NORMAN ROBERT POGSON AND OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF 1868 FROM MASULIPATAM, INDIA

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Abstract: Norman Pogson's observations of the 1868 total solar eclipse were significant in many respects. He not only distinguished the helium emission line from the Fraunhofer sodium D line, but also discovered the FeXIV green line. Until recently, he was never properly credited with these discoveries by historians of astronomy.

In this paper, we discuss in detail the observations made by Pogson and his small team at Masulipatam, after describing the background of their preparation for the expedition. We also describe how they were helped by some and sidelined by others, and how various factors led to the discoveries that they being hidden from colleagues. It was only with the publication of Nath's book *The Story of Helium and the Birth of Astrophysics* in 2013 that Pogson's achievements in 1868 became widely known and were able to take their rightful place in the annals of science.

Keywords: 1868 solar eclipse, India, Madras Observatory, Pogson, Masulipatam, spectroscopy, helium, iron green line

1 INTRODUCTION

The middle of the nineteenth century saw a gradual transition worldwide in the way scientific research was conducted, from the realm of the so-called 'gentlemen of science' to that of professional scientists. It was a slow process and in different countries it took different twists and turns (e.g. see Clerke, 1893). In India, particularly for astronomical studies, this evolution was accelerated by the singular event of the 1868 total solar eclipse (see Kochhar and Orchiston, 2017: 737–739). And the person whose role in this development has been somewhat understated in the annals of science is Norman Robert Pogson.

Pogson was the first Government Astronomer in India who had professional training as an astronomer. The previous appointees were mostly drawn from the East India Company Army personnel who had an interest in astronomical studies. For example, Major James Francis Tennant (1829–1915; Anonymous, 1915a; 1915b), who was the Government Astronomer before Pogson was appointed, served in the East India Company army, although he mostly worked with the Great Trigonometrical Survey of India, where he first picked up an interest in the workings of theodolites, and later on, in astronomy. The previous generation of Government Astronomers in India, therefore, were interested in astronomy out of self-interest and were mostly self-taught (Ansari, 1985; Kochhar, 1991). With the arrival of Pogson in India in 1861, a new era began in astronomical studies from colonial India.

Pogson's credentials as a professional astronomer were secured a few years before this, when he worked on a quantitative scheme of measuring the brightness of stars. When India was embroiled in the turmoil of the 1857 Sepoy Mutiny, Pogson worked at the Radcliffe Observatory in Oxford on a proper method of measuring stellar magnitudes (Jones, 1967). His method is still followed today by astronomers, a long-lasting legacy indeed (Hearnshaw, 1996).

But Pogson's career did not progress as smoothly as one would expect in retrospect, and his contributions to the study of the 1868 solar eclipse "… did not receive due credit because the Indian government authorized the printing of only three copies of his report." (Snedegar, 2014b: 1740). His story is rather curious in the history of science, and the history of 1868 eclipse will be incomplete without mentioning him.

2 THE EARLY LIFE OF NORMAN POGSON

Norman Robert Pogson (1829–1891; Figure 1) was born into a middle-class family in Nottingham, involved in manufacture of hosiery prod-

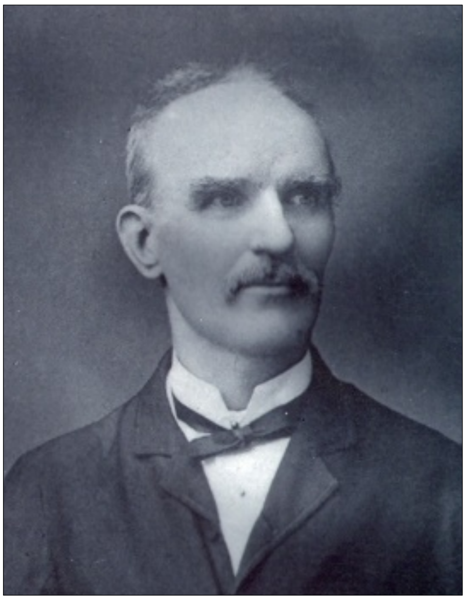

Figure 1: Norman Robert Pogson (courtesy: Indian Institute of Astrophysics Archives).

ucts. According to tradition, he would have continued the family business when he grew up. He was sent to a school to study commerce, but as a boy he was drawn to science (Snedegar, 2014b), but there was not much scope for scientific education in schools in mid-nineteenth century England. There was no clear-cut path to become a scientist. Interest in science mostly existed outside of educational institutions, and it was the age of 'gentlemen of science' who pursued scientific studies as a hobby (e.g. see Chapman, 1998; Stephens and Roderick, 1974; Timmons, 1996). Although it is not clear how young Pogson became interested in science, luckily for him, his mother knew about his passion and she encouraged him. It is said that she ensured his access to the works of local instrument-makers and opticians, so that young Norman would have hands-on experience with instruments (Snedegar, 2014b). When he was a teenager, his father moved to Manchester because of business commitments. There, Norman had the opportunity to take private lessons in trigonometry and other areas of mathematics. At sixteen, he began teaching mathematics to others.

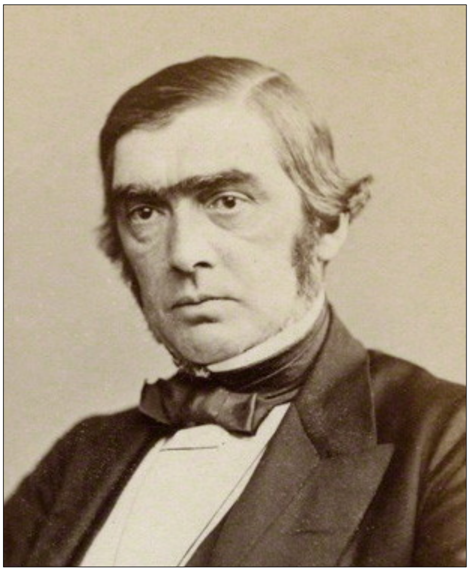

Figure 2: John Russell Hind (https://en.wikipedia.org/wiki/John_Russell_Hind#/media/File:John_Russell_Hind_-_1.jpg).

His life took a significant turn at this stage after a meeting with a lace manufacturer from Nottingham, John Hind, who had visited Manchester and was impressed by Pogson's mathematical skill. It happened that his son, John Russell Hind (1823–1895; Figure 2; Sheehan, 2014), was the Director of George Bishop's private South Villa Observatory in Regents Park, London. Russell Hind had earlier worked at the Royal Greenwich Observatory. John Hind suggested to Norman that he should go and meet his son and wrote a letter of introduction. This was early 1846, and Norman Pogson was on his way to becoming an astronomer.

Hind was working on asteroids, comets and variable stars. He started teaching Pogson the basics of positional astronomy. Pogson's first taste of research work came in the form of calculating the orbital elements of two comets (Pogson, 1847; 1848). The first of these papers was about Schweizer's Comet (C/1847 Q1 Schweizer), and this was published in the *Monthly Notices of Royal Astronomical Society* (*MNRAS*). At the time, Pogson was just eighteen years of age. That same year Hind had discovered an asteroid, named Iris, and Pogson (1849b) set about calculating its orbit. In the next two years, he provided an ephemeris for Goujon's Comet, C/1849 G2 (Pogson, 1849a) and calculated the orbits of another asteroid (Pogson, 1851a; 1851b) and a comet (Pogson, 1850). He also reported on observations of sunspots during the 28 July 1851 total solar eclipse (Pogson, 1852). His meticulousness impressed Hind and he offered Pogson the position of Assistant at the Observatory.

Soon, Pogson was married, and in 1851 he moved on to the Radcliffe Observatory in Oxford (Figure 3) as an Assistant (Snedegar, 2014b). There he worked with Manuel John Johnson (1805–1859; Snedegar 2014a), who was conducting pioneering research on the stellar magnitude scale at that time (e.g. see Johnson, 1853). While Johnson found that the ratio of two magnitudes was 2.43, Pogson suggested that a value of 2.512 would be con-

Figure 3: An 1834 lithograph of the Radcliffe Observatory at Oxford, from a painting by F. Mackenzie and engraved by John Le Keux (http://www.rareoldprints.com/p/22574).

venient, since the reciprocal of an often-invoked term 0.5 $\log_{10}$ (2.512) would be 5 (Jones, 1967). He mentioned this in one of his asteroid papers in 1856 (Pogson, 1856a), and within two decades, astronomers began to use this as the standard magnitude scale for their work. In the same year, he discovered an asteroid, and named it Isis, the middle name of his first daughter (Pogson, 1856b; 1856c; 1856d).

Despite his achievements at the Radcliffe Observatory Pogson had a difficult time working with Johnson, and started looking for other opportunities. He took up an offer from a private observatory, Hartwell House Observatory (Figure 4), to become the Director there (Snedegar, 2014b), and hoped that he ultimately would return to Radcliffe Observatory and a better position. Johnson died in 1860 and the post of Director became vacant. Pogson hoped that he would be offered the position, but in spite of a recommendation from Sir John Herschel (1792–1871) he did not get the job (the position went to Robert Main (1808–1878), who had a superior track record, having spent the previous 25 years as First Assistant at the Royal Observatory, Greenwich). It is believed that Pogson's lack of a degree from a prestigious university may have been an obstacle. George Biddell (later Sir George) Airy (1801–1892; Figure 5), the Astronomer Royal, did not view Pogson's candidacy favourably. According to Reddy et al. (2007: 237),

> Embittered by this reverse, Pogson learned that something of a glass ceiling existed in British astronomy, for without a university qualification—a Cambridge wrangler was Airy's ideal—the directorship of a public observatory was unlikely to be his.

This bit of history about Pogson's early career is important to keep in mind with regard to events that followed the 1868 solar eclipse, as we will see shortly. The relation with Airy was never going to be easy, and this ensured that Pogson's name would remain a footnote in the history of astronomy. The relation between professional astronomers and so-called amateurs, or self-taught astronomers, in the nineteenth and early twentieth centuries is an interesting facet of history (e.g. see Chapman, 1998; Hetherington, 1976; Lankford, 1981a; 1981b; 1979; Orchiston, 1998; 1999; 2015; 2016). Since the 1868 eclipse hastened the

Figure 4: A lithograph of Dr John Lee's Hartwell House and Observatory from William H. Smyth's *Aedes Hartwellianae*, 1851 (courtesy: Linda Hall Library of Science, Engineering & Technology).

development of astronomical research in India (and elsewhere) from amateurs to the arena of professionals, it would be worthwhile to examine this scenario more closely.

3 PROFESSIONALS AND AMATEURS IN ASTRONOMY

The introduction of spectroscopy in the study of astronomical objects in 1859, after the explanation of dark Fraunhofer lines by Kirchhoff and Bunsen, marked the end of the classical positional astronomy, which consisted of studying the positions of objects and events, and changes in their appearance (Hearnshaw, 1996). Spectroscopy transformed the skill set required for the new type of research—photography, chemistry, and above all an adventurous mind to delve into an uncharted territory. This suited a bunch of people who were self-taught, but were passionate about astronomy. Those who could afford, built their own observatories for this purpose.

Figure 5: George Biddell Airy (en.wikipedia.org/wiki/George_Biddell_Airy#/media/File:George_Biddell_Airy2.jpg

William (later Sir William) Huggins (1824–1910; Figure 6; Becker, 2011) was a silk merchant who built his Tulse Hill Observatory in his house in London and did pioneering research on stellar spectroscopy, along with his wife Margaret Lindsay Huggins, later Dame Margaret (1848–1915). Joseph Norman Lockyer (1836–1920; Meadows, 1972), who worked at the War Office in London, and picked up an interest in astronomy after moving to Wimbledon where he had a neighbour with a telescope, was also a self-taught astronomer. Naturally, there arose a territorial tussle between these 'rising stars' in the new fields of astronomical spectroscopy and photography and the professionals in old-fashioned observatories. Even as late as 1886, Russia's Otto Wilhelm von Struve (1819–1905; Batten, 1988) thought that the new science of 'astrophysics' was not quite a rigorous science like classical astronomy. In an 1886 letter to the St. Petersburg Academy of Science, Struve stated that the standards of accuracy of astrophysics were far below that in classical astronomy. He said:

> God forbid that astronomy should be carried away by a fascination with novelty and diverge from this essential basis, which has been sanctified for centuries, and even millennia. (Cited by Melnikov, 1957: 27).

It must be said that Pogson was neither primarily a spectroscopist—he discovered asteroids and calculated orbital elements of comets and worked on stellar magnitudes just as classical astronomy demanded—nor was he a self-taught astronomer (he had been trained by J.R. Hind and M.J. Johnson, both of whom were well regarded). The fact that he had to face the ire and reluctance of influential people like Airy was probably, as Reddy et al. (2007) suggested, a reflection of the class structure in British society and the implicit hierarchy it implied. Pogson was not wealthy enough to be able to build an observatory for himself, as Huggins, or the solar astronomer Richard Carrington did (Clark, 2007). Nor did he have connections, like those that Norman Lockyer had cultivated, which helped him at various stages of his career. Pogson's only option was to wait in silence. And so he did, until in 1860 he heard about the vacant post of Government Astronomer at Madras Observatory in India (Figure 7), and wrote to Airy seeking his support:

> We have just heard that the Madras Observatory is vacant … and my kind valued friends … seem to think so eligible an opportunity of promotion ought not to escape me without a struggle. (Pogson, 1860).

Apparently, Airy's (1860) letter of recommendation contained some rather unfavourable comments, such as:

> Mr Pogson was educated, I believe, at a German University. He was, for some years, assistant at the Observatory of Oxford, but quit that post upon some disagreement with the principal Mr Johnson.

Luckily for Pogson, Sir John Herschel (1860) submitted a strongly supportive letter of recommendation, including an approval for the pension benefits for the job, and Pogson duly received the appointment in early October of 1860. He and his wife reached Madras in February 1861, along with three of their children (the younger ones having been left in England with their aunts).

4 POGSON IN MADRAS

The struggle for a stable job and the dismissive attitude of some of his peers made Pogson rather sensitive about his status. He would often mention the title of 'Government Astronomer', and in a letter to Dr John Lee of Hartwell House, he even used the phrase 'Astronomer Royal of India' to describe his new position (Pogson, 1860). In the seven years at Madras before the solar eclipse of 1868, the relation between Pogson and his peers back in England steadily worsened for various reasons. One of them was the litany of complaints that peppered Pogson's missives to Airy.

Figure 6: A portrait of Sir William Huggins painted in 1905 by John Collier (died 1934) and donated to the National Portrait Gallery, London, in 1912 (https://en.wikipedia.org/wiki/William_Huggins#/media/File:Sir_William_Huggins_by_John_Collier.jpg).

One of the first complaints he made was about the equipment he found at Madras Observatory upon arrival. The primary instrument was a 6-inch equatorial refractor, and Pogson was shocked to see its condition. On 12 February 1861 he wrote to Airy:

> It is grievous to see fine weather passing … and so costly an instrument actually less efficient than the decayed old wreck it ought long since to have superceded [sic.]. (cited in Reddy et al., 2007: 241).

He was disappointed in the assistance he received from the native staff, among whom he found C.R. Chary to be the only skilled person, while "… the rest were dolts—machines without the certainty of machinery." (Pogson, 1871). The description of the first observations

Figure 7: The appearance of Madras Observatory at about the time of Pogson's arrival (courtesy: Indian Institute of Astrophysics Archives).

that he recorded in his diary is no less colourful:

> First observations in India taken in the compound, in happy, fearless ignorance of snakes, centipedes, scorpions, and all the filthy, dangerous vermin abounding in my new home. (cited in Reddy et al., 2007: 241).

He complained about his salary as well, which he thought was "… not befitting his rank in science …", mentioning that it was low compared to other British officers in the Trigonometric Survey, or even a principal of a high school in India (Pogson, 1863).

The immediate cause of the tussle between Pogson and Airy was the plan to make a survey of the Southern sky from Madras. Pogson thought that this was an understanding he had with Airy before he took up the Madras position, but when he announced his plans after reaching Madras the Royal Astronomical Society dissuaded him from doing so. Pogson (1862) wrote an angry letter to Airy:

> The remarks there fill me with surprise and regret, to think that of my many acquaintances, whom I have been accustomed to think were friends, and who knew well what my avowed objects and policy were in coming out to India … I could imagine willfully ignored.

What had happened was that a committee set up to decide on the cataloguing of the Southern sky (which included Hind) had decided to assign the survey to Sydney. However, Pogson decided to commence the survey anyway, despite Airy's reservations, straining their relationship even further.

Pogson (1864) had also managed to irk Airy by asking him to consider appointing his eldest son (who was trained at Kew Observatory in 1864) as an Assistant at Madras Observatory. And when there was a bureaucratic move to merge the Bombay and Madras Observatories, Pogson shot off a threatening letter to the Indian Government offering to resign. Luckily for him, the Government abandoned the idea, and also created a Department of Meteorology, for which Pogson was appointed as the Meteorological Superintendent (Government of India, 1867). As we will see, this came as a boon for Pogson and his 1868 eclipse expedition.

5 NEWS OF 1868 SOLAR ECLIPSE

The total solar eclipse of 18 August 1868 has been described as ". a watershed event in the history of astronomy …" (Orchiston, and Orchiston, 2017: 314). The renowned Irish chronicler of nineteenth-century astronomy, Agnes Mary Clerke (1842–1907; Bruck, 2002) explains why:

> In the year 1868 *the history of eclipse spectroscopy virtually began* … On the 18th of August 1868, the Indian and Malayan peninsulas were traversed by a lunar shadow producing total obscuration during five minutes and thirty-eight seconds. Two English and two French expeditions were dispatched to the distant regions favoured by an event so propitious to the advance of knowledge, chiefly to obtain the verdict of the prism as to the composition of prominences. (Clerke 1893: 209; our italics).

The path of totality of this eclipse (Figure 8) began near Aden, then crossed India, Siam (present-day Thailand), the island of Borneo, Sulawesi (at the time known as the Celebes) and other islands in the Dutch East Indies (now Indonesia), the extreme southern part of New Guinea and on to islands in the New Hebrides. The unique nature of this eclipse was stressed by Austrian astronomer Edmund Weiss (1837–1917):

> At the commencement of the eclipse the Moon has just passed a perigee of uncommon proximity, and reaches during it the ascending node of her orbit. The eclipsed Sun rises therefore nearly to the zenith of those countries where the eclipse takes place at noon: hence the augmentation of the Moon's diameter, due to her altitude, is a maximum, and the velocity, with which the shadow hurries over the surface of the Earth, a minimum. The result of the coincidence of all these favourable conditions is an eclipse, which, as to its size, belongs to the largest that can happen in general, and has indeed in the annals of mankind no rival … (Weiss 1867: 307–308).

Weiss (1867: 307) also noted that the maximum duration of totality of this eclipse, the longest on record, would take place "… in the Gulf of Siam where it reaches on the central line 6 m 50 s …", more than 1 minute longer than for those observing from India.

In the end, successful observations were carried out in Aden (De la Rue, 1869), at several locations in India (Launay, 2021; Orchiston et al., 2017; Venkateswaran, 2021), in Siam (Orchiston and Orchiston, 2017; 2021a; 2021b; Soonthornthum and Orchiston, 2021), off the coast of Borneo (Pope Hennessy, 1868) and in the Dutch East Indies (Mumpuni et al., 2017).

News of the upcoming solar eclipse of 1868 was announced in 1867 by James Francis Tennant (1829–1915; Figure 9), the Madras Observatory Director before Pogson, and Pogson's name was mentioned for one of the possible expeditions mounted from within India. Tennant (1867a: 80) specifically wrote:

> Mr. Pogson will doubtless do his part, but Masulipatam is readily accessible from both Calcutta and Madras by steamer, and is itself a port at which they call. It will be quite in the power of the Government, if so disposed, to collect at that place a corps of practiced observers; and even if they will not do this, I have little doubt that, if their

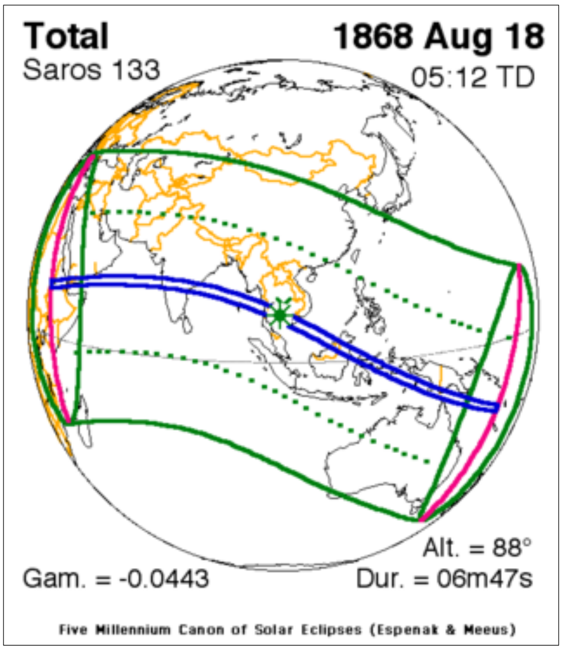

Figure 8: A map showing the path of totality of the total solar eclipse of 18 August 1868, which crossed peninsular India (after Espenak and Meeus, 2006).

Figure 9: John Francis Tennant (courtesy: Indian Institute of Astrophysics Archives).

> officers are permitted to go, there will be some (possibly enough) observers who would form a party for the occasion.

Tennant (1867b: 175–176) believed that it would be wise to divide the efforts in India, and to

> … organize at least two parties, each to be complete. One to be stationed near the sea in the neighbourhood of Masulipatnam [sic] and Guntur in such position as may be found best, and the second inland on the central line about 60 miles south of Hydrabad [sic].

Although Tennant's overall proposal included Pogson, there was not much enthusiasm from other quarters. Perhaps the gradual souring of the relation between Pogson and his peers back in England was partly to blame for this.

There were two relatively new components in the expeditions mounted for the 1868 eclipse. One was photography (see Hughes, 2013), which was to form the main pillar of Tennant's efforts. The first photographic study of a solar eclipse was made during the 1860 total eclipse, by Walter De la Rue (1861), and the six minutes of totality for the Indian eclipse offered a unique opportunity to take as many as half a dozen photographs of the eclipsed Sun. The other component was spectroscopy (Hearnshaw, 1996). This eclipse came hot on the heels of widespread discussion among physicists and astronomers of Kirchhoff's explanation of Fraunhofer lines. According to Gustav Robert Kirchhoff (1824–1871), the dark lines in the solar spectrum arose in the relatively cooler gas in the solar atmosphere, suggesting that the core of the Sun was hotter than the outer layers. This ran counter to the then conventional wisdom, going back to the time of Sir William Herschel (1738–1822), that the solar core was cooler than its atmosphere. The only test of Kirchhoff's ideas depended on the spectrum of the light from the outer layers of the Sun. If this light could be somehow isolated then its spectra should show bright lines, instead of dark Fraunhofer lines, and exactly at the same wavelengths. The dark lines should reverse, in other words. And the total solar eclipse of 1868 was going to be the testing ground for this hypothesis. Therefore, spectroscopes became an important component for all observers vying for a glimpse of the total eclipse.

Tennant was aware that it was not going to be easy for Pogson to mount an expedition. He had written in one of his papers that

> … there is hardly any instrumental means in India suitable for the making of these observations. All appliances must be procured from England, and soon enough for the intending observers to become used to them before the precious few minutes when they are to do their work. (Tennant, 1867b: 175).

There was an advantage on the side of the Indian Government though. Tennant (1867a; 1867b) had noted that the officers of the Trigonometric Survey could form a pool of skillful assistants, and suggested that they should be given special leave for this purpose. Since he was himself an engineer for the Survey, he knew how skilled they were.

But Tennant's own plan was not to use the resources in India at all, and to apply for a grant to the Royal Astronomical Society for this purpose (for details, see Orchiston et al., 2017). His emphasis was on photography, and he requested "… a silver glass reflector, equatorially mounted and driven by clockwork ..." (Tennant, 1867c: 323). He managed to arrange for a 9-in telescope for this purpose. For spectroscopy, he got a 4.6-in telescope (Orchiston et al., 2017), which was fitted with a spectroscope. He was also successful in obtaining the assistance of three non-commissioned officers from the Royal Engineers.

Pogson knew about these efforts and being left with no resources to prepare for the eclipse expedition, he wondered how he could best utilize the opportunity. We can assume that the frenzy of arrangements around him must have pained him because he had been sidelined. Airy had been generous in helping Tennant's expedition efforts, without giving Pogson any opportunity to participate. In his report of the eclipse, Pogson (1869: 1) would later write:

> I have never been able to comprehend the peculiar ground upon which European observers justified the needless and lavish expenditure incurred in their agreeable tours, for the observation of so ordinary and nearly annual an occurrence as a total eclipse of the sun.

It is not clear whether he really meant this, because he was surely aware of the extraordinary opportunity offered by the 1868 eclipse (see Cottam and Orchiston, 2015). But his emphasis was not on the uniqueness or ordinariness of the eclipse, but on the size and magnitude of solar eclipse expeditions (something that Pang (2002) also discusses):

> That it was of unusually long duration was undeniable, but with an eclipse of three instead of six minutes duration, just as much may be recorded by a judicious subdivision of labor and an increased number of observers … it is to be hoped that no similar rival expeditions at so great a cost, and so utterly needless in a scientific point

> of view, will be permitted upon future occasions of total eclipses in India. (Pogson, 1869: 1–2).

Pogson was aware of the importance of spectroscopy. He pointed out that

> The recent application of that most wonderful and novel invention, the spectroscope, to the analysis of the light of the red prominences and of the corona, was of course the general inducement which led so many observers so far from home, when by waiting another year or so they might have had much nearer and more convenient opportunities of witnessing similar phenomena … (Pogson, 1869: 20).

Tennant (1868) was given a spectroscope by the Royal Astronomical Society, and other observers got them from different sources. Sir John Herschel had sent a spectroscope to his younger son John Herschel (1837–1921; Shylaja, 2006), who was stationed at Jamkandi (for his report on the eclipse see Herschel, 1869). The Royal Society had sent spectroscopes to many people, including some who had no idea of how to use them. For example, there is an interesting report of the eclipse from Captain Rennoldson (1869), commander of the *S.S. Carnatic*, which stated:

> … the sky unfortunately was still overcast … disappointment was visible on every countenance, and the group of passengers and the … officers who had collected on the quarter deck, armed with a miscellaneous collection of instruments from the primitive 'bit' of smoked glass to the spectroscopes of the Royal Society, were exchanging these for buttered toast and hot coffee …

Rennoldson later sent the spectroscopes back to the Royal Society, with a note: "I return the spectroscope, and am only sorry I could not make more use of it." (*ibid.*).

The point of quoting this odd report in detail is to emphasize how Pogson was clearly sidelined by his peers in England. He had to procure a spectroscope personally, so he approached William Huggins, who sent him one, along with instruments for polarization experiments. Pogson (1869: 10) wrote in gratitude:

> Mr. Huggins' instructions were, however, so explicit and intelligible, that, notwithstanding all my disadvantages, I resolved to try what could be done; not altogether in anticipation of total failure, but fully aware that at least three similar instruments were under manipulation, by men who enjoyed every facility of preparation for the occasion.

The last sentence, tinged as it is with disappointment, is noteworthy.

6 POGSON AS A METEOROLOGIST

Pogson's choice of Masulipatam (see Figure 10) for his solar eclipse expedition had also to do with another bit of history. He had been appointed as the first superintendent of the newly established Madras Meteorological Department in 1868 (Pogson, 1869). Masulipatam had something to do with the reason for setting up the new Department, as it had witnessed a devastating cyclone four years earlier: in November 1864 the ocean was reported to have risen 13 feet above normal, flooding the coastal town, killing at least 16,000 people in the town, and another 20,000 in the adjoining areas. There was an urgent feeling of the need to set up a weather station at Masulipatam. As the new superintendent of the Meteorological Department, Pogson (1869) thought that he could combine that task with the eclipse expedition. It is not clear from his report how much of a financial and logistical help he got on account of this, but given the indifference from other quarters about helping him mount an expedition, it is fair to assume that there was logic behind his combining the two.

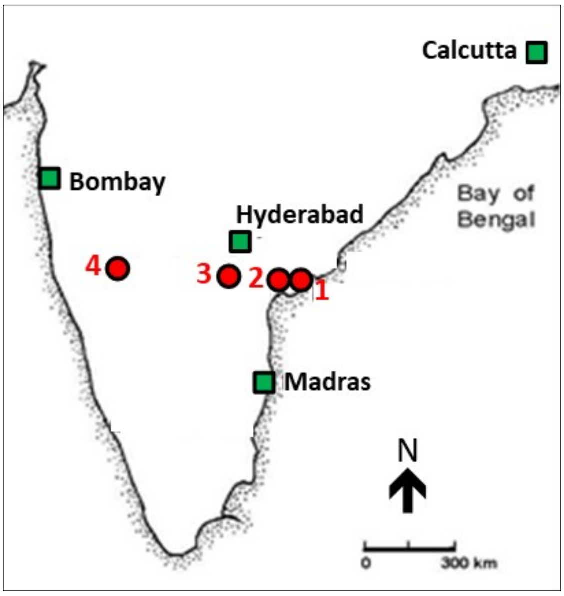

Figure 10: A map of peninsular India showing major cities (in green) and in red the four 1868 solar eclipse observing sites mentioned in this paper: 1 = Masulipatam; 2 = Guntoor; 3 = Vanpurthy, and 4 = Jamkandi (map: Wayne Orchiston).

7 POGSON'S EXPEDITION

Pogson took two assistants with him to Masulipatam, C.G. Walker from the Madras Civil Service, and G.K. Winter, a telegraph engineer of Madras Railway. It should be noted that the telegraph service in different parts of India had been established a decade earlier.

As far as instruments are concerned, apart from the spectroscope supplied by William Huggins, Pogson acquired a five-foot telescope of 3.75 inches aperture, sent to him by ex-RAS President Dr John Lee (1783–1866; Figure 11) of Hartwell Observatory (where Pogson had worked earlier). In Pogson's own words:

> The full aperture was employed throughout, the telescope being fitted with one of Mr. Cooke's admirable solar reflecting eye-tubes, which by transmitting most of the heat and light through its unclosed end, and reflecting only a small percentage of either, renders reduction of the aperture of the object glass unnecessary. A good parallel wire micrometer, bearing a magnifying power of fifty-two, was attached; a low power being preferred to enable the entire disc of the sun to be kept in view at once. Red and green sliding shades were provided, but the former only was required, and none during the total phase. (Pogson, 1869: 4).

Figure 11: A portrait of Dr John Lee (https://en.wikipedia.org/wiki/John_Lee_(astronomer)#/media/File:John_Lee._Lithograph_by_(P._J.)._Wellcome_V0003461.jpg).

The wire micrometer was used to continually measure "The distance between the points of intersection of the sun's and moon's discs …" (*ibid*.) near the beginning and end of the eclipse.

Pogson (1869) accessed a second five-foot telescope, which was made at the Public Works Department in Madras and used the 4-inch object (by Dollond) that previously had been in the old transit telescope at Madras Observatory. This new telescope was on a solid portable equatorial mounting made by Cooke and Sons. Pogson (*ibid*.) decided that the spectroscope would be used with this telescope.

There were two other telescopes, which would be used by Walker and Winter. Both had 2.5-inch objectives, 28 inches in focal length. The one to be used by Winter would be fitted with a polariscope, and had two eye-pieces. The other, to be used by Walker, had one erecting eye-piece, whose magnification could be adjusted between 30 to 55.

Besides the telescopes, there were three chronometers, but they proved to be much less helpful than expected:

> It was my intention to have kept the chronometers rated solely by equal altitudes of the sun, but cloudy and windy weather so frequently prevented the corresponding afternoon sets from being taken, and still worse the unsteady rate of the chronometer was so affected by alternate exposure to day and night temperatures, that I found it necessary to treat each set separately, and to adopt interpolated rates therefrom. Owing to the rustling of adjacent palm trees under the slightest breeze, the faint beat of the only good chronometer was inaudible, and I was, therefore, compelled to employ a loud beating but very inferior time-keeper as the standard. A third and usually pretty steady going chronometer, which had just been cleaned and repaired by a Madras Watchmaker for the occasion, was returned so discreditably injured as to be only serviceable as a hack-watch. (Pogson, 1869: 3).

These setbacks posed problems for Pogson during the determination of the longitude of Masulipatam, and in the end he had to rely on the old Trigonometric Survey determination of the longitude of the Masulipatam Flagstaff for this purpose.

The party arrived off the coast of Masulipatam on 5 August, after travelling for a day from Madras aboard *S.S. Bushire*. The landing at the shore took five hours using an open boat, the journey being "… anything but pleasant …" according to Pogson (*ibid.*) but the instruments survived without any damage. The party spent the next two days looking for a suitable observing site, finally deciding on a house that was provided by Lieutenant-Colonel G.V. Winscome. His tenancy was to expire around the day of the eclipse, but the owner of the premises, Daud Ali Khan Bahadur, the Nabob of Masulipatam (and a vassal ruler under the Nizam of Hyderabad), asked Pogson's team to carry on with their work, until their departure around 25 August. The veranda of the house provided a firm foundation for the instruments, and also gave convenient shelter at night.

Pogson immediately set about erecting a brick pier, two-feet broad and four-feet high, on which he could place a sextant stand, for time and latitude measurements. These measure-

Table 1: Pogson's observations of the eclipse (after Pogson, 1869: 7–8).

Event Description	Local Mean Time h	m	s
First contact of Moon's limb with a large sunspot (D)	08	33	35.4
Estimated bisection of the same	08	34	16.3
Complete obscuration of the same	08	34	41.2
Bisection of a small sunspot (C)	09	18	36.2
Simultaneous bisection of a considerable sunspot (B) and of a smaller one (b)	09	25	26.1
Commencement of the total phase	09	34	14.2
End of the total phase	09	40	05.8
Last measure of the large prominence	09	40	33.7
Bisection of the large sunspot (B) at emersion	10	45	04.5
Bisection of the small sunspot (b) at emersion	10	44	13.3
Last contact of limbs	11	04	47.4

ments were started on the morning of 9 August. On 13 August they deduced the latitude from meridian altitudes of Fomalhaut and on 23 August from those of α Gruis, α Cassiopeiae and Fomalhaut. Pogson (1869: 4) mentioned that the

> … height above the sea-level must have been inconsiderable, as it was within the limit of the great storm wave which dealt such ruin and desolation upon the occasion of the memorable cyclone of November 18th, 1864.

8 OBSERVATIONS DURING THE ECLIPSE

The morning of 18 August did not start promisingly at all. Because it was monsoon time in India and Masulipatam was a coastal town, it was not clear to Pogson's team whether or not their efforts would turn out to be futile. The sky was

> … covered with light clouds, which, however, gradually cleared off as the sun rose higher; but flying cirro-cumuli still rendered the chance of a fine interval during the totality very dubious. (Pogson, 1869: 4).

8.1 Principal Events: Description and Timing

Pogson (1869: 4) missed the time of the first contact, because "… no trace of the moon was discernible before its entry upon the sun's disc." Walker's description of this moment was vivid:

> At ten or twelve minutes past eight I began carefully to scrutinize the sun's neighbourhood, but I could see nothing of the moon's disc: while looking thus, with my eye wandering now to the sun's disc, now from it, I lost the absolute moment of first contact. (Walker, 1869: 16).

But he estimated it to be at 8 h 19 m 22 s, occurring at position angle 283° on the Sun's disc. According to him, "The sky at this time was partially covered with light fleecy clouds." (*ibid.*).

From this point onwards, they could note the gradual progress, and determine the contact of the shadow with four large sunspots. The associated measurements are listed in Table 1.

Table 2: Positions of sunspots b, B, C and D (after Pogson, 1869: 9).

Sunspot	Position
Large sunspot D	157" from 1st limb, 659" from south limb
Small sunspot C	669" from 2nd limb, 383" from south limb
Double sunspot B and b	509" from 2nd limb, 336" from south limb
	491" from 2nd limb, 348" from south limb

The positions of the sunspots were measured by Pogson (1869: 9) after the eclipse, "… immediately after the last contact of the limbs." and are listed in Table 2 and shown in Figure 12.

Alternatively, if the sunspots were to be measured from the nearest point of the Sun's limb towards their centers, and the position angles were to be measured from north (eastward being positive), then the distance and position angles of the sunspots D, B, b were as listed in Table 3:

Walker (1869: 16) had stationed his telescope on a verandah, "… beyond which projected for some 15 feet a pandal (a lightly thatched roofing)." He had a broad slit cut in this pandal, east and west. He made a map of the sunspots before 8 am. During the totality, he had a sheet of drawing paper stretched on a board, "… with 6 circles, each 2½ inches in diameter, and lightly divided into 60 degree sectors." (*ibid.*). They were for the purpose of mapping sunspots, sketching the red prominences and extent of the corona. He put this sheet on his knees. Beside him on a table were "… a chronometer, several pencils, a *pad* of paper for notes, and (during totality a lighted candle in a covered shade." (*ibid.*).

Table 3: The positions of sunspots b, B and D (after Pogson, 1869: 9).

Sunspot	Distance from the Limb	Position Angle
D	107"	250.2"
B, b	194"	140.4"

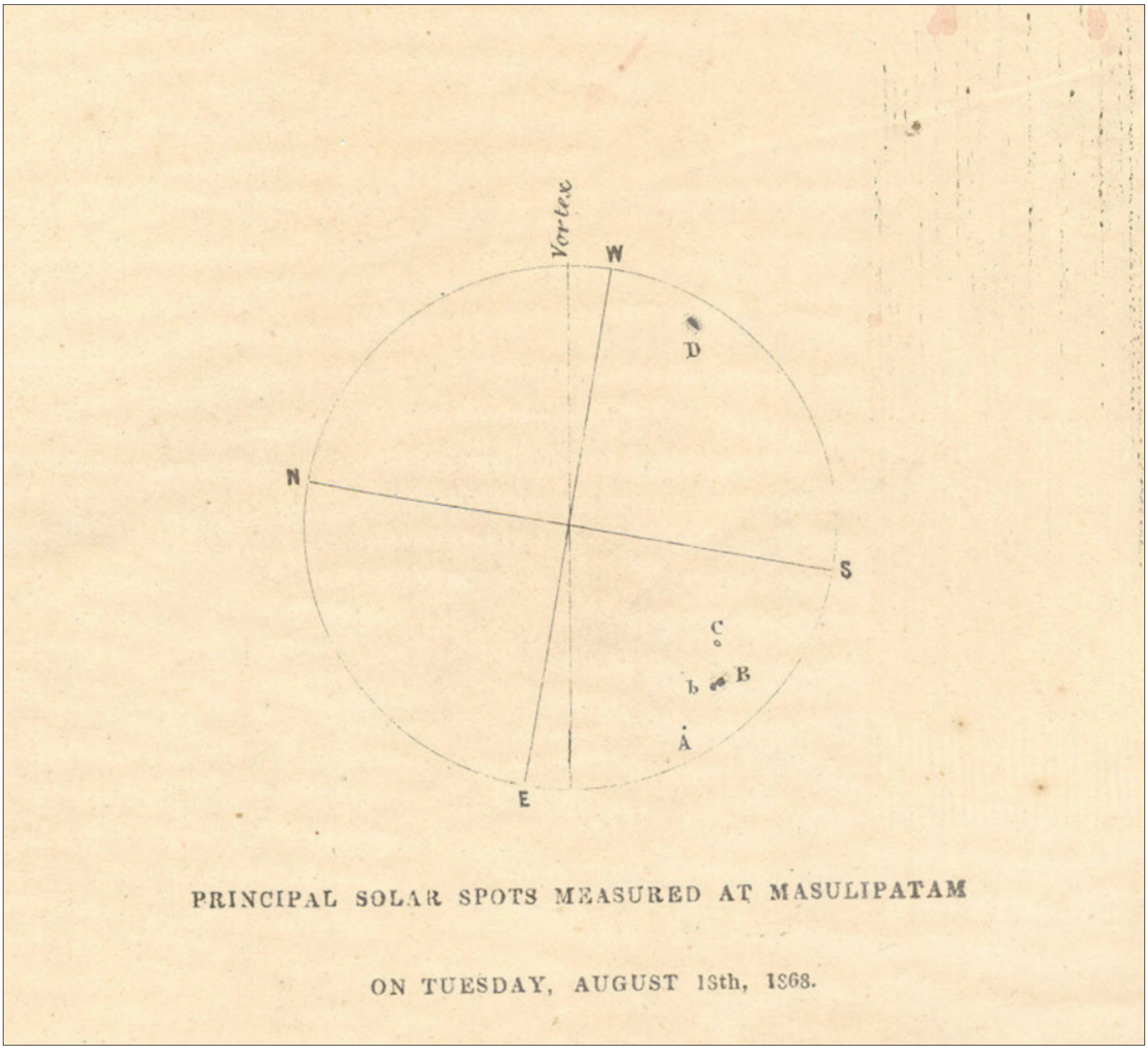

Figure 12: A sketch of the sunspots that were mentioned in Pogson's (1869) report (courtesy: Indian Institute of Astrophysics Archives).

He noted the time of contact of penumbra of the sunspot D at 8 h 32 m 41 s, and of the upper edge of the spot at 8 h 33 m 24 s. At this point, he noted that

> The light was now not only diminishing, but getting paler, and as if the sun were overcast, giving one the idea of the "sickly gleam" of sunlight coming out from a thunder cloud. (*ibid.*).

Also, the wind appeared to rise slightly.

After a few minutes, Walker noted that he could see another sunspot, which he marked A, at 8 h 44 m, and which he thought he could not see earlier because of brightness of the Sun's disc. Soon after this, the Sun was covered with clouds and he worried that "... the totality would be quite lost." (*ibid.*). The wind had become quiet by then. He moved the telescope to the roof of the verandah. The view from there was over a "... level plain intercepted by topes of coconut and palmyra ..." (Walker, 1869: 17). He felt nothing unusual about the general brightness, although it was diminished. He noted the time of the contact with the upper edge of sunspot B to be 9 h 24 m 57 s.

8.2 Baily's Beads and Prominences

Just before the totality, they witnessed Baily's beads:

> The peaks of the mountains seen along the edge of the moon's limb, divided the final thread of sunlight into unequal lengths, for more than a second before the actual commencement of totality. (Pogson, 1869: 5).

Pogson realized why some observers do not see this "... most ordinary and inevitable appearance." (*ibid.*). The reason has to do with whether or not one's eye can "... rapidly accommodate itself to changes of intensity ..." (*ibid.*). If it is able to do so, then, Pogson argued, it

> … will catch this brief but conspicuous inequality in the covering up of the sun's limb, while others will either entirely fail to remark it, or will receive a vague impression of beads or drops in relative motion, as the involuntary adjustment of the sight keeps pace more or less with the rapidity of the changes to be seen. (*ibid.*).

Pogson (*ibid.*) saw three distinct breaks at the start of totality, and at the end, "… a complete string of points, momentarily uniting to form the line of light at the sun's western limb." According to him the receding Moon's limb was less deeply serrated than the other side, which was why the duration of Baily's beads phenomena lasted shorter at reappearance of the Sun than at the time of vanishing.

Walker's description of the moment of beginning of totality was again very vivid. When he focused his telescope on the thin crescent, he found the Moon's limb to be serrated, and

> Upon the most prominent of these serrations I now fixed my attention, when, beginning at the cusps, the crescent rapidly broke up into *bits*, and all was dark. Absorbed in watching and keeping my time, I had omitted to slide off my dark glasses, which, however, hardly many seconds before, I had found it impossible to dispense with. As I slid those off I lost my time and took a hurried glance up, (I am very shortsighted, and had no glass on my eye,) and the silver *cloud* which met my eye sent me at once to look at it more closely. The time lost was so short that I almost still seemed to see the phenomenon burst into view, and its sudden appearance and still beauty (for all was deadly still except one chattering bird) made me listen as one listens for the faint report of a rocket bursting, after seeing its cloud of stars fall. (Walker, 1869: 17).

He described the Baily's beads thus:

> The formation of Baily's beads was very clearly seen. The excrescences on the lunar disc visibly first passed over the solar limb and obscured each its portion, while the depressions still remained clear, forming apparently rectangular *bits* of light, and in the re-appearance the phenomenon was equally clear. (Walker, 1869: 19).

No sooner had the last ray of sunshine vanished from sight than the coloured prominences appeared (see Figure 13). One prominence was extraordinary in "… length and figure, conspicuous even to the naked eye …" on the eastern and northern point of the Sun's disc, "… like a nearly straight finger." (Pogson, 1869: 5). It was

> … very slightly inclined eastward from a radial line, with a detached portion at the extremity, nearly at right angles to and a little above the trunk of the prominence. (*ibid.*).

According to Pogson, its colour at its first appearance was

> … of a salmon or straw color, with the faintest idea of pale pink at its upper extremity, but the space between the trunk and bent arm was unmistakably sky blue. (*ibid.*).

For Walker (1869: 17) the prominence had "… the most delicate tint of blush rose colour, and… backed by the silver light of the corona."

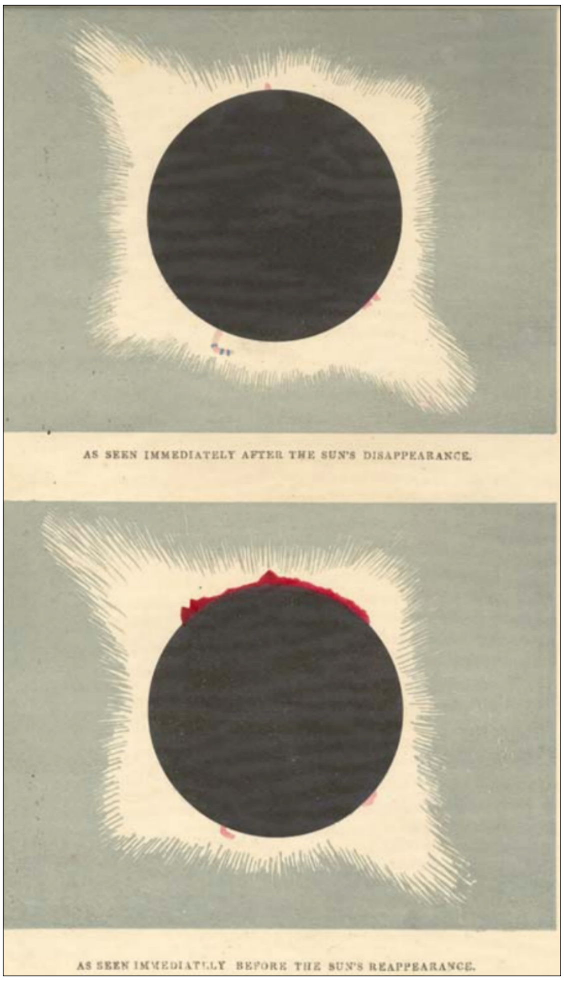

Figure 13: Solar prominences as observed by Pogson (courtesy: Indian Institute of Astrophysics Archives).

Pogson (1869) used the micrometer and at around 9.35am (roughly 45 seconds into totality), and determined its height to be 199.4 arc seconds, which implied 88,352 miles (or about 141,360 km). The angle from the Sun's northernmost point was 77.7°.

Walker had a mishap with his telescope while measuring the prominence. The tangent rod of the telescope (which had an alt-azimuth mount) became jammed, after which he gave it a 'vigorous wrench', but the effect of which was to tilt the telescope stand. Finally, when he was able to take the micrometer measurement, he determined the height to be 3′ 12″, "… which, with the sun's apparent semi-diameter at 15′ 51″, and assuming the diameter 887000 miles …" (Walker, 1869: 18), gave him a height of 89,539 miles, or "… a little over one-tenth of the sun's diameter." (*ibid.*). He estimated that the position angle was not far from 80°.

Winter, using another telescope, also noticed the big prominence, which he found to be "… long, narrow, and curved …" (Winter, 1869: 20), and that its 'concave side' was turned towards the south. He roughly estimated the position angle to be 70° from the north point, and thought its colour was "… rather deep rose." (*ibid.*).

Incidentally, this prominence was noted by the French astronomer Jules Janssen (1824–1907; Launay, 2021), who was stationed at Guntoor, as being "… more than three minutes high … [and resembling] the flame of a forge fire." (Janssen, 1869: 109). In total, Janssen reported seeing two big prominences, one on the eastern and another on the western side. It appears, after comparing Pogson's report on prominences with those of others, that his was certainly more detailed, yet concise.

Pogson (1869) saw four prominences in total besides the big one. Two of them near the southeastern and eastern point of the disc, separated by about three minutes or arc, of a pale red colour. Another was at the northwestern side, "… broad but low, of a deep rose color ..." (Pogson, 1869: 6). He tried to divide his time between observing the prominences with telescopes and measuring their positions and extensions, and looking at them through his spectroscope. At some point of time during the totality, he switched to the spectroscope, only to return to his micrometer measurements a minute before the end of totality. At that time, he reported being "… astonished at the vividly intense crimson which all the prominences had assumed …" (*ibid.*). There was also an irregular but almost continuous chain of protuberances, covering almost a fifth of the circumference of the solar disc, on the opposite side (western) of the big prominence he had seen first. Their colour was more vivid, he thought, than the big protuberance on the eastern side.

Walker (1869: 18) described the prominences to be unmoving, "… apparently solid, but not more solid than the evening wrack usually is." He described the view thus: "Their colour in relief on the pure silver behind (for it appeared behind) gave the prominences a very beautiful effect." (*ibid.*). To him, the big prominence seemed to have "... three holes right through. showing a clear blue behind." (*ibid.*). He described the 'holes' in some detail:

> The large aperture was at the bend of the head almost forming a crescent, and the other two were thin slits with sides parallel to the convexity of the larger aperture. The impression made, was, that they were holes *through* the cloud or flame, or whatever it may be. (*ibid.*).

After the totality, as the Moon's disc gradually moved away, the big prominence on the eastern side, although "It had remained apparently fixed … [was being] encroached upon, and to a great extent covered by the advance of the moon's disc over it." (Pogson, 1869: 6). This he took as a proof that prominences had nothing to do with the Moon, and remarked:

> The question as to whether these prominences belong to the sun or to the moon has long since been decided in favour of their purely solar origin; but this observation alone, shewing the moon's encroachment upon the large eastern prominence would have established their true relationship incontestably, had any doubt still remained upon this point. (*ibid.*).

Even when the big prominence was being gradually covered by the moon's disc, Pogson (1869) measured its height again, 28 seconds after the totality. He measured the perpendicular height from the Moon's disc to be about 49.5 arc seconds (compared to around three arc minutes during totality).

The following morning Winter revisited the part of the Sun where the large prominence had been seen. He found nothing remarkable on that part of the Sun, but noticed that

> … on the southeastern limb, near the lower group of spots, about the position at which another flame had been observed of greater breadth, faculae were distinctly visible … (Winter, 1869: 21).

8.3 The Corona

Pogson's time during the totality was taken up by micrometrical and spectroscopic measurements of the prominences, and he could not give justice to coronal observations: "Of the corona I regret to be able to give little or no account …" (Pogson, 1869: 6) he wrote in his report, and

> I cannot even say whether it came immediately or gradually into view in the telescope, but its light was of a pure white silvery nebulous nature for two or three minutes of arc from the moon's limb, when its homogeneous appearance ceased, and it seemed to radiate from the sun's centre until lost in the surrounding hazy sky. (*ibid.*).

However, while moving from one telescope to another, he noticed that the corona showed

> … two long and broad radial arms of unequal length, and two others, considerably shorter, nearly, but not quite perpendicular to the former pair … (Pogson, 1869: 6–7).

He did not have the time though to note in which directions they lay, and when he sat down to write the report, his recollections failed to serve him well. When sunlight reappeared, he saw no trace of the corona, either with the naked eye or with the telescope.

One of Pogson's assistants, Mr Winter, was at another telescope, viewing the corona. Winter (1869: 20) noted that "The corona seemed to burst into being at the first moment of totality." He saw its colour to be silvery white. In structure, it appeared to be "… slightly mottled near the sun, and nearer to its edges was beautifully striated, radially from the sun." (*ibid.*). His observations of the extension of the corona matched that of Pogson.

The other assistant, Mr Walker (1869: 18), described the corona as being "… radiant' [and as if] shot out from the sun's disc …" He found the "… radial character … [to be] most strongly marked as the edges were approached." (*ibid.*). He too found that there was a

> … strongly projecting branch of the corona at about 35° from the centre of the upper limb on the left, and exactly opposite, *i.e.,* on the lower right-hand side, a less prominent arm or branch. (*ibid.*).

There was another projection, "… rounded, not pointed …" at about 60° from the centre of the lower limb, and a similar one exactly opposite to it (*ibid.*). He estimated the respective angles of these projections as follows: 315° for the larger branch, 135° for the smaller one, and 40° and 220° respectively for the other two. He admitted though that his description of the shape of corona may have been compromised by the fact that he had used a rather high magnification of the eye-piece, which destroyed his idea of "… its shape, although its colour and *texture* were well seen." (Walker, 1869: 19). Meanwhile, see Figure 13.

Pogson expressed his astonishment at the brightness of the corona, which he had not expected: "I expected a very considerable amount of darkness …" (Pogson, 1869: 7) which he thought would make the lamp-light absolutely necessary. But he found that he did not need the bull's eye lantern, which he had kept in readiness, totally unnecessary, "… whether for entering my records, reading them, or taking the seconds off …" his chronometer dial (*ibid.*). He used the lamp only to read the small divisions on the micrometer and the spectroscope. According to Pogson (*ibid.*) the brightness of the corona was at least four times that of full moonlight:

> Distant houses, trees, and a native cooly gardener at work were never in the slightest degree indistinct. I have frequently seen a much deeper gloom cover the landscape before a storm, both in England and out in India.

At this point of the report, Pogson's typical 'colourful' language crept in:

> The animal-like apathy of a low class native was amusingly shewn in the cooly within sight. He continued his hedge operations up to the moment of totality, and was at work again immediately after, as if nothing had happened. He evidently feared no dragon eating up the sun, and had no more appreciation of the wonders of nature than the sticks he was cutting. (*ibid.*).

In the ensuing darkness during totality, Pogson saw stars between the hazy clouds. He could identify Venus, Mercury, Castor and Pollux, and guessed that stars down to third magnitude would have been distinctly visible wherever the sky was clear. He also "… had a strong impression of seeing Orion also through light clouds, but had no time to verify stars, so left them for others to record." (*ibid.*).

8.4 Spectroscopic Observations

William Huggins had sent Pogson a spectroscope, manufactured by Troughton and Simms, under Huggins' own supervision. Unfortunately, it arrived rather late in Madras, on 6 July, and then it had to be adapted to the telescope made locally by the Public Works Department. However, the spectroscope was rather heavy, which made "… counterpoising and adapting, so as to secure perfectly smooth tangent rod motion, far from easy." (Pogson, 1869: 9). These experimentations took a lot of time, and due to "… cloudy nights and pressure of current duties …" (*ibid.*), he could not practice well with the instrument, which, he admitted, was "… indispensable to ensure success with so new and difficult an instrument." (*ibid.*). It was also important that the telescope should be integrated with clock motion, in order to track any particular prominence, keeping it "… exactly in front of the narrow slit of the jaws of the spectroscope." (*ibid.*). But as ill luck would have it, although Pogson had clock drives at his disposal, he simply did not have the time to complete their attachment before leaving Madras, and it was impossible to do so at Masulipatam.

Pogson (1869: 10) was aware of the goals of spectroscopic observations during totality:

> The points to be decided were—first, the nature of the visible spectrum, whether continuous or broken by lines; secondly, whether such lines, if visible, were black, as in the solar spectrum, or bright, indicating gaseous matter in a state of combustion; and lastly, if time permitted, to determine the positions of the lines seen, so as to verify the actual kinds of gas to which the bright lines referred.

These concise, succinct words sum up the objectives of many observers who had gathered to view the eclipse.

After the eclipse Pogson (*ibid.*) reflected:

> It might be partly by accident, but I believe I may safely say that I secured as good results as could have been expected under far more favourable circumstances.

Pogson first felt that since others would be targeting the prominences for spectroscopic observations, he would devote his attention to studying the spectrum of the corona instead. He turned the spectroscope towards the Sun, a little before 9am, when the partial eclipse was well under way, and took the micrometer readings of seven emission lines, following, Pogson noted, Huggins' advice. Then, one minute into the totality phase, after making his micrometer measurements of the big prominence, he directed the finder of his spectroscopic telescope to a part of the corona, on the southern side, which was clear of any visible prominence. He did not see either dark or bright lines, only a faint light which was "… scarcely coloured …" (*ibid.*). His heart sank, then he was tantalized with a momentary view of the bright lines. He wrote:

> While wondering at the dreary blank before me and feeling intensely disappointed, some bright lines came gradually into view, reached a pretty considerable maximum brilliancy, and again faded away. Five of these lines were visible, but two decidedly superior to the rest. (*ibid.*).

Pogson made a point of immediately sketching the positions and relative strengths of these five lines, and later made the painting reproduced here in Figure 14.

At the time, Pogson noticed that there was something peculiar about two of these lines: they did not match any of the Fraunhofer lines. With the benefit of hindsight, we now know that one of them was probably the neutral magnesium double line at 516-518 nm, and the other was probably the ionized iron line at 530 nm (FeXIV). The dark counterparts of these lines are not seen in the solar spectrum. Iron is ionized to a high degree at the high coronal temperature (roughly 2 million K), whereas neutral magnesium is seen in the upper chromosphere because of ambipolar flow along magnetic field lines and the weakened strength of collisions between protons and neutral compared to proton-ion collisions (Wang, 1996).

Interestingly, the discovery of the FeXIV line at 530 nm is usually attributed to Dartmouth College's Professor Charles Augustus Young (1834–1908), during the 7 August eclipse in 1869, which was visible from North America. Later this was dubbed the 'coronium' line. Because Pogson's report was never circulated, he was not credited with its discovery—along with the other important contributions that he had made during the 1868 eclipse.

Incidentally, the prominence he had put against the slit was not the big prominence that

> … most other observers naturally singled out for examination, but one of the two seen side by side about the S. E. by E. point of the moon's black disc. (Pogson, 1869: 11).

The third most bright line that Pogson saw was in the yellow domain. Pogson (1869: 10; our italics) noted that

> The third line seen, in order of brilliancy, must have been *either coincident with, or very near the place of the sodium line D*, but it was much fainter than the two measured …

Pogson (1869) also noticed two more lines, which he thought were close to the Fraunhofer F line (the Hβ line).

Pogson preferred to use his micrometer on the spectroscope for measurement rather than the illuminated photographic scale, although it would have been quicker to do so, because he was worried the light of the lamp required for illumination of the photographic plate was likely to overpower the "… faint bluish white light of the lines …" (Pogson, 1869: 11), making them difficult to measure or even see them. As an afterthought, he noted:

> The light of the corona would, however, I believe, have sufficed to have rendered the photographic scale visible without lamp illumination; but it was impossible for me to venture an opinion upon that point until after the commencement of the totality, and so perhaps it was for the best that I decided upon the slower but surer resource of the micrometric scale. (Pogson, 1869: 11).

The following morning, he measured the Fraunhofer lines of the solar spectrum, and did this repeatedly before returning to Madras. His readings of the seven most prominent lines ('scale numbers') were as shown in Table 5.

In this scale, the two bright lines were situated at 1743 and 1763 in the green part of the spectrum. The existence of bright lines immed-

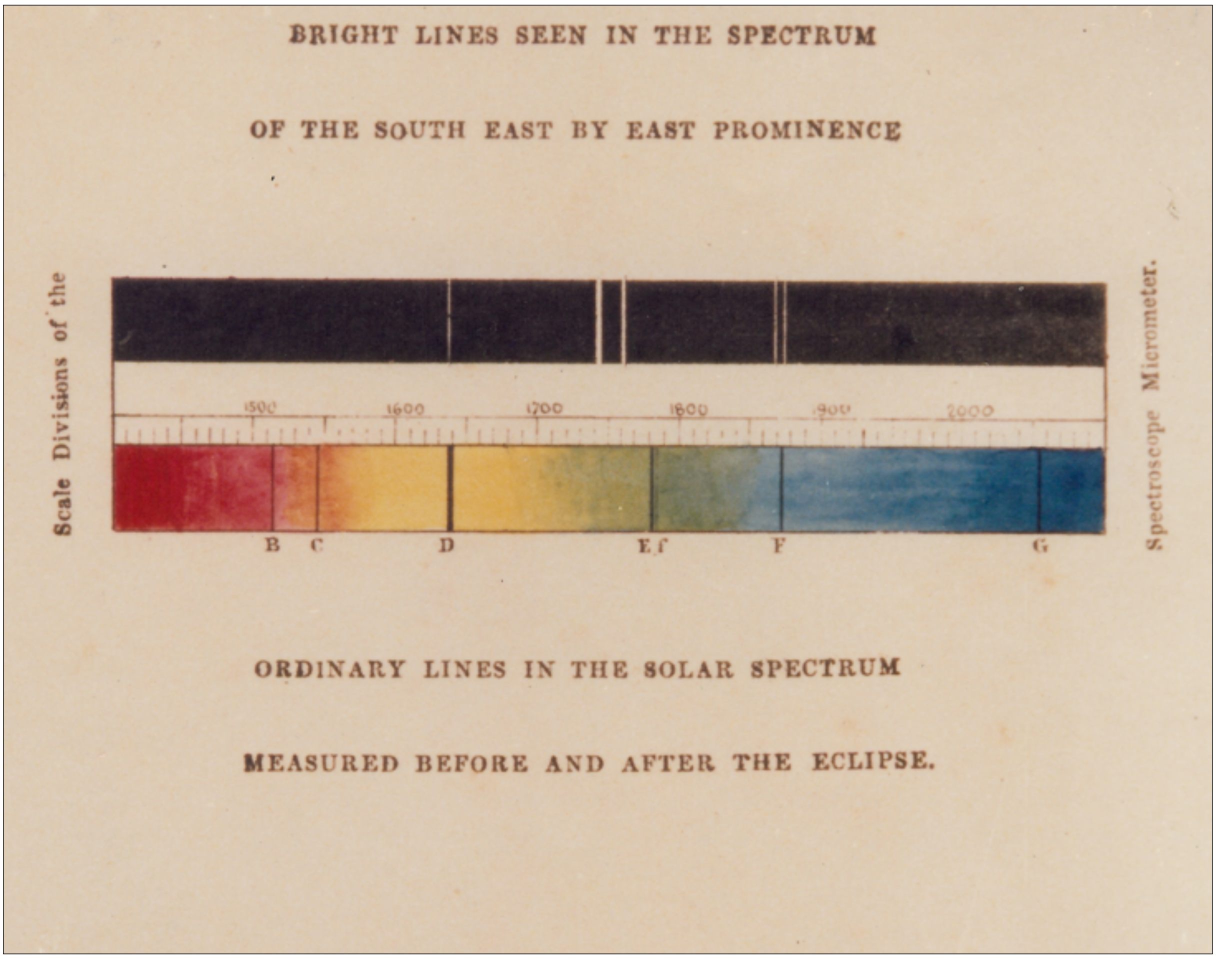

Figure 14: Spectrum of the prominence, hand-painted by Pogson (courtesy: Indian Institute of Astrophysics Archives).

iately confirmed Kirchhoff's contention that the Fraunhofer lines arose due to absorption of light in the solar atmosphere, and that the prominences were composed of hot gas, although cooler than the solar core, that therefore was capable of showing emission lines when seen in isolation. Pogson (*ibid.*) noted:

> The fact of bright lines being seen at all, shews that the red prominence which produced them was composed of incandescent gas, but whether similar to any of our known terrestrial elements or otherwise it would be premature for me to offer any opinion.

8.5 Polarisation Observations

William Huggins had also sent Pogson, at his request, a set of polarization prisms, made by Mr Ladd of London. Pogson noted that these were similar to those supplied to Tennant and Herschel by the Royal Astronomical Society and Royal Society. Pogson had entrusted Winter (1869) with the task of making the polarization observations.

The telescope at his disposal was of 2.5-inch aperture, focal length of 28 inches, and with an equatorial mount, made by Cooke and Sons. It had two eye-pieces. One was an ordinary erecting eye-piece of magnification power between 30 and 50x (they used a magniification of power 40x). This eye-piece had perpendicular cross-hairs in the focus, one of which was indexed. The position of the index could be read upon a cardboard disc—6 inches in diameter—that was fixed to the body of the telescope, and divided into divisions of 10°.

The other eye-piece was to be used with either a Savart's polariscope or a double image prism, although they used only the polariscope. Its quartz prism could not be removed and therefore could not be used with a Nicols' prism. It had an index corresponding to the direction of the bands, so that one could determine the

Table 5: Emission lines observed by Pogson during the 1868 total solar eclipse (after Pogson, 1869: 11).

Spectral Line	Wavelength	Colour
a	1513	Deep red
C	1547	Bright red
D	1639	yellow
E	1782	green
f	1785	green
F	1873	blue
G	2055	Deep blue

plane of polarization.

When Winter used the polariscope to view the corona, he found that "The corona was very strongly polarized in a plane passing through the centre of the sun." (Winter, 1869: 21). The bands appeared to be "… extremely vivid …" (*ibid.*) which he found be more than any that he had ever observed in a clear sky. He tried different locations in the corona, and discovered that

> … the white central band was brightest when it corresponded with the sun's radius, and the black band was equally marked when the bands were tangential to the limb. (*ibid.*).

There was no time, however, left for him to study the polarization of the prominences.

This was a major discovery of the 1868 eclipse, and was corroborated by other observers. As Winter (*ibid.*) noted:

> The fact that the light from the corona was polarized, proves that it shines chiefly, at all events, by reflected light; and the plane of polarization being everywhere radial to the sun, makes it as certain that its light is derived therefrom. This being so, from the great amount of polarization observed, we may conclude that the corona is caused by an atmosphere surrounding the sun and reflecting the solar light.

8.6 Other General Observations

Pogson's team had also built a new meteorological station in the compound of the Small Cause Court, which was half a mile from their temporary residence. The fact that it was some distance away from their station for eclipse expedition, Pogson noted wryly, had served their "… purpose in an unexpected and rather singular manner." (Pogson, 1869: 12). He was worried that general onlookers would create problems during the precious moments of totality, but it so happened that people of Masulipatam thought the meteorological station was going to be the spot where telescopes would be set up for the eclipse observations, and they had collected there in anticipation "… of beholding some astonishing performances or ceremonies in connexion with the eclipse." (Pogson, 1869: 13). Thus the expedition team was spared "… the dreaded annoyance ..." (*ibid.*). They still had to handle some onlookers though. They had set up the instruments on the roof and compound of the Court, but they were

> … compelled to have all removed to another position about two miles distant, out of the reach of the too inquisitive and meddlesome loiterers about the supposed magical spot; for not contended with looking, they must needs finger the thermometers and tamper with the instruments to such an extent as to render trustworthy records impossible. (*ibid.*).

But Pogson was relieved that

> To their credit, however, not an article was missing, simple curiosity, not acquisitiveness, being the sole cause of their troublesome interference. (*ibid.*).

8.6.1 Meteorological Observations

At the same time, measurements were taken with different thermometers and barometer, which were attended to by Mr Walker. They had a dry bulb thermometer that was kept in the shade, and a black bulb thermometer, exposed to sunlight.

There was nothing unusual about temperature until about a quarter of an hour before the totality, "… when the light and heat of the sun …" diminished palpably, and there was "… chirping of birds as at evening twilight." (Pogson, 1869: 4). Then,

> After this time the rapid diminution of temperature appeared to cause the formation of hazy clouds, which prevailed more or less until about a corresponding interval after the totality. (Pogson, 1869: 4–5).

But these clouds, fortunately, did not come near the Sun, according to Pogson's report.

There was a light north-west wind before the eclipse, but it became calm "… some time before and after the totality." (Pogson, 1869: 12). Pogson (*ibid.*) pointed out that

> A fresh westerly breeze sprung up with the increasing sunlight, and a fine solar halo continued visible for some time after the end of the eclipse.

The meteorological measurements made by Mr Walker were tabulated on Table 4.

9 ANALYSIS AND THE WRITE UP

After returning to Madras from Masulipatam Pogson focused an analyzing the accumulated astronomical and meteorological data, and around the end of 1868 he completed a monograph that reported the principal scientific results of his eclipse expedition, including the discovery of anomalous emission lines in the yellow and green sectors of the solar spectrum. His monograph was titled *Report of the Government Astronomer: Upon the Proceedings of the Observatory, in Connexion with the Total Eclipse of the Sun on August 18, 1868, as Observed at Masulipatam, Vunpurthy, Madras, and other Stations in Southern India*.

Although there is no publication date listed, it would seem that in 1869 the Government of India printed Pogson's report, which ran to just

Table 4: Meteorological measurements made at Masulipatam on the day of the 18 August total solar eclipse (after Pogson, 1869: 12).

Time (a.m.)	Barometer Reduced to 32^0	Thermometers in shade		Humidity (%).	Solar black bulb in vacuo.
		Dry bulb	Wet bulb		
8¼		85.4	82.6	89	
8½		85.1	81.6	86	105
8¾	29.763	84.8	81.3	86	102
9		84.6	81.0	86	98
9¼	29.766	84.1	80.8	87	94
9½		83.6	80.6	88	91
9 ¾		82.8	80.1	89	87
10		82.6	80.4	91	87
10¼		83.0	81.0	92	102
10½	29.772	83.8	81.4	90	110
10¾		85.1	82.2	88	119
11		86.6	83.1	86	128
11¼		89.1	85.3	85	130

32 pages.[1] But for some totally inexplicable reason (which they probably justified in terms of financial strictures) they only approved the printing of three copies!

One can imagine Pogson's reaction to this unbelieveable decision, which he may very well have attributed to Airy, and his continued attempt to minimize Madras Observatory's involvement in the 1868 solar eclipse campaign and at very least stifle any attempt to circulate the research outcomes of Pogson's solar eclipse expedition. This could also explain why Pogson decided not to prepare a paper or papers for publication in *Monthly Notices of the Royal Astronomical Society*, given Airy's association with this journal, but it does not explain why Pogson neglected to write a paper for *Astronomische Nachrichten* when he learnt that there would not be multiple copies of his Madras Observatory *Report* that he could distribute to internaltional observatories, universities and colleagues.

While we certainly are not advocating that Pogson should have emulated Janssen and immediately written five different papers based on his 1868 eclipse observations, a single paper in *Astronomische Nachrichten* would have reached a wide international audience and allowed Pogson to report his observations of what later became known as the helium and coronium lines.

10 CONCLUDING REMARKS

In hindsight, during the 1868 total solar eclipse Pogson and his team had discovered at least three important new facts about the Sun, although he never received full recognition for them. One was the polarization of the corona, as observed by Winter, but it could be said that this was also observed by most of the teams that gathered to study the eclipse. However, the credit for the other two discoveries should be given to Pogson.

One was his observation that the bright yellow line was "… either coincident with or very near the place of the sodium line D." (Pogson, 1869: 10). At the time, every other observer, including Janssen, Tennant and Herschel, stated that it was the sodium line. Only Pogson had a doubt, and that made all the difference. In his report in 1896 on the discovery story of helium, Norman Lockyer, wrote that it was Pogson's phrase that drew his attention to the uniqueness of this line, ultimately leading to his independent discovery of the helium line on 20 October from his house in London. The renowned Indian astrophysicist Subrahmanyan Chandrasekhar (1910–1995) once wrote:

> In the year 1868, during an eclipse of the sun visible in India, the spectroscope was first put into effective use for the study of the chromosphere by Lockyer, Pogson, and Janssen … we have illustrated Pogson's original diagram of the spectrum of the chromosphere. It will be seen that in the spectrum there is a bright line appearing in the position of the dark (Fraunhofer) D line of the normal solar spectrum. Referring to this yellow line, Pogson said that it was 'at D or near D'. Almost the whole story of helium depends on this distinction. (Chandrasekhar, 1947: 314).

There could not have been a better and more emphatic appreciation of Pogson's observation than this.

The second discovery was Pogson's observation of the green line, which traditionally has been ascribed to Charles Young and the North American eclipse of 1869. Since Pogson's report was never circulated, Pogson never got the credit for this discovery. As a recent paper on Pogson's life and work has summed up:

> … due to delays in government publications, Pogson lost credit for being the first to observe the spectrum of the solar corona, during the total solar eclipse of 1868. (Reddy et al. 2007: 242).

Pogson's trauma was to continue after the eclipse. The same paper states that "Airy dodged all letters from Pogson requesting instruments, instructions and nominations for the RAS." (*ibid.*). Personal tragedies also struck Pogson. A year after the eclipse Pogson's wife died of cholera. One can only imagine what more could have come out of his eclipse expedition if he had been able to access more manpower and better instruments, or if he had chosen to also report on the results of his eclipse expedition through papers submitted to *Astronomische Nachrichten* and *Monthly Notices of the Royal Astronomical Society* (journals in which he had published extensively in the past), instead of relying solely on publication of his official Madras Observatory Report. It would seem that this myopic attitude would delay him taking his rightful place in the annals of solar physics for nearly a century and a half.

11 NOTES

1. This report contains not only accounts of the Masulipatam expedition by Pogson, Walker and Winter, but also an account by Ragoonatha Charry of the Madras Observatory's expedition to Vanpurthy (see Venkateswaran, 2021), and brief accounts of other observations made from India and from Colombo in Ceylon. The final page lists lunar occultations of stars observed from Madras and Masulipatam at about the time of the total solar eclipse.

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