaporated.

The visibility of faint stars through the tail and coma of a comet demonstrated that the material of those parts must be extremely tenuous. Further, close approaches of comets to Jupiter's moons and to Mercury had caused no measurable perturbation in the motions of the latter bodies, demonstrating that the mass of a comet must be very low in comparison. However, Plummer's certainty in this was to be short lived for, only two years later, in developing a theory of stellar formation (see appendix 14.1), he proposed that comets acted within nebulae as centres of local concentration that accreted material to become stars. Once stars had formed, comets then provided a mechanism to transport fresh material to them, replacing that lost through combustion. The theory required that comets in general had appreciable mass.

Comets were thought to be visible both by reflecting sunlight and by self-luminosity. Spectroscopy had supposedly revealed self-luminosity but, in fact, this was a misinterpretation of the highly complex spectra of cometary nuclei; astronomers nowadays understand that comets shine purely by reflecting sunlight.

Nineteenth century astronomers had determined that one of the best-known periodic comets, Encke's Comet (2P), was slowly spiralling into the Sun. Encke had explained this by hypothesising the existence throughout the solar system of a *resisting medium*, rare enough not to perturb significantly the orbits of very massive bodies such as planets, but dense enough to retard the motion of tenuous objects such as comets. Nowadays, astronomers ascribe the orbital decay of periodic comets to the loss of material through outgassing on each perihelion passage.

Plummer noted the link between some comets and annual meteor showers. An annual meteor shower is associated with an annulus of small particles orbiting the Sun in a path that crosses that of the Earth. When the Earth crosses the annulus, its gravity pulls particles in the vicinity into its atmosphere where frictional heating causes them briefly to become incandescent, some becoming visible. Astronomers had found that material responsible for the Leonid meteors was co-orbital with comet 55P/Tempel-Tuttle and that responsible for the Perseid meteors with comet 109P/Swift-Tuttle.

A1.9 Stars

Plummer described the astronomy of stars in chapters three and nine. Astronomers had estimated the distances of stars by measuring parallaxes. (The parallax of a star is defined as one half of the angular displacement of its apparent position against the background of fixed stars when observed from opposite sides of the Earth's orbit.) Due to the difficulty of measuring accurately the minute angles involved, the technique worked well only over limited distances and, by the 1870s, astronomers had succeeded in obtaining satisfactory estimates for only approximately the dozen nearest stars. The first parallax measured was that of 61 Cygni, by Bessel, in 1838, who arrived at a figure of 0.3483" (equating to a distance of 9.3 ly, somewhat smaller than the modern figure of 11.1 ly.) Despite the paucity of reliable parallax measurements, Plummer believed that there was no limit to how distant a star could be: *each successive increase of optical power brings into view fainter and fainter specks of light, to which we are obliged to attribute greater and greater distance*. He returned to this topic five years later (see appendix 12).

He explained that by surveying stellar proper motions over the population of stars at large, astronomers had determined that the solar system was in motion towards π Herculis at a velocity of 240 million km *per annum*. The corresponding modern value is 615 million km *per annum*.

Some 6000 double stars were known, of which approximately 10% were thought to be gravitationally interacting systems. He speculated that *many others will probably, in the course of some years, be* *added to the number*. This was a prescient remark; astronomers nowadays generally accept that the majority of stellar systems comprise two or more gravitationally bound components. In some cases, the components of a double star shine with contrasting colours: he speculated that the inhabitants of a hypothetical planet orbiting such a system would enjoy days of gloriously varying coloured light.

The physics of novae and supernovae were unknown in Plummer's era and he referred to them as *temporary stars*. Astronomers had recorded approximately 20 instances of such stars but knew little about them. In the most recent instance, in 1866 in Corona Borealis (nowadays the star is designated T CrB, the *Blaze Star*), spectroscopic observations had indicated that the increase in brightness was associated with the ignition of hydrogen. Astronomers nowadays explain a nova as a close binary star in which one component accretes hydrogen from the other, causing an unpredictable increase in brightness, and a supernova as the sudden brightening of a star that has become unstable late in its evolution and exploded.

He next considered variable stars, describing the variety of phenomena exhibited and distinguishing three main classes of the object: long period variables such as Mira (ο Ceti), eclipsing variables such as Algol (β Persei) and irregular variables such as η Argus (η Carinae in modern designation). Only in the case of eclipsing variables could he offer a physical explanation for the variation in brightness.

Astronomers had discerned several thousand faint, misty patches in the sky, some of which they could resolve, showing them to be clusters of stars. Conversely, in some cases the objects defied all attempts to resolve them, even with very fine telescopes on nights of good seeing. Such irresolvable objects were termed *nebulae* and he indicated that they were situated at *extreme distances* from the Earth. He noted that if they were thought of as galaxies similar to the Milky Way, their distances would be enormous, several thousands of light years. Unfortunately, this was another instance where he had a complete change of mind only a few years later, writing (Plummer, 1875d): *the nebulae are our nearest neighbours*. (See appendix 14.1.) He forecast that improvements in optical instrumentation would be necessary to elucidate their structure; in this he was correct, indeed, it was not until the 20th century that some nebulae were proven to be galaxies like the Milky Way, situated at vast distances.

A2 Lunar Occultations

A lunar occultation occurs when the Moon passes in front of a star, temporarily hiding it from view. The occurrence of an occultation establishes the apparent position of the Moon in relation to the star at a specific moment, thus the timing of lunar occultations can be used to check theories of the lunar orbit.

Within days of starting at Durham Observatory, Plummer began a programme of work, lasting more than two years, to observe lunar occultations. In 1869, he published an analysis of occultations observed up to May 1868. In the same year, John Joynson[42] reported in *MNRAS* observations of lunar occultations made at his observatory, provoking an unexpectedly robust response from Plummer. There ensued a gap of over three years before Plummer's next publication on the subject: in 1873, he published a theory to explain the supposed phenomenon of *projection on the limb*, and there ensued a brief but lively debate about his views in the pages of *MNRAS* and *The Advertiser*. Subsequently, although he published no further observing reports of occultations, he clearly retained an interest in the subject, referring to it in four publications in the 1880s in relation to validating estimates of the longitude of Orwell Park Observatory, studying the figure of the Moon and investigating the phenomenon of projection on the limb.

A2.1 Observation Of Occultations, 1867-69

Durham Observatory MSS (1869) show that Plummer observed lunar occultations of 18 stars between 06 November 1867 and 21 December 1869. One of his first published papers, communicated to *MNRAS* by Professor Temple Chevallier (Plummer, 1869b), was a report of the first nine occultations, up to 04 May 1868; he did not publish observations of the second nine. Below, the analysis covers all the observations, both published and unpublished.

Table 3 summarises his recorded event times together with corresponding modern theoretical estimates. Columns one, two and three respectively list the date of the occultation, the star concerned and its magnitude. Column four lists the lunar phase and whether waxing (+) or waning (-). Column five lists the phenomenon, D for disappearance and R for reappearance, and column six indicates the state of illumination of the lunar limb at the point where the star appeared or disappeared, B for a bright limb and D for a dark limb. Columns seven and eight respectively list the empirical and theoretical event timings, rounded to the nearest second. Figure 18 plots the differences, observed time minus theoretical time, in seconds.

Many aspects of table 3 and figure 18 are familiar to visual observers of lunar occultations nowadays. Initially, Plummer's timings of disappearance events were generally earlier than theoretical estimates by a few seconds, the discrepancy being roughly proportional to the lunar phase (due to the effect of glare from the illuminated portion of the Moon). From 04 February 1868 onwards, his disappearance timings were generally approximately four seconds in advance of modern estimates with the exception, on 10 April 1868, of η Librae (28 seconds early) and, on 09 September 1868, θ^1 Tauri (nine seconds early) and Aldebaran (19 seconds early). The larger discrepancies were associated with difficult observations. The disappearance of η Librae was against the bright limb with the Moon close to full and Plummer noted: *Star faint. Observation not satisfactory.* Of the disappearance of θ^1 Tauri, he noted: *Not so good as preceding* [observation]. *The moon's limb boiling, clouds passing*. Of Aldebaran he wrote: *Dense clouds passing…*

[42] Joynson appears in the astronomical literature (principally *MNRAS*) between 1865 and 1871, mostly reporting observations of the Moon and planets.

Date	Star	Mag	Lunar Phase	Phen	Limb	Event Time: Plummer (GMT)	Event Time: Modern Calc. (UT)
06 Nov 1867	λ Aquarii	3.7	71%+	D	D	22:24:58	22:24:59
				R	B	23:33:52	23:33:50
06 Nov 1867	78 Aquarii	6.2	72%+	D	D	23:57:19	23:57:20
08 Nov 1867	10 Ceti	6.2	87%+	D	D	19:10:06	19:10:11
				R	B	20:23:08	20:22:56
11 Dec 1867	130 Tauri	5.5	100%-	D	B	20:47:39	20:47:50
				R	D	21:33:24	21:32:53
17 Dec 1867	c Leonis[43]	5.0	61%-	D	B	01:54:24	01:54:32
				R	D	03:01:57	03:02:02
04 Feb 1868	130 Tauri	5.5	82%+	D	D	18:55:09	18:55:13
28 Mar 1868	γ Tauri	3.7	22%+	D	D	21:01:05	21:01:07
				R	B	21:56:04	21:56:01
10 Apr 1868	η Librae	5.4	91%-	D	B	01:30:13	01:30:38
				R	D	02:06:15	02:06:06
04 May 1868	σ^2 Virginis	4.7	96%+	D	D	21:06:46	21:06:53
				R	B	22:17:43	22:17:39
09 Sep 1868	71 Tauri	4.5	59%-	R	D	00:32:24	00:32:29
09 Sep 1868	θ^2 Tauri	3.4	59%-	D	B	00:43:05	00:43:11
				R	D	01:44:20	01:44:23
09 Sep 1868	θ^1 Tauri	3.8	59%-	D	B	00:49:22	00:49:31
09 Sep 1868	Aldebaran	0.9	58%-	D	B	05:10:51	05:11:10
24 Sep 1869	χ^2 Ceti	4.3	91%-	D	B	00:21:13	00:21:18
				R	D	01:32:07	01:32:11
26 Oct 1869	ν Geminorum	4.1	73%-	D	B	00:26:31	00:26:37
				R	D	01:29:16	01:29:19
26 Oct 1869	16 Geminorum	6.2	73%-	R	D	00:52:31	00:52:35
14 Dec 1869	χ^2 Ceti	4.3	84%+	D	D	21:14:06	21:14:10
21 Dec 1869	δ^2 Cancri	3.9	90%-	D	B	21:41:04	21:41:08

Table 3. Plummer's occultation timings and modern theoretical estimates.

His reappearance timings also initially broadly follow the expected pattern for a visual observer. Timings of bright limb reappearances were generally several seconds later than the corresponding modern theoretical estimates, due to the need for the limb to separate from the star before he could discern the latter. There is an approximate correlation between the phase of the Moon and the magnitude of discrepancy; again, this is likely due to the effect of glare. In the observationally difficult case of 130 Tauri on 11 December 1867, with a full moon, the discrepancy amounted to 31 seconds, and he noted: *Not good; the star faint.*

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[43] c Leonis is a double star, the magnitude 5.0 primary component being accompanied by a magnitude 12.6 secondary component. Event times in the table concern the primary: the secondary is not visible close to the Moon due to glare.

Seven out of the eight timings of dark limb reappearance events are earlier by three to five seconds than modern calculations indicate; there is no obvious explanation for this. The exception is the reappearance of η Librae, for which his timing is 13 seconds later than the modern calculation.

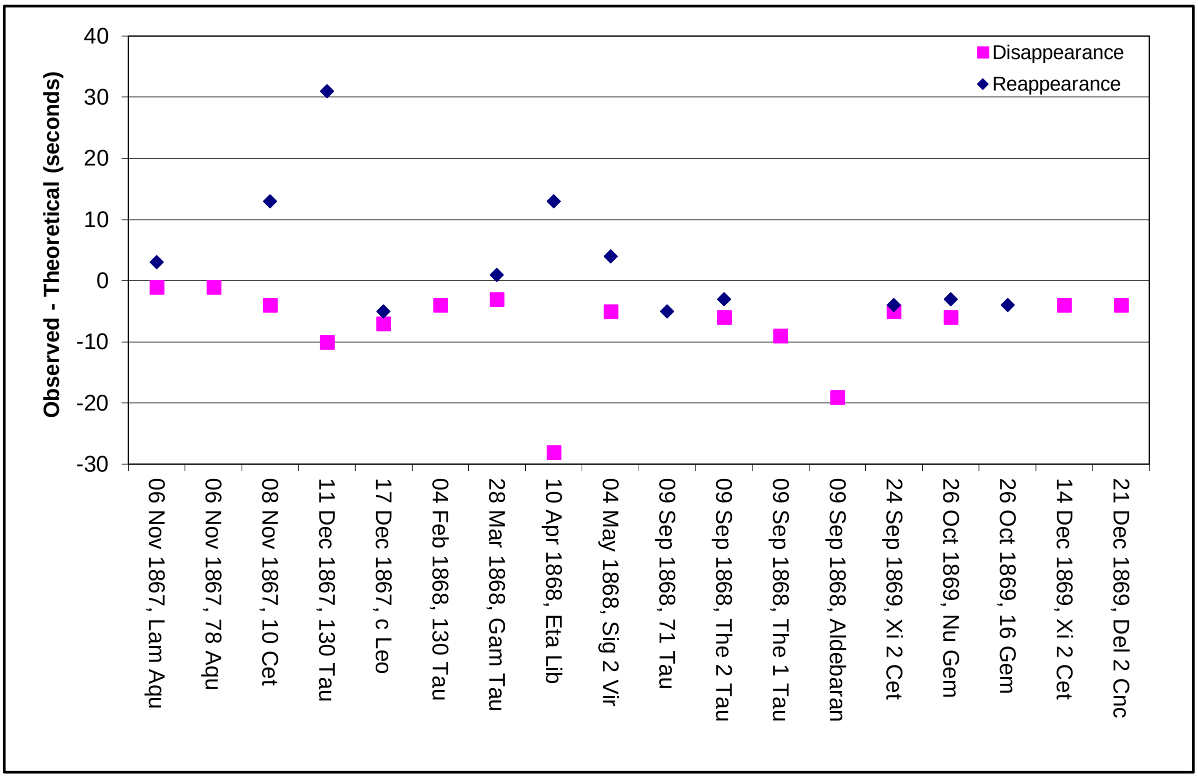

Figure 18. Plummer's occultation timings and modern theoretical estimates.

A2.2 Correspondence With John Joynson

Joynson (1869a) reported, in the pages of *MNRAS*, observations made at his observatory at Waterloo, near Liverpool, during December 1868 and January 1869. He timed lunar occultations of five stars and compared his results with predictions in the *Nautical Almanac*. Table 4 summarises his findings. Columns one, two and three respectively list the date of the occultation, the star concerned and the phenomenon, D for disappearance and R for reappearance. Column four lists his timing of the events, rounded to the nearest second, column five event times predicted by the *Nautical Almanac* for the ROG (quoted to a precision of one minute) and column six his comments.

Joynson considered the difference between prediction and empirical timing for each observation. For seven of the nine events, the discrepancy was at most approximately five minutes, but for the reappearance of 119 Tauri it was approximately nine minutes and for the reappearance of 120 Tauri approximately 12 minutes. Joynson anticipated some differences as the predictions were for the ROG, some 300 km distant; however, he believed that the discrepancies associated with the reappearances of 119 and 120 Tauri in particular were larger than expected.

Plummer (1869c) responded robustly in the pages of *MNRAS*, aiming to demonstrate that the problem was due to an error on Joynson's part rather than to a problem with the predictions in the *Nautical Almanac*. Early handwritten drafts of his paper in the Durham Observatory archive (Plummer, 1869d, 1869e) contain the following text, making it clear that he had little regard for Joynson: *The question of the difference of the effect of parallax upon an occultation is too complicated to be decided by a casual consideration of the position of the chord which the star described behind the moon, the hour angle and the relative positions of the places of observation, which seems to have been all that Mr. Joynson bestowed upon the matter. Calculations at once show that it is he who is in error.* In the published paper, the following more measured text replaced the above: *The effect of the difference of parallax upon the observed time of the occultation of a star by the Moon, evidently, cannot be obtained without systematic calculation.*

Date	Star	Phen-omenon	Joynson's Timing GMT	*Naut. Alm.* Prediction GMT	Joynson's comments
27 Dec 1868	BAC1526[44]	R	19:25:36	19:22	*~3 min later, as it should be**
23 Jan 1869	Aldebaran	D	20:44:16	20:49	*~5 min earlier, should be later*
		R	~22:00:00	22:05	*~5 min earlier, should be later. Passing cloud spoiled the view.*
24 Jan 1869	115 Tauri	D	17:27:05	17:29	*~2 min earlier, as it should be*
		R	18:16:39	18:12	*~3 min later, as it should be**
24 Jan 1869	119 Tauri	D	20:17:26	20:14	*~3 min later, as it should be*
		R	21:00:45	21:10	*~9 min earlier, as it should be – but hardly so much?*
24 Jan 1869	120 Tauri	D	20:46:27	20:48	*~2 min earlier, should be later*
		R	21:48:13	22:00	*~12 min earlier, as it should be – but hardly so much as 12 min?*

Table 4. Comparison of Joynson's timings with predictions in the *Nautical Almanac*. (Comments marked * are inaccurate[45].)

Concentrating on the three observations with largest discrepancies, Plummer calculated circumstances of the occultations of Aldebaran, 119 Tauri and 120 Tauri. For each he presented predictions, for the ROG and Waterloo, of the time of the event and the position of the star around the lunar limb. He did not state the method used to generate the predictions but it is likely that he relied upon elements tabulated in the *Nautical Almanac*. His predictions for the ROG agreed exactly (to the precision quoted) with those in the *Nautical Almanac*.

Table 5 compares his predictions with modern calculations. No systematic survey of the lunar limb had been conducted in the 19th century and occultation predictions therefore assumed a smooth, circular limb profile. To enable a like-for-like comparison, the modern calculations are based on a similar profile, with no correction for lunar topographic features – this typically makes a difference of several seconds to event times. Columns one, two and three of the table list the date of the occultation event, the star and the phenomenon. Columns four and five show theoretical estimates of event times and Position Angles (PAs) for the ROG, by Plummer and by a modern analysis, and columns six and seven show the same for Waterloo. (The PA is the angle of the star on the lunar limb, measured from the north point of the disk through east, south and west. Plummer presented the position of the star assuming a telescopic view; all positions are expressed below in terms of a naked-eye view. Note also that he presented predicted times to the nearest six seconds (0.1 minutes), whereas the modern predictions are rounded to the nearest second.)

Plummer's predictions of the PA of the occultations fall in all cases within 1° of modern calculations. However, there are in general differences of up to a few tens of seconds between corresponding event times. Figure 19 illustrates the differences, for the ROG and Waterloo, in the sense modern minus Plummer's. It shows the modern calculations give event times in most cases earlier than Plummer but there is no other obvious relationship between the two: sometimes the discrepancy is greatest for the ROG and sometimes for Waterloo. The differences highlight the effect of deficiencies in the lunar ephemerides and stellar positional data in use in Plummer's time, compared with their modern counterparts.

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[44] BAC is the British Association Catalogue of stars (Baily, 1845). A modern designation of the star is ZC741.

[45] Some of Joynson's comments on the differences between empirical timings and predictions are inaccurate. Rounding to the nearest minute, the discrepancy for the reappearance of BAC1526 is four minutes rather than three, and for the reappearance of 115 Tauri, it is five minutes rather than three.

Date 1869	Star	Phen	Estimates For ROG		Estimates For Waterloo	
			Plummer	Modern	Plummer	Modern
			PA (°) Time (GMT)	PA (°) Time (GMT)	PA (°) Time (GMT)	PA (°) Time (GMT)
23 Jan	Aldebaran	D	83° 20:48:42	83° 20:48:27	75° 20:44:36	75° 20:44:21
		R	251° 22:04:42	252° 22:04:30	258° 22:00:00	258° 21:59:55
24 Jan	119 Tauri	D	37° 20:14:30	37° 20:14:41	25° 20:18:00	26° 20:17:27
		R	303° 21:09:30	304° 21:09:27	315° 21:00:12	314° 21:00:40
24 Jan	120 Tauri	D	63° 20:47:48	62° 20:47:47	54° 20:46:42	55° 20:46:27
		R	280° 21:59:36	281° 21:59:18	288° 21:53:06	288° 21:53:05

Table 5. Comparison of Plummer's occultation predictions with modern calculations.

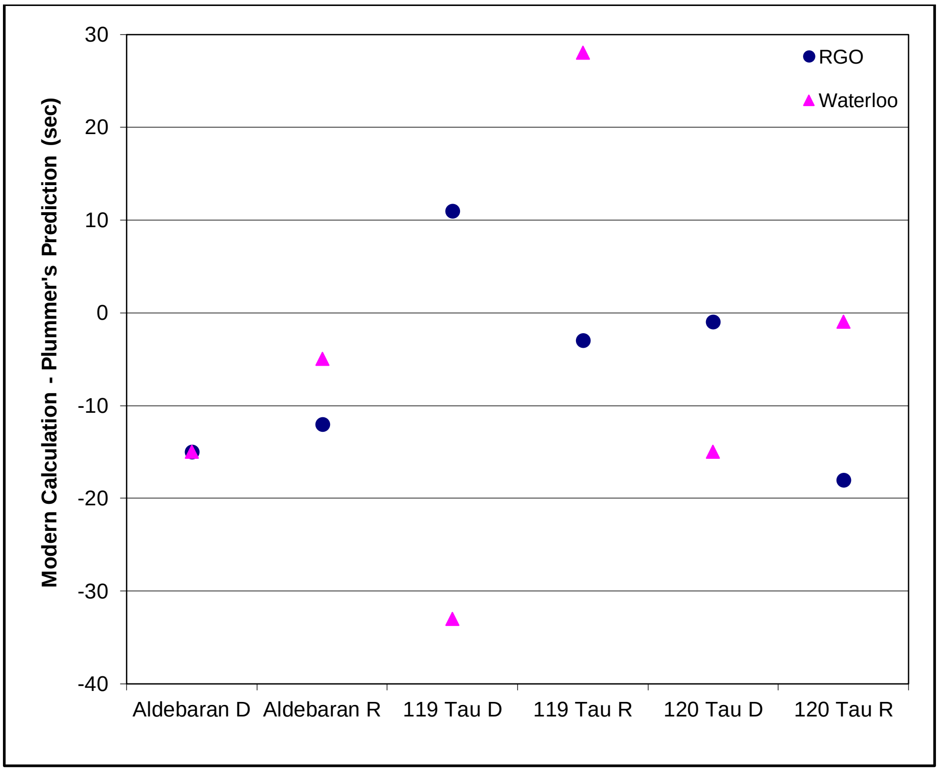

Figure 19. Differences between Plummer's predictions and modern calculations.

In the final part of the paper, Plummer described an approximate method devised by Chevallier for calculating occultation predictions for a location based upon knowledge of circumstances at another location. (Appendix 2.3 describes the method.) The implication (not stated explicitly) was that Joynson use the method to calculate, from the predictions for the ROG, corresponding predictions for the events as seen from Waterloo.

Joynson (1869b) replied politely in the pages of *MNRAS*, accepting Plummer's analysis and even apologising for *the considerable amount of trouble* that he had caused! He also reported further occultation observations of seven stars during February – May 1869. A comparison, for all of Joynson's observations, of reported event times with modern theoretical estimates provides some insight into the discrepancies that he highlighted on 23-24 January. Table 6 lists the data. Columns one to five are as described previously. Columns six, seven and eight respectively show the time reported by Joynson, the corresponding modern calculated time, and the difference in seconds between the two, in the sense Joynson minus modern. All timings in the table are rounded to the nearest second.

Date 1868 - 1869	Star	Lunar Phase	Phen	Limb	Joynson's Timing (GMT)	Modern Calculation (UT)	Observed - Calculated (seconds)
27 Dec	BAC1526	0.96+	R	B	19:25:36	19:25:18	18
23 Jan	Aldebaran	0.78+	D	D	20:44:16	20:44:19	-3
			R	B	22:00:00	21:59:53	7
24 Jan	115 Tauri	0.85+	D	D	17:27:05	17:27:07	-2
			R	B	18:16:39	18:16:11	28
24 Jan	119 Tauri	0.86+	D	D	20:17:26	20:17:26	0
			R	B	21:00:45	21:00:43	2
24 Jan	120 Tauri	0.86+	D	D	20:46:27	20:46:28	-1
			R	B	21:48:13	21:53:06	-293
19 Feb	48 Tauri	0.51+	D	D	21:04:40	21:04:44	-4
23 Feb	ζ Cancri	0.90+	D	D	22:11:40	22:11:50	-10
24 Feb	π^2 Cancri	0.96+	D	D	22:45:17	22:45:19	-2
			R	B	23:43:03	23:42:56	7
22 Mar	g Geminorum	0.68+	D	D	21:17:17	21:17:18	-1
			R	B	22:26:22	22:25:18	64
16 Apr	119 Tauri	0.21+	D	D	19:29:44	19:29:46	-2
			R	B	20:23:20	20:23:00	20
16 Apr	120 Tauri	0.21+	D	D	20:18:26	20:18:29	-3
			R	B	20:52:48	20:52:35	13
18 May	Regulus	0.50+	D	D	21:54:28	21:54:37	-9
			R	B	22:07:25	22:07:02	23

Table 6. Joynson's occultation timings and modern calculations.

Figure 20 plots the differences. Joynson's disappearance timings are generally a few seconds earlier than modern calculated times (maximum discrepancy 10 seconds). Excluding the reappearance of 120 Tauri on 24 January, he generally reported reappearance timings later than modern calculations indicate by up to a few tens of seconds, rising to 28 seconds in the case of 115 Tauri and to 64 seconds in the case of g Geminorum. So far, the situation is not unexpected. The large discrepancies between theory and observation that he reported for Aldebaran and 119 Tauri in January 1869 turn out to be due to the use of predictions for the ROG rather than for Waterloo: event times at the two locations typically differ by several minutes. However, something is clearly amiss with the occultation reappearance of 120 Tauri in January 1869: the data is far off the scale of the figure, as indicated by the arrow. For this event, Plummer's prediction agrees exactly with the modern calculation. The most likely explanation is that Joynson was mistaken in his reporting of the time of the event. If he had made a simple error reading the observatory chronometer and reported a reappearance time exactly five minutes too early, the true time of his observation would be seven seconds after the calculated time, a discrepancy comfortably within the range of his other reappearance timings.

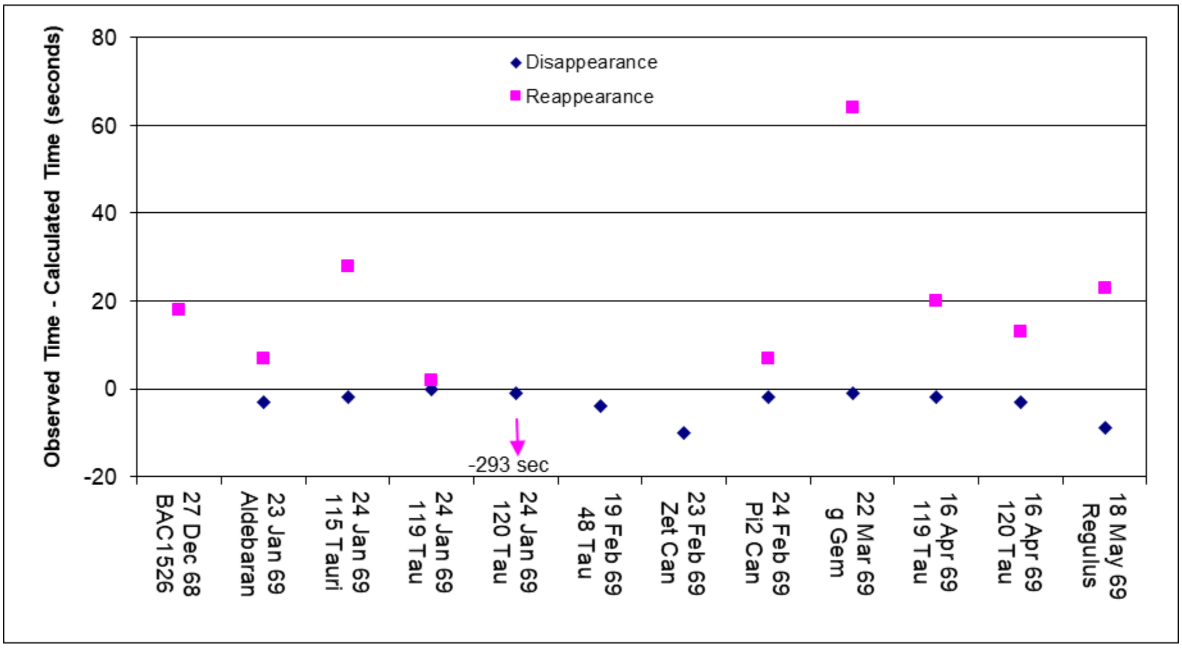

Figure 20. Comparison of Joynson's occultation timings with modern calculations.

A2.3 Local Circumstances Of An Occultation

At the end of his riposte to Joynson, Plummer described an approximate method devised by Chevallier (1850) for calculating the circumstances of an occultation for an observer based upon details of the event for another location. The method was a graphical one, executed as follows in the fundamental plane, i.e. the plane running through the centre of the Earth perpendicular to the line to the star. Suppose that occultation circumstances were known for the ROG and that it was desired to predict circumstances for another observing station, X. Plot in the fundamental plane the projections of the lunar disk and the ROG at the instant of occultation disappearance. At this moment, the two projections touch one another. Plot also the projection of X and calculate the offset, O, from the ROG to X – see figure 21(a). Next, add to the diagram the circumstances of the reappearance event at the ROG and the offset, O, to X. (At the instant of reappearance, again the projections of the ROG and the lunar limb are in contact.) The line segment D-R in figure 21(b) represents the course of the Moon between disappearance, D, and reappearance, R, at the ROG. By assuming the velocity of the Moon to be constant during the time in question it is a matter of geometry and linear interpolation/extrapolation to estimate the times of disappearance and reappearance at X and the associated PA of the star on the lunar limb.

Plummer used Chevallier's method on more than 20 occultations and found it to be of good accuracy (mean error 34 seconds in time, 0.7° in PA). Magnanimously, he offered to use the technique to calculate tables of occultation predictions for any observatory.

Modern computers enable an astronomer with suitable software to calculate accurate occultation predictions for any location at any epoch. As a result, there is little need nowadays for approximation methods such as Chevallier's to enable transformation of occultation parameters from one location to another. However, the BAA (2023) does still publish occultation predictions for the standard UK observing locations of the ROG and the Royal Observatory, Edinburgh (and locations overseas) and includes for each prediction the values of station coefficients that indicate how contact times vary with longitude and latitude. This provides a concise, modern-day analogue of Chevallier's method for the benefit of the astronomer who does not have the necessary computer and software to predict occultations directly for his location.

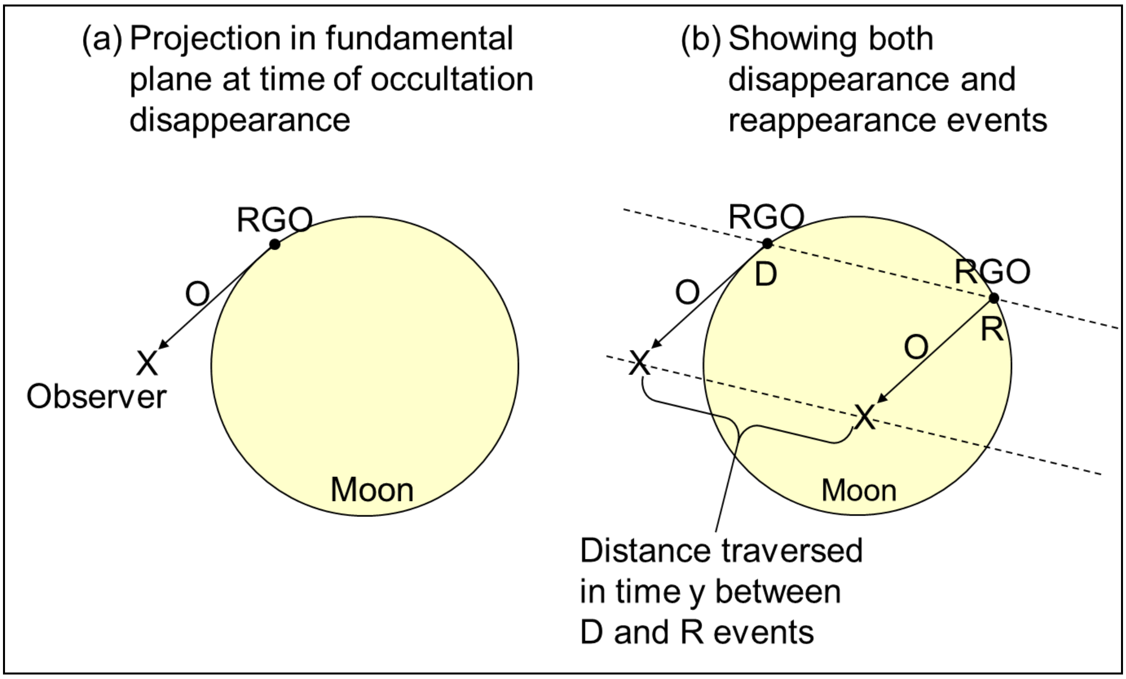

Figure 21. Graphical method for occultations. (After Chevallier, 1850.)

A2.4 Projection On The Limb

Nineteenth century astronomers reported the phenomenon of *projection on the limb* or *hanging on the limb* or *attached to the limb* when, just prior to occultation disappearance, the star appeared to linger on the lunar limb or be visible inside the limb for a few seconds before vanishing. Occasionally, they reported the analogous phenomenon at reappearance events. The phenomenon attracted much interest in the 19th century, but modern observers do not report it. (See Davidson (1890) for an explanation of the phenomenon in terms of atmospheric unsteadiness.)

In Plummer's first paper on lunar occultations (discussed above), he reported witnessing projection during the disappearance of γ Tauri on 28 March 1868: *The star was attached to the Moon's limb, which was distinctly visible by earthlight, at least 5 seconds before the disappearance, which was instantaneous*. (His published description follows almost verbatim that in his observing notebook.) A year and a half later, he suspected that the disappearance of Aldebaran on 24 September 1869 also exhibited projection: *Instantaneous. Dense clouds passing prevented the observer noting with certainty whether the star was attached to the limb, it was thought to be so. The noted time is exact*. These are his only first-hand descriptions of the phenomenon.

His next mention of projection in the published literature was in 1873 in a paper (Plummer, 1873k)[46] communicated to *MNRAS* by Professor A. S. Farrar (Professor of Divinity and Ecclesiastical History at Durham 1864-1905). Plummer referred to publications by Sir James South[47] and Sir George Airy for an overview of the phenomenon and then developed a theory to explain it. The descriptions by South and Airy provide a useful background to the subject so are summarised here.

South (1828a; 1828b) reported witnessing the phenomenon of *projection* when he observed the occultation disappearance of δ Piscium on 06 February 1821. He reported that the night was *beautifully fine*, the Moon was young, 20% waxing, and both the limb and the unilluminated portion of

[46] A draft of the paper (Plummer, 1873L) in the archive of Durham Observatory, prepared for reading at the RAS on 14 March 1873, contains the following text, some crossed out as shown. It seems that Plummer thought the better of chiding Joynson again! *These are the only instances I have been able to discover during the past 20 years ~~with one exception, namely the occultation of Aldebaran recorded by Mr. Joynson in Monthly Notices Vol XXVII, page 63, but it does not appear that the star separated itself from the limb and the atmospheric circumstances were certainly unfavourable and further the duration is very short (1.5 sec). I have therefore not computed this case choosing to regard it rather as doubtful or at best merely as hanging about the limb~~*.

[47] James South (1785-1867) was a founder of the RAS.

the disk were unusually distinct. The Moon appeared to draw closer to the star in the usual way until the two appeared to touch. The star then seemed to hang upon the limb, without any diminution in brightness or alteration in position, for almost nine seconds until it instantaneously disappeared. Francis Baily[48] and Karl von Littrow[49], who independently observed the occultation, reported nothing unusual. Later in the evening, South noted: *a star of the 8th or 9th magnitude suffered occultation by the Moon's dark limb, nearly at the same part, at which δ Psc entered upon the disk*. This time there was no projection on the limb. The star in question appears to have been the magnitude 8.1 star Hipparcos 3963.

South noted that although reports by UK observers of projection upon the limb were rare, many experienced observers on the continent had reported the phenomenon and there could therefore be little doubt as to its reality. He found in the international astronomical literature reports of more than 20 stars exhibiting projection. For most, he could locate only a single observing report, but for Regulus he unearthed three and for Aldebaran 20. In some cases, reports from different observers agreed as to whether or not projection had occurred and in others, they disagreed. Frustratingly, there was insufficient detail in many of the observing reports to draw firm conclusions.

He proposed five possible explanations for the phenomenon, dismissing each as follows:

1. Lively imagination of the observer. Experienced observers had reported more than 60 instances of projection, so he concluded that there was no doubt as to its objective reality.
2. Inferior optics, with chromatic aberration introducing a spurious lunar limb that confused the observers. South dismissed this possibility because of the range of good quality achromatic telescopes employed by observers reporting projection.
3. A lunar atmosphere. If there were a lunar atmosphere capable of explaining projection, it would manifest itself during all occultations, which it did not.
4. Irradiation. This could not explain projection on the dark limb.
5. Differing refraction of light from the star and from the Moon in passing through the Earth's atmosphere to the observer. Such an effect was possible in principle if light from the star had a significantly different wavelength to moonlight. Nonetheless, he dismissed the possibility by noting that astronomers had reported projection in the case of white stars (with spectra broadly similar to moonlight) as well as red stars such as Aldebaran, yet had not reported it in the case of Mars, which is even more pronouncedly red than Aldebaran.

He called upon observers to study the 1829-30 occultations of Aldebaran in the hope of finding an explanation for the phenomenon.

Airy (1859) reported that he had observed the phenomenon of projection in 1829, nearly 30 years earlier, and that it *made a strong impression* on his mind. (Unfortunately, he did not provide any details of the observation.) He attempted to provide an explanation for the phenomenon in terms of optical principles, noting that, in many cases, a red star was the subject of projection and for such stars, a potential difference in the degree of refraction between the light of the star and the (whiter) light of the Moon in passing through the Earth's atmosphere might provide an explanation for the apparent projection. (This is explanation #5 of South, which the latter dismissed.) Such a mechanism could produce, for an observer in the northern hemisphere, apparent projection for red stars incident on the upper limb of the Moon and apparent early disappearance of such stars on the lower limb (where upper and lower are understood in the sense of an inverted, telescopic view). Airy arranged for an assistant at the ROG to test this theory by analysing all recorded observations of projection: the findings did not support the hypothesis.

He then reported an observation by George Innes[50] at Aberdeen of a bright limb disappearance of Aldebaran on 23 October 1831. Innes (1831) stated that when the limb came within about six seconds

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[48] After the solar eclipse of 1836, Francis Baily (1774-1844) described the phenomenon of a string of brilliant points of light around the lunar limb, sometimes visible just before or just after totality. The phenomenon subsequently became known as *Baily's beads*.

[49] Karl Ludwig Edler von Littrow (1811-77) was an Austrian astronomer who became director of Vienna Observatory. A lunar crater and rille were named in his honour.

[50] Innes was an astronomical computer who worked at Marishal College in the University of Aberdeen.

of Aldebaran, the remaining distance appeared to decrease very rapidly, with an apparent closing velocity some five or six times that previously. When the star and limb appeared to touch, the star remained stationary for about five seconds then disappeared suddenly. Airy accepted Innes' account of the observation without question and attempted, in a very contrived manner, to explain it in terms of optical and physiological principles. He noted that a point source of light in a telescope produced a set of diffraction rings. By extension, considering the Moon's disk to consist of an infinite number of luminous points, the net result of the superposition of all the associated diffraction rings would be a band of illumination fringing the apparent geometrical limb. Although he was unable to calculate the amount of illumination falling outside the limb, he believed it to be *considerable*. Under normal circumstances, the observer would expect the intensity of light outside the limb to decrease with distance according to a given regime and would be oblivious to it. However, when intently observing an occultation, he could become sensitive to it, resulting in the Moon appearing to increase in size and rapidly approach the star. Airy could not explain why, for a given star, sometimes one skilled observer would report projection while another, equally skilled, would not, nor why reports varied so much.

In reviewing the work of South and Airy, Plummer noted that South had rejected all proposed explanations and Airy had proposed an explanation that unfortunately appeared to fail in the case of dark limb disappearance events. He suggested, therefore, that several mechanisms might be at work simultaneously.

He provided a further description of the instance of projection that he witnessed during the occultation of γ Tauri on 28 March 1868 (incorrectly referring to the star as ζ Tauri). He reported that *atmospheric circumstances were eminently favourable*, the lunar limb was clearly visible and *The star remained on the disk for at least five seconds, and very possibly longer, and its distance from the limb was considerable.* His report is not in accordance with his initial observing report, which simply stated that *the star was attached to the Moon's limb*.

He proposed a theory to explain some cases of projection. He assumed that the figure of the Moon was that proposed by Peter Hansen[51] (1856), namely a triaxial ellipsoid of rotation for which the centre of mass was 59 km further distant from Earth than the centre of figure. If the Moon had an atmosphere, at mean libration it would be distributed evenly around the point on the far side, diametrically opposite to the centre of the disk seen from the Earth. Libration would then determine the thickness of atmosphere on the limb and, if the atmosphere were dense enough to refract starlight, the resulting degree of refraction, and the apparent alteration in the position of the star. His explanation was a refinement and extension of South's explanation #3. He investigated his theory by examining all instances of projection of large extent that he could find in the literature in the preceding 20 years, for each evaluating the libration at the point of projection on the lunar limb.

Table 7 summarises the results. (Plummer stated that the occultation on 04 April 1854 was of α Geminorum but it was, in fact, of ε Geminorum.) The investigation was inconclusive; however, he noted that in no case examined was the libration zero and he concluded, somewhat wishfully, that the data therefore supported his explanation.

Date	Star	Observer	Location	Phen	Projection Duration	Libration
04 Apr 1854	ε Geminorum	E. Dunkin	Greenwich	R	4 sec	3º 43'
19 May 1858	Regulus	Two unnamed observers	Greenwich	R	5 sec	6º 58'
19 Mar 1866	31 Arietis	C. G. Talmage	Leyton	D	Not specified	2º 52'
28 Mar 1868	γ Tauri	J. I. Plummer	Durham	D	>5 sec	7º 14'
14 Oct 1870	ζ Tauri	W. H. M. Christie	Greenwich	D	Not specified	4º 47'

Table 7. Libration angles for instances of *projection*.

[51] Peter Andreas Hansen (1795-1874) was a Danish astronomer who created *Hansen's Lunar Tables*, published in 1857, for some years considered to embody the definitive theory of the motion of the Moon.

He accepted that the lunar atmosphere, if it existed, must be very tenuous, and briefly mentioned an unsuccessful attempt to use a spectroscope to search for it. He clearly had no expectation of success as the spectroscope was *manifestly ill suited*.

Richard Proctor[52] (1873a) of Cambridge University responded to Plummer and there ensued a brief but lively correspondence between the two in the pages of *MNRAS*. Proctor believed the shape of the Moon to be essentially a sphere with a meniscus superimposed on the side closest to the Earth, claiming that this was the configuration supported by Hansen. He believed that the lunar atmosphere would dispose itself around such a body to be thinnest at the points closest to the Earth and furthest from the Earth, and most dense around the limb. His argument supported Plummer's hypothesis that a lunar atmosphere would be preferentially disposed around the limb and therefore well positioned to refract the light of a star undergoing an occultation.

Plummer (1873m) appeared to mistake Proctor's comments for an attack on his work and responded promptly and belligerently. He pointed out that Hansen considered the Moon to have the form of a triaxial ellipsoid of rotation rather than the shape described by Proctor. The figure of the Moon was very close to spherical, as there was no obvious physical mechanism to produce a significantly different shape. Of the several methods of demonstrating the non-existence of a lunar atmosphere, none had given conclusive results and Plummer proposed to search for evidence of an atmosphere during the forthcoming partial solar eclipse, when it would potentially be visible as a bright line near the cusp of the Moon. Finally, he took issue with Proctor's explanation of the disposition of the supposed lunar atmosphere.

Proctor (1873b) replied that he had not intended his comments as an attack upon Plummer's paper. However, the fact that many highly experienced observers had never witnessed the phenomenon of projection tended to militate against the latter's explanation as, were it valid, some were certain to have observed occultations when the Moon was close to extremes of libration. Further, due to the low gravity of the Moon, a lunar atmosphere would distribute itself around the entire body and decrease in density only gradually with height above the surface; this would cause a projected star to appear to fade gradually rather than disappear suddenly. Instead, he proposed the existence of deep clefts in the lunar surface as a mechanism for the phenomenon; starlight could continue to reach the Earth through a cleft after the star had apparently passed within the circumference of the lunar disk. The vagaries of lunar geography explained why some observers of an event witnessed the phenomenon of projection whereas others at different locations did not: if the cleft were narrow, starlight passing through it would be visible from only a potentially small part of the Earth. He referred to work at the Imperial Observatory at Vilnius, in which analysis of photographs taken by Warren De La Rue[53] indicated that the Moon had the shape of an egg, with the sharper end pointing towards the Earth (although the non-sphericity was very minor). The finding was in line with his earlier description of the figure of the Moon as a sphere with a superimposed meniscus. He concluded with an attack on basic aspects of Plummer's terminology and assumptions and, although he couched his response in conciliatory phrases, he clearly considered Plummer's explanation to be fatally flawed.

"Mathetes" (1873) joined the fray in correspondence to *The Advertiser* published on 25 April 1873. He maintained that Plummer had accepted the theory that the Moon was not a sphere and used the fact to argue that the body had an atmosphere; but had not fully proven the point. Under Plummer's assumptions, a star on the limb would be affected by refraction whatever the lunar libration. Plummer (1873n) replied in the following week's edition of the paper. He stated that although Hansen's theory of the figure of the Moon was firmly established, not just a working hypothesis, it did not require that the figure differed significantly from a sphere. Yet this fundamentally undermined his argument since, if the figure were close to a sphere, the thickness of atmosphere on the limb, and therefore the degree of refraction of starlight, would be little influenced by libration.

From a modern perspective, the discussion of *projection* in the 19th century literature appears hopelessly qualitative and unscientific. However, because many respected observers reported the phenomenon, astronomers of the era accepted it as real and proffered explanations. Plummer's

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[52] Richard Proctor (1837-88), educated in Cambridge, was the author of numerous books and articles on astronomy, many of which dealt with the subject of life on other worlds.

[53] Warren De la Rue (1815-89) was an astronomer and chemist who pioneered astronomical photography.

hypothesis stood comparison with competing theories. Nowadays, observers do not report the phenomenon. Instruments left by the Apollo 17 astronauts on the lunar surface detected trace elements of gases and revealed that the density of the lunar atmosphere does not exceed 10^{-14} that of the Earth (Moore and Hunt, 1983). Photographs taken at close range by Apollo spacecraft and survey probes do not show deep clefts.

A2.5 Intended Later Observations

Plummer retained an interest in lunar occultations after the correspondence with Proctor and Mathetes, in four subsequent annual reports to the RAS mentioning observations that he had made or intended to make of the phenomenon.

In his annual report for 1879, Plummer (1880c) proposed to undertake occultation observations during 1880 as a means of validating his determination of the geographical coordinates of Orwell Park Observatory. Unfortunately, he provided no further details.

In his annual report for the following year, Plummer (1881a) confirmed that he had observed *a number of occultations of stars by the Moon* and proposed to *watch for the unpredicted occultations of small stars at the dark limb of the Moon during the early days of each lunation, in the hope of detecting and elucidating the phenomenon of projection on the limb*. He reported making trial observations and hoped to be able to observe many occultations in a comparatively brief period. Unfortunately, none of his later papers returned to this line of research.

His next mention of the subject was in relation to establishing the diameter of the Moon. Irradiation made it impossible to estimate the lunar diameter directly when the Moon was illuminated and astronomers had therefore resorted to indirect techniques such as those based on lunar occultations. However, such approaches had proven unsatisfactory because local features of the lunar limb caused a significant spread of results. Wilhelm Döllen[54] (1884) of Pulkovo Observatory, St. Petersburg, proposed to use occultations to estimate the diameter of the Moon, and to overcome the difficulties associated with limb features by pooling data from many observations. Further, he proposed to undertake the work during the total lunar eclipse of 04 October 1884 when, with the Moon in shadow, it would be possible to observe occultations of many faint stars without problems caused by glare. He provided a list of 116 stars down to magnitude 10 that the eclipsed Moon would occult on that date, and offered to provide occultation predictions for potential observers.

Plummer intended to participate in the project but, in his annual report for 1884 (Plummer, 1885a), reported that clouds had prevented observations. Unfortunately, cloud cover thwarted most would-be observers and Döllen was unable to estimate the lunar diameter. In fact, this was the second time that his project had been thwarted by cloud, the first being on 09-10 April 1884. Attempting the project on a third occasion, during the lunar eclipse of 28 January 1888, Döllen's luck changed, many astronomers enjoyed clear skies and, by March 1888, he had received 783 observing reports from across Europe and America (Döllen, 1888). Unfortunately, on this occasion too, Plummer was clouded out (Plummer, 1889b).

He published nothing concerning lunar occultations after 1889.

[54] Wilhelm Döllen (1820-97) was an astronomer and geodeticist.

A3 Transits Of Mercury

Plummer observed the transits of Mercury on 05 November 1868 and 06 May 1878. In 1868, he was based at Durham Observatory and Professor Temple Chevallier communicated his observing report (Plummer, 1868b) to *MNRAS*. He observed in *exceptionally favourable circumstances* under a cloudless sky. The transit began before the Sun rose and only the last one and a half hours of the phenomenon was visible. Due to atmospheric turbulence, the solar limb was tremulous and Mercury was ill defined when the Sun rose, but the situation improved towards the end of the transit, although the Sun was at an altitude of only 11° at the time of 4th contact. He used the 165 mm Fraunhofer equatorial, equipped with a wire micrometer, power 112, to make estimates of position that he later compared with theoretical calculations based on elements in the *Nautical Almanac*. Table 8 compares his empirical and theoretical estimates with the results of modern calculations.

Phenomenon	**Plummer's Estimate**	**Plummer's Calculation**	**Modern Calculation**
3rd contact	09:00:12.0 GMT	-	09:00:09 UT
4th contact	09:02:29.2 GMT[55]	-	09:02:46 UT
Difference in RA of centres, Mercury - Sun, at 08:08:42.0 UT	-42.338^s	-42.432^s	-42.187^s
Difference in RA of centres, Mercury - Sun, at 08:16:41.2 UT	-45.188^s	-45.354^s	-45.112^s
Difference in RA of centres, Mercury - Sun, at 08:22:19.0 UT	-47.442^s	-47.414^s	-47.175^s
Difference in RA of centres, Mercury - Sun, at 08:40:55.5 UT	-54.044^s	-54.222^s	-53.988^s
Difference in RA of centres, Mercury - Sun, at 08:44:24.7 UT	-55.267^s	-55.498^s	-55.270^s
Difference in dec, north limb Mercury - south limb Sun, at 08:32:36.7 UT	-7' 41.11"	-7' 37.46"	8' 31.56"
Difference in dec, south limb Mercury - south limb Sun, at 08:34:21.8 UT	-7' 35.73"	-7' 32.94"	8' 26.11"
Apparent diameter of Mercury	9.001"[56]	-	9.956"[57]

Table 8. Quantities estimated during transit of Mercury, 1868.

Plummer's estimate of the time of 3rd contact is in good agreement with modern calculations. His estimate of 4th contact is almost 17 seconds earlier than expected but, as he remarked, it was inexact due to undulation of the solar limb. Modern calculations give a difference in RA between the centres of Mercury and the Sun systematically greater than that given by the *Nautical Almanac* by almost 0.25^s throughout the period in question. His empirical estimates of the difference in RA in the main lie between the two theoretical estimates and are not consistently closer to one than the other. His estimates (both empirical and theoretical) of the difference in declination between the north limb of Mercury and the south limb of the Sun and between the south limb of Mercury and the south limb of the Sun were both negative. However, during the transit, the disk of Mercury appeared wholly in front of the solar disk, therefore both estimates should have been positive. It appears therefore that he

[55] Noted that the time was inexact due to undulations on the solar limb.

[56] Noted that he had to make the measurements rapidly and that the image of Mercury was unsatisfactory, so he did not consider the measurement "of any great value".

[57] Plummer did not specify the time at which he estimated the apparent diameter of Mercury, so the modern calculation here refers to the time of mid-transit, 07:14:45 UT.

estimated the difference in north polar distance (NPD) rather than in declination. Unfortunately, his numerical estimates, interpreted as differences in NPD, do not agree well with modern calculations.

He estimated the diameter of Mercury with a double image micrometer *of Mr. Airy's original construction*. His estimate was 9.001", which he stated was *a somewhat small result*, blaming the poor image quality and haste in undertaking the measurement. He compared the figure with an estimate[58] of 8.693" that he had made on an unspecified date in March 1868, which he stated agreed closely with the value determined some years earlier by the Rev. Robert Thompson[59]. Modern theory predicts an apparent diameter of Mercury at mid-transit of 9.956".

In 1878, Plummer was employed at Orwell Park Observatory. Only the ingress phase of the transit was visible from the UK as the Sun set before the event finished. He reported (Plummer, 1878c) observing the transit under unfavourable circumstances: from midday, cirrus cloud spread over the sky, gradually becoming increasingly dense. Fortunately, around the time when the transit started (some three hours before sunset), the clouds thinned and, although limb definition was poor, he was able to observe the Sun with the equatorial refractor using *a slightly tinted glass* and to estimate the times of 1st and 2nd contact. His description of the quality of his timings betrayed thinking that was, perhaps, wishful. Around the times of contact, the Sun was *well seen* but limb definition was *very bad and unsuited for scrutinising the phenomena of contact*. He considered his timing of 1st contact was *very good* but that it could be three or four seconds late *as the undulations of the limb were so considerable that a little hesitation could hardly be avoided*. Regarding 2nd contact he stated: *owing to the violent motion* [of the limb] *it is possible that this timing is one or two seconds too soon…* In fact, limb definition was so poor that he did not attempt to make micrometer measurements. Table 9 compares his empirical estimates of contact times with modern theoretical values.

Phenomenon	Plummer's Empirical Timing (GMT)	Modern Calculation (UT)
1st contact	15:11:34.2	15:11:25
2nd contact	15:14:19.7	15:14:33

Table 9. Plummer's empirical event times and modern theoretical estimates for the transit of Mercury, 1878.

His estimate of 1st contact is later than the modern theoretical result and his estimate of 2nd contact is earlier: this is not unexpected for visual observations made under conditions of poor limb definition. He noted that, at 2nd contact, the limb of Mercury appeared to disengage from the solar limb more suddenly than anticipated (the opposite of the "black drop" effect), writing: *there was the reverse of clinging… the planet disengaged itself from the limb more suddenly and rather earlier than the progress of the phenomenon led the observer to anticipate*. He claimed to remember seeing the same phenomenon during the 1868 transit, but was clearly in error as the ingress phase of the earlier event was not visible from the UK. He could discern no black drop, ligament, bright spot, aureole or other effects around the time of 2nd contact.

The final paragraph in his report of the 1878 transit (quoted in full below) is intriguing: he claimed that the silhouette of Mercury was visible against the solar corona before 1st contact. Papers in the archive of the NASA/Smithsonian ADS[60], recommending techniques to observe the transits of Mercury in 1868 and 1878 or reporting observations of them, help to place the claim in context. See also the review by Baum (2012).

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[58] In fact, the text is not entirely clear at this point. The value quoted by Plummer (1868b) is 18.693", presumed to be a misprint with a spurious leading "1". The apparent diameter of Mercury during March 1868 varied from a minimum of 8.2" to a maximum of 10.9".

[59] The Rev. Robert A. Thompson (1822-94) was Durham Observer 1846-49.

[60] National Aeronautics and Space Administration / Smithsonian Institute Astrophysics Data System accessible over the internet at http://adsabs.harvard.edu/index.html.

A search of the archive in April 2007 uncovered 59 such papers; table 10 shows how they treated observations of Mercury silhouetted against the corona. In 1868, astronomers clearly had no expectation of making such an observation. Huggins (1868a) was the only author to mention the subject, and he dismissed it casually, his main topic being a report of a bright aureole around the silhouette of the planet and a luminous point of light close to the centre of the planetary disk. He observed both phenomena consistently until the silhouette of Mercury left the solar disk, after which the planet was no longer visible. Ten years later, things had changed considerably and, in early 1878, the editor of *The Observatory* (1878) encouraged observers of the forthcoming transit to *examine carefully whether the planet could be seen outside the Sun*. Four observers reported searching for Mercury's silhouette against the corona unsuccessfully and three, amongst them Plummer, reported searching successfully.

Visibility of Mercury Silhouetted Against the Corona	**05 November 1868**	**06 May 1878**
Not mentioned	26 references: List A.	23 references: List B.
Published before the transit, encouraging observers to search for the silhouette	No references.	One reference: *The Observatory* (1878).
Observed transit and reported unsuccessful search for the silhouette	One reference: Huggins (1868a).	Four references: Macdonnell (1878), Pritchett (1878), Lindsay (1878), Ranyard (1878).
Observed transit and reported successful search for the silhouette	No references.	Five references: Plummer (1878c), Langley (1878a, 1878b, 1878c), Lindsay (1878).

Table 10. References addressing the visibility of Mercury against the corona.

List A: Abbott (1869), Airy (1868), Barneby (1869), Browning (1868), Buckingham (1868), Knott (1868), Lassell (1868), Maclear (1869), Mann (1869), Noble (1868), Nursing Row (1869), Penrose (1868), Piazzi Smyth (1868), Plummer (1868b), Pratt (1869), Prince (1868), Prowde (1869), Selwyn (1868), Secchi (1868), Stone (1868), Talmage (1868), *The Astronomical Register* (1868a, 1868b), Todd (1869), Whitley (1869) Williams (1868).

List B: Airy (1878b), Brett (1878), Chambers (1878), Cole (1878a, 1878b), de Konkoly (1878), Grant (1879), Hall (1878), Jenkins (1878), Ledger (1878), Mathison (1878), Noble (1878), Penrose (1878), Prince (1878), Pritchard (1878a, 1878b), Proctor (1878), Tebbutt (1878), Todd, C. (1878), Todd, D. P. (1878), von Ertbon (1878), Waldo (1878), Young (1878).

Note that the report by Lindsay (1878) summarises the experiences of six observers at his observatory at Dunecht, near Aberdeen. One observer succeeded in detecting Mercury off the solar disk, while five did not. The paper is thus listed in both successful and unsuccessful categories.

Table 11 summarises reports in 1868 and 1878 of attempts to observe Mercury silhouetted against the corona. The observation was clearly challenging. Lindsay, observing through thin cloud with an imaging spectroscope, reported seeing the silhouette approximately 14 seconds before 1st contact. Langley enjoyed exceptional skies and, observing with a polarising eyepiece, reported seeing the silhouette approximately 30 seconds before 1st contact. Several skilled observers, using equipment comparable to or better than Plummer, searched for but failed to observe the phenomenon. Plummer's wife, Marion, using the Orwell Park equatorial refractor with a slightly tinted glass claimed to see the silhouette of Mercury approximately 134 seconds before 1st contact, while Plummer, using the same equipment, reported detecting the silhouette 60 seconds later.

Observer	Location	Details of Search for Mercury off the Solar Disk	
W. Huggins	Tulse Hill, South London	Sky/seeing:	*The Sun's edge was a little tremulous from atmospheric agitation, but the solar surface was so well defined that the bright granules of which it is composed could be distinctly seen.*
		Equipment:	200 mm refractor with prismatic solar eyepiece. Magnification 120x and 220x. Sliding wedge of neutral tint glass.
		Results:	After Mercury passed off the solar disk, *...the form of the planet was no longer visible to serve as a guide to the eye*.
W. J. Macdonnell	Sydney, NSW, Australia	Sky/seeing:	Definition poor *owing to low altitude of the Sun, and unsteadiness of the air...*
			…not very favourable for successful observing, a good deal of haze and clouds impairing telescopic vision.
		Equipment:	110 mm refractor. Magnification 100x - 180x.
		Results:	*…the planet completely disappeared as it glided off the Sun's face…*
C. W. Pritchett	Morrison Observatory, Glasgow, MI, USA	Sky/seeing:	Edge of Sun's disk *clearly defined and remarkably steady*.
		Equipment:	310 mm refractor stopped down to 180 mm. Magnification 275x. Blue glass filter.
		Results:	Pre-ingress: *With my utmost scrutiny I could detect no trace of the outline of the planet projected on the solar corona…*
			Post-egress: *The search for the planet outside the Sun's disk was again unsuccessful…*
H. J. Carpenter (in Lindsay, 1878)	Dunecht Observatory, Aberdeen	Sky/seeing:	*The sky was until first contact covered with thin clouds, which were at times sufficiently thick greatly to diminish the Sun's light.*
			Before 2^{nd} contact, the sky had cleared and definition was good.
		Equipment:	330 mm Newtonian with unsilvered mirror. Magnification 171x.
			380 mm refractor stopped down to 250 mm. Magnification 380x. Merz polarising eyepiece.
		Results:	Using 330 mm Newtonian and 380 mm refractor: *I could not see Mercury outlined against the sky… The images were very bad…*
A. C. Ranyard (in Lindsay, 1878)	Dunecht Observatory, Aberdeen	Sky/seeing:	As above.
		Equipment:	95 mm refractor with spectroscope. 380 mm refractor stopped down to 250 mm. Magnification 244x. Merz polarising eyepiece.
		Results:	Before 1^{st} contact: used the spectroscope to search for Mercury in red light for 10 minutes. Swept the view in the spectroscope in RA outwards from the Sun looking for any change in intensity of the field marking the position of the planet. Detected no indications of the presence of the planet off the Sun's disk.
			Between 1^{st} and 2^{nd} contact: could detect no portion of the planet off the Sun's disk using either the spectroscope or the 380 mm refractor.
Lord Lindsay	Dunecht Observatory, Aberdeen	Sky/seeing:	As above.
		Equipment:	150 mm refractor with a direct vision prism and spectroscope giving an image of the Sun's limb and chromosphere.
		Results:	Glimpsed the planet silhouetted against the corona 14 seconds before 1^{st} contact.

Observer	Location	Details of Search for Mercury off the Solar Disk	
S. P. Langley	Allegheny Observatory, PA, USA	Sky/seeing:	*An unusually blue and transparent* sky at ingress.
		Equipment:	330 mm refractor, stopped down to 230 mm, with a polarising solar eyepiece.
		Results:	Observed the disk of Mercury outside the solar disk about half a minute before 1st contact. Speculated that it would have been possible to see the planet even earlier had he known exactly where to look.
J. I. Plummer	Orwell Park Observatory	Sky/seeing:	Haze. Cirrus cloud. Around the times of contact the Sun was *well seen.* However limb definition was *very bad and unsuited for scrutinising the phenomena of contact*. The limb suffered from undulations which were *considerable* and from *violent motion*.
		Equipment:	258 mm refractor, full aperture employed. Magnification 303x. Slightly tinted glass.
		Results:	Plummer's wife saw Mercury 2m 14s before 1st contact and Plummer saw the planet one minute later: *My wife, who assisted me at the observation, first detected the planet against the solar corona, though I had previously looked for it in vain. On taking my station at the telescope a minute later I also detected it, dimly visible, but sufficiently so to direct my attention to the exact point where contact was to take place, and to lead me to suppose that, but for the clouds through which the observation was made, it would have been fairly conspicuous.*

Table 11. Reports of attempts to observe Mercury against the corona.

Plummer likely realised the exceptional nature of his claim and, perhaps in self-justification, responded (Plummer, 1879b) to Langley in the pages of *The Observatory*. He noted that Langley had enjoyed an atmosphere of excellent transparency, which meant that light scatter did not significantly mask the difference in intensity between Mercury and the corona. Definition was at best moderate, but the quantity of light transmitted was maximised, a situation that astronomers preferred for glimpsing faint objects such as nebulae. Conversely, at Orwell Park, he saw Mercury *most sharply cut against the corona*. The sky was hazy, but a certain amount of haze was beneficial in terms of definition and was most favourable for judging slight differences of light intensity – and it was to this, together with *the fine optical qualities of the telescope*, that he attributed his success. However, he was disingenuous: although he admitted that the sky was hazy, he did not mention the *very bad* limb definition and the *violent motion* of the limb that he had endured. He returned briefly to the subject in his annual report to the RAS for 1878 (Plummer, 1879a), writing that his observation *afforded gratifying proof of the excellence of definition of the object glass.*

Plummer's claim is fanciful, and it appears that he was guilty again of wishful thinking in his observations of Mercury. It is simply not plausible that he observed, under *unfavourable conditions*, through a haze of cirrus cloud, with the limb suffering *very bad* definition and *violent motion*, the silhouette of the planet off the solar disk. Had Marion Plummer done so, 134 seconds before 1st contact, it would imply that she possessed exceptional eyesight and was skilled in observing: yet she was not known to be an astronomer and is not mentioned in any other observing report.

In modern times, members of OASI used the Orwell Park refractor to observe the transits of Mercury on 07 May 2003, 09 May 2016 and 11 November 2019 and transit of Venus on 08 June 2004 and were prevented by dense cloud from observing the transit of Venus of 06 June 2012 (Appleton, 2003, 2005, 2012, 2016, 2019). The observers employed projection around the times of initial and final contact and were therefore unfortunately unable to search for visibility of either planet off the solar disk.

A4 Venus

In the 1870s and 1880s, astronomers were greatly interested in Venus due to the transits of the planet on 09 December 1874 and 06 December 1882. They hoped that careful timings of the events would, when analysed, provide an improved estimate of the solar parallax and the scale of the solar system. Plummer shared in the general interest in Venus and, during 1873-77, published four papers about the planet and mentioned it in four of his annual reports to the RAS. He observed it at Durham Observatory, at Orwell Park Observatory and as leader of the expedition sent by the ROG to Bermuda to observe the 1882 transit.

A4.1 Ellipticity Of Venus

Plummer's first paper on Venus (Plummer, 1873a), published while he was at Durham Observatory and communicated to *MNRAS* by the Rev. Professor Farrer, DD, looked forward to the 1874 transit of the planet. The event would provide an opportunity to measure the planet's ellipticity, a parameter of practical importance that, if it were as great as the ellipticity of Mercury or Mars, would affect the determination of the length of the AU. He believed that the ellipticity of Venus was likely to be small and this would make the measurement difficult. He therefore recommended that fixed observatories, rather than the expeditions being organised to observe the transit, undertake the measurement, since the former generally had much larger instruments at their disposal. He believed that there were sufficiently many observatories in the British Empire positioned to undertake the measurement, but they were not in general equipped with the necessary large heliometers[61]. It would not be possible to provide such instruments to observatories lacking them in time for the transit, but it would be possible to supply portable Airy double image micrometers at relatively short notice and he believed that such instruments *would probably give us reliable results*.

Clearly, his argument was not entirely consistent: he recommended that fixed observatories undertake the measurement because they generally had larger instruments, but as most, in fact, lacked suitable instruments they should use relatively small portable instruments instead. He was though correct in one key aspect of the paper: the ellipticity of Venus is indeed small. The modern value is exactly zero, i.e. the apparent figure of the planet is circular (Seidelmann, (ed.), 1992). In any case, the paper had no discernible impact on preparations by astronomers to observe the transit.

Plummer went on in the paper to consider the apparent diameter of Venus: this aspect is considered below.

A4.2 Apparent Diameter Of Venus And Effect Of Irradiation

Plummer (1873a, 1873b, 1877b) addressed the apparent diameter of Venus and the effect of irradiation in three papers in *MNRAS*. His observing notebook in the Durham Observatory archive (Plummer, 1879c) provides additional insight. He drew on the work of the Rev. R. Main at the ROG and it is worth first considering this first, to provide context for his method.

Main (1856) provided a summary of estimates of planetary apparent diameters that he had made at the ROG, using an Airy double-image micrometer, from 1840, the year of invention of the apparatus, until 1851. In estimating the diameter of Venus, he took account of irradiation and therefore considered separately observations made during the day and in the evening. (Daytime and evening are, of course, generally associated with differing levels of sky brightness and therefore potentially differing amounts of irradiation.)

For purposes of analysis, Main grouped the daylight observations into two sets: those made while the planet was near inferior conjunction and those made while it was near superior conjunction. He formed an equation from the data in each set and solved them to provide an approximate estimate of the (true) apparent diameter of the planet at unit distance (1 AU) and the augmentation due to irradiation (denoted here D and x respectively). He also performed a full regression analysis of the

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[61] A heliometer is an equatorially mounted, double-image micrometer (see appendix 22) used originally for measuring the diameter of the Sun at different seasons throughout the year.

data. Table 12 presents his results. The quantity d is an estimate of the diameter of the planet that would be measured by a visual observer affected by irradiation.

Parameter	Estimate by Solving Eqns. (")	Regression Estimate (")
D	17.61	17.55
x	-0.61	-0.50
d (=D+x)	17.00	17.05

Table 12. Estimates by Main of the apparent diameter of Venus.

His estimates of the constant of irradiation were negative, implying that the visual observer reported a diameter smaller than was in reality the case. He believed that this was due to the *feebleness of the light at the cusps and borders of the planet*, which caused the observer to record not the true planetary limb, but a point lying within it by approximately 0.25", and asserted that this was *a result which might have been in some degree expected*. He found the evening measures of the diameter of Venus to be *totally free from the effects of irradiation*. As Venus is such a bright planet, this result was *startling and unexpected* and, perhaps as a result, he did not publish an analysis of the evening observations.

Plummer (1873a) reported making, between 19 March and 20 June 1868, a series of estimates of the diameter of Venus using a double image micrometer. His final estimate of the diameter of the planet at unit distance, based on 28 observations each of 12 contacts, was D=17.695", very slightly larger than Main's estimate. However, his estimate of the coefficient of irradiation was *considerably larger* than Main's and, for this reason, he did not publish the work.

A modern regression analysis of the data in his observing notebook, fitting the model

$$d = D/\Delta + x \quad (1)$$

where D, x and d are defined above and Δ represents the distance between Venus and Earth (calculated using the modern ephemeris DE-405), gives an excellent fit (adjusted coefficient of determination $R^2 = 0.9993$) and provides estimates for the coefficients D=17.83" and x=-1.57". This essentially validates his estimate D=17.695" and confirms that the value of irradiation associated with his early observations was indeed large and negative[62].

He repeated the observations with *greater care and precaution*, finding in a preliminary analysis that the new estimates confirmed the earlier results. The data suggested that estimates of the diameter of Venus at unit distance, made by Encke and Stone and in widespread use at the time, were too small. Encke's estimate, 16.61", was based on the analysis of observations of the 1791 transit of Venus. Stone's estimate (Stone, 1865), 16.944", was based on 589 estimates of the vertical diameter of the planet made by observers at the ROG using Troughton's Mural Circle and the Great Transit Circle during 1839-62. Astronomers regarded Stone's estimate highly (for example, Dunkin (1873) referred to it as *the best possible modern determination*) and Plummer displayed some temerity in his challenge of it.

In his second publication on the apparent diameter of Venus, Plummer (1873b) reported continuing the earlier work. He discarded the 1868 data and made a new set of measurements during the period 18 February - 23 July 1873 with the Airy double image micrometer. Conscious of the need to tread carefully in casting doubt over Stone's work, he took precautions to assure the quality of his measurements. He relied upon an initial calibration of the micrometer screw made over four evenings in 1868, prior to the first series of measurements. He endeavoured to achieve a steady image by equalising the air temperature in the observing room with the ambient temperature and rejected observations made when the definition of Venus was poor. He used an eyepiece providing a

[62] Plummer's published paper is not entirely consistent with his observing notebook. The latter indicates that, during 1868, he observed with the double image micrometer from 05 March until 19 June inclusive, making 30 estimates of the diameter of Venus, only 27 of which were between 19 March and 19 June. The apparent confusion over the precise set of observations may be responsible for the slight disagreement over the estimates of D.

magnification of 113x and made all measurements in full daylight with the planet near the meridian, correcting his estimates for the effect of differential atmospheric refraction on the cusps of the planet. He made 26 measurements and fitted the model (1) to the data, using the *Nautical Almanac* to calculate values of Δ. To minimise the complexity and labour of the calculations, he followed Main's approach and categorised the observations into two groups as follows:

- Group 1: 26 March - 16 June, Venus relatively close to Earth, around inferior conjunction.
- Group 2: 18 February - 12 March and 18 June - 22 July, Venus relatively distant from Earth.

He calculated the average values of d and 1/Δ associated with each group and formed two equations that he solved for D and x. The average temperatures associated with the groups were similar (56.1°F and 58.1°F) effectively nullifying possible linear effects of temperature on the estimates. Table 13 compares his results with those of a full regression analysis to fit model (1).

Parameter	Plummer's Estimate (")	Regression Estimate (")
D	17.321	17.260
x	-0.546	-0.423
d (=D+x)	16.775	16.837

Table 13. Estimates of the apparent diameter of Venus.

His estimate of the true apparent diameter of Venus at unit distance, 17.32", is slightly larger than the modern value, 16.82" (referring to the cloud tops (Meeus, 1991)). His estimate of the constant of irradiation, like that of Main, was negative.

The regression model achieves a very good fit, with adjusted coefficient of determination $R^2 = 0.9993$ (coincidentally the same value as for the 1868 data). The residuals of the model exhibit no apparent association with temperature, confirming Plummer's conclusion that *The results, however, do not appear to indicate that any sensible change* [in the value of irradiation due to temperature] *actually exists*.

Plummer examined in detail the residuals associated with model (1) and, although they were generally small (maximum absolute value 0.66"), he provided anecdotal evidence as follows to suggest that the transparency of the sky could influence irradiation and explain them, at least in part:

- During the first five observations, *the sky was unusually clear* and the measured diameter of Venus was greater than anticipated. (His empirical measurements exceeded the corresponding estimate of model (1) by an average 0.31".)
- During the observations on 17 June, 18 June and 23 July *the sky was hazy* and the measured diameter of Venus was smaller than expected. (His empirical measurements were lower than the estimate of model (1) by an average 0.35".)

He did not regard the anecdotal evidence as conclusive proof of an association between the transparency of the sky and irradiation and, indeed, noted contradictory cases. However, he clearly believed that such a link did exist and referred to it in his annual report to the RAS for 1875 (Plummer, 1876a) and in a further investigation of the effect of irradiation (Plummer, 1877b) (discussed in detail below).

Unfortunately, his published comments on meteorological conditions during the 1873 measurements are not faithful to the entries in his observing notebook and it seems that, in attempting to support the hypothesis of a link between the transparency of the sky and irradiation, he gave a biased interpretation of his notes. For example, his notes for 02 March 1873 state simply *Good, steady*, yet the published paper includes the observations amongst those covered by the remark *I have noted that the sky was unusually clear*. His observing notebook also contains several more exception cases to the hypothesis than he acknowledged in the paper. His 1868 observing notes further undermine the hypothesis: in particular, the three days in 1868 on which he recorded the sky as hazy (03 April, 03 May and 29 May) are all associated with empirical measurements of the diameter larger than predicted, the opposite result to that found in 1873. The state of the atmosphere clearly had a less predictable effect on irradiation than he believed and it is unfortunate that, although he could have estimated the transparency of the sky on a quantitative basis and undertaken further analysis to investigate the suspected association with irradiation, he did not do so.

Another problematic aspect of his approach is the assumption that irradiation may be represented as a constant, above denoted x, independent of the Earth-Venus distance, Δ. Figure 22 shows a direct estimate of irradiation, formed from Plummer's measurement of the diameter of Venus minus the corresponding value from the ephemeris DE-405, together with the value of 1/Δ, for each of the observations in 1868. The 1873 data shows a broadly similar relationship. The figure strongly suggests that the value of irradiation cannot be well represented by a constant and is much better represented by a model of the form

$$x = P/\Delta + Q \qquad (2)$$

where P and Q are constants. Fitting the model (2) via a regression analysis yields a good fit, with adjusted coefficients of determination $R^2 = 86.7\%$ for the 1868 data and $R^2 = 62.3\%$ for the 1873 data. Unfortunately, this demonstrates that one of the basic assumptions underpinning Plummer's data reduction was too simplistic, and that a more sophisticated analysis would have been appropriate.

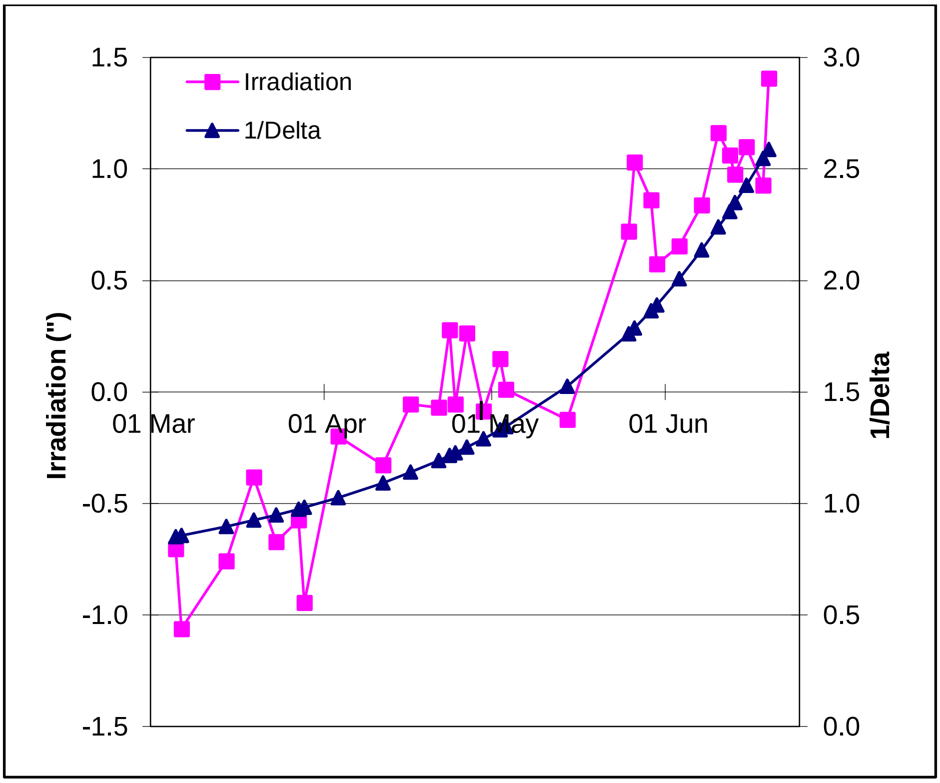

Figure 22. Irradiation and reciprocal Earth – Venus distance (1/Delta).

Plummer's third paper on estimation of the apparent diameter of Venus and the effect of irradiation was written in response to a call for observations by Dunkin (1876) in *MNRAS*. Dunkin reported that Dr. Carl Krüger[63] of Helsinki had drawn the attention of Airy to a forthcoming apparent close approach of Venus to the star λ Geminorum on the morning of 18 August 1876. He believed that a series of measures of the apparent distance between planet and star made in both hemispheres *would be of some importance*. Although he did not elaborate, it is likely that he intended to use the observations to estimate the distance from the Earth to Venus.

In Europe, the closest approach would occur after sunrise but Dunkin hoped nevertheless that astronomers with large telescopes would be able to make measurements. To assist potential observers, he published a table listing the geocentric apparent position of the planet and star for each hour from 04:00 to 12:00 GMT on 18 August 1876. His paper provides an opportunity to assess the accuracy of

[63] Carl Nicolaus Adalbert Krüger (1832-96) was Professor of Astronomy and Director of Helsinki Observatory.

the astrometry and ephemerides of the day. His position for the star differed by only 0.15^s in RA and 0.11" in declination from a modern calculation of its position for the epoch in question, based on astrometric data in the Hipparcos Catalogue. However, astronomers of the era did not have as accurate a command of planetary motion as of stellar positions and his figures for the RA and declination of Venus were respectively 1.2^s greater and 0.73" greater on average than those calculated using the modern ephemeris DE-405.

Plummer replied to Dunkin's paper with an observing report and analysis. The apparent closest approach of the two bodies as seen from Orwell Park Observatory occurred at 10:04 GMT on 18 August 1876. He began his observations at approximately 04:00 GMT, by which time Venus had attained an altitude of 20°, and continued until cloud obscured the sky at 06:46 GMT. His results spanned the period 04:27:16 - 06:39:56 GMT. He used the Orwell Park refractor and a parallel wire micrometer with a power of 315 to measure differences in the declination of the planet and star.

He had hoped to achieve an average measuring error better than 0.1" but, unfortunately, found that sky conditions were so poor that both the star and planet were ill defined. He believed that his measurements were not sufficiently accurate for their original purpose and instead analysed the data to estimate the irradiation of Venus. His logic here appears flawed, as a worthwhile study of irradiation would require measures of position no less accurate than those necessary to estimate the parallax of the planet. Nevertheless, summarising his efforts in his annual report to the RAS for 1876 (Plummer, 1877c), he recorded a *partial success* and stated that *some facts were elicited that have been thought of sufficient interest to merit the notice of astronomers.* He proceeded as follows.

1. He made ten estimates of the difference in declination between the limb of Venus and λ Geminorum (measured in the sense limb minus star). Denote the estimates D_i for i=1,…,10. His estimates alternated between the north limb (NL) and the south limb (SL) of the planet so that D_i for odd i referred to the NL and for even i referred to the SL. He formed each estimate from five individual comparisons of declination made with the parallel wire micrometer. He assigned a weight (confidence factor) to each estimate based on the condition of the sky at the time.
2. He converted each of the ten estimates to a difference in north polar distance (NPD), N_i, and applied a correction for atmospheric differential refraction, R_i, i.e. $N_i = -(D_i + R_i)$ for i=1,…,10. (The refraction corrections made no significant difference: the maximum absolute value of R_i was 0.141".)
3. He used the *Nautical Almanac* to calculate theoretical estimates, T_i for i=1,…,10, of the difference in NPD corresponding to each of his observational estimates. Astronomers of the era were uncertain of the precise value of the apparent semidiameter of Venus and in calculating the T_i he adopted the value of 8.698" at standard distance 1 AU (slightly larger than the modern figure of 8.41" (Meeus, 1991)). He stated that this value was *very slightly larger than that determined by myself with the double-image micrometer in 1873 (8.661"), but is less than the well-known determination of Mr. Maine* [sic] *(8.775").*
4. He calculated the discrepancies X_i between observed and theoretical estimates of the differences in NPD: $X_i = N_i - T_i$ for i=1,…,10. The probable error of the estimates D_i did *certainly not exceed 0.21*", implying that the measurements made with the micrometer had a relatively low variability and were repeatable. However, the X_i were much larger in absolute value (mean and maximum absolute value respectively 0.6" and 1.6") implying that they could not simply be accounted for by statistical variability and therefore some causal explanation was required. He proposed that irradiation was responsible for the discrepancies, and interpreted the quantities $-X_i$ for odd i and $+X_i$ for even i as estimates of its effect.
5. He then calculated X as a weighted sum of the X_i and formed the quantities Y_i as follows:

   $$Y_i = -(X_i - X) \text{ for } i = 1, 3, 5, 7 \text{ and } 9 \text{ (NL)},$$

   $$Y_i = +(X_i - X) \text{ for } i = 2, 4, 6, 8 \text{ and } 10 \text{ (SL)}.$$

   The Y_i represent the variation of irradiation about the value X. (Note that the value of Y_2 on p.104 of Plummer (1877b) is a misprint: the figure quoted as +0.806" should read +0.826".)
6. The Y_i exhibited considerable random variation, so, to make the underlying trend more easily visible, he aggregated them into four groups and calculated a weighted mean for each, using as weights the confidence factors for his observations. The resulting quantities W_i for i = 1, 2, 3,

4 represented in sequence the apparent excess of the semidiameter of Venus over the value X throughout the observing period as follows.

W_1: = wtd mean{Y_1, Y_2}	before sunrise,
W_2: = wtd mean{Y_3, Y_4, Y_5}	after sunrise with the Sun at low altitude,
W_3: = wtd mean{Y_6, Y_7, Y_8, Y_9}	Sun above the horizon haze,
W_4: = Y_{10}	observing through cirrus cloud.

7. He concluded that the W_i indicated a general, gradual decrease in the irradiation of Venus as the sky brightened and a more sudden drop around sunrise (which occurred at Orwell Park Observatory at 04:44 GMT). The effect of the cirrus cloud at the end of his observations was to diminish significantly the apparent planetary semidiameter. His analysis also showed that the irradiation of the planet varied significantly on a timescale of minutes.

He provided a tabulation of the main steps in his data reduction and it is possible to rework the calculations. Unfortunately, this reveals serious problems. He believed that it was possible to estimate the irradiation independently of the assumed theoretical value of the semidiameter of the planet, writing: *In comparing the observations with the ephemeris we may obviously employ whatever value of the planet's semidiameter we please…* Clearly, this is not true for individual estimates of irradiation. It would have been true in an average sense had he calculated the quantity X as the mean of the X_i; unfortunately, he did not do so, instead mistaking the sign of the X_i for odd i. As a result, the quantity X had no useful physical interpretation, the Y_i were calculated as offsets from this quantity and, most serious of all, any error in the assumed semidiameter of the planet propagated through the subsequent calculations into errors in the estimates of irradiation.

It is possible to salvage something from his analysis by omitting the calculation of the value X and the subsequent focus on variability about it. Let $Q_i = -X_i$ for odd i and $+X_i$ for even i; the Q_i for i=1,…,10 are then raw estimates of irradiation. The Q_i exhibit significant random variation that masks any obvious trend other than the sharp decline towards the end of the observations. Forming the weighted means of groups of Q_i (choosing the same groupings and weights used by Plummer in calculating the W_i) reduces the random variation and makes the trend visible. Let the weighted means be:
Z_1 = wtd mean{Q_1, Q_2}; Z_2 = wtd mean{Q_3, Q_4, Q_5}; Z_3 = wtd mean{Q_6, Q_7, Q_8, Q_9}; $Z_4 = Q_{10}$.

Figure 23 illustrates Plummer's estimates Y_i and W_i together with the estimates Z_i calculated using the ephemeris DE-405 and Hipparcos Catalogue for astrometric positions of Venus and λ Geminorum respectively. For ease of comparison, the figure shows all estimates as absolute values. By construction, the Z_i are in this form; Plummer's figures have been adjusted to exhibit them as such, rather than as values relative to the quantity X, which is how he presented them.

Although the modern analysis produces a smoothed estimate of irradiation larger than Plummer's, it confirms his conclusion that the empirical semidiameter of Venus decreased as the sky brightened, that the cirrus cloud at the end of the observations caused a significant reduction in irradiation and that the latter could alter markedly over a period of minutes.

Unfortunately, Plummer's three papers on the apparent diameter of Venus and the effect of irradiation do not present a coherent whole, but represent, rather, individual, unrelated pieces of work. Although they highlighted several areas of potential future investigation, he did not appear to undertake any further work in the area, and published no papers on Venus or irradiation after 1877.

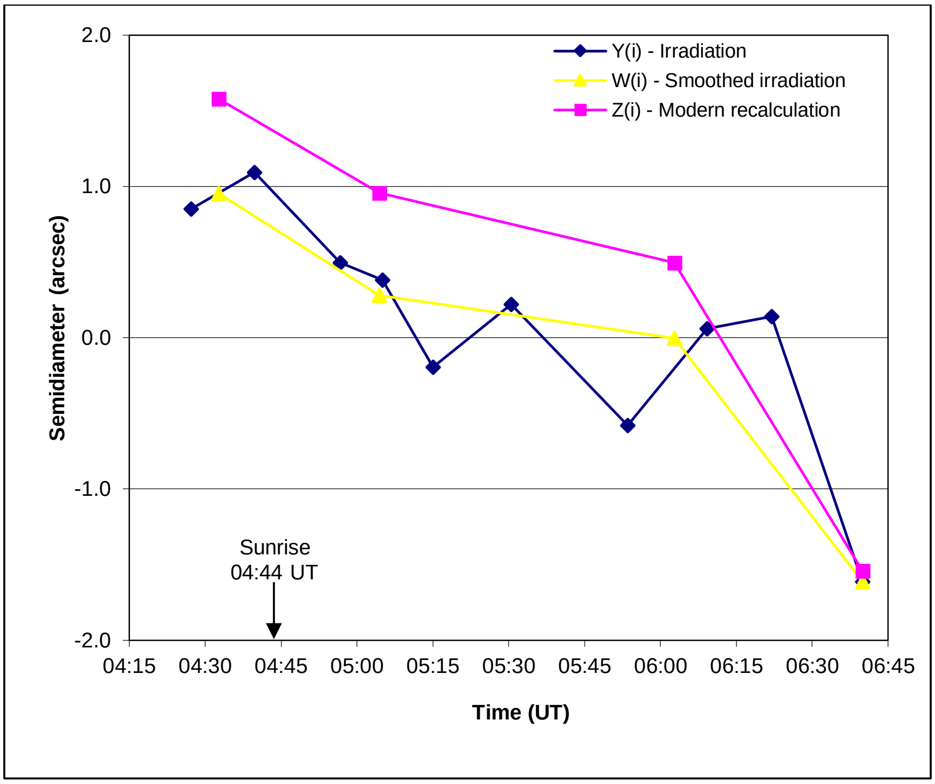

Figure 23. Estimates of irradiation of Venus.

A4.3 Brilliance Of Venus

In a paper that displayed considerable ingenuity, Plummer (1876b) noted that although Venus and Jupiter when at their brightest were capable of casting shadows, astronomers had not used this fact to compare the intensity of their light with that of the full moon or with any terrestrial light source. He set out to determine whether it was possible to use simple equipment rather than an expensive photometer to investigate the brightness of Venus and its variation as a function of the phase of the planet. He noted that several famous astronomers had addressed the problem of estimating the relative brightness of planets, but they had generally paid little attention to Venus due to its apparent proximity to the Sun.

He constructed a simple shadow photometer, comprising a reference light source, two identical 1.8 mm diameter wire rods and two identical white paper screens. (His photometer was a modification of the standard Rumford photometer, in which he replaced the customary single rod and paper screen with two of each.) He placed each wire rod 2.7 m in front of the associated screen and housed the rods and screens in a dark room. He arranged for the reference light source to cast a shadow of one rod onto one screen and for Venus to cast a shadow of the other rod onto the other screen. He operated the instrument by adjusting the distance of the reference light source such that the shadows were of equal intensity. The inverse square of the distance of the reference light source provided a measure of the brightness of the planet. He used a standard spermaceti whale oil candle, burning eight grams of oil per hour[64], as reference light source. For protection from the elements, he placed the candle inside a lantern, open on one side, in turn inside a wooden box, painted black on the inside, also open on one side.

Before attempting to make measurements with the photometer, he conducted trials to check that it operated satisfactorily. On 29 March 1876, with a four-day-old Moon situated only 12° distant from Venus, he observed the shadows cast by the two bodies simultaneously on the same screen and noted that the shadow cast by Venus was *conspicuous*. Further, he found that when direct moonlight was excluded from the observing room, even Sirius, with a light intensity only roughly 1/9th that of Venus,

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[64] In the units of the era, the candle burned 120 grains of oil per hour. This was the reference light source of its time; in the early 20th century, standards bodies formalised its light output as the SI unit the *candlepower*.

cast *an appreciable shadow*[65]. He believed that the photometer would work with any planet brighter than Sirius, but did not apply it to Mars and Jupiter due to the difficulty of attaining a sufficiently great distance at which to place the candle. (He indicated in a later publication (Plummer, 1877d) that Sirius was the only star bright enough to cast a certain shadow on the photometer screen and that the maximum practical distance to the candle was 125 m.) As further verification, he noted that, on 26 April, he observed the light from Venus and a three-day-old Moon fall upon a plaster wall in the open air, each casting a *distinctly observable* shadow of neighbouring buildings.

Trials complete, Plummer reported eight observations of the brightness of Venus, made during the period 20 March to 13 May 1876. Unfortunately, one was spoilt by moonlight and another suffered from the planet being at low altitude. This left six observations of acceptable quality, for each of which the sky was *brilliantly clear* and the *equality of the shadows has been considered satisfactory by at least two persons*. (He did not reveal the identity of the persons.) He restricted his subsequent analysis to the six good measurements, proceeding as follows.

1. He tabulated the distance between candle and screen for each observation. By virtue of the laws of illumination, the inverse square of the distance acted as a measure of the intensity of the light of the planet. The distance was typically around 90 m, and he could determine it to within 2 m.
2. Using tables by Ludwig Seidel[66], he estimated the effect of atmospheric extinction on the light from Venus and corrected the brightness measurements to a standard altitude of 18° (approximately the mean altitude of the planet during his observations). He then averaged brightness measurements to produce estimates for 22 March, 17 April and 11 May, concluding that *Venus approaches its point of maximum brilliancy on June 6 very gradually indeed*.
3. He normalised the brightness estimates for the distances Venus-Sun and Venus-Earth on 11 May 1876, the date of his last satisfactory observation. This produced estimates of the brightness of the planet as a function solely of its phase.
4. Again by averaging, he estimated the brilliance of Venus at its mean phase, 60.3%, during his observations.
5. He extrapolated to predict the greatest brilliance of Venus.
6. He estimated the brilliance of the full moon, using a Bunsen photometer rather than a Rumford photometer. (The Bunsen photometer uses a paper screen with a grease spot placed upon it such that when illuminated equally from both sides, the spot appears neither lighter nor darker than the paper but becomes almost invisible. Plummer positioned the spermaceti whale candle on the other side of the screen to the Moon.)
7. By comparing his brightness estimates, he concluded that the light from Venus at greatest brilliance had an intensity 0.125% that of the mean full moon.

He searched the literature for related work and found a publication by George Bond[67] (1861) that gave the ratio of the light of Jupiter at mean opposition to that of the mean full moon as 1:6430, and the light of Venus at greatest brilliance to that of Jupiter at mean opposition as 4.864:1. Combining the two figures gave the ratio of the light of Venus at greatest brilliance to that of the mean full moon as 1:1322, or 0.076%. Plummer's estimate was more than half as much again as that deduced from Bond's work but, because the two studies had employed different methods and been conducted under different observing conditions, he was not discouraged by the magnitude of the difference.

Modern estimates (Ridpath, 1989) of the magnitudes of Venus at greatest brilliance and the mean full moon are -4.7 and -12.7 respectively, giving a brilliance ratio of 0.063%, close to the value deduced from Bond's work.

Plummer presented intermediate steps in his calculations and, unfortunately, they reveal a badly flawed analysis. Table 14 shows his empirical data and the initial stages of the analysis.

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[65] In remarkable contrast to what may be achieved in the light-polluted skies around Orwell Park nowadays!

[66] Philipp Ludwig von Seidel (1821-96) was a German mathematician.

[67] George Phillips Bond (1825-65) was director of Harvard College Observatory from 1859 until his death.

Date (1876)	Time (GMT)	Distance to Candle (m)	Venus Altitude (°)	Altitude Correction (to 18°)	Phase, v (°)	C (m^2)
20 Mar	20:40	88.59	12.7	1.76	114.9	45,240
24 Mar	20:44	101.96	13.5	0.96	113.1	32,770
14 Apr	20:52	87.25	19.7	1.41	102.5	35,290
21 Apr	20:59	80.39	20.3	1.93	98.9	40,820
23 Apr	21:06	80.77	19.6	1.93	97.9	41,330
26 Apr	21:22	93.27	17.8	1.15	96.4	32,740
11 May	21:46	83.95	15.5	1.91	84.1	44,110
13 May	22:26	95.77	6.6	2.33	83.2	70,200

Table 14. Plummer's measurements of the brightness of Venus.

Rows shaded in grey are those not taken forward in the analysis (due to interference from moonlight on 26 April and to the low altitude of Venus on 13 May). Columns one and two specify the date and time of the observation. Column three details the distance to the candle: the inverse square of this quantity provides an estimate of the brightness of Venus. Column four details the altitude of Venus at the time of observation and column five the correction factor to normalise the distance in column three to an altitude of 18°. (Plummer did not tabulate the correction factors but it is easy to deduce them from the other data presented.) Column six, *Phase, v*, is a measure of the proportion of the planetary disk illuminated: it is 180° ahead of the modern quantity *phase angle*, which is defined (e.g. Meeus, 1991) as the angle between the vectors Venus-Sun and Venus-Earth. It is probable that he calculated v from the *Nautical Almanac*. Column seven tabulates the quantity C, the square of the distance to the candle, normalised to an altitude of 18°. The table reveals several problems with the data and the initial stages of analysis:

- The altitude of Venus on 13 May at 22:26 GMT is given as 6.6°; the modern ephemeris DE-405 gives a figure of 9.3°. The corresponding correction factors to normalise the results to an altitude of 18°, from a modern formula for atmospheric extinction (Ridpath, 1989), are respectively 0.45 and 0.62 – significantly different. In any case, because of the low altitude, he did not take this observation forward in the analysis.
- The correction factors to normalise the observations to an altitude of 18° fluctuated wildly, without any obvious relationship to the elevation of the planet. For example, on 14 April and 23 April, the altitude of the planet was almost the same (19.7° and 19.6°) yet he employed quite different altitude correction factors, 1.4 and 1.9 respectively. Figure 24 plots altitude correction factors by Seidel (1862)[68], evaluated from a modern table of extinction values (Ridpath, 1989) and used by Plummer. Agreement between Seidel's values and the modern data is fair, but something is clearly very wrong with Plummer's figures!
- The empirical distances of the candle on 20 and 24 March appear discordant one with another. The distance on 20 March was only 87% of that on 24 March although, on the earlier date, Venus was at a lower altitude and inherently less bright, implying a distance expected to be greater. Figure 25 plots the value of C (square of distance to candle), normalised to an altitude of 18° using a modern formula for atmospheric extinction (Schlosser *et al*, 1991). It indicates that the observation of 20 March is suspect, corresponding to an over-estimate of the brightness of Venus; unfortunately, this error propagates into the conclusions. This highlights one of the fundamental problems with the approach: Plummer had no means of correcting for the transparency of the sky in his analysis. Had the photometer been just a little more sensitive, he could have used bright stars of known magnitude visible during the observations

[68] Plummer did not specify a reference for Seidel's extinction tables, so it is not certain that the values in the figure are those that he used.

(e.g. Sirius, Arcturus or Spica) as references against which to estimate the luminosity of Venus.

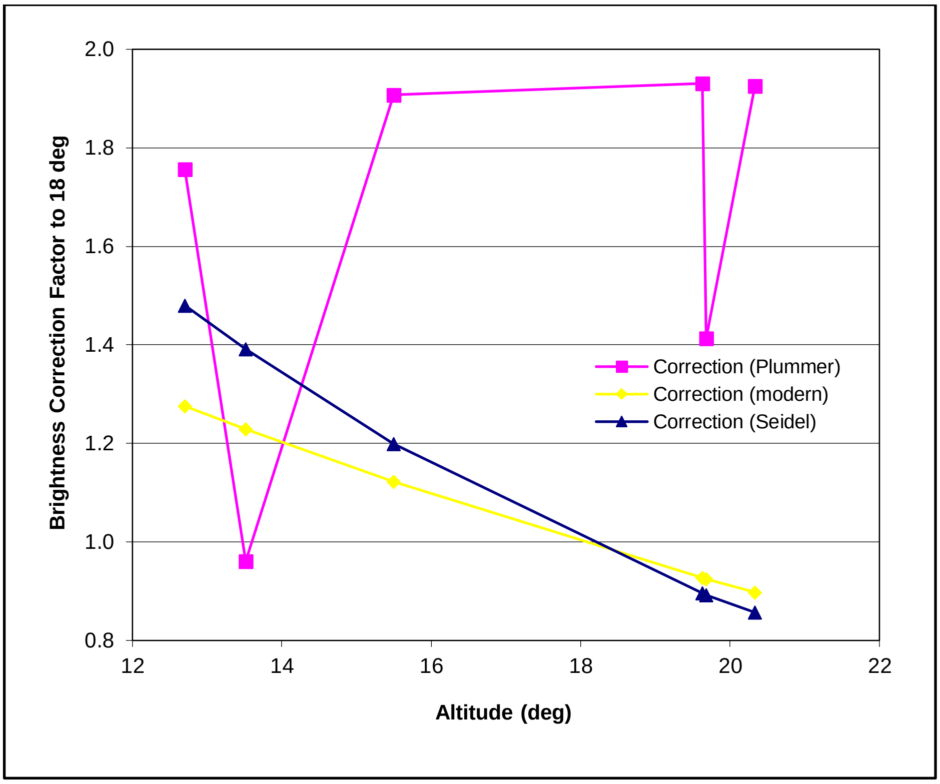


Figure 24. Altitude correction factors (normalised to reference altitude of 18°).

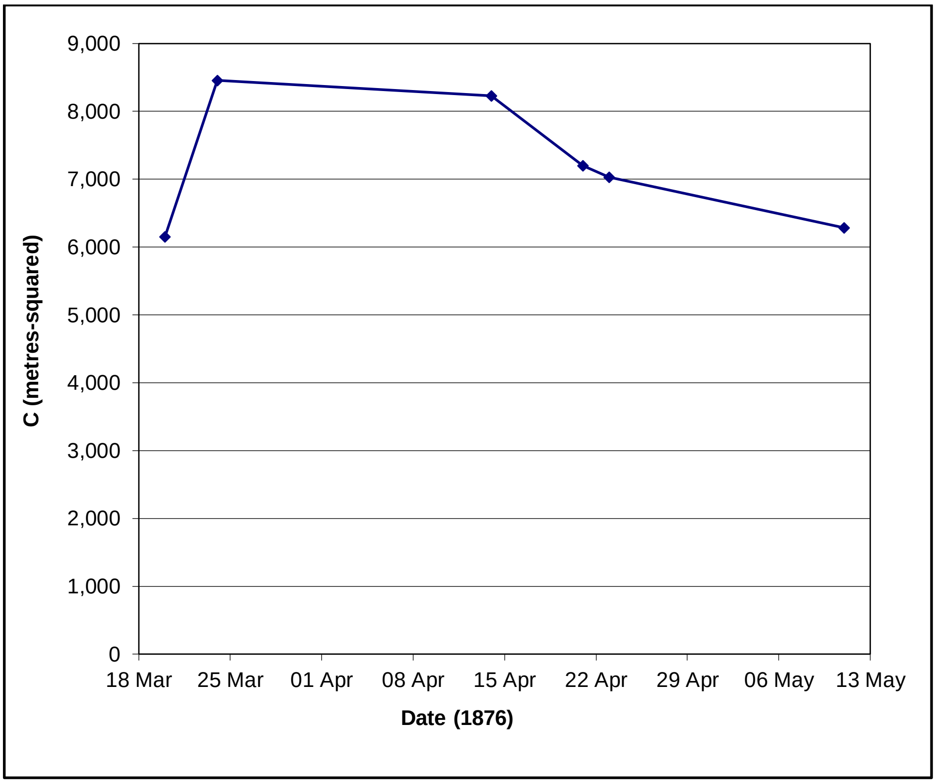


Figure 25. Squares of distances to the candle, normalised to an altitude of 18° using a modern formulae for extinction.

Unfortunately, as the analysis proceeded, further mistakes crept in. He averaged estimates of brightness on 20 and 24 March to estimate that on 22 March and averaged estimates on 14, 21 and 23 April to estimate that on 19 April. He then examined the rate of change of brightness from 22 March – 19 April – 11 May, concluding that *Venus approaches its point of maximum brilliancy on June 6 very gradually indeed*. Figure 26 compares his estimates of the brightness of Venus with estimates calculated using the modern ephemeris DE-405. (All data in the figure are normalised with respect to their values on 11 May.) His results show an increase over the period from 88% to 100%. Calculations using DE-405 indicate an increase from 80% to 100%, a considerably larger range. It appears, therefore, that his estimate of brightness on 20 March, as noted above, apparently greater than it should have been, contaminated the estimate for 22 March, in turn resulting in too low an estimate of the change in brightness over the period to 11 May. There are other difficulties too in following Plummer's analysis at this point, and it has proved impossible to relate the brightness estimates for 22 March, 19 April and 11 May to the data (in table 14) from which they were supposedly calculated.

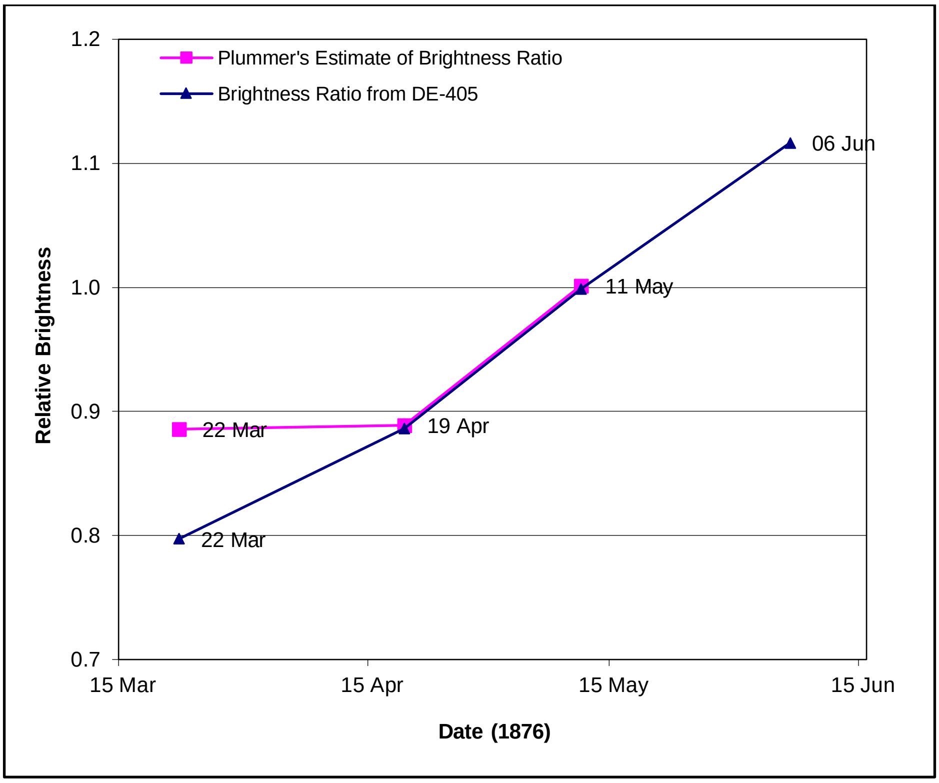


Figure 26. Plummer's estimate of brightness ratio versus modern estimate.

Figure 27 illustrates estimates of the brightness of Venus as a function of its phase, v. The estimates are normalised for the distances Venus-Sun and Venus-Earth on 11 May 1876. The abscissa of the graph runs from a phase of 120° down to a phase of 80°, corresponding to the period 09 March - 19 May. During this period, the illuminated proportion of the planet's disk shrank from 71% at the time of his first observation on 20 March to 45% at the time of his last on 11 May. The figure illustrates:

- Plummer's results, intended to be a comparison of the brightness of Venus with its brightness on 11 May 1876, showing individual data points and a second-degree best-fit polynomial. (He presented the data points together with a smooth curve that appeared to be fitted by eye.)
- Euler's formula: $\Theta = \sin^2(v/2)$, where Θ is the illuminated fraction of the planetary disk and v is the phase. Plummer compared his results against the predictions of the formula on the assumption that the brightness of Venus was proportional to Θ.
- Lambert's formula: $\Theta = (\sin(v) - v\cos(v)) / (\sin(v_0) - v_0\cos(v_0))$, where Θ and v are as above and v_0 is the phase on 11 May 1876. Again, Plummer compared his results against the predictions of the formula, assuming that the brightness of Venus was proportional to Θ.

- A modern reworking of the observational data, again, showing individual data points and a second-degree best-fit polynomial.

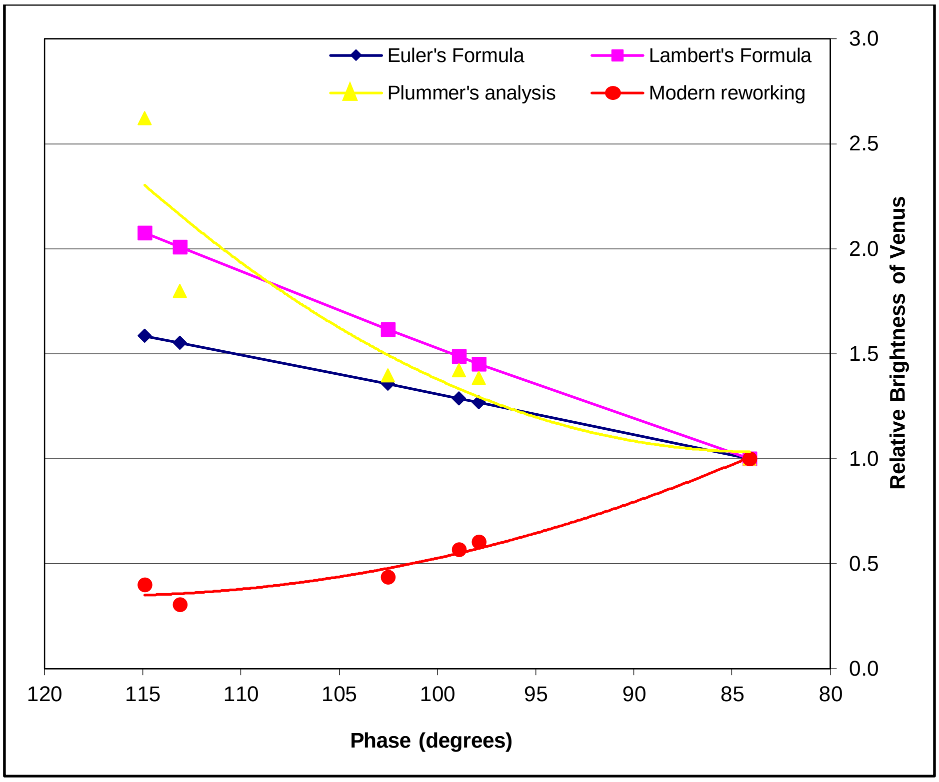


Figure 27. Brightness of Venus as a function of phase.

The graph shows Plummer's results to be broadly in line with Euler's and Lambert's theoretical formulae. Unfortunately, the agreement is purely coincidental as, in plotting the data, he mistakenly used C, the square of the distance to the candle, to represent the brightness of Venus, rather than 1/C, the correct quantity! The modern reworking of his data, adopting 1/C as measure of luminosity, shows a planetary brightness that increases as the phase decreases; the opposite of the anticipated result. He also appears to have introduced some minor arithmetic errors into the analysis, likely the result of excessive approximation. Thus, he estimated the ratio of the brightness of Venus at greatest brilliance to the brightness of the mean full moon as 0.125%; a modern reworking of his calculations performing exactly the same manipulations but using high precision arithmetic yields a ratio of 0.109%.

It is easy, from a modern perspective, to be critical of Plummer's mistakes. However, he undertook the work alone, with no assistant or colleague to offer advice, to help shape the methodology or to check the calculations. Working without the benefit of modern computational aids must have rendered the burden of data analysis considerable and, in the circumstances, it is not surprising that mistakes occurred. Of course, this cannot excuse the numerical errors in the analysis, which suggest a lack of rigorous checking, or the methodological problems, which indicate a poorly designed set of observations.

A4.4 Transit Of Venus, 06 December 1882

In Plummer's era, astronomers had used Kepler's third law to relate the orbital periods and radii of the planets and had developed techniques for estimating the absolute distance from the Earth to the Sun in order to fix the scale of the entire solar system. Observations of a transit of Venus provided a reasonably accurate method of determining the mean Earth-Sun distance. The method was an indirect one that relied on estimates of the times of contact, when the limb of Venus appeared to just touch the solar limb. In fact, observers generally distinguished four contact events:

1st contact:	on ingress, the disk of Venus off the solar disk. The instant when the limbs of the two bodies first appeared to touch.
2nd contact:	on ingress, the disk of Venus on the solar disk. The instant when the limbs of the two bodies last appeared to touch.
3rd contact:	on egress, the disk of Venus on the solar disk. The instant when the limbs of the two bodies first appeared to touch.
4th contact:	on egress, the disk of Venus off the solar disk. The instant when the limbs of the two bodies last appeared to touch.

Because of parallax, observers positioned across the surface of the Earth witness slight differences in the apparent path of the planet across the face of the Sun and different times for the phenomena of contact. The observed contact times can be analysed to estimate the mean distance from the Earth to the Sun (the analysis is not for the mathematically faint-hearted!)

Transits of Venus occur in pairs separated by eight years, each pair separated from the next by alternating periods of 105.5 and 121.5 years. Governments and observatories had sent astronomers to observe the transits of 1761, 1769 and 1874. Astronomers looked forward to the transit of 1882 to provide an opportunity to refine earlier observations and obtain a more accurate value for the Earth-Sun distance; in particular, many hoped that the recently developed technique of photography would facilitate estimation of contact times with unprecedented accuracy. Worldwide, numerous expeditions were therefore planned to observe the phenomenon in 1882.

Preparation

In 1881, the Royal Society appointed a committee to advise the government on arrangements for observing the transit. The committee believed that atmospheric unsteadiness had caused blurring of many photographic images of the 1874 transit and noted that there was insufficient time to devise new techniques or to develop new instruments to enable more accurate observations to be obtained. It therefore recommended that observations be made by eye[69]. Reliance on eye observations meant that, in addition to professional astronomers, many amateur observers were able to contribute to the endeavour.

Later in 1881, the government appointed an Executive Committee, under the direction of Edward Stone, then Radcliffe Observer at Oxford, to oversee arrangements. The committee anticipated receiving many observing reports and it thus became imperative to standardise techniques and conditions as far as possible so that a unified framework of analysis could be employed; to this end, it issued a set of instructions to observers. An international conference in Paris in October 1881 considered the instructions and produced a revised set (see Benjamin (1881) for an English translation). The committee then issued a supplement, which was widely distributed (e.g. Nature (1882)). Key points were as follows:

- The observer should use a refractor with an aperture of 150 mm. Larger instruments should be stopped down. Instruments as small as 100 mm could be used provided that they were “perfect”. If using a reflector, it should have an aperture of at least 175 mm.
- The observer should provide evidence of the optical quality of his instrument. This should include the appearance of a bright star when the eyepiece was pulled and pushed either side of the point of focus and the ability of the telescope to separate double stars and to reveal granulations on the surface of the Sun.
- The observer should use a first-surface reflecting prism to enable safe observation of the solar disk and a neutral-tint wedge between eyepiece and eye to control the apparent brightness of the field of view. Two approaches were specified to standardise the latter so that all observations of contact events were made in fields of similar brightness. The observer could employ an eyepiece with very fine parallel wires, spaced at an apparent distance of 1", and adjust the position of the wedge so that the wires could be readily used to estimate angular separations at or near the limb of the Sun to an accuracy of 0.1". However, this procedure was

[69] The advice contrasted with that provided in America, where a Congressional Commission (1882) recommended reliance on photography.

delicate and, as a more robust approach, the observer could instead choose simply to adjust the wedge to half-way between the setting at which, in a clear sky, the limb of the Sun could be observed with comfort and that at which it could just be seen clearly and distinctly; having memorised the resulting appearance of the image, he should use the wedge to achieve similar brightness in observation of the transit.

- The observer should use a *negative* or a *Steinheil's simple achromatic positive eyepiece*[70]. Use of a double-image eyepiece or a Dawes solar eyepiece was deprecated (except as below in the case of the former).
- The observer should use a magnification of 150x (even if definition was poor).
- Phenomena around the times of contact could be complex and, in an endeavour to improve the consistency of results, the instructions attempted as follows to define precisely what the observers should attempt to time. The definitions concentrated on 2nd and 3rd contact, which were expected to provide the most accurate results:
    - At ingress: *the time of the last appearance of any well-marked and persistent discontinuity in the illumination of the apparent limb of the sun near the point of contact.*
    - At egress: *the time of the first appearance of any well-marked and persistent discontinuity in the illumination of the apparent limb of the sun near the point of contact.*

  The phrase *well-marked and persistent* was intended to guard against observers reporting times when there was only a suspicion of a slight disturbance, perhaps due to atmospheric unsteadiness. If the black drop or similar feature were visible, the observer was instructed, in addition to the preceding, if the feature appeared as dark, or nearly so, as the outer edge of the planet, to record the time of greatest darkness. Of course, not all observations might fit exactly with the instructions and, in this case, the observer was to describe what he saw, with drawings, and provide timings.
- The observer with a double-image micrometer eyepiece was encouraged to measure the angular distances between the limbs of Venus and the Sun after 2nd contact and between the cusps of Venus at egress. However, he was cautioned when doing so against jeopardising timings of 2nd or 3rd contact.
- The observer was to specify the maker's name and number of the chronometer used. He should check its accuracy against the heavens for a few days before and after the transit.
- Great care was to be taken to ensure accuracy in recording time from the chronometer. (The instructions noted that observers had occasionally made mistakes by reading seconds from the "tail" of the seconds hand rather than the "head".)
- The observer should permanently mark the location of the observing site.
- Each observer should write his observing report independently and forward it to the Royal Society at Burlington House. In the case of government expeditions, copies of the reports were to be sent, the original being lodged with local officials until receipt of the copy was acknowledged, at which point the original could be mailed.

The Executive Committee organised observing expeditions from England to the following locations: Jamaica, Barbados, Bermuda, the Cape of Good Hope, Madagascar, New Zealand and Brisbane. Other astronomers stationed widely around the globe contributed to the British effort. Such a widely-spread set of observing stations provided a good baseline for analysis of results and had the important benefit of increasing the chance of some observers benefitting from clear skies.

Each observing expedition sent from England comprised a chief observer, a second observer and an assistant from the military. The three chief observers dispatched to the West Indies were all chosen from the ranks of astronomers in private employment in Britain. Thus, chief of the Jamaica expedition

[70] Carl August von Steinheil (1801-70) was a German physicist, inventor, engineer and astronomer. The eyepiece named after him is a doublet with a flint-glass lens towards the objective and a crown-glass lens towards the observer, together forming a weak positive lens with low chromatic aberration.

was Dr. Ralph Copeland, employed by the Earl of Crawford (1847-1913) at Dun Echt Observatory, Aberdeenshire, chief of the Barbados expedition was Charles George Talmage (1840–86), employed by Joseph Gurney Barclay (1816-98) at his private observatory at Leyton, and Plummer was appointed chief of the Bermuda expedition. Copeland was by far the most accomplished astronomer of the three, with a notable record of publications and discoveries, and went on to become third Astronomer Royal for Scotland, 1895-1905. However, Plummer was not least of the trio, the diversity of his work and his publication record being considerably superior to those of Talmage.

Plummer (1882a) was undoubtedly delighted at his appointment, writing in his annual report to the RAS for 1881, *In view of the value to science of the observation of the forthcoming Transit of Venus, Colonel Tomline has allowed the observer to volunteer for that service...* (The *Chelmsford Chronicle* (1881) also carried the news.) Tomline too, doubtless welcomed the appointment, relishing the prestige that reflected on him. Indeed, given Tomline's connections with the great and the good of society, it is likely that he engineered Plummer's selection for the role.

Second observer at Bermuda was Lieutenant Charles Burnaby Neate (1846-1916). Neate joined the Royal Navy in 1860 at age 13, progressed through the ranks and retired in 1891 with the rank of commander, after which he worked for a further 15 years for the Port of Dover. Although not primarily an astronomer[71], he clearly had a significant interest in the science and was a veteran of the 1874 transit, which he had observed from Point Venus, Rodrigues Island (Airy, 1881). His Admiralty record (The National Archives, 1860) shows that, on 06 January 1882, he was granted permission to join the transit of Venus expedition from May of the year, being authorised to draw full pay for the duration. Later, his record noted that, on 10 July 1882, he *left at own request to proceed to Radcliffe Observatory for work in regard to transit of Venus*. Reassuringly, he was not disadvantaged by his astronomical service, the record further noting: *Transit of Venus expedition allowed as full service for all purposes*.

The assistant at Bermuda was Sergeant Dobing RAM (*EADT*, 1883). In fact, Dobing appears to have been a last-minute substitution: *The Times* (1882), a few days prior to the transit, listed the assistant as Captain Washington, RE.

Captain G. Mackinlay, RA (1883), second observer in the Jamaica team, provided a detailed account of the expedition including the preparations before the observers set sail. His description is likely typical of all the expeditions; key aspects are as follows. Previous transits had demonstrated the importance of consistency in the estimation of event times. Accordingly, all observers, regardless of experience, assembled at the Radcliffe Observatory, Oxford, in summer 1882. There, Stone explained the instructions for observing the transit and, to provide an opportunity for practice, arranged for three telescopes to be positioned 180 m distant from a model of the Sun and Venus. The model represented the apparent motion of the planet across the solar disk but had no means of representing the brightness of the Sun or the atmosphere of Venus. The observers practiced recording the times of apparent contact of the limbs of the model Sun and Venus, finding the results to be *very fairly accordant*. Some astronomers, on the other hand, were profoundly sceptical of this approach, believing that over-reliance on training prior to the 1874 transit had in fact vitiated the results of several observers who had strained to record what they had been taught to observe rather than what they actually saw.

Each team then came again to the Radcliffe Observatory and stayed for about a month, allowing team members to practise setting up and using the telescopes and other apparatus and to pack equipment ready for transportation. The primary instruments of each expedition were two 150 mm equatorially mounted refractors and an altazimuth transit instrument. Of course, the instruments required shelter from the elements, provided in the form of wooden huts or tent-like structures, each fitted with a wooden floor. There appeared to be some tailoring of the temporary buildings to accommodate the instruments which they housed; thus the Bermuda expedition included a *hexagonal wooden hut, with revolving dome eight feet in diameter*, which does not accord with Mackinlay's sketches (figure 28) of the observing huts for Jamaica. Unsurprisingly, the total equipment requiring transportation with each team was considerable: *47 large packages and boxes*.

[71] Neate appears to have no publications to his name in the astronomical literature.

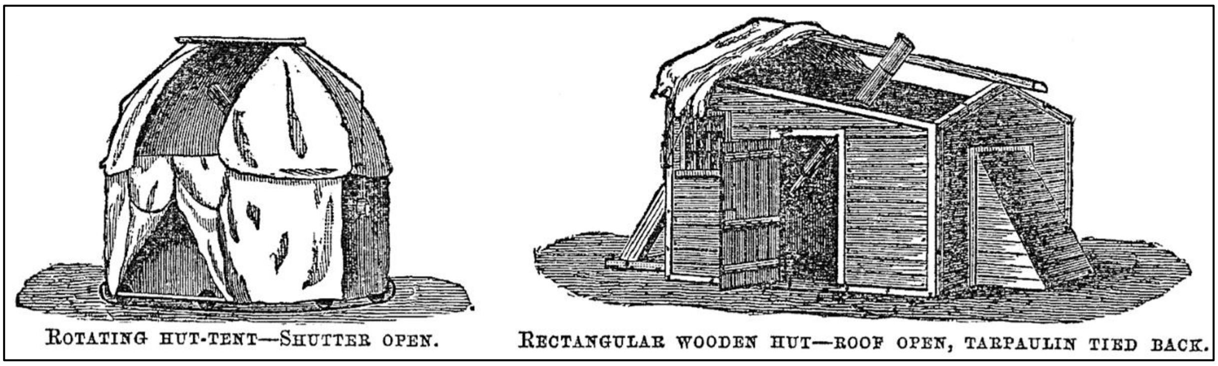


Figure 28. Observing huts. (From Mackinlay, 1883.)

Before leaving the UK, the observers researched the climate and possible observing locations at their intended destinations. The criteria used for selection of locations were (1) probability of a clear, unclouded sky, (2) a healthy location, so that the observers did not run a risk of being incapacitated through fever and (3) easy accessibility, to minimise costs and time pressures. The *Morning Post* (1882) noted that preparations were complete by mid-July.

The ROG Archives (1892) show that, on 29 September 1882, shortly before departing for Bermuda, Plummer collected a chronometer, *Kullberg 59S*, for use there. (It was subsequently lost when he was shipwrecked on the return voyage.)

Bermuda Observing Station

It is not known precisely when or in which vessel Plummer set sail across the Atlantic to reach Bermuda. However, the island's *Royal Gazette* (1882a) lists him and Sergeant Dobing entering the colony via the capital and main port, Hamilton, on 23 October 1882, having journeyed from New York aboard the mail steamer *Orinoco* (figure 29). Plummer travelled as a cabin passenger; Dobing steerage. The *Royal Gazette* (1882b) lists Neate arriving aboard the *Orinoco* at St. George, on the north tip of the island, on 07 November.

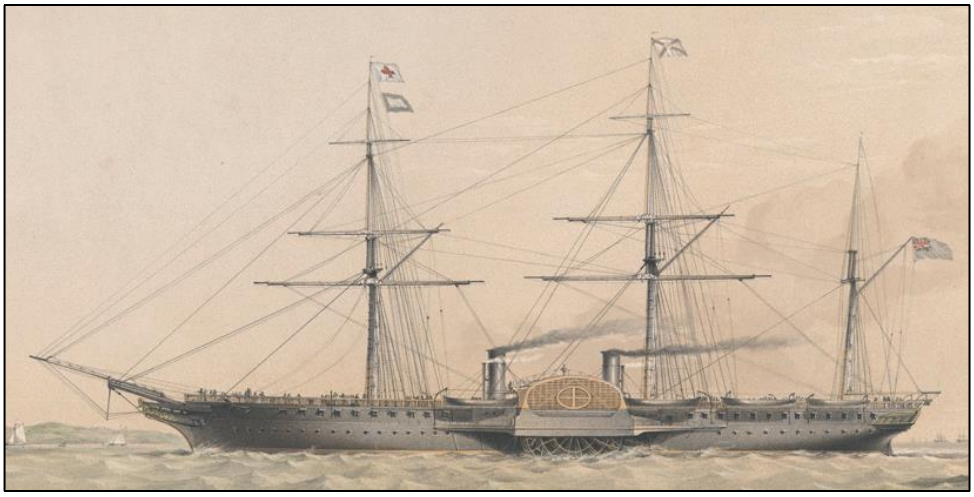


Figure 29. From *The Royal West India Mail Company's Steam Ship 'Orinoco'. (*Dutton, 1852.)

Plummer and Neate established their observing station in the immediate vicinity of Gibbs Hill lighthouse (figure 30) on the southern coast of the island (*Royal Gazette*, 1882c). (The beacon became operational in 1846 and is famous for its cast iron construction.) They would likely have relied upon the labour of military personnel stationed in the colony for the transport of equipment and construction of the observing station. The transit telescope and equatorials required substantial concrete foundations. As noted earlier, the instructions to observers included a directive to mark permanently the location of the observing station; construction of a concrete base upon which to mount instruments would have been a ready means of achieving this. No trace of the observing site appears to remain nowadays[72].

Once the observing station was established, an important duty of the observers was to determine its position accurately, as this formed a key factor in the analysis of results. Latitude could be determined relatively straightforwardly from observations of the altitudes of known stars (for example using Talcott's Method, much employed by Plummer several years later while working at Hong Kong Observatory). However, to determine longitude accurately from the stars, a reference time was required at the observing station. The final report of the Executive Committee (Stone, 1887) indicates that Neate was responsible for provision of reference time at Bermuda, a responsibility he discharged by means of "chronometer runs" to New York to access master chronometers kept to time by observations at Washington Observatory. Assuming that Neate's discharge of his responsibility was typical of the era, he would have transported several chronometers to New York, where they would have been synchronised with the master timekeepers and their rates compared with those of the latter. He would then have transported them to Bermuda, to synchronise and determine the error of the chronometers to be used in observations. The *Royal Gazette* (1882d, 1882e) listed Neate making a return trip to New York, likely for this purpose, on 09 and 19 November. He may also have transported chronometers to/from New York on his initial journey to Bermuda via the city and on finally leaving the island.

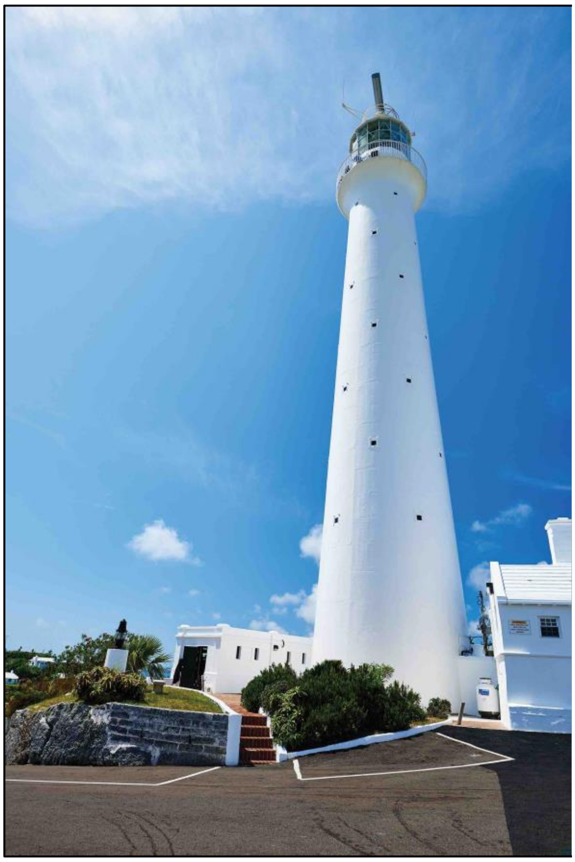
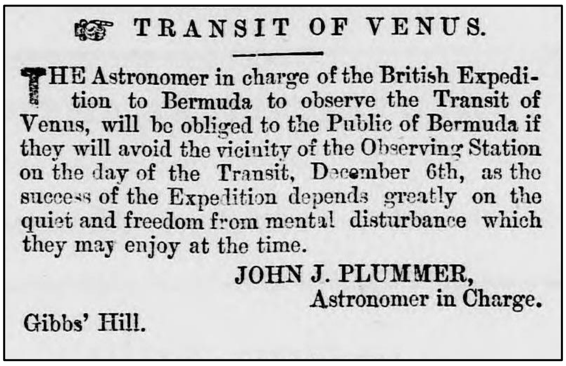


Figure 30. Gibbs Hill lighthouse. (From *Destination Bermuda*, 2023.)

The estimates by Plummer and Neate of the location of the observing station are intriguing. The *Royal Gazette* (1882f), referring to the previously-accepted coordinates of the location, noted that *while the longitude has been confirmed as being sufficiently exact; the latitude has been found considerably in error, showing that Bermuda stretches almost half a mile more into the southern sea than was formerly believed…* The Executive Committee, adopting the determination by Plummer and Neate, quoted the coordinates of the observing site as $4^h\ 19^m\ 20.45^s$ W, 32° 14' 46.6" N. A modern value for the position of the lighthouse (Google Earth, 08 July 2013) is $4^h\ 19^m\ 20.33^s$ W, 32° 15' 10.0" N; while the longitude agrees very well with the estimate by Plummer and Neate, the latitude corresponds to a location approximately 0.5 km (0.4 miles) further north. It seems, therefore, that Plummer and Neate were in error in their determination of the latitude and the earlier value, which they had sought to correct, was, in fact, accurate.

[72] In late 2013, relatives of OASI member Jennie Wood searched, without success, the vicinity of Gibbs Hill lighthouse for traces of the observing station. Enquires of staff at the lighthouse and of the Bermuda Maritime Museum similarly proved negative.

Once Plummer and Neate had determined the position of the observing station, they would have kept busy practicing using the instruments. There was likely considerable interest in their activities, and they would have had to host countless visits by local people. (At Jamaica, Mackinlay reported on local interest as follows: *Considerable interest in the object of the expedition was shewn by residents in Jamaica, but soon all visitors had to be refused till after the Transit, though there still remained rather more than a fortnight*.) Excitement must have mounted greatly as 06 December drew near. With one day to go, Plummer placed an advertisement in the *Royal Gazette* (1882g) asking the public to avoid the observing station on the day of the transit (figure 31).



☞ TRANSIT OF VENUS.

THE Astronomer in charge of the British Expedition to Bermuda to observe the Transit of Venus, will be obliged to the Public of Bermuda if they will avoid the vicinity of the Observing Station on the day of the Transit, December 6th, as the success of the Expedition depends greatly on the quiet and freedom from mental disturbance which they may enjoy at the time.

JOHN J. PLUMMER,
Astronomer in Charge.

Gibbs' Hill.

Figure 31. Request to avoid the observing station. (*Royal Gazette*, 1882g.)

Observations

The final report of the Executive Committee summarised the accounts by Plummer, Neate and the other observers. Plummer observed with a 150 mm Cooke equatorial, a Steinheil positive eyepiece providing a magnification of 177x and the clock Dent 2015. Clouds were passing at the time of 1st contact and he had to make such frequent changes between the thin end of the wedge and direct vision that, in subsequently writing his report, he was unsure whether or not he was employing the wedge at the instant when he first spotted the limb of Venus. Having discerned Venus, he then employed the thin end of the wedge to follow its motion, enabling him to estimate the instant (at an earlier time) of 1st contact itself. Almost four minutes later, he observed an aureole all around Venus, which persisted until 2nd contact, its width varying between 1" and 1.5". He recorded the times of three more events during the ingress phase: 2nd contact, believing his estimate to be accurate to within three seconds; the first appearance of sunlight between the limbs of the two bodies, describing it as a *sudden and marked phenomenon*; and the instant when sunlight between the limbs appeared *perfect and bright*. He witnessed the black drop effect, noting that it became less marked between the latter two times. Immediately after the ingress phase, the Sun was clouded out.

Dense cloud was present at the time of 3rd contact and Plummer observed without the wedge. Unfortunately, the image was *boiling greatly* and *very faint indeed* and suffered from *much tremor in the limbs, both of Venus and the Sun*, and he did not consider his timings *of any value unless confirmed*. Things were slightly improved by the time of 4th contact, and he stated that it was *well observed* and his timing of it was accurate to three or four seconds or better.

Neate observed with a 150 mm Naylor equatorial, a magnification of 180x and clock Arnold and Dent 715. His description of his observations started just after 1st contact, when he observed a fine light shading on the following limb of Venus. When the planet was approximately half upon the disk of the Sun, he described the following limb as bright and later in his report mentioned seeing, at about this time, a bright ring around the planet, approximately 2" thick at its widest. He found it difficult to estimate the time of 2nd contact. Thereafter, he observed the black drop effect through fleecy clouds and noted that approximately nine seconds after 2nd contact, the band between Venus and the Sun changed colour from dark to dusky brown; it persisted for another 20 seconds then disappeared. He had used the wedge at its minimum obscuration to time 2nd contact and at its nominal position to make the other timings. For a few seconds immediately after 2nd contact, cloud had necessitated continuous adjustment to the setting of the wedge.

Of course, Neate's observations of 3rd contact, like Plummer's, were hampered by dense cloud and he, too, did not consider his egress timings to be of any great accuracy. He saw no aureole during egress. In contrast to Plummer, who was confident in his timing of 4th contact, Neate was not, and provided both a "suspected" and "definite" timing for the event.

Table 15 compares timings reported by the Bermuda observers[73] with modern calculations[74] of event times (all rounded to the nearest second); the comparison reveals no surprises. Plummer's time of 1st contact is 14 seconds later than calculations suggest, Neate's 33 seconds later. Plummer studied the motion of Venus immediately after first discerning it in order to estimate the time of 1st contact, and his approach appears to have been reasonably effective. In contrast, it is unclear how Neate estimated 1st contact and it may be that his timing, some 19 seconds later than Plummer's, is simply when he first discerned the limb of the planet after it had intruded upon the solar disk. The reported times of 2nd contact (geometrical) by the two observers are within six seconds of one another and both are 20 seconds or more in advance of the calculated time. The "black drop" must have made timing of the event difficult. Plummer's estimate of 3rd contact (geometrical) agrees well with calculation, but Neate's is 44 seconds after the latter; again the "black drop" effect may be responsible for such discordant times (although Plummer, in his report, mentioned the phenomenon around 3rd contact, Neate did not). Both observers' estimates of the time of 4th contact are several tens of seconds earlier than calculation indicates; this situation is not unexpected. Overall, Plummer's timings agree with calculations much better than Neate's, perhaps a reflection of the fact that he was a professional astronomer whereas the latter was not.

	Times of Phenomena (UT)		
Contact	**Calculated**	**Plummer**	**Neate**
1st	14:03:23	14:03:37	14:03:56
2nd	14:24:05	Geometric contact: 14:23:45. First visibility of sunlight surrounding whole limb of Venus: 14:23:59. Last visibility of "black drop" effect: 14:24:13.	Geometric contact: 14:23:39. "Black drop" effect; band apparently linking Venus to solar limb changed colour and became lighter: 14:23:48. Band apparently linking Venus to solar limb disappeared: 14:24:08 (approx).
3rd	19:47:24	First visibility of "black drop": 19:47:03. Last visibility of sunlight surrounding whole limb of Venus: 14:47:19. Geometric contact: 19:47:34.	Geometric contact: 19:48:08.
4th	20:08:12	20:07:27	Suspected: 20:07:09. Definite: 20:07:14.

Table 15. Timings reported by Plummer and Neate compared with modern calculations.

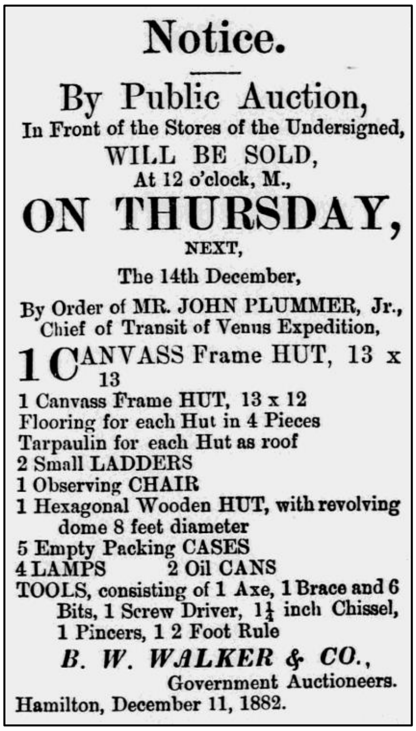
Homecoming

Neate left Bermuda the day after the transit (*Royal Gazette*, 1882i) departing aboard the *Orinoco* for New York; his Admiralty record noted his return to England on 24 December 1882. Mackinlay's report implies that, for a few days following the transit, Plummer would have continued to make observations of the heavens to check the regularity and accuracy of the chronometers. Then, on 14 December 1882, he arranged (figure 32) to auction surplus equipment of the expedition (*Royal Gazette*, 1882j, 1882k). A week later (*Royal Gazette*, 1882L), he left the island aboard the *Orinoco* bound for New York. He mailed his observing report to the Royal Society from New York (*The*

[73] The *Royal Gazette* (1882h, 1883a) listed three observers in Bermuda in addition to Plummer and Neate: the Chief Justice and Mr Barr observed at the Public Buildings using the Colonial Telescope and Captain Clapp observed at Ireland Island. Although they reported observations to the Royal Society, they were not included in the report of the Executive Committee and no record of them has to date been found.

[74] Event times were calculated by an enhanced version of algorithm *Ecltimer* in Montenbruck and Pfleger (1994). Positions of solar system bodies were provided by the NASA JPL ephemeris DE-405 and contact times were assumed to refer to the cloud-tops of Venus.

Times, 1883) and, shortly after Christmas, set sail for England aboard the Inman Line steamship *City of Brussels*[75] (figure 33). He must have looked forward to the transatlantic journey: he had been away from home for over two months and the liner offered the cabin passenger luxurious travel among the wealthy and influential of the age. Unfortunately, the journey turned out to be more eventful than he could have anticipated! His description of the passage, recorded in the *EADT* (1883) and repeated in the *Royal Gazette* (1883b), provides a vivid narrative:



Notice.

By Public Auction,
In Front of the Stores of the Undersigned,
WILL BE SOLD,
At 12 o'clock, M.,
ON THURSDAY,
NEXT,
The 14th December,
By Order of MR. JOHN PLUMMER, Jr.,
Chief of Transit of Venus Expedition,

1 CANVASS Frame HUT, 13 x 13
1 Canvass Frame HUT, 13 x 12
Flooring for each Hut in 4 Pieces
Tarpaulin for each Hut as roof
2 Small LADDERS
1 Observing CHAIR
1 Hexagonal Wooden HUT, with revolving dome 8 feet diameter
5 Empty Packing CASES
4 LAMPS 2 Oil CANS
TOOLS, consisting of 1 Axe, 1 Brace and 6 Bits, 1 Screw Driver, 1¼ inch Chissel, 1 Pincers, 1 2 Foot Rule

B. W. WALKER & CO.,
Government Auctioneers.
Hamilton, December 11, 1882.

Figure 32. Notice of auction. (*Royal Gazette*, 1882j.)

We left New York on December 28th, and experienced very severe weather for the first half of our voyage. We then encountered a severe gale, in which our maintopsail was carried away. The weather then abated, and all went well up to the time of our arrival at Queenstown on Saturday. At noon we left Queenstown under most favourable circumstances and expected to arrive in the Mersey about noon on Sunday. About five o'clock on Sunday morning we were within a short distance of the NW lightship, which is the extreme light from the mouth of the Mersey. Here we were arrested in consequence of meeting with a thick fog blown from the land by a SE wind, and which had detained vessels in the Mersey for a considerable time previously. A good look-out was kept on deck, and the captain and two other officers were on the bridge. About seven o'clock in the morning the fog horn of a steamer was heard and was replied to by the "City of Brussels". In a very short space of time, however, the form of a vessel which turned out to be the "Kirby Hall", screw steamer, 2700 tons burden, from Glasgow, was seen approaching with what appeared to be considerable velocity, and before the "City of Brussels" could get under weigh or do anything to avoid a collision, she was struck on her starboard bow, and a hole was cut in her side. The concussion felt on board was much less than might have been supposed; it was in fact scarcely alarming. At the desire of Captain Land, the "Kirby Hall" put off a short distance and was lost sight of in the fog. The injury to the "Brussels" was so severe, and the water gained so rapidly in her hold, that all hands were at once ordered to lower the boats. In a space not exceeding a quarter of an hour, five boats were lowered ready to receive the passengers and crew. In the mean while the majority of the passengers were awakened from their berths, and speedily dressed in what came nearest to hand. There was little or no confusion; indeed, the passengers did not appear to realize the extreme danger in which the ship was placed. One gentleman positively assured me that after he was awakened by the steward he fell asleep again, and I myself dressed very deliberately and proceeded on deck about ten minutes after the collision. My assistant then informed me that there was 14 ft. of water in the hold, and when I saw some of the passengers whom I had always looked upon as steady and self-possessed were putting on lifebelts, I felt that matters must be serious, and I procured a lifebelt for myself. By the exertion of the captain and purser the ladies were speedily hustled on board the boats, and they were followed at no great interval of time by the rest of the passengers, and such portion of the crew as was necessary to take charge of the boats. Doubtful how long it would be before it would be absolutely necessary to take to the boats, I made a rush below and secured my cash-box, which contained valuable papers as well as money, but I was not permitted to take it with me. I had barely time to extract a valuable bill, lock the box, and place it on the seat in the smoke room. I mounted the bulwarks and followed some of the passengers, who were getting into one of the boats. I believe I was the last cabin passenger who left the ship. There were severa1 steerage passengers, including Sergeant Dobing, RAM, assistant to the Expedition. As soon as we got into the boats we could see how much the ship had sunk, and we could judge how speedily she was likely to go down. All five boats put off to a safe distance from the ship, leaving on board what was supposed to be a few, but in reality about 17 officers and crew. For fear of injury to the boats, it seemed impossible to rescue these, and the moments of suspense were

[75] The ship was a holder of the record for the fastest Atlantic eastbound voyage, 1869-73.

probably the most terrible experience any of us had ever felt. Those left on board had really been employed in endeavouring to launch a sixth boat, which being a heavy one, and the crew being reduced in number, was more than they were able to manage. Having vainly cried for help, they for the most part took to the rigging, and when the ship heeled over to starboard, in all probability jumped for their lives as she sank. Several were now seen clinging to the spars and other wreckage, and two boats, already well filled, approached to take them off. Upon one of the spars were the captain and three others. They were rescued by a boat which had discharged her passengers already upon the "Kirby Hall", and was returning to the scene of the wreck, assisted by the boat in which I happened to be. Having seen the whole of these safely in the boats, we proceeded to the "Kirby Hall", and found her in a considerably damaged condition, but sufficiently sound to produce a comfortable feeling of safety. For some time the boats, now relieved from their numerous passengers, cruised about in the hope of finding some others, but owing to the thick fog, and perhaps to the distance to which the "Kirby Hall" had receded, none were found. My own interest was taken up at this time with endeavours which were being made to rescuscitate [sic] *two men, the second officer and carpenter, who had been brought on board in a drowning condition. In spite of all efforts they unfortunately succumbed. The muster of the crew and passengers was then taken, and it was found that eleven in all were missing. All hope of finding others alive was given up. Happily, however, the fog lifting for a few minutes enabled us to see clinging to the masts of the "Brussels", which having righted were considerably above water, the form of another survivor. A boat was speedily sent to his rescue, and thus the tale of deaths was reduced to 10. We had now to wait, with what patience we could, for the fog to lift, which it did after the lapse of about ten hours. The "Kirby Hall" was then got under weigh, and proceeded to Liverpool.*

Without wishing to throw any blame upon the officers of the ship, which of course must be a matter for judicial investigation, one could not help but see that she was very much under-manned, having only four deck hands on board, and being unable to launch even a single boat to aid in the rescue. The fact that five boats ware launched and manned from the "Brussels" in a space of time not exceeding 20 minutes, speaks greatly in favour of the steadiness of the men, the capacity of the officers, and the quietness and freedom from panic shown by the passengers themselves. It is a matter of intense regret that another boat was not at hand to take off the rest of the crew.

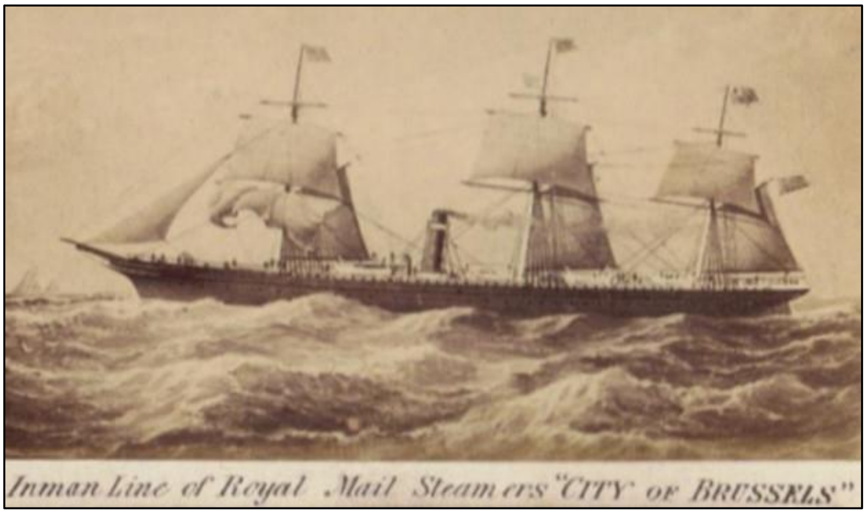


Figure 33. A postcard showing the *City of Brussels* in her original form - she was extensively modified and refitted over the years. (Wikipedia, 2023d.)

Many other papers also carried descriptions of the tragedy, see e.g. *The New York Times* (1883), *The Times* (1883), *The Morning Post* (1883), *The Liverpool Mercury* (1883), *The Western Daily Press* (1883), *The Ipswich Journal* (1883), *The Essex Newsman* (1883), *The Chelmsford Chronicle* (1883) and *Lloyds Weekly London Newspaper* (1883a, 1883b).

Fortunately, although all the passengers' baggage, papers, and effects were lost, the observing reports by Plummer and Neate, having been mailed on an earlier steamer, arrived safely.

Results

Although summary reports started appearing in print (e.g. *Royal Gazette*, 1882f; Stone, 1882) only a few days after the transit and the Council of the RAS (1883) published a summary of the observations in February 1883, it was not until 1887 that the Executive Committee completed the monumental task of gathering together and fully analysing the data and publishing its final report. Stone took responsibility for the analysis, and Henry Carpenter, an astronomer at Dun Echt, undertook most of the computation. As in previous transits, the black drop and atmospheric unsteadiness confounded many observers and Stone frequently struggled to select, out of several reported event times, the appropriate one upon which to base the analysis.

Stone (1887) eventually arrived at an estimate of the mean Earth-Sun distance of 148,960,000 km ±400,000 km. The modern estimate (Seidelmann (ed.), 1992) is 149,597,870.66 km. Except for observations of 4th contact, the absolute value of the residuals of the analysis for the timings by Plummer and Neate are all relatively small in comparison with those of their peers implying, in broad terms, that their results were of good accuracy.

Although governments and individuals around the globe invested considerable resources in observation of the 1882 transit, the technique was already falling into disfavour as a means of estimating the mean Earth-Sun distance. The black drop and atmospheric unsteadiness prevented precise determination of the instants of apparent contact of the limbs of the Sun and Venus and this imposed a fundamental limitation on the accuracy of the method. Astronomers had already begun to turn to other methods, such as the parallax of Mars at opposition, to provide more accurate estimates (see e.g. Sellers, 2001). The 1882 transit was the last used by professional astronomers to estimate the scale of the solar system.

A5 Comets

Plummer reported observations of 49 comets: four from Durham alone, one from both Durham and Orwell Park, and a further 44 from Orwell Park alone. He was likely involved too in observations of Halley's Comet from Hong Kong: although the last is not certain, it is highly plausible, so is included in the tabulation below of his observations.

As noted in section 2.6, he likely influenced Tomline's choice of comets as the principal subject of study of his observatory. At Orwell Park, he took this responsibility very seriously and aimed to observe every comet possible, thereby remedying what he considered a lack of interest in the bodies among other astronomers. In his annual report to the RAS for 1887 (Plummer, 1888a), he summarised his approach: *As this department of astronomical study is only intermittently taken up elsewhere in England, it will be the aim of this Observatory in future to make the observations as full as possible and to include all comets visible in the northern hemisphere*. He was successful in his aim, writing without exaggeration some two years later, in his statement for the vacancy of Chief Assistant at Hong Kong Observatory (see appendix 20): *...no comet observable in northern latitudes being allowed to pass unobserved at Orwell*. Table 16 lists his cometary observations.

Modern Designation	**Informal Name**	**Designation In Plummer's Era**	**Observed**	**Obs'y**	**Reference**
C/1868 L1	Winnecke	1868 II	24-28 Jun 1868	D	Plummer, 1869f
7P	Pons-Winnecke	1869a, 1869 I	01 May - 14 Sep 1869	D	Plummer 1869a, 1869g
C/1870 Q1	Coggia	1870b, 1870 II	20 Sep - 31 Oct 1870	D	Plummer, 1871d
2P	Encke	1871c, 1871 V	20 Oct - 22 Nov 1871	D	Plummer, 1873o
		1875a, 1875 II	31 Jan 1875 - ?	OP	Plummer, 1876a
		1884e, 1885 I	18 Feb - 01 Mar 1885	OP	Plummer, 1885a, 1886b, 1887b
C/1873 Q2	Henry	1873d, 1873 IV	29 Aug - 14 Sep 1873	D	Plummer, 1874e
C/1874 H1	Coggia	1874c, 1874 III	? - Nov 1874?	OP	Plummer 1874d, 1874f, 1875b
C/1874 Q1	Coggia	1874e, 1874 IV	24 Aug - 15 Nov 1874	OP	Plummer 1875a, 1875b
C/1877 C1	Borrelly	1877a, 1877 I	27 Feb - 17 Mar 1877	OP	Plummer, 1879d
C/1877 G1	Winnecke	1877b, 1877 II	13 Apr - 20 Jun 1877	OP	Plummer, 1879d
C/1877 G2	Swift	1877c, 1877 III	03-18 May 1877	OP	Plummer, 1879d
C/1877 R1	Coggia	1877e, 1877 VI	04-07 Oct 1877	OP	Plummer, 1879d
C/1877 T1	Tempel	1877f, 1877 V	04-14 Oct 1877	OP	Plummer, 1879d
5D	Brorsen	1879a, 1879 I	29 Mar - 19 May 1879	OP	Plummer, 1880b, 1880c, 1880d, 1881a
9P	Tempel	1879b, 1879 III	Unsatisfactory observation	OP	Plummer, 1879a, 1880c
C/1879 M1	Swift	1879c, 1879 II	27 Jun - 25 Jul 1879	OP	Plummer, 1880c, 1882b, 1884a
C/1879 Q1	Palisa	1879d, 1879 V	10 Sep - 15 Oct 1879	OP	Plummer, 1880b, 1880c, 1882b, 1884a
C/1879 Q2	Hartwig	1879e, 1879 IV	08-15 Sep 1879	OP	Plummer, 1880c, 1882b, 1884a
C/1880 G1	Schäberle	1880b, 1880 II	30 Apr - 10 Sep 1880	OP	Plummer, 1881a, 1882b, 1884a

Modern Designation	Informal Name	Designation In Plummer's Era	Observed	Obs'y	Reference
C/1880 S1	Hartwig	1880d, 1880 III	18 Oct - 25 Nov 1880	OP	Plummer, 1881a, 1882b, 1884a
C/1880 Y1	Pechüle	1880f, 1880 V	21 Dec 1880 - 31 Jan 1881	OP	Plummer, 1881a, 1882b, 1884a
C/1881 K1	Great Comet	1881i, 1881 III	24 Jun - 17 Nov 1881	OP	Plummer, 1881b, 1882c, 1884a
C/1881 N1	Schäberle	1881j, 1881 IV	28 Jul - 28 Aug 1881	OP	Plummer, 1882d, 1884a
C/1882 F1	Wells	1882a, 1882 I	24 Mar - 03 Jun 1882	OP	Plummer, 1884a, 1884b
C/1882 R2	Barnard	1882c, 1882 III	22 Sep 1882	OP	Plummer, 1884a, 1884c, 1885a
C/1883 D1	Brooks-Swift	1883a, 1883 I	03 Mar - 09 Apr 1883	OP	Plummer, 1884a, 1884c, 1885a
12P	Pons-Brooks	1883b, 1884 I	08 Sep 1883 - 28 Jan 1884	OP	Plummer, 1884a, 1885a, 1885b
D/1884 O1	Barnard	1884c, 1884 II	Unsatisfactory observation	OP	Plummer, 1885a
14P	Wolf	1884d, 1884 III	25 Sep 1884 - 07 Mar 1885	OP	Plummer, 1885a, 1886a, 1887b
C/1885 N1	Barnard	1885a, 1885 II	17 Jul 1885	OP	Plummer, 1886b, 1887b
C/1885 X1	Fabry	1885d, 1886 I	30 Jan - 11 Mar 1886	OP	Plummer, 1886b, 1887b
C/1885 X2	Barnard	1885e, 1886 II	08 Mar - 27 Apr 1886	OP	Plummer, 1886b, 1887b
C/1886 H1	Brooks	1886a, 1886 V	06-20 May 1886	OP	Plummer, 1886b, 1887b
15P	Finlay	1886e, 1886 VII	18 Nov 1886 - 25 Feb 1887	OP	Plummer, 1887b, 1887c, 1888a, 1888b
C/1886 T1	Barnard-Hartwig	1886f, 1886 IX	23 Oct 1886 - 10 Jan 1887	OP	Plummer, 1887b, 1887c, 1888a
C/1887 B2	Brooks	1887b, 1887 II	12 Feb - 23 Apr 1887	OP	Plummer, 1887c, 1888a
C/1887 B3	Barnard	1887c, 1886 VIII	13 Feb - 20 May 1887	OP	Plummer, 1887c, 1888a
C/1887 D1	Barnard	1887d, 1887 III	28 Feb - 10 Apr 1887	OP	Plummer, 1887c, 1887d, 1888a
C/1887 J1	Barnard	1887e, 1887 IV	09 Jun - 29 Jul 1897	OP	Plummer, 1887c, 1888a
13P	Olbers	1887f, 1887 V	13 Sep 1887 - 11 Feb 1888	OP	Plummer, 1888a, 1888b, 1888c, 1889b
C/1888 D1	Sawerthal	1888a, 1888 I	04 Apr - 10 Aug 1888	OP	Plummer, 1888c, 1889b
C/1888 P1	Brooks	1888c, 1888 III	29 Aug - 08 Oct 1888	OP	Plummer, 1889b, 1889c
C/1888 R1	Barnard	1888e, 1889 I	11 Sep 1888 - 22 Jul 1889	OP	Plummer, 1889b, 1889c, 1890a, 1890e
C/1888 U1	Barnard	1888f, 1888 V	13 Nov 1888 - 25 Mar 1889	OP	Plummer, 1889b, 1889c, 1890a
C/1889 G1	Barnard	1889b, 1889 II	06 Sep - 31 Oct 1889	OP	Plummer, 1890a, 1890e
16P	Brooks	1889d, 1889 V	29 Aug 1889 - 12 Feb 1890	OP	Plummer, 1889d, 1890a, 1890e
C/1889 O1	Davidson	1889e, 1889 IV	29 Aug - 13 Nov 1889	OP	Plummer, 1890a, 1890e

Modern Designation	Informal Name	Designation In Plummer's Era	Observed	Obs'y	Reference
64P	Swift-Gehrels	1889f, 1889 VI	11 Dec - 24 Dec 1889	OP	Plummer, 1890a, 1890e
C/1889 X1	Borrelly	1889g, 1890 I	25 Dec 1889	OP	Plummer, 1890a, 1890e
C/1890 F1	Brooks	1890a, 1890 II	17 Apr - 24 May 1890	OP	Plummer, 1890e
1P	Halley	1909c, 1910 II	17 Apr? - 25 Jun? 1910	HK	Figg, 1911

Table 16. Cometary observations. (D=Durham, OP=Orwell Park, HK=Hong Kong.)

In addition to the above, at Orwell Park, he searched unsuccessfully for three further comets:

- Swift's Comet (C/1878 N1). He missed it due to an *unfortunate misinterpretation of the telegram announcing its discovery* (Plummer, 1879a).
- Tempel's Comet (10P). Persistent cloud and haze near the horizon thwarted observations (Plummer, 1879a).
- Faye's Comet (4P). He looked for the comet on three occasions in 1888 when skies were clear but could not find it, concluding eventually that it was too faint (Plummer1889b).

Almost at the end of his time at Orwell Park, he described (Plummer, 1890a) his technique for determining cometary positions. He observed each comet whenever possible, making one positional estimate each night, generally based on eight separate measurements of the offset from a neighbouring star. Occasionally, if a comet were moving rapidly, he made multiple observations, with different neighbouring stars. (Appendix 22 describes the types of micrometer that he used in estimating the offsets.) Subsequent calculations enabled him to estimate the apparent position of the comet and, for the benefit of computers subsequently engaged in calculating orbital parameters, parallax factors. (Parallax factors in RA and declination are used, once the geocentric distance of a body is determined, to estimate a correction to its apparent position associated with the notional change of observing location from topocentric to geocentric. See Seidelmann (ed.), 1992.) He admitted occasionally adopting some shortcuts in the data analysis. For example, in the reduction of cometary positions measured in 1877, he reported (Plummer, 1879d) applying a correction for proper motion for only one comparison star, despite harbouring suspicions that it was required for four others. Clearly, data reduction was very time-consuming (section 2.6 quotes a contemporary estimate of one hour of computation for each hour of observation) and, in many of his annual reports to the RAS, he referred to a backlog of cometary observations awaiting reduction.

His observing reports detailed problems encountered, some of the more noticeable of which were as follows:

- At Durham, he made nine estimates of the position of Henry's Comet (C/1873 Q2) during the period 29 August – 12 September 1873 and undertook spectroscopic observations on 10 and 14 September (detailed in appendix 10). Unfortunately, tall trees blocking the field of view thwarted a further attempted observation on 15 September!
- In his observing report for Comet Pons-Brooks (12P) he stated (Plummer, 1885b) that, from 08 September - 05 October 1883, he used a dark bar micrometer. Its action was *not satisfactory*, so from 06 October to 26 November he used instead a ring micrometer. On 28 November, he returned to using the dark bar micrometer and continued to use it for the remainder of his observations, which concluded on 28 January 1884. He provided no further details to justify this course of action.
- Occasionally, Plummer (1882c, 1887c, 1888c, 1889c) reported difficulty hearing the observatory chronometer due to high wind. Astronomers of the era customarily adjusted the chronometer to beat sidereal seconds then counted the beats as a means of estimating time in the darkness of the observatory. A skilled observer could achieve quarter-second accuracy using this technique (Chapman, 1995).

Most of his cometary observations were unremarkable. His more noteworthy reports were as follows.

Pons-Winnecke's Comet (7P). He observed the comet on 13 May 1869, using the 165 mm refractor at Durham Observatory, through one of the densest streamers of *an aurora of surpassing magnificence* (Plummer, 1869a). He concluded that, despite the impressive spectacle presented by the aurora, it comprised extremely tenuous material.

Coggia's Comet (C/1874 H1). Plummer rarely described the comet under study and, when he did, he did so in brief. Only once, for Coggia's Comet (C/1874 H1), did he publish (Plummer, 1874f), sketches of the body, reproduced in figure 34. On 02 December 1874, he displayed his work at a *conversazione* of the Ipswich Science Gossip Society (see appendix 18.2); perhaps it was knowledge that he had an audience which would appreciate the sketches that led him to produce them.

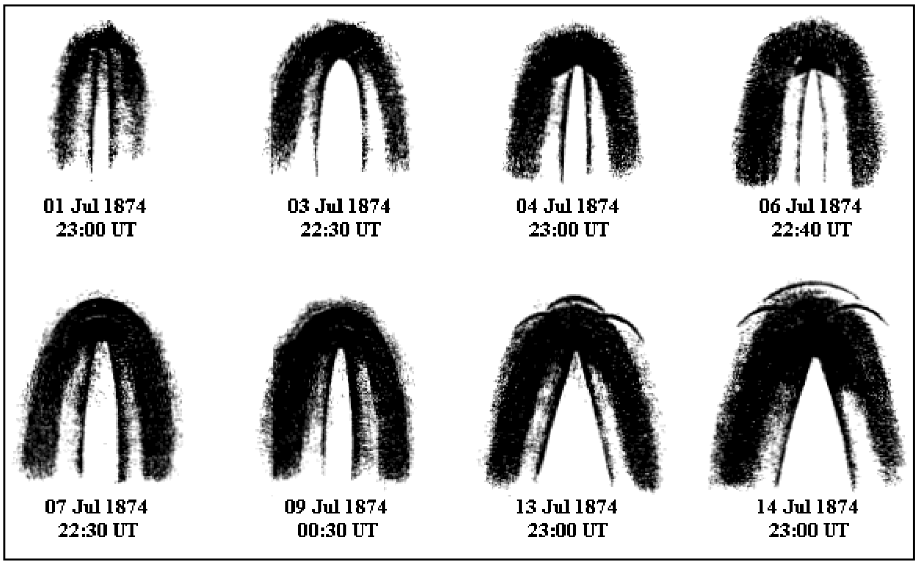


Figure 34. Coggia's Comet (C/1874 H1). (From Plummer, 1874f.)

Hartwig's Comet (C/1879 Q2) and Palisa's Comet (C/1879 Q1). Plummer (1880c) noted that his observation of the comets would have been more extensive *if intelligence of their discovery had reached the Observatory at an earlier date*. Whiting (2006a) comments that this was clearly a heartfelt remark! Plummer (1880b, 1882b) reported observations of Palisa's Comet in two other publications. In the first, he reported that during the period 25 September - 10 October 1879, a few days on either side of perihelion, the nucleus appeared fainter and more diffuse than predicted by theory but, by 15 October, it had returned to its expected brightness and definition. He was confident in his observations and noted that the peculiarity *is not to be accounted for by atmospheric conditions, as upon Oct. 5, 10 and 15 the most satisfactory state of the sky prevailed, particularly on the first-mentioned dates*. During the period in question, the distance of the comet from the Sun did not significantly change, so he dismissed this as a possible explanation. Such behaviour was unusual and he therefore requested other astronomers to provide confirmation of his findings. Unfortunately, no-one responded directly to his request: of eight references listed in the NASA/Smithsonian ADS archive[76] dealing with Palisa's Comet, none referenced his paper. However, Lord Lindsay (1879a) published observations from Dun Echt Observatory providing confirmation, reporting that on 23 September 1879 the comet appeared to have no nucleus even at high power (307x) whereas by 19 October 1879 it was *much brighter in the middle*.

[76] Searched on 21 August 2007. The references are: Lindsay (1879a, 1879b), Chandler (1879), Copeland and Lohse (1879), Tacchini (1879), de Konkoly (1879), Niesten (1880) and Schmidt (1880).

Unfortunately, in his final observing report on the comet, the description of sky conditions was at variance with the earlier report, somewhat undermining confidence in his conclusions:

Sept. 26-27: *Very faint from moonlight and haze.*

Oct. 5-15: *Comet faint and low down. The later comparisons are less reliable.*

As in several other instances, his observing reports were not consistent one with another.

Brorsen's Comet (5D). Julius Schmidt[77] (1879), at Athens, reported observing the comet 24 March - 20 May 1879, noting that it was a difficult object in a 2 m refractor. He reported the magnitude of the coma in the range 7-8 on various evenings and estimated the length of the tail variously as 3', 7', 10' and 30', describing it as *indistinguished* and *weak*. Plummer (1880b) also observed the comet, describing the tail as *inconspicuous,* and noted that Schmidt was the only other observer to mention the tail at all. He recalled that on the comet's previous apparition, in 1868, its tail had been *fairly observable*. Periodic comets tend to become fainter on each apparition and he suggested that it would be interesting to note the stages by which this occurred.

The Great Comet (C/1881 K1) and Schäberle's Comet (C/1881 N1). William Denning[78] (1881), observing at Ashleydown, Bristol, reported in *The Observatory* that, on 13 July 1881, the nucleus of the Great Comet made a close approach to the 4th magnitude star P Camelopardi. Denning observed with a 250 mm reflector, magnification 100x, at 23:25 GMT[79], at which time the two objects were within 3' and approaching. Unfortunately, at 23:30 GMT cloud rolled in and prevented further observations. On the following evening, the nucleus appeared approximately 40' distant from the star. As a postscript, the editor of *The Observatory* noted that observers at the ROG recorded the comet within 1' of the star on 14 July at 01:52 GMT.

Plummer (1881b) responded briefly to Denning, reporting an even closer approach of the comet to a star. On 29 June 1881, he had observed it pass within only 17.3" of the star Radcliffe 1661 (modern designation Tycho 4108-1401-1, magnitude 7.4). He noted that at the time of closest approach, the comet was moving very rapidly in declination, at almost 6" per minute. On 13 July 1881 (the day of Denning's observations), it had approached the star Radcliffe 2324 (modern designation Hipparcos 47193, magnitude 4.3) at a distance of 31.9".

Finally, in something of a digression, he reported that, on 04 August 1881, he judged by naked eye that the Great Comet and Schäberle's Comet were of equal magnitude. On the following night, Schäberle's appeared to be the brighter of the two. Such a direct comparison of the magnitudes of comets was only rarely possible. He predicted that Schäberle's Comet at maximum brilliance would equal the brightness of the Great Comet on 13 July.

Pechüle's Comet (C/1880 Y1). Plummer (1882b) reported that on 31 January 1881 the comet appeared *faint owing to light of aurora.*

Wells' Comet (C/1882 F1). Plummer (1884b) estimated the position angle of the comet's tail and noted that, from 21 May, it appeared slightly curved. This is the only occasion when he provided a description of the tail of a comet.

Barnard's Comet (C/1887 D1). In a short communication in *Nature*, Plummer (1887d) pointed out that there appeared to be no published ephemeris of the comet beyond late March 1887, but that it would likely continue to be visible in larger telescopes well into April. He therefore published a short ephemeris, calculated using orbital elements derived by Palisa, covering 13 – 23 April. He appeared to be unsuccessful in making observations of the comet during this period, as his last published observation was on 10 April 1887 (Plummer, 1887c, 1888a).

Barnard's Comet (C/1887 J1). Plummer (1887c) reported on 28 July 1887: *The comet has become faint and difficult to observe, especially in declination, owing to its peculiar form. It is much elongated from N to S, and narrow from W to E. This peculiarity has been noticed on several occasions recently.*

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[77] Johann Friedrich Julius Schmidt (1825-84) was a German astronomer and geophysicist.

[78] William Frederick Denning (1848-1931) discovered several comets and studied meteors and novae. He was awarded the RAS Gold Medal in 1898.

[79] Denning's reported times are assumed to be local times, here converted to GMT.

Sawerthal's Comet (C/1888 D1). Plummer (1888c) noted on 08 August 1888: *Comet very faint and the coma has almost disappeared. Nucleus small and starlike. On Aug 2 the nucleus was indeed thought to be a small star within the coma, and no observation was then taken, as it was considered that such observation would be that of a star and would not accurately represent the place of a comet*.

Brooks's Comet (16P). Edward Barnard[80] (1889a) reported observations of the comet during 01-05 August 1889 using the 300 mm and 914 mm refractors at Lick Observatory on Mount Hamilton, California. (At the time, the 914 mm refractor was the largest telescope of its type in the world.) He found that the comet had fragmented into nine components, the main body plus eight companions (which he designated A and B-I respectively.) The four faintest companions appeared simply as nebulous objects, while the four brightest showed structure like "mini-comets". Dr. Edmund Weiss[81] (1889) reported observations of the comet made during early-mid August at Währing, Vienna. Observing in poor weather, he and colleagues counted four distinct bodies surrounded by a dust cloud. Weiss's paper alerted Plummer to the phenomenon and he began observations, publishing his findings in *MNRAS* in an initial short paper in 1889 with a full set of positional estimates in 1890 (Plummer, 1889d, 1890e). He reported observing, in September and October, the main body and one fragment, which he identified as *the intermediate one of the three illustrated in… the Vienna observations*, corresponding to what Barnard termed fragment B. Comparison of his findings with Barnard's suggests that, in fact, it was C, not B, that he observed. From mid-September, he observed A and C grow further apart, but to an extent that was barely above the random error in his measurements. In late September, the two bodies appeared stationary relative to one another and, by mid-October, they began to approach and C faded. The description by Barnard (1889b) at this time is broadly similar to Plummer's although, observing with a vastly superior telescope, he could discern greater detail; thus he noted that, in late September, the tail of C disappeared, its head became large and diffuse and the object as a whole became much fainter.

Sekanina and Yeomans (1985) provide a modern account of the comet. They fitted ten orbital models to observations made during the period 1889-1980 and concluded that the comet made a very close approach to Jupiter on 21 July 1886, passing at a distance of only two Jovian radii (142,800 km). The gravity of the planet likely triggered a series of fractures in the cometary nucleus, resulting in the bodies that Weiss, Plummer, Barnard and others observed in 1889.

Halley's Comet (1P). Figg (1911), in the annual report of Hong Kong Observatory for 1910, reported that the comet was visible to the naked eye during 17 April – 25 June and described an unsuccessful attempt to photograph it in transit across the face of the Sun on 19 May. It is likely that Plummer had a role in the proceedings. (See section 2.7.)

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[80] Edward Emerson Barnard (1857-1923) worked at Mount Hamilton Observatory 1888-95, then at the newly built Yerkes Observatory where he remained until his death. He pioneered astronomical photography.

[81] Edmund Weiss (1837-1917) was Professor at the University of Vienna and Director of Vienna Observatory.

A6 Meteors

Plummer published two observing reports on meteors and one paper summarising contemporary knowledge of the composition of the bodies.

The Leonid meteor display of 12-13 November 1833 was one of the most spectacular on record, as evidenced by a contemporary woodcut, reproduced in figure 35. Meteor rates over the USA were intense throughout the night and briefly reached 200,000 per hour but, unfortunately, the shower was not visible from Europe. The 1833 Leonids rekindled interest among astronomers in observing meteors and stimulated the estimation of an accurate position for the radiant and the prediction of a 33-34 year return period for "great" Leonid showers. The Leonids of 1866, while not remotely as spectacular as the shower of 1833, were much anticipated and very impressive.

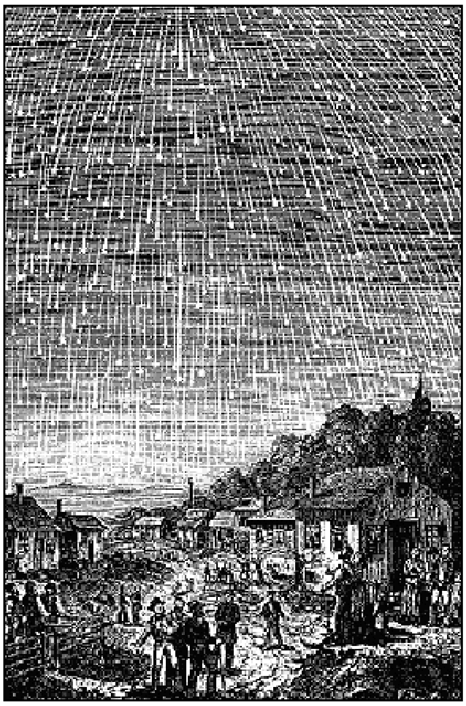

Figure 35. The 1833 Leonids in a contemporary woodcut.

The 1866 Leonids peaked on the night of 13-14 November. At this time, Plummer was an assistant under Professor Grant at Glasgow Observatory. Grant (1867) published an observing report giving a general description of the meteor shower. He reported that, during the early evening of 13 November, skies were not favourable, but conditions improved as time advanced and, towards 01:00 GMT on 14 November, *the sky became clear in every direction, and fortunately continued so during the remainder of the night.* After 01:00 GMT, *great numbers of beautiful meteors were now seen traversing every region of the heavens*. Most were whitish, but some had orange or blue tinges. Most meteors left trains, invariably a bright, emerald green, some spanning arcs as long as 50º-70º. Grant recorded a peak rate of 57 meteors per minute. He saw the aftermath of a fireball, evident as *an extraordinary blaze of light in the constellation of Ursa Major*. (He missed the fireball itself as he was writing in his notebook at the time.) He compared the immediate residual light of the fireball with *the blazing furnace of one of the great iron-works in the neighbourhood of Glasgow*. By 03:00 GMT, the meteor rate had declined to only two per minute and by 04:30 GMT to only one every two or three minutes. By 05:00 GMT, the shower was over.

Following his paper, Grant introduced Plummer's observing report (Plummer, 1867), which was the latter's first published paper. The report recorded the details of individual meteors, 26 timed to the nearest second and a further 43, typically of duration 2-4 seconds, timed to the nearest minute. He recorded the first meteor at 01:34:33 GMT and the last at 03:55:05 GMT. Six of the meteors were at least as bright as Sirius; three were as bright as Jupiter; while the remainder were 1st or 2nd magnitude.

Both Grant and Plummer estimated the coordinates of the radiant of the Leonids by plotting meteor trails on a British Association star map. Table 17 compares their estimates with the modern position quoted by the BAA (2023).

Estimate	RA	dec
Grant	147° 35'	22° 53'
Plummer	150° 30'	21° 36'
BAA	154° 0'	21° 24'

Table 17. Estimates of the Leonids radiant.

After moving to Orwell Park, Plummer (1876e, 1876f) described a brilliant fireball[82] that he witnessed near Ipswich on 24 September 1876 at approximately 18:36 GMT, during evening twilight. The course of the fireball comprised three approximately equal portions, spanning in total some 25°, which the body traversed in approximately three seconds. In the first portion, the fireball exhibited a uniform brightness in excess of 1st magnitude. In the second portion, it rapidly increased in brightness to many times that of Venus and then suddenly diminished to its previous brightness. In the third portion, it grew considerably brighter than its previous maximum then suddenly disappeared without bursting. A train marked the third portion only: it was visible as a luminous cloud approximately 6° long, which persisted for approximately 16 minutes. The disk of the fireball was small, no more than 2' in diameter, and pear-shaped in appearance, although Plummer noted that this might have been an artefact of retinal persistence. Overall, the phenomenon appeared like a vivid flash of lightning and, indeed, many people had mistaken it for such.

The following day, J. E. Taylor (1876) initiated correspondence about the fireball in the pages of the *EADT*. He had never seen a fireball so brilliant and described it creating a trail of length *about one-sixth of the heavens* then exploding before reaching the horizon. It created a line of white cloud which remained visible for approximately 10 minutes before dissipating. Taylor argued that the fact that the trail was so clearly visible proved that the fireball had been at no great distance. He believed it possible that fragments of the body could have survived descent through the atmosphere and would be found as meteorites near the coast.

Two days later, "Whittonian" (1876a) replied in the *EADT*, concurring with Taylor as to the brilliance of the fireball, but disagreeing that it could have created meteorites; instead, he believed that the body was purely gaseous, resembling a comet. (He recalled being advised by an eminent but unnamed astronomer that a typical comet had a mass no greater than the umbrella that the astronomer held in his hand at the time!) Whittonian claimed to hear a *somewhat detonating noise* when the fireball exploded. He added a description of the magnificent Leonids display on 13 November 1833, and stated that the brightest meteors then visible were representative of that on 24 September 1876.

Plummer (1876g) responded in the paper the following day, aiming to correct the more outlandish views expressed. He argued that the fireball was likely in no way special other than in brilliance. Two types of meteors were known to science: the stony and the metallic, and the rapidity of the fall of the fireball was compatible with a solid body rather than a gaseous one. Whether or not some fragments survived the fall and reached the surface of the Earth depended largely on the initial approach velocity of the body. Plummer then dealt with comets, advising Whittonian that most, possibly all, had a solid nucleus, and likely considerably more mass than he supposed. Finally, Plummer confirmed that he too had observed the meteor, and that it did not explode.

Two days later, Whittonian (1876b) had the last word, clearly confident in his understanding of what he had witnessed and rejecting Plummer's views. He remained convinced that the meteor was gaseous: other meteors that he had observed moved through the atmosphere more in the manner of a solid body and descended below the horizon. The rapid motion of the fireball, he argued, might be analogous to that of a comet, on approach to the Sun, when travelling at its fastest; the meteor had likely originally been travelling much faster, and had been retarded in its passage through the Earth's

[82] A meteor of peak brightness greater than magnitude -4.

atmosphere. Donati's Comet of 1858, through the tail of which a star of second or third magnitude had been visible, provided confirmation of the gaseous nature and minute mass of comets for, how, he enquired, could a comet be other than gaseous if a star were visible through its tail? Some people who believed that comets were solid bodies had asserted that their tails were inhabited by millions of beings, but such views had given way to more rational beliefs, and Whittonian was confident that that comets were indeed gaseous.

Plummer (1880e) published his final contribution on meteors in response to an address by Professor William Adams[83] to the Mathematical Section of the British Association. Adams called attention to the presence of iron, nickel and magnesium in meteorites and in the atmosphere of the Sun (revealed spectroscopically). Plummer noted that chemists had detected in meteorites 16 metals, of which 14, including very rare elements such as titanium, were known to be present also in the Sun. The two metals found in meteorites but not in the Sun, tin and lithium, were present in only minute quantities. Although none of the non-metallic elements found in meteorites was found in the Sun, spectroscopists generally believed that they were indeed present but in *more elementary forms*, preventing their identification. He believed that comets and meteors spiralling into the Sun brought with them significant quantities of material and energy, contributing to the Sun's longevity (see appendix 14.2). Other scientists (e.g. Dr. Henry Sorby[84]) believed on the contrary that meteors were ejected by the Sun during solar "eruptions". In either case, the existence of many materials common to both meteors and the Sun provided evidence of a link between the two.

[83] William Grylls Adams (1836-1915) was a younger brother of John Couch Adams. He was professor of Natural Philosophy at King's College, London.

[84] Henry Clifton Sorby (1826-1908) held a position at the University of Sheffield supported by the Royal Society. He invented the technique of thin-section studies of rocks and minerals, and applied the technique to study meteorites (Sears, 2004, page 4).

A7 Asteroids

During the years 1867-71, while at Durham Observatory, Plummer published observations of 39 asteroids, concentrating on those whose orbits were imperfectly known. Table 18 summarises his schedule of observations.

All the bodies observed by Plummer were already well-known to astronomers apart from (101) Helena, (109) Felicitas and (113) Amalthea; he observed the latter three within two months of discovery, respectively on 15 August 1868, 09 October 1869 and 12 March 1871.

During 1872, he found the 165 mm equatorial refractor at the observatory increasingly inadequate for the task and discontinued observation of asteroids. After leaving Durham, he did not publish further observations of the bodies.

Asteroid	Dates Observed	Reference
(79) Eurynome	06-18 Nov 1867 09 Dec 1871	Plummer, 1868c, 1872f
(89) Julia	15-28 Jan 1868	Plummer, 1868c
(6) Hebe	17-25 Jan 1868	Plummer, 1868c
(61) Danaë	19 Feb 1868	Plummer, 1868c
(34) Circe	05-28 Mar 1868	Plummer, 1868c
(28) Bellona	20 Mar - 14 Apr 1868 21 Sep 1870	Plummer, 1868c, 1871e
(65) Cybele	12-29 May 1868	Plummer, 1868c
(80) Sappho	09-10 Sep 1868 11 May - 07 Jun 1871	Plummer, 1869f, 1872f
(48) Doris	10 Sep 1868	Plummer, 1869f
(49) Pales	07-16 Oct 1868	Plummer, 1869f
(42) Isis	08-17 Oct 1868	Plummer, 1869f
(101) Helena	09-22 Oct 1868	Plummer, 1869f
(92) Undina	07-20 Nov 1868	Plummer, 1869f
(64) Angelina	03-11 Dec 1868	Plummer, 1869f
(60) Echo	11 Dec 1868 - 07 Jan 1869	Plummer, 1869f
(43) Ariadne	18-22 Dec 1868 05-22 Apr 1870 17-18 Nov 1871	Plummer, 1869f 1871e, 1872f
(19) Fortuna	08-25 Jan 1869	Plummer, 1869g
(52) Europa	18 Feb - 18 Mar 1869	Plummer, 1869f
(71) Niobe	19 Feb - 18 Mar 1869 19 Aug - 03 Sep 1870	Plummer, 1869f 1871e
(51) Nemausa	30 Mar - 04 Apr 1869 26-30 Aug 1870	Plummer, 1869f 1871e
(20) Massalia	01 Apr 1869 06-23 Jul 1870	Plummer, 1869f 1871e
(85) Io	10-20 Aug 1869	Plummer, 1869f
(67) Asia	25 Aug - 13 Sep 1869	Plummer, 1869f
(69) Hesperia	27 Sep - 13 Oct 1869	Plummer, 1870c

Asteroid	Dates Observed	Reference
(59) Elpis	09-23 Oct 1869	Plummer, 1870c
(72) Feronia	26 Oct - 06 Nov 1869	Plummer, 1870c
(109) Felicitas	06-10 Nov 1869	Plummer, 1870c
(82) Alkmene	24-28 Jan 1870	Plummer, 1870c
(29) Amphitrite	25 Feb - 24 Mar 1870	Plummer, 1870c
(37) Fides	25 Feb - 01 Apr 1870	Plummer, 1870c
(11) Parthenope	13-28 Sep 1870	Plummer, 1871e
(44) Nysa	11-23 Nov 1870	Plummer, 1871e
(63) Ausonia	16-23 Nov 1870	Plummer, 1871e
(113) Amalthea	22 Mar - 10 May 1871	Plummer, 1872f
(23) Thalia	22-23 May 1871	Plummer, 1872f
(12) Victoria	23 May - 08 Jun 1871	Plummer, 1872f
(41) Daphne	24 Aug - 15 Sep 1871	Plummer, 1872f
(88) Thisbe	09 Sep - 10 Oct 1871	Plummer, 1872f
(31) Euphrosyne	11 Oct - 10 Nov 1871	Plummer, 1872f

Table 18. Observations of asteroids.

He did not publish his technique for estimating the positions of asteroids and reducing the data, but it was likely similar to his technique for estimating cometary positions, described in appendix 5. Appendix 22 describes the types of micrometer that he used in the work. He reduced his observations to yield estimates of the RA, declination and parallax factors of each asteroid and, where possible, compared his results with ephemerides in the *Berliner Jahrbuch* as a means of checking for major errors.

A8 Aurorae

Plummer (1868a) published his first report of an aurora not in the astronomical literature but in *The Advertiser*. The report concerned an auroral arch observed from Durham Observatory on 19 October 1868. At its best, the phenomenon was *bright and conspicuous* but it fluctuated in intensity and, after some 22 minutes, faded and was lost in the clouds. He remarked that, in previous years, auroral arches were seen frequently and that, on one occasion, the phenomenon was observed simultaneously from Durham, York and Belfast, enabling its altitude to be calculated by triangulation[85]. He hoped that such arches would appear in future with cons*iderable frequency*, and he appealed to the public to send him details of any seen. There is no evidence that anyone responded to his appeal.

Plummer's first paper in the scientific literature on aurorae (Plummer, 1869a) described observations of the phenomenon that he made from Durham Observatory on 02 April and 13 May 1869. He reported using the 165 mm refractor to observe Pons-Winnecke's Comet (7P), through one of the densest streamers of the aurora of 13 May, with the only inconvenience being a bright field of view; he concluded that the matter of aurorae must be extremely tenuous. The remainder of the paper dealt with spectroscopic observations of the aurorae; it is considered in detail in appendix 10.

His second paper in the scientific literature on the phenomenon (Plummer, 1874g), also written at Durham Observatory, responded to a report by Captain S. P. Oliver (1874) in *Nature*. Oliver, writing from Buncrana, County Donegal, reported seeing on 05 February 1874, at approximately 21:10 local time, a *luminous meteor cloud,* which he described as *a broad band of silvery white and luminous cloud extending in an arc from SE by E to NW by W, from horizon to horizon, but tapering at the extremities*. The cloud, which had well-defined edges, passed 3° - 4° above the upper stars of Orion; stars shone brightly through it. He noticed several meteors during the evening, one of which appeared to come from the SE edge of the cloud; this, presumably, was what led him to describe the phenomenon as a *luminous meteor cloud*. Plummer, clearly anxious to dispel Oliver's misconception, responded in the following week's edition of *Nature*. He had observed the phenomenon from Durham and reported that it was an auroral arch, in fact the brightest and most complete example of the phenomenon that he had ever witnessed. It had been visible in the sky at the same time as an "ordinary" aurora, the two jointly presenting parallel bands of light. It had remained obvious for half an hour, crossed Ursa Major and drifted southward before disappearing.

The aurora of 05 February 1874 was widely seen and J. Rand Capron[86], observing[87] from Guildford, provided a description and a sketch in his book *Aurorae: Their Characters and Spectra* (Capron, 1879). Figure 36 reproduces the sketch. Capron referred to descriptions of the phenomenon by Oliver and Plummer (referring to the latter without naming him as *another correspondent* who had identified the phenomenon as an auroral arch).

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[85] Plummer appears to have been referring to work by Chevallier (1841) in relation to an aurora observed on 22 March 1841. Chevallier began observing shortly after 8.00 pm. Occasional bright beams and flashes shot from the horizon to the zenith and at 8.30 pm, two beams, one rising from the east and the other from the west met, *forming a brilliant arch of white auroral light*. The arch fluctuated in brilliance and, by 10.00 pm had disappeared, to be replaced with a diffuse glow in the west, strong enough to cast a shadow, and a beam in the east. At approximately 9.20 pm, the arch was oriented in an east-west direction, and Chevallier was able to use this fact, together with reports from other observers of the position of the phenomenon against the background stars, to estimate its height by triangulation; he arrived at a figure of 253 km.

[86] John Rand Capron (1829-88) was an English amateur scientist, astronomer and photographer.

[87] There was some confusion over the date of the aurora: Capron referred to observing it on 04 February, whereas Oliver and Plummer gave the date as 05 February.

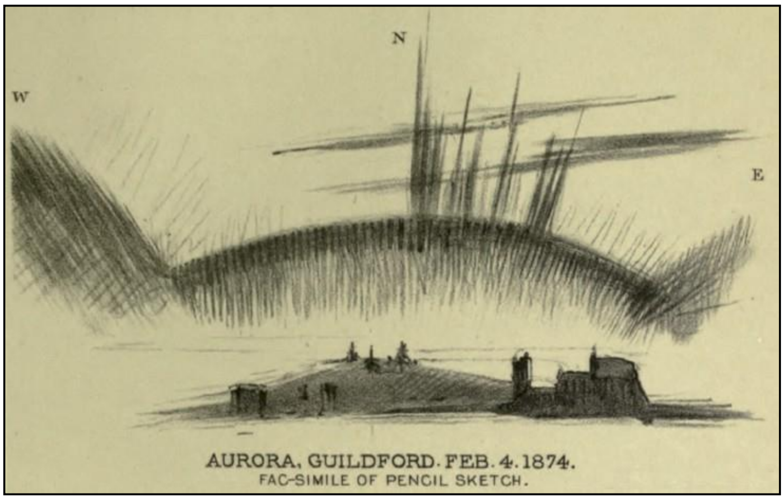

Figure 36. The aurora of 05 February 1874. (From Capron, 1879.)

Capron aimed to provide a comprehensive account of all aspects of the aurora including techniques to estimate the height of the phenomenon and the results obtained. He included estimates of height, made between 1621 and 1874, spanning the range from a few metres to 1600 km! He did not attempt to rank the estimates in terms of likely accuracy and summarised the position as follows: *The conclusions to be arrived at from the foregoing instances and opinions are certainly very puzzling. The terrestrial character of some Aurorae seems well established. The height to which these phenomena* ***may*** *ascend is left almost a matter of conjecture, and further observations are very desirable.*

In his third and final scientific publication on aurorae, written while at Orwell Park, Plummer (1880a) responded in *Nature* to Capron's views on the height of the phenomenon. He considered that there was less uncertainty than Capron supposed, and described two methods for its estimation. The first required the observer to estimate the altitude and amplitude of the auroral arch, and assumed that the latter had the form of a circle centred on the magnetic pole. It gave a wide range of results, probably because not all arches in fact conformed to the assumed configuration. The scientific consensus was that, if doubtful cases were excluded, it generally gave good results. It indicated that the ordinary white arch, which forms some 95% of auroral phenomena visible in the UK, occurred at an average height of approximately 160 km. The second method was triangulation of the aurorae from two or more observing stations. Astronomers in the UK had used this method since 1843, typically obtaining estimates in the range 110-120 km. It was inherently capable of an accuracy of approximately three kilometres. Surprisingly, he did not mention the triangulation performed by Chevallier in 1841[88].

Based on personal experience during 10 years of observing, having witnessed three auroral arches (although none from Orwell Park, because of its southerly latitude) he expressed doubt that the phenomenon formed at altitudes below approximately 110 km and dismissed as mistaken reports of low-altitude aurorae. However, he accepted that streamers at right angles to an auroral arch might reach to greater or lesser heights than the arch itself. His views were broadly in line with modern estimates, which put the height of aurorae in excess of 100 km (e.g. Ridpath (1989) or Illingworth (1994)).

As a footnote, he indicated that he was quoting from memory the height of the aurora estimated by triangulation as 110-120 km for he had *no library at hand to which to refer*. The cause of his loss of access to the library of Cambridge Observatory (see section 2.6) is not clear.

[88] Unless, of course, the date of 1843 which Plummer quoted was in error, and he did in fact intend to refer to Chevallier's 1841 observation!

A9 Zodiacal Light

The zodiacal light is a faint glow visible in the west after sunset and the east before sunrise. It has the shape of a slanting cone extending from the horizon, tapering along the direction of the ecliptic and visible over an extent of *circa* 20°. Its brightness varies slightly in response to fluctuations in solar activity. Imaging, spectroscopic analysis and the direct capture of material by spacecraft reveal the cause of the phenomenon to be a vast lenticular disk of interplanetary dust grains, predominantly located in the plane of the ecliptic, centred on the Sun and extending, perhaps, as far as the orbit of Jupiter. The particles are of a size that strongly reflects sunlight. They are in decaying orbits, spiralling towards the Sun, but are replenished by fresh dust transported to the inner solar system by comets, and by small particles generated by collisions in the asteroid belt.

Plummer addressed the zodiacal light in three papers published from Durham and Orwell Park Observatories. Doberck referred to observations of the phenomenon made in part by Plummer at Hong Kong.

Plummer first mentioned the phenomenon incidentally, noting simply that it had been *plainly visible* on the evening of 05 February 1874 prior to his observation of an aurora (Plummer, 1874g).

Later in the same year, in his first observing report from Orwell Park Observatory, Plummer (1874d) reported that while observing Coggia's Comet (C/1874 H1) in early-morning hours in the months up to and including November 1874, he witnessed *repeated brilliant exhibitions of the zodiacal light.* On seven mornings in September and October, it rivalled the Milky Way in brightness. He believed that it was more distinct and bright than usual and had been so too in spring 1866 and spring 1874. He speculated that it might be subject to a previously unrecognised annual variability and thus might be prominent again in spring 1875; he did not subsequently report observations to investigate the hypothesis.

In his last paper on the subject, an article in the popular journal *Science For All*, Plummer (1881c) described and attempted to explain the phenomenon. Although his description was in line with modern reports, at the time there were several competing theories no accepted definitive explanation. An early conjecture was that the zodiacal light was caused by the reflection of sunlight from tenuous material in the inner solar system. The material comprised myriad small meteors in decaying orbits, gradually spiralling towards the Sun; comets brought fresh material to make good the losses. The theory could not explain why the material lay primarily in the plane of the ecliptic whereas comets arrived at the inner solar system from every direction. Later, scientists misinterpreted observations made during total solar eclipses in the mid-late 19th century to conclude that the material was an extension of the solar corona and therefore likely to vary in brightness in line with the 11-year solar cycle. Although Plummer referred to the zodiacal light being very conspicuous in 1874, he did not repeat the suspicion, voiced in his first paper on the subject, that this was due to a previously unrecognised annual variability. Spectroscopic observations of the zodiacal light had yielded unsatisfactory, dissimilar results, but in broad terms suggested that the material closest to the Sun was self-luminous whereas that further from the Sun shone by reflected sunlight. Astronomers had no explanation for the self-luminosity.

The orbits of Mercury and Venus provided evidence that the material responsible for the zodiacal light was extremely tenuous. Both planets orbited the Sun within the disk of material, but analysis of their orbits showed no resulting retardation. However, Plummer speculated that retardation might be apparent for less massive bodies and could, perhaps, explain the gradual decay in the orbit of Encke's Comet. Nowadays, astronomers do not consider the material to offer significant resistance and ascribe the orbital decay of comets such as Encke's to the loss of material from the nucleus through outgassing on each perihelion passage.

Doberck (1899c) provided the final description of Plummer's work on the zodiacal light. In 1899, he detailed observations of the phenomenon made at Hong Kong Observatory from March 1895 to March 1899; Plummer had undertaken some of the observing during late 1896 and late 1897. Following Plummer some 25 years earlier, he suggested that the zodiacal light might be variable in intensity but, unfortunately, had insufficient data to confirm or refute the hypothesis definitively.

A10 Spectroscopy

While at Durham, Plummer published in the astronomical literature three papers on spectroscopic observations, complemented by related unpublished notes in the Observatory MSS (Plummer, 1869h). He had use of *a Browning star-spectroscope, furnished with two 30° prisms* (Plummer, 1873k). It is not known when the observatory acquired the instrument; however, his notes from mid-February 1869 refer to a calibration, performed in 1868, involving the use of five chemical elements, which would logically have been undertaken before the instrument was put to serious use. The spectroscope was limited in its capabilities. Unfortunately, his access to spectroscopic equipment ceased after he left Durham.

During the period 09 February – 31 March 1869, the Observatory MSS record his studies of the spectra of the Sun, Sirius, Procyon, Betelgeuse, Regulus, Denebola, Algieba, Pollux, Castor, Aldebaran and Capella. On 11 and 18 February he succeeded in measuring the positions of 10 lines in the solar spectrum, identifying them as A, a, B, C, D, E, b, F, G and H[89]. The other spectra were considerably fainter than that of the Sun and for each he saw or suspected at most a handful of lines.

On 18 February, he compared his measurements with work by William Huggins[90] and William Miller[91] (1864), two pioneers of spectroscopy, but came to no definite conclusion. The comparison merely highlighted the deficiencies of the Durham spectroscope; thus, Plummer could discern six lines in the spectrum of Betelgeuse and four in that of Aldebaran, whereas Huggins and Millar reported the positions of respectively 78 and 70 lines. His observations of spectra contributed little to the stock of human knowledge; this would have been apparent and likely explains why he did not publish the work. (He experienced equipment difficulties too: for example, on 12 February, the mount of the Fraunhofer refractor caused problems and he complained in his observing notes for Betelgeuse: *Owing to the shifting of the telescope on its support, the last four lines are considered doubtful*.)

Shortly after midnight on 02 April, he witnessed *a very fine aurora*. It appeared *white, perhaps slightly bluish, and not of the more common ruddy hue; there were few or no rays, but broad sheets or waves of light succeeded each other rapidly, proceeding from the arch to a height of about 30° from the horizon*. He found the spectrum of the aurora to consist of a single bright emission line, sometimes hazy and sometimes well defined. At the brightest part of the arch, the line was similar in intensity to the most conspicuous line in the Orion Nebula. He had difficulty determining the wavelength of the line, but was reasonably confident that it was not coincident with any of the main lines in the spectrum of the Sun or the Earth's atmosphere and instead was close to *the more conspicuous of the lines in the spectrum of α Orionis between the solar lines D and E*.

On 06 April, he drafted a paper on his observations earlier in the month. Chevallier (1869) forwarded the manuscript to the Secretary of the RAS and it was read (*The Astronomical Register*, 1869; *The Advertiser*, 1869b) at a meeting of the society on 09 April. Huggins, present at the meeting, commented that the paper was original and valuable and noted that Struve[92] in Russia, in about April 1868 had made a similar observation and that Angström[93], in Sweden, had made multiple similar observations. The line, he noted, was not of any terrestrial element. There then ensued a lively debate between Huggins, Airy and de la Rue, primarily about the origins of the line.

A modern physical description of the aurora provides an identification of the line. An aurora appears when electrons emitted by the Sun collide with atoms in the Earth's upper atmosphere, typically at an altitude of over 100 km, to produce light. Emission lines of atomic oxygen, specifically a greenish one

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89 Fraunhofer introduced the designations in 1814. The B line is due to absorption by oxygen molecules in the Earth's atmosphere, the a line to absorption by terrestrial water vapour, and the remainder to absorption in the Sun's photosphere. More advanced spectroscopes nowadays can resolve thousands of lines in the solar spectrum.

90 William Huggins (1824-1910) constructed specialist instruments and studied the spectra of stars and nebulae. He was elected FRS in 1865 and, in 1897, was knighted. A lunar crater is named in his honour.

91 William Allen Miller (1817-70) was a chemist. Elected FRS in 1845, in 1867 he won the Gold Medal of the RAS, jointly with Huggins, for the spectroscopic study of stars. A lunar crater is named in his honour.

92 Otto Wilhelm Struve (1819-1905) is nowadays best remembered for work on double stars.

93 Anders Jonas Ångström (1814-1874) was a Swedish physicist.

at 558 nm and a dark red one at 630 nm, usually dominate the spectrum of an aurora. The solar D and E lines occur respectively at wavelengths 590 nm and 527 nm, implying that the line seen by Plummer was the emission line of oxygen, the so-called *citron* line.

Oxygen atoms in the lower atmosphere are combined as molecules of O_2 and scientists did not identify atomic oxygen until 1925. Astronomers in Plummer's era were unable to associate the citron line with a chemical element, prompting the formulation of some highly speculative explanations. For example, in a lecture to the Ipswich Scientific Society in 1878 (see appendix 18.2.5), Plummer suggested that the line could be caused by a second atmosphere of the Earth, composed of a very light gas, situated above the familiar, relatively dense atmosphere that sustains life on the planet.

On 13 May, Plummer observed a second aurora, which he described as *surpassing magnificence… a corona was formed, and every part of the sky for a short time was filled with streamers*. Some of the streamers were of a deep red colour. The corona and streamers disappeared and a white arch formed. He examined the spectra of the streamers and arch and found that both exhibited the citron line. (In fact, his measures of the wavelength of the line differed slightly from the values found on 02 April.)

He revised his earlier paper to the RAS and added an addendum dated 17 May describing the second aurora (Plummer, 1869a).

Some four years later, in connection with the supposed phenomenon of *projection on the limb*, Plummer [1873k] made passing reference to using the spectroscope in an unsuccessful search for evidence of a lunar atmosphere. (See appendix 2.4.)

He conducted his last spectroscopic work in 1873. The draft of a letter (Plummer, 1873p) to M. Le Verrier, Director of the Paris Observatory, indicates that the latter had provided copies of the *Bulletin International* of Paris Observatory. In exchange, Plummer supplied a report on his spectroscopic observation of Henry's Comet (C/1873 Q2) in the hope that Le Verrier would publish it in the *Bulletin*. Key elements of the report are as follows:

> *The spectrum of the comet was first examined by me upon Sept 10 at about 14 hours of mean time when the comet was sufficiently high above the horizon. It was found to consist of three bright and very distinct bands of which the central one was considerably brighter than either of the other two. These bands were quite sharply defined upon the less refrangible side and appeared to fade away imperceptibly in the opposite direction. The width of the bands was estimated about equal to the distance of the solar lines E and b, the central one being rather greater than this. A faint continuous spectrum was barely discernible and the brightness of the sky, illuminated by the moon, would have been sufficient to produce the faint trace that was visible. As far as any observations are trustworthy therefore the comet was certainly of a gaseous constitution.*

On 10 September, he left the cross-wires of the spectroscope bisecting the sharply defined edge of the central band and, by comparison with the solar spectrum the following morning, found the position to be very nearly coincident with solar line b. He attempted to examine the spectrum of the comet again on 14 September, but the sky was too hazy for a satisfactory observation and, although he was able to confirm the existence of the three bands, their relative positions and intensities, he did not estimate their absolute positions.

He found Henry's Comet to be similar in general appearance to Winnecke's Comet (C/1868 L1) and believed further that the two had identical spectra. Huggins (1868b) had investigated the spectrum of the latter and concluded that the body consisted primarily of incandescent vapour of carbon. Plummer therefore concluded that Henry's Comet too produced light by *incandescent action*. He provided a short summary of his findings in a letter in *The Advertiser* (Plummer, 1873q) and again in his annual report to the RAS for 1873 (Plummer, 1874b).

The interpretation of spectra was still a nascent field in Plummer's era, and his conclusion is not completely in accordance with modern understanding. Nowadays, dust in both the coma and tail of a comet are understood to reflect incident sunlight while gases, ionized by the solar wind, glow. The green hue of some comets is associated with carbon, specifically molecules of dicarbon (C_2), which photodissociate in sunlight (see e.g. Borsovsky, J., *et al*, 2021).

A11 Star Catalogues

Much of Plummer's astronomical work concerned estimating the positions of comets and asteroids for the benefits of computers, who could use his results to calculate orbits for the bodies. He estimated the position of a body by using a micrometer (see appendix 22) to measure its offset from comparison stars of known position. Difficulties could arise if catalogue positions for the comparison star were discrepant or, more fundamentally, there was no suitable comparison star within the field of view.

While at Durham, Plummer (1869g), concerned about the accuracy of RA of comparison stars, stated that he *intended in future to observe the right ascensions of all the comparison stars upon the meridian, which will give a much greater reliability*… He adopted this approach for some subsequent observations; however, the labour involved meant that he soon abandoned it.

Initially, the situation at Orwell Park appeared promising and, in Plummer's (1875a) first report from there on cometary observations, he stated that *for the positions of the comparison stars I have to acknowledge the courtesy of Prof. J. C. Adams, who has kindly placed the library of the Cambridge Observatory at my service for the catalogue places*. Unfortunately, for reasons unknown, his access to the library was short-lived and, in his annual report to the RAS for 1877 (Plummer, 1878b), he complained that *the want of astronomical literature, and particularly of star catalogues, is found to be a great drawback to the successful prosecution of the work which is regarded as the proper sphere of labour for this Observatory*. The lack of access to the library forced Plummer to use old catalogues for stellar positions, which hampered his work considerably. In 1882, he expressed considerable frustration (Plummer, 1882a): *It is much to be regretted that many of the positions depend either on old Catalogue places of stars or, still more doubtfully, on micrometrical comparisons with such...* From 1886 onwards, in cases where different authorities quoted different positional data for a star, he adopted the weighted mean of data from up to five sources to improve accuracy.

In Plummer's era, Argelander's[94] *Bonner Durchmusterung* catalogue, compiled over a 25-year period and published 1859-62, was the most comprehensive and accurate available, containing data on 314,925 stars. Even the *Durchmusterung* provided an average density of only approximately 15 stars per square degree, too low to guarantee the presence of a comparison star within the field of view. In some cases, he could use for comparison a field star for which other observers had published positional data. When no positional data was available for any star in the field of view, he used a two-stage approach, selecting a field star as comparison star and either using a micrometer on the equatorial refractor to measure its offset from nearby stars with known position, or undertaking meridional measurements to establish its position. Of course, these approaches tended to reduce the accuracy of the end product. He complained (Plummer, 1884a) that 22% of the comparison stars in his observations of comets in 1882 and 1883 had not been observed on the meridian and that he needed to undertake such measurements before he could complete the data reduction.

Table 19 lists, for each of Plummer's reports on positional astronomy, the approach adopted, the number of comparison stars used and difficulties noted.

Reference	Subject of Study	Number of Comparison Stars Used	Approach Adopted and Difficulties Noted
Plummer, 1868c	Asteroids	23	Took positions of 17 stars from catalogues. Estimated position of one star by equatorial comparison with a catalogue star. For five stars took declination from catalogues and measured RA on the meridian.
Plummer, 1869f	Asteroids, comet	26	Took positions of 25 stars from catalogues. Estimated position of one star by equatorial comparison with a catalogue star.
Plummer, 1869g	Asteroids, comet	22	Took positions of 16 stars from catalogues. For six stars took declination from catalogues and measured RA on the meridian.
Plummer, 1870c	Asteroids	23	Took declination of all stars from catalogues. Used catalogue RA for four stars and for 19 stars measured RA on the meridian.

[94] Friedrich Wilhelm August Argelander (1799-1875) was a German astronomer specialising in astrometry.

Reference	Subject of Study	Number of Comparison Stars Used	Approach Adopted and Difficulties Noted
Plummer, 1871d	Comet	18	For all stars used catalogue places for declination and measured RA on the meridian.
Plummer, 1871e	Asteroids	24	Used catalogue position for one star. For all others used catalogue places for declination measured RA on the meridian.
Plummer, 1872f	Asteroids	28	No problems reported.
Plummer, 1873o	Comet	9	Used catalogue positions for eight stars and for one determined position by equatorial comparison with catalogue stars.
Plummer, 1874e	Comet	8	No problems reported.
Plummer, 1875a	Comet	26	Used catalogue positions for 19 stars and for seven determined positions by equatorial comparison with catalogue stars.
Plummer, 1877b	Venus	1	No problems reported.
Plummer, 1879d	Comets	41	Made allowance in the data reduction for proper motion of only one star but concluded that there was evidence of it for at least four others. Used catalogue positions for 35 stars and for six determined positions by equatorial comparison with catalogue stars.
Plummer, 1880d	Comet	28	Used catalogue positions for 26 stars and for two determined positions by equatorial comparison with catalogue stars.
Plummer, 1881b	Comet	1	No problems reported.
Plummer, 1882b	Comets	51	Used catalogue positions for 43 stars and for eight determined positions by equatorial comparison with catalogue stars.
Plummer, 1882d	Comet	12	No problems reported.
Plummer, 1882c	Comet	43	Used catalogue positions for 31 stars and for 12 determined positions by equatorial comparison with catalogue stars.
Plummer, 1884b	Comet	42	Used catalogue positions for 31 stars and for 11 determined positions by equatorial comparison with catalogue stars.
Plummer, 1884c	Comets	11	Used catalogue positions for eight stars and for three determined positions by equatorial comparison with catalogue stars.
Plummer, 1885b	Comet	33	Used catalogue positions for 29 stars and for four determined positions by equatorial comparison with catalogue stars.
Plummer, 1886a	Comet	17	Obtained positions of several comparison stars from reports by other observers. Used catalogue positions for 10 stars and for seven determined positions by equatorial comparison with catalogue stars.
Plummer, 1886b	Comets	25	Used catalogue positions for 21 stars and for four determined positions by equatorial comparison with catalogue stars. In the case of 12 comparison stars adopted a weighted mean of positions listed in up to four catalogues.
Plummer, 1887c	Comets	113	Used catalogue positions for 87 stars and for 26 determined positions by equatorial comparison with catalogue stars. In the case of 37 comparison stars adopted a weighted mean of positions listed in up to four catalogues. Noted five discrepancies between catalogue positions.
Plummer, 1888d	Comet	5	For three stars, used catalogue positions as listed; for the remaining two, adopted as position the average across two catalogues.

Reference	Subject of Study	Number of Comparison Stars Used	Approach Adopted and Difficulties Noted
Plummer, 1888c	Comets	50	Used catalogue positions for 43 stars and for seven determined positions by equatorial comparison with catalogue stars. In the case of 31 comparison stars adopted a weighted mean of positions listed in up to four catalogues. Noted five discrepancies between catalogue positions.
Plummer, 1889c	Comets	66	Used catalogue positions for 48 stars and for 18 determined positions by equatorial comparison with catalogue stars. In the case of 30 comparison stars adopted a weighted mean of positions listed in up to five catalogues. Noted six discrepancies between catalogue positions.
Plummer, 1890e	Comets	82	Used catalogue positions for 61 stars and for 21 determined positions by equatorial comparison with catalogue stars. In the case of 30 comparison stars adopted a weighted mean of positions listed in up to three catalogues. Noted six discrepancies between catalogue positions.

Table 19. Difficulties in positional estimates.

In contrast, the modern astronomer is served by a dense net of accurate stellar positions. For example, in 1996, the USNO (United States Naval Observatory) published the star catalogue A2.0 (Monet, 1996) containing data for 526,280,881 stars, giving an average density of 12,760 stars per square degree.

Plummer must have found his experiences of star catalogues frustrating. Perhaps in response, he undertook an investigation of the quality of proper motion data in the British Association Catalogue (BAC; Baily, 1845). The BAC was published in 1845 and in common use in the mid-1870s. It contained data on 8377 stars for the epoch 01 January 1850. It had been compiled from 32 donor catalogues and contained nearly all the stars in earlier catalogues by James Bradley[95] and Giuseppe Piazzi[96]. It relied for many proper motion estimates on a comparison of positions listed by Bradley or Piazzi with those measured subsequently. Errors in the early catalogues could translate into significant inaccuracies in proper motion estimates; although astronomers had found and corrected many such problems, the consensus was that many likely remained. Plummer believed that reliance on more recent observations, made with greater precision, would yield more accurate proper motion estimates and thus, in turn, more accurate estimates of position.

To gauge the opportunity for improvement, he aimed to identify stars in the BAC with inaccurate proper motion data. He began the project at Durham and continued it after moving to Orwell Park. In his annual statement to the RAS for 1875, he reported (Plummer, 1876a) that he had identified *a number of stars likely to show some irregularity of proper motion* and was pushing forward observation of them *with vigour*. The following year, he published (Plummer, 1876c) preliminary conclusions. He claimed to have found evidence that proper motions had varied during the time since Bradley's observations: *I do not know that we have any right to assume that proper motion is in all cases constant both in direction and amount during the long interval of 120 years which has elapsed since Bradley's observations, and indeed I believe that I have already discovered some evidence to the contrary*. Unfortunately, he did not present the evidence and did not appear to take this line of research further.

Instead, he set out to identify cases of discordant proper motion data for BAC stars that were listed in both the catalogues *Armagh Places of Stars* (Robinson, 1859) and *Greenwich Seven Year Catalogue* (Airy, 1870). The *Armagh* catalogue contained data on 5345 stars, listing for each the source of an

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[95] James Bradley (1692-1762) was Astronomer Royal 1742-51.

[96] Giuseppe Piazzi (1746-1826) supervised the construction of a new observatory at Palermo in 1787, and it was while working there, on 01 January 1801, that he discovered (1) Ceres, the first of the asteroids.

earlier authoritative assumed place, corrections to it and a resulting updated assumed place, with proper motion estimates obtained by comparison of positions with earlier catalogues. It covered epochs from the early 1830s to the early 1850s. The *Greenwich* catalogue contained data on 2760 stars reduced to the epoch 1864. It included estimates of proper motions by Main or Stone at the ROG or, for stars that they did not cover, from the BAC. The three catalogues had 2028 stars in common. Plummer's description of his method for identifying stars with doubtful proper motion estimates is not entirely clear; the most cogent interpretation is as follows.

He first ran a coarse search to identify stars for which *there was a fair case for enquiry as to whether the proper motion employed was correct*. His technique was to use, for each star common to all three catalogues, position and proper motion data in the *Armagh* catalogue to estimate its position at the epoch 1864 (ignoring the effect of precession), and to compare the calculated position with that listed in the *Greenwich* catalogue. If the difference in either RA or declination exceeded a threshold value, the star was marked for further study. Setting appropriate thresholds was a matter of judgement, and he settled on the following values in RA and declination respectively 0.25^s.sec(dec/2)/yr and 2.5"/yr, the former being based on a heuristic *that experience has shown to be sufficiently accurate for practical purposes*. He provided a table expressing the thresholds in terms of the probable error (PE) associated with estimates of position, but the reasoning here is particularly unclear.

Once a star was identified by the above procedure, he estimated its proper motion as follows:

1. Transform the position of the star in the *Greenwich* catalogue from 1864 to the date of observation.
2. Apply formulae for precession to bring up the position of the star in the *Armagh* catalogue to the epoch of observation.
3. Calculate the difference between the above positions (in the sense *Greenwich* minus *Armagh*) to give an estimate of proper motion deduced from the two catalogues.
4. Divide the difference in position by the difference between the epoch of observation and the epoch of the Armagh catalogue to give an estimate of the annual proper motion.

He found that declinations in the *Armagh* catalogue were systematically greater than those in the *Greenwich* catalogue. He had no explanation for this and therefore postponed further examination of declination proper motions. In regard of RA, though, he had greater success, listing 55 stars, covering the first six hours, with differences in proper motion estimates exceeding the threshold. The root mean square of the difference in annual proper motion in RA was 0.04^s/yr.

He provided (Plummer, 1877c) an update in the following year's annual report to the RAS. He had completed the analysis of all stars common to the catalogues, finding 196 that had discrepant proper motions in RA, each of which he had observed on the meridian on three separate occasions with a view to further investigations. His final update on the work (Plummer 1879a) was in his annual report to the RAS for 1878, which stated that he had completed reduction of a great number of transits of stars which he *expected to yield some interesting results bearing on proper motion*. He provided no further details.

He clearly invested considerable time and effort on observational work and data analysis for the project. However, despite identifying 196 stars in need of detailed investigation, he published details of only the first 55, and appeared to abandon the work unfinished. Although he was not alone in recognising problems with the BAC (see for example Downing, 1878) there is no evidence that other astronomers used his findings.

His technique to identify stars with discrepant proper motions was *ad hoc* but could, nevertheless, plausibly identify large discrepancies in proper motion. However, unfortunately, it was the relatively poor-quality astrometry of the era rather than genuine discrepancies in proper motion that led to his identification of the 196 stars, and he was mistaken in his claim to have identified stars with irregular proper motion.

A brief postscript to Plummer's work on star catalogues appeared a decade later. Professor Grant (1888), announcing a revised version of the *Glasgow Star Catalogue*, credited him as identifying errors in the original. It is not known whether he found the errors as a by-product of the investigations described above.

A12 Light Of The Stars

As astronomers turned ever more powerful telescopes to the night sky, the number of stars visible increased rapidly, implying that fainter stars are more numerous than brighter ones. Edward Stone (1877) considered why this might be so. At the time, astronomers had been able to estimate the distance to only the nearest dozen or so stars by measuring their parallaxes (defined in appendix 1.9). However, he believed that there was no physical limit to the distance of a star and, assuming that the determinants of apparent brightness were distance and intrinsic luminosity, developed a mathematical model, based on the following simplifying assumptions:

- Stellar intrinsic luminosities were constrained to the finite set of discrete values {1,…,n}.
- Each intrinsic luminosity was equally likely.
- Stars were constrained to distances from the Earth x_i, defined such that a star of magnitude m at distance x_i would, if relocated to distance x_{i+1}, be reduced in brightness to magnitude m+1.
- The density of stars per unit area was uniform across the spheres.

The model enabled Stone to predict the ratio R_i of stars of each magnitude i (for $i \geq 1$) relative to the number of stars of magnitude one as follows:

$$R_i = \sum_{j=1}^{i} \left(\frac{x_j}{x_1}\right)^2$$

Building on the work of Sir John Herschel and Richard Carrington, who had conducted empirical investigations, he used the model to show how definitions of stellar magnitudes influenced the relative numbers of stars in each magnitude class. The definitions of magnitude were:

- Herschel: adopted α Centauri as reference magnitude 0 and defined the brightness ratio of a star of magnitude n to that of a star of magnitude 0 as $1/(n+0.414)^2$, for n=1,…, 4.
- Carrington: defined the brightness ratio of a star of magnitude n+1 to that of a star of magnitude n as 1/2.75, for n=5,…, 9.

Stone extended Herschel's ratio to stars of magnitude six and Carrington's ratio to stars of magnitude one. He normalised the model so that it predicted exactly the number of stars of magnitude one in Argelander's *Durchmusterung* (see appendix 11) and then compared its predictions of the distribution of stars in the fainter magnitude classes with the corresponding numbers in the catalogue.

Unfortunately, in calculating the terms $\left(\frac{x_j}{x_1}\right)^2$ for the Herschel ratio, Stone omitted the exponent "2" in the ratio itself and e.g. calculated $\left(\frac{x_3}{x_1}\right)^2$ as $(3.414/1.414)^2$ rather than $(3.414/1.414)^4$.

Figure 37 summarises the results. Carrington's ratio generally resulted in good agreement with the *Durchmusterung*; although the model underestimated the number of stars of magnitude nine by more than 39,000, Stone noted that *this discrepancy is not greater than would arise from an uncertainty of estimation of about a tenth of a magnitude at the end of the scale*. He found that for Herschel's ratio, agreement was less good and the useful range of predictions much reduced. Recalculating the model with Herschel's ratio, retaining the exponent in the latter, shows a significant overestimate of the number of stars in magnitudes 2-6. Stone considered that, in general terms, his model was a *somewhat close approximation to the truth,* at least as regards the statistical mass of stars.

Plummer (1877e) responded promptly to Stone in the pages of *MNRAS* describing how, in undertaking work to determine the combined brightness of all the stars in the heavens, he had found a deviation from the latter's results around magnitude nine. His starting point was the observation that all stars, no matter how faint, contributed to the general illumination. He tabulated, for each magnitude class in the *Durchmusterung*, the number of stars in the northern hemisphere together with the number of magnitude six stars that would give an equivalent light level. He followed Littrow in defining the magnitude classes each to be of unit range, except for class nine, which spanned from magnitude 9.0 to magnitude 9.5. He calculated that, on a fine night under the northern sky, roughly three-quarters of starlight was produced by stars individually invisible to the naked eye and the total illumination from stars down to magnitude 9.5 was equivalent to 10.2 times that of Venus at greatest brilliance, or to

1.3% that of the mean full moon. He noted Norman Pogson's[97] ratio 2.512 between the brightness of stars with a difference in magnitude of precisely 1.0 (the ratio upon which the modern magnitude scale is based) but, in performing the calculations, adopted instead the rounded value 2.500, to ease the arithmetic. He aimed to extend the analysis to fainter stars but soon confronted the inevitable difficulty: if ever fainter stars continued to increase in number in the same proportion, the total brightness of all the stars would be infinite and the night sky would be brilliantly illuminated (the well-known Olbers' Paradox). He therefore restricted attention to northern hemisphere stars of magnitude 9.5 or brighter.

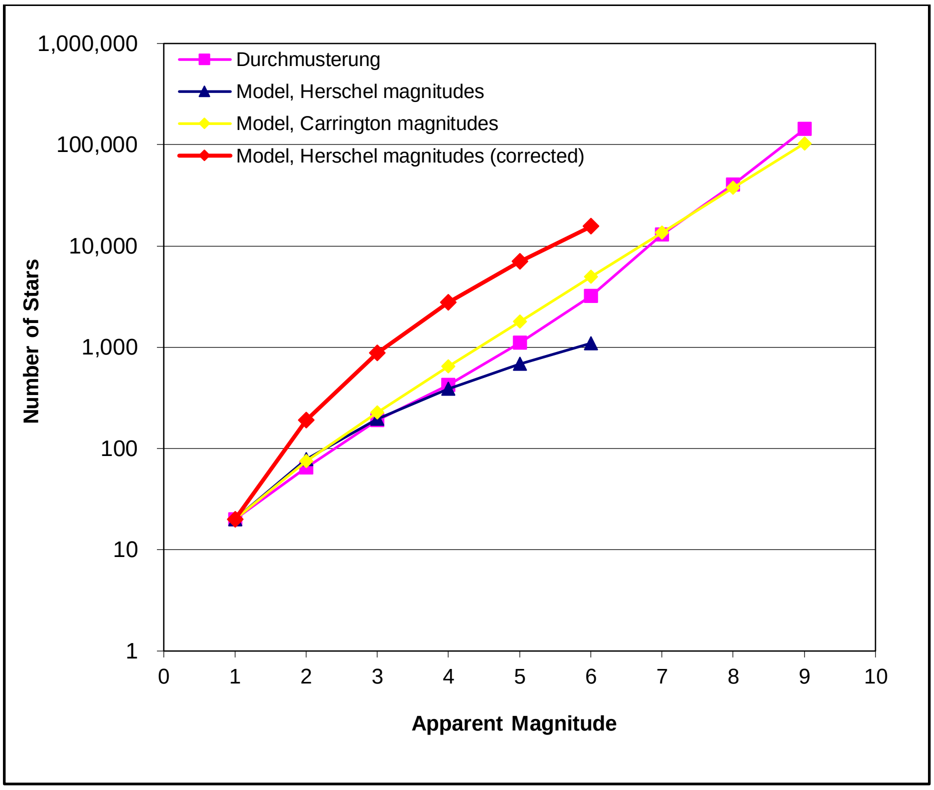

Figure 37. Number of stars by magnitude. (After Stone, 1877).

He developed a simple model of the distribution of apparent magnitudes of the stars, based on the assumption that they were uniformly distributed and each of average intrinsic brightness. (Thus, a star's distance was sole determinant of its apparent magnitude.) To calibrate the model, he set the proportion of stars in magnitude class eight in the model equal to the corresponding proportion of stars in the *Durchmusterung*. Calibration against magnitude classes four, five, six or seven produced similar results. A more natural calibration would, perhaps, have been across all magnitude classes, such that the overall number of stars predicted by the model equalled that of the *Durchmusterung*.

Figure 38 illustrates the results, showing the number of stars in each magnitude class in the *Durchmusterung* and predicted by the model. By construction, the model and the *Durchmusterung* were in exact agreement regarding magnitude class eight. Agreement was good too for classes four – seven; thus, in the mid-range of magnitudes, it captured well the bulk properties of the distribution of stars. For classes one, two and three, it significantly under-predicted the number of stars; however, as the *Durchmusterung* listed only 177 in this range, the discrepancy was not too important. There was clearly a more fundamental problem with magnitude class nine: the *Durchmusterung* listed 237,131 stars whereas the model predicted only 99,631. (The logarithmic scale of the figure tends to mask the discrepancy.) Plummer concluded that either the magnitude estimates in the *Durchmusterung* were

[97] Sir Norman Pogson (1829-91) was an English astronomer whose most notable contribution to astronomy was to suggest, in 1856, a rationalisation and extension of the system of stellar magnitudes that the Greek astronomer Hipparchus had introduced *circa* 150BC. His system defines the magnitude scale in use nowadays.

incorrect and the catalogue contained many stars which, although rated of magnitude class nine were in fact fainter, or there existed an unexpectedly dense stratum of stars at a distance from Earth corresponding to magnitude class nine. He recommended further investigation.

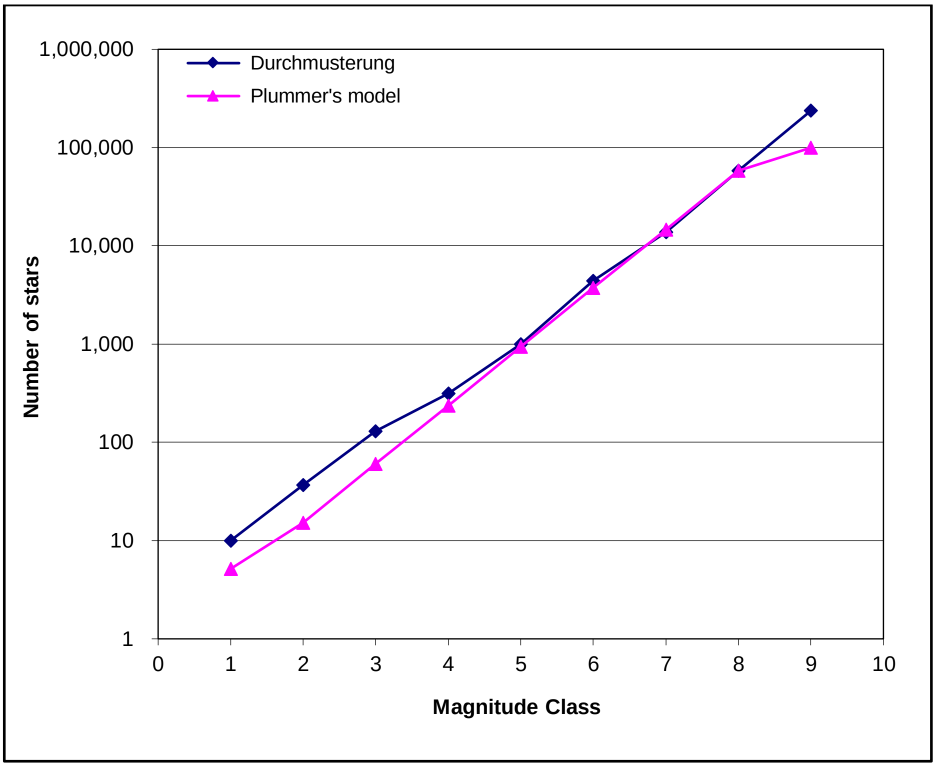

Figure 38. Distribution of stellar apparent magnitudes.

John Dreyer[98] (1877) responded to Plummer, indicating that work by Professor Eduard Shönfeld[99], extending the *Durchmusterung* to the south, suggested a slightly different classification of the faintest stars. Shönfeld believed that stars of magnitude class nine in the *Durchmusterung* were fainter than indicated, specifically that stars listed as magnitude 9.4 were of true magnitudes in the range 9.4-9.5, and that those listed as magnitude 9.5 were of true magnitudes in the range 9.5-10.0.

Plummer (1877f) responded with a brief paper describing the effect on his model if the stars in magnitude class nine of the *Durchmusterung* were instead considered distributed evenly over the magnitude range 9.0-9.9 or 9.0-10.0 rather than 9.0-9.5 as previously. The effect was to provide much improved agreement between the prediction of the model and the number of stars in the *Durchmusterung* for magnitude class nine. However, he noted that the limiting magnitude of the catalogue was uncertain and proposed further research to determine it. He proposed use of the brighter asteroids as a means of comparing the magnitudes of fainter stars with those of brighter ones; unfortunately, the intended procedure is not obvious and he provided no details.

Although to modern readers Plummer's approach appears hopelessly naïve, it was not out of keeping with the knowledge of the era. Stellar mapping was insufficiently advanced to reveal the distribution of stars on a galactic scale, making gross simplifying assumptions essential in constructing models of their distribution.

[98] John Louis Emil Dreyer (1852-1926) was an astronomer and historian of astronomy nowadays best remembered for the *New General Catalogue of Nebulae and Clusters of Stars*.

[99] Eduard Schönfeld (1828-91) was appointed Director of Bonn Observatory in 1875. His greatest work was the southern extension of the *Durchmusterung* to declination -23°, published in 1886.

A13 Orwell Park Transit Instrument

Orwell Park Observatory is equipped with a Troughton & Simms 75 mm transit telescope. Figure 39 shows the telescope and, in close up, the adjustments on its axis (described below). The small aperture of the instrument limits its capabilities; nonetheless, during Plummer's initial years at the observatory, he made extensive use of it. However, in his annual report to the RAS for 1881 (Plummer, 1882a), for reasons unspecified, he condemned it as follows: *the Observatory not being furnished with a meridian instrument suitable for the observation of the comparison stars*... His comment, unfortunately, casts a long shadow over all astrometric work that he reported from Orwell Park.

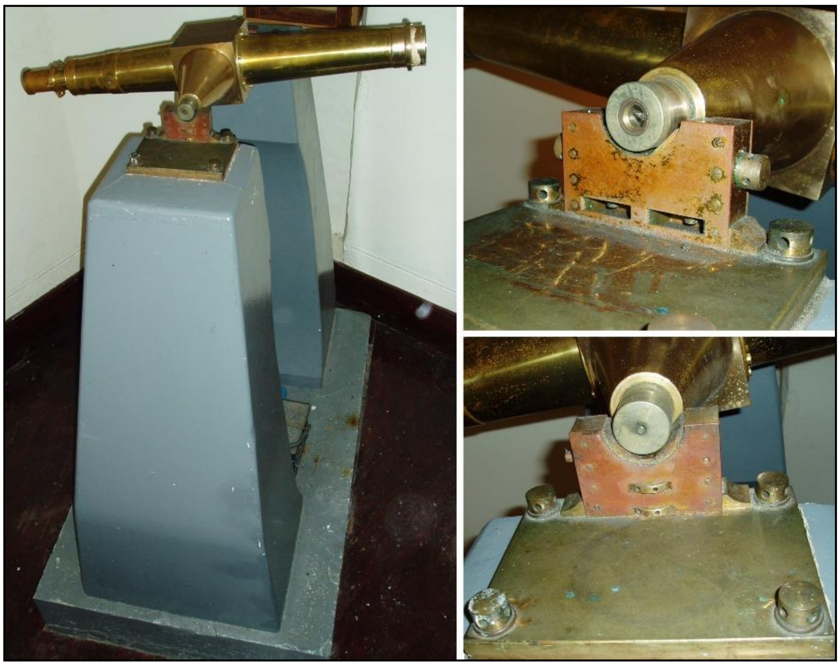

Figure 39. The transit telescope (left) and adjustments on its axis, east (top right) and west (bottom right). (James Appleton, 2007.)

A13.1 Determination Of The Position Of Orwell Park Observatory

The position of Orwell Park Observatory was an important element in the reduction of observations. In 1801, the Ordnance Survey (OS) began publishing maps of the UK, covering the Nacton region in 1838 at scale 1:63,360 and in 1889 at scale 1:10,560 (Ordnance Survey, 1838; 1889). A modern OS map of the region (Ordnance Survey, 2006) gives the location of the observatory as 1° 13' 55.8" E, 52° 0' 33.6" N. Table 20 shows the difference between the 1838 and 1889 estimates of the location[100] and the modern value (in the sense modern minus historic). It lists differences in latitude and longitude expressed as seconds of arc, and corresponding linear displacements on the surface of the Earth. By Plummer's era at Orwell Park, the OS had established the position of the observatory with high accuracy. However, he chose to estimate its position by astronomical means.

[100] Although the observatory had not been constructed in 1838, the location where it would later be built may be determined by reference to the remainder of Orwell Park Mansion. The scales on the map enable estimation of the longitude of the observatory with reasonable accuracy, but its latitude, unfortunately, only with a degree of approximation. Differences in latitude relative to the 1838 figure should therefore be regarded as indicative.

	Difference from modern OS position			
	Longitude		Latitude	
Date	**Arc (")**	**Linear (m)**	**Arc (")**	**Linear (m)**
1838	-3.0	-56	-1.2	-37
1889	0.2	5	-0.4	-12

Table 20. Estimates of the position of Orwell Park Observatory.

It is comparatively easy to establish latitude by astronomical techniques, for example by Talcott's method (see section 2.7); however, determination of longitude by observation of the stars is more difficult. In general, techniques for the latter rely on the fact that the Earth rotates once on its axis with respect to the fixed stars in a period of 24 hours sidereal time (a period approximately four seconds shorter than the length of the mean solar day used in civil time). Consider a star culminating at the ROG: for every 15° west of Greenwich, it will culminate one hour later in sidereal time and for every 15° east, one hour earlier. Therefore, an observer with access to a chronometer reading sidereal time at Greenwich can readily determine longitude by noting the difference in sidereal time between the culmination of the star at his location and at the ROG. The chief practical difficulty in implementing this approach lay in making Greenwich sidereal time available at distant locations: this generally required synchronising chronometers to reference time at the ROG and transporting them to the observing site or using telegraphy. Transporting chronometers was a cumbersome undertaking: a single chronometer might lose accuracy due to the rigours of the journey, so generally several were employed. The ROG was connected to the telegraph network and, of course, to enable the use of telegraphy, the remote observatory had to be connected too, although this could be on a temporary basis. Both techniques were expensive and not lightly undertaken; Plummer was not in a position to adopt either at Orwell Park and instead relied on less accurate methods.

He initially used a technique in widespread use at the time, the *Moon and culminators*. An astronomer employing the technique used a transit telescope and sidereal clock to record the delay between transits of the bright limb of the Moon and a nearby bright star (chosen from a defined set of stars). Using data tabulated in the *Nautical Almanac*, he could estimate his longitude. See Broadbent (1916) for an explanation of the technique; Hall (1873) noted that it was typically accurate only to within a few seconds of time (tens of seconds of arc of longitude).

Plummer (1875a, 1875b) soon estimated the latitude of Orwell Park Observatory, publishing the value 52° 0' 33" N, only 1" south of the 1889 OS figure, corresponding to a linear discrepancy on the Earth's surface of 31 m. Determination of the longitude of the observatory proved considerably more difficult, and table 21 lists the chronology of his endeavours. (See Whiting (2006b, 2007) for an earlier investigation.) Plummer's initial estimate was only 1.2" east of the modern value, with a corresponding linear discrepancy on the Earth's surface of 22 m. Unfortunately, his final estimate was 30.4" too far east, corresponding to a linear discrepancy of over half a kilometre; such a displacement could have affected the results of data reductions. Plummer did not state the position of the observatory adopted in his data reductions, and it is unknown even whether he used the same coordinates throughout his whole time at Orwell Park or varied the adopted longitude in line with his efforts to estimate its value.

Publication	Long. Estimate	Note
Plummer (1875a). Report on observations of Coggia’s Comet (C/1874 Q1).	4^m 55.8^s E 1° 13' 57.0" E	First published estimate of the longitude of the observatory.
Plummer (1875b). First annual report to the RAS from Orwell Park.	4^m 55.8^s E 1° 13' 57.0" E	Noted that his estimate of the coordinates of the observatory was based on a *preliminary determination*.
Plummer (1876a). Annual report to the RAS for 1875.	-	Reported making meridional observations of the Moon and culminators for the determination of longitude.
Plummer (1877c). Annual report to the RAS for 1876.	-	Reported completing work to determine the longitude of the observatory, but did not state the value.
Plummer (1878b, 1878d). Annual report to the RAS for 1877 and report on annual fluctuation in errors of transit instrument.	-	Reported that the level and azimuthal errors of the transit instrument were *subject to an annual fluctuation which is extremely regular in its development* and which he believed was caused by heat radiated from the nearby pillar of the equatorial refracting telescope.
Plummer (1879a). Annual report to the RAS for 1878.	4^m 57.75^s E 1° 14' 26.25" E	Estimated longitude by the method of the Moon and culminators. Noted that his estimate *exceeds by nearly two seconds* [of RA] *that inferred from the Ordnance Survey*. The discrepancy equates to 30".
Plummer (1880c). Annual report to the RAS for 1879.	-	Reported completing determination of the location of the observatory *after some difficulty*. Intended to supplement his results by observation of lunar occultations.
Plummer (1881a). Annual report to the RAS for 1880.	-	Reported observing *a number of occultations*. However, they were to support investigation of *projection on the limb*, rather than estimation of longitude.
Plummer (1882a). Annual report to the RAS for 1881.	-	Condemned the transit instrument as follows: *the Observatory not being furnished with a meridian instrument suitable for the observation of the comparison stars…* Published no subsequent papers on the longitude of the observatory.

Table 21. Estimates of the longitude of Orwell Park Observatory.

The significant difference between Plummer’s 1879 estimate and the location published by the OS appeared to stimulate him to undertake further investigations in the hope of obtaining better agreement. Although he reported completing the work (*after some difficulty*) in 1879, the fact that he intended to supplement the results by observation of lunar occultations betrays, perhaps, lack of confidence in his estimate. (He gave no details of how he intended to use the occultation observations; it may be that he intended simply to compare theoretical and empirical timings to search for differences which could be attributed to a discrepancy in the observer’s assumed location.) Two years later, without publishing the occultation work, he had evidently abandoned hope of ever obtaining accurate results from the transit telescope but, unfortunately, he did not enlarge on the problems that led him to this position. They may have been associated with the errors of alignment described below; however, he could readily estimate these and factor them into the reduction of observations, so there must have been other factors at work too.

A13.2 Errors Of The Transit Telescope

The adjustment mechanisms of the transit telescope are as follows. Two Y-shaped mountings support the axis; the eastern is adjustable laterally, providing an azimuth adjustment, and the western is adjustable vertically, providing a level adjustment. The adjustments are by means of screwed threads that may be secured in position by locking collars.

In principle, the observer adjusted the Ys so that the telescope was level and its optical axis aligned precisely with the meridian. In practice, adjustment involved a lengthy process of successive refinement and it was usual in the era to achieve the best alignment possible with reasonable effort, then to estimate the residual errors regularly and apply them in the reduction of observations. Plummer (1878d) described briefly his approach to measuring the errors of the instrument as follows. He estimated the level error *upon each evening of observation* and the azimuth error *as often as was deemed necessary or as circumstances permitted*. He gave no details of his procedure for checking the level error, but it was likely to have been primarily by use of a "striding" spirit level supplied for the purpose by the manufacturers of the telescope. His method for estimating the azimuth error was *generally the observation of a polar and a low southern star…* This approach provided a degree of cross-checking of individual estimates. Chapman (1995) provides a description of techniques for aligning a transit telescope.

Plummer went on to report the analysis of transit observations made during the period August 1875 - November 1876. He found that both level and azimuth errors followed a pattern whereby they remained relatively constant for an interval, then changed significantly to enter another interval during which they remained relatively constant, then changed significantly again, and so on. On 27 June 1876, the level error became unacceptably large and he altered the Ys to reduce it. The adjustment rendered the level errors less steady, so a month later he tightened the locking collars to minimise variation and, in doing so, appeared again to alter the error profiles. Figure 40 shows the mean error during each interval of relatively constant error; points plotted are at the end dates of the intervals.

Both azimuth and level errors showed evidence of cyclic variability, rising from a minimum in autumn 1875 to a maximum in winter 1875-76 then declining to a minimum again at the end of June 1876, when Plummer's adjustment altered the pattern of variability. Initially, changes to the azimuth and level errors occurred approximately in phase but, after winter 1875-76, the level error led the azimuth error by over a month. Although there was evidence of annual variability, the range of data was too short, with too much random variation after Plummer altered the Ys, to support a definitive analysis.

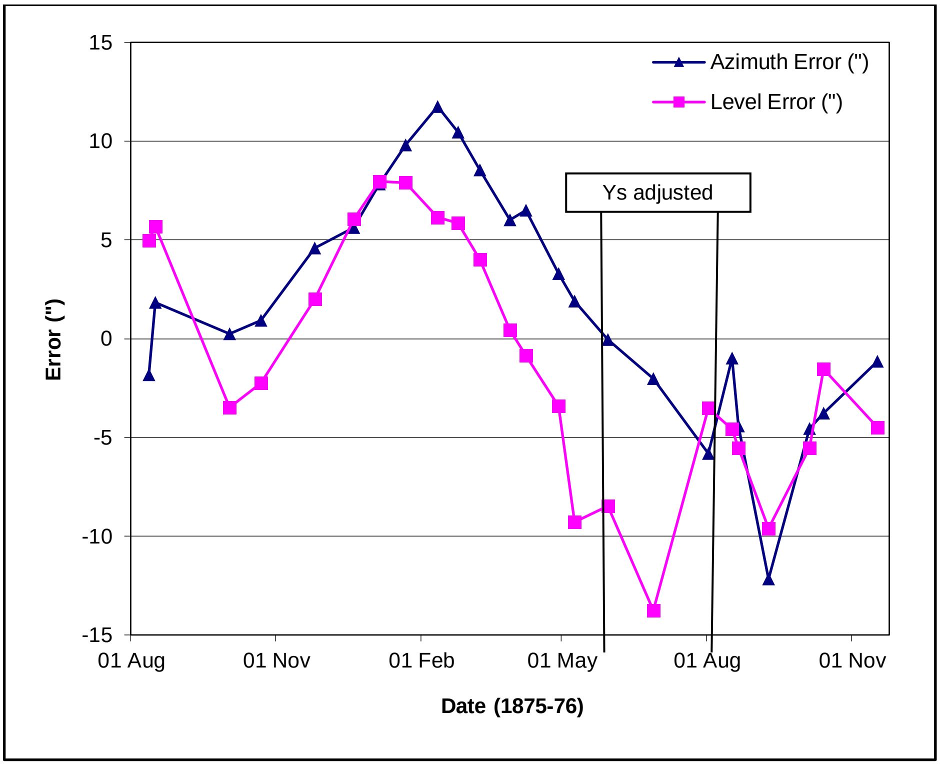

Figure 40. Errors of the Orwell Park transit telescope.

Undaunted by such qualms, Plummer wrote: *A casual inspection of the above azimuth errors is sufficient to indicate a marked and regular fluctuation, of which the maximum and minimum coincide closely with the periods of greatest cold and heat respectively, and for which no sufficient reason immediately suggests itself*. He noted that 4.3 m WSW of the western pivot of the transit instrument was situated the pillar of the equatorial refractor that, together with its surrounding wall, formed a masonry cylinder some 2.8 m in diameter. He suggested that heat radiated from the pillar caused unequal expansion of the mountings of the transit instrument, producing the seasonal error profile. He concluded by recommending that astronomers pay attention to the surroundings of important transit instruments, so that they did not suffer similar problems.

His explanation was plausible but unproven; indeed, he did not appear even to consider investigating whether it was valid. He could have attempted to do so, for example by measuring the temperature profile in the transit room, or by searching for a correlation between the temperature of the pillar and the errors of the transit instrument, but published no such work. Moreover, there existed other, equally plausible, explanations. For example, variation between summer and winter in the moisture content of the ground around the observatory tower could be responsible for slight changes in the angle of the entire edifice.

In fact, less than a year before Plummer's first reported measurement of the error of the transit telescope, Wilfrid Airy had articulated the most likely explanation. The occasion was an ordinary general meeting of RIBA on 16 November 1874 at which John Macvicar Anderson (1875), architect of the observatory, read a paper entitled *The Orwell Park Observatory*, describing the design of the facility, following which Airy, responsible for astronomical aspects of the observatory and the equipment, explained how he had set about the brief. There followed a discussion between Anderson, Airy and the audience of the notion that *buildings are really found to be sensibly influenced by changes of temperature, due to the hours and seasons* and that such an effect might make it impossible to undertake the most demanding astrometric positional measurements. Airy provided an illuminating insight into the design for the transit room and instrument: *With regard to the foundation of the transit instrument, it is not a perfect foundation; but seeing that it could not, with any convenience, be combined with the foundation of the equatorial; (and it seemed out of the question to carry up such a large mass of masonry as would be required for the separate foundation of the transit instrument), I was content with the sufficiently solid foundation afforded by some powerful wrought-iron girders which were used in the construction of the building, and these carried the transit room and instrument. I have already mentioned the transit instrument as being, in the present instance, not of the first importance, but mainly to be used as an adjunct to the equatorial. There is no fear of its getting seriously out of order: it may get a very little movement in consequence of the expansion and contraction of the iron girders, but iron, when entirely enclosed in masonry, does not contract or expand in the same degree as iron exposed to the atmosphere. I was therefore, content with a foundation of that kind, although I should not think of adopting such a foundation for a transit instrument used solely for transit observations of the highest accuracy.*

Documents in the Durham Observatory archive reveal a historical precedent to the difficulties at Orwell Park. Plummer (1869i) recorded level errors of the Durham transit instrument from 08 November 1867 (shortly after starting at the observatory) until 27 April 1869, basing the estimates generally on between eight and 12 individual readings. Figure 41 illustrates the data: there is clear evidence of seasonal variation, with level errors generally positive in summer and negative in winter, and a range of variability some 10" greater than at Orwell Park. Many years previously, Carrington (1855) had commented at length on the Durham transit telescope, noting its many deficiencies and problems. Indeed, he had arranged for a window of the observatory to be bricked up to prevent heat from the Sun falling more on the east pillar of the instrument than on the west, causing unequal expansion, resulting in errors of alignment of the instrument. The work appears to have been only partially successful. Plummer did not refer to Carrington's work and it is unclear how much he knew of the difficulties with the Durham transit telescope and its apparent similarity to the situation that he confronted later at Orwell Park.

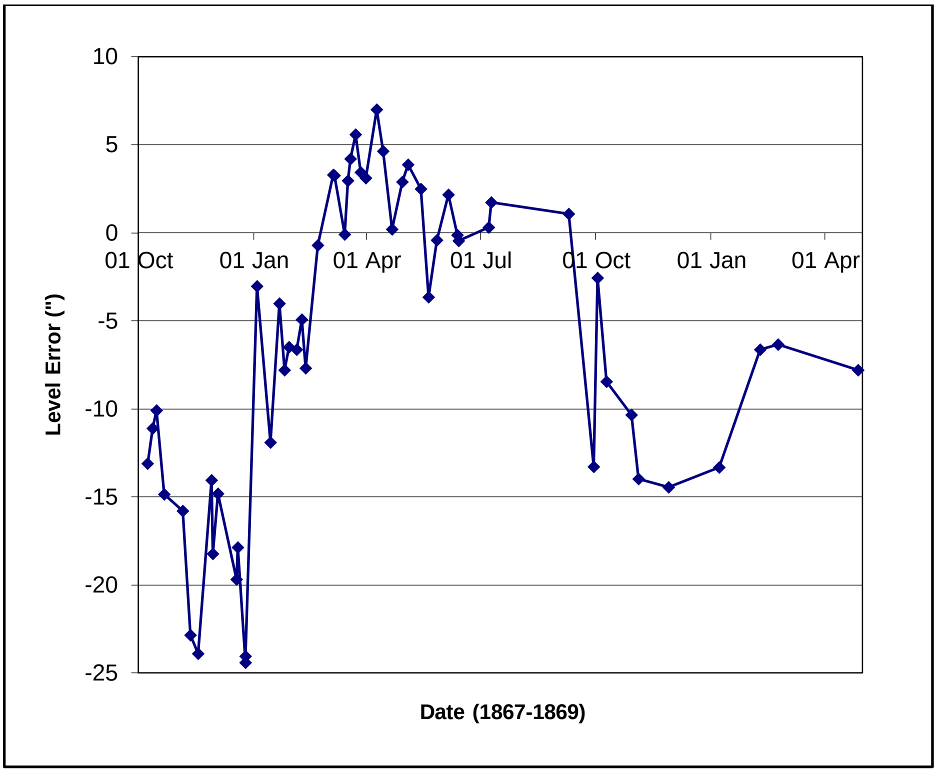

Figure 41. Level errors of the Durham Observatory transit telescope.

A14 Formation Of Planetary Systems

In 1755, the philosopher Immanuel Kant[101] proposed the *nebular hypothesis* to explain the formation of the solar system. In 1796, the French mathematician Pierre-Simon de Laplace[102] refined the theory. The theory proposed that the solar system formed from an enormous cloud of gas and dust that collapsed under own gravitational attraction, forming a flattened disk, the *solar nebula*. The disk was rotating and, to conserve angular momentum, spun more rapidly as it contracted. The central part of the disk became the Sun. Rings of material became detached from the spinning disk when the velocity at the edge exceeded a critical value and the material in them subsequently coalesced to form planets. In a similar manner, rings of material shed by the planets in turn became planetary satellites. Astronomers from Laplace's time onwards continued to refine the nebular hypothesis; indeed, it forms the basis of widely accepted modern theories of the formation of the solar system.

In the second half of the 19th century, although the theory provided astronomers with a plausible explanation of the formation of the solar system, there existed a significant problem concerning the longevity of the Sun. Geologists and palaeontologists were uncovering evidence that the Earth, and hence the Sun, was at least hundreds of millions of years old. However, there was no mechanism known at the time to explain how the Sun could sustain its prodigious energy output for such a lengthy period.

Plummer published a nine-page paper (his longest astronomical publication other than his textbook) providing a summary of the nebular hypothesis and arguing that the in-fall of cometary material to the Sun provided a mechanism to sustain its energy output. Three years later, James Croll[103] published an alternative theory. There ensued a brief debate between the two in the pages of *Nature*. By this time Plummer was muted in his support for his earlier explanation, as *recent discoveries* had caused him to *somewhat modify* his views, so was unable to offer a robust alternative explanation to that of Croll. (He gave no details of the discoveries and their effect on his thinking.)

A14.1 The Nebular Hypothesis

Plummer (1875d) noted that the simplicity and comprehensiveness of the nebular hypothesis were in its favour but that there was much evidence against it, because of which it had become one of the most debated scientific theories ever.

Prior to the advent of spectroscopy, it appeared as if ever-larger telescopes would eventually resolve all nebulae as star clusters. However, spectroscopy revealed that many of the nebulae unresolved by the largest telescopes of the time were in fact gaseous, composed of hydrogen, nitrogen and a third gas unknown at the time (suspected to be a terrestrial element under conditions radically different from those on Earth, rendering it unrecognisable).

Although the existence of enormous gaseous nebulae was no longer in doubt, there remained several serious problems with the nebular hypothesis, the three most significant being:

- Nebulae exhibited spectra with narrow lines, indicating that they were tenuous, with no evidence of dense regions undergoing collapse to form stars and planets. There might be a mechanism causing spectroscopes to indicate false densities, but this was speculation and unless evidence could be found to justify it, the tenuous nature of all the nebulae studied would appear to disprove the hypothesis.
- To form bodies such as the Sun at high temperature, the nebulae themselves must be at high temperature, but no mechanism had been identified to produce heat.

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[101] Immanuel Kant (1724 – 1804) was a German philosopher. One of the central thinkers of the Enlightenment, he was an influential figure in modern Western philosophy.

[102] Pierre-Simon, Marquis de Laplace (1749 – 1827) was a French scholar and polymath whose work was important to the development of engineering, mathematics, statistics, physics, astronomy, and philosophy.

[103] Dr. James Croll FRS (1821-90) was a self-educated scientist who was born, and lived, in Scotland. He developed theories explaining the ice ages and the effect on the climate of variations in the Earth's orbit.

- The gases identified in nebulae were not, of themselves, sufficient to form a star and planets similar to the solar system: other materials were required in addition.

He proposed that comets could bring fresh material into a nebula and, once inside the latter, form centres of concentration of matter associated with regions of high temperature. For his theory to be plausible, it was necessary both that nebulae were closer to Earth than the fixed stars and that comets had appreciable mass, so he first developed arguments as follows to support these prerequisites. He could not offer direct supporting evidence and his reasoning was indirect, unsubstantiated and contrary to the accepted thinking of the time, which he had summarised in his textbook only two years earlier. Although astronomers originally thought of many star clusters as nebulae, the advent of spectroscopy and large telescopes showed that star clusters and true *gaseous* nebulae were quite different classes of objects: therefore, the fact that some of the former were situated at great distances did not imply that the latter were too. Further, if the nebulae were at a significantly greater distance than the nearer fixed stars, they would be so much larger than the solar system as to make the latter uniquely small in comparison. He noted wishfully: *the mind experiences a sense of relief in believing that the nebulae are our nearest neighbours…* As a corollary, he concluded that the nebulae were almost within range of the comets that visited the solar system. He then challenged the notion that comets have insignificant mass. In 1842, Encke had estimated the mass of the comet named after him (Encke's Comet, 2P) by estimating the perturbation that it caused in the orbit of Mercury, and concluded that its mass was negligible relative to that of the planet. Similarly, in 1767 and 1779, Lexell's Comet (D/1770 L1) passed close to Jupiter but did not measurably perturb the Galilean satellites; Laplace estimated its mass to be less than 0.02% that of the Earth. However, both comets had short orbital periods and had completed many revolutions around the Sun, on each losing mass. Plummer maintained that the evidence, examined critically, although showing that short period comets had low mass, did not imply the same for comets in general.

The next stage of his explanation depended on the link between comets and meteors. Astronomers had undertaken spectroscopic analyses of many comets, detecting carbon in a handful and finding the spectra of several others similar to that of carbon. This provided some evidence that they were similar in composition to meteors, many of which have a high carbon content. Comets in their orbits are accompanied by streams of meteors and, he speculated, might be composed in part of dense aggregations of the bodies. If so, comets could have significant mass and transport into the nebula all the terrestrial elements found in meteors (for example iron).

Laplace did not assign comets a significant role in the nebular theory, but believed that if a comet encountered a nebula, friction would cause it eventually to adopt a spiral trajectory towards the centre. Plummer argued that friction between the comet and the material of the nebula, together with a chemical reaction between the two, would generate much heat. He admitted that *we cannot pretend to explain the exact chemical effects produced* but asserted confidently that *in any case, an enormous development of heat is certain to result*. He noted further: *Those familiar with the extraordinary convolutions of many of the nebulae will not fail to see how easily many such appearances may be explained, by imagining a long stream of meteoric bodies in the track of a comet pouring into the nebulous matter, and being retarded and absorbed in their passage through it*. He argued that the chemical reaction between comet and nebula would generally produce a liquid rather than gaseous outcome: the evidence for this was the faint continuous spectrum that accompanies the bright emission lines in many nebulae.

A comet inside a nebula would constitute a point of locally increased density. As each comet entered the nebula, it caused the mass and hence gravitational attraction of the latter to grow, increasing the likelihood of further comets being captured. After a nebula absorbed many comets and meteor streams it would comprise the remnants of the original gaseous constituents, within which many liquid nuclei moved in orbits spiralling gradually inwards to the common centre of mass, the latter comprising a white-hot, liquid or gaseous body. The nebula would have a high temperature that would tend to maintain a region of gaseous material, counteracting the increased gravitational pull from the liquid centre. It might evolve either into a gaseous object, with the intense heat at the centre vaporising the liquid nuclei, or a compact liquid mass. Some nebulae, among them the Andromeda Nebula, presented unusual observational aspects; even the largest telescopes of the time could not resolve them into stars and spectroscopes revealed anomalous spectra. He interpreted this as (weak) evidence that they possessed gaseous centres and speculated that a considerable number of nebulae with compact liquid centres awaited discovery.

Eventually, through chemical reactions between the material of the comets and that of the nebula, little of the original gaseous matter of the latter remained and the comets orbited the liquid centre. As the heat at the centre increased, a star formed. It began to radiate heat, and the accretion of material from incoming meteors and comets offset the associated loss of energy. He hypothesised that myriad meteoric bodies surrounding the Sun, gradually spiralling inwards in decaying orbits, bringing material to sustain combustion, were responsible for the zodiacal light. A *universally held belief* was that the Sun was hotter during years noted for large comets; this might be due to the bodies bringing with them large quantities of meteoric material that boosted its heat output. Another common belief was that the nearer and larger planets, when near perihelion simultaneously, could cause sunspots and other phenomena that affected the energy output of the Sun. This made it more plausible that comets, which could approach the Sun much more closely at perihelion than Mercury, could also affect the level of solar radiation.

In conclusion, he stated that understanding the role of comets was one of the key challenges of the time. Adopting a spiritual perspective, he declared *Every known body in the universe appears to have an important and appropriate function to perform in the development or maintenance of systems like our own…* and positioned his work as uniting the theories of others into a consistent whole.

Attributing the longevity of the Sun to the action of comets and meteors was an idea in widespread circulation in Plummer's era. He stated in his textbook that the arrival *per annum* of a layer of material 7.3 m deep over the entire solar surface was required to replace that consumed by combustion. He provided no details of the derivation of the figure, but it appears to rely on material arriving with much kinetic energy; if this is excluded, calculations indicate that a layer of coal (or equivalent material) almost 55 km deep would need to arrive annually[104] to sustain the Sun's energy output.

There are major problems with the nebular hypothesis in its original form. It implies that the Sun should be spinning so fast as to be on the verge of rotational instability and cannot explain why it accounts for almost 99.9% of the mass of the solar system but only 2% of its angular momentum. Further, more refined calculations than were possible in Laplace's era indicate that rings of material shed by the rotating nebula would not form planets. Modern theories are, in general, modifications of Laplace's theory and, in the late 1990s, images by the Hubble Space Telescope provided some confirmation by revealing proto-planetary disks (*proplyds*) forming around stars in the Orion Nebula.

Plummer's theory appears hopelessly naïve to modern eyes. His arguments concerning the distance of nebulae and the mass of comets are unconvincing and at variance with his textbook published just two years previously. They revealed a lack of appreciation of the enormous scale of the universe beyond the solar system: this is most apparent in his claim that the shapes of gaseous nebulae were due in part to bombardment by streams of meteors. However, he worked in an era when astronomers had been able to determine reliably the distance of only the nearest dozen or so stars and did not appreciate the scale of the universe as a whole. His thinking was not out of keeping with that of his contemporaries.

A14.2 Sustaining The Solar Output

In a contribution to *Nature*, Croll (1878a) considered the age of the Sun. He quoted its radiant power density as 56.2 MW/m^2, comparable to the modern figure (Ridpath, 1989) of 62.9 MW/m^2. Were it composed of coal, combustion would support this rate of radiation for only some 5000 years. Astronomers regarded gravitational collapse of the solar nebula, during formation of the Sun, as an additional source of heat energy that could extend its radiant life. However, detailed calculations indicated that the energy liberated in this way could be responsible for at most 20-30 million years' worth of solar radiation, whereas palaeontological and geological evidence indicated that the Sun must have sustained its radiant output for very much longer. Croll had demonstrated, from geological evidence, that the Earth, and hence the Sun, must be at least 90 million years old. Professor Ernst

[104] Assuming an energy density of coal (anthracite) of 36.3 GJ/m^3 (Forest Research, 2023).

Haeckel[105], *one of the highest authorities on the subject*, had indicated that evolutionary theory might require aeons measured in trillions of years to effect the transformation of species. There was, therefore, a pressing need for a satisfactory explanation of the longevity of the Sun.

Croll proposed an ingenious but implausible explanation. He supposed the Sun to be formed from the collision of two masses of approximately equal size, travelling at high speed towards one another. The kinetic energy associated with a mass depends upon the square of its velocity according to the formula $E = \frac{1}{2}mv^2$, where E represents kinetic energy, m mass and v velocity. When two masses collided head on, the sum kinetic energy was converted into heat that radiated into space. By choosing appropriate approach velocities for the masses, he could contrive to explain an arbitrary dissipation of heat energy following impact. He provided some numerical examples, postulating two bodies, each half the mass of the Sun, projected directly towards one another at the same speed and approaching head on. He made an allowance for the effect of gravity, estimating that it added 440 km/s to the final approach velocity of the bodies, but his reasoning here is unclear. He calculated the time taken to dissipate, at the rate of solar radiation, the heat created in the ensuing collision. Table 22 summarises his examples. By way of putting the assumed approach velocities into context, he noted that a Sun-grazing comet in an elliptical orbit extending at aphelion to the orbit of Neptune would attain a velocity of 630 km/s at perihelion.

Projected Velocity (km/s)	**Final Approach Velocity (km/s)**	**Time That Energy of Collision Could Power the Sun (million years)**
325	765	50
1090	1530	200
2740	3180	800

Table 22. Energy released during head-on collision of bodies.

He struggled to dismiss the obvious question: how did the two bodies gain their initial motions? He argued that it was as easy to conceive that such bodies were always in motion as to conceive that either or both were at rest. He wrote that, in the vastness of the universe: *the difference between a motion of 202 miles per second* [325 km/s], *and one of 1,700 miles per second* [2740 km/s] *to a great extent disappears, and the one velocity becomes about as probable as the other*. He envisaged many non-luminous bodes in motion through space, only generating light when they collided to form stars.

Plummer (1878e) responded the following month. Tongue firmly in cheek, he first congratulated Croll on the *boldness and originality* of his theory, then noted that *the great majority of scientific men* believed in both the theory of evolution and the nebular hypothesis, although each suffered from serious difficulties. Both theories would be stronger if they could be reconciled, but this Croll had conspicuously failed to do. Having thus dispensed with pleasantries, he highlighted three of the most significant difficulties with Croll’s work. Firstly, it was highly improbable that rapidly moving bodies would collide in the infinity of space and, indeed, there was no observational evidence of collisions. Secondly, the Sun’s motion through space was 6.5 km/s, stellar proper motions exceeding 50 km/s were rare and none were well-authenticated in excess of 65 km/s. It was not credible that the collision of two rapidly moving bodies would always result in a hot composite body with a velocity less than 65 km/s. Thirdly, Croll had proposed no mechanism to limit the rate of dissipation of heat following collision. The initial intense heat generated in the impact would rapidly dissipate into space and could not power a star for an extended period; for this, a mechanism for continuous generation of energy was required. Helmholtz’s theory of gravitational contraction could be one such mechanism, but Plummer believed it to be insufficient on its own; the accretion of meteoric and cometary material was a potential contributory factor.

[105] Ernst Heinrich Philipp August Haeckel (1834-1919), also written von Haeckel, was an eminent German biologist, naturalist, philosopher, physician and artist.

Croll (1878b) replied in the following week's edition. He maintained that both gravitational collapse and the arrival of material via comets or meteorites would provide only enough energy to maintain the Sun's current output for 20-30 million years, of which period only perhaps half would have supported the development of life on Earth, clearly insufficient to explain the timescales required by paleontological and geological evidence. Therefore, an additional source of heat energy was required. He acknowledged that the Sun's radiant output could have been greater in the distant past and maintained that there was no improbability in the collision of moving stellar masses. Based on the number of stars visible, he estimated that one star was created approximately every 15,000 years on average, explaining why there was no apparent record of creation events. He concluded by re-affirming that the conversion by collision of the kinetic energy of stellar masses into heat was compatible with low observed proper motions.

Two weeks later, Plummer (1878f) responded, pointing out that Croll had not addressed his main criticism. He reiterated that the chances were remote of rapidly moving stellar bodies colliding in such a way as to convert nearly all their kinetic energy into heat, leaving a composite body moving at low velocity. Modestly, he acknowledged that his earlier theory concerning the infall of meteoric and cometary material to the Sun only partially reconciled its lifetime with the timescales required by geological science or evolutionary hypotheses, leaving a gap requiring further explanation.

One month later still, Croll (1878c), clearly determined not to concede, had the final word. He addressed Plummer's objection directly, pointing out that proper motions were known accurately for only comparatively few stars, all close to the Sun (enabling their distances to be determined by measurements of parallax). Stars at greater distances, with proper motions yet to be measured, in many cases might be hurtling through space at speeds vastly greater than the 65 km/s quoted by Plummer as the empirical upper limit. He then articulated an ingenious extension to the theory that could explain the temporary stars (nowadays termed novae or supernovae) that astronomers occasionally observed. In order to form a long-lasting star such as the Sun, it was necessary for the moving pre-stellar bodies to collide in such a manner as to convert nearly all their kinetic energy into heat. If, instead, a collision left the bulk of the kinetic energy of the bodies not converted into heat, the result would be the creation of a star that would shine only briefly. Although collisions would be much more likely to create temporary stars than long-lasting stars, because of the enormous difference in lifespan between the two, the former would be visible only relatively rarely. At this point, the correspondence ended.

Plummer's views and his correspondence with Croll illustrate the difficulty that astronomers of the era faced in understanding the longevity of the Sun and the lengths of imagination to which they would go to furnish potential explanations. It was not until the mid-20th century that scientists developed theories describing how the Sun could sustain the production of energy for billions of years. Modern theories rely upon the mechanism of nuclear fusion, with hydrogen nuclei under extremes of pressure and temperature fusing to form helium with an attendant release of energy. By this process, the Sun converts approximately 4 million tonnes of matter into energy every second.

A15 Miscellaneous Astronomical Publications

Plummer published three astronomical papers that do not fit into the above categories.

A15.1 Astronomical Nomenclature

In a brief article, Plummer (1876d) expounded proposals for a new nomenclature for asteroids and stars. For asteroids he proposed a scheme based on the identifier “Pl” for planetoid, followed by a magnitude class indicating brightness at opposition when notionally at unit distance from the Earth and finally by discovery number. Thus, for example, Pl.IV.107 would indicate an asteroid of 4th magnitude at opposition (notionally) at unit distance, 107th in order of discovery. For labelling naked eye stars in constellations he proposed to employ three magnitude groups (a, b, c), take stars in RA order within each group, numbering them 1-100 in group (a), 101-200 in group (b) and 201-400 in group (c). A star’s number would be given after the nominative form of the constellation. Thus, for example, Canis Major 129 would be the 29th star in RA order of the 1st magnitude group of the constellation Canis Major. Unsurprisingly, astronomers at large ignored the proposals; it is difficult to believe that he could have expected a different reaction.

A15.2 Stellar Distance Scale

In a brief contribution to *Nature*, Plummer (1890g) noted that on a scale where the Earth-Sun distance is represented by one inch, the representative distance of an object from the Earth in miles is very close numerically to its true distance in light years (ly). This provided an intuitive idea of the isolation of the solar system in the vastness of space. On this scale, the distance 7.5 ly to the relatively nearby star 61 Cygni was represented by 7.5 miles. (Since Plummer’s era, astronomers have revised upwards estimates of stellar distances. Thus, the distance to 61 Cygni is nowadays listed as 11.1 ly (Ridpath, 1989).)

A15.3 Photometry

Following what he believed to be a successful measurement of the brilliance of Venus in early 1876 (see appendix 4.3), in his annual report to the RAS, Plummer (1877c) entertained the hope of undertaking photometry of stars. In the event, he did not report any such work. However, he did describe (Plummer, 1877d) an attempt to make photometric estimates of the lunar eclipse of 23 August 1877. He employed a Bunsen photometer to estimate the brightness of the uneclipsed Moon and a Rumford photometer to estimate the brightness of the eclipsed Moon, in each case using a standard 8 g/hour spermaceti candle as reference light source.

During the ingress phase of the eclipse, the *rapidity of diminution* of moonlight was *very great*. Unfortunately, the maximum distance at which he could place the candle was 125 m and, at the start of totality, this proved insufficient. He concluded that the light of the eclipsed Moon was certainly less than 0.04% and probably less than 0.02% that of the uneclipsed full Moon. Mars cast a shadow *of a sharpness, colour and beauty that contrasted vividly with the dull red light of the Moon and the penumbral edges to the shadow thrown by it*. At mid-totality, the eclipsed Moon became dimmer and its shadow similar in intensity to that of Sirius, the only star from which he had been able to obtain a certain shadow. There was a rapid increase of brightness during the egress phase of the eclipse, mirroring the rapid decrease during ingress. In his annual report to the RAS for 1877, Plummer (1878b) noted that although his efforts at lunar photometry were *only partially successful*, they showed that the Earth’s atmosphere refracted only a small fraction of the Sun’s light into the shadow cast by the planet. He stated that he found it *necessary to postpone entirely for the present the project to determine the photometric value of the magnitudes of the fainter stars* but, unfortunately, gave no details of why this was so, and published no subsequent reports on photometry.

A16 Meteorology

Plummer's meteorological work appeared in the literature in three publications during his time at Durham, two while at Orwell Park and one while at Hong Kong. He also created unpublished material held in the Durham Observatory archive.

A16.1 Durham Meteorological Record

Observers at Durham had begun recording the weather in 1850 and the meteorological record there is one of the longest in the UK. On appointment at Durham, Plummer assumed responsibility for the weather observations and took custody of a mass of meteorological data compiled during the previous 17 years. In his first meteorological paper (Plummer, 1873c), he resolved to make the weather data more widely available and the Durham Observatory MSS (1881) show that, to extract meaning from the data, he compiled monthly and annual meteorological summaries. The monthly summaries covered the following weather data during the period 01 January 1850 to 31 December 1867: atmospheric pressure, temperature, hygrometric readings, elastic force of vapour, wind direction and velocity, cloud cover, rainfall, and other occasional data. The annual summaries, compiled for each of the years 1868-73 during January of the following year, further summarised most of the data in the monthly summaries. Although he clearly invested an enormous amount of time and effort compiling the summaries, he did not appear to publish the material, so it does not in fact appear that he succeeded in making it widely available.

The main thrust of his first meteorological paper was to address a discontinuity in the temperature record and explore the validity of a method for estimating the mean temperature. The meteorologists at Durham had obtained the first ten years of temperature measurements from thermometers housed in a shed on the north side of the observatory (the "north shed") and later measurements from thermometers mounted on a Glaisher's[106] revolving stand. Unfortunately, they had not investigated the effect on readings of the change of location. Plummer described the north shed as *a large louvre-boarded enclosure, solidly protected from above, and open upon the south side, where the thermometers are sheltered by the north wall of the building. Upon the west side there is also a partial protection from a projecting angle of the wall, but there is everywhere ample space for a free current of air.* The thermometers were at a height of 1.4 m above the floor of the shed, and the floor itself was at a height of 5.2 m above ground level, sited on one of the balconies of the observatory. He considered it to provide a *fair, if not unexceptionable* environment for recording temperature data. The Glaisher's stand comprised a vertical board upon which the thermometers were mounted, 1.4 m above the ground, with a sunshade at the top. The board was arranged to rotate around a pole and he had to turn it during the day to ensure that the instruments were shielded from direct sunlight. The Glaisher stand at Durham was similar to that used at the ROG.

He estimated the effect of the change of location on temperature readings by placing a maximum and a minimum thermometer in the north shed and comparing their readings, over a period of almost five years, 1868-72, with those of a maximum and a minimum thermometer mounted on the Glaisher stand. To ensure comparability, he first calibrated all four instruments against a *reliable standard* thermometer kept at Durham Observatory. Averaging readings in various ways, he showed that:

- The daily range of temperatures recorded on the Glaisher stand exceeded that in the north shed by approximately 2°F in winter and 8°F in summer, with the maximum in the Glaisher stand exceeding that in the north shed, and the minimum in the Glaisher stand being lower than that in the north shed.
- The average temperature throughout a year was 0.475°F higher on the Glaisher stand than in the north shed.

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[106] James Glaisher (1809-1903) was an English astronomer, meteorologist and aeronaut. He served as Superintendent of the Department of Meteorology and Magnetism at the RGO for 34 years, was elected FRS in 1849 and was a founder member of the Meteorological Society (1850) and the Aeronautical Society of Great Britain (1866).

- The maximum difference between estimates of the mean monthly temperature made in the north shed and on the Glaisher stand was 1.3°F.

His results revealed a significant spread of readings that thermometers, mounted in positions generally deemed by meteorologists to be satisfactory, could record. This highlighted the need to investigate further the effect of different types of mountings and local surroundings. Ultimately, it was desirable to define a standardised regime for temperature measurement. He recommended Glaisher's stand over other types of thermometer housing and suggested that it could be improved by the addition of some light louvre-board to protect the thermometers from the weather on the side facing away from the Sun.

In the era in which Plummer undertook his investigation, there was debate among meteorologists as to the best way to estimate the mean monthly temperature. The method most commonly used relied on tables by Glaisher (1848) of the diurnal range of temperature. Glaisher had constructed his tables from thermometer readings made at the ROG every two hours during the period 1840-45. He analysed the data to produce "corrections" which enabled a meteorologist to estimate the mean temperature during a month from a daily reading of the temperature at a given hour. The corrections were independent of the mean daily range of temperature and were strictly applicable only to locations with daily temperature profiles similar to those of the ROG. The methodology was most unsatisfactory and, indeed, was roundly criticised in some quarters. (See for example James Stark (1860), secretary of the Scottish Meteorological Society, expressing sentiments widespread amongst his colleagues.) Despite the shortcomings of Glaisher's tables, meteorologists of the time used them frequently and developed *ad hoc* extensions enabling their application in other locations (see e.g. Hartnup, 1851). Glaisher had considered their applicability to locations other than the ROG and recommended *that for all places situated inland, the values contained in these tables may be adopted at once*.

Despite Glaisher's confidence in his tables, Plummer was uncertain of their applicability to Durham and, as meteorologists there had frequently employed them, set out to investigate whether their use was valid. He first compared estimates of the mean monthly temperature at Durham, calculated from the observatory's usual meteorological readings, with those based on an additional set of daily temperature measurements made at a different time of the day, in both cases employing Glaisher's tables in the analysis. The two estimates of the mean temperature were so similar that he discontinued the extra readings after four months. He then compared the mean monthly temperatures calculated from the morning readings and from the evening readings of the observatory thermometer, corrected according to Glaisher's tables, over the five-year period 1868-72. For nine months of the year, the two estimates agreed to within 0.4°F; for the three summer months, differences were much greater, up to a maximum of 1.3°F. However, he was not well disposed to accept the evidence of his own analysis and concluded that the estimates agreed very closely. He sought to justify this position by noting many similarities between the geographic locations and, therefore, likely the weather patterns, of Durham Observatory and the ROG (although he did admit of necessity that the former stood further north and at a higher altitude than the latter).

He then calculated correction factors to apply to the series of average monthly maximum and the series of average monthly minimum readings from the north shed and Glaisher stand to produce the same estimate of mean monthly temperature as that obtained from readings of a dry bulb thermometer calibrated to the Durham *reliable standard*. He compared the correction factors with Glaisher's corrections for the ROG, concluding that his corrections for the Glaisher stand at Durham agreed *fairly well* with the latter. This conclusion was subjective, as the mean discrepancy (in the sense Plummer's correction minus Glaisher's) was 0.6°F and the maximum discrepancy was 0.9°F, a difference that could be considered unsatisfactory. Plummer also noted that, as he had based his data on only five years' observations, his conclusions should not be regarded as definitive. However, this period was only slightly shorter than the period of observation that Glaisher had used to create his tables; he thus inadvertently highlighted one of the major difficulties with the whole approach.

Plummer (1873d) read his paper to a meeting of the Royal Meteorological Society (RMS) on 18 June 1873. The President of the RMS, John W. Tripe, MD, chairing the meeting, postponed discussion of the relative merits of various forms of thermometer stand until a later meeting and a member present promised by then to have available the results of experiments with different stands. Glaisher, present at the meeting, presented a robust defence of his tables against implied criticism from the upstart Plummer! He had created the tables from seven years data collected at the ROG and had no doubts about their accuracy and applicability. Further, he was preparing enhancements to extend their baseline: he was analysing 21 years of meteorological data recorded at the ROG and intended to use measurements from automatic recording stations operated by the Meteorological Office (MO) throughout the country to enable compilation of corrections for locations other than Greenwich. In any case, he was confident that the current tables should be as accurate for Durham as they were for Greenwich.

Plummer's (1874c) next contribution to the RMS was his annual report on meteorology work at Durham Observatory in 1873; it conveys a sense of his daily duties associated with weather observations. He noted that work at the observatory had proceeded throughout the year without interruption; this may have been an oblique reference to the unsettled state of the university at the time. He forwarded meteorological observations monthly to the MO and intended to publish his annual meteorological report and data in local papers and in the annual report of the Tyneside Naturalists' Field Club (the Club enjoyed national renown at the time). All of the meteorological instruments were in good order, but he intended to replace some aged thermometers and to add radiation thermometers. The observatory's anemometer had not proven sufficiently robust to withstand the gales that swept across Durham and had been repaired during the year. The times at which he took weather readings at Durham, 10.00am and 10.00pm, were not those preferred by the MO; therefore, in the interests of making his data easily comparable with that from other observers, he was participating in a scheme to make synchronised observations at locations in the northern hemisphere and, accordingly, had started, on 01 January 1874, making additional measurements, recording key meteorological readings at 12:45 GMT daily. He referred to his work comparing temperature readings made at different locations around the observatory and expressed the hope that he would shortly publish the results of further investigations into this subject: in the event, he did not appear to do so.

A16.2 Influence Of Observer On Measurements

In June 1875, *Nature* (1875) published an article concerned with the quality of data produced by the MO. The article was an example of the investigative journalism of its day! The journal reported that self-recording meteorological instruments had been in operation at the seven MO observatories since January 1869 and that they were the *best and most complete anywhere for recording continuously the atmospheric pressure, temperature, humidity and rainfall and the velocity and direction of the wind*. One of the principal objects of the observatories was to establish the meteorological "constants" for locations within the British Isles. Detailed regulations were in place to ensure accurate recording of data, incorporating adjustments to measurements of temperature as small as 0.01°. However, an investigation of the quality of data published by the MO in its Quarterly Weather Reports revealed a shocking catalogue of errors, including the following:

- At least two errors in every month examined by *Nature*. Errors abounded in the summary data, including mistakes in temperature, date, time and the state of the instruments (in service or out of service).
- Errata were themselves frequently in error.
- The distribution of digits after the decimal point in temperature readings was highly skewed: each digit should have had an equal chance of appearing but, in practice, there was a noticeable preponderance of the figure 0, implying rounding to the nearest whole degree.
- Problems with the placing of thermometers. Some were located in very confined locations and did not experience the true ambient temperature: this was especially manifest in anomalous readings for the mean increase of temperature during daytime hours in summer at Aberdeen.

Overall, *Nature* judged the published data to be of very poor quality, writing: *the results, as tabulated and published, can scarcely lay claim to a higher value than eye-observations of third-rate observers… it is not easy to see how one can make a scientific use of the tabulations*. Pressure of work could not excuse the poor quality of published information as the MO was in complete control of its schedule and published some reports almost four years after collecting the associated data. Further, in 1873 (the latest year for which data was available), the Meteorological Committee of Parliament employed 24 persons, with a total salary of £3727 and expenses of £2722; *Nature* adjudged this a generous level of remuneration. Parliament funded the MO through an annual grant of £10,000; although *Nature* expressed regret that such a negative report was necessary, expenditure on such a scale made it imperative to call the MO to account.

Three months later, Plummer (1875c) responded, addressing specifically the issue of the distribution of digits after the decimal point in temperature readings. Subjective factors could cause individuals making empirical measurements to prefer certain digits, resulting in a deviation from the expected uniform profile. By way of supporting evidence, he examined transit times recorded by the ROG in the *Greenwich Observations* for 1864 (the latest volume that he had to hand). He examined timings recorded on 19 April, 21 April and 05 November 1864, covering 1283 transits, and counted the number of times each digit occurred as the tenth of a second figure. Each digit should have had an equal chance of occurring but he found a preponderance of the digit zero, i.e. an excess of whole seconds, and other features that could be ascribed to subjective factors. Finally, he analysed transit timings that he had made in 1875 and those made by Dunkin and Ellis[107] at the ROG, in 1864. Again, he noted the non-uniform distribution of tenths of seconds digits. The observers' distributions showed personal idiosyncrasies and a remarkably similar fondness for the digit eight. Figure 42 shows the distribution of tenths of second digits for the three observers.

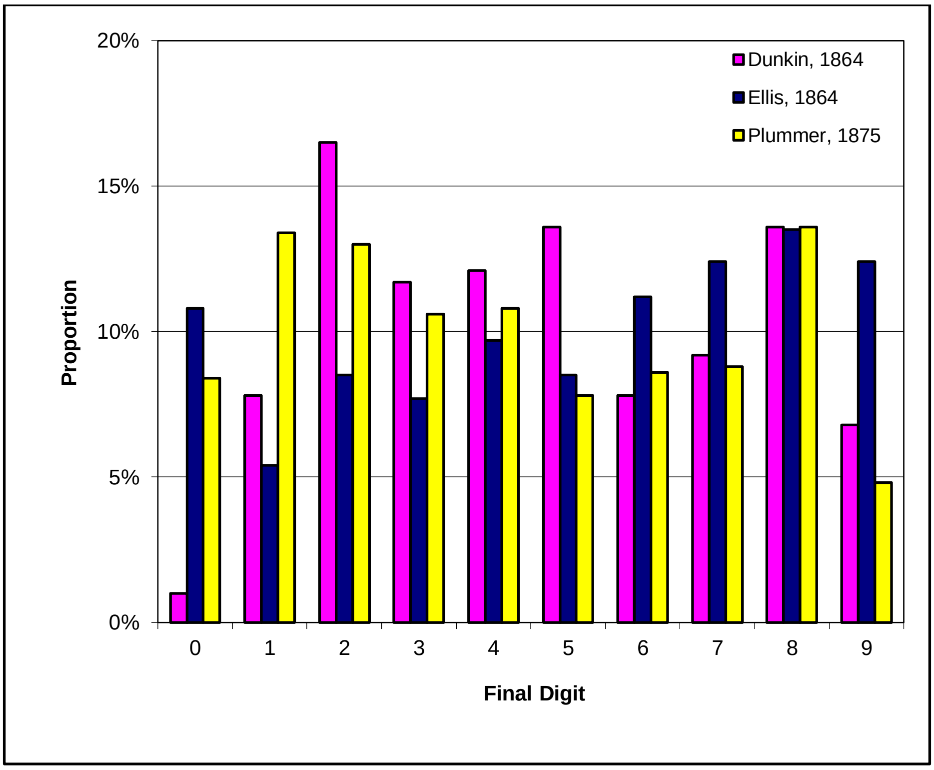

Figure 42. Distribution of tenths of seconds digits in transit observations.

The implication of his paper was clear even though he did not articulate it directly: subjective factors were entering into the recording and publishing of the meteorological data and were manifest in a skewing of the distribution of digits after the decimal point.

A16.3 Temperature Rise At Greenwich

In 1877, there occurred a brief postscript to Plummer's meteorological work at Durham. In the pages of *Nature*, Alexander Buchan, Secretary of the Scottish Meteorological Society, and Henry S Eaton, President of the RMS, debated the suitability of the ROG as a location for meteorological measurements. The average temperature there had increased slightly during the third quarter of the 19th century; Eaton ascribed the rise to the growth in population living in and around London and the attendant increase in artificial emission of heat in the locality, whereas Buchan ascribed it to a general, geographically widespread warming.

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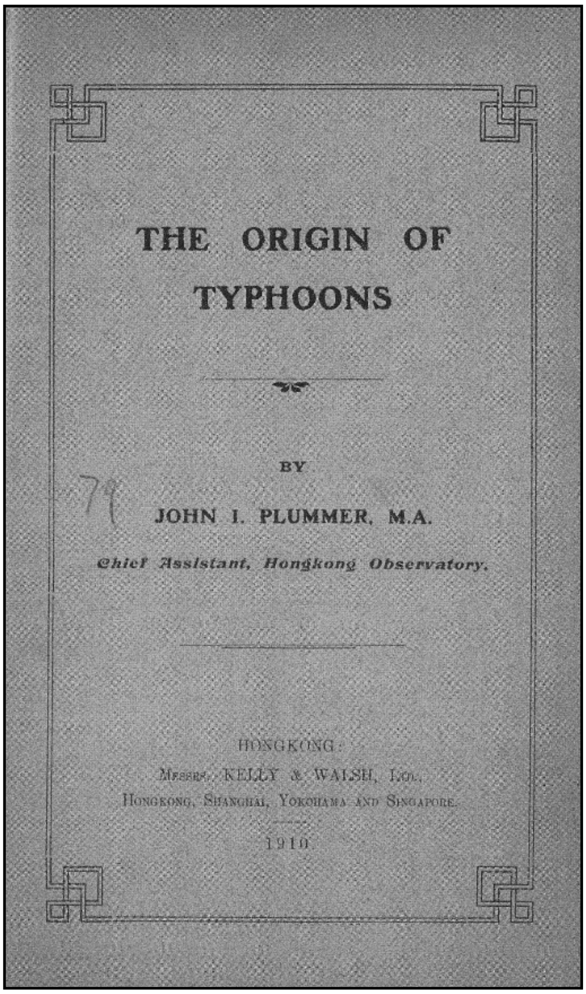
[107] William Ellis (1828-1916), FRS, FRAS, FRMS, was an English astronomer and meteorologist who worked at the RGO, first as a computer and later as an observer.

In a short letter to *Nature*, Plummer (1877a) contributed to the debate while it was at its height. He called attention to his first meteorological publication, in which he concluded that the Glaisher stand at Durham was associated with an average temperature reading 0.475°F higher than the traditional, fixed, thermometer housing. The temperature at the ROG was read from instruments mounted on a Glaisher stand, whereas at other locations it was read from instruments in fixed housings. The increase in average temperature readings at the ROG was almost the same as that associated with use of the Glaisher stand at Durham; Plummer therefore concluded that the apparent rise in temperature at Greenwich was not objectively real, but a consequence of the thermometer housing employed. Neither Buchan nor Eaton responded.

A16.4 The Origin of Typhoons

Hong Kong suffered badly from the many typhoons that struck the Colony and one of the principal aims of the observatory there was to understand the physical processes that shaped the formation and evolution of the storms so that meteorologists could provide reliable warnings to the populace and to shipping. Plummer contributed to efforts to track and understand typhoons during 1904 and 1908-09 and, in 1910, shortly before retiring, published the results of his work in a pamphlet entitled *The Origin of Typhoons* (Plummer, 1910). His obituary in the *Hong Kong Daily Press* (1925) indicated that the pamphlet was an elaboration of a public lecture delivered in Hong Kong. The front page of the work is reproduced as figure 43. The pamphlet was the only publication appearing under his name during his time at Hong Kong and is his last known publication.



THE ORIGIN OF TYPHOONS

BY

JOHN I. PLUMMER, M.A.

Chief Assistant, Hongkong Observatory.

HONGKONG:
MESSRS. KELLY & WALSH, LTD.,
HONGKONG, SHANGHAI, YOKOHAMA AND SINGAPORE.

1910.

Figure 43. Title page of *The Origin Of Typhoons,* Plummer (1910).

He began by noting that although the pamphlet encapsulated the results of 20 years of study of typhoons, his theory of their origin was new and had not been exposed to scientific opinion. He suggested, somewhat disingenuously, that the population of Hong Kong, much acquainted with typhoons, was better placed to judge his ideas than scientists located elsewhere who had no first-hand experience of the phenomenon.

Doberck had pursued a programme of investigation to trace typhoons back to the locations where they first became appreciable, and then study at those locations the circumstances responsible for their formation and growth. As part of the work, staff at the observatory copied details of meteorological conditions at sea from ships' logs (see section 2.7). However, the data thus obtained was too sparse to support any definite conclusions and Plummer preferred instead to investigate the phenomenon on the basis of physical principles.

He considered first an idealised representation of the Earth, similar to the planet that we know, but covered uniformly by a great ocean. On such a planet, the Sun would preferentially heat the location directly underneath it. The heating of the atmosphere at the sub-solar location would increase its ability to hold moisture and the air would rapidly take up water vapour from the ocean. The air would expand and ascend, lowering the atmospheric pressure and, as the planet rotated under the Sun, solar heating would create a trough of low pressure around the globe and reinforce it daily. The position of the trough would alter gradually throughout the year, travelling northward from the winter solstice and then southward again from the summer solstice. Cooler, denser air on either side of the low-pressure trough would move in to fill the void left by the ascending, warmed air, creating winds blowing towards the middle of the trough. The cooler air would chill the saturated warmer air, causing rain to fall. The atmosphere would therefore exist in a dynamic equilibrium and winds associated with solar heating would be gentle.

He believed that conditions in the southern hemisphere of the Earth approximated those that he had described, as the Southern Ocean is only invaded by a relatively small area of land. The annual appearance of the monsoon in southern India and its gradual, steady advance to the north provided some verification of the theory, but meteorological records at the time were insufficient to provide definitive confirmation.

The atmospheric trough of low pressure associated with solar heating marked the site of possible formation of typhoons, but it was impossible for them to form on the supposed ocean-Earth as the atmosphere was in a state of dynamic equilibrium. However, on the real Earth, many large continental land masses punctured the ocean, and he argued as follows that unequal solar heating of the sea and the land was responsible for creating circumstances favourable to the formation of typhoons. The bulk of the land mass of the Earth is congregated into continents. The interiors of the larger unbroken continents are generally occupied by arid deserts. The Sun during the day and radiation from the ground at night intensely heat the atmosphere above a desert, creating an area of permanently low pressure with hot, dry air rising and spreading out in all directions in the upper layers of the atmosphere, ultimately returning to ground level far away. Being far from the sea, the air in the low pressure area is very dry. The atmosphere around the desert is in a state of dynamic equilibrium, with steady air currents not likely to catalyse the formation of storms.

Plummer knew of only four regions of the world that regularly experienced typhoons: the neighbourhood of Mauritius, the West Indies, the Bay of Bengal and the South China Sea. All were under active meteorological study, which revealed very different rates of occurrence of typhoons; this suggested that the local configuration of land masses played an important part in their formation. All four regions were located to the east or south-east of continental land masses and all contained large tropical islands. The region suffering the highest rate of typhoons, the South China Sea, contained four large tropical islands, Borneo, Mindanao, Luzon and Taiwan (Formosa), with Sumatra, Java, Sulawesi (Celebes) and New Guinea just beyond its limits. He concentrated on Borneo to illustrate the role that tropical islands played in the formation of typhoons. Average rainfall there was 4 m *per annum*, which encouraged a moist atmosphere and the growth of particularly lush forests. During the summer months, the Sun intensely heated the island causing a column of hot moist air to rise above it. The column rapidly encountered the air current overflowing high in the atmosphere from the arid wastes of the Gobi Desert. The current from the Gobi was dry and cold, carried a positive electric charge and, having been chilled in the upper atmosphere, was gradually descending. The ascending column carried a negative electrical charge. When the two motions of air came into contact, the result was cooling of the ascending air column, thunderstorms and heavy rainfall, and the resulting mixing air was swept SE in an airflow. Before mixing was complete, the airflow reached the trough of low pressure created by solar heating. Hot air rising above the trough combined with the remaining hot air in the airflow to present enough of a vertical thrust to funnel in an upwards spiral towards a higher altitude and an equilibrium pressure, creating the rotatory winds of a typhoon.

He then addressed the question of what became of the air spilling out above the continental deserts in directions other than S or SE. The overflow of air to directions from E through N to W merged immediately into the general equatorial current, which it merely reinforced. The overflow of air to the S or SW, for most of the year, except when the Sun was near its extreme northern declination, met the equatorial current more or less head on. Although this resulted in some turbulence at high altitude, there was nothing to stimulate a circulatory airflow and cause typhoons.

He reviewed the recorded prevalence of typhoons. While Doberck was Director of Hong Kong Observatory, Plummer had drawn 12 maps, based on analysis of 22 years' worth of data around the South China Sea, showing the tracks of typhoons observed during each month of the year. The tracks crossed one another in all directions; however, by counting typhoons that crossed each square degree of the sea in a particular direction, he was able to establish that, in general terms, the storms occupied three broad bands, each associated with one of the islands Borneo, Mindanao and Luzon. Although meteorological records were sketchy, he believed that the evidence indicated a prevalence of typhoons some 800-1600 km S or SE of great tropical islands. Warm ocean currents were favourable to the existence of typhoons due to the increased heating of the atmosphere directly above them; therefore, the courses of typhoons generally followed such currents.

He struggled to explain the prevalence of typhoons between Luzon in the Philippines and Annan in Vietnam. Although by his previous arguments he could attribute it to the column of hot, moist air rising above the tropical island of Hainan, to the SE of the continental land mass, the island was sufficiently close to the mainland as almost to be part of it. He quoted examples of how the land masses defining the borders of the South China Sea greatly influenced the direction of winds in the region (causing very significant deviations from the directions indicated by isobars). In some cases, the influence of the land masses was so great as to set up a rotatory motion of the atmosphere within the South China Sea around a portion of the zone of low pressure caused by daily solar heating. Such a rotatory movement, once formed, could become very similar to a typhoon, although in general it would be classed a *less intense depression* than one that originated to the east of the Philippines.

Somewhat apologetically, he noted that, for the sake of simplicity, he had referred to N and S winds in general terms without making allowance for the rotation of the Earth, which caused a deflection in the apparent direction of the wind. Opposing air currents generally entered the vortex of a typhoon (in the northern hemisphere) as NE and SSW winds (SE and NNW in the southern hemisphere). The NE wind continually attempted to fill the zone of low pressure at the centre of the typhoon while the SSW wind acted to keep open the vent above the typhoon enabling the escape of hot, rarefied air into the upper atmosphere. The NE wind was the heavier, had a tendency downwards to the Earth and was responsible for the physical translation of the entire vortex; the SSW wind was lighter and had an upwards tendency.

The difference in nature of the two winds meant that when a cyclone struck land, the SSW wind was much more damaging to buildings than the NE wind as it created a pressure from below, which roofs of buildings are not usually constructed to resist. It also explained what happened when two typhoons came within proximity of one another (an occasional occurrence). Plummer considered a situation with two typhoons on the open sea, one north of the other by some 500-700 km. The SSW hot current would escape to the upper atmosphere through the more southerly typhoon and enlarge it, making it a more intense depression and would not be available to maintain the more northerly typhoon. The NE current would exert its influence primarily on the more northerly vortex, gradually filling up the associated depression, and would generally not drive the southern vortex, which would be more or less at a standstill. Such interactions meant that forecasting the speed and direction of movement of a typhoon was impossible without a detailed knowledge of the meteorological circumstances in a wide surrounding area: unfortunately, such knowledge was not generally available. Similar reasoning explained why a typhoon never exhibited two centres nor divided into two separate eddies: the southern centre would rapidly destroy the northern.

In conclusion, he summarised the main points of the pamphlet and then briefly gave his views on locations for high altitude observatories to study the meteorological phenomena involved in the formation of typhoons. The Peak of Hong Kong was not suitable, as it was too small and not at a sufficiently high altitude; his personal favourites were North Borneo and Madagascar. The final paragraph of the pamphlet comprised a plea for meteorologists to focus more effort on understanding the large-scale properties and movements of the atmosphere. Once the latter were understood, the science of meteorology would be on a much firmer base and the enormous mass of petty detail defining climatic meteorology would fall naturally into place.

Unfortunately, the pamphlet was badly out of keeping with the best meteorological science of the era. It was not an official publication of Hong Kong Observatory; indeed, it makes relatively little reference to work at the observatory and, rather, is a personal statement. Although the *Hong Kong Telegraph* (1910) gave a very favourable review, it appears to have received only one citation in the scientific literature. MacKeown (2011) describes it as *scientifically eccentric* and notes that a catalogue of Hong Kong Observatory library did not list it, indicating, perhaps, embarrassment over its contents.

Neither does the pamphlet accord well with modern meteorological science. According to current theories (e.g. Wikipedia, 2023c), there are six main conditions necessary for the formation of a tropical cyclone: warm sea surface temperatures, atmospheric instability, high humidity in the lower to middle levels of the troposphere, enough Coriolis force to develop a low pressure centre, a pre-existing low level focus or disturbance, and low vertical wind shear. (The six conditions are necessary, but do not guarantee that a cyclone will form.) Warm sea waters are required to sustain the warm, moist core of a cyclone. The monsoon trough, or inter-tropical convergence zone, is a potential source of vorticity that can create typhoons. This feature is analogous to the trough of low pressure around the globe, created by solar heating, which Plummer described. However, although he believed that the trough followed the Sun's zenith across the globe, modern theories assert that it does so over land but that over the sea its movement is much more subtle due to the equalising effect of the ocean on temperature. Other meteorological features are also capable of stimulating the formation of tropical cyclones. The Coriolis force is seen as an essential prerequisite to developing rotatory motion around a low-pressure area and a minimum distance from the equator of *circa* 500 km is generally required for it to be sufficiently powerful. The vertical shear must not be too great or it can destroy a forming cyclone. Modern maps of cyclone tracks indicate that the role of large tropical islands is incidental in the formation of the phenomenon.

A17 Durham Cathedral Clock

The Durham Observer was charged with ensuring the accuracy of the cathedral clock[108] (Goldney, 1875). Plummer's (1871a) notes in the Durham Observatory MSS provide some information on the approach that he adopted and contain a record of his efforts to keep it to time.

He used the Hardy chronometer as reference timekeeper, converting from sidereal to civil time via tables in the *Nautical Almanac*. By comparison of successive errors between the cathedral clock and chronometer, he estimated the rate of the former in seconds gaining or losing per day. He could correct the time of the clock and could adjust its rate by altering the quantity of small pellets, each weighing approximately 7 g, acting as ballast in the governor mechanism.

The bells of the cathedral clock peal on the hour, but there is no clock face. Plummer must, therefore, have "read" it by listening to the peal. There is no evidence that he made an allowance of 2.6s for the sound to travel the 880 m to the observatory, perhaps regarding the delay as typical of that which townsfolk would experience.

The surviving record of his efforts to regulate the clock covers the period 01 May 1869 – 16 May 1870. There is an unexplained gap during November and December 1869. (During this period, he continued astronomical observations, so could not have been incapacitated.) Other than during this gap, he recorded the clock error every 1.3 days on average, the data shown in figure 44.

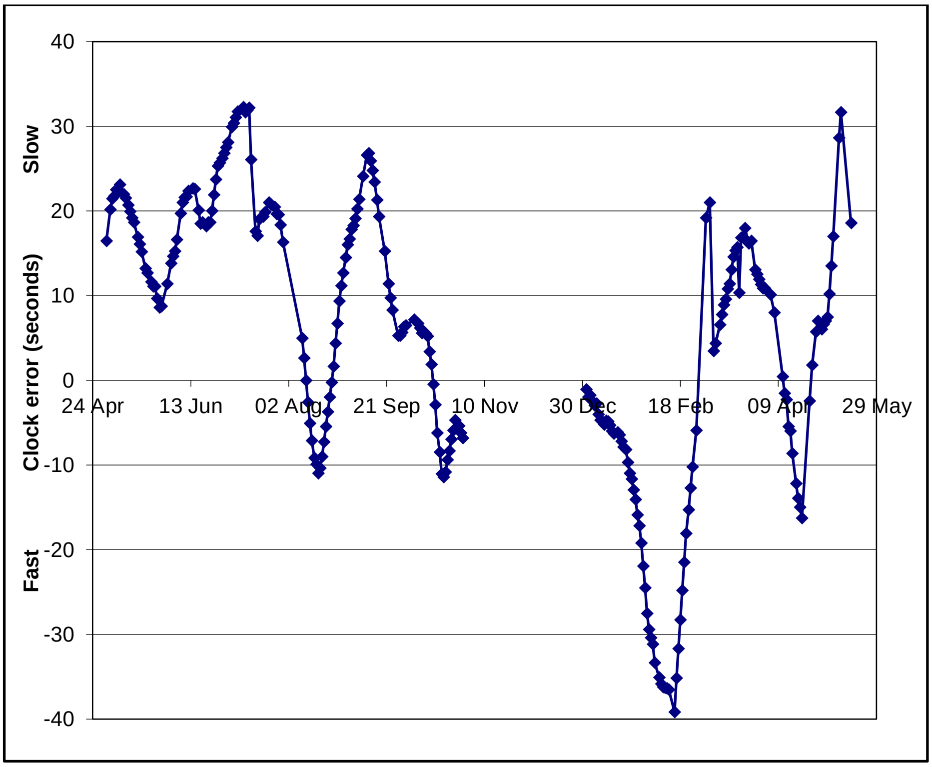


Figure 44. Errors of Durham Cathedral clock, 1869-70.

The clock was erratic and often lost or gained several seconds in a day. Plummer's notes show that many of the turning points, where it changed from gaining to losing or *vice versa*, were not associated with an adjustment of the regulator mechanism but were due instead to an external cause, perhaps a change in temperature or humidity. He found it necessary to adjust the rate of the clock on average every week or so; it must have been a frustrating chore.

[108] The cathedral clock is distinct from Prior Castell's clock, situated in the south transept of the building.

A18 Selected Press Reports

The press contains many references to Plummer, providing further insight into his professional activities and also illuminating his social activities and other interests. Several reports are summarised or reproduced below. Material extensively referenced in Section 2, the main narrative of Plummer's life, is not duplicated below.

A18.1 Durham Press

Plummer is mentioned as follows in *The Durham Chronicle* and *The Advertiser*.

- *The Durham Chronicle* (1868) lists him among the *large and fashionable attendance* at Durham School athletic sports day.
- Professor Sir William Thomson[109], in his presidential address to the British Association meeting in Edinburgh in 1871 (Thomson, 1894, pp. 132-205) espoused the theory that life did not originate spontaneously on Earth but was brought to the planet by meteorites. His hypothesis was that collisions between other life-bearing bodies resulted in fragments being hurled in all directions, bearing seeds or, more generally, elements of vegetation or animal life, and that some of the fragments ultimately reached Earth. A correspondent to *The Advertiser* signing himself E. M. (1872), argued the case against. He posed the questions: (i) what could be so barren of life as a meteorite, and, (ii) had minute examination of meteorites produced evidence of seeds? Claiming that life was brought to Earth from other bodies simply pushed the question as to the ultimate origin of life back one step! Had human infants developed from seeds carried by meteors, they would not have been able to survive; only fully developed humans could ensure the continuation of the species, in accordance with the account of creation in Genesis. Plummer (1872g) responded in the following week's edition, clearly sceptical of Thomson's theory, but determined nonetheless to defend it against charges that it was an attempt to overthrow the biblical account of creation. He took a swipe at E. M.'s evident lack of understanding of the theory of evolution, questioning whether he had read the *Origin Of Species*. Plummer's approach was pragmatic, regarding natural selection as not necessarily true in an absolute sense, but as a useful tool to understand the natural world, in the sense that a bad theory, partially successful in explaining the principles of Nature, is better than none. He argued that philosophy and religion both attempted to find truth, albeit in different ways, and should not be in opposition to one another.
- At a reading and concert on 05 November 1872 at St Margaret's Parochial School in Crossgate (*The Advertiser*, 1872), Plummer delivered a lecture on "Time", which was *attentively listened to throughout*.
- Plummer (1873r) advised readers of *The Advertiser* of the partial solar eclipse on 26 May 1873. The last such event visible from Durham had occurred on 22 December 1870.
- *The Advertiser* (1873a) listed Mr. and Mrs. Plummer as attendees at Durham School speech day on 04 July 1873. They were among the great and good of the city attending, including Chevallier and his surviving daughter, Alicia.
- The 15 August 1873 edition of *The Advertiser* carried a plea by Plummer (1873s) to improve lightning protection at Durham Cathedral. He advised installing lightning conductors on unprotected elevated sections of the building and queried whether the earthing for the recently installed gas supply was sound. The plea did not appear to elicit a response in the press from the ecclesiastical authorities.
- *The Advertiser* (1873b) carried a brief review of Plummer's textbook, thoroughly recommending it to anyone contemplating a study of astronomy.
- The appearance of Henry's Comet (C/1873 Q2) as a naked eye object in late 1873 prompted Plummer (1873q) to provide observational details to readers of *The Advertiser*. The comet was

[109] Thomson (1824-1907) was for more than 50 years professor of natural philosophy at the University of Glasgow. He was a pioneer in electromagnetism, thermodynamics and other fields and fostered the practical application of science. In 1892, he was elevated to the peerage as Baron Kelvin of Largs.

travelling through Ursa Major, and he provided details of its path relative to the main stars of the constellation. He went on to report that in fact, five comets (Henry's among them) had been visible during the previous month, of which three were new and two were known. He had made spectroscopic observations of Henry's Comet on 11 September, from which he concluded that it was composed of incandescent carbon.

- From November 1873 to May 1874, he gave lectures weekly on *Physics (Acoustics, Light and Heat)* as one of the subjects of evening classes organised by the City of Durham Science School in connection with the Science and Art Department, South Kensington (*The Advertiser*, 1873c, 1873d, 1873e, 1873f). The course fee was 5/-.

A18.2 Ipswich Press, Reports Of Lectures

The Ipswich local press detailed Plummer's lectures on astronomical topics as follows.

A18.2.1 The Cometary System, 02 December 1874

***The Suffolk Chronicle* (1874)**

Mr. Plummer took for his subject The Cometary System. *He expressed his conviction that this was a subject which would in the future occupy a much more important place in astronomy than now. From being regarded with something like awe and veneration comets had come to be regarded as things of very little moment, but he questioned whether that was altogether right. Mr. Plummer proceeded to give the reasons for his opinion that the importance of the subject would increase, which were found in the fact that the number of comets had increased as optical science had advanced, and that the supply of comets had always grown in proportion to the interest which was shown in the stars. In alluding to the latter point he spoke of the patience which comet seekers must display, and the difficulties under which they laboured. He believed* […text unclear…] *possibly considerably more comets visited the solar system every year, if they could be discovered. Mr. Plummer proceeding with his lecture said he believed that though there might be many things in the universe, the use of which was obscure, yet nothing existed in such great numbers, at least, as comets, without having some part to play in the economy of the universe, and he believed comets had a great part. That their part was not known should be a reason for careful research. He wished to be careful to discriminate between what was known of comets and what was merely conjectured. Mr. Plummer then described the nature of comets' orbits, and the influence of the great planets in slackening the velocity with which they travelled bringing them within the solar system, and causing them to travel round the sun in much smaller orbits giving examples from well known comets. Our knowledge of these points was pretty complete, but as against this completeness must be put the want of knowledge of a comet's mass* […text unclear…]. *The statement of a former president of the British Association, following no less an authority than Sir John Herschel, that the entire mass of a comet could, doubtless, be enclosed in a snuff box was founded on conjecture only. Mr. Plummer next spoke of the materials of which comets were composed, of which we had learnt a little, though it was but a little during the past few years. Two classes of spectra of comets had been observed and this led to the conjecture that it might be possible to classify comets according to the materials of which they were composed, but the extent of their knowledge at present was there were some composed of carbon and some which were not. In conclusion Mr. Plummer alluded to the marvellous and constant changes which comets undergo and remarked that he should have liked to say a few words on the connection between comets and meteors but time did not permit.*

***Ipswich Journal* (1874)**

Science in full dress. A happy combination of an evening party, and elaborate scientific instruction given in a monster class. Learning made easy. The nearest possible approach to the making of a royal road to it. This is about a free description, drawn by a favourable hand, of the conversazione of the Ipswich Science Gossip Society. The fifth of these interesting gatherings was held at the Public Hall on Wednesday evening, and was as crowded, as brilliant, and as instructive as its predecessors. The only complaint we have heard concerning the gathering of Wednesday evening is that the managers *gave their guests too much to see and hear, and that too many people went to see, hear and learn; it was too successful, in fact…*

…

Mr. Taylor was followed, at a short interval, by Mr. John J. Plummer, who lectured on the Cometary system. He observed that he wished to avoid, in the few minutes at his disposal, giving his audience merely such matter as they might find in the textbooks of the subject. He wanted to place his audience on the border land between the known and the unknown, and to enable them to advance science, which he was quite sure they were all as anxious to do as they were to acquire knowledge themselves. It was dangerous to prophecy, but he would venture to prophecy that the Cometary system would, in future, occupy a much more important place than it had in the past. A great change had come over our ideas with regard to comets, for from having been regarded with awe, and as the harbingers of wars, or of the death of kings and great men, we had come to look upon them as very harmless indeed. This was, in a certain degree, to be accounted for by the fact, that in the year 1864, we passed very nearly indeed to the confines of a large comet, and no one knew much of the fact, or was much the worse for it. Yet he thought they should not be held lightly, and he founded his respect for comets upon the fact that they were much more numerous than people generally were aware of. Of course only a very small portion of the actual number of comets in existence could have been visible to astronomers, and observed by them. Yet the number of comets recorded as observed was not inconsiderable, something like 300 having been observed with such a degree of certainty that astronomers had been able to calculate their orbits. But this was a very small proportion of those which had passed through our system. The invention of the telescope had given great assistance to the discovery of comets, as was shown by the numbers which had since that period been discovered. The telescope was invented in the first decade of the seventeenth century, and at that time the total number of comets visible was only 20. At the end of the first half of the century the average number had risen to 34; at the end of the second half to 90, or nearly at the rate of a comet per year. During the first 40 years of the present century the number of comets observed reached 150; while during the past 30 years the large number of 357 had been reached, or more than 3½ per year. That could only have arisen from the immense advance of optical science, and we might hope, therefore, that if the future mechanicians improved our instruments, a still larger number of comets might be made known to us. Yet there were reasons for believing that the information which astronomers could give as to the number of comets, could only give a small notion of their actual numbers. In the first place, they had discovered that the number of comets discovered in any particular year had always borne proportion to the degree of interest taken in them. The King of Denmark, for example, offered a reward for each comet discovered, and the number rose at once. He (Mr. Plummer) did not know whether these rewards taxed His Majesty's generosity too much, but after a time they were withdrawn, and the number of comets discovered fell at once. The Academy of Science offered medals at the present time, and that inducement was sufficient to keep up a good supply of these bodies, by keeping persons like himself engaged in watching for and calculating their movements. If anyone imagined that the love of science alone ought to have been sufficient to supply us with the number of comets which become visible to us, he would draw their attention to the kind of work which the comet-seeker had to perform. Night after night the patient astronomer took his place at the telescope, and watched for the faintest light in the heavens; and night after night he must return without having advanced one step towards the accomplishment of the object of his desire. If once a year he should be rewarded by the discovery of a comet he would consider himself fortunate. He thought, if they realised this, they ought to be very grateful indeed to the men who took upon themselves the arduous but thankless task. (Applause.) There were also physical reasons why the astronomers could not discover more than half, or a quarter, of the comets which were in existence. The Southern hemisphere had not been thoroughly searched, as the Northern had, and consequently a large number of comets had not been so much as sought for. Then, too, daylight was a great obstacle to the comet-seeker, as many comets had their paths near the sun, and were only above the horizon when the sun illumined the sky. Another reason why we did not know of all the comets in existence was that many of them were at too great a distance to be observed from our planet by our instruments. From all these reasons he was led to conclude that he did not exaggerate when he said that twenty or thirty times the number of comets visited our system more than were observed. As to the use of comets, he was prepared to admit that there were many things in nature the uses of which were inconsiderable or obscure, but he was not prepared to admit that there existed *anything in nature in such abundance, as he had shown comets to exist without having a most important part to perform in the economy of the universe. It was this consideration which led him to conclude that the cometary system must hold a higher place in the future estimation of astronomers than they had in the past. The cometary system had been somewhat neglected, but he wished to take stock of our knowledge in this sketch, and to discriminate between what was known and what was merely conjecture. Thanks to Newton and Halley they did know a great deal about comets, or at least about the orbits in which they travelled. Mr. Plummer then explained the nature of the parabolic curve in which comets travelled, and how the attraction of some large planets had been able to draw comets from their course, so as to convert the curve described by the track of the comet from its original form to an elongated oval. He described the group which revolved about Jupiter as revolving in periods of from three to seven years. As an illustration of the way in which comets were acted upon by the attraction of planets, Mr. Plummer gave the instance of a comet, which in the year 1759 had the misfortune to approach Jupiter. The result was that its motion was much retarded, and the comet afterwards travelled in an elongated orbit, and the period of its passage was reduced to 6½ years. It had scarcely, however, made two revolutions of this orbit when it had again the misfortune to come in contact with Jupiter, and the effect was that the comet went off into some new orbit, and had never been again observed. Another comet had by the attraction of Jupiter been brought into notice of astronomers in the year 1842, when but for that attraction it would have been too distant to be observed. In 1846 this comet was seen and might again, at about the year 1937, be expected to approach Jupiter and be thrown into some new orbit, and be subject to the same kind of catastrophe as befel* [sic] *the 1759 comet. The system of comets about Saturn was interesting to us, as they belonged to the meteoric system, through which the earth passed in the year 1866. Mr. Plummer showed that the astronomer's knowledge of comets was very limited in comparison with their knowledge of the planets. The planets were easily weighed, and they knew to a fraction of a pound how much the earth weighed. But their knowledge of comets was very limited, and such knowledge as they had was generally based on evidence of a negative nature. A few years ago a president of the British Association had actually stated that the entire mass of a comet could doubtless be enclosed in a snuff-box. That was a very disrespectful way to speak of comets; but the statement was made upon no less an authority than Sir John Herschell* [sic]. *He (Mr. Plummer) thought that very great injury was done to science from making such unfounded statements as that, for if they were not unfounded they were not founded on known facts. As to the composition of comets, two distinct classes of spectra had been observed which led to a conclusion, or rather conjecture, that it might be possible to classify comets according to the materials of which they were composed. One of these substances, as revealed by the spectrum analysis, was the well-known terrestrial element carbon. The comet of this year had been examined by the spectrum analysis, and it was found to give the same lines in the spectrum as carbon. Another comet in our system had shown lines indicative of another substance, which he (Mr. Plummer) conjectured was silica. He had said very little about the marvellous changes which comets underwent, for two reasons. One was that it would take too much of their time, and the other that little was known with certainty of those changes, or their causes. The changes of form were watched with the greatest interest, but they did not know what caused them. One agent, and one agent alone, was known as being in action to produce these changes, and that agent was heat. The real difficulty in dealing with the phenomena of changes of form of comets was that they were so numerous and so varied, that one single force in action did not seem sufficient to explain them. The illustrations before them, of the observations of Coggia's Comet, as seen on July 1st and July 14th this year would show how great those changes were. Mr. Plummer said that the want of time precluded his going into the question of the connection between comets and meteors, and concluded his brief address amidst much applause.*

A18.2.2 The Physical Constitution Of The Sun, 19 February 1875

***Ipswich Journal* (1875)**

A lecture on this subject was delivered on Friday evening to a large audience, in the Lecture hall at Ipswich, by Mr. John J. Plummer, MA, astronomer connected with Col. Tomline's Observatory in Orwell Park. Mr. Plummer said that after the interesting lectures on plants which had been delivered by Mr. Taylor (of the Ipswich Museum), his audience would probably like to hear something of that wonderful ruler of our system – the central orb, the powerful agent for the production of both animals *and plants,* viz.*, the sun. To exemplify the enormous vivifying power and energy developed in the sun, Mr. Plummer mentioned that the earth viewed from the sun would not appear of larger magnitude than a half-penny at a distance of 320 yards, and that it would require 2,380,000,000 of such planets to fill the entire vault of the heavens, all of which space the sun had power to warm and quicken into life. Firstly, then, the sun must be a very large and magnificent body; and secondly, it must be in a state of great commotion. The diameter of the sun, as far as was at present known, was 852,000 miles, but it was surrounded by so extensive an atmosphere, that the figure he had mentioned might be doubled in estimating its magnitude. The suggestion that the sun was a body in commotion dated back to the invention of the telescope. Before that it was one of the fundamental doctrines of the Aristotelian philosophy that the sun and the heavenly bodies were immaculate, and not subject to the same changes as the earth. Spots on the sun were discovered about the same time by Gallileo* [sic]*, Sheiner* [sic]*, and Fabritius, and were found to comprise a nucleus, bordered by a penumbra, the latter of radiated structure. These spots were very various, and apparently obeyed no law, though like all other natural phenomena, he supposed they had laws. Dr. Wilson, of Glasgow, about a century ago, introduced the theory that as the spots revolved with the sun, and that as they approached the solar edge, the penumbra appeared wider on the side nearest the edge of the sun, and narrower towards the interior; the nucleus was part of the sun itself, the penumbra one of its coatings, and that the gradations of width were according to the ordinary principles of perspective. This put an end to the theories as to clouds and smoke, which had too long been allowed to hold sway in men's minds. Subsequent discoveries by Dawes were confirmed by Sir John Herschel, who, in his definition of the sun, stated that the body was covered with two gaseous hemispheres, of which the interior one was dull and heavy, and the exterior bright, and gave out that light and heat for which we were so much indebted. The covering next the sun was known as the penumbra, the one next that as the photosphere, and, lastly, came the chromosphere, so named from its bright and distinctive colour. (Applause.) It was thought that the sun was rendered visible (or to us appeared spotty) owing to terribly cyclones, which corresponded to those occurring on the tropical regions of the earth, and which tore away the sun's gaseous coverings. Mr. Plummer spoke of the difficulty of confirming knowledge, owing to the fact that it was only during total eclipses that much information could be gained. He then proceeded to touch upon the component points of light, and the use of the spectroscope as invented by Newton, and subsequently enlarged upon by Wollaston, relating how about 1830 it was discovered that light derived from certain incandescent solids gave a spectrum similar to portions of the solar spectrum, though no connection between the two was for a time set up. Brewster, however, made various discoveries as to the spectra thrown by different substances, and some fifteen years ago a connection was established between the solar spectrum and the spectra of terrestrial substances by Kirchhoff, a German physicist of the highest rank. He arranged that the spectrum of the sun and the spectrum of sodium should be viewed in the same instrument together, and he found by comparison that the line of sodium occupied the same place in the spectrum of the sun as in its own, although not so bright. He, however, reduced the light given by the sodium spectrum to that of the spectrum of the sun by the application of the lime light. The spectrum reversed, giving a dark line on a coloured ground, showed the sodium line still in the same place, and it could not then but be concluded that sodium in some form or other existed in the sun. The presence of other substances, all in the form of vapours, was proved as clearly as any scientific fact could be, and these were hydrogen (a very important element), potassium, calcium, and many such heavy elements as copper, zinc, iron, cadmium, aluminium, manganese, &c. This fact was most startling. (Applause.) Most of these substances were also to be detected in the light of various stars and nebulae. As these metalloids and metals were to be found existing under these circumstances, we had the very best reason for believing that a community of substances existed throughout the whole universe, and were led to ask, might not life be equally commensurate with space and matter, as we learnt from geologists that it had been with all time? (Applause.) The penumbra was not properly to be called an atmosphere, as it was made up of different bodies, as might be seen by the telescope, for when the envelopes of the sun were rent aside by storms, bright bodies of floating vapour were seen to cross its surface. During such a phenomenon the phenomena of a magnetic storm and the appearance of the aurora borealis were to be noticed upon earth, and it was very remarkable that these should be found connected with the movement of spots across the photosphere. In respect to the state in which substances existed in the sun, Mr. Plummer said that much valuable information had been gained during the eclipses of 1868, 1869, and 1870, visible from India, America, and South Europe, and a quantity of literature existed on the subject. The* *spectroscope being fixed on the prominences at the edge of the sun during an eclipse, showed the existence of a number of substances; but were they solid or vapourous? Or were they in layers or mixed? As the totality of an eclipse must of necessity be of very short duration, it was not surprising that difficulty and doubt arose in respect of the result of some observations. In 1868 it was discovered that the principle component of the sun's atmosphere as shown by the spectrum was hydrogen. The spectroscope being placed at right angles to the limb of the sun would receive the entire light of the chromosphere and a part of the photosphere, and their component substances, amongst them hydrogen, sodium, and magnesium, and to some extent calcium, could then be determined. There was every reason to believe that iron, nickel, copper, zinc and other metals existed there also. In 1807 Professor Young, an American, obtained a magnificent glimpse, and established the fact that quite close to the photosphere existed the vapours of the heavier metals. Between the photosphere and the chromosphere, Professor Young had placed another layer, but the tendency of modern science was to identify this with the chromosphere. The tendency of these vapours was to precipitate, but they were constantly mixed by the action of the sun. Still it was not remarkable to find hydrogen at the extremity of the prominence, and the heavier substance lower down. There was not the slightest doubt that at the base of these prominences the heat was most intense, because the iron, copper, and so on existed there in an incandescent state. The spectroscope gave some information on this point also, for it showed by a broad or a narrow line the rarity or density of the gases. Mr. Plummer also showed how the speed of a star might be told by the change of position of its light upon the spectrum, such change of colour being produced by an alteration in the number and size of the waves of light much in the same way as a tone was altered by the advance or recession of the musical instrument. It could also be told whether the cyclonic action commenced from the interior or the exterior. In conclusion, Mr. Plummer said that it was in all probability from the exterior portions of the sun that in ages long past the earth was formed, and still the same wondrous store of light poured from that orb, as far as we know in undiminished force. Here arose a question which had not yet been solved, and it was one of the deepest interest. What was it that maintained the superabundant energy of the sun undiminished through such long ages. Might we not hope that after it had yielded to astronomy so many of its secrets, this last one would crown our researches! (Applause.)*

Mr. Wollaston proposed a vote of thanks to the lecturer, which having been seconded by Mr. F. Alexander and acknowledged, the assembly dispersed.

A18.2.3 The Moon, 04 February 1876

***Ipswich Journal* (1876a)**

On Friday evening, J. J. Plummer, Esq., MA, FRAS, of the Orwell Park Observatory, delivered a lecture at the Temperance Hall, in the place of one of Dr. J. E. Taylor's lectures, on "Facts and theories about the Moon." Mr. E. R. Turner was in the chair.

Mr. Plummer said there were very few subjects which interested the public more than the manner in which the various planets which compose our system existed. This fact had induced him to give the present lecture, taking for his subject "The Moon, a secondary planet which approached nearest our earth." There was no planet which approached the earth with anything like the nearness that the moon did, and this enabled us to view objects on its surface with much more distinctness than upon any of the primary planets. When the sun was shining upon the moon mountains and other objects could be distinctly observed, and the heights of the various mountains of the moon were as accurately ascertained as mountains upon our own planet. Although the moon was some 226,000 miles distant from us when nearest, we were, under favourable conditions and with the aid of powerful telescopes enabled to view objects on its surface as easily as if it were only 226 miles distant. Although objects could be viewed thus easily, it was not possible to see distinctly any objects smaller than a half-a-mile in diameter even with the best possible telescope. As the moon was about the same distance from the sun as our own planet was, it was quite clear that it received the same amount of light and heat as we did. It had been found that these conditions of light and heat were so unequally distributed that it was not probable that the moon was inhabited, or if inhabited at all, the inhabitants were of such a different character to ourselves, that it took away a great part of the interest in the subject. If people would only make a few observations for themselves, and not take things on hearsay as they generally did, it would be far more satisfactory to them, if they would only observe the moon for a few nights, it would do more in inducing them to believe the statements of astronomers, than any amount of reading *could possibly do. He did not hesitate to say that a great number of facts would come to them much more easily by a little observation, and would be much better understood. Therefore, if he could effect this by his lecture, he should have done something of which he should not be sorry. (Applause.) The moon revolved round the earth, and both of them revolved round the sun. Thus the moon had two motions; at the same time it was being carried rapidly around the sun with the earth in its course, it was also moving round the earth. This would be perhaps difficult to understand by his hearers, and the best illustration he could give them was the direction taken by the shot from a gun, say the 81-ton gun. There was the motion imparted to the shot by the explosion of the powder, and there was also the downward direction of the shot caused by gravitation. This was the same case with the moon. As surely as the moon was moving around the earth in its course around the sun, so surely was it being drawn towards the earth by the laws of gravitation. The lecturer here described the course taken by the moon around the earth, pointing out that the moon must receive nearly the same amount of heat, and light, and those other benefits which we derive from the sun. The moon also had day and night, the same as we had, although they were of very unequal lengths. In its course round the earth the moon always presented the same side to us, so that we had never been able to see more than about four-sevenths of its whole surface, thus leaving us in almost entire ignorance of what the other three-sevenths was like. Many people were unable to understand the reason of this, but it was explained by Herschell* [sic] *in a very amusing manner. He said if a person would place his hands around a post, and begin to go round it, at the same time keeping his face towards the post then he would be in exactly the same position as the moon; but if he walked round the post in a rapid manner, he would have such a distinct sense of giddiness that he would at once know that he had been turning upon his own axis. (Applause.) As the moon did not always present the same face to the sun, it was quite clear that each side of it would enjoy the blessings of light and heat. Another phenomenon which resulted from the direction taken by the moon in its course was that it had no seasons properly so called; it had alternations of temperature, but no seasons. The alternations to which the moon was subject were those of day and night. It would be seen that the moon's day was of much longer duration than ours; this meant greater heat by day, and greater loss of heat by night. Throughout the long lunar day, 15 of our days, it must receive such an enormous amount of heat from the sun, that unless there were some counteracting influences at work, the whole surface of the moon must be one arid waste, with which the deserts of Africa could not be compared for sterility. On the other hand the loss of heat during the long nights must make the atmosphere a great deal colder than the Arctic regions of our own earth. (Applause.) If, therefore, we were anxious to believe that the moon was inhabited as well as the earth, it was evident that these extremes of heat and cold, which by themselves were sufficient to prevent vegetable or animal life, would send us to look for some counteracting influences. It was the property of water of holding a very large amount of heat and giving it out gradually. Clouds, or even a dense aqueous atmosphere, would also tend greatly to mitigate the severity of these extremes, When we examine the moon we find that, at least upon the side visible to us, there was no indication of atmosphere, and as an indirect consequence, no water upon its surface. Mr. Plummer described the various methods by which this had been ascertained, explaining that in consequence of the absence of atmosphere, there was no rain to soften the arid and parched soil, and no clouds could ever shade the surface of the moon from the burning rays of the sun. The surface of the moon was in the same state as when it was first formed by volcanic action, it having had no rain to soften its parched and arid soil. This accounted in great measure for the fact that the mountains of the moon were in comparison much higher than those upon our own globe. There were several mountains upon the moon as high as the Andes, and remembering that its diameter was but one-fourth of that of the earth, and its bulk 1/49th, it would be easily seen that the heights were relatively much greater. Upon our earth the hills and mountains have been worn away by the action of the rain, the valleys being partially filled up; but upon the moon, these influences not being at work, they had always remained the same since geological disturbances had caused them, and would remain so for ever, or until another volcanic change altered their foundation. It would seem, all circumstances considered, that there was not the slightest ground for supposing that the moon had any inhabitants, at least, on the side presented to us. There, where there are no seasons, and where the day is fifteen of our days, and the night fifteen of our nights, and where, owing to its small size, a man would be able, supposing him to have the same amount of muscular energy that we have, to walk 250 miles in one day of twenty-four hours, and walk from one side of the moon to the other in one of her long days. The lecturer described at some length the details of the nebulous* [sic] *hypothesis of La Place* [sic], *and concluded a most interesting lecture* *by expressing a hope that the facts he had put before them might increase their desire for further information on the same subject, and lead them to study more closely the heavenly bodies. If he had done this his lecture would not have been altogether without good results. (Applause.)*

The Chairman moved a vote of thanks to Mr. Plummer for his very interesting lecture, observing that the audience would probably look at the moon when they got outside that night with more interest than they had ever done before.

Mr. Plummer, in acknowledging the vote, said he hoped at some future time he might have the pleasure of delivering a course of lectures in Ipswich on the heavenly bodies. (Applause.)

A18.2.4 The Stars, 16 March 1877

***Ipswich Journal* (1877a)**

On Friday evening a lecture was delivered at the Temperance Hall by Mr. J. J. Plummer, of the Orwell Park Observatory, on "The Stars". Walton Turner, Esq. (mayor), occupied the chair, and there was a very large attendance. The lecturer at the commencement observed that solar astronomy was of great value to human beings in an educational point of view, as it had a tendency to enlarge one's idea of space. It was no small triumph of human ingenuity that astronomers had been able to determine their distances, magnitude – or more properly masses – their velocity, the materials with which they are made, and the degree of heat to which they are subject. This knowledge had all been acquired by patience and dogged perseverance, and it must ever remain a monument to the human mind that man should ever have been enabled to do this. He wished to give them that evening such hints and brief explanations as to some facts as regarded stars, that he might, if possible, remove the veil of wonders which had too often been allowed to cloud the simplicity of astronomy, and which without these explanations might become still denser and more impenetrable. The popular notion that stars were innumerable was incorrect, inasmuch as the number of stars visible to the naked eye at one time was comparatively small – not more than 6,000. With the aid of the telescope about 315,000 were visible in the Northern hemisphere, and were known to astronomy. If, however, the smaller stars were included, it would be found that there were altogether from ten to twelve millions of stars. After making some further remarks on this subject, Mr. Plummer proceeded to describe the "Milky Way," and afterwards he dwelt at length on the subject of temporary stars, his remarks bearing more particularly on the star discovered during the latter portion of last year. Thew lecture concluded with a vote of thanks to Mr. Plummer for his lecture.

A18.2.5 Aurora Borealis, 05 June 1878

***The Suffolk Chronicle* (1878)**

At a meeting of the Scientific Society on Wednesday evening, Mr. J. J. Plummer, of the Orwell Park Observatory, introduced, in an able paper, the subject of the aurora borealis. Mr. Branford Edwards occupied the chair. Mr. Plummer having remarked on the want of precise and certain knowledge on the subject compared with what was known of other natural phenomena, went on to speak of the aurora under three different classes, the first of which was simply the auroral arch, devoid of colour, which at a great elevation spanned from east to west. The second was the ordinary aurora, which commenced as a bright arch low down in the north-western part of the sky, vivid streamers sometimes but not always ascending towards the zenith, forming and reforming every few minutes for a considerable time, the duration of [the] *phenomenon generally being from an hour or two after sunset to an hour or two after midnight. The third class, no instance of which had occurred for nine years, transcended, Mr. Plummer said, his descriptive powers. Brilliant streamers, mostly a greenish yellow and red, shot upwards apparently meeting near the zenith, affording a spectacle with which no sunset could vie in definiteness or beauty. Having mentioned that these phenomena were to be witnessed in south as well as north polar regions, and that their supposed connection with arctic conditions was only partially true, Mr. Plummer explained that they probably consisted of a discharge of negative electricity, and were most frequently to be seen when magnetic storms prevailed, observations showing that the magnetic storms and the accumulation of electricity which produced the aurorae had their origin in those violent movements of matters which were so frequent when spots abounded in the sun. Passing on, Mr. Plummer referred to the spectrum of the aurora, a single brilliant line between the green and yellow, and said it had been a great puzzle, inasmuch as that line was not coincident* *with any line in the spectrum of any known chemical element at ordinary temperatures. He suggested, as an explanation, that the earth, like the sun, had two atmospheres. In conclusion he spoke of the connection between the movements of the magnetic needle and solar heat. – An interesting discussion followed, and a vote of thanks was passed to Mr. Plummer for his paper.*

***EADT* (1878a)**

A largely attended meeting of the Ipswich Scientific Society was held at the museum on Wednesday evening, the president (Mr. Branford Edwards) in the chair, when Mr. J. I. Plummer MA, FRAS, of the Orwell Park Observatory, read a very masterly and comprehensive paper on the aurora borealis.

Mr. Plummer commenced by saying that there were, perhaps, few, if any, natural phenomena of the magnitude and splendour of the Aurora Borealis, about which so little was known with certainty and precision, as of the subject of his paper. It was but very lately indeed that it had been found possible to assign to it the proper position and definitely to fix upon the science to which its investigation belonged. Hitherto it had been regarded as a meteorological phenomenon, but lately meteorologists had succeeded in defining and circumscribing their own science, and in doing so had managed to throw the whole question of meteors upon the care of astronomers, whilst the latter must agree to share equally with them the question of the Aurora. The Aurora might generally be classed in three forms. The first and simplest was the auroral arch. This consisted of a single broad arch not unlike a rainbow in width, but devoid of all colour, spanning the heavens from west to east, and generally situated at a great elevation. This arch had usually a slow motion southward, but he was not aware of its having been known to disappear in consequence of its motion. It had only a short duration, and faded from sight like a cloud dispersed by heat. The second form might be designated the ordinary aurora. It commenced as a bright arch low down in the north-western part of the sky. The portion of the sky below the arch was always of intense blackness, as though it were a cloud, though this is not the case. This stage may last some hours, and may be the whole of the phenomenon visible. But should the causes which produced the display be more intense a further development will take place, and from every portion of the arch vivid streamers would ascend towards the zenith. These seldom last but a few minutes, but they form and reform so that for many hours the northern sky is illuminated by them, and the eye did not tire of watching the ever changing scene. The after development may, however, be of a different character, when waves of light continually pass one after the other with great rapidity across the arch. The duration of the ordinary aurora was various, usually commencing an hour or two after sunset and continuing till an hour or two after midnight. On the other hand, they had been known to last for days, being traceable even at noon. The third class must be seen almost to be credited. None have occurred for about nine years, and he was not sure that they would be visible so far south as Ipswich, and although the beauty of the scene would greatly transcend his powers of description he would attempt it. From every point of the horizon brilliant streamers proceeded upwards till they met at one clearly defined point. Most were coloured greenish yellow and red. This apparent meeting near the zenith was, of course, an effect of perspective, and the term auroral crown had been applied to it. The observer felt himself to be in the midst of a great number of parallel rays which stream away far above him. No sunset, however fine, could vie with it in distinctness or beauty, and the presence of stars shining clearly through the striped canopy added not a little to the glory of the scene. Although called the aurora borealis, the phenomenon was also visible near the South Pole, and there was some reason to believe that an exhibition near the North Polar regions was accompanied by a similar display in the South. There was a general impression that the aurorae were much more frequent in arctic regions, and had some connection with snow and ice; but this was only partially true. Mr. Plummer went on to say that the whole phenomenon was electrical, and probably consisted of a discharge of negative electricity, and next dealt with the height above the earth, and inclined to the figures given by Professor Temple Chevallier, of from 72 to 78 miles. In this he spoke only of the arches, as the streamers, he thought, must attain much greater altitudes. The next point dealt with was when the aurora may be most frequently expected. It was clear that there was some connection between magnetic storms and aurorae, and wherever the former prevailed the latter would be seen in greater or less brilliancy, and observations showed that whatever might be the cause of the magnetic storm and of that accumulation of electricity which produced the aurora it most certainly resided in the sun, and had its origin in some of those violent movements of matter which were so frequent at certain intervals when sun spots abound. These spots were much more numerous at *periods of about 11 years. At the present time we were experiencing an over protracted period of minimum disturbance of the sun, and consequently there had been for some years past no aurorae, nor any violent movement of the magnetic needle denoting a magnetic storm. We were now expecting a quick return of all three phenomena for in about a year and a half, or rather more, the time of maximum disturbance should again come round, but there were* [sic] *at present no indication of that, and we might have to wait for some time more. Mr. Plummer then contradicted the reports that magnetic displays were accompanied by cracking sounds. As to the seasons, there was no time of the year in which aurorae might not occur. The last point dealt with by the lecturer was the spectrum of the aurora. Here we may mention that Mr. Plummer was the first person in England who had thought of applying the spectroscope to the elucidation of auroral phenomena, and he was only anticipated by a few months by Angstrom in Sweden, and Struve in Russia. In the great majority of cases the spectrum of the aurora is of a most simple character, though the interpretation of its meaning was most puzzling. It consists of a single and very brilliant line in the green, or rather intermediate between the green and yellow portions of the spectrum. In all cases this line is present, though it is said to be less conspicuous when others are likewise to be seen. In ordinary cases, however, this line is alone visible, and the puzzling part of the business is that it is not coincident with any line in the spectrum of either oxygen or nitrogen, nor in the known spectrum of any known chemical element, solid or gaseous, at ordinary temperatures. For sometime it was considered likely that as we became more familiar with the spectrum of the gases under different conditions of pressure it would be found that one or other of these bodies would yield a spectrum agreeing with that of the aurora, but some nine years had elapsed since then and still the matter remained as much an enigma as ever. On some occasions and notably when a brilliant red aurora is the subject of investigation, some five or six other and much fainter are seen as well as the puzzling citron line. Several of these Mr. Plummer thought, might point to the presence of iron. But still the difficulty remained as to the citron line, and unless it could be identified with some chemical element in some particular form there seemed to be nothing to suggest other than that the earth has two atmospheres as the sun has. There appeared one point at least which must be considered established by the investigation of auroral phenomena, namely that the superior limit of the atmosphere is immeasurably beyond what was formerly believed. In conclusion, Mr. Plummer directed attention to the fact that there did exist a connection between the movements of the magnetic needle and solar heat, but we are not yet aware whether this affected auroral phenomena, because the connection at present made out is rather between the heat derived from the sun and the ordinary movements of the needle and not the extraordinary movements which are always simultaneous with the aurora.*

A brisk discussion ensued, in which Mr. Plummer's theory of a second and higher atmosphere of the earth was criticised, as being contrary to the law of the diffusion of gases. It was, however, suggested that a lighter atmosphere than even hydrogen might exist, composed of a substance of which chemists are as yet unacquainted, and to which the citron line of the spectrum of the aurora might be due. The popular idea of the common occurrence of aurora, in this district at least, was shown by Mr. Plummer to be incorrect, the zodiacal light being possibly mistaken for aurorae at certain times of the year. A vote of thanks was passed to Mr. Plummer by acclamation.

A18.2.6 Meteors, 03 March 1880

***EADT* (1880a)**

At the monthly meeting of the Ipswich Scientific Society, at this Museum, on Wednesday, the President (Mr. W. Hadden) in the chair, a highly interesting paper on "Meteors" was read by Mr. Plummer FRAS, astronomer at Colonel Tomline's Observatory at Orwell Park. *Mr. Plummer stated that meteors are the only bodies of an astronomical character which are to be met with in the immediate vicinity of the earth. However widespread they may be in the scheme of the universe, and there is reason to believe them to be scattered throughout the entire realm of space, it is only when they enter the atmosphere of the earth that we can have evidence of them, so that our knowledge must be acquired from their behaviour during their short but brilliant career. Although differing greatly in splendour, from minute stellar points, visible only in good telescopes, to large masses almost equalling the sun in lustre, the conduct of all is strikingly similar. They appear suddenly, they traverse a greater or less portion of the sky, generally with considerable velocity, they become suddenly extinguished, or bursting into fragments, with a noise resembling thunder, a like fate befalls the* *separate portions. The immense majority of meteors never penetrate beyond the outermost portions of the terrestrial atmosphere, the heat that is evolved by friction being sufficient to disintegrate them completely, leaving nothing but the finest dust, which filters slowly through the lower strata. That some, however, do reach the solid earth is now well established, and of late years the records of meteorites that have actually been seen to fall are of almost annual occurrence. Several falls of meteoric stone were particularised by the lecturer, and one of meteoric iron at Rowton in Salor, on April 20th, 1876, which weighed 7¾ lbs and when recovered was still quite warm. This was the seventh instance of meteoric iron being seen to fall from the sky, though falls of stone have been much more frequently observed. True meteoric masses, as seen to fall, or as subsequently found on the earth's surface, may be divided into three classes. The first, called meteoric iron, consists of a peculiar alloy of iron and nickel with only very slight traces of other substances. These are always recovered with a thin black rind or crust, which is no doubt caused by the action of heat. There is also to be found, interspersed through the mass, minute crystals of a phosphide of iron and nickel called Schreibersite. Both these substances are peculiar to meteorites and are not to be found on the earth, except in meteoric bodies. The second class, called meteoric stone, is a volcanic-like rock of greyish white colour also covered with black rind and usually containing a little of the stone alloy. The mass, however, consists of certain silicates of magnesia and alumina as olivine or bronzite and feldspar. All of these are found among the products of terrestrial volcanoes, and indeed the analysis of some modern lavas shows an almost identical composition with this class of meteorites. The third class possesses a more mixed character, and, besides containing more or less of the materials of the other two classes, contains also magnetic pyrites, and a variety of other substances. In all 21 terrestrial elements have been identified as existing in meteorites, but one of these, metallic iron, is very rarely found on the earth in an uncombined form, while such is so frequently the case in meteorites. Having thus explained what meteorites are, the lecturer next proceeded to answer the question whence they come. He stated, that upon any clear night a little patient watching will always be rewarded by the sight of one or more meteorites, but if the watch is kept up night after night for a whole year, it will be noticed that certain nights are specially rich in meteor displays and the records of past observations will show that occasionally these nights will have been distinguished by displays of surpassing splendour. The night of the 13th - 14th November, 1866, will be remembered as one such instance. On that occasion from six to eight thousand meteors fell in from three to four hours as seen from one locality, and the number that eventually fell towards the earth will have many times greater than this. Yet on some occasions, notably in 1799 and 1833, much more brilliant displays were witnessed on this same evening of the year. When a shower is of this character, a fact which may be noted on any evening, it becomes a conspicuous feature. It is that they all appear to proceed from one point in the heavens, those which appear near this point leaving short courses, as if foreshortened in consequence of coming directly towards us. The spectator is evidently in the midst of a shower of fiery bolts, which are dropping all around him as the earth carries him onward. If these were fixed objects through which the earth was running the gauntlet, the point from which they would appear to proceed would be that point to which the earth was tending at the moment, and that this is not the case, shows not only that the meteors had previously a motion of their own, but enables us to tell the direction and velocity of that motion. The next step was to determine the interval of time between successive exceptional displays of the November shower, which was found to be 33½ years. In this way the nature of the orbit pursued by these meteors gradually became known when it was found, chiefly by the labours of Schiapparelli, to be identical with that of a comet which had been visible in 1866. The entire track of this comet is marked out by an annulus or ring of meteors which has been dumping its meteorites on this earth in enormous numbers for a thousand years, and was yet very far from being exhausted, and a dense portion of the ring still existed in the vicinity of the comet itself. It seems highly probable that every comet is similarly accompanied, and it is certain that three others at least, whose orbits actually cross the earth's annual track, give rise to well-known showers of meteors, and it is suspected that a number of comets, which have passed pretty closely to the earth's orbit, are connected with a like number of less perfectly developed showers. At this stage we must ask ourselves the question. Of what nature is the connection between comets and meteors? We have learnt that they move precisely upon the same lines; what we want to know further is whether a comet is nothing more than a large meteor or a collection of small meteors or whether it is a foreign body that has attracted these attendants to itself, in its wanderings through space. Each of the former suppositions has been advocated, but the latter approved itself as more in accordance with the strange and varied* *appearances presented by comets. There was nothing improbable in the comet doing this, especially if it could be shown to be a body of considerable mass. It was well known that there were many meteors which did not group themselves into particular showers, but were irregular or sporadic, and such would be quite liable to be picked up by the passing comet when beyond the region of the sun's more powerful attraction. Moreover, this hypothesis explained how such incongruous objects came to be associated together, for our knowledge of the chemical constituents of comets and their physical conditions certainly did not point to any community of origin in these two classes of bodies. As there is no direction in space to which comets did not penetrate, so also there can be no region where the meteor may not be found, and the latter must of course undergo the same vicissitudes as the former. Thus occasionally they would have the fortune to pass near one or other of the major planets of the solar system, and would suffer such diminution of velocity as would cause them to pursue in the future closed orbits. This had been the case with Tempel's comet and its attendants the November meteors – which had been made permanent components of the solar system by the attraction of the planet Uranus. The reason why the meteors cover the whole track of this comet, producing thereby an annual shower, was because of the whole of the bodies forming the original group some were gaining slightly on the rest, and thus a tendency towards an equable distribution arose which may be completely effected in course of time. In conclusion the lecturer referred to the class of sporadic meteors and their supposed origin. He pointed out that the strong resemblance of many of them to terrestrial lavas gave strong support to the theory advanced by Dr. Hall that they may have been ejected from volcanoes upon the earth at some remote period when the explosive forces were much greater than at present. The principal difficulty in accepting this solution was that one of the invariable components of aerolite, nickel iron, was nowhere found in any quantity upon the earth. Still, all our knowledge was in favour of a volcanic origin for these bodies. Within the last year or two it had been found possible to make this peculiar alloy artificially by a process not unlike what would take place within the crater of a volcano, and this artificial alloy, when slightly acted upon by acids, was found to be etched upon, the markings closely resembling the Weidmann-statian* [Widmanstätten] *which are quite characteristic of meteoric iron, so that the formation of both the main classes of meteors is now to be traced to the main agency. He was strongly of* [the] *opinion that eventually the suggestion of Dr. Hall would be generally accepted, and that such difficulties as at present were opposed to it would be found capable of explanation. At the same time, it must be remembered that it applied only to a numerically small class of meteors and left the origin of the components of those following the tracks of comets as little explained as before. Unfortunately we did not possess a specimen known to have been originally a cometic meteor, so that as far as we know at present, these might be of an entirely different character, appropriate to an entirely different origin.*

At the close of the paper, which was constantly applauded, Mr. Plummer was subjected to a perfect battery of questions relative to comets, meteors, sunspots, etc. A fragment of a meteor given to Mr. Plummer by Mr. J. Breen of Cambridge, was handed round the room, and its peculiar structure observed. Dr. Taylor pointed out that this supposed meteor was exceedingly like the nodules of iron pyrites, frequently called thunderbolts in Suffolk, but which were not meteors but formed mechanically by aggregation. Mr. Napier, PCS, of Bramford, promised to analyse the meteor, and ascertain its actual elements. On the motion of Mr. Napier, seconded by Dr. Taylor, a cordial vote of thanks was passed to Mr. Plummer for his exceedingly interesting address.

A18.2.7 Stars, 03 December 1890

***EADT* (1890)**

At the usual monthly meeting of the Ipswich Scientific Society, held at the Museum on Wednesday evening, Mr. J. I. Plummer, MA, FRAS, read a paper entitled "Stars: Their Distances and Actual Movements". The chair was taken by Mr. Henry Miller, jun., and there was a full attendance of members. At the opening of the meeting, before the special subject was introduced, Mr. W. Vick exhibited the photograph of a solanum, covered with ice on both stems and united at the top, which was rightly described by the Chairman as a curious and beautiful object, and also some of the splendid views of Gifford's Hall, which was recently visited by the members. The secretary of the Ipswich Photographic Society wrote that on the 7th of January an interesting lecture would be given, in connection with their organisation, by Mr. H. M. Smith, of the Eastman's Photographic Materials Society. He invited the attendance of members of the Scientific Society, and it was resolved to defer the *next monthly meeting, which was fixed for the same date, in order that this invitation might be accepted. Mr. Plummer, who was welcomed with the heartiness due to his high reputation as an astronomer, then read an exceedingly interesting paper upon the subject announced, under the title (which he himself preferred) of Stellar Parallax and Stellar Motion. It is hardly possible, however, to summarise a lecture which was itself a close summary of facts relating to this branch of science, and we may perhaps be allowed to say that it pre-supposed a more intimate acquaintance of the elements of astronomy than the majority of newspaper readers would profess. But Mr. Plummer's conclusions, which were characterised by an earnest and even reverent enthusiasm, showed very clearly the wonderful fascination of a study which should be more generally followed. There was reason to rejoice, he said, in the success that astronomers had achieved, and in the special providence which had placed the inhabitants of this globe upon a spot so constituted that it would seem to afford a better chance of investigating these questions than any other that could be conceived of. If it were not intended that man should solve such questions, how easily might he have been placed in circumstances under which their solution would have been absolutely impossible. It was manifestly the Divine intention that man should so occupy himself. There was a time, within his memory, when a view of the aim of human existence not less exalted than this was common in this country; it might still exist possibly, although seldom heard of now-a-days; but they had to look abroad – to France, to Germany, and to America to find a practical expression for this reverential feeling for creation of which continued astronomical study was the outcome. – At the close, the Chairman said there could be but one opinion as to the merit of the paper, and he invited members to make the most of Mr. Plummer now that they had him present. – A discussion followed, in which several members showed a keen appreciation of the facts laid before them, and a very cordial vote of thanks was passed on the motion of Mr. E. P. Ridley, seconded by Mr. A. Harwood. – The question of holding a conversazione in February next was referred to the Committee, with instructions to suggest a definite proposal for consideration at the next meeting.*

***Ipswich Journal* (1890)**

At the monthly meeting of the Ipswich Scientific Society, held at the Museum, on Wednesday evening, a paper was read by Mr. J. I. Plummer, MA, FRAS, on "Stars, their distances and actual movements." Mr. H. Miller, jun., occupied the chair. Previous to the lecture Mr. W. Vick exhibited a beautiful photo of a solanum, covered with ice on both stems, and united at the top, and also some splendid views of Gifford's Hall, recently visited by the Society. It was resolved to defer the next monthly meeting, which was fixed for January 7th, in order to hear at that date a lecture to be given by Mr. H. M. Smith, in connection with the Ipswich Photographic Society. Mr. Plummer's lecture was a very interesting one. There was reason to rejoice, he said, in the success that astronomers had achieved, and in the special providence which had placed the inhabitants of the globe upon a spot so constituted that it would seem to afford a better opportunity of investigating these questions than any other that could be conceived of. At the conclusion a cordial vote of thanks was accorded on the motion of Mr. E. P. Ridley, seconded by Mr. A. Harwood.

A18.3 Ipswich Press, Earthquakes

At approximately 05:30am on 23 February 1887, an earthquake struck the Ligurian coast. It created widespread damage, centred on the Italian towns of Imperia and Dalio Marina, and resulted in the death of at least 600 people (perhaps many more), mainly through collapsing buildings. The disaster was widely reported in the press and, inevitably, after the initial reporting of the tragedy, attention turned to the matter of prediction of earthquakes.

In a short piece on 01 March of the year, the *EADT* (1887a) reported predictions by Dr. Rudolf Falb (1838-1903), of Austria, of dates when atmospheric disturbances and earthquakes were most likely to occur. Falb's predictions were based on the *lunisolar flood hypothesis* which he had developed. This considered earthquakes to be caused by tidal forces associated with the Sun and Moon acting on subterranean lakes of lava. The hypothesis was not accepted by the academic community at the time.

Plummer (1887e) responded the following day in the *EADT*, disparaging Falb's hypothesis, although without providing evidence to support his position. The Moon, he stated, could have *no possible connection with earthquakes*, nor could the partial eclipse of the Sun, on 22 February, have been the trigger for events the following day. Dr. Falb was a quack and imposter, and his like could be found everywhere! Plummer noted that five comets were visible at the time (four in northern skies and one in southern), a circumstance unique in the last 25 years. Mockingly, he invited Falb to make use of the fact, claiming that the occurrence disturbed the minds of men more than it did the Earth's crust.

In the same edition of the paper, the *EADT* (1887b) published a brief commentary (also carried in the *Evening Star* (1887)) on the correspondence, pointing out that *Mr. Plummer's unequivocal denial is not however quite borne out by Professor Darwin, son of the famous author of the "Origin Of Species"*. Darwin, writing shortly before the Ligurian earthquake, stated that the surface of the Earth could rise or fall by a few centimetres due to variations in barometric pressure and the tide. A tide of 3m equated to an extra weight of 8 million tonnes. Presciently, he noted that the soil of Italy trembled incessantly, that earthquakes generally followed the steeply sloping shores of continents and islands, and it was likely that the origin of the shocks was under the seabed, not far from the coast. Some years previously, Darwin had set up a huge pendulum at Cambridge and, although earthquakes in England are rare, found it to be subject to incessant, irregular oscillations. He also reported that in Italy, Michele Stefano Conte de Rossi (1834-98), had invented a very sensitive seismic microphone and with it discovered that the Earth's crust under Rome and under the slopes of Vesuvius emitted sounds like *roarings and explosions*. Darwin was confident that earthquakes were associated with the internal heat of the Earth and originated in the upper layers of the crust. A portion of the crust, in cooling, could sink below the remainder, doing so rapidly and creating noise. The process resulted in the origin of the shock being only a few miles beneath the surface. Darwin believed that external circumstances could influence the likelihood of earthquakes, that they were more likely to occur following a rapid change in air pressure, and that they might also be influenced by the motion of the Moon. Variation in air pressure could create a difference in weight on the Earth's crust of 630,000 tonnes per square kilometre, the tides could create a further difference of 3,100,000 tonnes per square kilometre, and it appeared plausible that such weights could be implicated in triggering earthquakes.

Some three weeks later, Plummer (1887a) contributed a substantial article to the *EADT*, addressing the supposed influence of the Moon on earthquakes. It was well known that the Moon attracted the waters of the ocean causing tides and, in principle, Plummer conceded, it could do the same to the land, although only to a *trifling* extent. While at Glasgow (see Section 2.4), he had worked with Professor J. D. Everett to attempt to measure the gravitational influence of the Moon on the Earth's crust, but the pair found no measurable effect. It seemed impossible that a force which did not register on delicate apparatus could fracture crustal rock. Regarding the enormous variation in loading which the Moon indirectly causes on the Earth's crust through the tides, he pointed out that the variation happened twice daily, and that the crust continually flexed and recovered in response. Although when the Moon was at its closest to the Earth it would raise a higher tide, the difference from the average was constrained. The frequency of earthquakes along the Mediterranean coast from Anatolia to Spain indicated a weakness in the Earth's crust, yet the Sea was virtually tideless, and so the crust there did not endure large variations in tidal loading; lack of tides evidently did not confer immunity from earthquakes. Touching briefly on the question of whether variation in atmospheric pressure could trigger earthquakes, Plummer was unable to rule it out, but noted that barometric readings were not, in any case, significantly influenced by the Moon; he recommended further investigations.

Summarising his views on the prediction of earthquakes, he concluded that Darwin's approach had not predicted the Ligurian earthquake, and that Falb's predictions were *the sheerest nonsense* as, near the time of the earthquake, the Moon was not on the meridian, not exceptionally close to the Earth, nor close to the zenith over the Mediterranean at any time during the day. Although the day had experienced a spring tide, it was unexceptional and did not touch the shores of Italy or France. Finally, he complained about the notion that the Moon undergoes sudden change. As nothing more than a misleading figure of speech, it contributed to sudden and unexplained phenomena being attributed to the Moon. Yet the Moon did not change, and its motion was gradual.

The notion that the Moon can influence the occurrence of earthquakes and possibly even trigger them has a long history, and research nowadays still addresses the matter. For example, in 2016, seismologists at the University of Tokyo found (Witze, 2016) that large earthquakes are more likely to occur near new or full moons, when the Sun, Moon and Earth align, and tidal strains are at their highest, although the effect is slight. In 2018, Susan Hough (2018), a seismologist at the U.S.

Geological Survey, concluded that there is no evidence that the occurrence of severe earthquakes is affected by the relative positions of the Earth, Sun and Moon.

A18.4 Ipswich Press, Other Reports

Local papers in East Anglia carried reports of Plummer's activities in the region as follows.

- Having worked at several observatories before arriving in East Anglia, Plummer appears to have been taken aback at the sometimes insular attitude of the local citizenry. Writing on 21 September 1875 to the editor of the *Ipswich Journal*, Plummer (1875e) provided details of the solar eclipse visible on the 29th of the month, including event times expressed as Greenwich Time, and went on to pour scorn on the fact that many of the public clocks in Ipswich still kept local time[110].
- *The Ipswich Journal* (1877b), reporting on a meeting on 08 August 1877 of Ipswich Town Council, listed Plummer among benefactors of Ipswich Museum.
- On 22 November 1877, Plummer acted as foreman of a coroner's jury convened in Nacton to determine the cause of death of Hannah Cowie, wife of a local labourer. *The Ipswich Journal* (1877c) reported the inquest, painting a grim picture of an exceptionally distressing case.
- Situations vacant in the *EADT* (1878c) for 10 July 1878 contained an advertisement, placed by Plummer's wife, for a *good General Servant, in a gentleman's family, aged about 21; wages £10, or more according to ability...*
- The *Ipswich Journal* (1878a) described a visit by Woodbridge Parish Choir to Orwell Park on Wednesday 28 August 1878 (Tomline opened the Park to the public on Wednesdays) during which Plummer showed some of the party around the observatory.
- Plummer was a golfer and reports in the *EADT* (1880b) and *Chelmsford Chronicle* (1880) of the inaugural rounds of the Felixstowe Ferry Golf Club, on 30 October 1880, mention him as playing *in very creditable form*. Tomline was patron of the club.
- On 27 July 1881, Plummer was invited, along with some 400 gentlemen, including the great and the good of Ipswich, to an official ceremony to mark the opening of a new lock at the town docks. *The Ipswich Journal* (1881a) described those present enjoying bunting, church bells, the ceremonial firing of a cannon, a trip along the River Orwell, and speeches.
- He enjoyed an association with schools in Nacton. The *EADT* (1884) reports him giving an *interesting reading* at an entertainment, well-attended and *including many of the leading inhabitants of the neighbourhood*, in the schoolroom at Nacton on 28 December 1883. *The Ipswich Journal* (1885, 1886, 1888) recounts him declaiming Dickens's *Eatanswill Election* at a *sumptuous supper* of the Nacton Night School on 09 April 1885 to mark the end of the winter academic session; judging the handwriting competition during a visit by some 200 pupils of Nacton and Levington Day Schools to Orwell Park on 04 August 1886; and, on 20 April 1888, presiding over the annual supper of the Nacton Night School and distributing certificates.
- On 08 September 1885, Plummer (1885c) informed readers of the *Evening Star* about a new star, or *nova*, found near the centre of the Andromeda Nebula. The nova was discovered by Dr. Hartwig at Dorpat on 31 August, and Plummer had observed it from Orwell Park on 04 and 05 September, describing it *as a sharply-defined star rather brighter than the 8th magnitude, and is not increasing in lustre.* Although astronomers of the era had been unable to resolve the Nebula, they suspected that it was a dense cluster of stars, as its spectrum was not consistent with that of a gaseous nebula. Plummer believed that the new star was likely to be visible only temporarily, like novae which had erupted in Corona Borealis in 1866 and Cygnus in 1876. The latest nova appeared different spectroscopically to the two earlier ones, and time and further observations would be required to deduce its true character and its relationship with the Nebula. Nowadays the object (catalogued as S And or SN1885A), is designated a

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[110] By 1875, local time was but a distant memory throughout almost the entirety of the UK. Some 20 years earlier, the spread of the railways had brought with it the widespread adoption of Greenwich Time.

supernova. Its apparent brightness led astronomers at the time to conclude (erroneously) that the Andromeda Nebula could not be very distant, and was not separate from the Milky Way.

- An article by W. Mattieu Williams (1887) in the Science Notes section of *The Gentleman's Magazine* concerned the calendar and a supposed change in the seasons. The transition in 1751-52 from Old Style (OS) to New Style (NS) calendar moved the start of the year from 25 March to 01 January, and struck out 11 days, so that Wednesday 02 September 1752 was followed by Thursday 14 September. Thus, dates and traditions concerning the seasons had all been moved back by 11 days; the seasons had, in fact, changed. (Williams went on to describe the rationale for the change, and details of when a year is a leap year). The *EADT* (1887c) reported Williams' article, none too accurately. Anglicising his name to Mr. Matthew Williams, the paper described the article as *very reasonable* and illustrated the point with two examples: a poet from former times referring to May Day (OS) was in fact referring to 12 May (NS) and Charles II, who was said to have hidden in an oak tree on 29 May (OS), did so on 09 June (NS). Exhibiting some extraordinarily muddled thinking, the *EADT* claimed that, in the Eastern Counties, the seasons were *quite a month behind*, due to the change to the calendar and attempted to bridge the gap between a lag of 11 days and a month by proposing to allow poets from before 1751 a fortnight's grace to bring their descriptions of the seasons into alignment with experience in the late 1880s. Plummer (1887f) responded two days later in the *EADT*, very charitably complaining that its reporting had been not incorrect, but inexact. The OS (Julian) calendar, he explained, was slightly in error, resulting in the seasons gaining almost one day each century. The gain from the time of the Council of Nicaea (325 AD), when the calendar was defined, until 1752, was 11 days. In 1752 the calendar and seasons were brought into alignment once more and the calendar was adjusted to fit accurately the length of the year. Thus, the maximum error in the calendar was 11 days and, at dates between the Council of Nicaea and 1752, the error was correspondingly less. In the mid-seventeenth century, at the time of Charles II and the oak tree, the error was 10 days, and the date of the incident NS was 08 June rather than 09 June. In the time from the beginning of 1800 to 1887, the seasons had advanced by approximately ¾ of a day. Therefore, he concluded, one week, not a fortnight, was all that could be allowed for the difference of calendar between the era of Chaucer and 1887. Four days later, another correspondent to the *EADT*, "A. C. P." (1887), had the last word. He responded to Plummer's reference to the date of Charles and the oak tree as 29 May (OS) / 08 June (NS). A. C. P. referred Plummer to Hume's *History of England*, to remind him that the incident followed the battle of Worcester, on 03 September 1651. The date itself, not a change to the calendar, accounted for the tree having sufficient leaf to hide the King! The date of 29 May 1660 was when, according to tradition, Charles returned to London, the event marked by loyalists wearing oak badges in memory of his escape nine years previously.

A18.5 *The Gentleman's Magazine*, Flat Earth

In 1876, Plummer joined in correspondence in *the Gentleman's Magazine* with John Hampden (1819-91), a fervent believer in a flat Earth. *The Ipswich Journal* (1876b), *EADT* (1876b, 1876c) and *The Essex Standard* (1876), reported briefly on the correspondence.

The dialogue began calmly enough in the July 1876 edition of the *Magazine* when *Sylvanus Urban, Gentleman* (1876a), pseudonym of the editor, remarked on a rant by Hampden in the June edition of *Terra Firma*, his main organ of publicity, against the numerous schoolmasters, professors, military officers and others who, in his view, were not competent to discuss the figure of the Earth. To be sure of provoking a vehement response from Hampden, well known for his fierce letters, Urban questioned how he could explain, in terms of a flat Earth, a ship circumnavigating the globe and arriving back at its starting point, and concluded by casting aspersions on Hampden's use of *vigorous* language rather than engagement with the arguments of his critics.

The tactic did not fail and, in the following month's edition, Urban (1876b) provided an update on the dialogue. Hampden had taken the bait, ignored the question of circumnavigation of the globe, and instead delivered some choice insults: *Pray do not expose yourself and your want of common sense…*, *…I have now but a set of dastardly cowards to deal with…* Hampden had sent Urban a pamphlet addressing the fact, often taken as proof that the Earth is a sphere, that a ship sailing out to sea appears to an observer remaining on land to disappear from the hull upwards. The pamphlet offered an explanation that a law of eyesight caused the surface of the Earth and the sea to appear to rise to the level of sight!

The following month, Urban (1876c) provided news of further exchanges. Hampden had written a further long and vehement letter, denying that the longest circuit around the Earth was in the tropics, asserting instead that it lay in the polar regions, and explaining the disappearance from the hull upwards of a ship leaving port as follows: *The vessel and the immediate water in which it floats disappears not from an actual but an artificial rise (not curve) of the water.* Hampden lashed out at *The Gentleman's Magazine* and other publications of similar ilk, arguing that until the matter of the flat Earth could be resolved finally and incontrovertibly, it was *wicked* for the *Magazine* to fill the heads of its readers, *ignorant boobies*, with *silly tales*.

Correspondence lapsed for the following month then the November edition carried a letter by Plummer (1876h), clearly determined to add fuel to the flames. He recounted the tale of a contractor who had excavated a canal three km long, within 16 km of Nacton, digging out the floor until it was flat, only to find that although the canal was at the correct depth at its ends, everywhere else it was too deep, the discrepancy rising to some 200 mm at the centre. The cause was failure to consider the curvature of the Earth. As the excess excavation incurred considerable unnecessary expense, he queried whether Hampden was prepared to compensate the contractor for adopting the flat Earth approach. Urban expressed confidence that Hampden would respond to Plummer and enquired how the contractor had cut a canal three km long with a flat bed, without following the curvature of the Earth.

Urban (1876d) reported further developments the following month. As expected, Hampden had responded to Plummer, promising to pay him £50 if he could *prove that there is one truthful statement in his letter…* and, in correspondence directly with Plummer, offered a further wager of £100 if he could show a curve of 10 cm in 32 km on the Bedford Canal in Norfolk. Plummer declined the wagers: *I must confess these offers are exceedingly tempting; it is seldom one has the chance of so easily pocketing so considerable a sum. Unfortunately there is one point that makes me hesitate. I have simply expressed a contrary belief to that so well known as being entertained by Mr. Hampden, and he at once politely charges me with presumption, insanity, and falsehood, as well as with a deliberate attempt to impose upon the credulity of the public and of "Cockney Editors." Could I withstand the brunt of his terrible wrath if I were to become the fortunate possessor of his £150?* Plummer also explained to Urban how he believed a canal could be cut with a perfectly straight bed: in essence, staves were set at the ends of the canal and a level sight used from the top of one stave to the top of the other to define the tops of points from which rods could be fixed into the ground to indicate the appropriate depth of the canal.

Another correspondent, Samuel T. Robinson, criticised Plummer's choice of terminology. He argued that if the contractor set a pole at the mid-point of the canal and cut the canal towards each end so that the bed was perpendicular to the pole, then the depth at the middle would indeed be 200 mm greater than that at the ends. But the term "level" could not then be applied to the bed, as a spirit level placed anywhere on the bed other than at the mid-point would show an incline towards the ends. In the case of the Earth, the terms *flat* and *round* ought to be used synonymously. Urban branded Robinson a *humourist in philology*, but his interest was evidently piqued by the notion, and he pondered whether, in ordinary daily usage, a level surface corresponded to a Euclidian plane, or to the curved surface of the Earth. The correspondence then ended.

A18.6 Hong Kong Press, Reports Of Alleged Poisoning

While Plummer was based in Hong Kong, on 29 December 1891, his cook and table boy were brought before magistrates on a charge of attempted poisoning. The alleged crime had taken place on Boxing Day. Local press reports of the case are reproduced below. (The reports adopt differing anglicisation of the names of the accused.) The case was remanded for a week, but appears to have been subsequently abandoned, as no later press reports have been located.

***China Mail* (1891)**

ALLEGED ATTEMPTED POISONING

At the Magistracy this morning two Chinese, Pun-To, cook, and Chan Sing, table boy, were brought before Mr. Wise on a charge of attempt to poison.

From the evidence of Mr. Plummer, chief assistant, Kowloon Observatory, it appeared that he and his wife went out on Saturday evening last to dine with some friends, leaving their daughter and son at home. At half-past seven, dinner was served to Miss Plummer and her brother. About five minutes after partaking of some soup they both turned ill, but subsequently recovered. Witness handed in a can containing a portion of the soup. There was a house-coolie in the place at the time, but the cook's mate was away all day. A good deal of complaints had been made against the prisoners.

Beatrice Plummer stated that she was dining at home with her brother last Saturday. They dined about half-past seven. They had some soup and felt ill five minutes afterwards. She noticed nothing unusual in the taste of the soup. Neither of them had taken anything after the soup when they began to feel unwell. They had tea about five o'clock. The soup produced in Court was a portion of the soup of which they had partaken. She had not personally had any trouble with the servants. It was the table boy who served the soup. The quantity of soup was less than was usually served up. She said she wanted some more and he refused to give it to her. Her brother was suffering from cold and was served with his soup in another room, and she afterwards learned that he had also turned ill after taking some soup.

John Plummer, brother of the previous witness, gave corroborative evidence. He stated that he had never been threatened by either of the prisoners. About a week ago, he heard a conversation about something that could not be done that night. He did not see the parties who were speaking, but believed he recognised the voice of the cook.

Sergeant Harkin produced a packet containing some powder which he had found in an unused fireplace in the house.

The accused were remanded.

***Hong Kong Daily Press* (1891)**

POLICE COURT, 29 DECEMBER, BEFORE MR. A G WISE

ATTEMPT TO POISON A FAMILY

Pun Ato, a cook and Chan Asing, a house boy, servants in the employ of Mr. J. I. Plummer, chief assistant at the Observatory, were charged with administering poison or some destructive or noxious thing to the children of complainant on December 26th with intent to do them grievous bodily harm.

John Isaac Plummer said that on the evening in question, dinner was provided for the family as usual at his house in Kowloon. Only two of his children partook. He was absent at the time, but when he returned he found that both children had been very ill, and they attributed it to the soup which they had just had. They were very sick. The soup was preserved. He produced it in Court.

Miss Beatrice Plummer said that she dined at half-past seven on the 26th. She noticed nothing in the taste of the soup, but immediately she had taken it she felt ill. She was perfectly well when she sat down at the table. The second defendant served her with the soup and refused to bring a second supply.

John Plummer, junior, said that owing to a cold which he was suffering from he took his dinner in the adjoining room. He had a little soup and was immediately sick. He had had nothing between tiffin and dinner and did not have anything after the soup before feeling ill. Beyond the cold he was perfectly well.

John Plummer, recalled, said that about a week ago he overheard a conversation between some of his servants and understood one of them to say, "It cannot be done."

The case was remanded for a week.

***Hong Kong Telegraph* (1891)**

At the Magistracy to-day a Chinese cook and house boy were charged with administering poison, with intent to do grievous hurt, to the son and daughter of a highly respected resident of Kowloon, on Boxing Day. According to the evidence, the master and mistress of the house were away at dinner; and when the soup was brought in, both the young people were at once affected by it, and seized with vomiting. A sample of the soup has been sent up for analysis. The servants in that house have always been troublesome. It is not yet certain, however, that the sickness was not the result of the previous day's mortal gorge; and evidence certainly ought to be called as to whether the old man had, before going out, locked up the whisky. The case was remanded to the 6th prox.

A18.7 Hong Kong Press, Obituaries

Plummer's obituaries appeared in three English-language newspapers in Hong Kong: the *South China Morning Pos*t, *Hong Kong Telegraph* and *Hong Kong Daily Press*. The latter two are reproduced below.

***Hong Kong Daily Press* (1925)**

OBITUARY.

Mr. JOHN ISAAC PLUMMER.

A cable reached the Colony from London on Saturday announcing the death of Mr. John Isaac Plummer, MA, who, for twenty years, was Chief Assistant at the Royal Observatory in Hongkong. The deceased gentleman was the father of Mr. J. A. Plummer, Managing Director of Messrs. Bradley and Co., Ltd., Hongkong, and of Mrs. Frank Smyth, who is now residing at Oxted, Surrey.

The late Mr. Plummer retired from Government service in Hongkong in 1911. He was born on February 5th, 1845, and was thus just eighty years of age at the time of his death. He was MA of Durham University. Before coming to Hongkong in 1891 he had held appointments as Chief Assistant at Glasgow Observatory (1863); Observer, Durham Observatory (1867); Astronomer, Orwell Park Observatory (1874); and was with a Government Astronomical Expedition to Bermuda in 1882. From 1874 he had been a Fellow of the Royal Astronomical Society. He was Chief Assistant at the Observatory here under Dr. Doberck, who retired in 1907, and who is still on the Colony's pension list, and later under Mr. F. G. Figg, who died some few years ago.

The late Mr. Plummer was the author of various astronomical papers, including an "Introduction to Astronomy" published in London in 1873. We recollect that shortly before his retirement he delivered an interesting public lecture in the Colony on "The Origin of Typhoons," which he subsequently elaborated and published. In this valuable little treatise Mr. Plummer advanced the theory that the earliest beginnings of typhoons must be sought for on land and not at sea. The great currents which have their birthplace in the Sahara, the central parts of Asia, the plateau of Mexico, and perhaps in the interior of Northern Australia, he wrote, must not be neglected in the meteorology of the world because they are aerial, and are not felt on the surface. They must, he declared, reach the sea level at some time and place, and then produce results comparable with the intensity of the forces to which they owe their existence. He affirmed that one typhoon is never the cause of another, and that if a succession of them is seen to proceed from one limited area at intervals of a few days, as it is well known they are very apt to do, they are caused by separate impulses impressed on a permanent if slowly moving zone which he called the meteorological equator of the globe. He was, we fear, looking very far into the future when he wrote that "once the actual condition of the whole world becomes thoroughly known there will be no difficulty in understanding the origin and mode of working of these devastating storms, and although it sounds more like a dream than a sober anticipation of science, so to turn the superabundant energy of the sun to beneficial account to mankind, that even such unruly disturbances may become more suave and gentle in their operation."

***Hong Kong Telegraph* (1925)**

OBITUARY.

MR. J. I. PLUMMER.

As we go to press, news reaches us of the death of Mr. John I. Plummer, MA, former Chief Assistant of the Hongkong Observatory, which occurred in London yesterday at the age of 80 years.

The late Mr. Plummer was for many years on the Observatory staff and retired on pension in 1911. He made many friends here, who will hear with much regret of his death. Mr. J. A. Plummer, head of Messrs. Bradley and Co., is a son of the deceased, and much sympathy will be felt with him in his bereavement.

A19 Minute Books Of Ipswich Science Gossip Society / Ipswich Scientific Society

In 1874, a visit by members of Ipswich Science Gossip Society (later known as Ipswich Scientific Society) to Orwell Park marked the start of an association between the Society and Plummer which lasted throughout the latter's time in the region. The Society's minute books (Ipswich Scientific Society, 1884, 1903) provide details as follows.

- On 11 July 1874, members of the Society visited Orwell Park, where they were introduced to Plummer. At the following annual meeting of the Society, on 06 January 1875, the Secretary described the visit as follows:

  > *On Saturday afternoon 11 July an excursion was made to Orwell Park, permission having been courteously given by Col. Tomline's reply to the Sec'tys application. The members inspected the grounds and choice collection of pictures and works of Art, and the Observatory, and were introduced to Mr J J Plummer, MA, the resident astronomer, who took them over the Observatory and showed and explained the magnificent telescope lately erected there under the superintendence of Mr Airy, son of Sir G B Airy. Refreshments were obtained at the "Anchor" Inn, Nacton. The journey was performed in two "breaks" from [text unclear] (Brook St, Ips) and 26 members attended. In point of numbers this was the most successful excursion during the existence of the Society....*

- On 02 December 1874, Plummer gave "lecturettes" on the *Cometary Syst*em at the fifth annual *conversazione* of the Society. (See appendix 18.2.1.)
- He became a member of the Society on 07 March 1877.
- He is listed as attending a meeting held on 02 May 1877.
- At a meeting on 05 June 1878 held at Ipswich Museum, he presented a paper on the *Aurora Borealis*. (See appendix 18.2.5.) The paper was among several eagerly anticipated by the local press earlier in the year (*EADT*, 1878b; *The Ipswich Journal*, 1878b).
- On 07 January 1880, he was made an honorary member of the Society.
- At the monthly meeting on 03 March 1980, he lectured on *Meteors*. (See appendix 18.2.6.)
- At a meeting on 02 February 1881, he described a display of the aurora borealis which he had witnessed from Nacton at 6.30pm on 31 January of the year. Unfortunately, the minute book does not record his description, nor did he report his observation in the scientific literature, other than a passing reference to it in his observing report of Comet Pechüle (C/1880 Y1) (see Appendix 5). The *Ipswich Journal* (1881b) described the display as follows: *January 31, a very fine evening, and after 6pm a rich display of the Aurora Borealis in fine variety of colours; some darted up to the zenith in defined columns, while rose-coloured flashings flickered between them*. Other observers reported the phenomenon (Backhouse, 1881b; Brown, 1881; Capron, 1881; Dennett, 1881; Johnson, 1881; Terby, 1881g): the display was most impressive, lasting for some three hours, with multiple arches and streamers, several observers reporting various colours.
- At a meeting held at Ipswich Museum on 06 April 1881, Plummer exhibited a drawing of a section of a meteorite.
- At the monthly meeting in Ipswich Art Gallery on 03 April 1889, Rev Ledger gave a lecture on *Celestial Photography* accompanied by a *splendid* series of transparencies. Members of the Society were invited to introduce their friends, 300 tickets were issued, and the meeting was very well attended. *The Ipswich Journal* (1889b) listed the photographs displayed by Ledger on a screen as: the Sun, with sunspots and prominences, the eclipsed sun showing the corona and an approaching comet, the Moon, Jupiter, comets, star fields, the Orion Nebula and the great nebula in Andromeda. The report conveys something of the sense of awe that the audience must have felt on seeing the images! At the conclusion of the meeting, Plummer proposed the vote of thanks.

- At the monthly meeting held on 08 October 1890, Plummer made some remarks on the newly-formed British Astronomical Society[111], and suggested that members of the Ipswich Scientific Society consider joining.
- At the monthly meeting held on 03 December 1890 at Ipswich Museum, Plummer read a paper on *Stellar Parallax and Stellar Motion*. (See appendix 18.2.7.) The minute book notes that, during a subsequent discussion, members acting on the advice of the Chairman made the most of Plummer's presence by asking many questions; no doubt the Chairman's advice referred to the fact that Plummer was soon to depart for Hong Kong.

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[111] At the first general meeting of the British Astronomical Society on 24 October 1890, members adopted the description *Association* rather than *Society*.

A20 Statement For The Vacant Post Of Chief Assistant At Hong Kong Observatory

8 Constitution Hill, Ipswich
January 10th, 1891

To the Astronomer Royal.

Sir,

In view of the probable appointment of a chief assistant astronomer at Hong Kong, for which I shall be glad to be a candidate, I have the honour of furnishing you with the following particulars of my scientific career.

I have been engaged in astronomical work in various observatories (including Greenwich) but principally in those of Durham University and Orwell Park.

I was appointed Observer to the University of Durham in 1867. I communicated from thence various papers to the "Monthly Notices of the Royal Astronomical Society", including some on spectroscopy, meteorology, and double image micrometrical work; as well as numerous observations of Minor Planets and of Comets to the "Astronomische Nachrichten".

In the year 1874 the University conferred on me the honorary degree of Master of Arts in recognition of my services.

I have for 16 years past been astronomer at Orwell Park. From thence I have communicated a great mass of observations of Comets to either the "Astronomische Nachrichten" or the "Monthly Notices"; no comet observable in northern latitudes being allowed to pass unobserved at Orwell: as well as papers on miscellaneous points as they have arisen. These include some early experiments in photometry, &c. The deficiency of astronomical equipment at this private establishment, and the total want of a library has always and considerably crippled the work which might otherwise have been done there.

In 1882 I was entrusted with the command of the Government expedition to Bermuda to observe the Transit of Venus and to determine the longitude of those islands. These operations were entirely successful, and were carried out to the satisfaction of the Director of the Commission.

I have recently given attention to photography in view of its increasing use in astronomy, but have not yet had the opportunity of applying this knowledge practically beyond taking photographs of the Moon with an ordinary 10 inch astronomical telescope.

I am 45 years of age, and am married with family (3). I have been a Fellow of the Royal Astronomical Society since 1876. I am the author of an elementary handbook on astronomy (published by Collins) and of numerous papers on popular science in various periodicals.

I have the honour to be,
Sir,
Your very obedient servant
John I. Plummer.

A21 Calibrating The Hong Kong Transit Telescope

During 1896-97, Doberck used Talcott's method to estimate the latitude of Hong Kong Observatory (see section 2.7). He based the estimate on the analysis of 1866 measurements of stellar zenith distances, made with the transit telescope, most by Plummer. Key to the data reduction were accurate knowledge of the amount by which one turn of the micrometer screw moved the wire of the eyepiece, referred to as the value of the screw revolution, and the deviation from horizontal of the transit instrument (Doberck, 1898a). Doberck's approach was very rigorous and included a comprehensive calibration of the instrument to determine these parameters.

He first established that transits could be used to estimate the value of the screw revolution with an accuracy that was virtually independent of the declination of the star concerned. He then arranged for Plummer to take, throughout the observations of zenith distances, a series of transit observations, one set of observations each month on average, each consisting of ten transits over 20 revolutions of the screw, for the purposes of estimating the value of the screw revolution. Not content with an average value, during March-April 1897, he made further observations to determine periodic errors. He used an observing target comprising two black dots on a piece of white paper positioned on the north collimator of the transit instrument. (From the observatory, the dots had an apparent separation of approximately 4".) Using the target, he was able to determine a correction for each segment of four revolutions of the screw, and to determine the range within which the micrometer retained acceptable accuracy. (He found the latter to be from 25 revolutions of the screw to 55; at lower revolutions, a spring became too relaxed, and at higher revolutions, too compressed, affecting the accuracy of positioning the wire.) Using further observing targets at the north collimator, he was able to estimate periodic errors of the screw for every one-tenth of a revolution. Collating all the estimates, he derived correction factors for the value of the screw revolution based on a mean value of 60.5191" ±0.0043" plus trigonometric terms with minute coefficients (measured in milli-arcseconds).

To estimate the deviation from horizontal of the transit telescope, he calibrated the level fitted to the instrument against the rotation of the micrometer eyepiece. This he did by sighting the instrument on the north collimator and adjusting the level screw, noting the reading on the level, then determining the eyepiece rotation necessary to restore the wire to the vertical. By repeating this procedure many times, he obtained the relationship between the reading on the level and the deviation from horizontal in arcseconds.

A22 Micrometers

Plummer reported using four types of micrometer: parallel wire, dark bar, ring and Airy double image. He used all four types at Durham Observatory; all except the Airy double image at Orwell Park; and a parallel wire model at Hong Kong. The following description of micrometers is drawn from King (1955) and Sidgwick (1979). For purposes of exposition, suppose that the observer is measuring the angular separation between a comet and a comparison star; figure 45 illustrates an idealised view through the eyepiece.

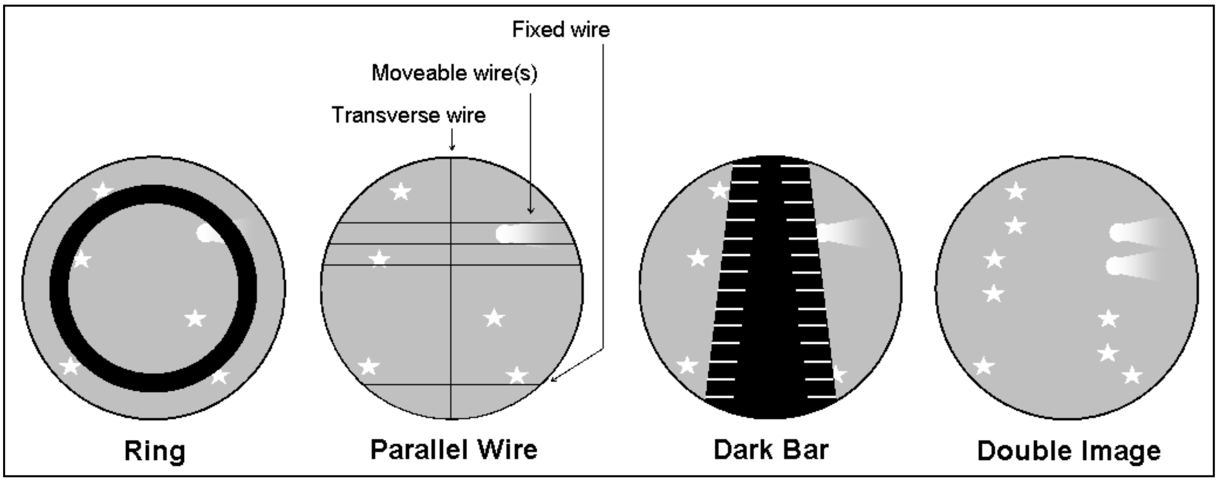

Figure 45. Idealised view through micrometer eyepieces.

Ring

The ring micrometer consists of a narrow, flat, opaque ring mounted at the focus of the objective glass. The advantages of the instrument are that it is simple to construct, no field illumination is required and it works with any form of telescope mounting. However, it requires preliminary calibration prior to use and a relatively complicated reduction of results. It operates with the telescope undriven; the observer positions the telescope ahead of the reference star and comet and records the times at which both objects transit the ring. For greatest accuracy, he records times of transiting both the inner and outer edges of the ring. Subsequent reduction of the transit times yields the difference in position between the comet and the reference star.

Plummer used ring micrometers with a variety of diameters: 806.26", 932.500", 1234.136", 1878.4" plus unspecified others. When he specified the diameter of the ring, he gave only one measurement, implying that he used only one edge of the ring and eschewed the potentially improved accuracy that could be obtained by using both.

Parallel Wire

This consists of several parallel wires, one fixed and one or more adjustable, placed at the focus of the objective glass. (The number of adjustable wires is always odd.) A calibrated screw determines the position of the adjustable wire(s). The micrometer may be rotated about the optical axis, its orientation being indicated by an engraved position circle. Many instruments also have a transverse wire, perpendicular to the parallel wires; indeed some variants provide several transverse wires, one or more being adjustable. Advantages of the parallel wire micrometer are its accuracy; its main disadvantage is cost. The instrument operates with the telescope tracking the comparison star. The observer adjusts the position of the telescope such that the comparison star lies on the fixed wire. He then adjusts the moveable wire to centre it on the comet and reads the displacement from the calibrated screw.

Dark Bar

This consists of a wedge-shaped, graduated bar mounted at the focus of the objective glass. The observer first calibrates the instrument by measuring the time taken by a star to transit the bar, at various elevations above its base, with the telescope undriven. The instrument operates with the telescope tracking the objects concerned. The observer moves the bar until its width spans the gap between the comparison star and comet, then reads from the graduations the width of the bar, enabling calculation of the angular separation of the objects.

Airy Double-Image

The Airy double-mage micrometer (Airy, 1845) uses a divided lens to produce two images of the field of view. The observer can rotate a threaded screw to move the components of the divided lens relative to one another: this causes the two images to move relative to one another. Let S and C be the images of the comparison star and comet respectively produced by one half of the divided lens and let S' and C' be the corresponding images produced by the other half. To estimate the angular separation of the objects, the observer rotates the micrometer such that the line S-C is aligned with the line S'-C' and then turns the threaded screw until C and S' overlap; the separation can then be read from graduations on the threaded screw. The instrument has the advantage that there are no wires to be illuminated or to cause diffraction effects. However, even if the segments of the divided lens are cut with great care, there is always roughness around the edges that causes diffraction effects, making it impossible to combine the images perfectly. Despite these problems, the double-image micrometer produces marginally more accurate measures of separation than the parallel wire micrometer.

Accuracy Of Use Of The Airy Double-Image Micrometer

Plummer's (1879c) observing notes provide an insight into the accuracy of measurements made with the Airy double-image micrometer. During 14 March 1868 – 17 June 1870, he used the instrument to make three observations of the star γ Andromedae and one each of the stars γ Leonis, γ Virginis, b^1 Ophiuchi, ζ Lyrae and Struve 1962. All the stars except b^1 Ophiuchi may be readily identified in modern star catalogues, and it is possible to use them as a means of estimating the accuracy of his use of the instrument. Table 23 lists, for each of the stars except b^1 Ophiuchi, the separation which he measured (the average separation in the case of γ Andromedae), a modern estimate of the separation at the epoch of his observation, and the basis upon which the modern estimate is derived.

Star	Measured Separation (")	Modern Est. of Separation (")	Source of Modern Estimate
γ And	10.6	9.8	Ridpath (1989). Displays *little change*.
γ Leo	3.4	3.2	Hartkopf and Mason (2010).
γ Vir	4.5	4.5	Hartkopf and Mason (2010).
ζ Lyr	42.9	43.7	Ridpath (1989). *Fixed*.
Struve 1962	12.2	12.0	Calculated from data in the Hipparcos catalogue. The stars are Hip76602 and Hip76603.

Table 23. Estimates of the separation of components of double stars.

Discounting the observation of ζ Lyrae, for which Plummer noted *Rather too wide for a satisfactory estimate*, the data indicates an average over-estimation by 0.29".

A23 Technical Matters

Nineteenth century astronomers used Greenwich Mean Astronomical Time (GMAT), which is Greenwich Mean Time counted from midday – it has the advantage for astronomical purposes of not involving a change of date in the middle of the night. However, astronomers nowadays do not use GMAT and therefore, for the convenience of modern readers, all times originally reported in GMAT are converted to GMT using the formula GMT = GMAT + 12^h. Note that this conversion advances some dates by one day. For example, the epoch of occultation disappearance of c Leonis reported by Plummer (appendix 2.1) as 13h 54m 23.9s (GMAT) on 16 December 1867 becomes 01h 54m 23.9s (GMT) on 17 December 1867.

In this work, GMT is equated to UT (Universal Time). This approach is not rigorously exact, but, given the inevitable problems with establishing a timing reference for observations made in Plummer's era, it is as accurate as can reasonably be achieved.

Theoretical calculations of the circumstances of astronomical events are based on the following reference material:

- Positions and motions of bodies in the solar system: the National Aeronautics and Space Administration Jet Propulsion Laboratories' reference ephemeris DE-405 (Standish *et al*, 1997).
- Positions and proper motions of stars: the European Space Agency's (1997) Hipparcos catalogue.
- Lunar limb profile (for calculation of the times of lunar occultations): International Occultation Timing Association's electronic limb data. This is an electronic version of limb profiles published by Watts (1963). Note that the profiles are of variable quality.
- Astronomical constants or values are taken where possible from Ridpath (1989) or Seidelmann (ed.) (1992) or from other sources specified.

In using the ephemeris DE-405 to calculate the circumstances of phenomena, it is necessary to specify the difference, denoted ΔT, at the time of observation, between Ephemeris Time, the uniform timescale employed by the ephemeris, and Universal Time, the variable timescale associated with the rotation of the Earth. In Plummer's era, ΔT ranged through a few seconds either side of zero. Table 24 lists the values of ΔT employed in the calculations, estimated by interpolation in the table of historical values by Meeus (1991).

Location	**Data**	**ΔT (seconds)**
Appendix 2.1, table 3	Lunar occultations, 1867-69	3.1 – 1.6
Appendix 2.2, table 4	Lunar occultations, 1869	2.2
Appendix 2.2, table 6	Lunar occultations, 1868-69	2.2
Appendix 3, table 8	Position of Mercury, 1868	2.4
Appendix 3, table 9	Position of Mercury, 1878	-4.8
Appendix 4.2, figure 22	Position of Venus, 1873	-2.1
Appendix 4.3, figures 23, 26, 27	Position of Venus, 1876	-3.9
Appendix 4.4, table 15	Transit of Venus, 1882	-5.4

Table 24. Values of ΔT.

Plummer and his contemporaries used imperial units in their publications. In this work, quantities are expressed in SI[112] units with the exception of quotations, in which original units are retained, and measurement of temperature, for which Fahrenheit is retained. To prevent spurious numbers of significant digits, except where precision is important, a degree of approximation is accepted in converting from imperial to SI units.

[112] Système international d'unités; informally the "metric system".

A24 Astronomer Relatives

A24.1 William Edward Plummer, FRAS

Plummer's younger brother (MNRAS, 1929) was William Edward Plummer, FRAS (1849-1928). Like his elder sibling, William was born in Deptford, and started from the bottom of the then astronomical career ladder by obtaining, at age 15, a position as a supernumerary computer at the nearby ROG. Such were William's talents that he received training on the Transit Instrument and qualified for occasional observing duties. In 1868, he left the ROG to become an assistant at George Bishop's private observatory at Twickenham.

At the time, John Russell Hind was superintendent of Bishop's observatory and, in later years, William would often say that the observing skills he possessed were due to the tutelage of Hind. William's work at Twickenham included cometary observations, orbit prediction and the charting of stars down to 11^{th} magnitude within three degrees of the ecliptic.

In late summer 1874 (almost the same date that his brother took up his post at Orwell Park), William was appointed First Assistant at Oxford University Observatory, working under Professor Pritchard. His work there included observation of satellites of Saturn, double stars, comets, photometric determination of the magnitude of stars visible to the naked eye, photographic measurement of stellar parallax and photographic investigation of the motion of Sirius B. In 1889, he received an honorary MA from Oxford University. He undertook much work in support of the *Astrographic Catalogue*. (Astronomers from around the world had agreed, at a meeting in Paris in April 1887, to create the *Catalogue* as a photographic atlas of the sky complete to magnitude 11.) William represented Professor Pritchard at a conference on the *Catalogue* in Paris, in 1891, when the latter's ill health prevented him from attending.

In 1892, William was appointed Director of Liverpool Observatory at Bidston. He remained in this post until his death in 1928. He utilised Bidston's 200 mm refractor for cometary work and the transit instrument for the determination of positions of circumpolar stars. He also maintained a time service, rated and issued chronometers and undertook meteorological observations.

Figure 46 reproduces a photograph, kindly provided by Richard Bellamy-Brown, which may be of William and his wife.

Figure 46. Possibly William Edward Plummer, FRAS and his wife. (Courtesy of Richard Bellamy-Brown.)

A24.2 Henry Crozier Plummer, FRS, FRAS

William Edward Plummer's son (Smart, 1947) was Henry Crozier Plummer, FRS, FRAS (1875-1946). Henry was born at Oxford and educated at St. Edward's School and Hertford College. He studied physics and mathematics, excelling in the latter. In 1899, he was appointed Lecturer in Mathematics at Owen's College, Manchester. In 1900, he was appointed Assistant at the Oxford University Observatory (where his father had served with distinction) staying there for the next 12 years.

At Oxford, he worked on numerous questions surrounding the *Astrographic Catalogue* (to which his father had contributed). He also turned his attention to occultations, binary star orbits, cometary orbits, the theory of planetary and satellite orbits, instrumentation and the accuracy of naked eye observations of meteors. He was able to bring great mathematical ability to the subjects that he investigated. He took a year out from Oxford as a Fellow at Lick Observatory on Mount Hamilton, California, where he studied the rapidly expanding discipline of spectroscopy and developments of the science at American observatories.

In 1912, Henry was appointed Royal Astronomer for Ireland and Andrews Professor of Astronomy at Trinity College, Dublin. Working at Dunsink Observatory with the 380 mm reflector, he began a long programme of photometric observations of short-period variable stars and analysis of their light curves. In 1918, he published the book *An Introduction to Dynamical Astronomy*; it remains a standard work on the subject. His papers published at Dunsink included work on radial pulsations of Cepheid stars, work that would later be built upon by Harlow Shapley and Sir Arthur Eddington. However, against the background of the Irish struggle for independence, he retreated into an almost hermit-like existence at the observatory.

In 1921, he was appointed Professor of Mathematics at the Military College of Science at Woolwich, remaining there until his retirement in 1940. In the congenial atmosphere of the Military College, more suited to his quiet manner, he went on to publish further mathematical books and papers. He was well known for his study of the history of science and he worked on the Committee of the Royal Society formed to publish Newton's papers. He also researched Edmund Halley and presented the Halley Lecture in Oxford in 1942. He was elected a Fellow of the Royal Society in 1920 and served as President of the RAS from 1939 to 1940.

Figure 47, reproduced by kind permission of the RAS, shows the Society’s presidential portrait of Henry.

Figure 47. RAS presidential portrait of Henry Crozier Plummer, FRS, FRAS. (Courtesy of the RAS.)

A25 Visit By Great-Grandson To Orwell Park Observatory

In late 2004, Richard Bellamy-Brown, John Isaac Plummer’s great-grandson, while researching his family history on the Internet, discovered the OASI website and the Society's interest in Plummer. On 18 September 2004, he contacted the Society; chairman Ken Goward, FRAS, responded, inviting him to visit Orwell Park Observatory. On 20 December 2004, he did so and Ken, together with OASI members Garry Coleman and Paul Whiting, took great delight in showing him the observatory and explaining his family ties to it. Richard kindly posed at the eyepiece of the equatorial refractor (nowadays known as the Tomline Refractor) and the transit instrument, recreating scenes from more than a century previously. Luckily, the sky was clear and Richard was impressed with an *ad hoc* solar projection using the Tomline Refractor, which revealed a large sunspot group on the Sun's disk. Following a brief meeting with Andrew Auster, Headmaster of Orwell Park School, and a photo-stop at *Orwell Dene*, the party retired to the *Shepherd & Dog Carvery* for lunch after which Richard took his leave. At the OASI AGM on 15 January 2005, Richard was elected an honorary member of the Society. Figure 48 shows Richard at the eyepiece of the Tomline Refractor.

Figure 48. Richard Bellamy-Brown at the eyepiece of the Tomline Refractor, 20 December 2004. (Ken Goward, 2005.)

A26 Observations By Dolman At Durham

Table 25 summarises Dolman's published observations.

Body	Discovered	Dates Of Observation	Reference(s)
(20) Massalia	19 Sep 1852	14 Feb – 03 Mar 1865	Dolman, 1865b
(51) Nemqusa	22 Jan 1858	14-25 Feb 1865	Dolman, 1865b
(16) Hygiea	12 Apr 1849	15 Feb 1865	Dolman, 1865b
(48) Doris	19 Sep 1857	20 Feb 1865	Dolman, 1865b
(64) Angelina	04 Mar 1861	20-26 Feb 1865	Dolman, 1865b
(84) Klio	25 Aug 1865	10 Sep – 21 Oct 1865	Dolman, 1865c, 1865d, 1865e
(85) Io	19 Sep 1865	25 Oct – 24 Nov 1865	Dolman, 1865e, 1865f, 1866
(88) Thisbe	15 Jun 1866	03 Aug – 03 Sep 1866	Dolman, 1867a
Comet I 1867 (38P/ Stephan-Oterma)	27 Jan 1867	06–08 Feb 1867	Dolman, 1867b

Table 25. Dolman's observations at Durham

In the mid-1860s, a new asteroid was being discovered every few months or so. The German astronomer Karl Theodor Robert Luther (1822-1900) discovered (84) Klio (on discovery known as Clio), the German-American astronomer Christian Heinrich Friedrich Peters (1813–1890) discovered (85) Io and (88) Thisbe and the French astronomer Édouard Jean-Marie Stephan (1837–1923) discovered Comet I 1867. Dolman began observations of the four bodies shortly after their respective discoveries, when his results would be of most value in facilitating calculation of accurate orbits.

Amusingly, in a report of the discovery of (86) Semele, *The Advertiser* (1866) incorrectly credited Dolman with discovery of the immediately preceding asteroid, (85) Io!

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