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SOLAR PHOTOGRAPHY IN THE NINETEENTH CENTURY: THE CASE OF THE INFANTE D. LUIZ OBSERVATORY IN LISBON (1871-1880)

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Abstract: The Infante D. Luiz Observatory, located in Lisbon, was one of the leading Portuguese meteorologic and magnetic research institutions in the second half of the 19th century. Following the distribution of the equipment bought by the Portuguese government for the total solar eclipse expedition of 1870 December 22, the D. Luiz Observatory acquired an equatorial telescope. João Carlos de Brito Capello, one of the two Infante D. Luiz chief observers, seized this opportunity and decided, in early 1871, to embark in a programme of daily solar photography to study the relationship between the solar activity, in particular the sunspots, and the terrestrial magnetic field. The programme was active between 1871 and 1880, albeit intermittently, having been well received by the international community and led to a couple of publications. For a time the Infante D. Luiz Observatory solar photographs not only kept a record of the sunspot activity complementing similar work done elsewhere but were amongst the best available everywhere. This article proposes to give an account of its implementation and development in the context of the solar photography of the period.

Keywords: Portuguese Astronomy, Solar Photography, 19th century, Infante D. Luiz Observatory, João Carlos de Brito Capello

1 INTRODUCTION

In this paper we start by giving a short account of the early history of the Infante D. Luiz Observatory, before proceeding with an overview of the status of solar photography prior to 1871 and the techniques then in use. This will provide the background against which we will compare the research programme implemented at the Infante D. Luiz Observatory and the decisions made by João Carlos de Brito Capello, its main driving force. A detailed section concerning the execution of the programme from its beginnings in 1871 to its end approximately ten years later then follows. Finally, we will track the impact of this research on contemporaneous scientists and in the nineteenth century specialised literature.

2 THE INFANTE D. LUIZ OBSERVATORY

On 21 July 1853, sixteen years after its foundation (in 1837), staff at the Lisbon Polytechnic School decided to create Portugal's first meteorological observatory. From the beginning the observatory strategy was clearly defined. The new institution would have a research component in which an uninterrupted series of observations, as complete as possible, would be performed in a proper environment (Malaquias et al., 2005). Construction of the Observatory was concluded by the end of the summer of 1854, and the first published observations date from 1 October of that same year. Magnetic readings were taken from 1857 onwards. The original building was replaced in 1863 by a new one (see Figure 1), thanks to generous financial support from the Portuguese King, D. Luiz (Peixoto, 1987: 220). New equipment was purchased in England, specifically from the Kew Observatory, and one of the observers from the Lisbon Observatory, João Carlos de Brito Capello, went to London in 1863 where he was instructed in its use (Capello and Stewart, 1864).

Figure 1: The 1863 Infante D. Luiz Observatory building (after *Annaes do Observatório do Infante D. Luiz*, *Volume 1*, 1863).

The creation of the Infante D. Luiz Observatory must be viewed in the context of a wider international push for the study of meteorological and magnetic phenomena in the nineteenth century, which included the 1834 'Göttingen Magnetic Union', the 1853 Maritime Meteorological Conference in Brussels and the 1857 Paris International Meteorological Service (led by LeVerrier). Portugal was represented at all of the earliest meteorological conferences (Brussels 1853, Viena 1873, London 1874, and Rome 1879), and contributed, via the Infante D. Luiz Observatory, to the International Meteorological Service from 1857 onwards, just as soon as the telegraphic connection between Lisbon and Paris was established; it also joined the Magnetic Union in 1857. The *Annaes do Observatório do Infante D. Luiz* was published regularly beginning in 1863. From this date, João Carlos de Brito Capello (Figure 2) published several papers on the analysis of geomagnetic observations in the *Proceedings of the Royal Society* (of London) (see Capello, 1869; Capello and Stewart, 1864), and he also contributed to the 1865 and 1885 annual meetings of the British Association for the Advancement of Science (see Capello, 1876b; 1886).

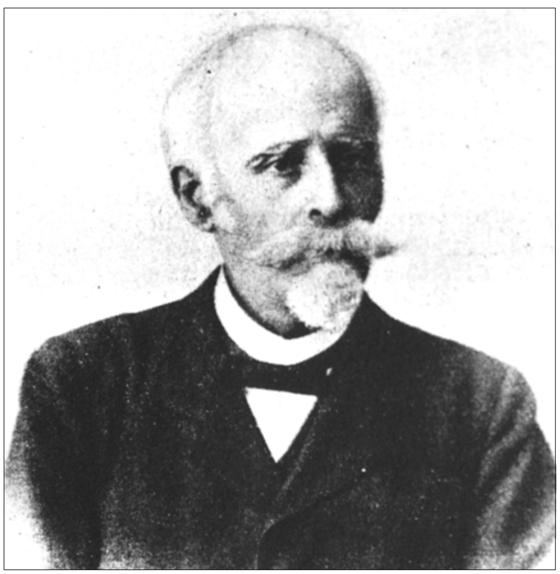

Figure 2: Portrait of João Carlos de Brito Capelo (1831–1901) (after *O Occidente*, *Volume 24*: 100 (1901)).

Meteorological and magnetic studies are intrinsically co-operative sciences, if a global data analysis is to be successfully performed. Consequently, international meteorological observatories were involved in a network of data collection, analysis and exchange, mainly via observatory publications (see Malaquias et al., 2005). From the start, the Infante D. Luiz Observatory in Lisbon played an active role in these networks, primarily because of the quality of the instruments, the work performed, and the geographical location of the country. In 1878 the Director of the *Bureau Central Météorologique* in Paris wrote to Capello:

> I have written today to the Director General of the French telegraphic lines asking him to speed up the transmission of the Portuguese messages. These telegrams have for the meridional Europe the same importance as the English ones for northern Europe. (Mascard, 1878).

Thus, the Infante D. Luiz Observatory was in an ideal position to exchange ideas and information with other observatories, and surviving correspondence from this period (1870-1880) illustrates this: there are letters from scientists or institutions in Japan, Russia and the United States of America, as well as from several European countries. This situation turned out to be very useful during the development of the solar photography programme, as we shall see later.

3 SOLAR PHOTOGRAPHY FROM ITS BEGINNINGS TO 1870

The application of photography to the study of the natural sciences has a long history. On 19 August 1839, Arago made a public presentation about the daguerreotype at the French Academy, and *Comptes Rendus* contained the main passages of a report previously presented by Arago to the 'Chambre des Députés' in which he predicted the future use of the photographic technique in the fields of selenography, photometry and spectroscopy (Arago, 1839). The inevitability of this application was later recognised by Arago in the third volume of his *Astronomie Populaire*:

> The idea of applying the photographic processes of Nièpce and Daguerre to the reproduction of some scientific subjects was a natural one; it is then difficult to conceive that the persons that have published their projects in this respect may consider them something to be proud of. Claiming the priority of obtaining photographic images of the Sun and Moon, seems to me childish. (Arago, 1867: 469).

The first astronomical photographers concentrated, not surprisingly, on the two brightest objects in the sky, the Sun and the Moon, even though these involved quite different technical problems. Lunar photographs were constrained by the slow speed of the early photographic plates and therefore required long exposure times and good tracking mechanisms, while the Sun's brightness demanded very short exposures, i.e. fast shutters (see de la Rue, 1860). John William Draper obtained the first successful lunar photograph in 1840 (Brothers, 1866), and correctly-exposed daguerreotypes of solar features were obtained in the early 1840s. According to Arago (1858: 247), Fizeau and Foucault "… took a large number of solar photographs in 1844 and 1845 …", one of which, taken on 2 April 1845 at 9h 45m, still survives. The first photographs of the partial phase of a total solar eclipse and of the solar spectrum were also obtained in the 1840s. From this point on, the range of celestial objects exposed to photography gradually increased (e.g. see Bajac et al., 2000; de Vaucouleurs, 1961; Lankford, 1984; Mouchez, 1887; Pasachoff et al., 1996; Rayet, 1887).

In an 1849 communication to the French Academy, Hervé Faye implicitly proposed the continuous photographic observation of the Sun:

> If a solar image is formed in the daguerrotype plate ... the same measurements can be repeated later on and compared with contemporaneous ones ... The same procedure may be applied to the determination of the heliocentric sunspot co-ordinates ... (Faye, 1849).

Then on 24 April 1854 John Herschel wrote in a letter to Edward Sabine that

> I consider it an object of very considerable importance to secure at some observatory, and indeed at more than

> one, in different localities, daily photographic representations of the sun, with a view to keep up a consecutive and perfectly faithful record of the history of the spots. (Herschel, 1855).

This idea was expressed again later in the year at the Liverpool meeting of the British Association for the Advancement of Science. Herschel's solar observing plan was seized upon by Sabine and a grant was allocated to Warren de la Rue for the construction of the necessary photographic equipment for the Kew Observatory (Rothermel, 1993). After several trials, successful solar photographs were taken in 1858 (Selwyn, 1864), and the work was continuously executed from 1862 onwards. In all, 2,778 solar photographs were obtained with the Kew photoheliograph between 1862 and January 1872 (RAS Council Report, 1872). A series of papers dealing with the data analysis was subsequently published, most notably about a possible planets-sunspot connection (see Charbonneau, 2002).

Following the Kew example, other solar photographic programmes were started. At least as early as 1860, the Ely helioautograph operated by Professor Selwyn was taking daily solar photographs (Solar Physics Committee, 1889: 38), a work which was classified by Warren de la Rue (1863) as being "… extremely valuable." The Imperial Academy of Sciences of St. Petersburg also became interested in solar photography and ordered a photoheliograph from England. Although de la Rue provided the design—which was basically an improvement on the Kew instrument—the photoheliograph was actually built by the London firm of Dallmayer. The instrument was unpacked in Pulkowa in August 1864, coinciding with a visit by de la Rue to Russia (see de la Rue, 1864), and became operational, in Vilnius, in 1868. During the period 1868-1876, about 900 photographs of the photosphere were obtained, and the series was only terminated in 1876 because of a fire (Vilnius University - Astronomical Observatory, 2007).

The continuous study of the photosphere required observatories located at different longitudes and latitudes around to globe, in order to minimize the effect of unfavourable weather at any particular locality, and this scenario was outlined by Herschel in the aforementioned 1854 letter to Sabine:

> Three or four observations in tropical climates, distant several hours in longitude (suppose 3, at 8h distance in longitude), each recording at, or nearly at noon, would, when the results were assembled, keep up a continuous history of the solar disk. (Herschel, 1855).

We have an analogous situation today:

> The Global Oscillation Network Group (GONG) is a ground-based set of telescopes that are positioned so that, at one station or another, they are continuously monitoring the Sun. (Golub and Pasachoff, 2001: 70).

The hope of increasing the number and location of daily solar observatories appears in several occasions in the *Monthly Notices of the Royal Astronomical Society* during the 1860s. For example, in the Council Report of the Forty-sixth Annual Meeting we read:

> In addition to the establisment of a photoheliograph at Wilna [Vilnius], there is a prospect of the erection of a third at Quebec. If this hope is realized, there will then be a station in England, in Russia, and in America, by means of which, on account of the difference of longitude, we may hope to have an almost uninterrupted self-register of solar phenomena. (RAS Council Report, 1866).

Two years later, upon referring to the Kew photographs, de la Rue states:

> ... certainly a better climate would be desirable. There is a photoheliograph at Wilna [currently Vilnius], but it is not yet at work, and one at Melbourne would be very valuable. (RAS Council Report, 1868b).

There were only four observatories involved in taking daily solar photographs by the end of 1870: Kew and Ely in England; Vilnius in Lithuania and Harvard College in the United States of America. Elsewhere solar photographs were taken from time to time—for instance in France by M.L. Sonrel (Capello, 1871h) and in the United States by Lewis Rutherfurd (Rees, 1906)—but not on a regular basis.

3.1 Solar Photographic Apparatus

As is well known, a thin converging lens of focal length f_0 produces a linear image size, h_0, in the focal plane equal to

$$h_0 = 2f_0 \tan(\alpha/2) \quad (1)$$

where α is the angular diameter of the object and the distance between the object and lens is infinite. From this equation it is clear that increasing the focal length, f_0, increases the focal plane image size. Consequently, a long focus telescope is preferable if large images are required. During the solar eclipse of 15 March 1858, which was visible from Paris, Porro obtained photographs of the Sun with a 15m focal length equatorially-mounted telescope (Faye, 1858).

A different approach, proposed by Herschel in 1854, was to use a medium-power equatorial telescope and photograph the Sun's image after amplification by a secondary lens. This was the system used in the Kew photoheliograph where the secondary amplification was provided by a Huyghenian eyepiece. The solar image produced by the first lens underwent an 8 times linear amplification by the secondary, and the final solar photograph that was obtained was 10 cm in diameter (de la Rue, 1860: 150).

A third option would involve securing a small prime focus image followed by a posterior enlargement, but:

> Even the portraitists tried to dissuade their costumers from having carte de visite and cabinet negatives enlarged, unless they were going to be painted over. The definition was low, the contrast even lower, and the potential profit hardly worth the time involved. (Hannavy, 1997: 54).

That is, if the initial solar image was not 'big enough', any enlargement was an unpractical proposition. Enlargements were nevertheless made to magnify solar surface characteristics like individual sunspots or if short exposures were needed.

During the 18 July 1860 solar eclipse Laussedat utilised a new approach to solar photography by using a fixed horizontal telescope combined with a Silberman heliostat (Laussedat, 1860b), and several photographs of the partially-eclipsed Sun were obtained. On 6 March 1867 there was an annular solar eclipse, and Laussedat tried again a similar apparatus in Italy but without success (Laussedat, 1868). In the papers that were presented to the *Académie des Sciences de Paris* (Faye, 1870; Laussedat, 1860a; Laussedat 1860b), there is no evidence that the telescope used was a long focus one. What is certain is that at Harvard on 4 July 1870 four photographs were taken with a forty foot focal length and a 4-in aperture lens made by A. Clark & Sons placed horizontally with independent supports for the movable unsilvered plane mirror, lens and photographic apparatus. In 1870, a newer lens corrected for the 'chemical rays' from the same maker accompanied the solar eclipse expedition to Spain (Searle, 1876: 40).

During the 1870s the main photographic apparatus used in solar photography was either a medium focal length equatorially-mounted telescope with amplifier (as proposed by Herschel and used at Kew, Vilnius and later on in Lisbon and Greenwich) or a horizontal long focus configuration without amplification (as used in Harvard College). Both approaches were used in the 1874 transit of Venus observations. The British, German, Dutch and Russian preferred the Kew model, while the French and Americans used the horizontal long focus telescopes (see Sheenan and Westfall, 2004: 245).

3.2 Photography Versus Drawing

The debate about the advantageous use of astronomical photography over drawing was not solved when the first celestial images were obtained with this new technology. Each new technical advance had to be thoroughly tested before it could be accepted, but there were early converts for whom photography will "… suppress the unfaithful eye of the observer." (Faye, 1849). Solar physics is a particular good example of a field in which the two different techniques coexisted for several decades. While some important early scientific results were obtained using photography—like limb darkening in the 1840s and the nature of prominences in 1860 (Meadows, 1970)—visual observations and drawings also contributed major advances, like Schwabe's 1843 sunspot cycle period and Carrington's (1863) investigation of differential solar rotation. In the 1868 "Statement of the Work Done at the Kew Observatory with the Heliograph" which was presented at the Forty-eighth Annual General Meeting of the Royal Society we find two examples of this ambiguity. In the first example, the heliographical elements obtained from the Kew photographs "… may in a measure be regarded as a continuation of Mr. Carrington's results …", and in the second one, area measurements of Schwabe's solar drawings will be used to establish a more trustworthy curve of periodicity (see RAS Council Report, 1868a).

Following observations in Sicily of the solar eclipse of 1870, steps were taken the following year to found the Società degli Spettroscopisti Italiani (Bònoli, 1998: 21). In the list of tasks to be performed, drawings of prominences and of the chromosphere were listed—as tasks 2, 6 and 9 respectively (Tacchini, 1872b). Nowhere are photographs mentioned in connection with the proposed solar program, a stance that draws criticism from Faye in his report on the new society to the Paris Academy:

> Concerning the relationship that might exist between the faculae, sunspots and the chromosphere that the Italian Society rationally plans to study, I believe that simple drawings executed by projection onto a screen are not enough today. (Faye, 1872a).

These comments provoked a reply from one of the Society's founders, Pietro Tacchini:

> That photography might be employed in an establishment with advantage is something I believe myself, but to study the relation between the faculae and the prominences, I believe that the results I have obtained by comparing the measured position angles and the positions of the prominences would be the same if I had used solar photographs, assuming that the photographs can reproduce exactly what is visible by projection, something I am not sure about … (Tacchini, 1872a).

In a counter reply Faye states that

> ... photographic observation which does not forget and does not exclude the visual observation is infinitely preferable in all situations. (Faye, 1872b).

This declaration somewhat conceals Faye's true position. In the previously-quoted paper (Faye, 1872a), a more pragmatic approach concerning the possible roles played by the two techniques is presented. Drawing as the only available solution would be used to register the spectroscopic images of the chromosphere while the record of the photosphere would be pursued photographically. The situation of solar photography versus drawing is, we believe, clearly summarised by Young (1881: 57) in his book *The Sun*:

> The character of the picture produced depends very greatly upon the proper timing of the exposure ... This circumstance detracts considerably from the value of the photographic method. The skillful draughtsman can show in the same picture details differing to any extent in intensity, while the photograph is, so to speak, limited to the reproduction of only one certain class of details at a time. Still we can always be sure that, whatever a photograph does show, is an autographic representation of fact, and not a figment of the imagination. This is not the case with drawings; for it is remarkable how widely two conscientious artists will differ in their representations of the same object, seen by both with the same telescope, and under the same circumstances. As an accurate record of the number, position, and magnitude of the solar spots at any given time, the photograph is, of course, unexceptionable.

In a letter to the French Academy, Father Angelo Secchi (1872) states:

> I am actually engaged in discussing the relationship between these two phenomena (sunspots and prominences) using the drawings made during the year. The comparison of these drawings with the fine photographs of Mr. Capello has convinced me that our drawings, without attaining the perfection of the photographic images, might be useful to science.

This judgement was expressed by a renowned scientist with practical experience in astronomical photography. Secchi photographed the Moon in the 1850s, obtained photographs of the partial solar eclipse of 28 July 1851 and was involved in the famous 18 July 1860 solar eclipse photographs obtained in Spain by José Monserrat (Gasparini, 1999).

A good example of the quality and detail attained using the drawing technique is the remarkable drawings of sunspots made by Samuel Pierpoint Langley (see Figure 3). George Ellery Hale is quoted saying that "… in the best views of sunspots he has ever had, the better they were seen, the more nearly they appeared as shown in Langley's drawings …" (Abbot, 1906). Meanwhile, Wittmann (2000: 86) presents an enlightening comparison between an 1873 Langley sunspot drawing and a modern CCD image.

Not surprisingly, the new technology—photography—did not immediately replaced the 'old' one—drawing. Instead both techniques co-existed for a long time, either in 'competition' or by complementing one another (see Pang, 1995, 1997; Tucker, 2005).

4 SOLAR PHOTOGRAPHY AT THE INFANTE D. LUIZ OBSERVATORY

During the nineteenth century the meteorological observatories kept expanding their measuring capabilities as time went by. At the Infante D. Luiz Observatory, for instance, magnetic measurements were introduced in 1857 and quantification of the atmospheric electrical potential in 1877 (Peixoto, 1987). Following the establishment of a relationship between solar activity and the Earth's magnetic field in the 1850s by John Lamond, Edward Sabine, Richard Carrington and Richard Hodgson (Dewhirst and Hoskin, 1997: 265), several observatories included the study of solar activity alongside that of geomagnetism and meteorological phenomena. Two well-known cases were the Kew Observatory (between 1858 and 1872) whilst operated by the British Association for the Advancement of Science, and the Collegio Romano in Rome, which was under the directorship of Father Secchi (Proverbio and Bufoni, 2004).

Those at the Infante D. Luiz Observatory were aware of these trends, for the importance of studying the relationship between sunspots and terrestrial magnetism was stressed in a 1861 report about magnetic work done at the Observatory and presented to the *Academia Real das Sciencias de Lisboa* (Lisbon Royal Academy of Sciences; see Silva, 1861). Photography was also performed at the Observatory, with self-registering instruments. In fact, "... Senhor Capello resided there [at Kew Observatory] for some time [in 1863] in order to become acquainted with the photographic processses." (Capello and Stewart, 1864). It is highly probable that during his visits to Kew Observatory, Capello became acquainted with the Kew solar programme. Close scientific links existed between the Portuguese Observatory and the Kew Observatory from the early 1860s onwards, and the Infante D. Luiz Observatory was one of the first to install Kew magnetographs, in 1863 (Malaquias et al., 2005). Following this event, research papers were published in collaboration with Balfour Stewart, who at the time was the superintendent of the Kew Observatory, and the scientific collaboration between Capello and Stewart survived Stewart's move to Owens College in Manchester in 1870, and continued throughout his life. For instance, in his 1885 report "Suggestions for the Committee [of the British Association for the Advancement of Science] on Magnetic Reductions", Stewart (1886: 68) writes:

> The following suggestions are founded on the methods proposed by several magneticians ... To Senhor Capello I am especially indebted for the trouble he has taken in explaining his views, with which these suggestions are almost identical.

Nevertheless, while they were aware of the new photographic and spectroscopic techniques, no Portuguese scientists tried to apply them in an astronomical context prior to 1870. The breakthrough only occurred in 1870, thanks to the solar eclipse of 22 December (see Bonifácio et al., 2006a).

4.1 The 22 December 1870 Total Solar Eclipse

The path of totality of the total solar eclipse of 22 December 1870 crossed the southern part of the Portuguese continental territory. Local scientists seized upon this opportunity, and an eclipse expedition was prepared with Government support and involving all of the Portuguese meteorological and astronomical observatories (Bonifácio et al., 2006a). Unfortunately, bad weather thwarted the sizeable effort made in preparing and equipping the expedition, and no results were obtained from the Portuguese station located at Tavira (Algarve). Nevertheless, this eclipse facilitated the acquisition of new equipment, and it also introduced Portuguese scientists to astronomical photography and spectroscopy. Both of these techniques were learned and experimented with prior to the eclipse. Following the eclipse, and in accordance with a recommendation by the eclipse commission, the Government decided to distribute the new equipment among some of the scientific institutions involved in the expedition (Folque, 1871).

Figure 3: Langley's drawing of the 23-24 December 1873 sunspot (after Young, 1881).

The 1870 eclipse also led to several attempts to start up solar physics in Portugal, but an important unsolved point remains: were these later aspirations a direct consequence of the eclipse experience and the possibilities opened up by the new equipment, or was the entire eclipse endeavour planned from the start with the objective of broadening the scope of astronomical research in Portugal? Doubts arise because the main protagonists, Luiz Albano and Brito Capello, both belonged to the eclipse planning commission and were observers at the Algarve station (Freire, 1872).

Albano was based in Coimbra, and was Professor of Practical Astronomy in the Faculty of Mathematics and second astronomer at the Coimbra Observatory. Although he received a photoheliograph and started teaching astrophysics, the implementation of a serious scientific research programme was not possible in a cramped understaffed Observatory constrained by its duties in classical astrometry (i.e. elaboration of the Coimbra Ephemerides), the complex rigid organisational structure and the economic difficulties the country found itself in at that time (see Bonifácio et al., 2006b).

Following Capello's involvement in the solar eclipse expedition, in early 1871 the Infante D. Luiz Observatory received a 12 cm aperture, 1.98 m focal length refractor by Repsold, with optics and a clockwork drive by Merz.

4.2 The Daily Solar Photography Research Project

In the beginning of 1871 Capello stated that in order to

> ... study the relationship between the sunspots and the magnetic perturbations we will perform both visual and photographic observations of the sunspots especially during the strong perturbations. (Capello, 1871e).

This statement was repeated during 1871 to different correspondents, including Father Secchi and Warren de la Rue.

Photography was preferred as the chosen image-recording medium even if initially that was before experimentation, but a mixed approach was considered best:

> I will try to photograph enlarged sunspots directly using the strongest eyepieces of the telescope ... If I am not able to do so I will try to draw the different sunspots and prominences while their positions will be established from full-disk photographs. (Capello, 1871f).

Later, in a letter to Faye, the choice of the photographic medium over drawing is explicitly made:

> You are right the use of photography is incomparably more exact and less tiring than drawings made by hand. (Capello, 1872i).

As far as equipment was concerned, the equatorial telescope provided by the Government implied that an approach similar to the one used at Kew Observatory would be adopted. This involved making minor alterations to the Repsold refractor and converting it into a photoheliograph.

4.3 The Beginning: 1871

In February 1871 the Director of the Infante D. Luiz Observatory, Fradesso da Silveira, submitted requests to the Government for funding (Pereira, 1871) and to the Polytechnic School for authorisation to construct a modest building to house the photoheliograph on the grounds of the school's planned Botanical Garden (Corvo, 1871). Simultaneously, Capello was busy gathering information from his network of correspondents. Scientific queries and requests for publications went far afield, and in February 1871 he wrote to Kew:

> I am asking you if at Kew you have tried to enlarge the sunspots seen in the solar photographs and if you were successful. I would like to know some details concerning Mr. Carrington's sunspot drawings: what was the diameter of solar drawings where all the groups of sunspots were represented & did Mr. Carrington make separate drawings of the outstanding sunspots and in that case what was the size of these sunspots in comparison with those in first drawing which contained all of the sunspots? ... Would it be possible to send me an original or a facsimile? Another question: I would like to have all the publications about the Kew sunspots by Mr W. de la Rue, Stewart and Loewy. (Capello, 1871c).

In an April 1871 letter to Father Secchi, Capello (1871j) presents his research plan, asks several technical questions and requests printed materials. Later that same year his plans and queries, coupled with requests for solar photographs, were sent to de la Rue in London (Capello, 1871g) and to M.L. Sonrel in Paris (Capello, 1871h).

At the same time technical tests were being performed. Initially Capello was using grey density filters to reduce the excessive solar radiation, but their frailty (they tended to break) led him to experiment with a glass with parallel surfaces (Capello, 1871c). Finally, he ordered a Herschel eyepiece from Kew (Capello, 1871b). In August a photographic workshop was installed near the photoheliograph building, and photographs of the Moon and the Sun were obtained. While poor tracking hampered the lunar photographs, the solar efforts were more successful, but they still needed improvement, which Capello thought could be obtained by using shorter exposure times. Shutter apertures of 1.5 mm and 12 mm were used for the whole-disk photographs and for enlarged sunspots, respectively. Exposure times were not indicated (Capello, 1871a). September was not very suitable for photography owing to adverse weather conditions, but by October the 'chemical' (or photographic) focus was established to be 6-7 mm longer than the visual one, and the first results began to appear:

> The 13 October image of the entire Sun seems very sharp and it is hardly possible to make the sunspots better defined, even though the amplifying lenses were not specially made; one belongs to a microscope and the other which is achromatic is a short focus eyepiece, 12 cm, from a small telescope. (Capello, 1871a).

The quality Capello attributed to the 13 October photograph may be inferred from the fact that he sent it to Secchi, de la Rue and the Paris and Kew Observatories (Capello, 1871a; 1871d; 1871g; 1871i). Capello's earliest known published photograph dates from 30 December 1871, and it appeared in the 1870-1871 Infante D. Luiz Observatory Service Report (Observatorio de Infante D. Luis, 1872). Subsequently, complimentary replies were received from Secchi ("The full Sun's image is of an admirable precision. It will be difficult to do better …") and from Marié Davy, head of the Paris Observatory's Meteorological section (ibid.).

4.4 The Year of Confidence: 1872

According to Capello by March 1872 the definition of the Portuguese Observatory's solar photographs was better than ever before, allowing the observation of the 'willow leaves' or 'rice grains' (granulation) on the solar surface (Capello, 1873b). The difficulty of this achievement may be ascertained by the fact that when Janssen succeeded in photographing these same features in 1877 he announced them at a meeting of the *Académie des Sciences de Paris* (Janssen, 1877a). In a later communication, Janssen (1877b) claimed the 'rice grains' had not previously been photographed, a statement that was promptly contested by Lewis Morris Rutherfurd. He stated that his solar photograph of 11 August 1871 that was presented to the Royal Astronomical Society showed the 'rice grains' (Rutherfurd, 1878), although it was of a poorer quality than Janssen's result. So it would seem that Capello's photographs can be compared favourably with the best contemporaneous efforts available elsewhere, even if some information was lost in the negative-to-positive 'translation':

> The nucleus is crossed by filaments seen perfectly on the negative; they are difficult to print on paper ... we have the same difficulty in printing the faculae. (Capello 1872e).

In April, stimulated by the description of the newly-formed *Società degli Spettroscopisti Italiani*, Capello (1872i) writes to the Secretary of the French Academy and reports "… our modest solar physics progresses …", even if "… the service is not totally organised. It lacks personnel and funds to function regularly." Several photographs accompanied the two letters sent to Hervé Faye. As a consequence, a note describing the Infante D. Luiz Observatory solar photographic programme subsequently appeared in the *Comptes Rendus*, where Faye took the liberty of elaborating upon Capello's comments about petitioning the Portuguese Government:

> We hope that the Portuguese government will want to take advantage of the fair Lisbon weather as well as of the skills already acquired by the Infante D. Luiz observers and will allow the scientific world to count with a vast harvest of important documents for the history of the solar physics. (Capello, 1872i).

From the start, the Lisbon climate was a distinct advantage:

> Since April 1st I took photographs of the solar disk in all clear sky days; during May, I only missed four or five days and none in June. (Capello, 1872e).

In July, the wet collodion response to the summer heat, plate manipulation and possible distortions of the optical apparatus were discussed with Secchi (Capello, 1872a), and the following month a Dallmayer eyepiece was ordered from London—through the good will of Warren de la Rue (Capello, 1872c). Meanwhile, Carrington's book, *Observations of Spots on the Sun from November 9, 1853 to March 24, 1861 Made at Redhill*, was bought via George Whipple (Capello, 1872b). Capello would later analyse the observations following Carrington's method (Capello, 1872h). Having seen a 9 August drawing of the solar photosphere, published in the 19 August issue of *Comptes Rendus* (Cheux, 1872), Capello (1872h) quickly sent the French Academy solar photographs for 8, 9, 10 and 11 August, and these were published in the 23 September issue (e.g. see Figure 4).

During this period Capello increased the definition and amplification of his photographs. Table 1 reveals his growing confidence in successfully enlarging photographs of sunspots.

In April Capello considered the possibility of obtaining "… an enlarged sunspot from the small photographs." (Capello, 1872g; 1872f), and by November results had been obtained (Capello, 1872j). This search for better and more enlarged positives might explain the existence of four unsigned sunspot photographs, corresponding approximately to an 88 cm diameter Sun and dating 9 and 11 November 1872, 17 December 1872 and 27 January 1873 in the Library of the *Instituto Geográfico Português* (Portuguese Geographic Institute, hereafter IGP) (see Figure 5). The IGP was the continuation of the 'Direcção Geral dos Trabalhos Geodésicos Topográficos, Hidrográficos e Geológicos do Reino' (the nation's General Direction of the Geodesic, Topographic, Hydrographic and Geological works) whose Photographic Section, run by José Júlio Rodrigues, was in the 1870s a centre of excellence in the field of photographic reproduction. Rodrigues was a Professor at the Lisbon Polytechnic School and we know that in 1875 Capello reproduced an engraving through the Photographic Section. If the identification of these photographs is correct, they are the only surviving unpublished enlarged sunspot photographs known that were taken at the Infante D. Luiz Observatory.

From his experiments Capello concluded:

> The principal problem affecting the sunspot enlargements and one, which I believe is beyond solution, is due to the agitation of the hot air; the sunspots are quite good if the image on the screen is stable; if the image is dancing the photograph will be blurred. It will take a very sensitive collodion. During winter the air is less agitated and I took several sunspots with lots of detail. (Capello, 1872d).

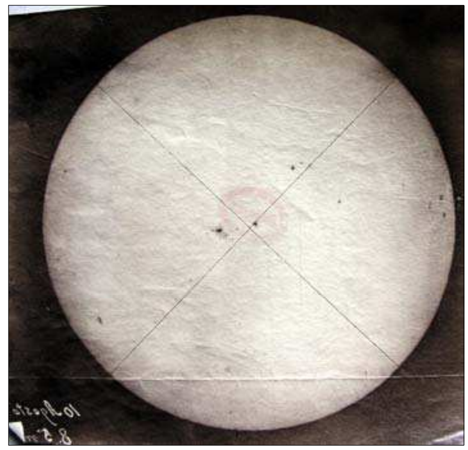

Figure 4: Capello's 10 August 1872 solar photograph (courtesy: *Académie des Sciences de l'Institut de France*; Note manuscrite de M.J. Capello conservée dans la pochette de séance du 23 Septembre 1872: "Sur l'aspect du Soleil vers le 9 Août").

Table 1: The Sun's equivalent diameter, *D*, as a function of time, derived from different sunspot photographs. *D* represents the Sun's diameter if the entire solar disk is photographed with the same magnification as the sunspots.

Date of photographs	*D* (cm)	Reference
August 1871	41.2-63	(Capello 1871a)
August 1871	32-65	(Capello 1871g)
October-November 1871	38.2-57.5	(Capello 1871d)
December 1871-January 1872	89	(Capello 1872k)
February 1872	72	(Capello 1872f)
April 1872	77	(Capello 1872l)
May 1872	90	(Capello 1872e)

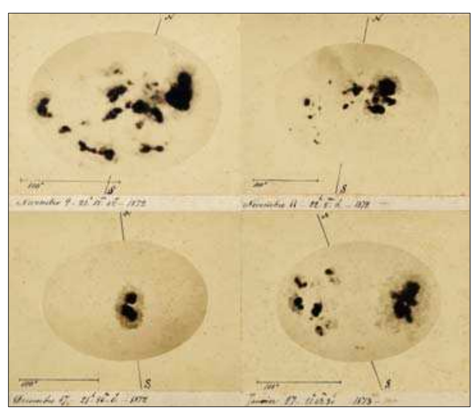

Figure 5: Four sunspot groups photographed on 9 and 11 November 1872, 17 December 1872 and 27 January 1873 (courtesy: *Instituto Geográfico Português*, F101F, F102F, F103F, F104F).

Once again the proposed solution involved a faster collodion i.e. shorter exposure times avoiding the Earth's atmospheric blurring effect. The photographic work continued throughout 1872, even though a compelling distraction—the 1874 transit of Venus—started to divert some of Capello's attention.

4.5 The Transit of Venus Hiatus: 1873-1874

An event that led to a surge of interest in solar photography was the 1874 transit of Venus. Astronomers waited for decades for the possibility of making this observation. Not surprisingly preparations started several years before 1874. At the time there was a widespread consensus amongst the astronomical community that the photographic observation of the transit would provide the necessary unbiased data for the exact determination of the Astronomical Unit.

The precision required demanded answers to very specific questions concerning the properties of the different photographic media, their corresponding techniques and the stability of the exposed plates. Wet, dry collodion and even the old daguerreotype were all tested with regard to durability, practicability and, most importantly, if any deformation occurred between the exposure and the final image. In his 1872 address to the British Association meeting in Brighton, de la Rue (1873) stated that "… in such observations as that of the transit of Venus, no refinement or correction ought to be neglected.", a sentence we know now to be prophetically true. The precision of the plate measuring turned out to be the weak link of the transit data analysis, even when care was taken with the machines that were employed for the purpose. While theoretically the idea seemed feasible, the lack of results from the 1874 transit of Venus is a stark reminder of the difficulty of carrying out experimental work in extraordinary circumstances.

The Portuguese astronomers did not manage to escape the transit of Venus 'fever' and as early as 1872 were planning a national expedition. In the summer, Capello was already writing to de la Rue asking for information concerning the British transit of Venus programme and sharing the still vague idea of a possible Portuguese observing station in the Far East, probably in Macao (de la Rue, 1873). We believe that some of the photographic experiments done in 1872, like the previously-mentioned photoheliograph distortion tests, were connected with the planned transit of Venus observations. This trend continued in 1873. For instance, Capello (1873a) tried the 'Uranium dry plates' developed by Colonel Stuart Wortley. The Infante D. Luiz Observatory's photoheliograph had to be altered to prepare it for the transit observation. With only one instrument available, this meant that the daily solar photographic work was interrupted from September 1873 (Capello, 1873a). Despite an initially favourable Government response to the Portuguese observation plans, the promised funds did not materialize and the expedition had to be cancelled (Campo, 2005).

4.6 The Decline: 1874-1880

After this disappointment, the solar photographic work resumed in February 1875 (Capello, 1875), but several factors contributed to the programme slowly fading away. The sunspot cycle was progressing from its 1870 maximum to its 1878 minimum (der Linden and the SIDC team, 2007) and Capello (1875) noted: "In this part of the year [i.e. February to August] I have seen only one remarkable sunspot." Later, on 10 March 1876, Capello (1876a) wrote to Secchi: "In these last times, 1875 and 1876, the sunspots and faculae are extremely rare." Since Capello seemed to be particularly interested in the problem of sunspot enlargements, the absence of sunspots or interesting sunspot groups for days at a time was far from encouraging.

From the documents consulted we conclude that the Portuguese solar photography project depended very heavily on Capello's efforts. From the start we find complaints concerning the need for more personnel and financial assistance. In 1871 Capello wrote of "My plan (if I am able to carry it out ... due to all the varied works I have) …" (Capello 1871a), and while the increased workload was taken over by Capello sometimes the strain involved appears in his correspondence. In an 1872 letter to Secchi he wrote: "… we have not yet obtained the necessary funds for the work and we lack personnel. At present I am alone in this need and I dedicate one hour and a half every morning to the work and I prepare the [photographic] baths during the night." (Capello, 1872g). We could not find any evidence of an increase in the staff of the Infante D. Luiz Observatory during the 1870s, to alleviate this problem. To make matters worse, on 30 April 1875 Capello was appointed Director of the Observatory, following the untimely death of Silveira (Ferreira, 1940). Obviously, this new position brought with it increased responsibilities.

Nor did the instrumental set-up at the Observatory change significantly during the 1870s, as the same 'old' equatorial was used, albeit with different eyepieces. If the main interest was to keep a consistent daily record of the solar photosphere this would not be a problem. For instance, the Kew photoheliograph was kept in the same state to avoid possible instrumental variations. But we have seen that Capello was very interested in experimenting, with the goal of obtaining the highest possible definition and magnification of the sunspot groups. In this sense, his equipment was slowly becoming outdated.

During this period at least two potential developments could have changed this *status quo*. In 1872, a 15-inch equatorial by Merz—still large by world standards—was to be installed in the Real Observatorio Astronomico de Lisboa (Royal Lisbon Astronomical Observatory) and Capello (1872a) wrote: "I possibly will have the opportunity to take a photograph with that large objective." In fact, the installation of the equatorial took longer than expected, and the instrument was not operational until 1876 (Raposo, 2006). Then in 1877, an 11-inch Alvan Clark refractor specifically dedicated to photography—the largest of this kind in Europe—was expected at the new Observatório Astronómico da Escola Politécnica de Lisboa (Lisbon Polytechnic Astronomical Observatory), founded in 1875 following the closing down of the Observatório da Marinha (Navy Observatory) in 1874, but for some unknown reason it never arrived in Lisbon (Silva, 1996). It therefore became impossible for Capello to compete in solar photography, especially after the breakthrough attained by Jules

Janssen in 1876 (see Janssen 1876). According to Young (1881: 59), Janssen "... has carried solar photography to a point far beyond any previous attainment …", a statement with which Capello agreed: "I have seen M. Janssen's fine work at Meudon I am much in doubt as to its being worth the trouble to take pictures as I did in former years." (Solar Physics Committee, 1882: 239).

We believe that the combination of these different factors contributed to the end of the solar photography programme at the Infante D. Luiz Observatory. In 1881, when responding to a circular from the Solar Physics Committee, Capello wrote:

> With reference to the collection and publication of sunspots, I would acquaint you that I possess a certain number of negative plates of the sun, about 4 inches diameter, taken during the years 1872 (the end), 1873, 1874 [we believe this is a printing error and that the correct date is 1875—see Capello (1875)], and some which are more recent. (Solar Physics Committee, 1882: 239).

While we know that these photographs cannot represent the entire output of the programme since there is no doubt that successful photographs were taken in 1871 and that several were damaged over the years (Capello, 1883), one might be tempted to conclude that no significant solar photography occurred at the Infante D. Luiz Observatory in the years 1876-1879. We did not find any reference to solar photographs being taken after 1880, and we consider this year to mark the end of the programme.

5 THE INFANTE D. LUIZ OBSERVATORY'S SOLAR PHOTOGRAPHY PROGRAMME AND THE NINETEENTH CENTURY LITERATURE

To our knowledge only two scientific research papers, both published in the widely-read *Comptes Rendus*, resulted directly from the Infante Infante D. Luiz Observatory's solar photography programme (see Capello, 1872i; 1872h). The real impact of the Observatory's photographs is difficult to assess but we believe its profile was increased by two factors. Firstly, there is the extensive network of contacts that Capello established (see Figure 6), which allowed the photographs to become known to a large number of important scientists and institutions.

Secondly, we believe that the quality of the photographs made them more noticeable, as can be ascertained by the flattering remarks published by Father Secchi in *Comptes Rendus* and from the medal of merit that was awarded at the 1873 Vienna Universal Exhibition (Silveira, 1874: 157). This visibility also led to an invitation from the *Societé Française de Photographie* for Capello to exhibit "… the interesting work done at the observatory …" in the 1874 Paris *Exposition Universelle de Photographie* (Koziell 1874), but Capello (1874) was forced to decline because he was busy preparing for the 1874 transit of Venus. We believe it significant that the Solar Physics Committee (1882: 231) included Capello in their short-list in 1880 when they were seeking "… to communicate with men eminent in solar inquiry, with a view of obtaining suggestions and ascertaining to what extent they might hope for help …"

In a non-exhaustive search of the nineteenth century astronomical literature, we found the following references to the Infante D. Luiz Observatory's solar photography programme:

- 1872, photographs published in the *Comptes Rendus de l'Académie des Sciences* (Capello, 1872h).
- 1877, Secchi, *Le Soleil*, second edition, first volume: "In the observatories where it is possible to sacrifice a telescope to this work one adopts solutions that make it easier: for example, one can enclose the eyepiece in a dark chamber fixed to the end of the telescope: that is, the method used at Kew, Lisbon and elsewhere." (Secchi, 1875a: 42).

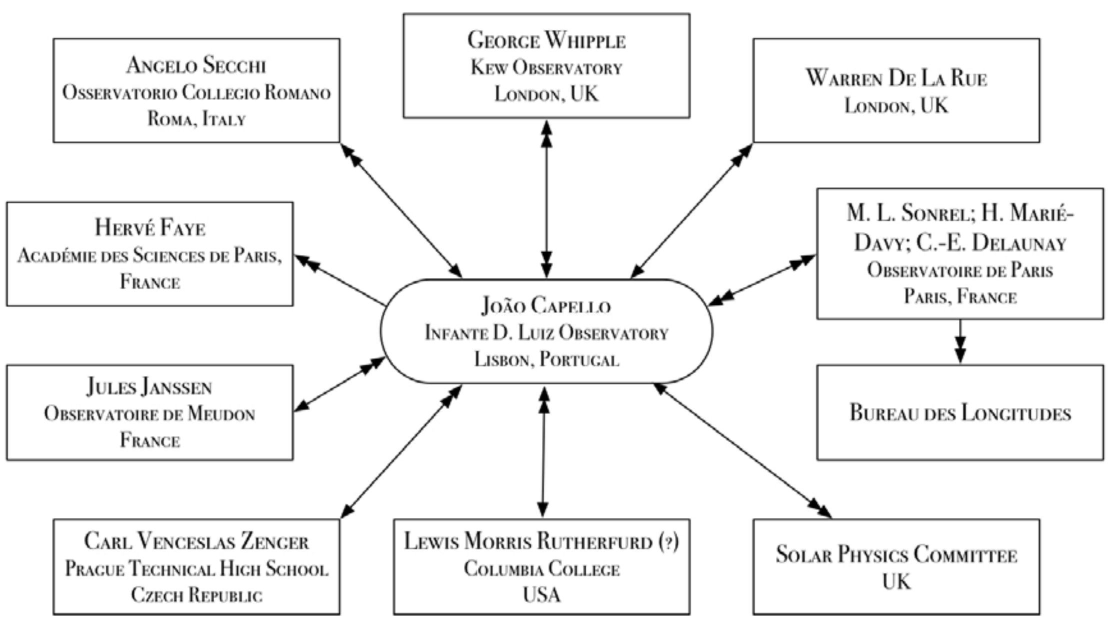

Figure 6: Diagram constructed from the *Biblioteca do Instituto Geofísico* correspondence volumes illustrating Capello's solar photography communications. Single arrows indicate letters that were sent, double arrows show that photographs were also exchanged. None of the photographs sent to Lisbon seem to have survived. Note: The identification of Lewis Rutherfurd is based on a single ambiguous Capello draft letter. This is the reason why we use a question mark in front of his name.

- 1877, Secchi, *Le Soleil*, second edition, second volume reproduces the sunspot group photographed on 23 April 1872 (Secchi, 1875b: 188)—see Figure 7, overleaf.
- 1878, Radau, *Revue des Deux Mondes*: "Mr. Dallmayer was responsible for building the Wilna [Vilnius] and Lisbon photoheliographs, where the instruments are functioning regularly." (Radau, 1878).
- 1887, Rayet, *Notes sur L'histoire de la Photographie Astronomique*: "Photoheliographs similar to the Kew one were several years ago installed in Vilna [Vilnius] and Lisbon." (Rayet, 1887: 879).
- 1896, Janssen, *Annales de l'Observatoire d'Astronomie Physique de Paris*: "The Kew solar photographic work was the starting point for similar programmes organised in Lisbon, Wilna [Vilnius], and after that in several other places." (Janssen, 1896: 32).
- 1897, Scheiner, *Die Photographie der Gestirne*: "Instruments build in a similar fashion [to the Kew photoheliograph] exist in Wilna [Vilnius] and Lisbon." (Scheiner, 1897: 268).

Not surprisingly, the Portuguese mathematician, Rudolfo de Guimarães (1909: 96) wrote that Capello's "… sunspot studies granted him a universal reputation."

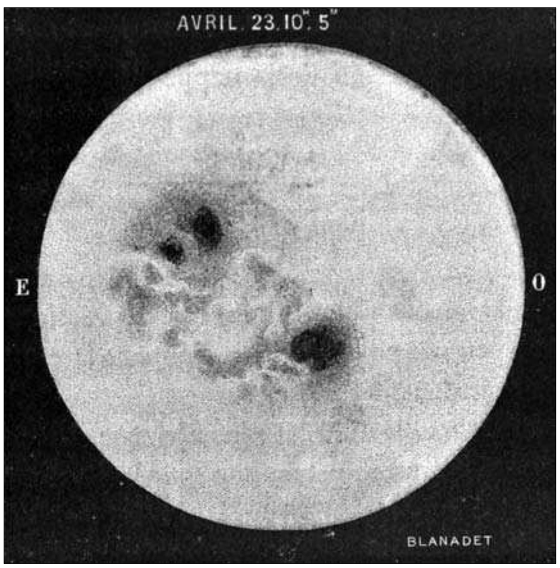

Figure 7: Capello's enlargement of a sunspot group, taken on 23 April 1872 (after Secchi's *Le Soleil*, *Volume 2*, 1878: 879).

6 CONCLUSIONS

Taking advantage of the Government's gift of a quality equatorial telescope to the Infante D. Luiz Observatory, the institution's prior involvement in geomagnetic work and the support of his Director and the Polytechnic School, João Carlos de Brito Capello decided to embark on a 'hot' research topic, the relationship between solar activity and the Earth's magnetic field. The choice of photography as the medium to register the solar photosphere placed the Observatory in a very restricted club of institutions. The analysis that Capello wanted to perform on the collected data is not completely clear. We have not found statements concerning the planetary-sunspot hypothesis pursued at Kew in the 1860s and early 1870s or the possible physical causes behind the solar activity-terrestrial magnetism connection. Rather, the information we can deduce from the available documents indicates, on one hand, that Capello did not expect a short-term response to the complex Solar-terrestrial connection problem, which is not surprising for someone with a meteorological background, while on the other hand, his pursuit of high-definition enlarged photographs of the solar surface, and in particular of sunspots, may have been connected with the hope of inferring information not available to naked-eye observers. This is a plan that was not dissimilar to one followed by Jules Janssen a few years later, which did produce well-known results.

The fate of the Portuguese solar photography project rested on the shoulders of just one man, João Carlos de Brito Capello, and the programme met its demise in about 1880 after he experienced ten years of increased responsibilities, stress, equipment short-falls and limited financial support. When at its peak, the Infante D. Luiz Observatory solar programme produced first-class results, and was recognised by its peers as a leading institution in this field. Later references in the works of several important scientists, including Angelo Secchi and Jules Janssen, provide a sparkling reminder of the programme's overall achievements.

7 ACKNOWLEDGEMENTS

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