COSTA LOBO AND THE STUDY OF THE SUN IN COIMBRA IN THE FIRST HALF OF THE TWENTIETH CENTURY

António José F. Leonardo, Décio R. Martins and Carlos Fiolhais
Department of Physics and Centre for Computational Physics
Faculty of Sciences and Technology, University of Coimbra
3004-516 Coimbra, Portugal.
E-mail: ajleonardo@iol.pt; decio@pollux.fis.uc.pt; tcarlos@teor.fis.uc.pt

Abstract: In 1925 the first scientific unit devoted to astrophysics was created in Portugal as a section of the Astronomical Observatory of the University of Coimbra. A spectroheliograph, the state-of-the-art instrument for solar physics was installed at the Observatory. This achievement was due to the efforts of Francisco Costa Lobo, Professor of Mathematics in the Faculty of Sciences and astronomer at the Observatory. As President of the Institute of Coimbra (IC), an academy associated with the University which had been founded in 1852, he managed to get Government support and to establish some international scientific contacts which were essential to his goals. Several articles published in *O Instituto*, the journal of the Institute, reveal the chain of events leading up to the beginning of solar studies in Coimbra and the outcome of the first investigations at the new section of the Observatory. Coimbra benefited from the cooperation of the French astronomers Henri Deslandres and Lucien d'Azambuja, both of whom were at the Meudon Observatory in Paris. D'Azambuja visited Coimbra to help install the spectroheliograph. Costa Lobo's son, Gumersindo Costa Lobo, also played a pivotal role in this endeavor. Together they gave birth to the cooperation between Meudon and Coimbra, which persists today and is one of the oldest scientific exchanges between the two countries.

Keywords: astrophysics, solar phenomena, Francisco Costa Lobo, Gumersindo Costa Lobo, Astronomical Observatory of the University of Coimbra, Institute of Coimbra

1 INTRODUCTION

On 25 July 1914, Francisco Costa Lobo (Figure 1), the first astronomer at the Astronomical Observatory of the University of Coimbra (henceforth UC) in Portugal, arrived in Paris accompanied by Captain Carlos Nogueira Ferrão (1871–1938) and the Captain's son, Álvaro Ferrão, carrying the optical components of all instruments they would need to observe the total solar eclipse of 21 August. Following an invitation from Nikolay Donitch (1874–1956), an astronomer at the Imperial Academy of St. Petersburg, Russia, they wanted to travel to Theodosia in the Crimean Peninsula, which was the most suitable place to observe this particular eclipse. The remaining instruments had already been shipped on 10 July and, in the short time they spent in Paris, Costa Lobo met Henri Deslandres, Director of the Meudon Observatory who warned him of the serious difficulties he would face in getting to Russia given the prevailing political situation. On 31 July Costa Lobo reached Berlin, and found a city which was preparing for war. That same night Germany issued an ultimatum to Russia, which ignited the First World War. At 6 a.m. the following day, Costa Lobo met Sidónio Pais, the Portuguese Ambassador in Berlin and his former colleague in the Faculty of Mathematics at the UC, in order to try to obtain transportation to Theodosia, but this was to prove impossible. He was eventually persuaded to give up, and he and his entourage took the last train to Basel, Switzerland. Over the next five days Costa Lobo kept hoping that he would find some sort of transportation which would allow him to fulfil his long-prepared mission. His aim was finding answers to two questions that had occurred to him while observing the solar eclipse of 17 April 1912. One question concerned the Moon's polar flattening and the other the refracting effect in the Moon's valleys. Unfortunately he was obliged to return to Portugal, and the only alternative left was to observe the partial solar eclipse that would be visible from Coimbra, using instruments at the Observatory. Meanwhile, the instruments that had been sent to Theodosia were only returned to Portugal after the war had ended (Costa Lobo, 1914).

Figure 1: Francisco Miranda da Costa Lobo, 1865–1945 (after Amorim, 1955: frontispiece)

This episode reveals Costa Lobo's determination when pursuing scientific knowledge. He had graduated from the UC in mathematics and philosophy in 1884, obtaining a high grade, and was immediately invited by both faculties to become a teacher. He chose the Faculty of Mathematics, where he completed his Ph.D. on 27 July of that same year with a thesis on the "Resolution of Undetermined Equations". On 7 January 1885 the by-then 21 year old Costa Lobo became a substitute Professor of Integral and Differential Calculus and in 1892-1893 he was appointed a full Professor of Astronomy.

Francisco Costa Lobo participated actively in Portuguese political life. In 1889 he was appointed substitute Governor of the Coimbra District. As a member of the Progressist Party he was elected Deputy to the National Parliament on 11 March 1905 by the same District, and was re-elected on 13 September 1906. Costa Lobo returned to the Parliament in 1908, after the dictatorial Government of João Franco ended with the regicide of King Carlos. With the proclamation of the Republic on 5 October 1910, politics lost its initial appeal and although he became a member of the new Monarchic Party his political involvement was considerably reduced, and was largely replaced by his increased academic activity.

As a researcher, Costa Lobo specialized in the study of the Sun. On 18 November 1904 he became First Astronomer at the Coimbra Astronomical Observatory (Reis, 1955: 31). His interest in solar physics began in 1907 when he went on a scientific excursion to some of Europe's important astronomical observatories, and meet Henri Deslandres (1853–1948), Director of the Meudon Observatory. Deslandres convinced him that the Coimbra Observatory needed to acquire a spectroheliograph, that recently-invented instrument which was revolutionizing the study of the Sun.

On 17 April 1912 Costa Lobo arranged with his students and with a Captain Ferrão who was an excellent photographer, to observe a solar eclipse from Ovar, which was close to Porto. They succeeded in registering the most important phases of this eclipse with a small cinematographic apparatus (see Bonifácio et al, 2010),[1] and a report that he sent to the Academy of Sciences in Paris was published on 28 May in the *Comptes Rendus* (Costa Lobo, F., 1912). Gumersindo Sarmento da Costa Lobo (1896–1952), the son of Francisco Costa Lobo, also worked in the field of solar physics, and participated in some of the investigations carried out by his father in Coimbra.

The history of Coimbra's Astronomical Observatory dates back to 1772 when the Marquis of Pombal reformed the old University. The new statutes demanded that an observatory be installed so that the University could offer practical lessons of astronomy and longitude determination. At first an ambitious building located over the ruins of Coimbra's medieval castle was projected, but work was suspended in September 1775 due to problems with the location and a shortage of funding. In 1799 a new and less ambitious building (Figure 2), located in the courtyard of the University and quite close to the beautiful Baroque University Library, was inaugurated (Bandeira, 1942; Pinto, 1893).

In this paper we report, on the basis of several articles published in *O Instituto* (*The Institute*), how the first spectroheliograph was installed in Portugal and how it allowed not only the beginning of solar physics in this country but also cooperation with France—which continues to this day. We also analyse the scientific research carried out in Coimbra, based on several articles published in the same journal, and the involvement of the academic society Instituto de Coimbra, its publisher, in the creation of the solar physics section in Coimbra. This was mainly due to

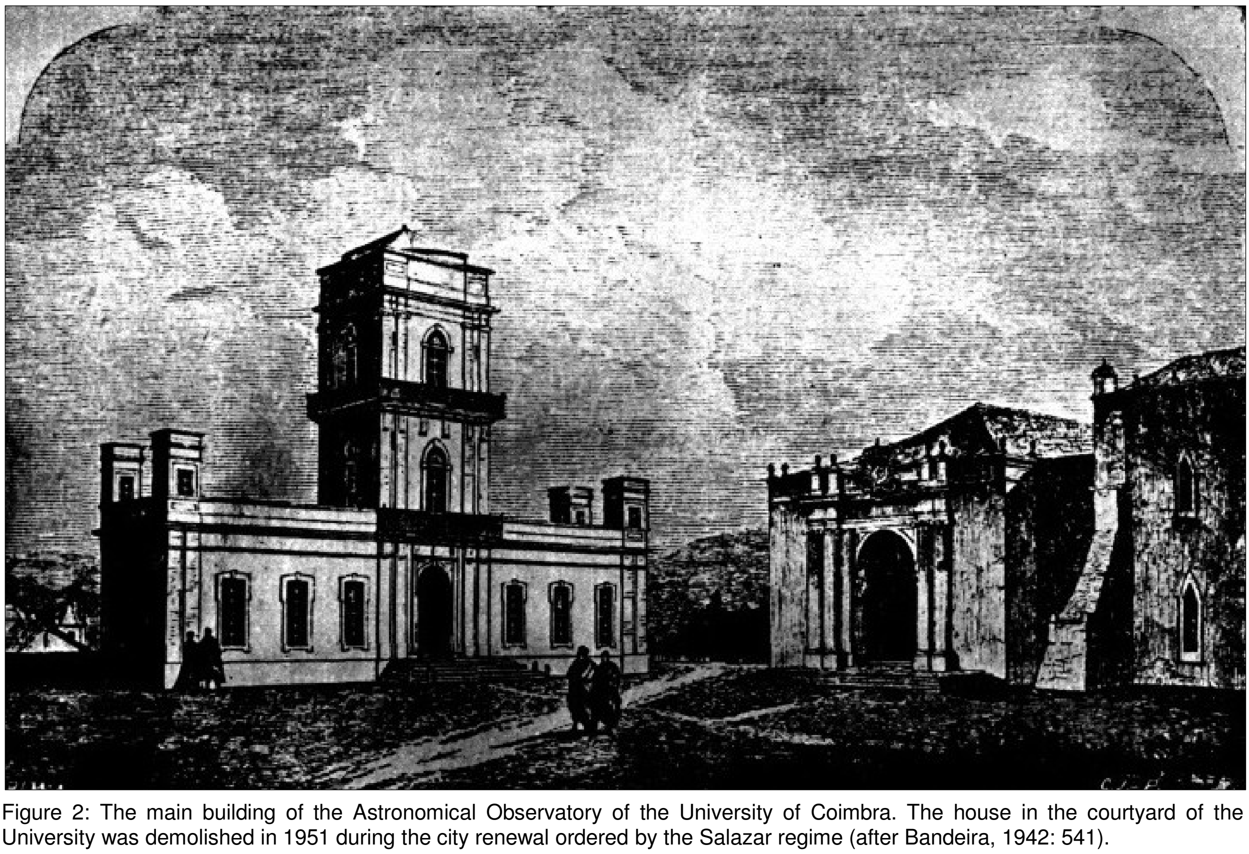


Figure 2: The main building of the Astronomical Observatory of the University of Coimbra. The house in the courtyard of the University was demolished in 1951 during the city renewal ordered by the Salazar regime (after Bandeira, 1942: 541).

its President, Costa Lobo. Among the people involved in the project, we devote special attention to Costa Lobo's son and to Lucien D'Azambuja. Their articles and conferences on solar physics were an outcome, at least in part, of the observations performed in Coimbra and the cooperation between the observatories at Coimbra and Meudon, following the general recommendation on international cooperation made by George Ellery Hale (1868–1938).

2 COSTA LOBO AND THE INSTITUTE OF COIMBRA

The Institute of Coimbra (IC) was an academic society founded in 1852 to promote sciences, literature and arts, and to develop Portuguese culture (Leonardo et al, 2009a). It was divided into three classes: the moral and social sciences, the physical and mathematical sciences, and literature and fine arts. Besides participating in the general assemblies, the IC fellows were supposed to produce works in their fields of expertise and to attend conferences organized by their class. Initiated by a group of professors, this academy had its most visible part in the journal *O Instituto*, which was published for almost one and a half centuries. When it closed, after 141 volumes, it was the scientific and literary journal with the greatest longevity in Portugal. Of its articles, 18% were devoted to science, and, within them, almost 10% were on astronomy and astrophysics (Leonardo et al, 2009b).[2] Reading these articles, mostly authored by members of the IC, one can learn a lot about science in Portugal in the second half of the nineteenth century and the beginning of the twentieth. The IC, which had a library and a reading room on its premises, regularly organized congresses and conferences. Its influence may be measured by the list of its associates, including some of the most renowned Portuguese scholars in various fields, and by the list of distinguished foreign correspondents.

Costa Lobo was elected President of the IC in 1913, and held this position until his death in 1945. This period was also one of the most productive in the history of the Institute: the congresses and conferences organized or attended by the IC members were numerous. We only mention the Congresses of the Spanish and Portuguese Associations for the Development of Science (Porto, 1921; Coimbra, 1925, and Lisbon, 1932), the Congresses of the International Astronomical Union (Cambridge, England, 1925, Leiden, 1928, and Cambridge, United States, 1932) and the General Assemblies of the Geodesic and Geophysics International Union (Stockholm, 1928, and Lisbon, 1933). The organization of the 5th General Assembly of the Geodesics and Geophysics International Union, held in Lisbon from 17 to 25 September 1933, benefited from the personal engagement of Costa Lobo.

He also managed to include many international astronomers as corresponding members of the Institute, including the following British colleagues: Frank Dyson (Director of the Royal Observatory Greenwich and Astronomer Royal), Harold Spencer Jones (Chief Assistant at the Royal Observatory and later Astronomer Royal), John Henry Reynolds (President of the Royal Astronomical Society), Arthur Stanley Eddington (a distinguished Professor at Cambridge) and Frederick J.M. Stratton (Director of the Solar Physics Observatory at Cambridge) who wrote Costa Lobo's obituary in the *Monthly Notices of the Royal Astronomical Society of London* (Stratton, 1946). French corresponding members were Henri Deslandres, Lucien D'Azambuja and Armand Lambert, from Paris and Meudon Observatories. Reviewing the minutes of the General Assemblies of the IC from 1924 to 1939 we find at least 16 European astronomers and directors of observatories who became corresponding and/or honorary members of the IC. Beside those already mentioned above, the list includes scientists from the French observatories of Lyon (J. Mascart), Marseille (I. Bosler) and Strasbourg (Ernest Esclangon);, the Canadian Observatory in Ottawa (F. Henroteau);, the Italian Observatory at Arcetri (Antonio Abetti), the Greek Observatory of Athens (M. D. Enginitis), the Spanish Observatory in Madrid (Enrique Gastardi); and the Polish Observatory at the University of Warsaw (J. Kanawsi). Many articles on astronomy were published in *O Instituto* by Costa Lobo himself and by some of the corresponding members (e.g. see Dyson, 1932; Stratton, 1940). As a whole they portray the evolution of this discipline in Portugal, and in particular the work done at the UC Astronomical Observatory with the creation and initial activity of the solar physics unit and the study of the Sun during the early twentieth century.

The IC and the Astronomical Observatory of the UC always had a connection, as shown by the succession of articles in *O Instituto* emanating from the Observatory. Of the almost 70 articles about astronomy that were published in *O Instituto*, many reported the results of observations made at the Observatory. Examples include the observations of eclipses and comets by the astronomer Rodrigo Ribeiro de Sousa Pinto from 1858 to 1862 and determinations of the longitude and latitude of the Observatory. Costa Lobo became Director of the Observatory on 23 September 1922 while continuing to serve as IC President.

3. THE STUDY OF THE SUN IN THE NINETEENTH CENTURY

The historical development in the eighteenth and nineteenth centuries of so-called 'solar-terrestrial physics' was strongly influenced by numerous European scientists (Schröder, 1997). The systematic observation of solar eclipses and planetary transits gave rise to the discovery of new structures on the solar surface. One example was the solar corona, that whitish halo that encircles the Sun during a total solar eclipse. On 8 July 1842, a total eclipse was visible in southern and central Europe, and many observers reported seeing rose-colored prominences extending from the solar limb (e.g. see the photo in Becker, 2010: 115). In 1852, observations confirmed that these prominences emerged from a reddish layer with the aspect of a sierra, which was named the chromosphere. The Portuguese astronomer Professor Matias de Carvalho de Vasconcelos (1832–1910), assisted Belgian's Adolphe Quetelet (1796–1874) in observing the solar eclipse of 15 March 1858 at the Observatory of Brussels. Carvalho was on a scientific trip to several European observatories and universities, and he delayed his departure from Brussels after being invited by Quetelet to participate in the eclipse observation. He took responsibility for the magnetic measurements, which he described in a report to the Faculty of Philosophy at

UC which was published in *O Instituto* in that same year (see Vasconcelos, 1858).

An important new approach to solar studies was spectral analysis, a technique developed in Heidelberg in 1859 by two Germans, the physicist Gustav Kirchhoff (1824–1887) and the chemist Robert Bunsen (1811–1899). In 1863, an article titled "The Sun, under the recent discoveries of Kirchhoff and Bunsen" (our English translation) by the French historian and engineer Auguste Laugel (1830–1914) was published in *O Instituto*. The discovery of Fraunhofer lines in the solar spectrum provided an excellent means to investigate the chemical composition of the Sun (and stars) (see Hearnshaw, 2010). Spectroscopic analysis laid the foundations of solar physics, and the explanation of the Fraunhofer lines confirmed the existence of a solar atmosphere enveloping the photosphere.

The impact of sunspots and other solar events on the Earth generated a strong interest in the study of the Sun, especially since they could cause magnetic disturbances to telegraphic transmissions, that new technology that was flourishing worldwide in the second half of the nineteenth century (see Leonardo et al., 2009c). One of these events, on 29 August 1859, became famous for its effects on international telegraphic communications and for the simultaneous observation of a white light solar flare by Richard Carrington (1826–1875) (Clark, 2007a; 2007b). This confirmed the importance of acquiring tools to predict their occurrence or, at least, to explain their origin.

In the second half of the nineteenth century many scientists became interested in solar eclipses as a consequence of the availability of new techniques and instruments. Whenever a solar eclipse was predicted, many groups vied for the best spots in the world to perform their observations. Portuguese astronomers also had this interest. Even though it was only partial in Portugal, the eclipse observed in Belgium by Matias de Carvalho in 1858 was monitored in the two national observatories, and the First Astronomer at the Observatory of Coimbra (who would become Director in 1866), Rodrigo Ribeiro de Sousa Pinto (1811–1891), published his measurements in *O Instituto* (see Pinto, 1858).

Although the determination of exact longitudes was an important by-product of these eclipse observations, the interest of the new solar gazers was the possibility of photographing the chromosphere and the solar corona, which were only visible on those rare occasions. The French physicists Louis Fizeau (1819–1896) and Léon Foucault (1819–1868) took the first successful photograph of the Sun in 1845. At the Königsberg Observatory in Prussia, in 1851, Berkowski obtained the first useful Daguerreotype of a solar eclipse (De Vaucouleurs, 1961). Then the British astronomer and chemist Warren De la Rue (1815–1889) introduced the wet collodion process and devised a method to avoid the sensitive collodion plates being overexposed by the Sun's glare. This technique showed a record number of visible sunspots and was used to photograph a solar eclipse at Rivabellosa, Basque Country (Spain) on 18 July 1860 (see Hufbauer, 1991; Costa Lobo, 1933b). Using a photoheliograph from the Observatory at Kew, De la Rue managed to register the successive appearance and disappearance of the prominences, on both sides of the lunar disc, an achievement that proved conclusively that they belonged to the Sun (Hingley, 2001).

An official Portuguese expedition comprising Sousa Pinto and Jacinto António de Sousa (1818–1880) from Coimbra, João de Brito Capello (1830–1901) from the Infante D. Luiz Meteorological Observatory in Lisbon, and a technician, was sent to Spain to observe this same July 1860 eclipse (Pinto, 1861; cf. Bonifácio et al. 2007a). The outcome of the mission was restricted to further calculations of longitude differences, due to the inefficiency of the observing instruments hastily gathered from the Observatories of Coimbra and Lisbon, which proved incapable of performing their required photographic or spectroscopic functions. In August and September 1860, following this eclipse mission, de Sousa[3] was commissioned to visit the most important European scientific institutions, especially those having meteorological and magnetic observatories (Malaquias, et al., 2005). He visited the Observatory at Kew on 26 August 1860, and in his report he referred to the Dallmeyer Photoheliograph, presumably the one used by De la Rue, but because of its high cost and the prospect of further improvements occurring in this field, he did not recommend that Portugal should purchase one. He added:

> The observation of sunspots, in relation to the discussed question [determining a relationship between their position, magnitude and number and variations in the elements of the Earth's magnetic field], can meanwhile be performed by an ordinary telescope … (Sousa, 1861: 149; our translation).

In 1871 the Coimbra Observatory bought a photoheliograph made in Germany by Repsold & Söhne and Steinheil (Bandeira, 1942: 557), and in this same year a daily solar photography research program started at the Infante D. Luiz Observatory in Lisbon in which Capello was actively engaged. In the process, he developed important contacts with De la Rue at Kew, the Angelo Secchi (1818–1878), in Rome and Pierre Jules Janssen (1824–1907) at Meudon Observatory. This programme ended in 1880, after several years with no significant progress (Bonifácio, et al., 2007b).

By then it was imperative to find a way to study the solar atmosphere on a regular basis, outside the brief periods allowed by total solar eclipses, but the intensity of the light emitted by the Sun's photosphere made this difficult. Janssen solved this problem during his observation of the 18 August 1868 solar eclipse in India. Using spectroscopic methods, he observed that the vapours of the prominences emitted a characteristic spectrum with bright emission lines. These lines included those of hydrogen and a line from a new element, which was named helium and assumed at the time to exist only on the Sun. When, after the eclipse, he directed his spectroscope to the same prominence on the Sun's limb, the bright lines were still visible. Isolating one of them, by means of a second slit, and slowly moving the first slit to the point where the light fell upon it, he managed to draw the outline of the prominence (see Launay, 2008). By a strange coincidence, the very same idea occurred at the same time to the Englishman Joseph Norman Lockyer (1836–1920) (see Lockyer, 1873-79).

Janssen laid the foundations of the first astrophysical observatory in the world, at Meudon, on the outskirts of Paris, and initially research there was mainly devoted to the study of the Sun (Launay, 2008). Based on the ideas of Janssen and Lockyer, Henri Deslandres, Janssen's successor at Meudon, and George Ellery Hale in the U.S.A., independently developed a new instrument, the spectroheliograph, which is still used today for studying the solar atmosphere. Hale was the first person to build a usable instrument, in 1890-1891, based on an idea that occurred to him in 1889 and was the theme of his senior thesis at the Massachusetts Institute of Technology, entitled "The Photography of Solar Prominences" (Glass, 2006: 161-163). His goal was to obtain a monochromatic photograph of the Sun's chromosphere. The first challenge was to get a device capable of projecting a steady image of the Sun, obtained by a coelostat[4] comprising two flat mirrors (Figure 3). One of the mirrors could track the Sun and direct a fixed image on the second mirror, which was then refracted by an objective. The light was then projected through a first slit into a spectroscope, with a second slit used as a monochromator to isolate a single wavelength. In order to record a complete monochromatic image of the Sun on a photographic plate the synchronous motion of several parts of the apparatus was necessary. The alternatives were to maintain a fixed monochromator and move the solar image in the first slit at the same rate as the photographic plate or move only the monochromator and fix all the constituents, reproducing the equivalent motions by optical or mechanical devices (Kuiper, 1953: 617).

4 SOLAR PHYSICS AT THE BEGINNING OFTHE TWENTIETH CENTURY

In August 1869, the Americans Charles Young (1834–1908) and William Harkness (1837–1933), working at the U.S. Naval Observatory, detected a green emission line in the coronal spectrum at 5303 Å, very close to a known line of iron (Hufbauer, 1991: 62). The origin of this line was a complete mystery, and several scientists proposed that it belonged to a new element, which they called 'coronium'. When news of this new line reached Portugal in July 1870 António dos Santos Viegas (1835–1914), a Professor in the Faculty of Philosophy of the UC, went to Rome in order to study the spectral analysis of the Sun with two of Italy's leading specialists: Secchi and Lorenzo Respighi (1824–1889). Viegas' plan was to invite the international community to observe the total solar eclipse which would be visible from Portugal—weather permitting—on 22 December 1870 (Bonifácio et al., 2007a).

However, Young preferred to observe from Jerez de la Frontera in Spain, and was clever enough to make a another discovery. Besides the dark lines of the ordinary solar spectrum, he also noted the appearance of bright lines, as the slit of the spectroscope moved along the Sun's limb (Frost, 1910). This was called the 'flash spectrum' since it only lasted a few seconds. These lines, which originated from a lower layer of the chromosphere, were identical to those from the prominences. The absorption lines were dark, in the midst of the solar spectra, in spite of being bright in the flash spectra.

Hydrogen, helium and calcium were identified in the spectrum of the chromosphere, and by isolating the light from one of these lines an image of the solar chromosphere could be taken. The monochromatic images of the Sun, obtained with the spectroheliograph, differed from the selected line, a phenomenon that suggested that they were being emitted at different altitudes in the chromosphere. For the calcium spectrum, the H and K lines were used, while for hydrogen the Hα (red) line was used. The H and K lines provided more information, since getting three photos, one using the central region of the streak (K_3), another the intermediate region (K_2) and the last one using the edge portion (K_1), provided three distinct images, each relating to a specific height.

As the photographic data on the Sun's chromosphere were accumulating, new findings were made. The most important was that some spectral lines coming from sunspots were split, as occurs in a magnetic field. Hale (1908) confirmed this Zeeman Splitting was due to magnetic fields by showing that many doublets were polarised in opposite directions. The polarisation of the sunspots was related to the direction of their vortices (Hufbauer, 1991).

The first decade of the twentieth century, when a new breed of scientists made a deep commitment to understanding the Sun, was a turning point in solar science. Knowledge of the Sun surpassed the positional estimates and measurements of distance, size, mass,

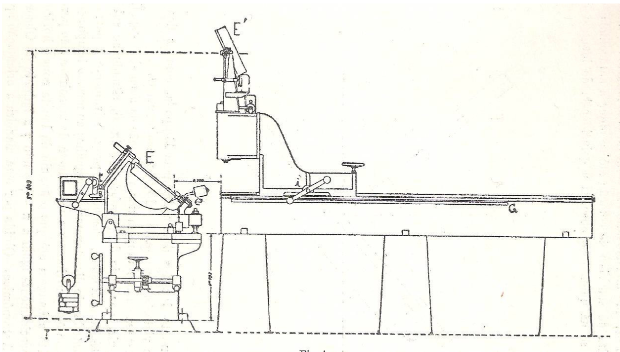


Figure 3: Schematic representation of the Coimbra coelostat (after Costa Lobo, 1933b: 453).

rotation rate and direction of motion and moved on to their physical and chemical constitution. It was established that the Sun was composed of terrestrial elements, that the temperature of the photosphere was about 6000 K, and that sunspots followed an eleven-year cycle and were associated with strong magnetic fields (ibid.).

The *O Instituto* published a lecture given at the Valladolid Congress of 1915 by Victoriano Fernández Ascarza, an astronomer of the Madrid Observatory. In the first half of the lecture, which was devoted to solar problems, Ascarza (1916) reported on recent major advances in solar physics and problems that were still pending. Reference was made to the spectroheliograph, since Spain already had two of these instruments, the first having been installed at the Ebro Observatory in Tortosa, Catalonia, in 1908, and the second at the Madrid Observatory, in 1911.[5]

By the second decade of the twentieth century, solar physics was an internationally well-established field, being studied by well-respected investigators such as Deslandres and Hale. Many were the solar phenomena that needed further investigation, like the sunspots, the faculae, the prominences and the filaments. In his article, Ascarza (1916: 31) renewed Hale's appeal for an international cooperative effort to investigate the sunspots. This cooperation should be based on the uniformity of the observational methods and its world-wide articulation to guarantee the continuity of the information gathered long-term. Costa Lobo who was at Ascarza's lecture, eagerly answered this appeal and started procedures that would culminate in the creation of a centre devoted to solar physics at the UC.

5 POLITICAL AND SCIENTIFIC CONDITIONS FOR THE CREATION OF SOLAR PHYSICS IN PORTUGAL

Costa Lobo's accomplishment was rare in Portugal, due to the precarious social and economic conditions of the country at that time. The establishment in 1910 of the Republic, which inherited not only a poor continental country but also a decadent empire, gave way to political instabilities that hindered the needed reforms and generated social turbulence in an illiterate society hoping for the implementation of the promises of the Republican revolution. The First World War aggravated the situation, since the participation of a Portuguese expeditionary corps in combat in France and Belgium led to an immense number of casualties. This situation hindered any investments that might not generate an immediate financial return.

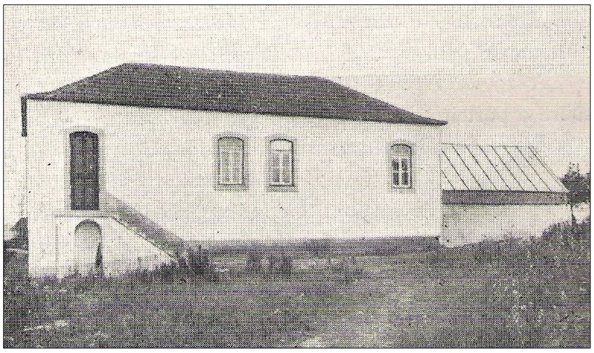


Figure 4: The pavilion where the spectroheliograph was installed (after Bandeira, 1942: 548).

In spite of this bleak scenario, Costa Lobo relied on his good political connections. Despite his political affiliation with the Monarchist Party, he only re-entered active politics when his friend and former Faculty colleague, Sidónio Pais (1872–1918), became President of the Republic in 1918, after leading the revolution on 5 December 1917 that deposed the Government of Afonso Costa (1831–1937) and removed from the Presidency Bernardino Machado (1851–1944), another Coimbra professor.[6] Costa Lobo was again elected Deputy to the Assembly of the Republic and became Chairman of a Commission for Education Reform (Amorim, 1955). The assassination of Sidónio Pais on 14 December 1918, less than one year after his inauguration, was certainly a major blow for Costa Lobo, who called it a "… great loss for the nation …" when he addressed the IC General Assembly of 26 September 1918 (*O Instituto,* 66: 1). At least, it was enough to make him return to Coimbra.

Interest in this new field of solar physics already existed in Coimbra, as a study of Coimbra's climate between 1866 and 1916, published in 1922, shows. Its author was Anselmo Ferraz de Carvalho (1878–1955), who was then Director of the Magnetic and Meteorological Observatory of the UC and who succeeded Costa Lobo in 1945. The study provided a statistical treatment of all observations of temperature, humidity, rainfall, etc. made at the Magnetic and Meteorological Observatory during the previous fifty years. One chapter was devoted to a comparison of air temperature and other weather phenomena with the number of sunspots and solar irradiance. Based on sunspot numbers collected by Alfred Wolfer and published in the *Monthly Weather Review* before 1914, Carvalho was not able to confirm the idea that an increase in the number of sunspots should correlate with a decrease in temperature. Indeed there was no clear correlation between temperature variations and the number of sunspots. There was also no clear relation between sunspots and rainfall, although low rainfall was generally associated with a maximum of spots (Carvalho, 1922: 41-46).

On the scientific side, after attending the Congress of Valladolid in 1915, representing the IC, and having also been present at the Congress of Granada in 1911 (which was promoted by the Spanish Association for the Advancement of Science), Costa Lobo laid the foundation for the establishment of the Portuguese Association for the Progress of Science, and he served as its President for a number of years. The creation and intensification of scientific relations between Portugal and Spain was one of his goals.[7] As mentioned, Ascarza's paper in *O Instituto* motivated Portuguese scientists to follow the Spanish example. It was no coincidence that the chosen area was the study of the Sun, since Spain had already responded to Hale's appeal by installing two spectroheliographs, and since the two Iberian countries are the European countries with the largest solar exposure. In 1925, simultaneously with the installation of a spectroheliograph in Coimbra, the second Joint Congress of the Portuguese and Spanish Associations for the Advancement of Sciences[8] took place in that city with the collaboration of the IC. The inauguration speech by Costa Lobo, titled "Astronomy in Portugal in the Present Time" (our English translation), was published in *O Instituto* (Costa Lobo, 1925a) and was certainly a response to Ascarza's earlier lecture.

Costa Lobo also represented Portugal in the First and Second Congresses of the International Mathematical Union, which took place in Strasbourg (France) in 1920 and in Toronto (Canada) in 1924. Costa Lobo was a well-known personality in the international scientific community, his contacts being numerous and notable. That was a clear advantage not only for his astronomical projects but also for the IC and the UC.

6 INSTALLATION OF THE SPECTROHELIOGRAPH IN COIMBRA

In 1912 Costa Lobo started to implement his plan to install a spectroheliograph in his Observatory. The instrument, similar to that in place at Meudon Observatory, was constructed following Deslandres' specifications. Due to the lack of a suitable place for this apparatus in the Observatory building, another site was selected, at Cumeada (Figure 4), next to the old Meteorological and Magnetic Observatory which had been founded in 1864.

As Costa Lobo's good friend, Deslandres had offered his support and assistance in 1907 and turned out to be a key figure in the whole process (he even provided some pieces of the instrument). There were many problems associated with this enterprise, the most notorious being the budget, in view of the cost of the imported equipment and the technical expertise necessary. In the words of Gumersindo Costa Lobo (1940: 10-11; our translation):

> The accomplishment of this enterprise was full of difficulties, if not impossible … the necessary equipment is extremely expensive, its assembly is considered very delicate by those who are authorities in this area, and the problem had never before been approached in Portugal. In short, the problem of erecting what we might consider a major physics laboratory for the new study of the Sun had to be solved in such a way that investigations could be performed at the same level of perfection as those achieved abroad and efficiently managed at the beginning of this area of research in Portugal, while allowing for our effective international collaboration in this work. (Costa Lobo, G., 1940: 10-11).

The various components of the spectroheliograph were ordered from instrument-makers in several countries. With the outbreak of the First World War these actions had to be suspended, but as soon as peace was established Francisco Costa Lobo re-activated the previous settlements and also resolved some problems associated with price increases.

Francisco's son, Gumersindo Costa Lobo, played an essential role in the installation of the spectroheliograph. Being aware of the novelty of this new technology and the reluctance of Portuguese technicians to handle it, he decided to specialise in the subject himself, so in 1923, at the age of 27, he went to Meudon where he was trained under Deslandres and his assistant, Lucien d'Azambuja (1884–1970). On his return to Portugal, later that year, "… all the services of the installation and scientific investigation of the [new] section of Astrophysics at the Astronomical Observatory were entrusted to him." (Amorim, 1955: 26).

The construction of the spectroheliograph pavilion started immediately after Gumersindo Costa Lobo's return from Paris. Deslandres sent d'Azambuja (Figure 5) to Coimbra on an official mission at the expense of the French government to provide the instruments with the required precision. D'Azambuja had Portuguese ancestry in that he was the grandson of Diego, a Portuguese immigrant from Azambuja, a small city close to Lisbon (Mouradian and Garcia, 2007: 7). He went on to become one of the most eminent astronomers in France, succeeding Deslandres as Director of the Meudon Observatory. His career at this Observatory started when he was only 15 years old, but he received a doctorate in 1930. Throughout his career his wife, Marguerite Roumens d'Azambuja (1898–1985), who shared his interest in the Sun, was his scientific assistant (Martres, 1998).

In "Les Nouveaux Instruments Spectrographiques de L'Observatoire Astronomique de l'Université de Coimbra", published in *O Instituto* in 1926, which followed his communication titled "Astronomy in Portugal in the Present Time" (1925b; our English translation), Costa Lobo senior described the new instrument. It was identical to that at Meudon, but contained new improvements that, in Costa Lobo's words, made it "… the most remarkable instrument for the study of the solar atmosphere installed in Europe …" (Costa Lobo, F., 1926: 129; our translation).

The spectroheliograph had a coelostat, made in France by the engineer Georges Prin, which was composed of two flat mirrors, each with a diameter of 40-cm, and placed in an external pavilion with a removable ceiling (Figure 6). The lower mirror facing the Sun rotated by means of a precise clock-drive which completed a full rotation in 48 hours. This generated a fixed image of the Sun that was projected through a small window to an objective, with an aperture of 25-cm and a focal length of 4-m. Constructed by the optician Marie Amédée Jobin and specially adapted for producing images using the K_3 calcium line, it was located in a isolated room. The objective rested on top of a movable platform connected to a speed transformer propelled by a Baudot motor.

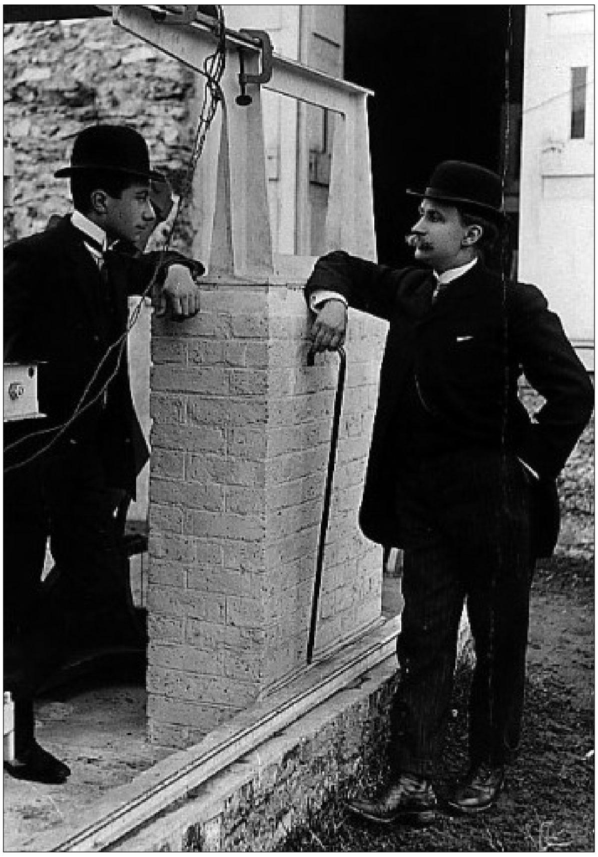


Figure 5: Lucien d'Azambuja (left) and Henri Deslandres (right) in 1903 (after Mouradian and Garcia, 2007: 7).

The light beam was then projected through a first slit and a collimator lens, mounted in a linear support, and ended up in the dispersive system composed of three flint prisms with an angle of 60º and 15-cm on the edge. The dispersed light was then projected into a second slit, which selected the spectral line, just before a photographic plate. These components rested in a movable platform similar to that of the objective and connected to a second Baudot motor. The motions of both motors, made in Jules Carpentier's workshop, were synchronised (Figure 7).[9] Some of these pieces were manufactured locally (Costa Lobo, 1926: 129-134).

On 12 April 1925 the first spectroheliogram of the Sun in the K_3 line was obtained. The spectroheliograph has been operational ever since.

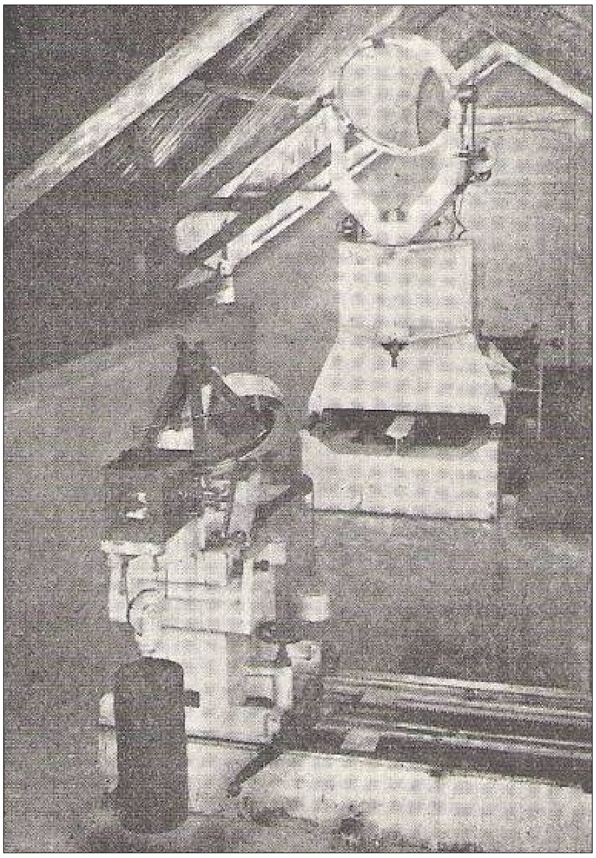


Figure 6: The ceolostat of Coimbra's spectroheliograph (after Costa Lobo, 1933b: 145).

7 SUBSEQUENT SCIENTIFIC ACTIVITY

As a part of an international scientific effort, the requisites were very demanding. One of the first resolutions by Costa Lobo was to publish all the results in a new publication titled *Anais do Observatório Astronómico da Universidade de Coimbra – Fenómenos Solares* (in English: *Annals of the Astronomical Observatory of the University of Coimbra – Solar Phenomena*). His expressed goal of this new publication, as outlined in his Introduction in the first volume, was to "Record the investigations performed and the results obtained in several branches of astronomical science at the Astronomical Observatory of the University of Coimbra." (Costa Lobo, 1929: 5). Notwithstanding its stated purpose, the *Anais* focused solely on solar physics.

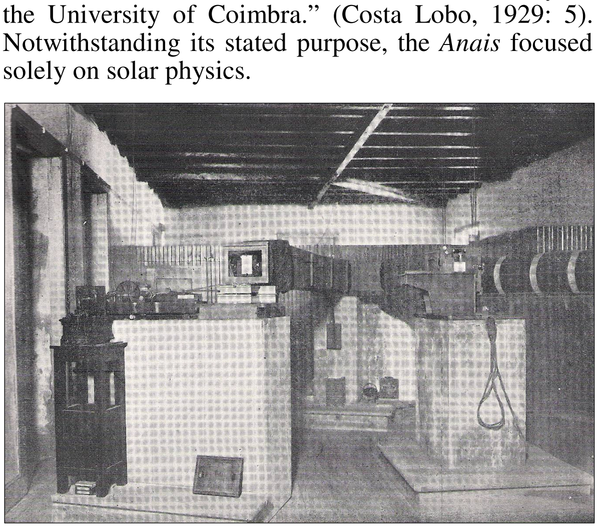


Figure 7: The spectroheliograph room (after Costa Lobo, 1933b: 146).

Each volume of the *Anais*, which was divided by the months of the year, contained charts of the major chromospheric phenomena, like facular regions, sunspots, prominences and filaments, and reported on their daily numbers and relative areas. The local spectroheliograms were also included. In the last pages, the annual data were depicted graphically.

In the first phase of the observational program, when meteorological conditions allowed, spectroheliograms were obtained using the calcium II K_3 line, but, in 1926, at least two images were being taken daily, one with the K_3 line and the other with the K_1 line. In this way it was possible to compare the aspect of two different altitudes of the solar chromosphere. To use the Hα line of hydrogen some adjustments and further equipment were necessary, like a diffraction grating, which was ordered from Adams Hilger & Company and arrived in 1932 (Costa Lobo, 1940). These images were sent to Meudon, which worked as an international hub, compiling all information that arrived from cooperating observatories worldwide. Since March 1919, d'Azambuja had been responsible for preparing continuous maps of solar phenomena (filaments, faculae and spots) that he reported in "Cartes synoptiques de la chromosphère et catalogue des filaments de la couche supérieur" (Coffey and Hanchett, 1998), whose publication in the *Annales de l'Observatoire de Paris*, *Section de Meudon* started in 1928 (Martres, 1998). He used images from other observatories (e.g. Mount Wilson in the USA, Kodaikanal in India, and Coimbra in Portugal) to fill in the missing days (Kiepenheuer, 1953: 402). Since the Meudon and Coimbra instruments were identical, the spectroheliograms sent from Coimbra did not need any adjustments.

The publication of the *Anais* … was announced at the Third General Assembly of the International Astronomical Union, held in 1928 in Leiden (Netherlands), where Costa Lobo (1928) presented a paper on "Several results obtained from spectroheliograph observations made in the years 1926 and 1927" (our English translation of the original French title). In his paper Costa Lobo used a graphical representation that he had invented to depict the image of the solar chromosphere (see Figures 8 and 9). By dividing the initial photographic image into 36 equal-angle sectors and displaying them in a radial manner he could strongly reduce the image distortion. Deslandres also mentioned the first volume of the *Anais* … in a communication to the Academy of Sciences of Paris, which was subsequently reproduced in an article that was published in the *Comptes Rendus*:

> This first volume assembles the observations from the year 1929. It reproduces the photographic samples of the solar upper layer and adds a very original depiction that, by a new projection method, presents all the details of the Sun, keeping the surfaces. Finally, the coordinates of all the interesting points are given in specific tables. This publication brings great credit to the Coimbra Observatory and to its director. (Deslandres, 1932: 2265; our translation).

Through the examination of the daily spectroheliograms, the number, position and dimension of the principal solar structures—sunspots, faculae, filaments and prominences—were measured. All parameters of solar activity were classified, and its evolution was carefully documented.

Costa Lobo pointed out that the photospheric facular regions, bright areas in the solar surface with a wider extension than the sunspots, were more important than the sunspots. By 1929, quite a variety of explanations of the sunspots had been proposed, so Costa Lobo summarized them in his Introduction to Volume I of the *Anais* .… Some authors considered them the result of a local and irregular cooling of the solar surface or of falling vapours producing cavities in the photosphere, while others explained them with convection currents, regions of high pressure, condensations of the photosphere, irregularities of gaseous matter, or special solar atmospheric movements. None of these theories related the formation of sunspots to faculae, so Costa Lobo proposed that sunspots were a consequence of faculae and had the same nature, in spite of their different dispositions. The formation of all sunspots within a facular regions, their disappearance before the faculae, and the fact that they were more numerous in areas of maximal facular activity, supported this theory. This had consequences in the influence of solar activity on terrestrial phenomena, since the effect of faculae was contrary to that of sunspots. The contradictory results between the frequency of the sunspots and the values of temperature and magnetic variations on Earth could therefore be explained. These influences were monitored in the *Anais* …, which also included data received from the Coimbra Meteorological and Geophysics Institute, such as maximal and minimal temperatures, solar irradiance and magnetic variations.

Costa Lobo classified the prominences as eruptive—those which appeared everywhere in the solar surface except in the facular regions, and as explosive—those which were supposedly produced by the impulsion of facular matter. Filaments were related to the eruptive prominences, being classified as thin, large, curved or discontinuous.

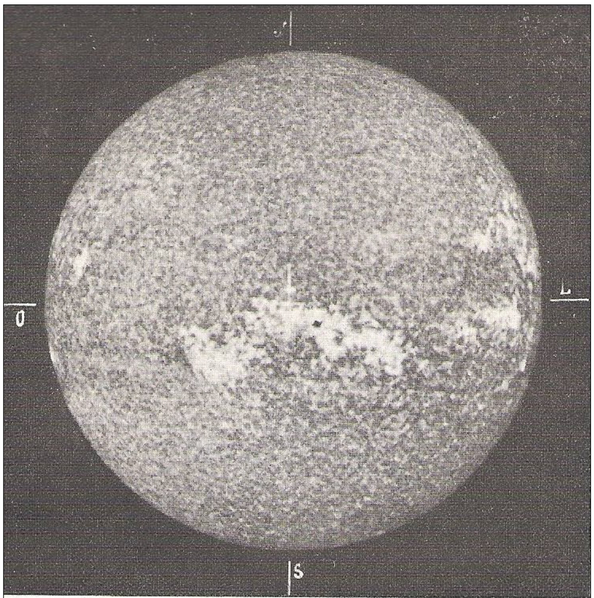
Gumersindo Costa Lobo's participation in these investigations was highlighted, with his father writing that:

> The cooperation of the assistant Dr. Gumersindo Sarmento da Costa Lobo has been of remarkable competence and of unsurpassable care, after showing special knowledge of the work in solar physics conducted at the Meudon Observatory. (Costa Lobo, F., 1929: 19; our translation).

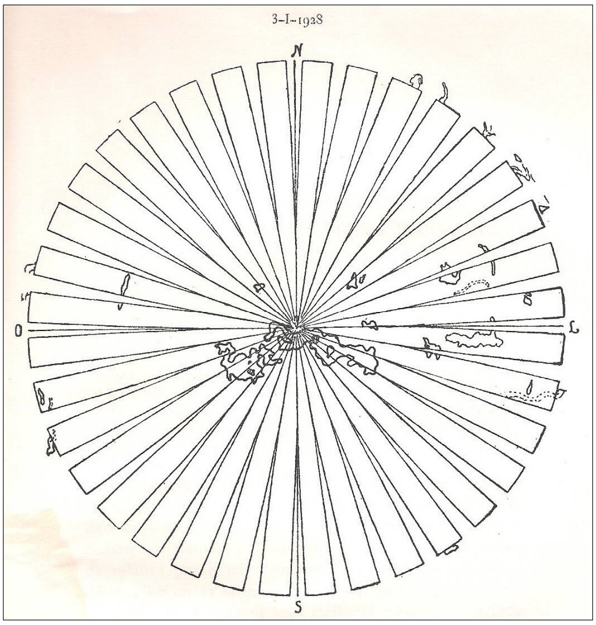
The importance of the new research centre in solar physics prompted a visit to Coimbra by British Astronomer Royal Frank Dyson on 26 November 1931. Dyson attended the celebrations organized by the Faculty of Sciences at the UC and the IC in honour of Isaac Newton (Costa Lobo, F., 1934).[10]

As a representative of the Portuguese Government, Costa Lobo (1933b) attended the General Assembly of the International Astronomical Union in Cambridge, Massachusetts (USA), from 2 to 9 September 1932. At this meeting, the Commission of Solar Physics approved with applause a resolution that acknowledged the great importance of the work done at the Observatory of Coimbra and expressed the wish that these observations should continue to be sent to Meudon and also to Zurich (Switzerland) in order to be included in the *Bulletin for Character Figures of Solar Phenomena*, a publication of the IAU directed by the Swiss astronomer William O. Brunner, which was initiated in 1928 to report solar data from observatories around the globe.[11]

Despite all the enthusiasm and commitment of Francisco and Gumersindo Costa Lobo, the exiguity of the Observatory's staff was an obstacle, especially in view of the exceedingly large amount of data collected that had to be carefully logged and analysed.



K_3, $10^h\ 7^m - 14^m$



Figures 8 (upper) and 9 (lower): Spectroheliogram taken on 3 January 1928 with the calcium II K_3 line and the corresponding graphical representation by F.M. Costa Lobo (after Costa Lobo, 1928: following page 356).

In 1933 the second volume of the *Anais* … appeared, again supervised by Francisco Costa Lobo, and focusing on the 1930 observations. In the Introduction a second invention of Costa Lobo is presented—a special sphere for facilitating the visualisation of the position of solar structures (see Figure 10). He characterized his sphere as "… an instrument with which it was possible that a single person can acquire the transformations that demand at least five persons using ordinary processes." (Costa Lobo, F., 1933a: 9;

Figure 10: Costa Lobo's solar sphere (courtesy: Museum of Science of the University of Coimbra).

our translation). Also in 1933, the Congress of the Geographic and Geophysics International Union took place in Lisbon, and was organized by Costa Lobo. His son also participated, giving a lecture on "Means and Methods of Observation of Solar Activity".

In an article published in *O Instituto* in 1931 the Polish astronomer, Ladislas Gorczynsky, wrote:

> Portugal is one of few countries that possess valuable and modern scientific appliances for solar investigations. Due to Prof. Dr. Costa Lobo, President of the IC and Director of the Astronomical Observatory, the creation in Portugal of an important centre of solar studies imposes on the country the broadening of these investigations to the numerous and wide possessions that this great country holds, located in advantageous positions, even if we only consider those bathed by the Atlantic waters. (Gorczynsky, 1931: 110; our translation).

Figure 11: Gumersindo Sarmento da Costa Lobo, 1896–1952 (after Amorim, 1955: following page 24).

8 GUMERSINDO COSTA LOBO AND CONTINUATION OF THE SOLAR STUDIES

When he became 70, on 18 February 1934, Costa Lobo was made emeritus, and had to leave his job as Director of the Observatory and the Chair he had held at the UC for 50 years. He was replaced by Manuel dos Reis (1900–1993), a Professor of Mathematics who supervised the following volumes of the *Anais* …, which maintained the structure established by Costa Lobo. No major scientific analysis was tried by Reis, the merit of the publication being that of the photographs, the numerical charts and the annual graphics, although at the end of each month there were some notes that referred to particular events. The exchange of spectroheliograms with Meudon was maintained, except during the years of the Second World War (Reis, 1946: 8). Meanwhile, Gumersindo Costa Lobo (Figure 11) continued the solar investigations initiated by his father.

Unfortunately, Gumersindo had long lived in the shadow of his father, which probably prevented him from receiving the recognition that he deserved. He concluded his graduation in mathematical sciences in 1919 with a higher grade than his father achieved (i.e. 19/20 vs. 18/20), and was then appointed Second Assistant in the Mathematical Section. Always committed to astronomy, he became deeply involved in the installation of the solar physics section. As already mentioned, in 1923 he was sent on a scientific mission to Meudon Observatory, and other trips would follow in 1930, 1935, 1938 and 1950, all made on his own. This made him the most capable investigator in the field in Portugal. He took his doctoral examination in 1926, defending a thesis on fluid resistance. He was promoted to First Assistant in 1930 and lectured on rational mechanics and celestial mechanics as well as giving practical courses of rational mechanics, probability calculus and astronomy, and astronomical progress. An active member of the IC, he was elected its Secretary on 6 March 1935. Besides his academic tasks, Gumersindo was a painter and a musician, and he was also an accomplished pianist.

His scientific activities, which led to many published and conference papers, were largely devoted to his special area of expertise—solar physics, and in particular the study and classification of chromospheric events. Based on an analysis of around 4000 photos of the Sun, taken from 1925 onwards, Gumersindo Costa Lobo (1933a) presented his first conclusions in a paper titled "The classification of some chromospheric phenomena and their comparison with terrestrial phenomena" (our translation) which appeared in the journal *A Terra – Revista de Sismologia e Geofísica*. He concluded that some events should be regarded as components of others, which were more general, like filaments and prominences. In 1933, he presented an extensive article in the *Revista da Faculdade de Ciências,* with the title "Spectroheliographic instruments and their application to the study of the solar atmosphere" (1933b; our translation), where he described the working of the equipment in Coimbra and reported the major investigations and results of the last few years. In this memoir, he introduced new spectroscopic methods to determine the velocity, based on the Doppler-Fizeau effect, and he referred to the most important findings associated with the variation in the

Sun's rotation with latitude. The Astronomical Observatory was also equipped to determine velocities of solar chromospheric structures, and he was able to acquire pictures of the Sun, by successive sections, using a wider slit. In this way, instead of getting a monochromatic image, he could obtain an approximately circular picture, with each section containing a small portion of the spectrum (Figure 12). By analysing the displacement of each spectrum, it was possible to determine the speed of that portion of the solar chromosphere.

The calculations described and performed by Gumersindo Costa Lobo included the correction due to the relativistic effect proposed by Einstein in his theory of relativity. This correction was particularly interesting because Gumersindo's father was strongly opposed to Einstein's Special and General Theories of Relativity, supporting an alternative theory (till the end of his life) that retained the concepts of absolute time and absolute space (see Costa Lobo, F, 1917; 1936; 1937).

Following in his father footsteps, Gumersindo Costa Lobo attended the General Assembly of the International Astronomical Union which took place in Paris in 1935, where he was elected a member of Commission 10 (Sunspots and Characteristic Solar Figures). He was already there in Paris on one of his scientific visits to the Meudon Observatory, one of the places where the sessions took place, another being the Paris Observatory. Gumersindo described the General Assembly and, in particular, the discussions of the two solar Commissions (10 and 11) in which he participated in a report published in *O Instituto* (Costa Lobo, 1938). The 90th volume of *O Instituto* included another paper written by Gumersindo Costa Lobo (1936) on "The observation of solar phenomena and some contributions for its interpretation" where he explained some interpretations of the solar structures observed in the Coimbra spectrographic data. He also pointed to the close connection between filaments—those dark streaks observed in the solar surface—and the prominences, seen beyond the solar limb. He concluded that filaments and prominences were different aspects of the same thing.

In Volume 100 of *O Instituto*, Gumersindo Costa Lobo published a synoptic report of his activities at the 1938 General Assembly of the IAU as a representative of Portugal. He was elected a member of Commission 11, which was devoted to Chromospheric Phenomena and the Solar Corona (Costa Lobo, G., 1942: 646). There he expressed the necessity of a scale for the eruptive phenomena and a choice of symbols based on a more detailed study of these phenomena. Taking part in the Congress of Portuguese Scientific Activity, in 1940, he presented a communication on "The Creation of Astrophysics Studies in Portugal (Costa Lobo, 1940) where he mentioned Hale's (1924) invention of the spectrohelioscope. This instrument was a modified form of the spectroheliograph that allowed direct viewing of the Sun in one wavelength through the replacement of the photographic plate by an optical device. Gumersindo proposed in 1935 to use Coimbra's spectroheliograph as a spectrohelioscope, but the relevance of the spectroheliograms that were obtained by the first instrument and the small dispersion of the first spectroscopes delayed this operation (Costa Lobo, 1940).

The elder Costa Lobo published his three final papers in Volumes 102 and 103 of *O Instituto*. One of these papers related to the origin of sunspots, and Costa Lobo gave his final interpretation of these phenomena. He reaffirmed his belief—now shared worldwide—of the relationship between sunspots and faculae, and that the sunspots always appeared inside faculae, the former disappearing before the latter, which meant that sunspots were a process resulting from faculae and both had a common cause. According to Costa Lobo, convection currents that sometimes caused eruptive prominences also produced sunspots in facular regions. Faculae had an origin external to the Sun. In regard to the solar cycle and its periodicity, Costa Lobo cited a reference in the *Transactions of the 6th IAU General Assembly in Stockholm* of 1938 which stated that the sidereal orbit period of Jupiter (11.8 years) around the Sun agreed perfectly with the main sunspot period during the interval 1880-1925 (Costa Lobo, 1943: 461). Based on this fact, Costa Lobo suggested that some rogue masses of external origin were captured or deflected by Jupiter and directed towards the solar surface. It was their collision

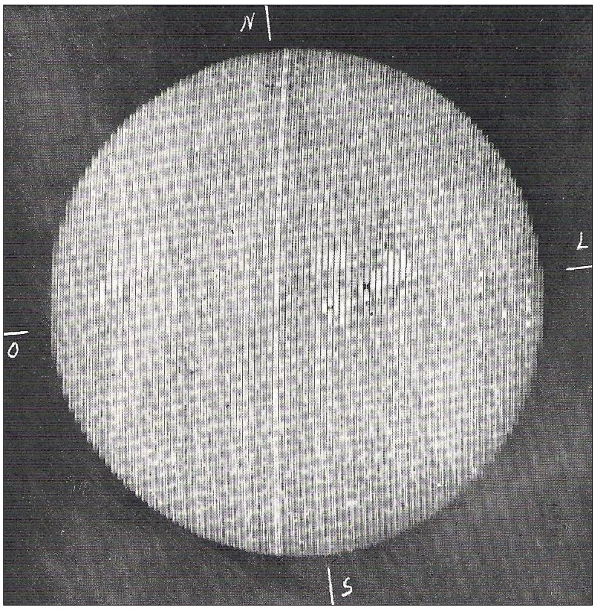


Figure 12: Picture of the Sun taken 2 July 1932 by the method of a wider second slit (after Costa Lobo, G, 1933b: Plate IV).

with the photosphere that induced the formation of faculae. This scenario could also explain why faculae only occurred in the 'royal zone', between 2° and 40° latitude; in 1630 Christoph Scheiner (1573–1650) used this expression in reference to the narrow belt on both sides of the Sun's equator where the sunspots appeared (Brody, 2002).

Francisco Costa Lobo continued working until the end of his life and in the process collected a long list of honours including the Jansen Gold Medal of the *Académie des Sciences de Paris*. He remained President and an Honorary Member of the IC until his death, which occurred on 29 April 1945.

In the session on 2 May 1949, the IC received Lucien and Marguerite d'Azambuja, who were corresponding members of the IC and were invited to present their work in Coimbra. After addressing the audience with a few words in Portuguese, Marguerite d'Azambuja read her communication, "Some present problems relative to sunspots and solar faculae" (D'Azambuja, M., 1949; our translation). In her lecture she commented on the rotational velocity of the Sun and its variation with latitude, with a maximum value at the solar equator, and the variation in the number of sunspots during the solar cycle. There was a mean duration of 11 years between two sunspot minima, and the first sunspots were generated at symmetrical higher latitudes between 30º and 40º N and S, increased in number towards the equator during the cycle and disappeared before quite reaching it. Within the faculae, sunspots were places with very high magnetic fields, which were opposite in the two hemispheres, and reversed each cycle.[12] Proposed explanations for the sunspot cycle were of two kinds: some people considered an external cause linked to tides caused by the planets, while others deemed the cause was internal to the Sun.

Lucien d'Azambuja later presented a report (1949) on "Progress of research on the solar atmosphere during the last fifty years." (our translation). He drew his conclusions from the observations collected in Meudon, including those sent from Coimbra. Lucien d'Azambuja assumed the existence of *activity centres* with similar evolution, a concept that incorporated several solar events. In a region of the solar disk a very bright and circular zone was formed and in this facular speck little sunspots would almost immediately appear. In the following days two principal spots surpassed the others in the enlarged facular region, one on the West (the leading sunspot) and the other on the East (the following spot) with the axis that joined them slightly slanted in relation to the solar equator. These spots would grow and, after a stability period, the following spot would fragment and disappear and, sooner or later, the same would happen with the leading spot. Gradually, the facular region attenuated and, in most cases, all traces would fade away after two months. An activity centre was also a stage for such other luminous phenomena as *chromospheric eruptions*. D'Azambuja also discussed the influence of solar activity on the Earth, especially the effects following chromospheric eruptions.

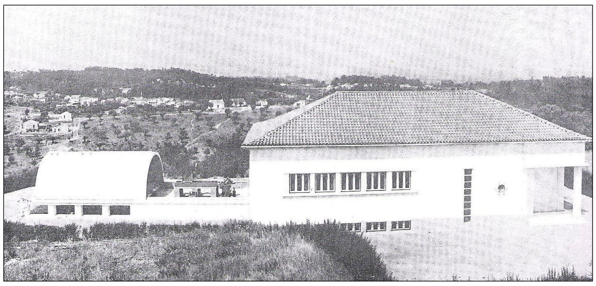


Figure 13: The present spectroheliograph building in Santa Clara, Coimbra. (after da Silva, 1969: after page. 235)

In the same year the lectures were delivered by the d'Azambujas, an article appeared in *O Instituto* authored by the Swedish astronomer Yngve Öhman (1903–1988), a corresponding member of the IC, who explained the new methods of "Astronomical investigation based on the polarization of light" (Öhman, 1949; our translation) and their application to the study of the Sun.

In 1951, answering a new request for cooperation made by the Meudon Observatory, the Director of Coimbra's Observatory, Manuel dos Reis, issued a request to the Dean of the University who promptly dispatched it to the Ministry of Education. Reis requested that Portugal send Gumersindo Costa Lobo on another scientific mission to Meudon to gather information on the construction of a new device that would allow the cinematographic registration of solar events. This instrument was to be installed in Coimbra and it would allow Portugal's participation in an international effort to obtain a continuous daily photographic record of solar activity. Reis thought that Gumersindo Costa Lobo was ideal for this assignment, given his vast expertise. The request was granted, but it would prove to be the last time that Gumersindo went to Meudon and the first trip that he did not have to pay for from his own pocket.

9 CONCLUDING REMARKS

The cooperation between the Coimbra and Meudon Observatories was one of the oldest scientific programmes that involved two nations (Mouradian and Garcia, 2007). From 1925 to the present day, the two Observatories have been exchanging observations, which were collected using similar instruments. In 1966, Coimbra's spectroheliograph was transferred to its new location in Santa Clara, Coimbra (Figure 13), where it is still working—although the observations are now automated (Silva, 1969). The renovations were undertaken from 1980 onwards, but without changing the optical layout, although they included new optical components, new dispersion gratings and high quality slits. The computer control, storage and data processing were enabled by the installation of a CCD camera (see Mouradian and Garcia, 2007).

Today 240 to 260 observations are made per year, using the old spectroheliograph, but the UC Astronomical Observatory now has an archive with about 30,000 solar spectra collected since 1926. This database is available online, and visitors may observe approximately 20,000 images of the Sun by accessing the web site http://www.astro.mat.uc.pt/novo/observatorio/site/index.html and obtain complementary information on any particular day.

Solar activity is an astronomical problem that has prompted considerable attention due to the effect that major solar events have on the Earth. As Francisco Costa Lobo mentioned back in 1925, the key question is: "What might occur if profound alterations [here on Earth] should extend beyond the limits where human life can subsist?" (Costa Lobo, F., 1925a: 566; our translation), and with an average of 250 clear sunny days each year, Portugal is in a privileged position for solar observations. Coimbra's spectroheliograph was among the first ten to be built in Europe (Kuiper, 1953), and was one of the most advanced apparatus of this type at that time. In a report to the National Board of Education on his training in the Observatories of Paris and Greenwich in 1932, the geographical engineer José António Madeira (who later became Chief-observer in the astrophysics section of the Coimbra Observatory) compared the methods for studying solar phenomena in Greenwich with those performed at Coimbra and concluded that "… this observatory does not possess, like the one of Coimbra, modern spectroheliographic installations that permit the permanent study of the Sun by spectral means." (Madeira, 1933:

373; our translation), and this fact justified Frank Dyson's decision to visit Coimbra. According to Gumersindo Costa Lobo, in 1940 there were only three heliophysical installations in the world that could match that of Coimbra (Costa Lobo, G., 1940: 25-26). While Gumersindo did not mention their locations, we can assume that two of them were at Meudon and Mount Wilson.

The *Anais do Observatório Astronómico de Coimbra* collected a massive amount of solar data in the 16 volumes that cover the period 1929-1944, and the spectroheliograms sent to Meudon and Zurich were, undoubtedly, indispensable to the world effort in solar physics, not only for their quality but also for their uniqueness on some days. However, international historians of science have largely ignored Coimbra's solar investigations.[13] Several authors assign the whole merit to Lucien d'Azambuja and the Meudon Observatory, and they disregard the contribution made by the Coimbra Observatory since 1931 to the *Bulletin for Character Figures of Solar Phenomena*. This situation could be due to the delayed publication of the results, especially after Volume XI (for example the last volume of the *Anais do Observatório Astronómico de Coimbra*, Number 16, containing the observations of 1944, was only published in 1975). Nevertheless, the spectroheliograms collected at Coimbra were sent regularly to Meudon, where they were preferred to any other (Costa Lobo, G., 1940: 20). Unfortunately, the Coimbra Observatory and, in particular its solar physics section, always faced a lack of skilled personnel to process the over-abundance of observations.

The presence of the D'Azambujas in a conference in Coimbra in 1949 confirms their gratitude for the cooperation they received from Coimbra. In their presentations, we may see the confirmations of some of the hypotheses on the chromospheric activity raised by the Costa Lobos. Francisco Costa Lobo, besides his invention of the planar transformation to depict solar events (also called 'Costa Lobo's system') and his solar sphere, was one of the first astronomers who recognized the connection between faculae and sunspots and provided a new explanation for their appearance. He was also a pioneer in classifying a new species of explosive prominences. Although Francisco Costa Lobo is relatively well-known in Portuguese academic circles, his son is largely unknown. Although Costa Lobo senior had the means and the contacts to create the solar physics section, it was Gumersindo Costa Lobo who provided the necessary technical know-how. Gumersindo made continuous and impressive progress in classifying solar structures, and established the common nature of filaments and prominences when some authors still considered them different and independent events. In the words of Coimbra's Professor of Mathematics Diogo Pacheco de Amorim, speaking in memory of Gumersindo at the IC, destiny wanted that it would be in this house and at its service that he fell victim to the disease that took his life (Amorim, 1955: 28). Gumersindo Costa Lobo died prematurely in 1952 while still in his mid-50s.

10 NOTES

1. This film showed the variation in the luminous intensity of Baily's beads, the beads of sunlight observed near the beginning and the end of a solar eclipse, due to irregularities in the Moon's surface.
2. Although having an encyclopaedic attribute, this periodical was also the most important scientific publication in Coimbra until the creation of the *Revista da Faculdade de Ciências da Universidade de Coimbra* in 1931. This latter journal was also the initiative of Francisco Costa Lobo, who was by then the Director of the Faculty of Sciences at the UC. All volumes of *O Instituto* are available online at the following web site: http://www.uc.pt/bguc/BibliotecaGeral/InstitutoCoimbra/EdDigital.
3. Jacinto de Sousa was a Professor in the Philosophy Faculty at the UC who became an expert in meteorology. He was secretary of the IC from 1855 to 1860. The goal of his journey abroad was to gather information and to select instruments for a new Meteorological and Magnetic Observatory in Coimbra. This was eventually built in 1862 under Sousa's supervision and he was its first Director. The first meteorological and magnetic observations were made in 1864.
4. The heliostat and the siderostat, devices with applications similar to those of the coelostat, used a single mirror, but produced rotating images of the Sun. A long paper about these instruments was published in *O Instituto* in 1934 (see Pinto, 1934).
5. The Jesuits had founded the Ebro Observatory in 1904, and its principal instruments had been in use since 1905. It was the observation site of the solar eclipse on 30 August 1905, when astronomers from France, England, the United States, Germany, Belgium, Spain and Portugal came together (see Selga, 1915: 22).
6. Pais, Afonso Costa and Machado were all active members of the IC. Afonso Costa was a member of many Governments and Prime Minister on three occasions, and he even participated in a course of popular lectures organized by the IC to educate those in Coimbra belonging to the lower social classes. Bernardino Machado was elected President of the Republic in 1915 and in 1925, and was President of the IC between 1896 and 1908.
7. Costa Lobo also attended two other congresses of the Spanish Association for the Advancement of Science, which took place in Bilbao in 1919 and in Salamanca in 1923.
8. The first congress of the two associations was held in Porto in 1921, but Costa Lobo did not integrate the IC delegation. A third joint congress of the two associations would occur in May 1932 in Lisbon, also organized by Costa Lobo.
9. In the same article, Costa Lobo (1926) also described the stellar spectrograph, which had been acquired at the same time and complemented the astrophysics section of the Observatory.
10. Frank Dyson's successor as Astronomer Royal and Director of the Royal Observatory at Greenwich was Harold Spencer Jones, who came to Coimbra on 17 April 1942 as a guest of the IC to give a lecture on the determination of the Earth-Sun distance (Boletim do Instituto, 1943. *O Instituto*, 103, 377-378).
11. In 1939 it would be renamed the *Quarterly Bulletin on Solar Activity* (Hufbauer, 1991).
12. This discovery was made by Hale in 1923, confirming his hypothesis of 1915 when the beginning

of a new solar cycle demonstrated that the newly-formed sunspots, in higher latitudes, had opposite magnetic polarity to those of the previous cycle, near the solar equator. This situation gave way to a redefinition of the solar cycle period as a 22-year magnetic cycle (Hale and Nicholson, 1925; Hufbauer, 1991).

13. As an example, see Martres (1998) or Hufbauer (1991), where the participation of the Astronomical Observatory of the UC is completely ignored.

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A. J. Leonardo is a high school teacher of physics and chemistry in Lousã, Portugal, and a Ph.D. student in history of physics at the University of Coimbra. The title of his thesis is "The Institute of Coimbra and the evolution of Physics and Chemistry in Portugal from 1852 to 1952." He is also interested in physics and chemistry education, and has a Master's degree in this subject.

D.R. Martins is a Professor in the Department of Physics at the University of Coimbra and a mem-

ber of the Scientific Commission of the Museum of Science at the University of Coimbra. He has published several works on the history of physics in Portugal and is a specialist in the history of scientific instruments.

C. Fiolhais is a Professor in the Department of Physics of the University of Coimbra and Director of the General Library of the same University. He is a member of the Scientific Commission of the Museum of Science at the University of Coimbra. In parallel with his research and teaching, he has been active in science outreach, being the author of various popular science books.